

The London School of Economics and Political Science

# **Representing Complexity: The Material Construction of World Politics**

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## DECLARATION

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## ABSTRACT

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This thesis weaves together the themes of complexity, technology, and power. It does so by examining how actors in world politics gain leverage over complex systems through the use of specialised ‘representational technologies’ that make these systems intelligible and amenable to manipulation. In response to the increasing complexity of regional and global systems, political actors are expanding their use of these representational technologies in order to augment limited individual and institutional means for cognition. A first conclusion from this research is that through these technologies, power is being expanded in novel and unique ways. Building upon an insight from actor-network theory (ANT), power is examined here as something that must be constructed via material technologies. Yet unlike previous research which has focused primarily on infrastructural technology, this thesis examines the unique role of representational technologies in constructing power. Following constructivism, this thesis accords a significant role to knowledge, discourse, and representations in how world politics are presented and acted upon. However, a second conclusion of this thesis is that the standard idealist accounts in constructivism must be expanded by examining the increasingly material means through which such ideational representations are constructed. Thirdly, this thesis aims to illuminate a neglected type of technology within International Relations (IR) scholarship – by moving away from the standard analyses of military and communication technology, and instead showing how representational technology contributes to the practices of world politics. Lastly, in emphasising the materiality of power and knowledge, this thesis also aims to revive a moderate version of technological determinism by arguing that technology is a platform which shapes both possible political behaviours and pathways for technological development.

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# I / COGNITIVE MAPPING IN A COMPLEX WORLD

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“What has happened? Simply that our means of investigation and action have far outstripped our means of representation and understanding. This is the enormous new fact that results from all other new facts. This one is positively transcendent.”<sup>1</sup>

-Paul Valéry

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This thesis weaves together the themes of complexity, technology, and power. It does so by examining how actors in world politics gain leverage over complex systems through the use of specialised ‘representational technologies’ that make these systems intelligible and amenable to manipulation. In response to the increasing complexity of regional and global systems, political actors are expanding their use of these representational technologies in order to augment limited individual and institutional means for cognition. A first conclusion from this research is that through these technologies, power is being expanded in novel and unique ways. Building upon an insight from actor-network theory (ANT), power is examined here as something that must be constructed via material technologies. Yet unlike previous research which has focused primarily on infrastructural technology, this thesis examines the unique role of representational technologies in constructing power.<sup>2</sup> Following constructivism, this thesis accords a significant role to knowledge, discourse, and representations in how world politics are presented

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<sup>1</sup> Valéry, “Unpredictability,” 69.

<sup>2</sup> Callon and Latour, “Unscrewing the Big Leviathan: How Actors Macrostructure Reality and How Sociologists Help Them To Do So”; Guldi, *Roads to Power: Britain Invents the Infrastructure State*; Headrick, *The Tools of Empire: Technology and European Imperialism in the Nineteenth Century*; Schouten, “The Materiality of State Failure: Social Contract Theory, Infrastructure and Governmental Power in Congo.”

and acted upon. However, a second conclusion of this thesis is that the standard idealist accounts in constructivism must be expanded by examining the increasingly material means through which such ideational representations are constructed. Thirdly, this thesis aims to illuminate a neglected type of technology within International Relations (IR) scholarship – by moving away from the standard analyses of military and communication technology, and instead showing how representational technology contributes to the practices of world politics. Lastly, in emphasising the materiality of power and knowledge, this thesis also aims to revive a moderate version of technological determinism by arguing that technology is a platform which shapes both possible political behaviours and pathways for technological development.

### **The Problem of Complexity**

One of the most common themes amongst the major crises of the modern world is the repeated reminder that our world is increasingly complex. Compared to previous periods of history our world is more interconnected (spreading crises further and less predictably), more dynamic (diffusing risks at a quicker pace), and more fragmented (with experts becoming specialised in solving local problems rather than systemic problems).<sup>3</sup> This complexity involves a massive amount of elements, nonlinear dynamics, unintended effects, sensitivity to initial conditions, and feedback loops.<sup>4</sup> These features of complex systems strain the limits of the human mind's finite and embodied capacities.<sup>5</sup> The 2008 financial crisis, the ongoing climate change crisis, the 2003 North American electrical blackout – all of these point to widely distributed complex systems which already surpass human capacities to cognise. If rational action requires a minimal capacity to represent the problems to be confronted, then the complex systems of today's world are threatening to undermine the cognitive basis of political action. Given that

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<sup>3</sup> Perrow, *Normal Accidents: Living with High Risk Technologies*; Jervis, *System Effects: Complexity in Political and Social Life*.

<sup>4</sup> Cederman, "Complexity and Change in World Politics: Resurrecting Systems Theory"; Geyer and Rihani, *Complexity and Public Policy: A New Approach to 21st Century Politics, Policy and Society*, chap. 1.

<sup>5</sup> Jervis, *System Effects: Complexity in Political and Social Life*, 45.

“legibility [is] a central aspect of statecraft”<sup>6</sup>, then the world today is characterised by systems that outpace any actor’s ability to comprehend them.

According to the cultural theorist Fredric Jameson this situation indexes a lack of ‘cognitive mapping’ – the means to make our own world intelligible to ourselves through a situational understanding of our own position.<sup>7</sup> Here Jameson draws upon urban theory which argues that in designing liveable spaces one must take into account how people navigate their way around cities. In encountering a new city, the individual is left without any cognitive map of the space and is forced to develop one through habit. The urban designer can in turn assist this process by strategically situating landmarks and other easily recognizable symbols in order to provide the grounds for the development of a cognitive map.<sup>8</sup>

In Jameson’s work, this idea of cognitive mapping encompasses not only an individual’s relation to a city, but also their relation to an entire socioeconomic system. As he states, the function of cognitive mapping is “to enable a situational representation on the part of the individual subject to that vaster and properly unrepresentable totality which is the ensemble of society’s structures as a whole.”<sup>9</sup> In charting through a loose set of historical periods from national to imperialist to globalised capitalism, Jameson argues that at one time the nature of capitalism was such that one could potentially establish a correspondence between our local phenomenological experiences and the economic structure that determined it. We could, in other words, establish a cognitive map of our economic space, thereby making intelligible the world around us. With the rise of globalisation, however, Jameson claims that this is no longer the case. We can no longer simply extrapolate from our local experience and develop a map of the global economic system. There is a deficiency of cognitive mapping, i.e. there is an essential gap between our local phenomenology and the structural conditions which determine it.

This separation between experience and the system within which we operate results in increased alienation – we feel adrift in a world we cannot

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<sup>6</sup> Scott, *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed*, 2.

<sup>7</sup> Jameson, “Cognitive Mapping.”

<sup>8</sup> Lynch, *The Image of the City*.

<sup>9</sup> Jameson, *Postmodernism: Or, the Cultural Logic of Late Capitalism*, 51.

comprehend. For Jameson, the proliferation of conspiracy theories is symptomatic of this situation. Conspiracy theories act by narrowing down the agency behind our world to a single figure of power (whether it be the Bilderberg Group, Freemasons, or some other convenient scapegoat). Despite the extraordinary complexity of some conspiracy theories, they nevertheless provide a reassuringly simple answer to ‘who is behind it all’. They, in other words, act precisely as a cognitive map.

Other responses to the lack of cognitive mapping include the extrapolation of everyday experiences to model global problems – often a manipulation designed to further some political goal. The use of the household metaphor to understand national economies is particularly prevalent today. Here, government debt is equated with household debt and the former denounced on the basis of the comparison.<sup>10</sup> In the process, the unique complexities of government debt are effaced.<sup>11</sup> In other cases, the problem of African underdevelopment becomes embodied in the figure of a starving child, acting as a synecdoche for the complex structural problems that maintain states of poverty. The act of ‘charitable giving’ takes on the appearance of a meaningful gesture, without ever encroaching upon the systemic problems. These representations and the actions that issue from them demonstrate that cognitive mapping is crucial for political action, precisely because our actions are often strongly shaped by the representations we construct of complex systems.

### **The Rise of Cognitive Assemblages**

The problem of complexity is therefore that it is outpacing human cognitive abilities to map and manipulate; the solution this thesis proposes is ‘cognitive assemblages’. One of the main hypotheses of this work is that it is technology which is allowing individuals and institutions to extend their cognitive and practical capacities in such a way that complex global systems become intelligible.<sup>12</sup>

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<sup>10</sup> My thanks go to Alex Williams from whom this example originates.

<sup>11</sup> Wray, *Modern Money Theory: A Primer on Macroeconomics for Sovereign Monetary Systems*.

<sup>12</sup> For Jameson, the answer to the problem of cognitive mapping is dialectical thought and aesthetic representations. These options are rejected here on the basis that dialectical thought is no longer sufficient for a world better characterized by complexity science, and that aesthetic representations avoid the necessity of scientific inference for epistemic claims.

Through the development, diffusion and use of various representational technologies, human actors have come to create novel cognitive maps of today's world. For instance, computer simulations are being employed to generate representations of the global climate; specialised models are used to produce visible diagrams of global finance; and automated software is being used to filter through social media data and present a geographical image of a crisis. It is through technology that humans are enriching their world and coming to terms with complexity.

As such, the central conceptual element of this thesis will be 'cognitive assemblages', defined as:

Cognitive assemblages are hybrid systems comprised of individuals, institutions, norms and representational technologies which have as a primary goal the production of linguistic, numeric, and/or visual representations about some phenomenon in the world.

This definition is broad enough to include scientific laboratories and the experiments of big science (e.g. the Large Hadron Collider or the climate change observation network). This definition is also broad enough to encompass both small-scale assemblages (e.g. individuals employing hand-held devices) and large-scale assemblages (e.g. global data sensors analysed by large scientific communities and modelled by massive supercomputers). It is also a broad enough definition to include relatively apolitical cognitive assemblages.

The past few years alone have witnessed a variety of such assemblages emerge and expand. The US Federal Reserve is experimenting with sentiment analysis to monitor consumer confidence and more accurately represent the current state of the economy.<sup>13</sup> There have been proposals for a financial monitoring system that replicates the climate observation and modelling system.<sup>14</sup> Others are planning an Earth simulator to provide a real-time simulation of health

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<sup>13</sup> *Sentiment Analysis and Social Media Monitoring Solution RFP.*

<sup>14</sup> Haldane, "To Navigate Economic Storms We Need Better Forecasting."

pandemics, economic bubbles, and conflict hot spots – all in an effort to make global dynamics intelligible.<sup>15</sup> Global cities now routinely use centralised systems to monitor and modulate traffic flows. And macroeconomic modelling has been used for decades now as a policy tool by governments.<sup>16</sup> The expansion of representational technologies has been accelerated by both drastic improvements in computing power and increasingly ubiquitous data collection. As late as 2000, 25% of data was non-digital; today a striking 98% of it has been digitised.<sup>17</sup> With the surge in recorded and digitised information, ‘big data’ has become a mainstream term featuring in numerous news articles and spawning a number of popular books.<sup>18</sup>

Similar to the disciplinary and biopolitical tactics that Michel Foucault analysed in his work,<sup>19</sup> these new technologies centred on complexity and computation are being created in a variety of places and then dispersed throughout the social fabric. They do not reside in governments alone. Casinos use algorithmic behavioural recognition software in order to uncover probable cheaters;<sup>20</sup> companies are adopting sophisticated big data analytics in order to fine tune marketing and pricing mechanisms;<sup>21</sup> and governments are constructing databases to track and code the risk threat of individuals.<sup>22</sup> Once generated, these techniques go on to filter through the social fabric. Machine learning techniques are optimised in high-frequency trading firms and adopted by governments in facial recognition software; algorithmic advancements are constructed by climate scientists and put to use in the modelling of social unrest; and corporations create new analytics for sorting big data which then get employed by politicians in their elections

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<sup>15</sup> Helbing, “The FuturICT Knowledge Accelerator: Unleashing the Power of Information for a Sustainable Future.”

<sup>16</sup> Kenway, *From Keynesianism to Monetarism: The Evolution of UK Macroeconomic Models*.

<sup>17</sup> Cukier and Mayer-Schoenberger, “The Rise of Big Data.”

<sup>18</sup> Mayer-Schönberger and Cukier, *Big Data: A Revolution That Will Transform How We Live, Work, and Think*; Lohr, “Big Data’s Impact in the World.”

<sup>19</sup> Foucault, *Discipline and Punish: The Birth of the Prison*; Foucault, *Society Must Be Defended: Lectures at the Collège de France 1975-1976*; Foucault, *Security, Territory, Population: Lectures at the Collège de France 1977-1978*.

<sup>20</sup> *Identity Management’s Role in an Application-Centric Security Model*.

<sup>21</sup> Duhigg, “How Companies Learn Your Secrets.”

<sup>22</sup> Ansorge, “Digital Power in World Politics: Databases, Panopticons and Erwin Cuntz.” While little is known about the details at this time, the National Security Agency’s PRISM program appears to be the largest and most prominent example of this particular technology.

campaigns. There is no single centre of production: this is rather a multi-centric production of representational technologies. The creation and use of such technology as a means to augment our cognitive abilities is becoming pervasive.

The focus of this thesis, however, is on the role of cognitive assemblages within the politics of global phenomena. In fact, it will be argued that it is these cognitive assemblages which are increasingly necessary to make the global visible as such. By making the global visible, one significant consequence is that representational technologies provide a new means through which power can be constructed. They can allow a small group of individuals to construct levers of power by producing actionable representations of complex situations which can provide them with a comparative epistemic advantage over other actors. A major theme of this thesis will be to demonstrate how such epistemic power is being constructed and employed today.

The products of such technologies – representations themselves – can be approached in at least two different ways. On the one hand, they can be approached as truth-bearing (or obscuring) entities, which can be subject to ideology critique in order to unmask the real entities and relations behind them. On the other hand, they can be approached as entities which have real effects on what it is possible to say and do, regardless of their truth value. The approach taken here is a combination of both approaches, with an emphasis on the latter aspect. Representations are important in this thesis because of what they make possible, yet in many ways these representations develop over time as a result of norms of truth.<sup>23</sup>

It should therefore be made clear from the beginning that the emphasis in this thesis is not on a critical approach – this thesis does not aim to provide an ethical critique of these new technologies, modes of knowing, and rationalities of governance. Instead it seeks to analyse the possibilities they are creating: the

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<sup>23</sup> In fact, in many ways, this is a process that has developed over centuries – from the first efforts to quantify probability and risk, to more recent efforts to generate statistical images of the national economy, and to modulate populations via statistical tools. See: Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*; Tooze, *Statistics and the German State, 1900-1945: The Making of Modern Economic Knowledge*; Desrosières, *The Politics of Large Numbers: A History of Statistical Reasoning*.



statements they make it possible to say and the actions they make it possible to do.<sup>24</sup> While my own inclinations are towards a critical approach to power, the goal here is to describe and analyse what are largely new phenomena, and to clarify what the stakes are. This attempt to analyse the developments without making explicit prescriptions in part stems from the belief that the traditional criticisms of technology are inadequate here – new ethical approaches are required.

### **Assemblage Theory**

With the representational technologies employed in world politics being produced by multiple types of actors, this study necessarily has to avoid the traditional IR focus on the inter-state system and instead focus its attention to technology's effects on the interconnected system of states, NGOs, international organisations, and other political actors.<sup>25</sup> It is networks of humans and nonhumans which are combining together to generate the infrastructure and dynamics of world politics. Therefore, instead of a state-centric approach, this thesis embodies an assemblage approach. Drawing from Gilles Deleuze and Felix Guattari's work,<sup>26</sup> we can outline four aspects of assemblages: (1) they consist of heterogeneous entities, both social and material; (2) they are assembled through historical (intentional and unintentional) processes; (3) they function together to produce an emergent whole, while also (4) maintaining the potential independence of parts from wholes.

This independence of the assembled parts implies a particular understanding of their essence. Rather than any particular *property* being the essential core of an entity, these objects consist of particular *capacities* to interact – only some of which are capable of being exercised in any particular assemblage.<sup>27</sup> A knife, for instance, has the emergent property of 'being sharp' since none of the

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<sup>24</sup> In this sense, this thesis follows in the Foucauldian line within IR: Dean, *Governmentality: Power and Rule in Modern Societies, 2nd Edition*; Miller and Rose, *Governing the Present*; Sending and Neumann, "Governance to Governmentality: Analyzing NGOs, States, and Power."

<sup>25</sup> Fritsch, "Technology and Global Affairs"; Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*.

<sup>26</sup> Deleuze and Guattari, *Anti-Oedipus: Capitalism and Schizophrenia*; Deleuze and Guattari, *A Thousand Plateaus*.

<sup>27</sup> DeLanda, *A New Philosophy of Society: Assemblage Theory and Social Complexity*, 10.

individual atoms of a knife have this property.<sup>28</sup> A knife also has the capacity ‘to cut’ – a capacity which may never be exercised, depending on whether the knife is ever used or not. The capacities of such an object always exist, though as unactualised potentials rather than actualised properties. While the past provides an empirical indication of the various potentials comprised within any particular entity, the essential openness of the future means that this list can never be closed. As Deleuze often quoted of Spinoza, “we know not what a body can do”.

While the components of an assemblage maintain independence, they do enter into relatively coherent (and empirically contingent) relationships in order to form the emergent wholes known as assemblages. In Deleuze and Guattari’s terms, there are process of ‘territorialisation’ which make an assemblage more unified, and processes of ‘deterritorialisation’ which tend to break apart the coherence of a particular system.<sup>29</sup> The unity and individuality of an assemblage is therefore always capable of changing, making it an empirical matter of delineating their existence.

Finally, the ontology taken here is also realist in the sense of arguing for the existence of a mind-independent reality. In terms of social ontology, total mind-independence is impossible since the entities under discussion only exist *in* minds. However, the autonomy of social entities (such as social structures) above and beyond our conceptions of them points to their realist character – they are not reducible to an individual’s idea of them.<sup>30</sup> This will be particularly important for a discussion of technology, the study of which has too often ignored the autonomy of socially-constructed materials.

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<sup>28</sup> DeLanda, *Philosophy and Simulation: The Emergence of Synthetic Reason*, 3–4.

<sup>29</sup> DeLanda, *A New Philosophy of Society: Assemblage Theory and Social Complexity*, 12. The similarity of ‘capacities’ to critical realism’s notion of ‘dispositions’ can perhaps help in bridging the gap between this philosophical work and the more traditional philosophy of IR. In both cases, the real aspect of an object is its dispositions or capacities which may go unexercised in any particular situation due to the multiple causal influences in effect in any non-laboratory situation.

<sup>30</sup> *Ibid.*, 1; Elder-Vass, *The Causal Power of Social Structures: Emergence, Structure and Agency*.

*The Problem of the Local and the Global*

This ontological notion of assemblages is also implicitly in tension with the standard readings of the ‘global’ within International Relations.<sup>31</sup> Typically in IR, three analytically distinct conceptions of the global are often invoked either explicitly or implicitly: (1) the global as container; (2) the global as the highest position in a hierarchy; and (3) the global as a level of detail.

The first conception of the global visually imagines it as being the larger container *within* which regional and local dynamics occur. The global, in such a perspective, is what provides the basic framework for the dynamics occurring inside of it. We see this most explicitly in analyses of social structure, as a limiting construct within which other processes occur. Similarly, analyses which see economic globalisation as a constraint on state action also tend to subscribe to this sort of ‘container’ approach.

The second conception of the global visualises it as being situated at the *top* of a hierarchy, with the regional and local placed below it. Contrary to the first conception, the other regions are not necessarily embedded within the global. Rather, what makes this visual metaphor unique is that the global is seen as operating at a largely independent level, rather than a foundational level. Each level has its own unique dynamics, which may or may not have any effect on the others. A classic example of this is Robert Putnam’s work on ‘two-level games’, where the domestic and international levels each constitute their own separate dynamics with interaction between them occurring at regulated points.<sup>32</sup>

The third common conception of the global is an epistemological one which visualises it as a level of *resolution*. Like a microscope, one can zoom out to the global macro features of the phenomenon under investigation, or one can zoom in to the local details involved. Depending on whether one is interested in generalised features or a singular case study, one chooses to examine a phenomenon at either a global or local level. This clearly occurs in the

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<sup>31</sup> It should be made clear that this thesis will focus on the global rather than the international. As the previous section argued, assemblages and the networks of entities they incorporate have ontological priority over bounded units such as states. In addition, the next section will argue that the global is a more encompassing idea than the international, with the latter being only a partial perspective.

<sup>32</sup> Putnam, “Diplomacy and Domestic Politics: The Logic of Two-Level Games.”

compromises between case studies and large-N studies, but it is also explicit in David Singer's work on the levels of analysis when he notes the "dearth of detail" that a focus on the international system requires.<sup>33</sup> In these conceptions of the global, the 'large' is assumed to be aligned with the 'general' and the 'abstract'.<sup>34</sup>

The problem with these notions of the global is that they presuppose multiple levels of reality and are intelligible only in such a framework. Yet, each level of reality produces an insurmountable gap between them, or it requires wilfully ignoring the connections that lead out to other levels. Moreover, whenever we go out into the field looking for these multiple levels of reality, all we see is the single, same world. One goes to look for neoliberalism, and finds economists and macroeconomic models working at the World Bank. One goes to look for financial globalization, and finds traders and computer systems in New York and London. One goes to look for global governance, and finds diplomats arguing at Security Council meetings. Everywhere we look, we run into more and more local networks, and never some independent realm labelled 'the global'. The question is therefore what are global (and other macro-level) phenomena if they are not a separate ontological space?

### *Flattening Global Actors*

What appears before us is a single plane of existence, rather than differing levels of reality. There are no discrete realms; the local and the global are not separate. Instead the argument that will be made here is that there are only actors of different *sizes*. Some actors, simply put, are capable of exerting force on a wider range than others and are therefore larger than others. Yet the existence of these macro-actors causes us to run into a theoretical problem. If, as assemblage theory suggests, the world consists of independent parts acting according to their own immanent dynamics and logic, it would appear unlikely that something like a macro-actor would ever arise. The chaos of multiple, conflictual, divergent actors would seemingly be too much for something like an institution, a rebel group, a

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<sup>33</sup> Singer, "The Level-of-Analysis Problem in International Relations," 80.

<sup>34</sup> Brey, "Theorizing Modernity and Technology," 63.

state, or a state system to ever emerge. They presuppose too many actors, acting in cooperation (though not necessarily harmony),<sup>35</sup> to appear achievable in a world of divergent actors. Yet macro-actors clearly do exist, and so the question becomes, ‘how?’ Following the insights of actor-network theory, the answer is that macro-actors are constructed through a process of associating durable materials:

“By associating materials of different durability, a set of practices is placed in a hierarchy in such a way that some become stable and need no longer be considered. Only thus can one ‘grow’. In order to build the Leviathan it is necessary to enrol a little more than relationships, alliances and friendships. An actor grows with the number of relations he or she can put, as we say, in black boxes. A black box contains that which no longer needs to be reconsidered, those things whose contents have become a matter of indifference.”<sup>36</sup>

Thus, for instance, a monarchy does not rely solely on transient social relations, but rather develops on the basis of a palace, an array of status symbols, a mercenary force, inherited wealth, various legal documents, claims to divine authority, papal support, property, etc. Crucial here is the fact that these networks of force rely not simply on social relations, but instead incorporate more durable materials as well. It is the latter which overcomes the fragility, fluidity, and flightiness of pure social relations and begins to build up a solid foundation for complex societies to emerge.<sup>37</sup> The introduction of material mediators between individuals helps to stabilise social relations and raise them out of an anarchical

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<sup>35</sup> Robert Keohane makes the important distinction between cooperation and harmony. The latter occurs when actors act together out of mutually shared interests – in this case, there is no discord that needs to be overcome. Cooperation, on the other hand, only occurs when there is discord among actors, and they must be brought together in order to operate as a cohesive unit. Keohane, *After Hegemony: Cooperation and Discord in the World Political Economy*, 51–55.

<sup>36</sup> Callon and Latour, “Unscrewing the Big Leviathan: How Actors Macrostructure Reality and How Sociologists Help Them To Do So,” 284.

<sup>37</sup> Strum and Latour, “Redefining the Social Link: From Baboons to Humans.”

state of nature.<sup>38</sup> Such networks of material and social components must be slowly and patiently constructed (not always intentionally) and arranged so as to be taken as ‘black boxes’ – relatively stable conduits of force that can be relied upon under normal circumstances.

But the notion of a black box highlights a distinction that can be drawn between two types of global actors. On the one hand, there are the established (institutionalised, organised, materialised) networks for creating a global actor – the realm of black boxes that Callon and Latour examine. On the other hand, there are the global actors which operate *without* the need for a series of black boxes. In this regard, al-Qaeda perhaps exemplifies the macro-actor that need not rely on black boxes. Instead, al-Qaeda used the tight interconnections of modern networks against those very networks, in order to act upon key nodes which then created disproportionately large effects. Al-Qaeda required only a minimal construction of conduits through which it could exert itself reliably; yet it remains a global actor because it caused a wide range of other actors to be affected. From this it can be concluded that a minimal condition for being global is the capacity to affect large numbers of actors that are widely dispersed throughout a series of assemblages. Whether an actor is global or not is determined as much by the range of effects it can carry out, as it is by the conduit of networks it can ally itself to.<sup>39</sup> The consequence is that there is no intrinsic property of an actor that makes it global – instead it dependent upon the network it finds itself within and the particular structural position it occupies.<sup>40</sup> This is particularly the case insofar as we exist and operate within complex and unpredictable systems. It is a basic property of such systems that small acts can have large consequences, meaning that what consists of a global actor is always up for renegotiation. We can therefore make a distinction between macro-actors that are founded upon a network of ‘intermediaries’ (i.e. black boxes) and macro-actors that are founded upon a network of ‘mediators’ (i.e.

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<sup>38</sup> Schouten, “The Materiality of State Failure: Social Contract Theory, Infrastructure and Governmental Power in Congo,” 559-562.

<sup>39</sup> Daniel Drezner comes to a similar conclusion. See: Drezner, “Contagion in World Politics.”

<sup>40</sup> The field of social network analysis has done much to analyse the particular structural properties of formal networks, delimiting the specific points at which power can be disproportionately leveraged from.

relatively independent actors). Contra Callon and Latour, what makes an actor ‘macro’ or global is not just its construction of conduits for power and the use of durable materials, but also the potential *range* of the effects stemming from an action. A single pedestrian standing in front of a tank in Tiananmen Square is therefore comparably as global an actor as the CEO of Goldman Sachs. The Board of Governors of the International Monetary Fund is as global as the individuals responsible for the destruction of Iraq’s Al-Askari mosque.<sup>41</sup>

The ‘global’ is therefore not a separate ontological realm, nor is it independent of the local, nor is it foundational, nor is it more general. An analysis of the global must focus on the interactions between macro-actors, specifically by tracing their actions through the networks they have organised and affected. The global is an extension of the local, but precisely for this reason, an examination of global actors and events must focus on the local. What this all entails is that any given social field is constructed by actors of varying sizes, materials, relations, and degrees of systemic importance. The analysis of a situation must examine micro-level dynamics and ‘follow the actors’ in order to determine how macro-structures arise. This thesis will undertake this project by examining precisely the interface between practitioners and the technologies of the global they use, with the wager that disproportionately large effects emanate from this space. This general ontology of assemblages and macro-actors therefore provides the basic framework for examining the elements and effects of technology.

### *Power in a Networked World*

With an ontology of assemblages set out, and the global refigured as a series of constructed macro-actors, the notion of power takes on new connotations as well. In one of the most widely cited frameworks of power in IR, Steven Lukes argues for a common definition of power: “*A* exercises power over *B* when *A* affects *B* in a manner contrary to *B*’s interests.”<sup>42</sup> Yet in his additions to the second edition of

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<sup>41</sup> The Al-Askari mosque is one of the holiest sites for Shiite Islam, containing the remains of the 10th and 11th Shia Imams, and was attacked in June 2007, nearly bringing Iraq to a full-out civil war, and eventually leading the entire American military system to change direction.

<sup>42</sup> Lukes, *Power: A Radical View, Second Edition*, 30.

the book, Lukes revises this position and argues that power must not be equated with its use. Rather power is a capacity which may or may not be exercised.<sup>43</sup> If power is a capacity though, and (as we will argue) capacities can be altered through technological augmentation, then power itself is something that can be constructed and augmented.

Power is therefore in accordance with the notion that macro-actors are constructed: it is not something that a priori exists or that is a natural attribute of an actor. It is something that must be built and woven together.<sup>44</sup> As something that must be constructed, power can therefore be altered by changing the material and social infrastructures of societies. Indeed, the operation of power only travels through such conduits.<sup>45</sup> Therefore, one of the main ways in which macro-actors consolidate their control is through the construction of networks of materialised power:<sup>46</sup> “artefacts such as statistics, vessels, maps and sextants start to explain how humans can arrive at keeping relations stable and controlling them from a distance.”<sup>47</sup> In general, therefore, building power involves (1) constructing multiple chains of allied actors, (2) maintaining and expanding these chains, and (3) the effort required to propagate a command through them. From this understanding of power being constructed as a capacity,

“Generalised historical sociology can thus focus on the development of collective and distributive power, measured by the development of

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<sup>43</sup> Ibid., 109.

<sup>44</sup> As Latour will argue, “power and domination have to be produced, made up, composed.” (Latour, *Reassembling the Social: An Introduction to Actor-Network Theory*, 64.) As a side note, this notion of networks of power should make clear that the notion of networks being used here is not in any way opposed to hierarchy. Rather, networks consist of a set of actors who function together in a coherent way – this can be both centralized and decentralized systems.

<sup>45</sup> ‘Power’ must be understood in all of its multi-faceted senses here – it is a capacity for limiting, commanding, constructing, organising, creating, determining, etc. In this sense, it is a capacity of every actor. What is variable is only its strength.

<sup>46</sup> Barry, “The Translation Zone: Between Actor-Network Theory and International Relations,” 415.

<sup>47</sup> Schouten, “The Materiality of State Failure: Social Contract Theory, Infrastructure and Governmental Power in Congo,” 560; Law, “Technology and Heterogeneous Engineering: The Case of the Portuguese Expansion.”



infrastructure. Authoritative power requires a logistical infrastructure; diffused power requires a universal infrastructure.”<sup>48</sup>

As this quote makes clear, traditionally approaches which have adopted this conception of power have focused on infrastructure as a primary medium of power. By contrast, the focus in this thesis will specifically be on how representational technologies construct power capacities and conduits for action. These technologies are similar to the means through which one can “see like a state”, yet these new technologies are distinct in being more flexible and more dispersed than those of state institutions.<sup>49</sup> By constructing a representation of a complex system, such technologies allow particular actors to intervene, manipulate, modulate, and control these systems in ways that other actors are incapable of. Whereas infrastructural forms of power alter the speed and extent of power’s reach, representational technologies create new points of intervention within a sociotechnical assemblage. These technologies also give actors a comparative epistemic advantage and allow them the leverage to spread their actions comparatively further than actors without such technological advantages. This thesis will undertake an examination of how these representational technologies are constructing power and allowing various actors to become larger (in the sense of expanding their range of effectiveness) and carry out new interventions.

## **Methodology**

To demonstrate these claims, the methodological approach taken here will be heavily reliant on a case studies approach. This method has been employed here since it provides the best means to examine the causal mechanisms and effects of technology on actors’ practices. In the first place, given the proposed ontology of the global, the singular nature of these sociotechnical assemblages puts limits on the usefulness of large-N statistical studies. Secondly, the intention of this thesis is to generate new theoretical approaches and entities, and as such is better served by

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<sup>48</sup> Mann, *The Sources of Social Power, Volume 1: A History of Power from the Beginning to A.D. 1760*, 10.

<sup>49</sup> Scott, *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed*.

detailed accounts of individual cases.<sup>50</sup> Thirdly, by focusing on individual technologies, one can open up the black box of technology.<sup>51</sup> If one wants to understand a particular technology's effects on society, then one can adequately understand it by black boxing the internal technical details. Yet if one also wants to argue that technologies develop in a certain way and that this has effects on society, then it is required that one look at the internal details of a technology. This thesis will be arguing for the latter claim, and so the internal details of technologies are therefore significant – something that is missed by high-level methodological approaches. Fourth, and more generally, the nature of technologies is such that making general statements about them is incredibly difficult. It will be argued in this thesis that it is their very nature to constrain and make possible actions, but beyond this broad effect it can be difficult to narrow down a clear causal statement about 'technology' in general. As a consequence, the study of technology is best accomplished through focusing on individual cases.<sup>52</sup>

The case studies have been chosen to provide a broad enough range of empirical material to begin to draw out some interesting conclusions.<sup>53</sup> These cases are chosen to range from the very well-developed and infrastructurally large-scale (climate change models) to the relatively recent and meso-scale (option pricing models) to the new and (so far) small-scale (crisis mapping software). In addition, each draws upon a different area of interest to world politics: nature, markets, and crises. They span a broad variety of issue areas – from climate policy, to financial trading, to humanitarian relief efforts. Finally, each case offers a different type of representational technology: climate models are simulations, option pricing models operate as heuristics, and crisis mapping software is effectively a real-time data synthesiser. From this broad range of examples it is hoped that some preliminary conclusions can be drawn for further research on representational technologies.

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<sup>50</sup> George and Bennett, *Case Studies and Theory Development in the Social Sciences*, 20–21.

<sup>51</sup> Arthur, *The Nature of Technology: What It Is and How It Evolves*, 14.

<sup>52</sup> George and Bennett, *Case Studies and Theory Development in the Social Sciences*, 19–20.

<sup>53</sup> Alternative cases that could also have been chosen include the macroeconomic models used by central banks. Particularly in the wake of the 2008 financial crisis and the prominent role of monetary policy in responding to this crisis, such models have come to play a major role.

In choosing case studies this way, the potential problem of case selection bias arises. However, given that general studies of technology are blind to the specific variations of how different technologies operate, this is an unavoidable risk – cases must be chosen on the basis of their likelihood of providing interesting material. This need not be a problem though, as one researcher writes,

“The important thing is to ask similar questions of each case to consistently apply the theoretical framework developed, and to explore the possibilities of variance within each case – process-tracing – to establish the strength of the claims being made.”<sup>54</sup>

This will be the approach taken here, with the aim of examining unique cases in detail in order to illuminate and test the strength of the theoretical claims being made.

A caveat is necessary first though. With case studies on such technical issues, combined with my own outsider status with regards to these areas, it is possible that some errors have arisen in the technical details. Nevertheless, I believe that the broad picture will stand up to scrutiny. In addition, it should be specified that this thesis does not aim to make an original contribution to evidence or data on the history of these technologies. For most of the technologies examined here, thorough histories have already been written by people far better positioned than myself to do so. Instead this thesis aims to contribute by bringing together disparate fields and technologies in order to try and highlight the commonalities between them, and to organise them according to a unique theoretical framework.

In its general inclination, this thesis is guided broadly by a similar worldview to that of actor-network theory. Actor-network theory has, at this point, become a wide-ranging and internally pluralistic approach. Claims about ANT in general are therefore inevitably bound to miss the mark. Instead we will here briefly take Bruno Latour as representative of a dominant ANT approach and highlight

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<sup>54</sup> Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*, 42.

what is problematic and what is useful. In the first place, there is the problematic reduction of different entities to a basic level of ‘actors’ – a reduction that overlooks important distinctions to be made between entities. Second, there is a lack of scientific realism in his work. Despite claiming to move beyond the realism/anti-realism debate, Latour tends to situate himself on the side of anti-realism by eliding the distinction between concepts and object.<sup>55</sup> Finally, and most problematically for our purposes, Latour tends to explicitly reject the goal of producing explanations.<sup>56</sup> This stems from Latour’s desire to look at the sociology of knowledge – how knowledge is diffused and is legitimated – yet it means that he can (ostensibly) make no contribution of his own. This is not to say that Latour’s work does not make contributions (it most certainly does), but it means there is a tension between the explicit methodological prescriptions that Latour makes<sup>57</sup> and the explicit knowledge claims he draws elsewhere. For the purposes here, what is most important about ANT is three factors. First, as we have already seen, the notion of macro-actors and their conception of the local-global relationship is a significant advance upon previous theorising about the ‘global’. Second, there is the minimal sense of agency that ANT argues exists in nonhuman objects, which correctly acknowledges their relative autonomy from humans. This leads directly to the third point which is the general (and useful) prescription that one should attend to both material and social elements in trying to understand a phenomenon. For the most part, IR has left aside the material aspects as mere background and neglected how they contribute to explaining events.

## **Conclusion**

The remainder of this thesis builds upon the theoretical proposals set forth here, and is oriented around three case studies: general circulation models in climate change policy, option pricing models in financial markets, and crisis mapping software in humanitarian relief projects.

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<sup>55</sup> Brassier, “Concepts and Objects.”

<sup>56</sup> Latour, *Reassembling the Social: An Introduction to Actor-Network Theory*, 147.

<sup>57</sup> *Ibid.*, 141-156.

The next chapter will begin by outlining a theory of technological autonomy, establishing the mechanisms through which technology shapes society and shapes its own development. It will put forth a theory of technology as a platform upon which social dynamics operate, thereby emphasising the contributions that materiality makes to the social world of global politics. The third chapter will turn towards specifically representational technologies, drawing upon research in cognitive science, media theory, and philosophy of science. It will articulate a theory of the ways in which representational technologies augment cognition, and highlight how this alters traditional conceptions of knowledge production within IR.

The fourth chapter turns to the first case study: the development and use of general circulation models in making the global climate visible and intelligible. Here it is shown how frictions within the materiality of these models helped channel the development of these technologies along certain paths. These models then served to make new perceptions of the global climate available, which in turn have made possible a new series of behaviours that political actors are beginning to employ. The fifth chapter looks at option pricing models in global financial markets. In the face of an increasingly complex ecosystem of financial actors and products, options traders have repurposed an existing technology in order to compare, contrast, and simplify the available data. Through the technologically produced representation of implied volatility, traders are able to enter into the market and conduct interactions. The sixth chapter turns to the more recent technology of crisis mapping software. Initially developed to map post-election violence, it is now being employed by humanitarian institutions as a means to generate real-time situational awareness of crisis situations. This chapter will look at the development of this technology and how it is altering the possible behaviours of humanitarian actors.

The final chapter steps back from the detailed case studies in order to summarise some of the general conclusions from the evidence. In addition, it sets out a framework for understanding the politics of these particular representational technologies. Significant here is the ways in which such technologies alter the

infrastructure of power and where a critical approach to these technologies might lead.

## 2 / THE MATERIAL CONSTRUCTION OF WORLD POLITICS

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“Yes, society is constructed, but not socially constructed.”<sup>1</sup>

-Bruno Latour

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In the introductory chapter, the basic problem of cognitive mapping was laid out and a wager on the solution put forth. On the basis of the ontological, epistemological and methodological framework set out there, this chapter will attempt to lay the theoretical groundwork for understanding the role of technology in world politics. The argument will be made here that the technological infrastructure of the world contributes to the practices and thoughts of political actors, and that technology and its effects must therefore be given due consideration. The first part of this chapter will examine the nature of technology and explicate the basic analytical categories of research. The second section will undertake a review of existing work in IR on technology, while noting its limitations. The third part will argue for the relative autonomy of technology – i.e. its irreducibility to social explanations – which therefore makes it an important independent factor in understanding world politics. It will be shown that technology operates as a platform for social practices and for further technological development. The overall aim of the chapter is to make distinct what type of technologies are being examined in this thesis, at what level of technology this is being approached, and how technology factors into explanations of political events.

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<sup>1</sup> Latour, *Pandora's Hope: Essays on the Reality of Science Studies*, 198.

## The Levels of Technology

As the term ‘technology’ often conflates a number of different aspects, it is important to clarify these distinctions and establish the level of technology that is being examined. Generic invocations of an all-encompassing Technology are often of little use for making sense of how technologies interact and affect the surrounding world. Instead, the following section will examine three distinct levels of technology – first as an ontological category, second as an object (i.e. technologies), and third as a large sociotechnical system (i.e. assemblages).<sup>2</sup> These will help to specify the uniqueness of technology, and provide the analytical framework for understanding technology’s capacity to act.

### *Ontology*

At the broadest level of analysis one finds technology to be understood as a particular mode of being. Martin Heidegger’s analysis of technology is the most prominent of these approaches, having influenced generations of critical humanist scholars since its initial publication. He begins his analysis with a description of the standard answers to ‘what is technology?’: “Everyone knows the two statements that answer our question. One says: Technology is a means to an end. The other says: Technology is a human activity.” However, according to his project, this “instrumental and anthropological definition of technology [...] makes us utterly blind to the essence of technology.”<sup>3</sup> In arguing that instrumentalist and anthropological approaches miss the essence of technology, Heidegger proposes an alternative: to understand technology as a way of Being revealing itself – a mode of Being that turns it into mere ‘standing-reserve’ which makes possible the instrumental view of nature in the first place. Yet problems with this generic and overarching conception of technology quickly arise. Placed at an abstract ontological level, Heidegger’s analysis largely ignores actual technologies in favour

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<sup>2</sup> While it would take us away from the main aims of this project, it is also possible to examine technology as an ecosystem with its own holistic dynamics. The most suggestive and sophisticated approach here is arguably: Arthur, *The Nature of Technology: What It Is and How It Evolves*. Though also see: Kelly, *What Technology Wants*; Basalla, *The Evolution of Technology*.

<sup>3</sup> Heidegger, “The Question Concerning Technology,” 4.



of philosophically elaborating his own metaphysical system.<sup>4</sup> Moreover, Heidegger's ontological reading of technology compels him to efface the differences between technologies, as well as ignore the dynamics of technology. Pitched in such a generic formulation (as a mode of Being's unconcealment), technology has significance only for the broadest of analyses (e.g. epochal shifts in Being). In other words, Heidegger's analysis is both too simple and too general. By contrast, while the philosophy of technology since Heidegger remains influenced by his work, it has predominantly taken a distinctly empirical approach since.

This empirically-grounded work has since made it clear that Heidegger's own implicit sense of technology is of industrial technology.<sup>5</sup> While arguably appropriate for his time, particularly with the rise of mechanised warfare, his view of technology neglects more recent developments in information technologies, biological technologies, nanotechnologies, and representational technologies. What Heidegger's analysis of technology demonstrates is that a focus on its ontological nature necessarily obscures the ontic (empirical) variation in technological objects. The problems with this approach arise not only in Heidegger's classic text, but also in similar attempts to pitch technology at overly abstract levels. With the empirical specificity lost, technology is set against some other equally grand abstraction – one which almost invariably is taken to be the “human” side of the equation.<sup>6</sup> Lifeworlds, selves, phenomenology and so on, are articulated in opposition to technology, leaving their mutual interconnections and their empirical variations to the side. Moreover, the abstraction of technology-in-general inevitably leads to despairing and unjustified conclusions about technology's dominance over humans.<sup>7</sup> An analysis of technology should therefore begin with technologies themselves and work from the ground-up, rather than beginning with the most general aspects and ignoring important empirical differences.

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<sup>4</sup> Ihde, *Heidegger's Technologies: Postphenomenological Perspectives*, 19.

<sup>5</sup> *Ibid.*, 119.

<sup>6</sup> Misa, “The Compelling Tangle of Modernity and Technology,” 8-9.

<sup>7</sup> Marcuse, *One-Dimensional Man: Studies in the Ideology of Advanced Industrial Society*.

### *Objects*

If technology is not usefully characterised as an ontological mode of being or as a singular entity in itself, one must instead turn towards the multiple *technologies* which act in the world according to a variety of means. The definition of technological objects used here will therefore follow Langdon Winner's definition: "tools, instruments, machines, appliances, weapons, gadgets – which are used in accomplishing a wide variety of tasks."<sup>8</sup> This formulation excludes technical know-how and excludes immaterial technologies such as institutions. On the basis of this definition, we can also draw an initial distinction between individual technological objects and the larger sociotechnical assemblages they are embodied within. Each of these analytic categories encapsulates unique dynamics.

The first general aspect of technological objects concerns their invention. The creation of technologies appears to be summed up in the common sense notion that "necessity is the mother of all invention" – a phrase which sets technological innovation as the response to a particular need. Yet both empirically and theoretically this claim falters. An examination of the historical record shows many (often important) examples of inventions created without any pre-given need for them. An exemplary case here is the automobile, which was invented without a prior need or problem to respond to. It was originally the preserve of a few wealthy individuals and considered a frivolous gadget. Its creation, however, shifted the very space of possibilities and eventually created its own need.<sup>9</sup> It became a necessity retroactively. Theoretically, as well, the argument that necessity produces invention falters on the inability to precisely determine what is a 'need' and what is a 'solution'. Basic agriculture may be a need, for instance, but is the tractor a need? This is not to deny that necessity can be the mother of invention in particular cases, yet many inventions originate in more speculative ventures (with Leonardo da Vinci's sketchbooks of wild inventions being a paradigmatic example here).

A second general aspect of technological objects has to do with their relationship to their environment – both material and social. Here we can follow

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<sup>8</sup> Winner, *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*, 11.

<sup>9</sup> Basalla, *The Evolution of Technology*, 7.

Deleuze and Guattari's insight when they write, "The principle behind all technology is to demonstrate that a technical element remains abstract, entirely undetermined, as long as one does not relate it to an assemblage it presupposes."<sup>10</sup> As was argued in the previous chapter, any given technological object consists of multiple potentials, and particular sociotechnical assemblages act to reinforce particular capacities while restraining others. Consider for instance, the wheel which is often taken as the paradigm of human invention – a seemingly clear cut case of technological advancement. Yet in Mesoamerica, the wheel was used widely in toys but not for transportation. In other words, while these polities evidently had the capacity to produce wheels, they never put them to what we consider to be their archetypal use. The answer to this apparent puzzle is to recognise that in their geographical context, the wheel-as-transportation was ill-suited to an environment with dense jungles and a lack of domesticated pull-animals. Similarly, in North Africa and the Middle East, wheels were invented but eventually superseded by travel via camels.<sup>11</sup> The particular social and material assemblage this technological object found itself within constrained the capacity of the wheel to provide efficient transportation. The need for quick transportation and large hauling capacity were more efficiently solved by camels in this case, rather than oxen pulling wagons.

With these examples, we can mirror the important distinction made earlier between capacities and properties with a distinction between capacities and uses. While the latter is what technology is most often reduced too, ontologically speaking it is capacities which are primary. *Uses* are derivative and secondary characteristics of objects, grounded in the last instance upon their *capacity* to do things.<sup>12,13</sup> A wheel, for instance, has multiple potential capacities (as transport, as toy, as mechanical cog, etc.), yet the actual uses it is put to are dependent on the sociotechnical assemblage. Whereas uses are reliant on humans, capacities are based primarily on the physical properties of the object. If the nature of

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<sup>10</sup> Deleuze and Guattari, *A Thousand Plateaus*, 397-398.

<sup>11</sup> Basalla, *The Evolution of Technology*, 9-11.

<sup>12</sup> Don Ihde evokes a similar idea in terms of postphenomenological variations: Ihde, *Postphenomenology and Technoscience: The Peking University Lectures*, 16-19.

<sup>13</sup> Bryant, "Of Concepts and Philosophy: Further Meditations."

technological objects is not reducible to their uses but rather to their capacities, then technology is already relatively independent of social forces.

A similar independence arises in relation to their environment, where technological objects do not merely adapt to an existing context but also shape their context. In Deleuze and Guattari's terms, there is a mutual becoming between the two. Important here are two types of mutual adaptation by technologies to their environment: first, one which leaves the autonomy of the object intact, the second which makes it inseparable from the environmental conditions. The former case arises with early planes, for instance, which were capable of taking flight and landing in any flat space; most modern planes on the other hand require a built-up environment in the form of long landing strips and the social organization of air traffic controllers.<sup>14</sup> These later planes have become inextricably intertwined with a very specific environment – a more restricted environment than earlier planes required (though with more capacities in other areas as a result). There has, in other words, been a co-evolution between the object and its environment. Technological objects also enter into pre-existing assemblages and must undergo some process of transformation in order to be slotted into these networks – a process which both shapes the object and its specific assemblage. For instance, the nature of the automobile varies when it enters into assemblages comprised of different weather conditions, legal structures, national driving habits, etc.<sup>15</sup> Similarly, a “tool or contrivance that has been designed to function in one natural setting often must be altered if it is to work properly in a new environment.”<sup>16</sup> To reiterate Deleuze and Guattari's point, individual technologies are therefore abstract when not related to the sociotechnical assemblage within which they function at particular times and places.

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<sup>14</sup> Simondon, *On the Mode of Existence of Technical Objects, Part I*, 52.

<sup>15</sup> Basalla, *The Evolution of Technology*, 91.

<sup>16</sup> *Ibid.*, 88. This mutual conditioning of airplanes and their environment has of course brought about numerous advances in the capacities of flight, yet the point still remains that this flight technology is now reliant upon a much larger sociotechnical system.

## Systems

These discussions of the environment of a technology – both the environment that it depends on, and the environment that depends on it – demonstrate that technological objects already implicate larger sociotechnical systems.<sup>17</sup> It is here that a second sense of technology emerges: in the notion of a large technical system (LTS) or sociotechnical system that has a distinct nature and operates with unique dynamics. Sociotechnical systems such as railroad networks, electrical grids, water supply systems and telephone infrastructures are all comprised of multiple individual technological objects that function synthetically, but that also include organizations, legal systems, and natural resources (hence the ‘socio’ prefix).<sup>18</sup> The importance of these massive infrastructures is hard to overstate:

“[These] ‘large technical systems’ [are seen] as new, human-made ‘deep structures’ in society. Strongly influencing where and how people live, work, play, and make war, they may have surpassed politics and natural geography in prominence.”<sup>19</sup>

The massive scale of these systems can be seen in the worldwide sociotechnical system for computing networks which now involves over 170 quadrillion computer chips, and is alone responsible for nearly 5 per cent of the world’s energy consumption.<sup>20</sup> In addition to providing a basic deep structure to society, sociotechnical systems are also important for understanding the regional and global infrastructures that make particular technologies functional.

Analytically at least two different types of sociotechnical systems can be discerned. In the first place, there are those which enable some material to circulate – whether it be people, goods, energy, or information. Secondly, it is also

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<sup>17</sup> A similar distinction is drawn between Level I and Level II technologies in Allenby and Sarewitz’s work. (Allenby and Sarewitz, *The Techno-Human Condition*.)

<sup>18</sup> Hughes, “The Evolution of Large Technical Systems,” 51.

<sup>19</sup> Van der Vleuten, “Infrastructures and Societal Change: A View from the Large Technical Systems Field,” 399. There are clear resonances here with Marx’s famous quote that “People make their history, but not in the circumstances of their own choosing.”

<sup>20</sup> Kelly, *What Technology Wants*, 14.

possible to speak of sociotechnical systems that take certain inputs, perform some transformation on the material, and produce certain outputs – such as global climate observatories, financial networks, and scientific research communities. The spatial scale of these systems also provides another variable factor, ranging from relatively regional systems to more expansive systems that encompass global networks.

The origins of sociotechnical systems tend to result from the concerted efforts of multiple actors. Thomas Hughes' now famous examination of Thomas Edison and his creation of the electrical system demonstrates the multiple actors who came together to produce that specific LTS. The political actors changing legal regulations, the business people modelling electrical distribution after gas distribution, the engineers creating new mediums to transfer electricity, along with Edison himself and his innovative vision.<sup>21</sup> In other words, the social and the technological were irreducibly intertwined. Yet the building of a sociotechnical system is never entirely completed. Most notably, there is always an internal tension within these systems between the aims of the system-builders and the requirements of individual users. Whereas the former aims at a homogeneous, standardised system, the latter group individualises technical interfaces for their own purposes. Sociotechnical systems are, in other words, co-constructed by users and technology.<sup>22</sup>

While this thesis will choose to focus primarily on technologies rather than sociotechnical systems, the analytic distinction between the two is nevertheless useful to keep in mind. Before examining how technology has featured in the IR literature, two final comments are necessary to both complicate and clarify the nature of technology. First, at a fundamental level, there is little to distinguish between technical objects and sociotechnical systems: both consist of components that cohere together in functional, physical, and social ways. As both Gilles Deleuze and Brian Arthur will argue in different ways, assemblages consist of

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<sup>21</sup> Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*.

<sup>22</sup> Oudshorn and Pinch, *How Users Matter: The Co-Construction of Users and Technology*.

components, and these components are themselves assemblages.<sup>23</sup> It is assemblages all the way down. The second point to make is that the dominant approach today is to approach these assemblages as immediately sociotechnical in nature – and to argue that it makes no sense to separate out the social from the technical.<sup>24</sup> While in practice one always finds these two in mixtures, it is nevertheless revealing that these recent approaches still retain terms like ‘social’ and ‘technical’ in their works. There is an analytical usefulness to separating out the two, even while recognising that they are always mixed together in the world.<sup>25</sup> It is for this reason that this thesis will self-consciously choose to employ terms like the social, the technical, the ideational, and the material.

### **Materiality in IR**

Within the IR literature, technology has rarely been the central focus of research, instead typically acting as a background given or a derivative factor.<sup>26</sup> In the instances where technology has been taken as a central component, the dominant emphasis has been on technological objects rather than sociotechnical systems.<sup>27</sup> More specifically, this attention on technology has tended to focus narrowly on three types: communications, military, and interaction. This section will examine the existing research on technology in IR in order to uncover how technology is typically understood to play a role in world politics. The final part of this section will turn to analyses of materiality in IR as well, whose approaches parallel some of the arguments that will be made later for technological autonomy.

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<sup>23</sup> Deleuze and Guattari, *A Thousand Plateaus*; Arthur, *The Nature of Technology: What It Is and How It Evolves*.

<sup>24</sup> Representative here is: Bijker, *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*, 274.

<sup>25</sup> Barry, *Political Machines: Governing a Technological Society*, 8–9.

<sup>26</sup> The literature in IR which has directly focused on technology is relatively small: Granger, *Technology and International Relations*; Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*; Ogburn, *Technology and International Relations*; Skolnikoff, *The Elusive Transformation: Science, Technology, and the Evolution of International Politics*; Rosenau and Singh, *Information Technologies and Global Politics: The Changing Scope of Power and Governance*; Sanders, *International Dynamics of Technology*.

<sup>27</sup> One major exception is: Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*.

### *Military Technology*

Perhaps the most obvious type of technology IR has focused on has been military technology. From the role of the stirrup in producing the possibility of knights, to the role of cannons in siege warfare, to the role of aviation and industrialization in modern war, and nuclear weapons in the stalemate of the Cold War – technology has clearly been an important element in determining the dynamics of war. While there are many general studies of technology and war,<sup>28</sup> two specific examples can illustrate how technology is typically incorporated into IR: the machine gun and nuclear weapons.

With the introduction of the machine gun into the military assemblages of WWI, it has been argued that this innovation wrought repercussions throughout the entire system. It was already clear after the American Civil War that “repeating rifles, large calibre artillery, armoured ships and Gatling guns were the new weapons of the Industrial Revolution and as such were bound to fundamentally alter the most basic concepts of war.”<sup>29</sup> Yet the military strategists of WWI had largely ignored this shift and continued to wage war with standard military organizations, tools, tactics, and strategies. The result was the utter disaster of WWI’s war of attrition. On the one hand, the generals believed war was still a matter of wills – the stronger willed would be the victors. (In fact, there are even instances of generals explaining the success of machine gunners by attributing to them stronger wills.)<sup>30</sup> On the other hand, there was the sheer firepower made available by the new machines of war. The success of battles was no longer determined by will, courage, moral strength, or intentions – it was a war determined in the last instance by machines.

What can be seen here is how, despite ingrained attitudes resistant to change, the introduction of the machine gun revolutionised warfare by altering the behavioural possibilities. It coerced military strategists to (eventually) reject centuries of doctrine, bias, and tradition. It changed the education of soldiers, and

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<sup>28</sup> van Creveld, *Technology and War: From 2000 B.C. to the Present*; McNeill, *The Pursuit of Power: Technology, Armed Force, and Society Since A.D. 1000*.

<sup>29</sup> Ellis, *The Social History of the Machine Gun*, 51.

<sup>30</sup> *Ibid.*, 138.



the production of weapons. Finally, it changed the tactics of war, the strategies formulated by the generals, the organization of battalions, and the entire institutional culture of the military. The old values of a gentleman's war, premised upon romantic ideals of heroism and courage, were tossed violently aside by the inhuman force of the new weapon. It led to the new era of defensive, entrenched war rather than offensive war. The battles of the past, with armies facing each other and duelling in close quarters, were gone.<sup>31</sup>

A similar paradigm shift in warfare occurred with the invention of nuclear weapons. Nuclear weapons provide one of the more intriguing cases of how material entities can shape international politics because unlike the machine gun, nukes produce effective change even (and perhaps, particularly) when they are not actively used. Their mere existence is sufficient to alter behaviours and strategic calculations because of the rapid advance in force capacities they represent.<sup>32</sup> As Waltz argues in a somewhat overstated way, "*Nothing can be done with them other than to use them for deterrence.*"<sup>33</sup> The entire theory of deterrence is premised upon this effective and passive power of nuclear weapons. Rational actors are taken to understand the retaliatory consequences of attacking a nuclear power, and therefore change their own behaviours as a result. It is this certainty of mutual destruction which alters the entire international system: "The superpower relationship is now deprived of the basic principle defining an anarchic international system: the ever-present possibility of recourse to force."<sup>34</sup> The types of calculations that derive from a state of deterrence – whether the number of nuclear weapon is sufficient for deterrence, whether second-strike capabilities are credible, whether extensions of deterrence to allies are viable, etc. – are all impositions on the actions of actors by *inert* material forces. With nuclear

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<sup>31</sup> It is worth noting that while some theorists of military technology present it in a deterministic way, this is not always the case. Technology – as will be shown – acts by shaping general behavioural possibilities, not by determining specific practices. There is always room for manoeuvrability and interpretation to affect how a weapon is precisely taken up into military doctrine. See, for instance: Price, "A Genealogy of the Chemical Weapons Taboo." I thank Paul Kirby for highlighting this to me.

<sup>32</sup> Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*, 184-186.

<sup>33</sup> Sagan and Waltz, *The Spread of Nuclear Weapons: A Debate*, 98.

<sup>34</sup> Weber, "Realism, Detente, and Nuclear Weapons," 63.

weapons, therefore, we see perhaps one of the clearest cases where technology shapes international politics just by virtue of its existence.

### *Communications Technology*

In addition to military technology, with neoliberal institutionalism and globalisation theorists comes an increased recognition of the effects of communications technologies on world politics. Globalisation, the rise of complex interdependence, and the ensuing changes in the nature of the international system are all considered to partially result from advances in transportation and in communications technologies. For instance, in an influential account, David Held's first 'driver of globalisation' is listed as "the changing infrastructure of global communications linked to the IT revolution".<sup>35</sup> Such changes are considered to bring communities closer together, knitting them into a global web of communication.

Yet for all the importance attributed to technological changes, technology and its dynamics remains exogenous to these theories. Neoliberal institutionalists recognise that technology plays an important role in setting the conditions for increased interdependence and the rise of non-state actors, yet these are considered to be events that occur outside of the system and which slowly dissipate their way into affecting the international system.<sup>36</sup> It is considered that technological dynamics can safely be left outside IR theory.

One major exception to this tendency has been Ronald Deibert's work. Here the attention has been on the specific materiality of communications technologies, focusing not on the *content* of communication but rather on the *medium* of communication. In this view, the technology of communications has produced effects along two lines: distributional consequences, and social epistemological consequences. In both cases, the effective action of technology operates not in terms of linear causal relations, but instead in terms of evolutionary

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<sup>35</sup> Held, *Global Covenant: The Social Democratic Alternative to the Washington Consensus*, 11.

<sup>36</sup> Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*, 20; Fritsch, "Technology and Global Affairs," 38.

selection, i.e. a structural cause.<sup>37</sup> Distributional consequences refer to the changes in social forces that result from a new communications environment. For instance, the rise of the printing press facilitated (that is to say, selected) those interested in breaking down the medieval Church's monopoly on communication and knowledge.<sup>38</sup> Cheaper, easier, and more ubiquitous texts were made available and increasingly rendered Church censorship impotent. The breakdown of the medieval world order is thus partially attributable to the capacities of action made possible by these new tools. Along another dimension lie changes in social epistemology. In this case, communications environments select not for social forces, but instead for ideas and beliefs about the world. To cite just one example, ideas about the individual (modernist) self were aided with the printing press as well. With the diffusion of this technology it became easier to attribute a single author to a work, texts could be mass produced and standardised, and the shift from oral communication to silent reading fostered a sense of internal space.<sup>39</sup> In neither case of distributional and social epistemological changes did the content of the works have to be taken into account. It was the sheer material nature of these tools which brought about changes in politics and society. In Deibert's work, therefore, there is a sophisticated and nuanced approach to how technology shapes behaviours and international politics.

### *Interaction Capacity*

While most studies of technology in IR have focused on specific types of technological objects, there are a handful of more recent approaches which have begun to examine the influence of sociotechnical systems on world politics. Barry Buzan and Richard Little's work on international systems, along with recent extensions by Geoffrey Herrera, have placed these systems into a prominent role in understanding international relations. In explaining the shifting structures of the

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<sup>37</sup> Deibert, *Parchment, Printing, and Hypermedia: Communication in World Order Transformation*, 32-35.

<sup>38</sup> *Ibid.*, chap. 3.

<sup>39</sup> *Ibid.*, chap. 4.

international system over world history Buzan and Little give a major explanatory role to what they call interaction capacity, which they define as:

“The amount of transportation, communication and organisational capability within the unit or system: how much in the way of goods and information can be moved over what distances at what speeds and at what costs? [...] *It refers to the carrying capacity of a social system, its physical potential for enabling the units within it to exchange information, goods, or blows.*”<sup>40</sup>

Interaction capacity is here considered to place fundamental limits on what a given social system is capable of – it provides the ‘capacity’ and ‘potential’ that outline the possibilities of a system.<sup>41</sup> It is within such confines that international systems can arise and act. In particular, the ability to wage war over long periods of time and space is a relatively recent achievement. Such an ability is dependent on the possibilities afforded by high levels of interaction capacity: the existence of supply lines, transportation routes, and communication capacities. As a result, these physically-determined abilities make possible both the units of the international system as well as the system itself.<sup>42</sup> (Technologically-based interaction capacity also highlights the mutability of even natural factors like geography – seas are transformed from limits to possibilities once seafaring technology becomes available, for instance.)

A recent work from Geoffrey Herrera has extended this concept and operationalised it in terms of sociotechnical systems.<sup>43</sup> The goal of his work is to

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<sup>40</sup> Buzan and Little, *International Systems in World History: Remaking the Study of International Relations*, 80 (emphasis added) This idea of interaction capacity also shares many features with what Michael Mann has examined in terms of networks of power – namely, the essentially *logistical* means to achieve goals. See: Mann, *The Sources of Social Power, Volume 1: A History of Power from the Beginning to A.D. 1760*.

<sup>41</sup> A similar claim is made in Ferguson and Mansbach’s work, where technology is deemed a permissive cause rather than a compelling cause. Ferguson and Mansbach, *Remapping Global Politics: History’s Revenge and Future Shock*, 273.

<sup>42</sup> Buzan and Little, *International Systems in World History: Remaking the Study of International Relations*, 82.

<sup>43</sup> Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*, 8.

bring technology into international relations as an endogenous source of systemic change.<sup>44</sup> This occurs in two ways – first, by noting that some technological systems are systemic and not unit-based; and second, that technology is political (e.g. the development of the atomic bomb). As a consequence, the development of global sociotechnical systems must be analysed in both their international development and diffusion, and then in terms of their effects on the interaction capacities of the system.

Despite the sophisticated systematic approach taken by Herrera, he tends to remain bound within a socially-mediated vision of reality by claiming that, “If technologies are systemic but not political, we would have no need to think about them as inside the international system.”<sup>45</sup> In other words, despite the nuanced theorisation of how technology affects international politics, Herrera claims that if technology were autonomous from politics and humans it would therefore be of little theoretical interest. By contrast to such a thesis, it will be argued later that technology has a variety of autonomous dynamics that must be acknowledged by any theory of the international system. These have political effects, yet they are *not* reducible to their uses, effects, or the intentions behind them. To say that technology’s effects interact with political and social entities is one claim; yet to say that technology has no autonomy from these entities is to entirely neglect their physical *and* systemic nature.

### *Rump Materialism*

In addition to communications, military, and interaction technologies, various strands of IR have also attempted to incorporate materiality in general. While being a broader category than technology, materiality in IR has occupied a similar explanatory role – seeking to demonstrate that something outside of the social world impinges on that world and shapes it in some way. Constructivism, despite being typically associated with the role of ideas, norms, and intersubjective structures, is also notable for various attempts to incorporate some modicum of

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<sup>44</sup> Ibid., 4.

<sup>45</sup> Ibid., 27.

materialism. In an effort to maintain the independent role of ideas while avoiding the (purported) excesses of ungrounded poststructuralism, constructivists often pay token allegiance to the idea of a material world. In Emanuel Adler's work, for instance, matter is taken to provide resistance to human individuals – yet nothing more is said about it.<sup>46</sup>

Alexander Wendt's work elaborates on this constructivist materialism slightly more in his notion of rump materialism. In outlining this materialism, Wendt points to three areas where materiality has an independence from any social meaning: the physical distribution of states' material capabilities, the nature of these material capabilities (i.e. the specific type of weapons and tools), and the geographical landscape and natural resources of a state.<sup>47</sup> Yet considering the lack of any reflection on *how* these factors affect international relations or how they change in themselves, this rump materialism remains – at best – an exogenous variable in the theory.<sup>48</sup> Worse, in two aspects, Wendt backs away from even this minimal materialism, thus remaining stuck within a more ideational-based ontology that reduces materiality to a secondary status.

In the first place, Wendt argues that – in principle, if not yet in fact – all materiality is alterable by human intervention and therefore could be reduced to the human intentions behind this intervention.<sup>49</sup> The implicit argument here is that technology has no autonomy beyond its uses and intentions – technology is at least potentially explainable as a derivative effect of human intentions. Secondly, Wendt states that “ultimately it is our ambitions, fears, and hopes – the things we want material forces *for* – that drive social evolution, not material forces as such.”<sup>50</sup> In other words, despite according independence to material factors Wendt remains convinced that they do no explanatory work in understanding social dynamics. They provide a background element to human action, but do not themselves act.

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<sup>46</sup> Adler, “Seizing the Middle Ground: Constructivism in World Politics,” 92.

<sup>47</sup> Wendt, *Social Theory of International Politics*, 110–112. Wendt also supplements his rump materialism with what he argues to be a materialist theory of human nature (p. 130–135), yet there is no justification given for why these aspects form human nature. As with classical realists, the highly problematic idea that there is an identifiable human nature should be left aside.

<sup>48</sup> Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*, 25.

<sup>49</sup> Wendt, *Social Theory of International Politics*, 112–113.

<sup>50</sup> *Ibid.*, 113.

### *Geopolitics*

A similar understanding of materiality occupies much of geopolitics. In this tradition, a focus on geography was crucial because it was considered to form one of the most permanent factors involved in a state's struggle for existence and power.<sup>51</sup> The early geopolitical theorist Harold Mackinder's most basic thesis was that with the completion of world exploration, there had occurred an epochal shift to a closed world system.<sup>52</sup> Such a transition dramatically altered the nature of great power strategy as a result, and made possible the ability to produce universal generalizations about the effects of geography (since there was no longer an outside to interfere with the system). In geopolitical thinking, the history of conflicts has been shaped by the affordances offered by different geographical features. Thus, throughout history the steppes of southern Russia had provided the open space for nomadic peoples to rush into the more settled lands of Eastern Europe and Russia. Yet once they reached these settled civilizations, their effective power was altered by the new geographical territory and nullified.<sup>53</sup> Similarly, the 'pivot' of power was determined by material locations and features – Russia's great interior and situatedness between Asia and Europe made it into the key area for regional and world dominance.<sup>54</sup> Other geopolitical theorists extended this project by analysing the ways in which territorial size and the location of capitals within states affect defensive capabilities.<sup>55</sup>

Similarly, modern-day geopolitical thinkers have continued these lines of argument and contended that there are shifts occurring in the spatial centres of world power.<sup>56</sup> Again, the determination of this shift is premised upon the

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<sup>51</sup> Spykman, "Geography and Foreign Policy, I," 29.

<sup>52</sup> Mackinder, "The Geographical Pivot of History," 422.

<sup>53</sup> *Ibid.*, 427.

<sup>54</sup> *Ibid.*, 434–436.

<sup>55</sup> Spykman, "Geography and Foreign Policy, I," 32.

<sup>56</sup> Walton, *Geopolitics and the Great Powers in the Twenty-First Century: Multipolarity and the Revolution in Strategic Perspective*.

geographical positioning of the great powers and the locations of crucial resources. With the emerging multipolar structure of power, it is argued that the geographical focus of strategic attention is shifting to Eastern Eurasia (roughly from Pakistan to Japan and Australia).

Notably for the purposes here, there is a recognition by contemporary geopolitical thinkers that technology alters the effects of geography on states.<sup>57</sup> In its most sophisticated varieties, geopolitics is deemed to be concerned with the ‘forces of destruction’ understood as the conjunction of technology and geographical features.<sup>58</sup> In this vein, the introduction of railroads mitigated the negative aspects of sizeable territories; and the revolutions in communications technology made long-distance control a viable possibility.<sup>59</sup> Some have gone so far as to argue that geopolitics is now obsolete as the old constraints of geography and space have withered under the advance of new technological means.<sup>60</sup> Yet a quick glance at the mountainous terrain of the Afghanistan-Pakistan border or the supply logistics of the Khyber Pass – and the difficulties these have posed for the most powerful military in human history – demonstrates that this claim overstates the significance of technology.

Throughout this literature, geography is often taken explicitly as a *conditioning* factor, not a determining factor. As Nicholas Spykman wrote,

“Geography does not determine, but it does condition; it not only offers possibilities for use, it *demand*s that they be used; man's only freedom lies in his capacity to use well or ill or to modify for better or worse those possibilities.”<sup>61</sup>

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<sup>57</sup> Deudney, *Bounding Power: Republican Security Theory from the Polis to the Global Village*, 14.

<sup>58</sup> Deudney, “Geopolitics as Theory: Historical Security Materialism,” 88.

<sup>59</sup> Spykman, “Geography and Foreign Policy, I,” 46–48.

<sup>60</sup> Walton, *Geopolitics and the Great Powers in the Twenty-First Century: Multipolarity and the Revolution in Strategic Perspective*, 20–21.

<sup>61</sup> Spykman, “Geography and Foreign Policy, I,” 30n3. (emphasis added)



Similarly, others have rejected any geographical determinism and spoken of uncovering the ways in which geography “disciplines” politics.<sup>62</sup> When contemporary geopolitics expands its concerns to include the ‘material context’ not only of geography but also of technology, it comes to formulate the role of materiality in a way that will closely mirror the approach of this thesis. Material contexts end up providing a series of constraints and opportunities for political actors to then face up to and take advantage of.<sup>63</sup>

Ontology	Object	System
Rump Materialism	Military Technology  Communications Technology  Representational Technology	Interaction Capacity  Material Context (Geopolitics)

Figure 1: Technology in IR

### *The Immateriality of IR*

From all of this research on technology and materiality in IR, a few conclusions can be drawn. In the three primary paradigms of contemporary IR, the role of materiality tends to be reduced to a minimal shell of action.

First, and most obviously, there is a focus on social factors to the detriment of material factors. While physical elements are often casually mentioned as important factors, the focus of the mainstream paradigms is resolutely on social interactions. Secondly, the research that does look at technology has been dominated by attention to military and communications technology (and to a lesser degree by interaction technology). The representational technologies that form the focus of this thesis have been overlooked in the existing research. Thirdly,

<sup>62</sup> Walton, *Geopolitics and the Great Powers in the Twenty-First Century: Multipolarity and the Revolution in Strategic Perspective*, 22.

<sup>63</sup> Deudney, *Bounding Power: Republican Security Theory from the Polis to the Global Village*, 59–60.

when materiality does enter into these accounts, it tends to instrumentalise technology and other material elements. The reason why technology can be profitably ignored in these accounts is because of the argument that it contributes nothing in itself. It may accelerate existing intentions and dynamics, but these are ultimately explainable in social terms (interests, ideas, power, etc.). To explain these underlying factors is therefore considered to be an explanation of technology as well. This is supplemented by the tendency to see technology as a transparent conductor of human intentions. That is to say, there is no acknowledgement of the ways in which technology shapes and channels intentional actions. Lastly, there remains a certain irony in IR's neglect of technological structure, made most apparent by its enthusiasm for exploring international social structures. In the first place, while no reasonable theorist has made the claim that social structure determines agency completely, when technological structure is referenced it is often collapsed into such an unrealistic and deterministic position. Secondly, while IR theorists have long acknowledged that international social structure provides a constraining role on states – and is therefore an important element of international politics – similar considerations are not given to technological structures. This is despite the widespread belief that technological structures operate in the same way as social structures: through constraint.

Ultimately, the major point to draw from this review of mainstream IR is that protests to the contrary, it is imbued with a thorough immaterialism. Disembodied actors, interests, intentionality, and instrumental rationality are the substance of much IR. The effects of technology, weapons and nature are casually mentioned, yet these remain exogenous to most IR theories. The result is theories of the international system which operate between disembodied rational actors and the objective social structures which constrain them.

### **Technological Autonomy**

This chapter turns now to approaches in the philosophy of technology which have explicitly sought to understand the ways in which technology contributes to the production, maintenance, and transformation of social formations. In broaching

this question, a number of different theoretical positions present themselves. Ranging from determinism to social constructivism to momentum, each of these positions proffers different responses to the question of what role technology has in understanding and explaining social phenomena. Put simply, determinism accords an all-important role to technology by making it the key driver in social changes and developments. Social constructivism instead sees technology as an expression of deeper social forces. Finally, the more recent theories around momentum seek to show how technology can come to take on some of the qualities ascribed to it by determinists. More specifically, each of these positions diverges on three separate questions:

- 1) Do social and/or technological factors<sup>64</sup> explain how a technology shapes society?
- 2) Do social and/or technological factors shape the temporal development of a technology?
- 3) Do social and/or technological factors shape the spatial diffusion of a technology?

The following sections will present each position in an idealised form (a form which few individual thinkers would adhere to) in order to examine the answers and arguments each position has for these questions, before proceeding to put forth a moderate version of technological determinism. The aim here is to explicate a conception of technology which avoids the extremes of both technological determinism and social constructivism, while recognising the implicitly social nature of many momentum theories. In the end, we intend to demonstrate that technology has some modicum of autonomy above and beyond social forces.

The significance of this autonomy postulate is that if accepted, it entails that social scientists' typical categories like class, interests, identities, and so on are necessary but not sufficient for understanding social phenomena. As one theorist notes, "the influence of technological artefacts on human action can be of a

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<sup>64</sup> By factors, we mean the material characteristics of a technology.

nonlingual kind. Artefacts are able to exert influence *as material things*, not only as *signs* or *carriers of meaning*.”<sup>65</sup> The influence of technology can therefore operate at a different level than that of intentions and meanings. Yet we need to be clear from the beginning that the claim of autonomy for technology is not simply that it resists human actions. The political theorist Jane Bennett puts this point well when she declares,

“By 'vitality' I mean the capacity of things - edibles, commodities, storms, metals - not only to impede or block the will and designs of humans but also to act as quasi agents or forces with trajectories, propensities, or tendencies of their own.”<sup>66</sup>

Yet while incorporating tendencies, technological autonomy must also be distinguished from intentional actions, which remain the prerogative of rational entities. So autonomy here cannot be about resistance, nor can it be about intentional action. These are the basic parameters of the discussion.

It is also important to note the differences between technological matter and matter in general: namely, that technology has an ontological dependence on human beings. Technology cannot exist without some human (or primate) having created it. Oftentimes this is taken as a knockdown argument against the idea of technological autonomy - technology cannot do anything without humans creating, designing, implementing, modifying, and maintaining technologies. But the question of technological autonomy is not about whether or not humans must be involved; it is a question of what is the source of directedness for these actions? If technological creation and development turn out to be entirely the product of self-conscious choices by individual human actors, then autonomy for it would be refuted. If, on the other hand, technological creation and development turn out to have their own intrinsic directedness, then humans will turn out to merely be pawns in a technological game. The comparison to make here is with social

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<sup>65</sup> Verbeek, *Moralizing Technology: Understanding and Designing the Morality of Things*, 10.

<sup>66</sup> Bennett, *Vibrant Matter: A Political Ecology of Things*, viii.

structures: just as technology relies for its existence on human beings, so too do social structures rely for their existence on a substrate of rational beings. To say that either of them is ontologically dependent on a world of humans is not equivalent though to saying they are reducible to that substrate. Likewise, just as social structures have a relative autonomy, so too – it will be argued here – does technology.

It is also important to be clear that technological agency has an ontological dependence on meta-social imperatives as well – in particular, what Robert Friedel has called a ‘culture of improvement’.<sup>67</sup> (Though others have argued that these meta-social imperatives operate instead at a religious level.<sup>68</sup>) This culture of improvement is a particular social norm that drives the process of change by setting an imperative that holds throughout society. Importantly, though, it operates on a very generic level – there is very little intrinsic content to the idea that technology must be improved, as ideas of improvement vary both across history and across cultures. It is a necessary social condition for technological change though. One can imagine a counterfactual situation where the drive for improving technologies was absent, and it is unlikely here that technology would ever change. But the generic quality of its imperative means that it is up to the material aspects of technology to provide some measure of specificity. A meta-social norm of improvement and a substrate of rational beings are therefore the two ontological foundations for autonomous technology. Remove either of them and technology loses even the relative autonomy it has. With these preliminary remarks, we can turn now to three dominant positions on technology.

### *Technological Determinism*

Technological determinism occupies perhaps the most prominent standing in the popular eye, though it has been academically discredited for some time now. From this perspective, the introduction of a technology imposes a clear effect onto

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<sup>67</sup> Friedel, *A Culture of Improvement: Technology and the Western Millennium*.

<sup>68</sup> Noble, *The Religion of Technology: The Divinity of Man and the Spirit of Invention*.

society.<sup>69</sup> The technology requires – and in fact *causes* – a social transformation once it enters into a given social formation. For the determinist, moreover, technology (both in general and in terms of individual objects) follows a linear and progressive path. It determines where and how individual actors must develop a technology, irrespective of interpretations or social interests.<sup>70</sup> Lastly, the technological determinist position exerts a force on societies which lack the latest technology, compelling them to follow and adopt the infrastructures of “modern” societies.

Prominent historical cases in international relations include ideas that the printing press caused the Reformation, along with the ensuing transformation of the international system. Similar determinist notions emerge in claims that the emergence of gunpowder transformed feudal relations and led to a competitive arms race. More recently there has been claims from a number of commentators that the Arab Spring was caused by the rise and spread of social media platforms, which lowered the boundaries to organisation and eventually led to the downfall of a number of regimes.<sup>71</sup>

In terms of the organising questions about the society-technology relationship, in its idealised form technological determinism adheres to three claims: first and most importantly, that technology uniquely determines social and political formations, and does so with a force approaching necessity.<sup>72</sup> The examples of the printing press and contemporary social media give two instances of this claim, but it is particularly the case with large-scale technological systems. According to the determinist position, such systems end up coercing humanity into maintaining their existence. To give one example,

“The people of Japan have learned a lot about technological [necessity] since the tsunami hit the Fukushima reactors. They’d love

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<sup>69</sup> McCarthy, “Technology and ‘the International’ or: How I Learned to Stop Worrying and Love Determinism,” 8.

<sup>70</sup> Bimber, “Three Faces of Technological Determinism,” 83–85.

<sup>71</sup> Pfeifle, “A Nobel Peace Prize for Twitter?”

<sup>72</sup> Cohen, *Karl Marx’s Theory of History: A Defence*; Heilbroner, “Technological Determinism Revisited.”

to get rid of nuclear power altogether, but their leaders are telling them that to do so invites economic disaster. In much the same way we Americans, along with most of the rest of the developed world, are trapped by our automobiles. We know that for lots of reasons we'd be better off if we stopped driving them tomorrow, but we can't. If we did, life as we know it would collapse, since in one way or another we depend on the internal combustion engine for our jobs, our food, and virtually everything else we need."<sup>73</sup>

It is important to clarify what is being maintained here though: it is not the technological system of nuclear power or the automobile per se, but instead it is the standard of living that is being maintained. If an alternative technical infrastructure was possible with the same standard of living, nuclear power would be on its way out. Similarly, if society changed its values about the standard of living, the apparent necessity of the automobile could quickly evaporate. So contra the determinist position, the necessity of a technological system ultimately stems from the social values of a particular culture – not from the materiality itself.

With regards to the second question, the pure determinist position holds that technology develops temporally according to some internal and unilinear logic, with human individuals being mere means to this technological evolution.<sup>74</sup> From such a position it is claimed that,

“Technology moves steadily onward as if by cause and effect. This does not deny human creativity, intelligence, idiosyncrasy, chance, or the wilful desire to head in one direction rather than another. All of these are absorbed into the process and become moments in the progression.”<sup>75</sup>

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<sup>73</sup> Hill, “Technological Autonomy: Greasing the Rails to Armageddon.”

<sup>74</sup> Ellul, *The Technological Society*; Kelly, *What Technology Wants*.

<sup>75</sup> Winner, *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*, 71.

The crucial point is the necessity involved: it approaches mechanical causation in its certainty. Those working to develop a technology are compelled by physical constraints and an internal imperative to follow a unique path of developmental progress. Typically these imperatives stem from a pursuit of innate instrumental rationality, efficiency, or from economic necessities (classical Marxism being an exemplar here).<sup>76</sup> In either case though, technology is argued to develop progressively and necessarily along a single track. It coerces individuals into developing it in such a way.

Thirdly (and less commonly stated), determinism holds that technology spreads spatially according to certain patterns of diffusion.<sup>77</sup> Often put forth under the rubric of modernisation theory (and implicit or explicit in many Eurocentric theories), technology is here taken to “naturally” spread from advanced to less-advanced societies. In classical modernisation theory, there was a single pathway from traditional to modern societies, and this path was one heavily shaped by technological forces.<sup>78</sup> Countries seeking to “catch up” to advanced nations were taught to rationalise society and to incorporate the latest technologies into their cultures, following the lead of the most modern countries.<sup>79</sup> Similar assumptions about technology (and particularly its symbolic power) played a significant role in establishing the US as a world power in the nineteenth and twentieth centuries.<sup>80</sup>

### *Social Constructivism*

In direct opposition to the technological determinist thesis lies the social constructivist thesis. Central to this approach is the idea that “one should never take the meaning of a technical artefact or technological system as residing in the technology itself. Instead, one must study how technologies are shaped and acquire

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<sup>76</sup> Brey, “Theorizing Modernity and Technology,” 50; Winner, “Where Technological Determinism Went,” 13.

<sup>77</sup> McCarthy, “Technology and ‘the International’ or: How I Learned to Stop Worrying and Love Determinism.”

<sup>78</sup> For a recent attempt to rethink the relationship between modernity and technology, see: Misa, Brey, and Feenberg, *Modernity and Technology*.

<sup>79</sup> Rostow, *The Stages of Economic Growth: A Non-Communist Manifesto*.

<sup>80</sup> Adas, *Dominance by Design: Technological Imperatives and America’s Civilizing Mission*.



their meanings in the heterogeneity of social interactions.”<sup>81</sup> In its purest form, this position holds that technologies are radically underdetermined and open to contestation over their design and development, and open to interpretation about their uses and role in society. Any idea of technological autonomy is therefore typically left aside in these approaches (though there is usually no explicit rejection of all autonomy).

In the IR literature, prominent examples have focused on military technology and argued, for instance, that the categorisation of a military technology as offensive or defensive in fact stems from social perceptions on these technologies, rather than from any intrinsic material capacity.<sup>82</sup> As a result, the offensive realism versus defensive realism debate falters at its core theoretical level, and the implicit theoretical basis for a number of arms control treaties falls apart. Yet even in this case, the conclusions remain constrained to claiming that “it is difficult to categorise the impact of technological change *in offense-defence terms*.”<sup>83</sup> Outside of these narrow terms, the possibility of technology determining social forces is left open. In other research, the development of ballistic missiles is analysed from the perspective of competing social interests. Here it is shown that a wide variety of paths were taken, with different groups prioritising different problems and different values. While some emphasised accuracy, others focused on reliability, for instance.<sup>84</sup> The temporal developments of this technology were therefore initiated and sustained by a variety of social groups – and not by any imperatives internal to the technology itself.

In relation to the questions which divide these positions, the social constructivist presents arguments opposed to the determinist on each account. First, it is argued that social and political forces determine which technology gets developed and what effects it has on society.<sup>85</sup> From this perspective, the creation and initial design of a technology is open to multiple choices, with social groups

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<sup>81</sup> Bijker, *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*, 6.

<sup>82</sup> Lieber, *War and the Engineers: The Primacy of Politics over Technology*.

<sup>83</sup> *Ibid.*, 151. (emphasis added)

<sup>84</sup> MacKenzie, “Missile Accuracy: A Case Study in the Social Processes of Technological Change,” 211.

<sup>85</sup> Bijker, Hughes, and Pinch, *The Social Construction of Technological Systems*; MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*.

and powerful interests struggling to determine the eventual design and the point at which a technology gets stabilised.<sup>86</sup> In its purest form, the socially constructed origin of a technology “means that all aspects of this sociotechnical ensemble [are] subject to variation”.<sup>87</sup> This variation includes not just which material components are used and how they are fit together, but also the purpose of the technology itself. In other words, *how* a technology is going to shape society is flexible and determined by competing interpretations about what its function should be.

Second, the social constructivist position argues that the evolution of a technology is shaped by economic and political factors instead of by some internal teleology. Once a new technology arises, the initial stages of technological innovation almost always suggest multiple paths that can be taken. It is rare for one path to be the clear way forward. In the first place, even the use of an object may not be particularly clear and must be made precise. The tape recorder, for instance, floundered as a product and eventually had to be marketed with a pamphlet entitled ‘999 Uses of the Tape Recorder’. It was not until it became used to record music that it finally took off as a successful invention.<sup>88</sup> There are also contentions over technical requirements, over different solutions to the same problem, and over moral imperatives, for instance.<sup>89</sup> Each of these provides the space for conflict between alternative paths. From its very origins, therefore, technology evolves not according to any linear plan, but instead according to a multidirectional path.<sup>90</sup> It is one of the significant advances of social constructivist approaches to demonstrate that it is only retroactively, once a path has been chosen for various contingent reasons, that a linear model of development can be discerned.

Lastly, with respect to spatial development, the social constructivist position argues that the diffusion and adoption of technologies is explainable by economic

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<sup>86</sup> Pinch and Bijker, “The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other,” 40–44.

<sup>87</sup> Bijker, *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*, 277.

<sup>88</sup> Basalla, *The Evolution of Technology*, 140–141.

<sup>89</sup> Pinch and Bijker, “The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other,” 35.

<sup>90</sup> *Ibid.*, 28.

and political contexts.<sup>91</sup> Research which has attempted to reproduce the dynamics of technological adoption, for instance, has focused on advertising and early adoption by small groups of innovators as key factors in the speed and distribution of new technologies.<sup>92</sup> In these cases, fashion and trendsetters are important for the diffusion of technology, more than any inherent material properties.

### *Momentum*

Between the opposed poles of social constructivism and technological determinism, recent work has attempted to clarify a middle ground for technological autonomy. The consensus here has settled upon what is commonly called ‘momentum’.<sup>93</sup> Momentum stems in part from the fact that technologies have a logistical footprint: any given technology implies an entire system of production, distribution channels, technical experts, and subsidiary technologies. A technology, in other words, always already implies a larger sociotechnical assemblage, and as a result a set of shifts that emerge from adopting it. For instance, gunpowder, and the military advances it enabled, drove a number of shifts.<sup>94</sup> In the first place, the production of gunpowder required intensive capital investment and generated economies of scale as a result. Warfare became increasingly the preserve of wealthy groups. But secondarily, gunpowder changed the logistics of war. No longer were soldiers capable of living off the land; instead they now had to receive and transport large quantities of guns and gunpowder. This drove the production of new managerial systems that were capable of organizing these logistical networks. We can see, condensed in this example, the primary source of momentum. A technology is adopted for some reason (here, comparative military advantage), but individual technical objects rely on larger sociotechnical assemblages (e.g. factories and transportation networks). So the adoption of a technology also implies (logically and materially) the adoption of the

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<sup>91</sup> Kroenig, *Exporting the Bomb: Technology Transfer and the Spread of Nuclear Weapons*; Gonçalves, Laguna, and Iglesias, “Why, When, and How Fast Innovations Are Adopted.”

<sup>92</sup> Gonçalves, Laguna, and Iglesias, “Why, When, and How Fast Innovations Are Adopted,” 9–10.

<sup>93</sup> Hughes, “Technological Momentum.”

<sup>94</sup> Allenby and Sarewitz, *The Techno-Human Condition*, 129.

larger system which produces it. A more recent example is the mobile phone. Adopting this technology means also adopting the higher demand for rare earth minerals, which means also adopting China's dominance in this resource, as well as adopting the role these minerals play in funding conflicts in the Democratic Republic of the Congo. So momentum emerges from the adoption of an entire associated assemblage if one wants to adopt an individual technology. Technology forces society to readjust.

With respect to the first organising question, momentum approaches tend to agree with social constructivists about the radical flexibility of a technology's initial design. The emergence of a technology or a sociotechnical assemblage is itself open to a series of political contestations over the design of every aspect. These can involve entrenched interests, powerful corporations, influential individuals, and many others.<sup>95</sup> However, once a technology reaches a certain stage of stabilisation, it comes to exert a force on the social environment surrounding it. Particularly with sociotechnical systems, they can "become severed from the ends originally set for them and, in effect, reprogram themselves and their environments to suit the special conditions of their own environments."<sup>96</sup> In this sense, technology not only introduces new possibilities into assemblages, but also introduces new demands – both in the form of economic demands for the resources necessary to keep it working, and in the form of operational demands for the technologies and environment which a particular technology relies upon.<sup>97</sup> Certain organisations of labour and capital arise from these demands of the system.<sup>98</sup> The rise of the railroad in the 1850s, for instance, brought forth the requirement of a highly centralised German military structure.<sup>99</sup>

As a result of momentum, the temporal development of technologies can tend to push in one direction. This is particularly the case with large sociotechnical

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<sup>95</sup> Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*.

<sup>96</sup> Winner, *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*, 227.

<sup>97</sup> *Ibid.*, 100-106.

<sup>98</sup> Heilbroner, "Do Machines Make History?," 60-62.

<sup>99</sup> Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*, 87.

systems, which research has suggested follows a loose temporal pattern.<sup>100</sup> The internal dynamic of sociotechnical systems arises from their interrelated components. Thomas Edison once noted that since the components of a large technical system must be compatible, in some sense the whole itself was simply a large machine.<sup>101</sup> Much like individual technologies, this entails that changes in one component can and do often have effects on the other components. The early electrical infrastructure highlights the ways this occurs – a change in a generator, for instance, required changes in a motor’s resistance, voltage and amperage, which can cause even further changes being needed.<sup>102</sup> As a result, the system is internally dynamic and often in constant fluctuation. This leads to what are termed ‘reverse salients’, which are “components in a system that have fallen behind or are out of phase with the others.”<sup>103</sup> As aspects of a sociotechnical system shift over time, they create internal pressures for other components to continue apace, thereby letting the system take on its own relative autonomy independently of our intentions or conceptions of it. Moreover, the individuality and unity of a specific system must be recognised as always contingent and open to change. While the literature on sociotechnical systems has tended to install a strict separation between a system and its environment, the notion of assemblages prohibits such a barrier except as a contingent and temporary construction.<sup>104</sup>

Once these large-scale systems have been adopted, they then take on a further sense of momentum. Beyond the force of their interconnected components, sociotechnical systems tend to take on limited goals and some measure of velocity, in the first place because of “vested interests, fixed assets, and sunk costs”.<sup>105</sup> In this vein, Langdon Winner suggests that,

“The freedom to develop technology primarily to serve human needs was lost with the spread of industrialization and the growth of

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<sup>100</sup> Hughes, “The Evolution of Large Technical Systems,” 56–76.

<sup>101</sup> Basalla, *The Evolution of Technology*, 47.

<sup>102</sup> Hughes, “The Evolution of Large Technical Systems,” 73.

<sup>103</sup> Ibid.

<sup>104</sup> Callon, “Society in the Making,” 100.

<sup>105</sup> Hughes, “The Evolution of Large Technical Systems,” 76–77.

modern megatechnical systems in communications, transportation, power production, and manufacturing. These gigantic, complex, interconnected technological systems overwhelm human values and defy human control.”<sup>106</sup>

Implicitly invoked here is a sense of the path-dependency produced by technological systems. As with institutions, technological systems create path-dependencies.<sup>107</sup> This shift from the contingency of initial development decisions to the virtual necessity of sociotechnical infrastructures is premised upon their fixed and sunk costs, the existence of habits resulting from learning to use a technology, the benefits gained from a community of existing users, and the expectations of the technology’s continued existence.<sup>108</sup> Path dependency helps explain why sociotechnical systems evolve a momentum that resists change.<sup>109</sup>

The initial limitation with momentum being equated to a form of technological autonomy is that, strictly speaking, path dependence is primarily conceived as a social constraint and not as a material constraint. So for instance, factories took forty years to shift from powering their buildings with steam engines to powering their buildings with electrical motors. The reason was because adopting the electrical motors involved rebuilding the entire factory, which was an expensive and lengthy process.<sup>110</sup> Close attention reveals that the most significant explanatory factors in such an example are economics, power, interests, beliefs, and psychology. We can see this by virtue of the counterfactual situation – if the costs of adopting electrical motors had been cheaper, factories would have incorporated them much quicker than they did. Instead, the old technology had been locked-in for economic reasons, and an essentially obsolete technology continued onwards. The second limitation with momentum is that despite the suggestion of active

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<sup>106</sup> Basalla, *The Evolution of Technology*, 205.

<sup>107</sup> Pierson, *Politics in Time: History, Institutions, and Social Analysis*; Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*, 4.

<sup>108</sup> Pierson, *Politics in Time: History, Institutions, and Social Analysis*, 24.

<sup>109</sup> In an alternative view, Donald MacKenzie will argue that this momentum stems in part from self-fulfilling prophecies about the future trajectory of technological development. (MacKenzie, “Economic and Sociological Explanations of Technological Change.”)

<sup>110</sup> Arthur, *The Nature of Technology: What It Is and How It Evolves*, 157–158.

directedness in its name, momentum almost always refers to a resistance of technological systems to human intervention. In this regard, it is no different from other passive conceptions of matter which take resistance to be the paradigmatic quality of matter.

Lastly, with regards to spatial diffusion, most theorists who subscribe to a momentum position tend to (at least implicitly) adhere to a social constructivist view of diffusion: economic and social interests determine where a technology goes and how it is modified in transit.<sup>111</sup> However, while not often stated in the literature, one can interpolate a conception of spatial diffusion from the idea of momentum. In this case, the pervasiveness and dominance of a particular technological form would instil a certain imperative on other actors to adopt the same form.<sup>112</sup> A commonly cited case – the relatively inefficient QWERTY keyboard setup – provides an excellent example of this sort of spatial diffusion by momentum.<sup>113</sup> Again, however, path dependency in the social sense remains the key explanatory factor here, rather than any material imperative.

## **Platforms**

Each of these positions contributes to an overall theory of technology and its relation to society, yet falls short in certain respects. The social constructivist critique of the determinist position clearly makes the latter untenable. Technology is not as unilinear, necessary, or autonomous as the determinists claimed (and often feared). Yet the social constructivist position tends too far in the opposite direction. While rarely explicitly rejecting the materiality of technology, the physical impositions of matter typically remain silent in this research program. Interpretative flexibility and multi-directional development become the focus at the expense of technological constraints. Lastly, momentum marks a significant advance in bridging the two positions – demonstrating how determinism can appear to come about, while simultaneously recognising the socially embedded nature of all technology. Yet even here, this determinism is typically of a purely

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<sup>111</sup> Hughes, “The Evolution of Large Technical Systems,” 67.

<sup>112</sup> Arthur, “Competing Technologies, Increasing Returns, and Lock-In by Historical Events.”

<sup>113</sup> David, “Clio and the Economics of QWERTY.”

social kind – stemming not from any physical imperatives but instead from the engrained values and interests of a particular society. The materiality of technology is again often implicitly side-lined.

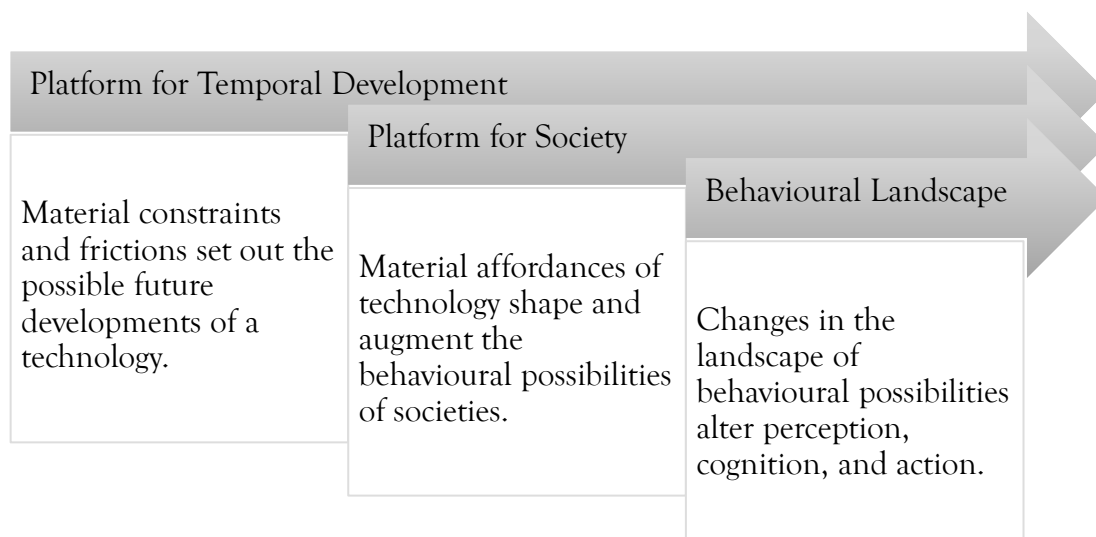


Figure 2: Technology as a platform

By contrast, the position that will be set out here aims to start from the materiality of technology and take its significant (and relatively autonomous) influence into account, while recognising the important contributions of other approaches. The perspective put forth here agrees with the social constructivist insight that the development of a technology is always underdetermined. Similarly, it accepts much of momentum theory though with more emphasis on the material conditioning of effects and development. Yet it also returns to classic determinist ideas to argue that technology does orient its uptake and its development in particular directions.<sup>114</sup> By reviving the determinist emphasis on the materiality of technology, this position attempts to emphasise technology's durability and momentum. Technology is seen here to provide a stable, albeit flexible, *platform*

<sup>114</sup> It should be noted here that in terms of the orienting questions about the technology/society relationship, the position developed here will neglect the third question about spatial diffusion since the case studies will not be focused on how technologies are distributed geographically.



which shapes the movement, interaction, and organisation of social entities.<sup>115</sup> As a platform, technology functions as a basic ground which sets the constraints and opportunities for further development and use.<sup>116</sup> In particular, technology provides a platform of affordances at three levels: perception, cognition, and action. Insofar as it strongly determines what is possible at a given moment, it is also possible to refer to technology as a material transcendental of society – invoking Kant’s famous transcendental idealism which sought the conditions of experience. Figure 2 schematises the argument to be made in the following sections.

### *A Platform for Society*

The perspective taken here is therefore a platform theory of technology, or a qualified version of technological determinism. In the first place, technology does shape society – but it does so in a more flexible fashion than classical determinism suggests. Rather than there being a singular and unambiguous outcome of a particular technology entering into a given society, there are a variety of possibilities. What a technology determines is not the specific effect, but instead the general landscape of possible actions and thoughts. A given technology affects social interactions by (1) making certain behaviours more likely, by (2) constraining other behaviours, and – most importantly – by (3) creating entirely new types of behaviours. Technologies have specifiable amplifying and dampening aspects.<sup>117</sup> Technology, in other words, operates as a platform for social forces. For instance, the question of whether social media is liberating or not misses the point that its effects are to act as a platform which transforms an entire landscape of possible behaviours.<sup>118</sup> These technologies both lower the costs of communicating with geographically dispersed individuals and lower the costs of monitoring this communication. How actors make use of these technologies is then open to the

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<sup>115</sup> I owe this idea to conversations with Benedict Singleton and Alex Williams.

<sup>116</sup> It should be made clear that elements of this position can be found in many accounts of technology. What this approach here aims to do is to make these aspects explicit as a unique theoretical perspective.

<sup>117</sup> Ihde, *Heidegger’s Technologies: Postphenomenological Perspectives*, 142n26.

<sup>118</sup> Plattner and Diamond, *Liberation Technology: Social Media and the Struggle for Democracy*.

influence of economics, politics, and culture – but all within the constrained set of affordances that the technology offers.

Technological platforms do not merely alter existing social possibilities though; their most significant function lies instead in their capacity to create entirely new possibilities. This novelty can be emphasised with a thought experiment in which a technology is replaced by its equivalent in human labour. It would appear at first glance that given enough time and resources any technology is replaceable (and hence in principle reducible) to such an equivalent. Bruno Latour's famous (and pseudonymous) article on the sociology of a door-stopper highlights well the kinds of convolutions necessary to replace even the simplest technology with a human equivalent:<sup>119</sup>

"Every time you want to know what a nonhuman does, simply imagine what other humans or other nonhumans would have to do were this character not present. This imaginary substitution exactly sizes up the role, or function, of this little figure."<sup>120</sup>

There is a significant problem with this idea though: at best it only holds for more mundane technologies. In what sense is an fMRI replaceable by any number of humans? Is a nuclear weapon replaceable? Is even a railroad replaceable by human labour in any meaningful sense? With the computing revolution, this irreducibility is even more striking. To match the world's currently fastest supercomputer would require all 7 billion inhabitants of earth to each process 3 million calculations per second.<sup>121</sup> Meanwhile, the climate modellers behind climate change policy are pushing for exascale computers that are 1000 times faster than this current supercomputer. From this it is clear that while computing power is theoretically reducible to a human equivalent, there is nevertheless a qualitative

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<sup>119</sup> Johnson, "Mixing Humans and Nonhumans Together: The Sociology of a Door-Closer."

<sup>120</sup> Ibid., 299.

<sup>121</sup> Storm, "Meet the Fastest, Most Powerful Science Machine in the World: Titan Supercomputer."

shift involved here.<sup>122</sup> To put it simply: technology is doing things humans are not even in principle capable of. There is real novelty here, a real expansion of what is possible.

With these capacities to expand and alter the material platform of society, technology can be seen to operate on three general possibilities: action, perception, and cognition. Each of these intermingles, and indeed, the case studies in this thesis all demonstrate that changes in perception and cognition can lead to changes in what is behaviourally possible.

The most intuitive notion of how technological platforms shape possibilities is simply through what actions they make possible. The most prominent social influences that technology produces are often of this type: the introduction of a new technology creates and warps behaviours through causal interactions which are then diffused outwards into ever larger patterns of social change. For instance, the introduction of the automobile changes the behaviours of travelling in individuals and (through a longer chain of causes) eventually alters the way urban planning is done. Or the introduction of a new technology such as the shipping container makes new behaviours economically possible and revolutionises international trade patterns.<sup>123</sup> On the level of users, technical objects set out specific procedures that must be followed in order for the object to be usable in the first place.<sup>124</sup> Objects therefore instil patterns and habits of behaviour onto individuals and collectivities.<sup>125</sup> In the same way that individuals have to respond to alterations in their natural environment, so too do individuals change in virtue of alterations in their technological environment.

Technologies can also change the perceptions of individual actors. This can be seen most obviously in cases of scientific instrumentation being used to make

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<sup>122</sup> Shukla et al., "Revolution in Climate Prediction Is Both Necessary and Possible: A Declaration at the World Modelling Summit for Climate Prediction."

<sup>123</sup> Levinson, *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger*.

<sup>124</sup> Winner, *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*, 198.

<sup>125</sup> A similar argument is made by geopolitical thinkers when they articulate how geographical features make certain political demarcations and systems more or less likely. See: Mackinder, "The Geographical Pivot of History."

the previously unobservable into the observable.<sup>126</sup> Technology makes different spectrums of light visible, or makes complex systems like the climate visible. More indirectly, this affection of perception can be seen with the emergence of rail networks and their capacity to make long-distance travel easier for many. They not only shorten the time between locations, but through their separation of the distance travelled from the physical labour of travel they helped produce a new experience of distance.<sup>127</sup> In a similar manner Paul Virilio notes of modern transatlantic air travel that “we have finally achieved states bordering on sensory deprivation” with the “thrills of the old voyage [...] now compensated for by the showing of a film.”<sup>128</sup> The very phenomenology of travel (and hence, of distance and time) is now partially produced through technology.

Lastly, technology also shapes the possibilities of conceptual space, including shifts in concepts, inferences, economic calculations, and imaginative possibilities. This will be the focus of the next chapter, but for now it suffices to say that the production of new concepts, new inferential relations, new economic calculations, and new imaginations involve some of the most significant shifts initiated by technology. It is not only a shift in how the world is interacted with, but in how the world is thought about.

From understanding technology as a platform that shapes the possibilities available for action, perception, and cognition, a number of implications follow. In the first place, such a framework makes precise the debate over technological autonomy. By conceptualising technology’s effects in terms of degrees of possibility, a much more nuanced approach can be presented.<sup>129</sup> In some cases, technology will heavily constrain possibilities, thereby approaching classical determinism. In other cases, technology will leave the possibilities relatively open and thereby

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<sup>126</sup> Humphreys, *Extending Ourselves: Computational Science, Empiricism and Scientific Method*; Daston and Galison, *Objectivity*.

<sup>127</sup> Van der Vleuten, “Infrastructures and Societal Change: A View from the Large Technical Systems Field,” 402.

<sup>128</sup> Virilio, *The Art of the Motor*, 85.

<sup>129</sup> A close parallel to the idea of technological development being elaborated here is from ‘affordance theory’ as developed by Gibson and Norman. But whereas affordance theory focuses on how technology creates possible actions for a user, the theory proposed here also includes the ways in which technology creates possible actions for other components within the technical system. Gibson, “The Theory of Affordances”; Norman, *The Design of Everyday Things*.

approximate the social constructivist view. With this in mind, it now becomes possible to refine the notion of changes in possibility structure into a series of more specific mechanisms (a task that the case studies will attempt to accomplish).

Secondly, by understanding technology as a platform which affects an array of possibilities, one avoids any clean functionalism or simple rationalism. For these approaches, not only is there one optimal social formation from a given set of material conditions, but existing social formations can be *explained* by virtue of optimising these given conditions. Yet while there may be certain optimal social formations discernible from a given material context, this is distinct from saying that a given social formation arose because of its functional optimisation.<sup>130</sup> It is the latter argument which must be refused, while still recognising that material infrastructures do provide a determinate set of affordances. One can theoretically derive an optimal social formation (in some cases), while still recognising that practically other outcomes are equally possible.

Lastly, the focus on technology changing behaviour and cognition also highlights the specifically political nature of technological objects. It is simply no longer plausible to hold the thesis that technologies are politically and ethically neutral.<sup>131</sup> Their political nature may include multiple possibilities that are in tension with each other, but the introduction of a technology still involves changes in the behavioural landscape. Bruno Latour's example of the speed bump is emblematic here – as he argues, the speed bump is literally the expression of a particular norm. Instead of “appeals to morality, enlightened disinterest and reflection”, the speed bump operates to slow vehicles through “appeals to pure selfishness and reflex action”.<sup>132</sup> It is neither a neutral object nor a simple norm. Rather it is a hybrid mixture of both norms and materiality. A similar case of non-neutrality arises in Langdon Winner's famous example of a bridge that was designed precisely to block public transportation like busses.<sup>133</sup> To be clear, actions involving technologies do not delegate sole responsibility to the technologies

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<sup>130</sup> Deudney, *Bounding Power: Republican Security Theory from the Polis to the Global Village*, 59–60.

<sup>131</sup> Gun advocates' idea that “Guns don't kill people, people kill people” is representative of this thesis of neutrality.

<sup>132</sup> Latour, *Pandora's Hope: Essays on the Reality of Science Studies*, 186.

<sup>133</sup> Winner, “Do Artefacts Have Politics?,” 123–124.

themselves. It is not a case of ‘guns kill people’ rather than ‘people kill people’. Instead, the action has to be distributed between these actors involved – both human and non-human.<sup>134</sup> The production of music, for instance, is attributable neither to the musician nor to the instrument – but instead *only* to the entire emergent assemblage of musician-instrument itself.

The technologies examined in this thesis will follow this platform theory of technology and be shown to have made possible a certain set of perceptions, thoughts, and behaviours. Yet while evidence will be given to demonstrate that actors have made use of these new possibilities, it should not be therefore taken that the technology *caused* these actors to act this way. Instead, by expanding the possible space of actions, these technologies have been combined with existing social and political forces in order to bring about the observed behaviours. Technology, as the theoretical discussion has attempted to show, operates by expanding the landscape of possible behaviours, and not by directly forcing actors to act in a certain way. (Only in exceptional cases does the latter type of strict determinism hold.)

#### *A Platform for Development*

A similar platform approach holds for the study of technology’s temporal development (whether for a given technology or for technology in general). As with technology as a platform for society, the materiality again sets the basic ground from which future developmental paths can emerge. Physical constraint is the initial condition, and interpretation and social contestation can only emerge afterwards. Technologies are in a constant state of becoming and this becoming takes on a specific tendency by virtue of the frictions between components.<sup>135</sup> The temporal development of a technology involves an overcoming of the internal tensions within it: pieces that produced friction (literal and metaphoric) with other pieces compel an evolution of the object towards ever more internally coherent

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<sup>134</sup> Latour, *Pandora’s Hope: Essays on the Reality of Science Studies*, 182.

<sup>135</sup> Simondon, *On the Mode of Existence of Technical Objects, Part I*, 12.

forms.<sup>136</sup> These include tensions between computational demands, data demands, speed demands, accuracy demands, power demands, as well as frictions between non-computational physical components and other mechanical frictions. It is these sorts of frictions which set out the broad developmental path forward for a technology. They place demands on individuals to overcome these frictions and organise the technology into a coherent whole.

As the philosopher Gilbert Simondon puts it, a technology “evolves by convergence and by adaption *to itself*; it is unified from within according to a principle of internal resonance.”<sup>137</sup> This somewhat cryptic remark is elaborated on by one of his commentators:

“When he looks at the individuation of machines from the angle of the process of invention, Simondon sees a passage from an abstract, analytical, logical system toward a concrete, synthetic, practical system. Inventors begin designing machines with an eye to accomplishing a single task, which they diagram in an abstract, analytic fashion; but as they actually use the machine, the design itself begins to demand practical adjustments, bringing into play other aspects of its basic elements, adding new elements, and creating new relations among elements. For instance, you design a motor to turn a wheel without necessarily thinking about the materials, but when building and operating it, you discover that certain materials, forged in a such as way as to produce specific qualities, work better. In effect, it becomes self-regulating.”<sup>138</sup>

To put it otherwise, technological objects transition from being a series of independent components to merging into a system that resonates internally.<sup>139</sup>

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<sup>136</sup> This notion of frictions is adapted from Paul Edwards’ use of the term, where frictions are taken as an important organising principle for understanding the progression of climate change models. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*.

<sup>137</sup> Simondon, *On the Mode of Existence of Technical Objects, Part I*, 13. (emphasis added)

<sup>138</sup> LaMarre, “Afterword: Humans and Machines,” 92–93.

<sup>139</sup> Simondon, *On the Mode of Existence of Technical Objects, Part I*, 16.

Throughout this process, “the nascent technology must now be based on proper components, made reliable, improved, scaled up, and applied effectively to different purposes.”<sup>140</sup> Or as Simondon puts it, “the antagonisms and reciprocal limitations are progressively effaced, the functioning of the machine tending to become a global functioning, and in sum, the technological object approaches the natural object but by other ways than those of nature.”<sup>141</sup> In this sense, therefore, technologies have an internal dynamism that exerts an independent pressure on those who go on to develop it. The possible paths of progression are set out by material factors internal to the object itself.

This internal process can be seen in a variety of technologies: from variations in engine design, and other technologies such as the internal evolution of firearms and the dynamics of personal computers.<sup>142</sup> Since technologies are always internally filled with tensions between material components and different functions, the development of a technology involves modulating these tensions to minimise them and generate a more efficient technology. For instance,

“The F-35C [carrier-based fighter jet] needs to pull off a set of design objectives that conflict. It needs to be structurally strong and heavy enough to withstand the high forces of carrier launches and tailhook-arrested landings, yet preserve the high manoeuvrability and long-range fuel performance. It needs to have excellent low-speed control for carrier landings, yet be able to fly at more than 1.6 times the speed of sound. And it needs to have the angled surfaces that make it almost undetectable to radar, yet fly properly.”<sup>143</sup>

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<sup>140</sup> Arthur, *The Nature of Technology: What It Is and How It Evolves*, 131.

<sup>141</sup> Hart, “Preface,” xii.

<sup>142</sup> Bousquet, “Opening up the Black Box: Rethinking Military Technology through a Social Theory of Assemblages”; Mackenzie, “The Strange Meshing of Impersonal and Personal Forces in Technological Action”; Marx and Smith, “Introduction.”

<sup>143</sup> Arthur, *The Nature of Technology: What It Is and How It Evolves*, 39.



The development of a technology is the process of modulating such internal tensions along paths determined by the materiality of the technology.<sup>144</sup>

Empirically, this progression can occur in leaps and bounds, as well as with minor modifications.<sup>145</sup> It should be emphasised though that this direction of internal progression is only setting out the possibilities of change in technologies. Yet these internal dynamics are entirely material – they are not guided by social norms or values, but instead outline a set of strict possibilities for future development. The process of development provides an independent material dynamic to the evolution of technologies.

A similar dynamic of individuation can be perceived at the largest scale of technology as well: the entire ecosystem of technologies available at a particular time. While a number of theorists have attempted to develop an evolutionary theory of technology,<sup>146</sup> the classical ideas of evolution cannot explain the types of radical innovations that occur in the technological world. Biological evolution does not produce radically new species; instead it builds piecemeal upon random variations and hereditary mechanisms. Nowhere in standard evolutionary mechanisms is there an explanation for how something like radar could emerge from radio, despite being obviously related in retrospect.<sup>147</sup> The solution complexity theorist Brian Arthur argues for is to recognise that individual components of technologies can themselves provide the building blocks for radically new technologies.<sup>148</sup> In addition, technologies are also built out of the use of various natural phenomena – for example, the radar uses electromagnetic waves in such a novel way that the natural phenomenon becomes a component of the new technology. That is to say, new technologies do not spring forth from nothing, but instead emerge from the combination of existing technologies, components, and

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<sup>144</sup> It should be noted that one limitation with Simondon's account is that it presumes a single function for a technology. The technologies examined in this thesis will reveal instead that, often, technologies have multiple functions. This means that the development of a technology has a somewhat wider scope of possibilities than Simondon would suggest – yet it nevertheless retains the same dynamics of internal self-regulation that Simondon claims.

<sup>145</sup> Simondon, *On the Mode of Existence of Technical Objects, Part I*, 38.

<sup>146</sup> Basalla, *The Evolution of Technology*; Kelly, *What Technology Wants*.

<sup>147</sup> Arthur, *The Nature of Technology: What It Is and How It Evolves*, 17–18.

<sup>148</sup> Arthur, *The Nature of Technology: What It Is and How It Evolves*.

harnessed natural phenomena. *Combination* becomes the mechanism of global technological evolution and the means for the radically new to emerge.

Emerging from combination, each new technology recursively opens up new paths and sets the stage for further technological development.<sup>149</sup> For instance, the smartphone emerged from the existing conjunction of computer technology, cellular technology, camera technology, gyroscope technology, touchpad technology, and of course, phone technology. Understood as an ecosystem and understood historically, the technological world therefore seems to evolve new forms over time – they share a common ancestor in a way.<sup>150</sup> But the stronger claim from this is that not only does the technological ecosystem shape possible developments at any given moment, it also actively drives sociotechnical assemblages towards particular outcomes. There is an important sense in which once the components of a technology are available, that the new technology will inevitably emerge soon after. Much of the literature on invention highlights that an invention is rarely – if ever – the product of only one group of people.<sup>151</sup> Almost always, a new technology is created near simultaneously by multiple groups working on the same project.<sup>152</sup> This makes sense insofar as technology in general provides the material platform of the possible. Given certain conditions set out by the technological ecosystem, the evolution of technology will continue apace by virtue of its own internal dynamics. Even more specifically, the evolution of the technological ecosystem will move ahead in roughly predictable fashion being drawn towards particular ends.<sup>153,154</sup> As Arthur argues, the next decade of technological progression is fairly easy to predict. The paths down which human innovation will go are set out by the material systems in place now. As a complex system, there are strict temporal limits to prediction though – small changes today can invoke unpredictable changes in the future. Yet this does not change the fact that the near-term paths of technological evolution are largely predictable. As with

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<sup>149</sup> Fleming and Sorenson, “Technology as a Complex Adaptive System: Evidence from Patent Data.”

<sup>150</sup> Arthur, *The Nature of Technology: What It Is and How It Evolves*, 15.

<sup>151</sup> Merton, “Singletons and Multiples in Scientific Discovery: A Chapter in the Sociology of Science.”

<sup>152</sup> Arthur, *The Nature of Technology: What It Is and How It Evolves*, 125.

<sup>153</sup> Heilbroner, “Do Machines Make History?,” 57-59.

<sup>154</sup> ‘Attractors’ in the sense used by complexity science would perhaps be a better term than ends, though the explanation of this term would take us too far adrift from the main argument.

individual objects, the material infrastructure of the technological ecosystem produces particular pathways.

So at the largest scales and the smallest scales, technology's material nature provides a platform for temporal development. Its path is individuated within a particular set of possible outcomes shaped by internal frictions, and social contestation takes place within these materially-delineated possibilities. As we will see, each of the three technologies in this thesis illustrates this theory – each encounters fundamental frictions in fulfilling their functions and the overcoming of these frictions forms the contours of their possible temporal development. This means that in order to understand their development, one must understand the frictions that arise and the material nature of these technologies. Broadly speaking, we will see that climate models face the frictions of calculating capacities; financial models face the frictions of speed; and crisis mapping faces the frictions of mobile technology.

## **Conclusion**

This chapter has attempted to cover and synthesise a diverse array of literature on technology, while drawing out some broad conclusions: (1) the distinction between technologies and sociotechnical systems; (2) IR's tendency to neglect technological dynamics and effects; and (3) the notion of technology as a material platform for society and development. Most important is (4) the idea that technology ultimately transforms the world by shaping possibility spaces within society. Technology acts as part of the material transcendental for the social sphere. It establishes the conditions of possibility for a given era and in this sense, the value of a technology “lies not merely in what can be done with it but also in what further possibilities it will lead to.”<sup>155</sup> So just as the materiality of technology grounds the basis for its own evolution, it also grounds the transformation of what is possible in a society. (And indeed, technology often appears today as the only thing that can accomplish the properly political gesture of transforming what is possible.<sup>156</sup>)

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<sup>155</sup> Arthur, *The Nature of Technology: What It Is and How It Evolves*, 170.

<sup>156</sup> Barry, *Political Machines: Governing a Technological Society*, 210.

The claim that materiality independently acts by shaping the possibility structure of behaviours can therefore be distinguished from: (1) arguments that materiality acts as an inert and politically neutral backdrop for social action, (2) arguments that materiality is reducible to the intentions, interpretations and uses of it, and (3) arguments that technology is exogenous to IR and of little relevance. To the contrary, the claim here is that (1) materiality shapes (in productive *and* constraining ways) the space of possible and likely behaviours, (2) materiality is to some degree independent of human actions and intentions, and (3) by shaping possibilities, materiality is inherently political and therefore useful for understanding the dynamics of world politics.

While the emphasis in this chapter has been on what materiality contributes to technology, it should nevertheless be reiterated that the development of technologies is also shaped by social factors. The difference between determinism and social constructivism is one of degree rather than kind: the former is simply the zero degree point where the material dynamics force only one possibility of development. The latter, by contrast, neglects the ways in which material factors channel development and behaviour in certain directions. The next chapter will continue this focus on technology, but will examine the specificities of representational technologies and what they entail in shifting cognitive possibilities.

### 3 / COGNITIVE ASSEMBLAGES

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“The 'world images' that have been created by 'ideas' have, like [railway] switchmen, determined the tracks along which action has been pushed by the dynamic of interest. 'From what' and 'for what' one wished to be redeemed and, let us not forget, 'could be' redeemed, depended upon one's image of the world.”<sup>1</sup>

-Max Weber

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In the last chapter we set out a theory of technology – as a platform for social behaviours and for technological development along a determinate spectrum of future paths. This chapter seeks to build upon that foundation and establish a framework for understanding a particular type of technology: representational technologies. These are the material technologies which are being used to generate knowledge claims (in the form of numbers, maps, graphs, videos, and indicators) about complex situations.<sup>2</sup> These technologies include simulations, formal models, agent-based models, data analytics, and other instruments used to produce representations of some phenomenon.

While representational technologies have existed historically in a number of ways (e.g. maps), the latest generation of digital representations are significantly different.<sup>3</sup> On a fundamental physical level, digital representations provide an immense expansion of optical possibilities. Whereas previous visual media remained bound to the optical laws of refraction and reflection (e.g. photography

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<sup>1</sup> Weber, “The Social Psychology of the World Religions,” 280.

<sup>2</sup> It should be noted here that this notion of representation goes beyond just numbers, which a variety of other authors have excellently analyzed: Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*; Desrosières, *The Politics of Large Numbers: A History of Statistical Reasoning*; Hansen and Mühlen-Schulte, “The Power of Numbers in Global Governance.”

<sup>3</sup> Kittler, *Optical Media*.

and film), the computer opens up the now everyday possibility of directly constructing images imperceptible pixel by imperceptible pixel.<sup>4</sup> This invisibility of the individual pixels lends the images the potential aura of reality (see, for instance, Apple's attempt to invoke this reality by branding their high-resolution screens as 'Retina displays'). With this expansion of visual qualities, perspective is easily manipulated, impossible objects are easily constructible, and the difficult techniques of experimental cinema become a simple software effect.<sup>5</sup>

In fact, while the term 'representation' suggests a direct relation between the images on a screen with a phenomenon in the world, it is perhaps more accurate to state that computers *generate* rather than *represent* images.<sup>6</sup> This generative aspect entails that they are algorithmic through and through – nothing that appears on the screen has avoided this step.<sup>7</sup> This generative aspect is also what makes possible another unique aspect of digital representations. For some theorists the rise of digital imaging portends the separation of images from reality. This quality of digital representation stems from the fact that they can construct enclosed simulations. Given a few assumptions and rules, these models generate self-consistent worlds. In particular, these digital representations are capable of modelling dynamic systems (not just static images), visuals (not just numbers), and complex interactions (not just simple linear relations). Moreover, these media are interactive – they allow users to manipulate them in increasingly intuitive ways, lending them an amplified sense of being an extension of the real world (rather than a mere virtual world).

Lastly, digital representations have different properties than other recent representational media (particularly oral and written media) – they last longer than photographs or film; they have a larger storage capacity for information; and they are more easily transported than the bulky media of earlier ages.<sup>8</sup> This builds on

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<sup>4</sup> Kittler and Ogger, "Computer Graphics: A Semi-Technical Introduction," 35.

<sup>5</sup> Galloway, *The Interface Effect*, 8.

<sup>6</sup> Chun, "On Software, or the Persistence of Visual Knowledge," 27.

<sup>7</sup> For a theoretical discussion of some of the image-producing algorithms, see: Kittler and Ogger, "Computer Graphics: A Semi-Technical Introduction."

<sup>8</sup> Sutton, "Exograms and Interdisciplinarity: History, the Extended Mind, and the Civilizing Process"; Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*; Latour, "Visualization and Cognition: Drawing Things Together"; McLuhan, *Understanding Media: The Extensions of Man*.

the shift from a literary-based world to an image-based world which entails that “we experience, perceive, and value the world and ourselves differently, no longer in a one-dimensional, linear, process-oriented historical way but rather in a two-dimensional way, as surface, context, scene.”<sup>9</sup> It is on the basis of these material differences that contemporary representational technologies are coming to play increasingly significant roles in cognition and knowledge production.

The first section of this chapter will demonstrate how modern science and knowledge are intricately interwoven with material infrastructures. Particularly in the latter half of the twentieth century, representational technologies have come to occupy important roles in providing the basis for human knowledge. The second section will look at recent research in cognitive science and philosophy of mind to argue that it is not only that knowledge is *stored* in technology, but also that technology plays a role in *thinking*. From here, the third section will go beyond the general proposition that thinking occurs with machines and outline some specific mechanisms through which representational technologies augment cognition. The latter half of this chapter will then turn towards existing ideas of knowledge production in IR and show how the idea of representational technologies modifies concepts such as epistemic communities. From here, a new concept will be put forth: the idea of cognitive assemblages as the sociotechnical production of knowledge for actors involved in world politics.

### **Materialising Knowledge**

In one sense, the focus on knowledge and representations in this thesis is nothing new for IR. Constructivism has long emphasised the processes of knowledge production, highlighting the ways in which identities, norms, interests, and knowledge contribute to the formation of world politics. In Emanuel Adler’s exemplary words, knowledge for IR “means not only information that people carry in their heads, but also, and primarily, the intersubjective background or context of expectations, dispositions, and language that gives meaning to material reality”.<sup>10</sup>

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<sup>9</sup> Flusser, *Into the Universe of Technical Images*, 5.

<sup>10</sup> Adler, “Communities of Practice in International Relations,” 4.

Knowledge here is both mental (inside the head) and social (distributed via intersubjective communication).

The problem with this formulation of what knowledge is (and what distinguishes the approach taken here from traditional constructivist approaches) is that decades of research in other disciplines have shown this to be a partial view of the nature of knowledge. Instead, knowledge has come to be recognised as being comprised of a heterogeneous set of materials, of which only a portion are in fact identifiably ‘social’ or ‘in our heads’. It is precisely this heterogeneity – and more specifically, the materiality of knowledge – that this thesis is attempting to focus our attention on. Knowledge is inseparable from measuring instruments, from data collection tools, from computer models and physical models, from archives, from databases and from all the material means we use to communicate research findings. Highlighting the significance of these material means of knowledge production, Latour argues that a major factor which separates pre-scientific minds from scientific minds is the technologies that became available during this period.<sup>11</sup> There was, in other words, no sudden advance in brainpower which made seventeenth century humans more scientific than fifteenth century humans. Similarly, as philosophy of science has shown, there is no clear scientific method that we simply started to follow.<sup>12</sup> Instead, Latour argues the shift was largely in the production and circulation of various new technologies which enabled our rather limited cognitive abilities to become more regimented and to see at a glance a much wider array of facts and theories. The printing press is the most obvious example here, but also the production of rationalised geometrical perspectives and new means of circulating knowledge – all of this contributed to the processes of standardisation, comparison, and categorisation that are essential to the scientific project. Similarly, the instruments of knowledge production themselves come to embody and embed particular theories, permitting a boot-strapping process of further technological and scientific development.<sup>13</sup> The thermometer, for instance,

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<sup>11</sup> Latour, “Visualization and Cognition: Drawing Things Together.”

<sup>12</sup> Feyerabend, *Against Method*.

<sup>13</sup> Humphreys, *Extending Ourselves: Computational Science, Empiricism and Scientific Method*.



“...has been designed to take one quantitative reading (e.g. mercury volume) and systematically translate it into another quantitative reading (e.g. degrees Celsius). This is a very simple computation, but it is a kind of reasoning process. Modern science is built upon a panoply of much more complicated instruments that automate lengthy series of calculations which we previously would have had to wind our own inferential path through.”<sup>14</sup>

This condensation of inferences into instruments is one of the primary means of expanding our limited cognitive capacities. Therefore, the shift between the pre-scientific to the scientific world was heavily indebted to shifts in the materiality of knowledge, not our minds.

Today sees a similar revolution in the material infrastructure of knowledge production. Since the emergence of computers, science has been increasingly beholden to their abilities to the extent that modern science is almost entirely premised upon computational infrastructures with knowledge existing distributed across these systems. The large-scale experimental apparatus such as wind-tunnel testing grounds and particle accelerators are all essential to the production of knowledge, and the amount of data generated by these systems demands computational analysis. These ‘knowledge infrastructures’ are comprised of “robust networks of people, artefacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds.”<sup>15</sup> They function as widely dispersed systems of observation, calculation and data storage. Contrary, therefore, to poststructuralists like Jean Baudrillard and Paul Virilio, the West is not shifting into a post-physical virtual world, since symbols themselves have become increasingly dependent on material structures.<sup>16</sup> Such is the dependency of science on these systems that a number of commentators are beginning to worry about the costs of ‘big science’ and whether these computational infrastructures can grow

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<sup>14</sup> Wolfendale, “No Givenness Please, We’re Sellarsians.”

<sup>15</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 17.

<sup>16</sup> Baudrillard, *Simulacra and Simulation*; Virilio, *Open Sky*.

much further with diminishing funding.<sup>17</sup> Yet these infrastructures remain essential to contemporary knowledge production:

“Get rid of the infrastructure and you are left with claims you can’t back up, facts you can’t verify, comprehension you can’t share, and data you can’t trust. Without the infrastructure, knowledge can decay or even disappear. Build up a knowledge infrastructure, maintain it well, and you get stable, reliable, widely shared understanding.”<sup>18</sup>

Knowledge, therefore, is both produced and sustained by these material systems, to such a degree that progress in scientific knowledge is now tied to progress in computational technology.<sup>19</sup>

With this increased reliance on material (and specifically, computational) infrastructures, knowledge production is undergoing a transformation on multiple levels. The much heralded rise of ‘big data’ is but one recent symptom of this shift. This increasing reliance on computational science has been equated with an overall revolution in which the very style of scientific practice and institutionalisation gets transformed.<sup>20</sup> Others highlight the tendency of this new science to shift from reductive analysis of components to emergent synthesis of wholes – one premised upon networks and complex systems.<sup>21</sup> Perhaps most significantly, the novelty of computational science stems from the fact that it “uses methods that push humans away from the centre of the epistemological enterprise.”<sup>22</sup> The rise of digitised information and increasingly ubiquitous data collection has meant that science is becoming too vast, too filled with unrelated data, and too complex for traditional

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<sup>17</sup> Weinberg, “The Crisis of Big Science.”

<sup>18</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 19.

<sup>19</sup> Humphreys, “The Philosophical Novelty of Computer Simulation Methods,” 625.

<sup>20</sup> Schweber and Wächter, “Complex Systems, Modelling and Simulation.”

<sup>21</sup> Barabási, “The Network Takeover.”

<sup>22</sup> Humphreys, “The Philosophical Novelty of Computer Simulation Methods,” 616.

methods and for individual comprehension. There is a shift occurring here in what ‘science’ and ‘knowledge’ mean.<sup>23</sup> As one commentator puts it,

“With the new database-based science, there is often no moment when the complex becomes simple enough for us to understand it. The model does not reduce to an equation that lets us then throw away the model. You have to run the simulation to see what emerges.”<sup>24</sup>

In order to make these systems compatible with human limitations, their operations must be output into particular human-sized representations (often, though not always, visual) – a problem which is increasingly being recognised by studies of data visualisation.<sup>25</sup> Lastly, with this shift in the methods of knowledge production comes a shift in decision-making as well. Whereas historically, decisions have been made on the basis of experience and judgment, with the rise of complex societies we have had to shift to a new mode of understanding and acting that is premised upon data, algorithms, and interfaces.<sup>26</sup>

Modern science is therefore increasingly reliant on materialising knowledge. Yet this idea of ‘materialising knowledge’ has at least two senses that need to be distinguished. The first we have already mentioned: the relatively common sense notion that technologies *embody* knowledge in their very construction. A telescope, for instance, embodies certain principles of refraction, along with certain engineering principles. A nuclear weapon embodies knowledge of atomic structure and uranium enrichment. In this sense, materializing knowledge means quite literally turning knowledge into a concrete artefact. The second – and for our purposes, more important – sense is of embedding and extending cognitive systems into material infrastructures. In this sense, technology (particularly computing

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<sup>23</sup> Weinberger, “To Know, But Not Understand.”

<sup>24</sup> Ibid.

<sup>25</sup> Tufte, *The Visual Display of Quantitative Information*.

<sup>26</sup> Sarewitz, Pielke, Jr., and Byerly, Jr., “Introduction: Death, Taxes, and Environmental Policy,” 3; Brynjolfsson, Hitt, and Kim, *Strength in Numbers: How Does Data-Driven Decisionmaking Affect Firm Performance?*; Ayres, *Super Crunchers: Why Thinking-By-Numbers Is the New Way To Be Smart*.

technology) *does* cognitive activities such as perception, memory and processing, and then presents the outcome of these processes in a form amenable to human cognition. It is one of the unique components of the modern world that such representation-producing technologies widely exist, inaugurating a new way to speak of the material construction of world politics.

### **Extending Cognition**

It is this latter sense of materialising knowledge which has been the focus of recent research in cognitive science and philosophy of mind. While the notion of *embedding* cognition into material processes (the brain, most obviously) is no longer controversial, this research has argued for *extending* cognition beyond the boundaries of the human body. Rather than cognition being limited within the physical boundaries of an organism, the literature on distributed cognitive systems argues that technology can and does extend cognition beyond these arbitrary borders. What this entails is that certain information processing functions can be carried out by objects external to our physical bodies.<sup>27</sup> In a famous example, the philosophers Andy Clark and David Chalmers imagine the case of a man with amnesia who uses a notebook as the primary storage medium for his memories.<sup>28</sup> If examined closely, we realise that the notebook itself plays all the functional roles we would typically attribute to internal memory – meaning that once we ignore our inner/outer assumption we should be willing to acknowledge that this external object is itself a part of a distributed cognitive system.

This argument relies on what Clark calls the Parity Principle. It is a weak form of functionalism which states that if an external object consistently carries out a causal-functional role for a cognitive system, then it should be considered a part

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<sup>27</sup> A few important qualifications: first, most proponents of EMH argue for a human-*centric* view of cognition, but not a human-*bound* view. That is to say, the human brain remains a necessary component of cognition. (Clark, *Supersizing the Mind: Embodiment, Action, and Cognitive Extension*, 122–123.) Secondly, cognition must also be distinguished from consciousness – an element can play an information-processing (cognitive) role without becoming part of a system of consciousness (involving self-reflexivity). For instance, our mind does not maintain all of its memories in consciousness at once, but instead cognitively processes these at a pre-conscious level before making them available for self-reflection.

<sup>28</sup> Clark and Chalmers, “The Extended Mind.”

of that cognitive system. As Clark argues, what the Parity Principle does is suspend the arbitrary *a priori* separation between the inner and the outer. If some external object – a notebook, a computer, a smartphone – plays a role in a cognitive sequence, then the simplest explanation is that it *is* part of an extended system. The picture of human cognition emerging from the research in this field is one of humans who are experts at offloading information processing into their environment. “The real power of human cognition lies in our ability to flexibly construct functional systems that accomplish our goals by bringing bits of structure into coordination.”<sup>29</sup> The result is an image of the human that is more managerial than anything else. We excel at mobilizing decentralised processes, while maintaining minimal internal cognitive capacities.

Yet in order to draw the boundaries of such extended systems, a distinction must be drawn between external elements that are merely causally important and external elements that play a truly cognitive role.<sup>30</sup> This, in turn, requires a definition of cognition. Such a definition of cognition and cognitive roles must not be so fine-grained as to limit it to the idiosyncratic nature of human cognition; yet neither must a definition be so general as to negate any possible explanatory advances.<sup>31</sup> In the words of the cognitive scientist Edwin Hutchins, the requirements for a conception of extended cognition are such that,

“the sort of computation that cognition is [has] to be as applicable to events that involves the interaction of humans with artefacts and with other humans as it is to events that are entirely internal to individual persons.”<sup>32</sup>

With the criteria in mind, cognition will here be taken to mean thought understood as a matter of information-processing and which thus takes a cognitive system as “a complex system that receives, stores, retrieves, transforms, and

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<sup>29</sup> Hutchins, *Cognition in the Wild*, 316.

<sup>30</sup> Rupert, *Cognitive Systems and the Extended Mind*, 94-95.

<sup>31</sup> Rupert, *Cognitive Systems and the Extended Mind*.

<sup>32</sup> Hutchins, *Cognition in the Wild*, 118.

transmits information.”<sup>33</sup> For our purposes, the primary debates in cognitive science over connectionist versus dynamic systems versus computationalist approaches are immaterial. Whatever way cognition is processed within the brain is secondary to an abstract definition of cognition that allows for its embodiment in multiple physical instantiations. The strength of this definition is that it points to a minimal notion of cognition involving computation, representation, and the circulation of representations within an individuated system. It does not *a priori* bias the study of cognition towards a particular material realisation (e.g. the neural circuitry of the human brain), thus it falls silent on *where* cognition resides. The demarcation of the causes of cognition from the constitutive elements of cognition (i.e. what is external to cognition from what is internal to cognition), is not something that can be determined in advance but can only be determined by virtue of empirical research and explanatory success.<sup>34</sup>

While later chapters will substantiate this with empirical detail, already there are theoretical reasons to reject the critics of distributed cognition and argue that an extended system is a valid entity irreducible to the summation of the individual plus its environment of technology.<sup>35</sup> Most obviously, the entire sociotechnical system is oriented towards a specific functional goal (e.g. producing true representations of the climate, inferring the state of a global market, and orienting action within a crisis situation) and this function cannot be located simply within any individual component. It only exists and is carried out by the entire system. Similarly,

“the computational power of the system composed of person and technology is not determined primarily by the information-processing capacity that is internal to the technological device, but

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<sup>33</sup> Dawson, *Understanding Cognitive Science*, 5; This leaves aside the arguably important element of affect in understanding human phenomenology, which is an aspect that could be developed in parallel with the cognitive ideas sought here. (See, for instance: Protevi, *Political Affect: Connecting the Social and the Somatic*; Connolly, *Neuropolitics: Thinking, Culture, Speed*.)

<sup>34</sup> Wilson, “Review of Robert Rupert, ‘Cognitive Systems and the Extended Mind’.”

<sup>35</sup> For some of the most sophisticated critiques, see: Fodor, “Where Is My Mind?”; Rupert, *Cognitive Systems and the Extended Mind*; Adams and Aizawa, *The Bounds of Cognition*.

by the role the technology plays in the composition of a cognitive functional system.”<sup>36</sup>

In other words, in order to fully understand the roles and uses of technology, or human cognitive systems, one must take into account the functional system within which they operate. As representations are circulated through this system, changing their medium in the process and affecting responses, it is relatively simple to understand this system as something bound and distinct from an external environment. Similarly, the distribution of cognition takes on new properties above and beyond individual cognition – including parallel cognitive activities, and the emergent significance of bandwidths for communication.<sup>37</sup> Thus distributed cognitive systems are valid entities by virtue of the fact that they produce emergent properties irreducible to their component parts. We cannot simply analyse the human mind in interaction with an environment, but must instead take the perspective of the system itself.

There is one further dimension of the extended mind that also needs to be examined – a dimension which moves the debate beyond the Parity Principle’s conservative functionalism. Whereas the Parity Principle invokes the extension of already existing functional roles to external objects, there is also the possibility for extension to create emergent and novel functional possibilities.<sup>38</sup> In fact, it is this capacity which makes studying extended cognitive systems particularly significant since it entails that they incorporate possibilities that are irreducible to either human cognition or the technological extension.<sup>39</sup> In this dimension there are therefore three possibilities. The first is the purely ‘instrumental’ level where a technology simply replaces a function that a human is already capable of. The second level is ‘extensive’ – it takes an existing human capacity and extends it beyond what a human is normally capable of. In principle, the capacities of

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<sup>36</sup> Hutchins, *Cognition in the Wild*, 155.

<sup>37</sup> *Ibid.*, 284.

<sup>38</sup> This focus on the emergent and novel functional aspects of the extended hypothesis counters Robert Rupert’s criticism that EMH adds no explanatory value to existing cognitive science work. It is precisely these types of emergent functions that are neglected by a focus on the individual alone. (Rupert, *Cognitive Systems and the Extended Mind*, 18.)

<sup>39</sup> Sutton, “Exograms and Interdisciplinarity: History, the Extended Mind, and the Civilizing Process.”

extensive technologies can be accomplished by humans (though often with great difficulty), and so it is a fluid boundary between instrumental and extensive technologies.<sup>40</sup> The final category is ‘transformative’ technologies, which are those which produce entirely new capacities for humans – capacities which humans are not innately capable of even in principle. We can think here, for instance, of the many scientific instruments which allow the ability to ‘perceive’ unobservable entities like positrons, alpha particles and electron spin.<sup>41</sup>

### **Reasoning with Technology**

Given that cognitive science and the philosophy of mind persuasively argue that cognition can extend outside the physical body of an individual, the question to be settled in this section is how are representational technologies employed to accomplish this cognitive augmentation? The literature on this question is large and growing, albeit scattered across multiple disciplines and with numerous diverging case studies. Moreover, the products of representational technologies can take a diverse array of forms (e.g. visual, numerical, and linguistic). The aim here will be to provide a wide angle view on how such technologies affect and augment cognition. It is on the basis of these augmentations that the case studies will make possible new behaviours.

To begin with, one can broadly distinguish between different types of representational technologies. Essential to each is that they allow for manipulation and offer affordances for reasoning. Users can use them, change them, experiment with them, and play with them, in an effort to make a phenomenon intelligible. With this characteristic in mind, the most basic level of representational technologies can be considered images. While some have argued that images alone are incapable of manipulation and therefore are incapable of augmenting cognitive abilities,<sup>42</sup> there are cases which permit of manipulation and therefore afford the

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<sup>40</sup> Depending on the reference point, what is instrumental for one case may be extensive for another case. For instance, a wheelchair may be instrumental for an able-bodied individual, whereas it becomes extensive for a paraplegic. These categories are therefore relative, and not absolute.

<sup>41</sup> Humphreys, *Extending Ourselves: Computational Science, Empiricism and Scientific Method*, 4.

<sup>42</sup> Morgan, *The World in the Model: How Economists Work and Think*, 13.



possibility to reason with. A navigational chart, for instance, “is a carefully crafted computational device” that is used to simplify the calculation of distances and directions via the drawing of lines on it.<sup>43</sup> In other words, such charts are designed for manipulation, despite being a static image.

The focus of this thesis, however, will be on computational instruments which incorporate a much more expansive range of possible manipulations. The scope of technologies included here is broad: some are more formal and abstract, others are more data-driven and empirical; some are more real-time analysis, others are more long-term and predictive; and so on. It is the automation and computational power which distinguishes these contemporary technologies from earlier representational technologies.

In this thesis, three different means of producing representations will be analysed: simulations, pricing models, and real-time data processors. Simulations act as idealised laboratories, suitable for examining the dynamics of processes that are difficult or impossible to experiment with in reality. They embody particular scientific theories and computationally encode inferences that can be repeated multiple times in order to uncover the likely outcomes of the real processes.<sup>44</sup> Climate change simulations are the example that will be covered here. The climate is far too complex of a system to intervene in an experimental way, and must instead be tested on computer simulations.

Pricing models are close but analytically distinct from simulations. At their basis they also encode particular theories, but they are not used to test theories nor are they usually run multiple times. Instead they take certain inputs and run them through algorithms in order to produce a particular output. The case study that covers these means of producing representations will be derivatives pricing models, which use complex mathematics to combine empirical variables and non-empirical probability distributions in order to produce rational prices for various derivatives.

The last type of representational production covered in this thesis will be real-time data processing and visualization. This process takes in information

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<sup>43</sup> Hutchins, *Cognition in the Wild*, 61.

<sup>44</sup> Winsberg, “Sanctioning Models: The Epistemology of Simulation,” 276.

received simultaneously from multiple sources and synthesises and analyses this information, producing some form of representation as an output. The algorithms involved here do not embody theories, as in simulations and models, but instead function to combine massive amounts of disparate data. Crisis mapping is the primary example that will be analysed in this thesis, looking at how this amalgamation of real-time data provides new perspectives and capacities for action in humanitarian situations.

The traditional approach to representational technologies, largely emerging out of philosophy of science, has been to examine them in terms of their representational qualities.<sup>45</sup> This approach is itself divided into two research programs – one is focused on scientific models in fields like physics, economics, and biology, and examines the relationship between a model and the theory which it embodies (an approach itself divided between a syntactical and semantic view).<sup>46</sup> A second program is to focus on the relationship between a model and the world (whether it is aiming to either fully represent the data or to provide a caricature of it).<sup>47</sup>

A third approach widens the scope beyond these representational aspects and examines models as technologies that *do* things.<sup>48</sup> Representational technologies, by virtue of being relatively autonomous from both theory and data, are capable of having their own instrumentality that is irreducible to a representational function.<sup>49</sup> This latter approach spans research on how representational technologies act as exploratory instruments,<sup>50</sup> how models shape the world towards their own image,<sup>51</sup> and how models construct social realities.<sup>52</sup> It is this approach to representational technologies, which sees such cognitive augmentations as instruments rather than just representations, that is the focus

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<sup>45</sup> Hughes, “Models and Representation.”

<sup>46</sup> Suppes, “A Comparison of the Meaning and Use of Models in the Mathematical and Empirical Sciences”; van Fraassen, *The Scientific Image*; Giere, *Explaining Science: A Cognitive Approach*.

<sup>47</sup> Frigg, “Scientific Representation and the Semantic View of Theories.”

<sup>48</sup> Morrison and Morgan, “Models as Mediating Instruments”; Knuuttila, *Models as Epistemic Artefacts: Toward a Non-Representationalist Account of Scientific Representation*.

<sup>49</sup> Morrison and Morgan, “Models as Mediating Instruments,” 32.

<sup>50</sup> Morgan and Morrison, *Models as Mediators: Perspectives on Natural and Social Science*.

<sup>51</sup> MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets*.

<sup>52</sup> MacKenzie, Muniesa, and Siu, *Do Economists Make Markets?: On the Performativity of Economics*.

here. These technologies make possible a variety of cognitive actions that are otherwise prohibitively costly or simply impossible. In their computational form, they oversee a shift from expert judgment to engineered algorithms; they facilitate learning processes by virtue of their manipulative abilities; and they can be used for stigmergic coordination between decentralised individuals, amongst other tasks. In making new cognitive extensions and new political actions possible, these technologies function in a similar way as intersubjective ideas do for constructivists – they are “the medium and propellant of social action; they define the limits of what is cognitively possible and impossible for individuals.”<sup>53</sup>

In large part, these technologies gain their power via embodying two general sets of rules for manipulation: the rules imposed by the material of the model, and the rules imposed by the subject matter of the model.<sup>54</sup> In the former, the material can be physical (e.g. models that attempt to build scale replicas of the phenomenon in question) or ideational (e.g. models built in algebraic language or a particular computer language). In both cases, one is bound by the rules of how one can manipulate such material. The second broad set of rules comes from the subject matter itself – the theoretical concepts and their interrelations that the model builders have implemented into the technology.

A consequence of the two sets of rules imposed by modelling is that one can have a precise pathway for following a chain of consequences. On the basis of this, what gives contemporary computational models their peculiar power is their capacity not only to organise but also outsource cognition. While organising cognition is a virtue in itself, it is when these rules and chains of consequences are outsourced into a computational medium that they take on their uniquely modern power. With such a representational technology in hand, one can allow the calculative and inferential processes to expand far beyond any human capacity. It is here where the mechanisms of extending cognition take hold.

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<sup>53</sup> Adler, “Seizing the Middle Ground: Constructivism in World Politics,” 94.

<sup>54</sup> Morgan, *The World in the Model: How Economists Work and Think*, 26–27.

## **Knowledge Production**

At this point, it has been argued that cognition extends outside the physical brain and that representational technologies are providing new capacities for reasoning, representing, and intervening that go far beyond what has previously been possible. The question to be tackled in this section will be how such new modes of knowledge production transform traditional concepts of knowledge production in IR. In particular, the closely related concepts of ‘epistemic communities’ and ‘co-production’ all provide insights into knowledge production in world politics – yet in the end each neglects the contributions of materialised cognition. As a result, this section will aim to develop the idea of ‘cognitive assemblages’ as an extension of communities of knowledge into material infrastructures.

### *Epistemic Communities*

The literature surrounding the concept of ‘epistemic communities’ is the most well-known intervention into how knowledge and politics interact in IR. In the standard definition, epistemic communities are considered to be “a network of professionals with recognised expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge within that domain or issue-area.”<sup>55</sup> In contrast to a simple group of scientists working on a technical problem, an epistemic community also shares a particular value orientation and seeks to further their goals by providing expertise to policymakers. Epistemic communities are therefore significant for the study of policy coordination because they “may convey new patterns of reasoning to decision makers and encourage them to pursue new paths of policymaking.”<sup>56</sup> As a consequence, the concept helps explain how state interests change over time; how actors’ estimates of cost, benefits and probability change; and how ideas about how to attain an outcome change.

Developed and popularised in the 1990s, research on this concept has since come to adopt a few key areas of interest. In the first part, it has tended to focus heavily on professional scientists and science. The approach taken here is to

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<sup>55</sup> Haas, “Epistemic Communities and International Policy Coordination,” 3.

<sup>56</sup> *Ibid.*, 21.

instead follow recent work on the concept and take knowledge production to include more than simply a group of scientists. Instead the term invokes any group that seeks to construct and transmit knowledge, and to influence politics via their expertise in knowledge (though not necessarily policy).<sup>57</sup> Moreover, one of the main findings in recent research on the science-politics relation is how often the divide between the two becomes an instrument wielded by political groups to either strengthen their position or weaken an opponent's.<sup>58</sup> While the authority of certain knowledge claims will be an important element in some of the case studies presented here, the strategy will be to reject any strict divide between science and non-science. The focus will instead be on knowledge claims, which can vary in the strength of their epistemic support (akin to Latour's notion of how reference circulates).<sup>59</sup> The value of these moves is that they recognise the necessity of constructing knowledge in all areas of international politics – the process of producing knowledge is not limited solely to highly technical areas, but is instead ubiquitous.

The second major focus within the epistemic community literature has been on how knowledge production is aimed at influencing states. In particular, standard analyses of the role of scientific knowledge in politics have focused on the policy process, often separating it into a tripartite (albeit overlapping) division: agenda setting, legislation, and implementation.<sup>60</sup> However, once one recognises the widespread significance of knowledge production (and not just that by scientists) then the scope for *where* knowledge is relevant becomes increasingly widespread as well. Privatised governance is but one example of this, yet this thesis will also examine how knowledge production affects actors in financial markets and actors in humanitarian crises.<sup>61</sup> The state-centric focus of the epistemic community literature is too constricting. In addition, this focus on policy-relevance

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<sup>57</sup> Cross, "Rethinking Epistemic Communities Twenty Years Later"; Adler, "Communities of Practice in International Relations"; Barry, "The Translation Zone: Between Actor-Network Theory and International Relations," 423.

<sup>58</sup> Jasanoff, *The Fifth Branch: Science Advisers as Policy Makers*, 14.

<sup>59</sup> Latour, "Circulating Reference: Sampling the Soil in the Amazon Forest."

<sup>60</sup> Mitchell, *International Politics and the Environment*, 80; Keller, *Science in Environmental Policy: The Politics of Objective Advice*.

<sup>61</sup> Cross, "Rethinking Epistemic Communities Twenty Years Later," 141.

tends to assume the external formation of an epistemic community, which only enters into the policy process after it has formed. The directionality of the influence goes from consensus to policy coordination. Similarly, the formation of consensus on a piece of knowledge is presumed to occur outside of and before the political process.<sup>62</sup> “Rarely do people adopt convergent ideas and then decide to band together in communities or form new institutions; rather, they come to share ideas as a result of social interactions that help constitute the community in the first place.”<sup>63</sup> The messiness of knowledge production, and its always tentative certainty, is typically left aside in these analyses.

By contrast, an alternative concept that has arisen to take into account this interaction between science and politics is the idea of ‘co-production’. In this framework, rather than a deficit model of communication (with information being transferred linearly from scientists to policymakers),<sup>64</sup> what is seen to occur in practice is more akin to a dialogue model whereby policymakers are increasingly voicing their needs to scientists and vice versa. This recognition of the messiness of the science-policy distinction in practice has led science and technology scholars to speak of ‘boundary work’ and ‘boundary organisations’.<sup>65</sup> In this view, the divide between science and politics is not an a priori given and is instead the boundary is something that must be constructed in the process of interaction. Boundary organisations are those organisations which straddle the two worlds of politics and science. They create products which can be used by both sides (e.g. Intergovernmental Panel on Climate Change (IPCC) assessment reports), they involve members of both worlds, and they are responsible (in different ways) to each world.<sup>66</sup> The concept of boundary organisations therefore recognises that science and policy are often highly intermixed, and that interaction between the two is the rule not the exception.

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<sup>62</sup> Miller and Edwards, “Introduction: The Globalization of Climate Science and Climate Politics,” 4.

<sup>63</sup> Miller, “Challenges in the Application of Science to Global Affairs: Contingency, Trust, and Moral Order,” 248.

<sup>64</sup> Hulme, *Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity*, 217-222.

<sup>65</sup> Jasanoff, *The Fifth Branch: Science Advisers as Policy Makers*; Guston, “Boundary Organizations in Environmental Policy and Science: An Introduction.”

<sup>66</sup> Guston, “Boundary Organizations in Environmental Policy and Science: An Introduction,” 400-401.

The epistemic community literature has been useful for acknowledging the significance of knowledge in shaping world politics, and as this short review has shown, has been expanded in a number of different directions.<sup>67</sup> What perhaps calls for a new term though is the introduction of specifically material aspects of knowledge production. Once one goes beyond social relations and starts looking at how technological infrastructures are being incorporated into knowledge production, the term ‘community’ begins to lose its grasp. As a result, we here prefer to use the term ‘cognitive assemblages’ in order to emphasise the always material nature of knowledge production.

### *Cognitive Assemblages*

Cognitive assemblages share many of the features of these earlier concepts: they highlight the intermingling of knowledge and politics in contemporary societies; they recognise the often competing demands of both worlds; and they recognise that the products of these systems are designed to bridge the two worlds. Where they go further is in highlighting the material infrastructure of boundary organisations, and emphasising the technological dynamics.<sup>68</sup> With regard to representational technologies, we can draw a distinction between such technologies (the physical components) and cognitive assemblages (the sociotechnical whole).<sup>69</sup>

With relation to the approaches covered in the previous section, what is particularly novel about cognitive assemblages is the delegation of thought to machines. Epistemic community and boundary organisation approaches maintain cognition as a solely human process and one shaped by social factors such as power and authority. With the cognition of problems delegated to machines though, the factors affecting the outcome begin to include properly material aspects of

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<sup>67</sup> Cross, “Rethinking Epistemic Communities Twenty Years Later.”

<sup>68</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 388.

<sup>69</sup> Within contemporary media theory, a broad division exists between theorists who focus on the nonhuman physical aspects of technological media (how media operates as a physical entity) and theorists who focus on the human phenomenological grasping of these media (how physical signals get translated into meaningful signs). In our terms, the former would consist of representational technologies, whereas both aspects combine into cognitive assemblages. (Parikka, “Media Archaeology as a Transatlantic Bridge,” 23.)

technology as well. Incorporating technology is significant therefore because it brings with it the dynamics analysed in the previous chapter – as a platform that shapes social formations and temporal development. Thus technological dynamics become an important explanatory factor in when, where and how political issues arise and are approached. Knowledge becomes collective and distributed rather than individual or solely social:

“These descriptions of the temporally extended and collective work of producing objective displays contrasted with the established view of observation and representation as individual, and largely instantaneous, perceptual acts. Instead of being a confrontation between a world and a prepared mind, the research *act* began to resemble a form of factory production in which material inputs were transformed into readable data to be disseminated widely in a community.”<sup>70</sup>

Secondly, the concept of cognitive assemblages highlights the way in which epistemic communities and boundary organisations can be a derivative effect of technological infrastructures.<sup>71</sup> For epistemic communities, ideas are situated in and organised by a collective. It is the members of this collective who then spread the ideas around. By contrast, the idea of cognitive assemblages highlights that ideas can also be situated in and organised by representational technologies. For instance, regardless of a community existing beforehand or not, option pricing models have become hegemonic tools to intervene in derivatives markets. To interact with these markets means to accept the framing of the market provided by these instruments. Similarly, the climate modelling infrastructure produces communities that incorporate atmospheric scientists, software engineers, physicists, data designers, chemists, technicians, and others. These communities are brought together by virtue of the needs of the technological system itself, and the scientific

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<sup>70</sup> Lynch, “The Production of Scientific Images: Vision and Re-Vision in the History, Philosophy, and Sociology of Science,” 29–30.

<sup>71</sup> Edwards, “Global Comprehensive Models in Politics and Policymaking,” 152.



representations produced by the models can and do form the basis for shared beliefs in epistemic communities. Much like newspapers for the constitution of national imagined communities, scientific visualisations can constitute particular epistemic communities.<sup>72</sup>

Third, cognitive assemblages focus on the decentring of rational thought. Government rationality exists neither in a unified mind (the statist view), nor in competing bureaucracies (the foreign policy analysis view). Rather, government rationality is an extended material infrastructure, complete with the unique advantages and hindrances that such a situation brings. This also means looking at alternative places where the understanding of a situation may go wrong – namely, in the political or otherwise biased nature of the models themselves. For instance, one of the main observational gaps for climate modelling is currently in Africa, leading to greater uncertainty over short- to mid-term predictions for this region. The political consequences of this model shortcoming could be significant given that it is among the most vulnerable areas in the world to climate change.

Finally, as was emphasised earlier, externalised cognition has different properties and capacities from internal cognition. Certain forms of nonhuman cognition become available for use (e.g. thinking nonlinearities and second- and third-order effects), but also bring along new problems of parameter-setting, tuning, computational friction, and data arms races. In addition, technological cognition, as opposed to internal cognition, has the properties that it can be more durable, easier to communicate, have greater capacities, and be simpler to consciously manipulate.<sup>73</sup>

In all these ways, therefore, the concept of cognitive assemblages shifts the focus of attention and changes the potential explanatory factors involved in understanding world politics. The cognitive assemblage becomes a *necessary* mediating point between the problem and those charged to solve it. The problem (e.g. the changes in the climate system) must pass through a technological mediator

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<sup>72</sup> Jasanoff, “Image and Imagination: The Formation of Global Environmental Consciousness,” 311; Anderson, *Imagined Communities: Reflections on the Origin and Spread of Nationalism*.

<sup>73</sup> Sutton, “Exograms and Interdisciplinarity: History, the Extended Mind, and the Civilizing Process,” 189; Stiegler, *Technics and Time, 2: Disorientation*.

(e.g. GCMs) in order for them to become thinkable by a policymaker. The result is that the technology introduces a particular series of representations of the problem into the cognitive assemblage and these go on to have consequences in a variety of ways.

### **Cognitive Mapping**

In looking back at this chapter and the previous one, they can be usefully framed as a division between the hardware (chapter 2) and the software (chapter 3) of representational technologies. The overall conclusion of these chapters is that technological autonomy combined with cognitive assemblages entails that perception and cognition of the world shifts as technology shifts. These transformations are accomplished through the introduction and diffusion of various cognitive-enhancing technologies into the fabric of world politics. The state, and indeed any actor in world politics, must be recognised as a complex network of various mechanisms that incorporate and expand perceptual, cognitive, and action functions (the latter typically being the sole idea of power).<sup>74</sup>

With respect to the initial problem posed in chapter 1 of cognitive mapping – the gap between phenomenological experience and global structures – it should be clear by now that it is technology which enables human cognition to asymptotically bridge this gap. In this final section, we will examine what this entails and why it is necessary for the contemporary era.

The fact that the modern world is increasingly complex has been declared by many scholars before. This complexity can be divided into a number of different aspects. First, and most intuitively, today's crises are often truly global in scale – they span and spread throughout global networks. These interconnections, moreover, involve feedback loops, nonlinear dynamics, and unintended second- and third- order effects. The second aspect of complexity is that these global problems spread with an unprecedented amount of speed. The increasingly tight interconnections mean there are ever more channels through which crises can diffuse. A third aspect of complexity results from the simple finite limits of human

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<sup>74</sup> Jessop, *State Power*.

cognition. The increase in specialization has been a consequence of these limits, as individuals are forced to focus on ever smaller areas in order to maintain pace with the front lines of human knowledge. Yet this specialization has meant that an understanding of large systems has come under increasing stress. It is technology which is increasingly being used (implicitly and explicitly) to overcome the cognitive limitations of individual humans and map the complexity of today's world.

This metaphor of cognitive maps suggests a few different qualities. First, maps occupy a middle ground between the purported neutrality of scientific perspective and the practical exigencies of a particular situation. They cannot eschew representation entirely, nor can they ignore the demands of human action. Maps require specific limitations and abstractions precisely in order to fulfil their functions. "Without visual limits there can be no, or almost no, mental imagery; without a certain blindness, no tenable appearance."<sup>75</sup> It is specifically the complexity of the contemporary conjunction which leaves action immobilised; thus mapping calls precisely for a condensation of this complexity in order to make action effective. An effective map needs to condense (with this word's dual sense of making-smaller and bringing-together) the global structures. Maps also inscribe and embody accumulated bodies of knowledge – they are a technology in themselves, in this sense.<sup>76</sup> Finally, maps entail the production of an abstract perspective as well. Such perspectives do not correspond to any actual point of view, but instead aim to provide a universal viewpoint on a situation which allows for a lived experience to be situated within it.<sup>77</sup> On the other hand, the risk of the map metaphor is that it too closely suggests a spatialisation of relationships. The essence of maps, however, is less a matter of spatialising relationships than it is of making abstractions sensible to individuals. In the words of one map theorist, they create "categories, boundaries and territories."<sup>78</sup>

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<sup>75</sup> Virilio, *The Art of the Motor*, 4.

<sup>76</sup> Pickles, *A History of Spaces: Cartographic Reasoning, Mapping and the Geo-coded World*, 60.

<sup>77</sup> *Ibid.*, 128.

<sup>78</sup> *Ibid.*, 94.

Importantly, cognitive maps do not merely represent a pre-existing reality. Instead they also *materially construct* the global. As examples from later chapters will show, it is on the basis of these maps that further developments of the global become possible. We can see weather, but we cannot see the global climate. We can see stock exchange floors, but we cannot see a global financial market. We can see destroyed buildings, but we cannot see a humanitarian crisis. In these cases, abstraction and conceptual representation become the sole means of perceiving the phenomenon. The ‘global’ as a conceptual representation that permits of rational action does not exist outside of the material representations of it. To be sure, cognitive maps index some real aspects of the world in the same way that any knowledge does. Yet the science of the global focuses on an object that is invisible without the proper conceptual and material tools to make it perceptible. There is a parallel here with the natural sciences and their extension to unobservable entities: “The notion of a detectable unobservable can be extended outside the natural sciences with one minor modification: the recognition that detection equipment need not be *physical* equipment, but can also be *conceptual* equipment.”<sup>79</sup> It is precisely cognitive maps and the material cognitive systems they presuppose which provide the equipment to make visible an otherwise unobservable ‘global’.

Today, many global actors are already using variations of this technology. The US military is now modelling first-, second-, and third-order effects of airpower attacks on vital infrastructure.<sup>80</sup> The US Federal Reserve uses massive econometric models involving over a thousand variables, one hundred equations, and observations from around the country in order to forecast the future of the economy.<sup>81</sup> Automated algorithms filter through the proliferating surveillance cameras around the world, using specialised software to detect ‘threats’ and report them to a human observer.<sup>82</sup> These can all be understood to produce cognitive maps, or what Buckminster Fuller called ‘geoscopic vision’ – the use of technology, data collection, algorithms, data visualization, material infrastructures, social

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<sup>79</sup> Jackson, *The Conduct of Inquiry in International Relations: Philosophy of Science and Its Implications for the Study of World Politics*, 87.

<sup>80</sup> Graham, *Cities Under Siege: The New Military Urbanism*, 274–283.

<sup>81</sup> Knoop, *Modern Financial Macroeconomics: Panics, Crashes and Crises*, 150.

<sup>82</sup> Crandall, “The Geospatialization of Calculative Operations: Tracking, Sensing and Megacities.”

organizations, and user adaptability to produce (at the limits) a real-time visualization of global dynamics.<sup>83</sup>

As can be discerned from these examples as well, they are all oriented towards political action and intervention in particular situations. It is, paradoxically, the condition of concrete political action that it be premised upon abstraction. As Jameson says, “abstraction from the ‘blooming, buzzing confusion’ of immediacy was always a radical intervention in the here and now and the promise of resistance to its blind fatalities.”<sup>84</sup> It is these technologies which are making possible new interventions and new actions in the world – and it is predominantly elite organisations which control such technology. The construction of material infrastructures of power is lending ever more capacity to macro-actors to shape the world according to their own interests.

The remainder of this thesis will attempt to use the theoretical framework set out here in order to examine three case studies and show how such technologies are altering the behavioural and cognitive landscape of actors in world politics. With the world increasingly enmeshed in ubiquitous computing and digitised data collection, the issues surrounding these technologies are likely to only become more significant. While there are some general dynamics that will be examined in the concluding chapter, each case study is a relatively independent study on its own. The variety of technologies and users makes it difficult to draw many general conclusions without doing harm to the empirical data, yet each of them points to important dynamics.

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<sup>83</sup> The neologism ‘geoscopic’ borrows from Buckminster Fuller’s 1962 proposal for what he termed a Geoscope – a visualization tool which he summarizes as such: “The complete census-by-census of world population history changes could be run off in minutes... The total history of transportation and of world resource discovery, development, distribution, and redistribution could become comprehensible to the human mind, which would thus be able to forecast and plan in vastly greater magnitude than heretofore. [...] The consequences of various world plans could be computed and projected. All world data would be dynamically viewable and picturable and relayable by radio to all the world, so that common consideration in a most educated manner of all world problems by all world people would become a practical event.” (Fuller, *Education Automation*.)

<sup>84</sup> Jameson, *Postmodernism: Or, the Cultural Logic of Late Capitalism*, 400.

## 4 / SEEING NATURE

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“Unlike the wind which we feel on our face or a raindrop that wets our hair, climate is a constructed idea that takes these sensory encounters and builds them into something more abstract. Neither can climate be measured directly by our instruments. We can measure the temperature of a specific place at a given time, but no one can directly measure the climate of Paris or the temperature of the planet.”<sup>1</sup>

-Mike Hulme

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Amongst the complex problems facing the world today, it is climate change which most clearly condenses within itself the issues and messiness that such complex problems tend to produce. The knowledge generated to understand the earth system has mobilised the largest collective scientific project ever, while the response to the challenges of climate change has attempted to bring about a radical shift in the very way of life for humanity. It is inspiring wide-ranging transformations in the fabric of world politics – from shifts to green economies,<sup>2</sup> to new institutional arrangements,<sup>3</sup> to shifts in the behaviours of individuals in their everyday lives. At every level of social reality, changes are being made on the basis of climate science. And at the epistemic basis of all of this is computer modelling of the Earth system. Since climate change is not empirically observable in the same way weather is, it is “a danger described only by computer programs.”<sup>4</sup> Relative to weather, the time

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<sup>1</sup> Hulme, *Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity*, 3-4.

<sup>2</sup> Newell and Paterson, *Climate Capitalism: Global Warming and the Transformation of the Global Economy*.

<sup>3</sup> Yamin and Depledge, *The International Climate Change Regime: A Guide to Rules, Institutions and Procedures*.

<sup>4</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 155.

frames are much longer, the human-scale changes much subtler, the spatial horizon much larger, and the nonlinear effects much less predictable. The result is that climate change has had to be constructed as an object of cognition first – it required the material production of representations – and the representational technology which has been most responsible for this is general circulation models (GCMs). The primary aim of this chapter is to show how these technologies have been incorporated into larger cognitive assemblages that are now changing the behaviours of actors in world politics.

A significant driver of this change in behaviour is the evolving ways in which we see nature. As recently as 1941, climate was still considered to simply be an average of local weather patterns. One of the earliest assessments of human's impact on the climate defined it as being relative to a specific place: "The climate of a place is merely a build-up of all the weather from day-to-day."<sup>5</sup> It was not until the mid-1980s that climate routinely began to be conceived of in global terms.<sup>6</sup> The recognition that global climate change was both theoretically possible and empirically occurring has been the culmination of centuries of research. Yet it has only been the past few decades – with the rise of GCMs – that it has become possible to make predictions, to attribute responsibilities, and to establish adaptation procedures. A simulated baseline is necessary for understanding how the climate would have developed without the influence of humanity, and therefore for being able to pinpoint the causal factors. Insofar as the political question of climate change revolves around whether the changes are produced by human actions or by natural cycles, it is only GCMs which have been capable of transforming it into a potentially solvable political issue.

This chapter will explore the emergence and integration of climate modelling into the fabric of world politics. It will be argued that in the face of the complex system that is the climate, only representational technologies that extend cognition are capable of representing it and reacting to changes in the system. Moreover, these technologies are now making possible new political actions – in

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<sup>5</sup> Miller and Edwards, "Introduction: The Globalization of Climate Science and Climate Politics," 7.

<sup>6</sup> Edwards, "Representing the Global Atmosphere: Computer Models, Data, and Knowledge About Climate Change," 32.

particular, new ways of adapting to climate change. The first section will outline the ways in which nature poses a complex system and a complex problem for political actors. The next two sections will proceed through a short history of climate science and climate modelling (which became indistinguishable in the 1970s), viewing their development as being shaped by technological frictions. On the basis of this history, it will be shown how the knowledge of climate change – in all of its significant aspects – is instantiated in the technological infrastructures that form the global climate observation and modelling network. In terms of politics, this system developed relatively independently with climate scientists, computer programmers, software engineers, and other technical professionals. In the past two decades, though, this system has come to be integrated with governments around the world. The fourth section will summarise the sorts of perceptual and cognitive possibilities that these representational technologies have constructed. The fifth section will turn towards the cognitive assemblages which have been making use of these new perceptual and cognitive possibilities. In particular, the focus will be on climate modelling centres that are tightly interwoven with government demands to *think* the future of a changing climate. Complex systems demand such extensions of cognitive capacities, and governments have been increasingly developing these technological extensions in order to inform their policies. On the basis of these cognitive assemblages, new political actions are being created and employed – with localised adaptation measures being one of the clearest examples. The final section will return to the question of how representational technologies construct the actors of world politics and highlight some of the unique qualities involved in climate change.

### **The Complexity of Nature**

In what precisely does the complexity of the climate consist of? On a straightforward level, this complexity consists of the multi-levelled nature of the system: modelling the climate involves 14 levels of magnitude – from the level of



aerosol particles to the level of global circulation patterns.<sup>7</sup> A decade ago, only the top two levels were capable of being modelled (about a 300km resolution) – with the expectation that in five years and the advent of teraflop computers, another level could be incorporated (equivalent to a resolution of 50km).<sup>8</sup> By 2007, “the smallest we can make these chunks in the atmosphere is around 100 miles [160km] in the horizontal and a few hundred yards in the vertical, and a bit smaller in the ocean. The problem here is that many important processes are much smaller than these scales.”<sup>9</sup> Since individual molecules cannot be modelled, these variables must be aggregated into larger chunks of data – they must be set as parameters. Quite simply, the computing power necessary to incorporate additional levels of magnitude is massive.

It is not simply the sheer scale of the system which has to be tackled though. In addition to this, the climate system meets the criteria for the standard conception of a complex and chaotic system: involving nonlinearities, tipping points, and sensitivity to initial conditions. As the climate is a chaotic system, small initial discrepancies will produce solutions that diverge from each other over even a few days.<sup>10</sup> Research into such systems has demolished the popular idea of a ‘balance of nature’. There may be equilibrium points, but these are themselves subject to fluctuations and disruption. These emerging conceptions of a complex system have important implications for the response to climate change. Policies that seem intuitive in an equilibrium system (e.g. stop forest fires at all costs) can in fact be counterproductive when seen from the perspective of a non-equilibrium system.<sup>11</sup> Finally, the complex nature of climate can be seen in the uncertainty surrounding predictions. Because of their sensitivity to initial conditions, simulations of the climate raise important epistemological issues about the accuracy of predictions.

The response has been to produce climate models that are themselves an additional source of massive complexity. These models can include simple toy

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<sup>7</sup> Kerr, “Forecasting Still Cloudy,” 1040.

<sup>8</sup> Ibid.

<sup>9</sup> Emanuel, *What We Know About Climate Change*, 40.

<sup>10</sup> Wells, *The Atmosphere and Ocean: A Physical Introduction*, 295.

<sup>11</sup> Forsyth, *Critical Political Ecology: The Politics of Environmental Science*, 65.

models that are capable of being run on a standard desktop computer. Yet others are only possible on the latest supercomputers – and even then they strain the resources available.<sup>12</sup> One overview of climate science notes that,

“Computer modelling of global climate is perhaps the most complex endeavour ever undertaken by mankind. A typical climate model consists of millions of lines of computer instructions designed to simulate an enormous range of physical phenomena, including the flow of the atmosphere and oceans; condensation and precipitation of water inside clouds; the transfer of solar and terrestrial radiation through the atmosphere, including its partial absorption and reflection by the surface, by clouds, and by the atmosphere itself; the convective transport of heat, water, and atmospheric constituents by turbulent convection currents; and vast numbers of other processes.”<sup>13</sup>

There is simply no way to bypass the use of these complex models. As the historian of technology Paul Edwards has outlined, models are necessary for climate science in at least five senses: to make data sets compatible, to analyse past climate records, to predict future climate situations, to distinguish human from natural climatic variation, and to simulate the effects of policy decisions.<sup>14</sup> While Edwards has done much to examine the first four areas, it is the final sense that will be the focus of this chapter. How are models used to produce a global vision of the climate, and to produce effective policy responses?

This leads to the final major source of complexity in the climate change world: the transition from the best available science to the world of policymaking. “The interconnectedness of ecosystems means that many problems are non-

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<sup>12</sup> Edwards, “Representing the Global Atmosphere: Computer Models, Data, and Knowledge About Climate Change,” 34. See p. 37-39 for more descriptions of the varieties of models.

<sup>13</sup> Emanuel, *What We Know About Climate Change*, 39-40.

<sup>14</sup> Edwards, “Representing the Global Atmosphere: Computer Models, Data, and Knowledge About Climate Change,” 62-63.

reducible: they cannot be resolved by addressing individual parts in isolation.”<sup>15</sup> Moreover, climate change policy incorporates an asymmetry – we are embedded within a *global* climatic system, yet the effects of climate are *local* and heterogeneous. Fully taking climate change into account therefore means travelling from the local to the global and back. Often these complexities of effective intervention have been resolved by resorting to overly simple policies. As a response, complex truths about climate causes and effects have been simplified into distorted narratives about phenomena like desertification, soil erosion and deforestation. The results of these mistaken ‘facts’ are counter-productive interventions into natural systems and unintended (and often unjust) social consequences.<sup>16</sup> The complexity of policymaking therefore has its own unique dynamics in contributing to the messy problems of climate change and the “clumsy” solutions required for them.<sup>17</sup>

It is because of these complexities that policymakers have to incorporate representational technology in order to extend their cognitive capacities. The past two decades have seen modelling shift from being a matter of validating scientific theories, to being a matter of supporting policy decisions.<sup>18</sup> On one level, this support would appear to arise from the extension of predictive abilities via simulation, making climate models different from financial models (which are used for their perceptive capacities) and crisis mapping software (which is used for its coordinating capacities). Yet in practice, as we will see, climate models provide a wide variety of extensive capacities with prediction playing a relatively minor role.

## **A History of Climate Science**

Despite the modern-day reliance on technology in order to produce knowledge of the Earth’s climate, this has not always been a possibility. Theories about climate have traditionally arisen from a variety of sources – from authorities such as elders

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<sup>15</sup> Carter, *The Politics of the Environment: Ideas, Activism, Policy (Second Edition)*, 177.

<sup>16</sup> Forsyth, *Critical Political Ecology: The Politics of Environmental Science*, 2.

<sup>17</sup> Verweij and Thompson, *Clumsy Solutions for a Complex World: Governance, Politics and Plural Perceptions*; Verweij, *Clumsy Solutions for a Wicked World: How to Improve Global Governance*.

<sup>18</sup> Sarewitz and Pielke, Jr., “Prediction in Science and Policy,” 17.

or religious leaders; from the gathering of large amounts of observational data in particular areas; from first principles about the physical basis of the climate; and only recently from the use of technology in all its varied forms.<sup>19</sup> The latter form is the latest source of knowledge, and its history can be traced back to the early 1900s.<sup>20</sup>

Theories about the climate in fact stem back thousands of years to at least Aristotle. This inaugurated a long history of philosophers meditating on the effects of climate (and weather, more narrowly). Thinkers as varied as Baron C.-L. de Montesquieu and David Hume both subscribed to variations of climate determining cultural changes, their ideas themselves being based on readings of ancient philosophers.<sup>21</sup> Intriguingly, within these discourses there was a common acknowledgement of humanity's capacity to alter climate. For instance, the New World colonialists actively saw themselves as shaping the raw nature of America into a more moderate (and survivable) climate. Climate in the colonies was perceived to be warming because of human action – yet this was also perceived as a good thing because of the harsh weather in North America (a judgment of the local weather which was to be borne out by modern climatology).<sup>22</sup>

The origins of more rigorously scientific climatology can be traced back to Italy in the mid-seventeenth century.<sup>23</sup> It is here that the first efforts at systemic measurement and analysis of climate patterns emerge. Yet most efforts at the time were an unstandardised set of disparate observations – both the recording formats and the measurement tools were subject to individual fluctuation, making comparison and aggregation difficult. It was not until the late nineteenth century that most countries would have established national services devoted to recording weather observations.<sup>24</sup> Yet the advances in the seventeenth century were formative

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<sup>19</sup> Fleming, *Historical Perspectives on Climate Change*, 5–6.

<sup>20</sup> It should be mentioned that the history of climate science presented here is a self-consciously Whiggish history. While the history understanding the earth system presents an array of fascinating speculative hypotheses, they are secondary to establishing how today's climate science and climate models came about. Readers interested in a more in-depth history are referred to James Fleming's *Historical Perspectives on Climate Change*, and Spencer Weart's *The Discovery of Global Warming*.

<sup>21</sup> Fleming, *Historical Perspectives on Climate Change*, 1.

<sup>22</sup> *Ibid.*, 2.

<sup>23</sup> *Ibid.*, 34–35.

<sup>24</sup> *Ibid.*, 34.

in making climatology into a scientific discipline. Figure 3 presents a quick overview of the main developments made after this emergence of more quantitative and empirical methods.

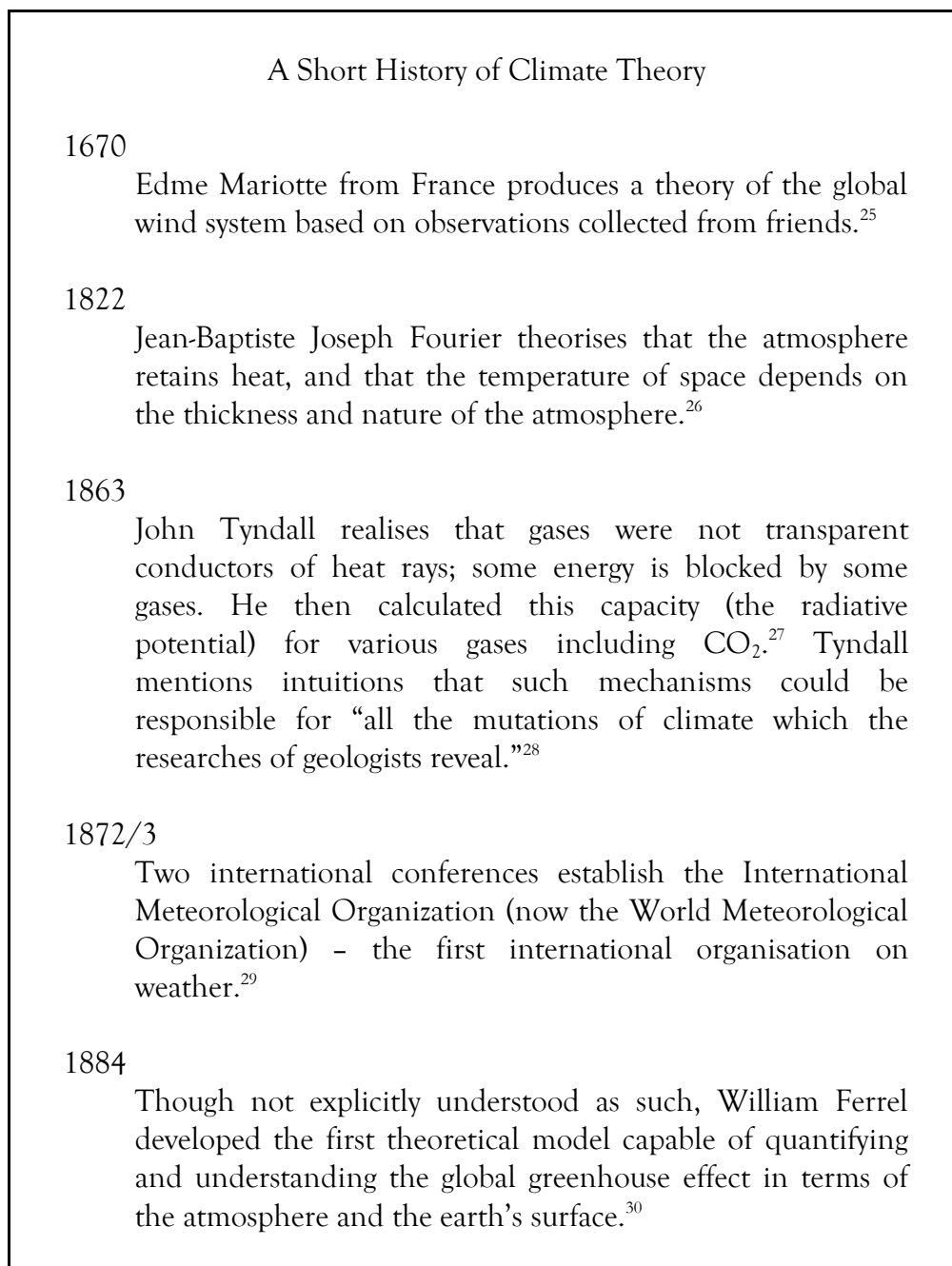


Figure 3: A short history of climate theory

<sup>25</sup> Fleming, *Historical Perspectives on Climate Change*, 36.

<sup>26</sup> *Ibid.*, 62-63.

<sup>27</sup> *Ibid.*, 66-68.

<sup>28</sup> *Ibid.*, 73.

<sup>29</sup> *Ibid.*, 42.

<sup>30</sup> *Ibid.*, 52.

It took until 1896 for Svante Arrhenius to first calculate the possible contribution of CO<sub>2</sub> to the changes in the climate. In a published article, Arrhenius calculated the contribution of CO<sub>2</sub> to the earth's surface temperature, and suggested that it could be responsible for the ice ages.<sup>31</sup> At the time, he believed the most likely source of excess CO<sub>2</sub> was from volcanic eruptions. In 1899, Nils Eckholm argued that burning coal would eventually double the CO<sub>2</sub> in the air and lead to the earth warming – the first modern suggestion that human actions could have a significant influence on the atmosphere.<sup>32</sup> Building on this work, over a period of months, Arrhenius painstakingly calculated a rough estimate that human-produced CO<sub>2</sub> could raise the earth's temperature.<sup>33</sup> Drawing upon the work done on radiative potential before him, and from empirical observations, Arrhenius produced what was likely the first rudimentary climate change model. Based upon relatively simple calculations, Arrhenius was able to produce predictions about the effects that decreases and increases in CO<sub>2</sub> would have on the climate. On the basis of this evidence, in 1904 Arrhenius publically raised the first warning that anthropogenic climate change is a possibility (though he saw it as a benefit to counter a secular decline in temperature).<sup>34</sup> Soon after this period though, various experimental results and theoretical proposals made the CO<sub>2</sub> theory of climate change appear unlikely. It fell into disrepute and even some of its main proponents rescinded their support. Decades would pass before the theory was rejuvenated and became a prime focus of research again.

In the meantime, in 1938 the amateur climatologist Guy Stewart Callendar revealed the most comprehensive evidence to date for the actual warming of the earth. Beyond just the theoretical models which showed that climate *could* change, Callendar's thorough dataset demonstrated for the first time that the climate *was* changing.<sup>35</sup> At the time though, this was a heretical position and it remained so until the second half of the twentieth century. It took a series of social and natural

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<sup>31</sup> Ibid., 74-77.

<sup>32</sup> Ibid., 111.

<sup>33</sup> Edwards, "Representing the Global Atmosphere: Computer Models, Data, and Knowledge About Climate Change," 39-40.

<sup>34</sup> Fleming, *Historical Perspectives on Climate Change*; Weart, *The Discovery of Global Warming, Revised and Expanded Edition*.

<sup>35</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 2.

consequences from warming in the 1950s for increased attention – in both the scientific and popular media – to be paid to the possibility of rising temperatures. Climate change was becoming something increasingly palpable, imposing itself onto the public’s consciousness.

### **A History of Climate Modelling**

With the increased attention and the development of computing technology, climate science began to merge into climate modelling. The aim of this section is twofold. First, it will demonstrate that knowledge of the climate system and the technology of computer modelling are inseparable. Climate science *is* climate modelling, and vice versa. The significance of this is that any discussion of scientific knowledge about the climate and climate change is one-sided if it neglects the material infrastructure which both constrains and makes possible our understanding of this complex system. In order for knowledge to be dispersed globally, to become stabilised as a scientific fact, and to take on the authoritativeness of scientific expertise, it requires these material infrastructures. They provide the solidified chains of inference that support any given claim about climate change,<sup>36</sup> and they maintain the standards which make possible the reproduction and dissemination of knowledge.<sup>37</sup> In other words, many of the properties attributed to scientific knowledge (solidity, accuracy, predictive power) stem from their material embodiment. Conversely, attempts to dislodge and refute claims about climate change have to grapple with the materialities of ice core samples, ships’ logs, satellite readings, supercomputers, and simulated maps. The material infrastructure is, to put it simply, at the heart of climate science.<sup>38</sup>

The second aim of this section is to formulate the progression of climate science technology in terms of its materiality. While other scholars have examined progress in climate modelling in terms of social ideals (pragmatism versus

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<sup>36</sup> Latour and Woolgar, *Laboratory Life: The Construction of Scientific Facts*.

<sup>37</sup> Jasanoff and Wynne, “Science and Decisionmaking,” 20.

<sup>38</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*.

accuracy,<sup>39</sup> most notably), this section will follow the theory of technological development set out in Chapter 2 and argue that the material nature of technology funnels developments along particular pathways. In particular, the materiality of technology generates certain frictions between competing functions and components of any particular object. These frictions (e.g. between the desire for computational speed and the desire for quantity of data) channel technological progress down certain paths. With climate modelling technology, a number of general frictions can be discerned throughout its history: data frictions, computational frictions, and model frictions. In the first place, “data always have a material aspect. Data are *things*. They are not just numbers but also numerals, with dimensionality, weight, and texture. Data friction refers to the costs in time, energy, and attention required simply to collect, check, store, move, receive, and access data.”<sup>40</sup> Computational friction, on the other hand, “includes not only the physical and economic limits on processor speed and memory capacity, but also the human work involved in programming, operating, debugging, and repairing computers.”<sup>41</sup> Finally, there is the model friction, which involves the trade-offs between creating the model in different ways: for instance, the accuracy of inputs versus the accuracy of outputs, the choice of parameters, and the tuning of variables. Schematically, model friction can be seen to supervene on data and computational frictions (since it must be embodied by them), yet it is a friction that results from the functionality of the technology and not from the pure physicality of its components. The development of a technology therefore involves overcoming these frictions and making the object function as a coherent whole.

The models employed by climate scientists are a simulation type of representational technology. At its most abstract level, a simulation “imitates one process by another”.<sup>42</sup> In the case of climate science, this imitation is typically

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<sup>39</sup> Mesinger, “Numerical Methods: The Arakawa Approach, Horizontal Grid, Global, and Limited-Area Modeling,” 374; Shackley, “Epistemic Lifestyles in Climate Change Modeling”; Shackley et al., “Adjusting to Policy Expectations in Climate Change Modeling: An Interdisciplinary Study of Flux Adjustments in Coupled Atmosphere-Ocean General Circulation Models.”

<sup>40</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 84.

<sup>41</sup> *Ibid.*, 83.

<sup>42</sup> Petersen, *Simulating Nature: A Philosophical Study of Computer-Simulation Uncertainties and Their Role in Climate Science and Policy Advice, Second Edition*, 7.



accomplished via a set of differential equations relating changing variables to each other and including some rules for how the system will evolve through time.<sup>43</sup> With today's climate models this includes momentum equations, temperature equations, water vapour equations, equations of state, and hydrostatic equations – usually programmed with 30,000 to 60,000 lines of code.<sup>44</sup> These equations can be split up into two overall model components: a dynamical core, and the model physics.<sup>45</sup> The dynamical core is formed by the basic primitive equations derived from physics – these are responsible for modelling the large-scale processes of fluid motion in the atmosphere and ocean. The model physics, on the other hand, simulate all the other processes going on – in particular, transfers of heat and moisture, and interactions between oceans, land, and the atmosphere. These equations are then represented in an abstract grid of the atmosphere and the ocean. Since the earth is spherical, square grids proved to be problematic, particularly at the poles where the time steps between grid points began to diverge from those at the equator.<sup>46</sup> As a result, there have been a variety of different grids used: not only the familiar square grids, but also triangular, hexagonal, polyhedral, and icosahedral grids, each with their own drawbacks and benefits.<sup>47</sup> Contemporary models can have tens of millions of grid points. The model is then run forward over time steps (today, these can be down to the order of minutes).<sup>48</sup> For each time step, the equations are applied to every grid point, moving the model forward. This process is then repeated until the model has simulated days (in terms of weather forecasting) or decades (in terms of climate forecasting). The output of this is numerical in its most basic form, yet visualisations have arisen to present the data output in more

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<sup>43</sup> Winsberg, *Science in the Age of Computer Simulation*, 4.

<sup>44</sup> Edwards, “Representing the Global Atmosphere: Computer Models, Data, and Knowledge About Climate Change,” 37–38.

<sup>45</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 145.

<sup>46</sup> Randall, Heikes, and Ringer, “Global Atmospheric Modeling Using a Geodesic Grid with an Isentropic Vertical Coordinate,” 510.

<sup>47</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 145.

<sup>48</sup> Edwards, “Global Climate Science, Uncertainty and Politics: Data-Laden Models, Model-Filtered Data,” 442.

cognitively amenable forms (for instance, graphs and maps). They form the basic products of these representational technologies.

#### *Numerical Weather Prediction Models*

Computer models of the climate arose with the technological development initiated by WWII, the devastation having spurring on the production of a vast array of new tools. Combined with the context of increased public attention and the sheer complexity of the climatic system, it was perhaps inevitable that the new computing technology would be applied to climatology. Earlier attempts had been made at modelling, though without the efficiency of computers these all failed to achieve their goals of weather prediction. The first numerical (as opposed to graphical) weather prediction system was created in the early 1900s by Vilhelm Bjerknes, who produced a series of seven equations that represented the relationships between heat, air movement and moisture.<sup>49</sup> These were ‘primary equations’ – fundamental and derived from essential principles of physics. The hope was that on the basis of these, Bjerknes would be able to produce the essential characteristics of the climate and make weather predictions on that basis.

In 1922, Lewis Fry Richardson simplified these equations and made them into a model that could be solved by hand.<sup>50</sup> On the basis of this, he imagined a massive system of calculation that would be capable of producing accurate real-time predictions. Yet his model was unwieldy and inefficient – even with the labour of an entire factory working to produce calculations, the model would have been incapable of generating predictions in time. As late as 1955, the calculation time provided by computers was only just keeping pace with real-time: a 24-hour forecast took 24 hours to produce.<sup>51</sup>

In parallel with these shifts in technology, the 1940s saw universities (such as the University of Chicago and Cambridge University) begin to teach their students to think of the climate as a physicist would. Early models were developed,

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<sup>49</sup> Weart, “The Development of General Circulation Models of Climate,” 208.

<sup>50</sup> Edwards, “Representing the Global Atmosphere: Computer Models, Data, and Knowledge About Climate Change,” 41.

<sup>51</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 56.

though rather than being digitally simulated, they were actual physical models of the atmosphere. The simplifications involved in these models made accurate predictions impossible, but they were important in demonstrating that natural systems need not be balanced or stable and that they can be subject to rapid changes.<sup>52</sup> (The cultural belief in equilibrium was one of the main reasons that thinking about climate change was so difficult to accept at the time.) These were the first hints to climate scientists that the climate was a dynamic, complex and nonlinear system. Not only could the climate change drastically (as the ice ages had revealed), but it could do so much more rapidly than anyone had previously thought possible.

Immediately post-WWII, the mathematician John von Neumann began to call for the use of computers in numerical weather prediction. Gaining support from the Office of Naval Research, von Neumann's project had developed a rudimentary computer model by 1949 that was capable of computing air flows across three-dimensional structures.<sup>53</sup> In 1950, the Meteorology Project used the ENIAC to run its first computer-based weather forecast.<sup>54</sup> Between 1953 and 1959, Gilbert Plass used the new digital computers and latest spectrographic data on the absorption bands of various gases to construct small models of radiative transfer – the primary mechanism behind global warming.<sup>55</sup>

### *General Circulation Models*

By the mid-1950s, these models remained at the level of regional climates. Yet researchers knew that to truly understand the climate, a global climate model was necessary.<sup>56</sup> It took until 1956 for what is now considered to be the first functioning GCM to be constructed by Norman Phillips – a model which

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<sup>52</sup> Fleming, *Historical Perspectives on Climate Change*, 52–53.

<sup>53</sup> Charney, “On a Physical Basis for Numerical Prediction of Large-Scale Motions in the Atmosphere.”

<sup>54</sup> Edwards, “Representing the Global Atmosphere: Computer Models, Data, and Knowledge About Climate Change,” 43.

<sup>55</sup> Fleming, *Historical Perspectives on Climate Change*, 121.

<sup>56</sup> What follows is necessarily a partial overview of the climate models available, focusing on the models which made significant contributions to the development of modelling. For more specification of models, including an analytical framework for categorising them, see: Ghil and Robertson, “Solving Problems with GCMs: General Circulation Models and Their Role in the Climate Modeling Hierarchy.”

produced a realistic looking jet stream as well as a simulated weather disturbance.<sup>57</sup> Yet this model faced fundamental computational frictions which forced the model to presume a cylindrical rather than a spherical shape to the earth.

Researchers, however, had begun to realise the fundamental interconnectedness and complexity of the climate system. In the first place, as the understanding of the climate system grew, the nonlinearities involved began to set hard limits to existing GCMs. Regardless of the accuracy of initial conditions and equations, without implementing nonlinearities into the models the predictions diverged significantly from observations after short time periods. Guided by Akio Arakawa's work, a method for implementing nonlinear equations into GCMs was developed – not only advancing the technology, but also giving concrete shape to the new nonlinear understanding of the climate system.<sup>58</sup> Furthermore, while the nineteenth and early twentieth centuries had focused on mono-causal explanations of climate change, new findings were demonstrating how a variety of causes could produce rapid and significant change in climate patterns.<sup>59</sup> This emerging vision of nature was bolstered in 1959 when Harry Wexler and Charles David Keeling produced the first evidence that CO<sub>2</sub> concentrations were increasing even in a single year. When mapped out in a chart, this data produced the now well-known Keeling curve (see Figure 4).<sup>60</sup>

Significant technical advances were also made during this time. The technical problems associated with primitive equations were largely overcome and became the standard approach. The 1950s had seen modellers use quasi-geostrophic models that employed simplifying assumptions used to reduce three equations of atmospheric motion down to one.<sup>61</sup> Computational frictions required these models to assume that the Coriolis force generated by the earth's rotation cancelled out the pressure-gradient force.<sup>62</sup> The new models based on primitive

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<sup>57</sup> Phillips, "The General Circulation of the Atmosphere: A Numerical Experiment."

<sup>58</sup> Arakawa, "A Personal Perspective on the Early Years of General Circulation Modeling at UCLA," 12-13.

<sup>59</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 61.

<sup>60</sup> Fleming, *Historical Perspectives on Climate Change*, 126.

<sup>61</sup> Schubert, "A Retrospective View of Arakawa's Ideas on Cumulus Parameterization," 197.

<sup>62</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 119.

equations proved to provide much more accurate results though, and with their technical hurdles overcome they became the dominant approach. In addition to this shift to primitive equation models, another major advance was the heating variable being determined by motion rather than by latitude – a much more accurate approach that allowed for heat to become a cause of motion as well.<sup>63</sup> Baroclinic models also replaced barotropic models, meaning the density of the atmosphere was now dependent on temperature in addition to pressure. This led to new possibilities for modelling storm patterns.<sup>64</sup>

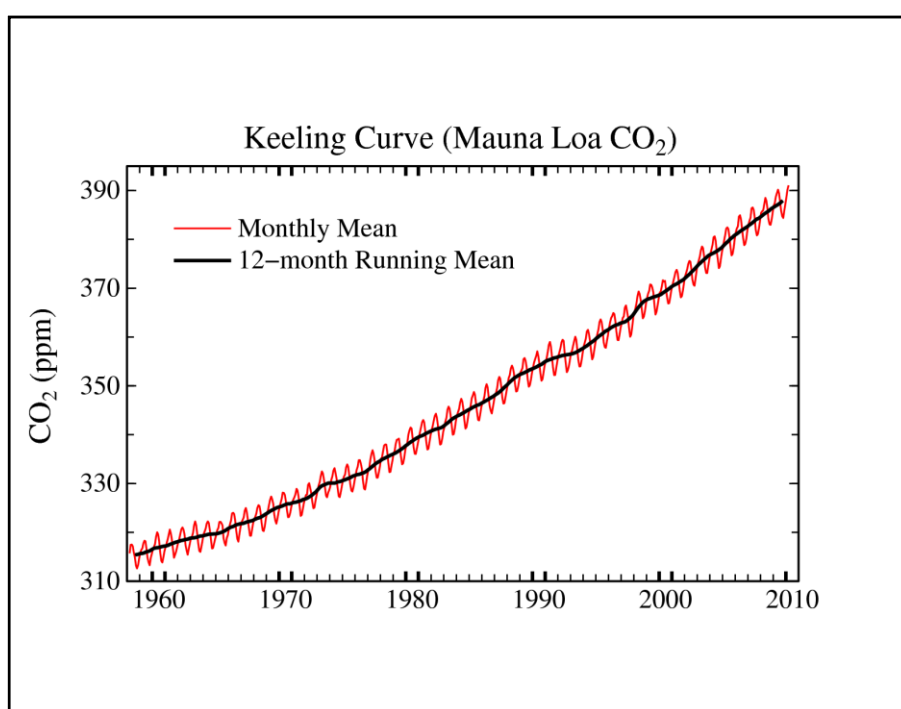


Figure 4: Keeling curve

The 1960s and 1970s saw the final demise of the historical tradition of climatology and its focus on local trends. The classic model of climatology – collecting data and sometimes statistically analysing it – was being replaced by a more theoretical approach. Theories of how the climate operated were being built from the ground up with a foundation in the fundamental principles of physics

<sup>63</sup> Arakawa, "A Personal Perspective on the Early Years of General Circulation Modeling at UCLA," 21.

<sup>64</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 127.

and chemistry. The traditional model of climatology was rapidly replaced by this new world of climate science and computer modellers.<sup>65</sup>

With this new approach to climatology, the limits of technology began to shape the future developments of these models. Broadly speaking, two different paths were open for computer modelling. On the one hand, there were those that tried to represent the environment as accurately as possible. Given the limitations of the technology though, this was a costly method – both in terms of money and time. On the other hand, there were those who took a more modest approach. These simpler models had the virtue that they could be solved quickly, thereby allowing intuitions about the relations between different elements of the environment to be tested quite easily. These models were nowhere near the level of accuracy for predictions, but they did begin to systematise inferences about the environmental in a computerised format.<sup>66</sup> However, tensions were frequent between computational and data frictions on the one hand, and scientific norms of creating an accurate picture on the other hand. Progress in knowledge production was becoming dependent on progress in technological infrastructures.

For both approaches, the path for future GCM development was to overcome existing frictions in order to incorporate an increasing amount of factors. In 1967, a simple one-dimensional model was published that incorporated radiation and convection effects, and in 1969 this was extended to include some oceanic aspects as well.<sup>67</sup> The 1970s later saw soil, rainwater and vegetation become the objects of early modelling efforts.<sup>68</sup> Models at this point began to indicate that the Earth's climate was in a fragile range of stable temperatures. Much colder and the climate would plunge into an ice age; much warmer and the Earth would speed off into a warming loop.<sup>69</sup> The pathway to more complex and accurate models was led by Syukuro Manabe and Joseph Smagorinsky teaming up to produce the most

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<sup>65</sup> Edwards, "Representing the Global Atmosphere: Computer Models, Data, and Knowledge About Climate Change," 32–33.

<sup>66</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 81.

<sup>67</sup> Manabe and Wetherald, "Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity"; Manabe and Bryan, "Climate Calculations with a Combined Ocean-Atmosphere Model."

<sup>68</sup> Dahan, "Putting the Earth System in a Numerical Box: The Evolution from Climate Modeling Toward Global Change," 284–285.

<sup>69</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 81–83.

sophisticated GCM seen yet. They operated on a first principles basis: all the equations should be derived from the physics of fluids and energy. By 1965, they had eventually constructed a three-dimensional model that had nine different atmospheric altitudes, and that realistically produced global water vapour flows.<sup>70</sup>

The shift to GCMs with multiple levels in the atmosphere created a significant new computational friction as modelling the vertical redistribution of moisture was a computationally heavy process.<sup>71</sup> Manabe and Smagorinsky's model was also forced to neglect the differences between land and oceans, instead presuming a homogeneous damp surface. Working within these material constraints, others at the time took an opposite approach – attempting to model realistic territories while minimizing the complexities of the atmosphere (for instance, taking it to contain two rather than nine levels).<sup>72</sup> At each point, the choices of how to develop models were themselves channelled down particular paths set out by the material limits of computation at the time. In each case, computational and model frictions limited what was possible at the time and encouraged modellers to develop their technology in particular ways. Yet at this time, major uncertainties still existed about the climate: “climate theorists did not agree on the relative roles of such factors as solar variability, sunspots, and cloud feedbacks in climate change.”<sup>73</sup>

In addition, all these models were beginning to bounce up against significant data frictions. In the first place, most observations were analogue, while the computations performed on them were digital. This meant not only increased the difficulties in manipulating the data, but it also introduced noise in the data through the process of transforming analogue into digital data.<sup>74</sup> Even more fundamentally, data observations were spotty around the world – thorough and consistent in some areas, while absent or disparate in many others. One of the primary data frictions in modelling arose from trying to convert existing

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<sup>70</sup> Ibid., 92.

<sup>71</sup> Arakawa, “A Personal Perspective on the Early Years of General Circulation Modeling at UCLA,” 50.

<sup>72</sup> Weart, “The Development of General Circulation Models of Climate,” 210.

<sup>73</sup> Edwards, “Representing the Global Atmosphere: Computer Models, Data, and Knowledge About Climate Change,” 49.

<sup>74</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 105.

observational networks into the abstract grids of climate change models. Since the former are incommensurate with the latter, acts of smoothing and interpolation are required to make observational data useable.<sup>75</sup> The partial resolution to this tension began with the rise of satellite reconnaissance which was no longer limited to the stable (and random) placement of ground-based observations. Satellites to monitor the weather were initially launched in 1960, with the number of satellites greatly expanding over the ensuing decades. Already by 1969, the *Nimbus 3* satellite's "infrared detectors could measure the temperature of the atmosphere comprehensively at various levels, night and day, over oceans, deserts, and tundra."<sup>76</sup>

Yet satellite data creates its own problems, making it a good exemplar of the difficulties in data production for climate science. In the first place, obtaining accurate readings from raw data involves taking into account "instrument design, calibration, orbital drift over time, atmospheric structure, and chemical composition."<sup>77</sup> Once the raw data is collected, analysis faces an 'inverse-problem' – each observational point in fact aggregates different atmospheric layers and different frequencies together, and the problem is to disaggregate these sums in order to get accurate estimates for each layer and frequency.<sup>78</sup> Data from satellite observations must then be transformed into the gridded format used by computer modelling. This entails both a spatial and temporal grid, and is produced through a variety of methods including by hand, and through "automated procedures involving function fitting, methods of successive corrections, and statistical interpolation schemes."<sup>79</sup> As some areas of the world still had only a few observations available, techniques were required to project information into these gaps. In particular, numerical weather prediction was used to take information from densely observed areas and extend the projected weather patterns into the sparsely observed areas. The result was a much more accurate estimate of the data in the gaps. Finally, datasets for atmospheric observations can contain hundreds of

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<sup>75</sup> Ibid., 125.

<sup>76</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 95.

<sup>77</sup> Norton and Suppe, "Why Atmospheric Modeling Is Good Science," 76.

<sup>78</sup> Ibid., 78.

<sup>79</sup> Ibid., 85.



terabytes worth of information, making storage, retrieval and analysis exceedingly difficult.<sup>80</sup> Despite these difficulties, satellites are the only truly global method of gathering homogeneous temperature data and resolved a number of problems with traditional observation methods.

Lastly, this period of time saw a significant shift in the end products of these representational technologies. While the new simulations were designed to provide insight on how the global climate functioned, their output was rows and rows of numbers that were themselves in need of analysis, interpretation and synthesis.<sup>81</sup> Cecil Leith advanced upon this by being the first to create proper visualisations of the models' outputs, accomplished by working with a Hollywood company to produce actual movies of the simulations. This was a significant innovation since it was the first time modellers could see their model's outputs, rather than being forced to imagine it.<sup>82</sup>

### *Coupled GCMs*

By the 1970s, the stage was set for the next major advance in GCMs: the shift from modelling just the atmosphere to now including ocean dynamics in so-called coupled atmosphere and ocean general circulation models (AOGCMs). The focus previously had predominantly been on the atmosphere as the most important factor of energy circulation. Yet the oceans, as a major transmission belt of energy, as well as a giant sink for CO<sub>2</sub>, were also crucial to understanding how the climate functioned. In particular, AOGCMs are key for understanding how quickly heating of the top ocean layers will get mixed into deeper ocean layers, and thus how quickly climate change will occur and significantly upset the thermal circulation in the oceans.<sup>83</sup> Two differences made modelling oceans more difficult than modelling the atmosphere though: the relative lack of observed data points,

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<sup>80</sup> Ibid., 72.

<sup>81</sup> Weart, "The Development of General Circulation Models of Climate," 211.

<sup>82</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 162–163.

<sup>83</sup> Shackley et al., "Adjusting to Policy Expectations in Climate Change Modeling: An Interdisciplinary Study of Flux Adjustments in Coupled Atmosphere-Ocean General Circulation Models," 419.

and the increased difficulty in using averages to represent large ocean areas.<sup>84</sup> In the first case, the lack of stable observation stations within the oceans made collecting data a significant challenge. Datasets were reliant on ships travelling around the world and collecting systematic observations. Fortunately, the 1970s also saw the emergence of a more complete dataset for ocean circulation, which allowed modellers to move beyond the material limitations of the previous data.<sup>85</sup> The US Geochemical Ocean Sections Study has been designed to track radioactive fallout from nuclear weapons testing as it circulated through the oceans. In doing so, though, scientists gained access for the first time to a massive wealth of observational data about the oceans. Datasets such as this provided the basis for the first realistic coupled OGCM: Syukuro Manabe and Kirk Bryan's 1975 model (itself based on an earlier initial attempt in 1968).<sup>86</sup>

The second challenge in modelling oceans was that the major transmission belts of the ocean consisted of both microscopic whorls, and vast country-size whorls. These whorls, it turned out, were more important to energy transfer than the more familiar currents. As a result, more of the complexity of oceans also had to be modelled – something which was far beyond the capacities of the computers at the time. Initial attempts to develop ocean models coupled with atmospheric models therefore used simple 'swamp' models of the ocean that incorporated its essential dynamics, but only its surface layer evaporation mechanisms. As the technological platform expanded the possibilities of modelling, more sophisticated mixed-layer models began to include a heat capacity for the ocean that varied according to the depth of the ocean layer. Eventually models began to incorporate heat transfer by ocean currents as well.<sup>87</sup> As before, progress in producing knowledge of the climate system was constrained and channelled as much by the technological platforms available as by the imperatives of science.

The inclusion of ocean models into coupled GCMs also raised the crucial question of how to actually couple them together. Since OGCMs and AGCMs

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<sup>84</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 131.

<sup>85</sup> *Ibid.*, 133.

<sup>86</sup> *Ibid.*

<sup>87</sup> Charney et al., *Carbon Dioxide and Climate: A Scientific Assessment (Report of an Ad Hoc Study Group on Carbon Dioxide and Climate)*, 13.

began as independent models, there needed to be some means to connect them and this gave rise to novel frictions. In particular, coupled GCMs require some mechanism for simulating the exchange of energy, heat, wind and water between the different areas.<sup>88</sup> It soon became a major focus of the decade to overcome the problems involved in coupling these models together, leading Arakawa to call it one of the “great challenges” of the time.<sup>89</sup> These difficulties would continue to play themselves out in the 1990s debates over flux adjustment (a topic that will be returned to in the next section).

In terms of computational friction, one of the most significant advances was the use of spectral methods to replace finite difference GCMs. Advances in computing power and in algorithmic efficiency eventually made these new methods possible, thereby expanding the material possibilities of these technological platforms.<sup>90</sup> Finite difference methods had been used to approximate solutions to difficult partial differential equations – a key component of complex systems modelling.<sup>91</sup> As Edwards explains, the new spectral methods “express the horizontal variation of dynamic model fields in terms of horizontal spherical harmonics. The technique simplifies the solution of many of the nonlinear partial differential equations used in general circulation modelling.”<sup>92</sup> Essentially, these methods were designed to overcome the problems with using grid points to model a spherical earth by exploiting the mathematics of wave space. Motion in the atmosphere could be calculated in wave space using spectral methods, and then translated back into the abstract physical space of the computer model, thereby bypassing the main computational frictions involved with grids.<sup>93</sup>

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<sup>88</sup> Meehl, “Global Coupled Models: Atmosphere, Ocean, Sea Ice,” 561–570.

<sup>89</sup> Edwards, “A Brief History of Atmospheric General Circulation Modeling,” 80; Arakawa, “Future Development of General Circulation Models,” 723.

<sup>90</sup> Edwards, “A Brief History of Atmospheric General Circulation Modeling,” 80.

<sup>91</sup> Finite difference methods essentially replace the infinitesimal, continuous difference of differential equations with a small, finite difference. They thereby transform equations with variables into equations with numbers, making them simpler to solve yet also an approximation. For complex nonlinear systems, such approximations can significantly misrepresent the actual behaviour of the system.

<sup>92</sup> Edwards, “A Brief History of Atmospheric General Circulation Modeling,” 80.

<sup>93</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 165–166.

By the 1975-1985 period the general focus in GCM development had turned towards greater resolutions, better parameterisations, and bringing together atmospheric and ocean models.<sup>94</sup> The main technical developments in this period were focused on improving (but not radically altering) spectral transforms, hydrological cycles, coupling of AGCMs and OGCM, radiative transfer, moist convection, continental surfaces, and boundary layer turbulence.<sup>95</sup> The 1980s also saw GCMs gain increasing prominence for their experimental capacities, altering the behavioural possibilities of those who had access to them.<sup>96</sup> Given that the climate was a complex and open system, there were no real possibilities for traditional scientific experiments on it. Instead, experimentation had to take place entirely via the mechanised reasoning processes of computer simulations. This meant that “by the 1980s, computer models of atmosphere and ocean general circulation had become the primary tool in studies of climate.”<sup>97</sup> In other words, the development of these representational technologies had begun to make possible such experimental actions, along with the associated cognitive insights they provided on the climate.

#### *Earth System Models*

By the late 1980s and 1990s, the international community had begun to seriously focus on climate change as a political problem.<sup>98</sup> In the technological sphere, what became known as the flux adjustment problem emerged from the attempt to couple atmospheric GCMs with ocean GCMs. The two separate models were in tension with each other, producing numerous complications in the attempt to stitch them together. Flux adjustment was an attempt to overtly modify the surface fluxes of heat and moisture in order to make the independent AGCM and OGCM components compatible with each other and with the observed climate dynamics.

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<sup>94</sup> Edwards, “A Brief History of Atmospheric General Circulation Modeling,” 82.

<sup>95</sup> *Ibid.*, 83-84.

<sup>96</sup> Manabe and Wetherald, “The Effects of Doubling the CO<sub>2</sub> Concentration on the Climate of a General Circulation Model.”

<sup>97</sup> Edwards, “A Brief History of Atmospheric General Circulation Modeling,” 84.

<sup>98</sup> Mitchell, *International Politics and the Environment*, 83; O’Riordan et al., “Institutional Frameworks for Political Action,” 366-367.

The point to note here is that the possibilities available to modellers were set out by the technological limits of the time: either one introduced adjustments that were known to violate physical laws (the pragmatist solution), or one rejected the idea of coupling models until better technology was available (the purist solution). Whereas most modellers thought that flux adjustment was valid as temporary fix, it was also known to introduce new errors, insofar as the appropriate adjustment is calculated on the basis of a climate in equilibrium – which does not reflect the actual system. The result of this correction was an underestimating of existing tendencies.<sup>99</sup> Nevertheless, the flux adjustment episode highlights clearly how the development of modelling technology was shaped by computational, data, and model frictions. The social contestation between pragmatists and purists took place within the framework set out by material possibilities.

In general, the 1990s saw the gradual, but not revolutionary, development of more sophisticated GCMs. New factors were constantly being introduced – in particular, the effects of greenhouse gases other than CO<sub>2</sub>, as well as new ways of modelling clouds and wind.<sup>100</sup> ‘Earth system models’ – models which incorporate elements such as the biology on land and ocean surfaces, as well as greater roles for chemistry – became commonplace. Carbon cycles became implemented as focus turned towards how carbon sinks would both affect and be affected by climate change.<sup>101</sup> There was an expansion of vertical levels; an expansion of latitudinal and longitudinal resolution; and the introduction of more realistic surface topography.

Major hardware developments in supercomputing underpinned this model development – including the development of vector processing and parallel computing.<sup>102</sup> The former made possible the simultaneous application of the same equation to multiple grid points, whereas the latter allowed multiple instructions to be carried out at the same time rather than sequentially. This allowed the partial mitigation of some of the computational friction involved in calculating millions of

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<sup>99</sup> Shackley et al., “Adjusting to Policy Expectations in Climate Change Modeling: An Interdisciplinary Study of Flux Adjustments in Coupled Atmosphere-Ocean General Circulation Models,” 422.

<sup>100</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 162–163.

<sup>101</sup> Dahan, “Putting the Earth System in a Numerical Box: The Evolution from Climate Modeling Toward Global Change,” 286. Ibid.

<sup>102</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 176.

grid points. The hardware requirements (multi-petaflop supercomputers) of these new high-resolution earth system models have created new model tensions though, with algorithms having to be re-written in order to take advantage of parallel processing.<sup>103</sup>

New simulation methods were introduced as well: multiple simulations began to be run in order to explore the likely possible outcomes of the simulations. Given that the climate system is a chaotic one, the sensitivity to initial conditions entails that any errors in the initial state can cause major errors later on. Repeatedly simulating the same model with slightly modified initial conditions attempts to overcome this problem by producing an estimate of how robust the results are.<sup>104</sup> By the mid-1990s these methodological and conceptual advances were demonstrating significant payoffs as three different GCMs could – for the first time – accurately reproduce the entire climate of the twentieth century.<sup>105</sup> In addition, by the time of the IPCC’s Fourth Assessment Report, models could accurately simulate the regional variations in heating.<sup>106</sup>

Today, GCMs continue to incorporate an ever expanding series of elements into their models, including the unique effects of urban spaces. Resolution has continued to increase – as of 2009, a Japanese modelling centre had been experimenting with GCMs using resolutions as low as 3.5-10km.<sup>107</sup> At the level of hardware, today’s most advanced models are employing multi-petaflop parallel processors, and even looking to use probabilistic chips to employ stochastic processes.<sup>108</sup> A 2009 state of the discipline report notes that,

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<sup>103</sup> Shukla et al., “Revolution in Climate Prediction Is Both Necessary and Possible: A Declaration at the World Modelling Summit for Climate Prediction,” 18; Mechoso, Yu, and Arakawa, “A Coupled GCM Pilgrimage: From Climate Catastrophe to ENSO Simulations,” 568; Wehner et al., “Performance of a Distributed Memory, Finite Difference Atmospheric General Circulation Model.”

<sup>104</sup> Pasini, *From Observations to Simulations: A Conceptual Introduction to Weather and Climate Modelling*, 140.

<sup>105</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 163–164.

<sup>106</sup> Manning, “The Climate for Science,” 38.

<sup>107</sup> Shukla et al., “Revolution in Climate Prediction Is Both Necessary and Possible: A Declaration at the World Modelling Summit for Climate Prediction,” 16.

<sup>108</sup> *Ibid.*, 17–18.

“There are atmospheric GCMs currently in use at 50km resolution that can run 1,000 times faster than real time. With the existing and projected technology, models with 25km resolution are within reach in next 3 years or so. However, global nonhydrostatic cloud system resolving models of the atmosphere using 2-5km grids (with comparable resolution in the ocean) are not likely to be attained within the next 5 years. As models reach 2-5km-scale resolutions, they will generate aggregate output data on the order of hundreds of exabytes, stored at widely distributed modelling centres.”<sup>109</sup>

In terms of data, one of the more significant advances has been the emergence of an autonomous observation network featuring gliders, buoys, and subs.<sup>110</sup> This observational network is spanning an unprecedented range of areas and multiplying greatly the frequency of observations. It is becoming a key part of the input system for climate modelling. Yet this has led to an emerging need for data centres as newer models are expected to produce hundreds of exabytes of data.<sup>111</sup> The data friction involved in handling this immense amount of information has created a desire for a global modelling centre. Such a centre would include creating a network of national weather forecasting centres in order to incorporate the best regional data available.<sup>112</sup>

The contemporary landscape of climate science is therefore one populated by globe-spanning infrastructures of observation networks, computing centres, and data visualisations. It is these infrastructures which have fed representations of nature into the world of politics. Moreover, progress in climate science has become inextricably intertwined with progress in these material infrastructures (particularly supercomputing). At each stage of progress, regardless of social interpretations or differing norms of science, model builders have had to face up to the frictions

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<sup>109</sup> Ibid., 18.

<sup>110</sup> Wells, *The Atmosphere and Ocean: A Physical Introduction*, 311–312.

<sup>111</sup> Shukla et al., “Revolution in Climate Prediction Is Both Necessary and Possible: A Declaration at the World Modelling Summit for Climate Prediction,” 18.

<sup>112</sup> Ibid., 17.

involved in trying to incorporate all the different functions and goals of models into one representational technology.

### **Seeing Nature**

This infrastructure of climate modelling has come to be incorporated into cognitive assemblages, expanding the capacities of decision-makers. As with any other technology, the effects of climate modelling operate through the expansion of possibilities. Technologies may make entirely new options possible, they may make existing possibilities pass the crucial threshold of usability, or they may simply extend existing possibilities further. The primary effects of climate modelling have been to expand specifically cognitive abilities. Human cognition is no longer bound by tedious hand-written calculations, nor is it limited to mathematical equations that have closed form solutions. Cognition can now think nonlinearity in all of its complexity, and human thought can simulate different earths rather than remain bound by the limited opportunities for experimenting with the actual climate. The feedback loops of the climate system can now be thought, and probabilities given to the effects of sensitivity to initial conditions. Complexity, in a substantial way, is now capable of being thought via these cognitive assemblages. It is technological extensions of cognition which have produced the shift in scientific practice and the subsequent shift in how we conceptualise the natural world.<sup>113</sup> A variety of capacities have been transformed and augmented as well.

Among the capacities that these cognitive assemblages have made possible, it is often assumed the most significant is their predictive capacities: “Science in policy making is asked to be predictive and to answer questions under conditions of high uncertainty.”<sup>114</sup> Yet in fact there is little evidence that this is its most useful function. For complex systems, prediction is often a futile gesture: “uncertainty about the probabilities of outcomes is pervasive, multiplicative, and often

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<sup>113</sup> For some recent outlines of this shift in the nature of science, see: Mitchell, *Unsimple Truths: Science, Complexity, and Policy*; Winsberg, *Science in the Age of Computer Simulation*; DeLanda, *Philosophy and Simulation: The Emergence of Synthetic Reason*; Petersen, *Simulating Nature: A Philosophical Study of Computer-Simulation Uncertainties and Their Role in Climate Science and Policy Advice, Second Edition*.

<sup>114</sup> Keller, *Science in Environmental Policy: The Politics of Objective Advice*, 153.



nonlinear in complex systems.”<sup>115</sup> The limits of cognitive capacities arise again here. While climate forecasts are intended to supplement our cognitive abilities, limitations remain – particularly in users’ understandings of uncertainty and in interpreting probabilistic claims.<sup>116</sup> There is also an important disjuncture between the temporal horizons of predictions and policymaking. Whereas there are fundamental epistemological concerns about the validity of fine-grained predictions outside of a relatively short time period, many adaptation policies seek to plan decades in advance.<sup>117</sup> Traditional methods of decision-making therefore fail to meet the demands of a complex system. To understand how these models are changing practices requires moving beyond a focus on representational concerns and instead looking at the pragmatic dynamics of what the models allow actors to do.

As a result, a large part of what climate models do is not to provide answers per se (the prediction paradigm), but instead to highlight otherwise unseen problems in a complex system. Rather than prediction, for instance, the IPCC prefers to speak of ‘projection’.<sup>118</sup> Unlike prediction and its implicit sense of certainty (even if this certainty is expressed probabilistically), projection relies on projecting out from specific given assumptions. Models can also be used for actions other than prediction – they are employed as “tools for organising inquiry, identifying interdependencies, and developing a better overall understanding of complex issues.”<sup>119</sup> Within the adaptation framework, for instance, alternatives to prediction-centred policy focus on building resilience to whatever may come.<sup>120</sup> Models, in this variant, are used to discover robust strategies – strategies that work sufficiently well over a variety of possible outcomes, rather than maximising one single outcome.<sup>121</sup> The existence of uncertainty in complex systems means that such

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<sup>115</sup> Mitchell, *Unsimple Truths: Science, Complexity, and Policy*, 89.

<sup>116</sup> For an overview of various cognitive biases, see: Nicholls, “Cognitive Illusions, Heuristics, and Climate Prediction.”

<sup>117</sup> I owe this insight to Roman Frigg.

<sup>118</sup> Rubino, “What Will a New Generation of World Climate Research and Computing Facilities Bring to Climate Long-Term Predictions?,” 475.

<sup>119</sup> Rayner, “Prediction and Other Approaches to Climate Change Policy,” 279.

<sup>120</sup> *Ibid.*, 285.

<sup>121</sup> Lempert, Popper, and Bankes, “Confronting Surprise.”

a unique outcome is impossible to discern. Yet the discovery of robust strategies is only made possible by ensemble runs and the general simulation of the climate system. We can summarise by stating that models make possible the capacity to simulate, which in turn makes possible the capacity to consider the value of various strategies to deal with complex systems. It is only through repeated simulations of the future that strategies can be adequately assessed for their robustness to the variations involved in a complex system.

### **The Rise of Adaptation**

On the basis of these new perceptual and cognitive capacities made possible by the representational technologies, new behavioural options have opened up for policymakers. This section will argue that, in particular, the material development of GCMs has made possible new adaptation policies that were previously impractical. Adaptation primarily requires local information that until recently was unavailable.<sup>122</sup> With technological development though, the information has arisen to instantiate already existing political desires. A focus on political interests is therefore insufficient for understanding this shift, unless one also takes into account the transformations of the technological platform which have made it possible in the first place.

#### *The Transformation of Climate Change Policy*

In the past decade policymakers have been moving their attention away from global mitigation and more towards regional adaptation. On one level, the desire for the latter type of scientifically-informed and politically-relevant knowledge has been in existence for at least thirty years. In the political sphere, the 1978 US National Climate Program Act set itself the goal of discovering short-term effects on economic and social issues – though the program largely ignored global warming.<sup>123</sup>

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<sup>122</sup> Dessai and Hulme, “Does Climate Adaptation Policy Need Probabilities?,” 109.

<sup>123</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 373.

The influential 1979 Charney report (“the first policy-oriented assessment”<sup>124</sup> on climate change) for the US National Research Council also noted the significance of regional variations in possible climate change and expressed a desire for more to be known about it.<sup>125</sup> Similarly, in the scientific sphere, the desire for accurate regional forecasts was the initial impetus for the development of numerical weather prediction in 1922.<sup>126</sup> In some important senses, the knowledge for regional forecasts has been available for decades as well: early attempts in the 1980s had the models and data for a variety of the issues at hand, but the models had been developed independently and were impossible to integrate into any synthetic global vision.<sup>127</sup> Why then, given the political desire, the scientific desire, and the basic scientific knowledge, did regional forecasts for adaptation only arise within the past decade? The answer, it will be argued here, is that it took the emergence of cognitive assemblages – with their technological embodiment in computer models – in order to integrate all the components together into an effective cognitive adjunct for government policy.

Until the past decade, the vast majority of global climate modelling was aimed at determining the macro effects of doubling CO<sub>2</sub> – deemed to be the standard measure for deciding how significant climate change was going to be. This measure was co-constructed by both the scientific modelling community and the political imperative of producing a ‘manageable’ problem.<sup>128</sup> The central policy issue at this point was of demonstrating whether or not human-caused climate change was real and important. This focus had existed since the 1980s when climate modelling became a policy tool, and had produced the general outlines and measures for determining how severe climate change was going to be.<sup>129</sup> In this instance, the focus on CO<sub>2</sub> emission levels is the archetypal example. This metric

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<sup>124</sup> Ibid., 376.

<sup>125</sup> Charney et al., *Carbon Dioxide and Climate: A Scientific Assessment (Report of an Ad Hoc Study Group on Carbon Dioxide and Climate)*, 2–3; Peterson, Connolley, and Fleck, “The Myth of the 1970s Global Cooling Scientific Consensus,” 1333.

<sup>126</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 92–96.

<sup>127</sup> Ibid., 374.

<sup>128</sup> Jasanoff and Wynne, “Science and Decisionmaking,” 70–71.

<sup>129</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 359.

provided a simple and easily comprehensible standard against which to measure *how much* effect humans were having on the climate, and *how severe* the effects of climate change were likely to be. It allowed for the construction of a simple story built around the mitigation of carbon emissions, and it allowed for easy comparison of models. The aim of this program was, to put it simply, to prove that human-made climate change was real and that the best solution was mitigation on a global level via focus on a global cause (CO<sub>2</sub> emissions). The IPCC and the United Nations Framework on Climate Change (UNFCCC) are archetypes of this approach: global scientific consensus marshalled for global action.

Yet in the past two decades - and particularly the last decade - this focus has begun to shift: first in the modelling world, and subsequently in the policy world. The emphasis is now increasingly focused on producing regional climate modelling *downscaled* from a GCM. The shift began in the modelling world, as modellers began to downscale GCMs to provide finer detail about possible regional dynamics. Up to the 1990s, the impact studies on the effects of climate change have been run at immensely crude levels. As one review notes,

“There is a very serious mismatch of scale between the scenarios of climate change (for example, developed from GCMs with 500-km resolution) and the scale of operation of many climate impact models. For example, typical crop-climate models calculate crop yield on a m<sup>2</sup> basis and are designed to accept climate input from a single meteorological station representing a very local area. Similarly, climate information at the catchment scale, which maybe as small as a few kilometres, is needed to assess the effect of climate change on many hydrological basins.”<sup>130</sup>

The disjunction between scales severely hampered earlier attempts to draw out regional forecasts for policymaking purposes. GCMs would agree on the general changes made to the Earth's climate, but regional predictions would

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<sup>130</sup> Giorgia and Mearns, “Approaches to the Simulation of Regional Climate Change: A Review,” 193.

produce conflicting accounts – for instance, drought in one model, and excessive rain in another model.<sup>131</sup> These problems drove modellers to develop downscaling techniques to bypass the technological limits on GCM resolution.<sup>132</sup> This downscaling was attained through three primary means: the empirical approach avoids the computational frictions by limiting the role of modelling and instead uses historical examples of regional warming as a guide: for instance, paleoclimatic data and warm years in recent decades. The semi-empirical approach uses correlations and known relations between elements to translate low-resolution GCM outputs into higher-resolution regional estimates. Lastly, the modelling approach attempts to run high-resolution models but only for limited issues and areas. In this case, high-resolution models are often nested into coarse resolution GCMs, with the latter providing the input data for the former.<sup>133</sup>

As the anthropogenic sources of climate change have become solidified as a piece of scientific knowledge, the pressure now is to use these downscaling methods and the latest high-resolution GCMs to produce models that can illuminate regional dynamics. More specifically, while global models are sufficient for mitigation decisions and demonstrating the existence of climate change, complex downscaled global models are needed for adaptation decisions that are necessarily local. The political stakes of this shift in the modelling community are well-recognised.<sup>134</sup> A recent 2009 statement of intent by the World Modelling Summit for Climate Prediction is particularly clear: “The climate science community now faces a major new challenge of providing society with reliable regional climate predictions.”<sup>135</sup> As with earlier periods of modelling technology, there remain fundamental trade-offs between the resolution of a model and the

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<sup>131</sup> Weart, *The Discovery of Global Warming, Revised and Expanded Edition*, 159–160.

<sup>132</sup> See Figure 3 for a visual overview of how resolution has changed over the years.

<sup>133</sup> Giorgia and Mearns, “Approaches to the Simulation of Regional Climate Change: A Review,” 200–212; Mearns, “The North American Regional Climate Change Assessment Program: An Overview.”

<sup>134</sup> Pirtle, Meyer, and Hamilton, “What Does It Mean When Climate Models Agree? A Case for Assessing Independence Among General Circulation Models,” 351; Shukla et al., “Revolution in Climate Prediction Is Both Necessary and Possible: A Declaration at the World Modelling Summit for Climate Prediction”; *Advancing Adaptation through Climate Information Services: Results of a Global Survey on the Information Requirements of the Financial Sector*, 3.

<sup>135</sup> Shukla et al., “Revolution in Climate Prediction Is Both Necessary and Possible: A Declaration at the World Modelling Summit for Climate Prediction,” 19.

complexity of the components it includes. The higher resolution of this new regional modelling means that computational, data, and model frictions are all raising their head yet again.<sup>136</sup>

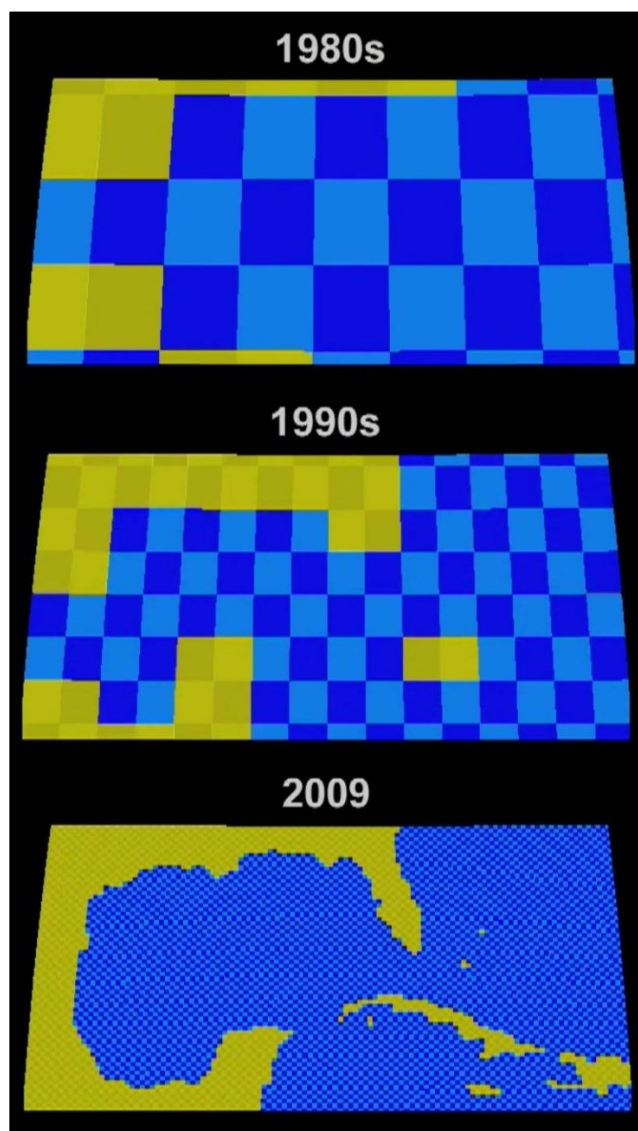


Figure 5: Resolution progress in GCMs<sup>137</sup>

With the representational technology and the political desires for regional modelling in place, policymakers have begun to shift their attention towards regional adaptation measures. This is not to say that adaptation policies have not existed in the past; but they have remained crude and based on general principles

<sup>136</sup> Ibid., 17.

<sup>137</sup> Images taken from a Geophysical Fluid Dynamics Laboratory video.

for resiliency. They have not been capable of being based on targeted adaptation measures simply because such information was outside the realm of human cognition. For decision-makers who want to understand how to respond and locally adapt to climate change, forecasts about the changing regional climate are absolutely necessary. How will precipitation patterns change? How should water resources be managed? How will infrastructure hold up? How much will sea levels rise and how high do barriers have to be? How will vegetation respond to the increased local temperatures? How will local ecologies be transformed? All of these questions require high-resolution regional modelling in order to provide an overview of the most likely outcomes.

In order to obtain these technological requirements, governments have progressively incorporated climate modelling centres into their circuits of knowledge production and decision. There has been a creation of two-way interactions between climate models and policymakers, fully integrating the two together into a single cognitive assemblage. Rather than scientists simply working on their own projects and eventually bringing issues to the political sphere, politics is now actively reciprocating the flow of information and dictating to modelling centres what information they require. As a result of this, governments are now seeking to integrate climate modelling not only as a tool to prove climate change, but also as a cognitive prosthesis for making decisions about adaptation.<sup>138</sup> An early adopter of this strategy was the International Research Institute for Climate Prediction, created in 1996 with the specific aim of providing seasonal climate predictions for government (though focused more on the El Nino Southern Oscillation (ENSO) instead of global climate change). This institution was among the first to introduce the idea of a true integration of modelling, science, and policy-relevance via “the notion of an end-to-end system running from climate

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<sup>138</sup> It should be noted that while the focus here will be on government-centred cognitive assemblages, the notion of extended cognitive systems can be incorporated at a variety of scales and organisations. The non-governmental working groups Study of Critical Environmental Problems (SCEP) and the Study of Man’s Impact on Climate (SMIC) were early precursors to this – using GCMs in the 1970s in order to produce knowledge and advocate changes. (Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 361.)

researchers to consumers of climate information, and back again.”<sup>139</sup> Today, this creation of cognitive assemblages has expanded around the world. For instance, in their national plan for responding to climate change, the South African government has placed information as a central input to any effective response:

“In order to make informed proactive decisions in respect of interventions aimed at reducing predicted climate change risks, reliable medium- and long-term impact predictions must be available to, among others, establish the scale of the projected change and associated impact and establish the potential costs of the impact and the potential benefits of a response intervention. Furthermore, as much of the on-the-ground responses will be planned and implemented by local authorities, it is imperative that these predictions are down-scaled to levels where they are of use in informing these plans.”<sup>140</sup>

A similar recognition of the importance of regional modelling for any effective governmental response can be found in Brazil. Their *National Plan on Climate Change* notes that,

“Some studies have been carried out in the country seeking to understand the regional dynamics of climate and the environment, social and economic impacts, both at a national and local level, which can occur due to changes in climate in the coming century. Attempts will be made to increase the production of scientific knowledge about all aspects related to the problem, in order to achieve an adaptation that minimises the costs incurred by the country in relation to the new climatic conditions.”<sup>141</sup>

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<sup>139</sup> Agrawala, Broad, and Guston, “Integrating Climate Forecasts and Societal Decision Making: Challenges to an Emergent Boundary Organization,” 459.

<sup>140</sup> *National Climate Change Response Green Paper 2010*, 36.

<sup>141</sup> *National Plan on Climate Change*, 21.



Turning this programmatic statement into concrete action requires “using the supercomputers of the National Space Research Institute (Instituto Nacional de Pesquisas Espaciais – INPE), which will contribute to carrying out studies on Vulnerability and Adaptation.”<sup>142</sup> In all of these cases there is a recognised need for regional and local information that has been downscaled from GCM predictions. Moreover, there is an explicit demand from governments for policy-relevant forecasts for regional adaptation measures. In both the policymaker world and the climate modelling world there is a simultaneous turn towards making climate models into effective tools of policymaking. It is, in other words, the emergence of a cognitive assemblage incorporating government institutions and representational technology.

In the end, the shift in policy focus towards regional adaptation and away from global mitigation can be seen as the product of a number of different developments: the political desire to better prepare for climate change; the political stalemates of mitigation measures; the scientific desire to accurately understand the Earth system; and their integration in materially-embodied cognitive assemblages. Given that the first two have been constants for some time, it is the latter which helps explain why this shift in focus is arising at this particular time. The emergence of cognitive assemblages has in turn been the product of a number of different trends: the development of supercomputing (e.g. parallel processing, multi-petaflop processors, and probabilistic chips); the development of climate models (e.g. Earth systems modelling, higher resolution, and better parameterisations); and the development of observational networks (e.g. satellites, greater dispersal of observation stations, globally centralised data centres). These lines of development have contingently come together to make possible the emergence of these assemblages, which have in turn come to embody the desires of governments and scientists to make forecasts about local and regional climate changes. Climate modelling centres have therefore come to effectively provide the cognitive means for government bodies to conceptualise and work through the

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<sup>142</sup> Ibid.

medium- to long-term consequences of a changing complex system. They provide the necessary mediating point through which planning and action must pass.

### *The Met Office Hadley Centre*

It is in the United Kingdom (UK) where this emergent cognitive assemblage of government and modelling centres has arguably reached its current peak. As with Brazil and South Africa, the Met Office Hadley Centre is turning towards regionalising global dynamics.<sup>143</sup> Formed in 1990 as a means to centralise climatology work being done by various UK government bodies, the Hadley Centre has from the beginning been explicitly oriented towards providing policy-relevant information. Yet the same shift seen in other modelling centres is now under way here too: whereas “previously regional information was used to answer: ‘Is there an issue?’ now it's more: ‘How do we respond?’”<sup>144</sup> The Hadley Centre also provides an ideal illustration for understanding the relation between technical climate models and policymaking because it has consistently avoided the extremes of what Simon Shackley calls ‘climate seers’ and ‘climate model constructors’. The former group aims to use models in order to make predictions and explore the effects of changes on the climate system. The latter group looks to develop the most accurate and realistic model of the climate possible; prediction and usefulness being secondary concerns.<sup>145</sup> This distinction, far from being a mere psychological predilection of individual climate modellers, is a social factor that plays into the development of climate models. National systems of modelling which take a climate seer approach will tend towards more pragmatic models. With the recent call for more regional models, the division between the two sides is being somewhat effaced and the Hadley Centre is emblematic of this. The need for pragmatic models of regional systems requires the accuracy and realism of the more complex models.

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<sup>143</sup> The Hadley Centre is named after the English scientist, George Hadley, who constructed the first conceptual model of atmospheric dynamics in 1735. (Hadley, “Concerning the Cause of the General Trade-Winds.”)

<sup>144</sup> Gordon, “Climate Science Programme,” 5.

<sup>145</sup> Shackley, “Epistemic Lifestyles in Climate Change Modeling,” 115.

The Hadley Centre is therefore unique in that it occupies a middle ground between seers and constructors. At the same time, it is “the main national source of scientific input on climate change issues not only to the wider scientific community, but also to all departments of government, to industry, and to NGOs.”<sup>146</sup> Hadley also uniquely takes much of its strategic priorities from government (via policies and funding which is primarily through the Department of Energy and Climate Change (DECC) and the Department for Environment, Food and Rural Affairs (Defra)). The Defra funding program which makes up nearly 80% of Hadley’s total 2011 funding is explicitly oriented towards producing policy outputs.<sup>147</sup> “Modelling to address policy-relevant questions thus becomes a priority for research.”<sup>148</sup> In all these regards, therefore, the Hadley Centre provides a prime exemplar for how policymakers and climate modelling are interacting to produce an extended cognitive system.

The Hadley Centre uses a variety of model in order to achieve its scientific and policy-oriented goals, with each model providing insights on different aspects of the climate. These range from complex state-of-the-art earth system models (HadCM3LC and HadGEM2-ES, which as of this writing is one of the most advanced models in the world<sup>149</sup>); models of intermediate complexity; simple models used to provide baselines and test major climate drivers; and integrated assessment models that attempt to incorporate social, political, and economic aspects into the modelling sphere. (See Figure 6 for a quick overview of the Hadley Centre’s main models.)

Having demonstrated the tight interconnections between the government and climate modelling, it is unsurprising to see the Met Office respond directly to the demands of adaptation outlined here, and to the cognitive possibilities opened up by developments in technology. The latest strategy document of the Met Office reiterates the changes in the climate modelling community that were outlined earlier:

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<sup>146</sup> Ibid., 126.

<sup>147</sup> Gordon, *Climate Science*, 2–3.

<sup>148</sup> Shackley, “Epistemic Lifestyles in Climate Change Modeling,” 126.

<sup>149</sup> New work is currently being done to produce and tune the family of next generation models, the HadGEM3.

“Even without climate change, society is increasingly vulnerable to hazardous weather and natural climate variability. This means that information is required not at a global scale, but at a regional and local scale and increasingly for lead-times of months to decades rather than for the end of the century. At the same time, there is a growing awareness that the most serious impacts of climate change will be felt through changes in rainfall patterns, extremes of climate variability, and the intensity and frequency of hazardous weather events. This new agenda is revolutionising climate science and prediction, and the urgency of the problem is requiring an increasingly operational delivery of climate services.”<sup>150</sup>

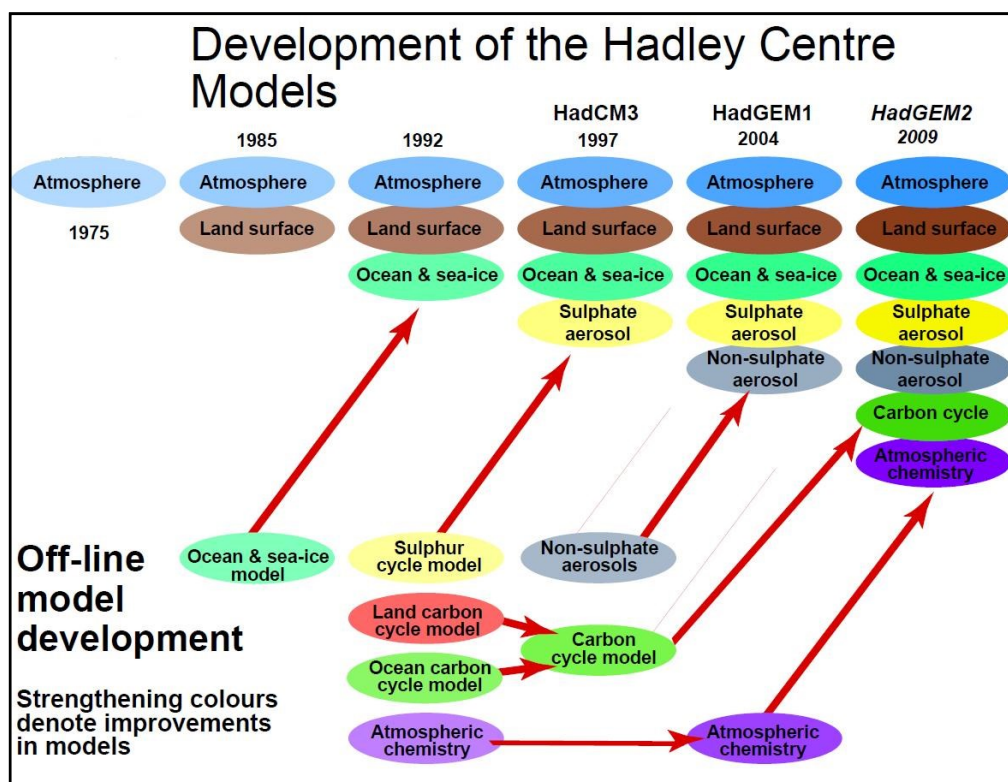


Figure 6: History of the Hadley Centre models<sup>151</sup>

<sup>150</sup> Met Office Science Strategy 2010–2015: Unified Science and Modelling for Unified Prediction, 2.

<sup>151</sup> Gordon, “Climate Science Programme,” 21.

As a result of these demands, the Hadley Centre is focusing its research over the next five years on a few key areas: better predictive capacities for hazardous weather; increased predictive abilities for the water cycle and precipitation patterns; producing monthly to decadal climate predictions; and to integrate human activities and reactions into the models. These areas of focused research are all aimed at providing the operational means for decision-makers to perceive the likely areas where climate change will have the most negative effects (a point made repeatedly throughout the strategy document). Firstly, the prediction of extreme weather events is of obvious interest to any government, with flooding and snowfall being particularly significant for the UK. Secondly, precipitation patterns are also crucial for the UK government, as their placement between the Atlantic Ocean on one side (with its associated jet streams and ocean currents) and the European continent on the other gives rise to particularly unpredictable weather.<sup>152</sup> As droughts affect southern parts of the UK, while floods affect other parts, planning for how to react to these medium-term changes is crucial for the UK government. Thirdly, the shift to monthly and decadal predictions is also a significant indicator of government interests. Rather than the standard century long predictions used for the IPCC assessment reports, monthly and decadal predictions are more actionable for policymakers. Lastly, and quite obviously, the human-climate interaction is of interest primarily to governments having to make estimates of the likely future. A climate purist is interested first and foremost in creating an accurate scientific model of the climate system; in this pure vision, human interactions are an extraneous factor.

Materially, these four strategic goals require not only the further development of climate models, but also investment in specific hardware and specific technical skills. The Met Office notes that currently far too much time is devoted by modellers to fixing computing problems, and therefore there is a need to incorporate more computer scientists and software engineers to accomplish these necessary tasks. This is particularly significant insofar as upcoming supercomputers involve multi-cores and massive parallel processing which will

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<sup>152</sup> McKie, "UK Weather Defies Prediction, Say Forecasters."

require rewriting every model's code in order to take advantage of the new computing architecture.<sup>153</sup> Additionally, the distinction between operational climate projections as opposed to research-based climate projections requires specific supercomputing abilities in order to make the strategic goals possible. Whereas research-based modelling involves running simulations that takes months of time to accomplish, operational-based modelling requires much quicker turnarounds in order to make the projections useful for more immediate decisions.<sup>154</sup>

The products of these investments in the technological infrastructure are intended to be direct inputs into policymaking. In the words of one UK-based modeller, "Building models of these problems serves a dual purpose – it provides predictions, but also, in describing the model, you describe the problem in a way that can really help policy-makers."<sup>155</sup> The emphasis on "operational delivery of climate services" highlights that the intended audience of the modelling centre's products are to be political users. Already, the Hadley Centre models have been used to help businesses stress test their infrastructure in the wake of extreme weather events.<sup>156</sup> Hadley's Providing Regional Climates for Impact Studies (PRECIS) program is aimed at producing a model which requires minimal computational capacity and is designed to be made easily available to developing countries to simulate their own regional projections. This is another step in the overall strategy of making regional productions more accurate, more widely dispersed, and more easily usable for decision-makers at every level.

The Hadley Centre therefore exemplifies a cognitive assemblage, whereby the development of representational technologies and the development of policies become intertwined. The Hadley Centre takes its research priorities from government requests (e.g. regional and local modelling, the inclusion of the water cycle, and the forecasting of extreme events) and is focused on producing policy-relevant information. This marks a significant shift from the 1990s where it was

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<sup>153</sup> *Met Office Science Strategy 2010–2015: Unified Science and Modelling for Unified Prediction*, 11.

<sup>154</sup> *Ibid.*, 12.

<sup>155</sup> Emmott et al., "New Ecologies (Interview)," 109.

<sup>156</sup> Slingo, *Unifying Weather and Climate Research*, 37.

thought that GCMs would only affect policy indirectly via means such as raising an issue.<sup>157</sup> Now climate modelling is seen to contribute specifics to how decision-makers understand their actions. Government rationality is distributed across social and material components. Intriguingly, in the emergence of these cognitive assemblages, the distinction between weather forecasting and climate projections is increasingly disappearing as the technology makes the accuracy and resolution of climate projections more closely approximate that of numerical weather prediction. There is a breakdown of the traditional division between scientists in favour of accurate representations and those in favour of pragmatic representations. Or more specifically, the division is being displaced to a new debate over *how* to use the more accurate representations.

## **Conclusion**

In summary, this chapter has attempted to demonstrate how technologically produced representations can augment cognition and contribute to shaping the possibility space of political action. In particular, this has been traced out by following the emergence of cognitive assemblages resulting from a number of different dynamics in climate science and politics. First, there is the technological development of regional models downscaled from GCMs, and the ensuing effacement of the climate projection/weather forecast distinction. This development was guided by material frictions along the way, with social contestation over the best path forward being set within these limits. Second, there was the political recognition of the inevitability of climate change and the need for adaptation measures. Since these measures require local information, regional downscaled models are the only current means to provide estimates about the likely outcomes of climate change and thus the necessary policy responses by governments. These two movements have coalesced together in climate modelling centres that are guided by policy needs, with the Hadley Centre exemplifying this trend. New state powers of perception and cognition are arising as a consequence. The power to act meaningfully in response to climate change is premised upon the

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<sup>157</sup> Edwards, "Global Comprehensive Models in Politics and Policymaking," 157.

capacity to ‘see nature’ – a capacity which is only possible by virtue of the heavy technological mediation this chapter has set out. GCMs, as representational technologies, have augmented the perceptual capacities of states and international organisations as a result.

Yet despite the significant cognitive advances afforded by these technological extensions, there are still limits – some fundamental, some more temporary. There is not a complete evacuation of humanity’s roles in making decisions about the climate. To begin with, there are always multiple models available, and thus the selection of which model to employ is partly a political choice.<sup>158</sup> This choice is somewhat mitigated by the emergence of ensemble forecasting though, which downplays the contribution of any particular model and its possible biases. On the output side, “the practical problem is that numerous and even contradictory policy positions can be supported by legitimate interpretations of the scientific record.”<sup>159</sup> Moreover, values inevitably enter into the discussion of how to respond to climate change:

“The way in which climate change is framed – as an environmental, security, economic or social justice problem – fundamentally affects the way that climate is governed, the types of policy interventions that are sought, and the actors to be involved.”<sup>160</sup>

Further complications arise in the economics of climate change: not only what will be affected, but how much and what will it cost. Key here is (1) the discount rate assumed for future events, and (2) the damage function of temperature rises.<sup>161</sup> These calculations rely less on empirical or theoretically grounded analyses though, and more on ethical principles about the value of future humans, the stance towards the precautionary principle, and the relation to uncertainty.

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<sup>158</sup> Brunner, “Alternatives to Prediction,” 303.

<sup>159</sup> Keller, *Science in Environmental Policy: The Politics of Objective Advice*, 132.

<sup>160</sup> Hulme, *Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity*, 288.

<sup>161</sup> *Ibid.*, 128-129; DeCanio, *Economic Models of Climate Change: A Critique*.



On an even more fundamental level, prediction with climate models is limited by a fundamental characteristic of complex systems: the climate system is inherently random – while there are predictable aspects, there is also necessary randomness that sets limits on the accuracy of any possible prediction.<sup>162</sup> The fundamental limit of weather prediction, for instance, is estimated to be two weeks.<sup>163</sup> And even within that limit, human expertise is still required to interpret computed outputs and recognise the signs of extreme weather.<sup>164</sup> Therefore, there will always remain a space for human decision in the response to climate change.

This leads to some of the explicit and implicit political aspects of GCMs. As with any representational technology, these GCMs shape behavioural and cognitive possibilities – which necessarily entails political consequences. For instance, in presenting a numerical and abstract vision of nature, interactions between different sciences are represented synthetically, and the local and individual variations in any component are often effaced by this abstraction. Soil chemistry, hydrology, and plant physiology are all abstracted from their original scientific disciplines in order to be represented and included with climate models.<sup>165</sup> Similarly, GCMs tend to “favour certain disciplines and approaches over others, for instance, by giving more weight to the present than the past, to near-term meteorological timescales over geological ones, and to physical processes (which may be more tractable at global levels of representation) than to biological parameters.”<sup>166</sup> Within this representational technology there is simultaneously a blackboxing of the cognitive processing that goes on behind simulations. Regional variations, statistical outliers, and contentious assumptions can and do disappear behind the opaqueness of the final product. For instance, the simplicity of an earlier sea model made pollution appear to be a more universal concern than it actually was. Regional variations in pollution were glided over by scientists in an effort to bring about political

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<sup>162</sup> Stewart, “Uncertainty, Judgment, and Error in Prediction,” 53.

<sup>163</sup> Hooke and Pielke, Jr., “Short-Term Weather Prediction: An Orchestra in Need of a Conductor,” 62.

<sup>164</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, 267.

<sup>165</sup> Jasanoff and Wynne, “Science and Decisionmaking,” 61.

<sup>166</sup> *Ibid.*, 49.

agreement on the Mediterranean Action Plan.<sup>167</sup> The material infrastructure of cognitive assemblages and the knowledge they produce can encode a variety of other political assumptions. The most common of these are debates about the relationship between models and data, as well as debates over whether GCMs are tuned to give the results modellers want to find.<sup>168</sup> But more significant is that even if the validity of the science is not questioned, GCMs can still encode political assumptions – for instance, giving weight to problems that affect developing countries less than developed countries. (See, for instance, the WRI-CSE controversy).<sup>169</sup> In this regard, the choice of model outputs is partially political as well: what variable, for instance, does one choose to represent soil depletion or deforestation? In every case, “predictions must be generated primarily with the needs of the user in mind. [For instance,] television weather predictions focus primarily on temperature, precipitation, and wind, rather than temperature gradients, behaviour of aerosols, and barometric pressure.”<sup>170</sup> The global nature of the outputs means they have tended to predict risk independently of local circumstances and reactions.<sup>171</sup> “Such ‘global’ statements may suppress a number of important differences and insights at the local level that can either contribute to understanding the nature of risks, or indicate the local meaning attached to environmental changes often referred to as problems.”<sup>172</sup> Lastly, the basic acknowledgement that climate change is dangerous says nothing about what in particular is dangerous (e.g. increased flooding, more extreme weather, soil depletion, ocean acidification, changing migratory patterns, etc.) and to whom in particular it is dangerous (e.g. developing countries, rural areas, the global poor, the insurance industry, etc.). All of these aspects must be selected (or ignored) as part of the output of the model.

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<sup>167</sup> O’Riordan et al., “Institutional Frameworks for Political Action,” 369.

<sup>168</sup> Edwards, “Global Climate Science, Uncertainty and Politics: Data-Laden Models, Model-Filtered Data,” 457.

<sup>169</sup> Forsyth, *Critical Political Ecology: The Politics of Environmental Science*, 174; Ahuja, “Estimating National Contributions of Greenhouse Gas Emissions: The CSE-WRI Controversy.”

<sup>170</sup> Pielke, Jr., Sarewitz, and Byerly, Jr., “Decision Making and the Future of Nature: Understanding and Using Predictions,” 382–384.

<sup>171</sup> Forsyth, *Critical Political Ecology: The Politics of Environmental Science*, 176.

<sup>172</sup> *Ibid.*, 171.

Further political processes of inclusion and exclusion arise in that “the use of technologically sophisticated methods such as computer simulations [are not always available to] viewpoints from less scientifically and technically resource-rich states and regions of the world.”<sup>173</sup> Projects like the DFID funded Climate Science Research Partnership (CSRP) program at the Hadley Centre are specifically focusing on providing regional projections for Africa, where early warning systems are crucial for preparing aid and relief before a crisis strikes.<sup>174</sup> This diffusion of regional modelling to local areas also extends the computer-mediated vision of nature that GCMs embody. It is part of the infrastructural project of creating a network with standardised and shared representations.<sup>175</sup> This diffusion of modelling capacities is conjoined with the move towards regionalised projections and the subsequent transformation in the locus of decision-making they make possible. This changes the object of governance – from the global space of emissions controls to the local space of adaptation measures. It makes possible a change in who is governing – from a small community of climate modellers and politicians to a much wider group of local stakeholders. Higher resolution regional models, for example, can allow for more specificity about precipitation patterns: a key aspect for managing local water resources. Whereas the academic focus and public attention has largely been on the state and inter-state levels,<sup>176</sup> the most effective actions for adaptation are at the local and regional levels. The spread of regional modelling towards these affected localities promises to make the computer-mediated vision of the world even more pervasive in the future.<sup>177</sup>

Yet despite all the political implications of these representational technologies, GCMs remains the sole means available for making nature qua complex system intelligible as a whole. In particular, models act to condense a dispersed spatiotemporal problem into an immediate and intuitive representation.

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<sup>173</sup> Jasanoff and Wynne, “Science and Decisionmaking,” 49–50.

<sup>174</sup> Gordon, *Climate Science*, 4.

<sup>175</sup> Jasanoff and Wynne, “Science and Decisionmaking,” 22.

<sup>176</sup> O’Riordan et al., “Institutional Frameworks for Political Action,” 393.

<sup>177</sup> Hoffman, *Climate Governance at the Crossroads: Experimenting with a Global Response after Kyoto*; Selin and VanDeveer, *Changing Climates in North American Politics: Institutions, Policymaking, and Multilevel Governance*; Suzuki and Dressel, *More Good News: Real Solutions to the Global Eco-Crisis*.

One of the well-known difficulties with solving the problems of climate change is that the responsible parties, the victims of climate change, the effects of current behaviours, and the likely effects, are all dispersed over decades and thousands of miles. In situations such as these, those responsible can have both incentives to ignore problems and the means to obscure their role.<sup>178</sup> What GCMs effectively do is to take this entire complex network and make the connections intelligible, thereby bringing concreteness to what is otherwise an abstract and often invisible problem. This complexity is made visible and intelligible through charts, maps, and simulated time-lapse videos. In this regard, “the computer functions not merely as an improved typewriter, [...] but rather as a general interface between systems of equations and sensory perception.”<sup>179</sup> GCMs and their cognitive assemblages come to form a necessary technical mediator between nature and politics. The ability to see the evolution of the global climate “at a glance” allows new means of comparison and helps to highlight problems in advance.<sup>180</sup>

What this chapter has attempted to demonstrate is that political decisions increasingly require technological extensions of cognitive capacities. Complex systems far surpass our intrinsic abilities to understand them, and therefore demand that humanity develop technology to supplement our finite capacities. The next chapter will examine another such system – global financial markets – in order to show one way in which non-state actors are making use of representational technologies in order to create new possible actions.

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<sup>178</sup> Mitchell, *International Politics and the Environment*, 104.

<sup>179</sup> Kittler, *Optical Media*, 228.

<sup>180</sup> Pasini, *From Observations to Simulations: A Conceptual Introduction to Weather and Climate Modelling*, 145.

## 5 / SEEING MARKETS

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“What one thinks of as ‘market data’ are often prices filtered through another model or calculation.”<sup>1</sup>

-Emanuel Derman

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Once a relatively obscure field of financial economics, derivatives have burst into popular consciousness over the past decade, culminating in the financial implosion of 2008.<sup>2</sup> From the shadows of the over-the-counter (OTC) financial world, stories about the proliferation, ubiquity and dangers of derivatives suddenly became front page news. It was commonly cited that prior to the collapse the notional value of outstanding derivatives was \$683 trillion.<sup>3</sup> While this number is an exaggeration of derivatives’ real significance (notional value includes the value of the underlying), it does point to the sheer pervasiveness of derivatives. Similarly, a 2005 report found that 92% of the top 500 companies were using derivatives.<sup>4</sup> Even many individuals who ostensibly never invested in derivatives were nevertheless participating in them through pensions, municipal bonds, mutual funds and other investment bodies for personal finance. Derivatives were everywhere and they were playing an important role throughout the global financial system.

Yet forty years earlier, derivatives trading was a minuscule market. This rapid growth of derivatives (the quickest in history<sup>5</sup>) and their markets is a bit of a mystery (see Figure 7 and Figure 8). The expansion of the world’s financial markets

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<sup>1</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 165.

<sup>2</sup> Derivatives are so called because their value derives from some sort of underlying asset (e.g. commodities, stocks, bonds, interest-rates, and credit). They are financial contracts (also called instruments or products). They can be roughly broken up into four different types of derivatives: futures, forwards, swaps, and options.

<sup>3</sup> *OTC Derivatives Market Activity in the First Half of 2008*.

<sup>4</sup> Bernstein, *Capital Ideas: The Improbable Origins of Modern Wall Street*, xx.

<sup>5</sup> LiPuma and Lee, *Financial Derivatives and the Globalization of Risk*, 94.

has been given a number of explanations, ranging from American and UK-led, IMF-led, and neoliberal-led processes of financial liberalization; institution-based, ideas-based, and state-based sources of change; along with liberal analyses and Marxist analyses.<sup>6</sup> While making important contributions, these explanations tend to overlook a key component of this financial expansion: the role of technology in constructing global financial markets. It is the aim of this chapter to demonstrate what precisely that role is – not as an opposed explanation to the previous theories, but as a crucial supplementary cause. In this vein, one aim of the chapter will be to show how representational technology began to be used to grasp the complexity of financial markets, which in turn enabled the construction of new markets in new financial instruments. In part, this technology facilitated the growth of derivatives markets by altering modern perceptions of the ‘global financial market’.

The chapter here concentrates specifically on the creation and spread of derivative pricing models and derivative markets (both OTC and exchange-based), with a particular focus on options.<sup>7</sup> Despite their current popular affiliation with the 2008 financial crisis, derivatives were in fact initially developed in order to minimise risk – that is to say, to manage complexity. Financial instruments are produced (‘engineered’) as mathematical means to try and distribute risk in the most optimal manner. They provide a way to fine-tune the risk that a particular investor is willing to take on. As financial engineer Emanuel Derman writes, “the asymmetry between upside gain and downside loss is the defining characteristic of derivatives.”<sup>8</sup> Despite the complexity of the nuances involved in derivatives, at their most basic they consist of three fundamental products: options, futures, and swaps.

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<sup>6</sup> Helleiner, *States and the Reemergence of Global Finance: From Bretton Woods to the 1990s*; Gindin and Panitch, *The Making of Global Capitalism*; Krippner, *Capitalizing on Crisis: The Political Origins of the Rise of Finance*; Chwieroth, *Capital Ideas: The IMF and the Rise of Financial Liberalization*; Harvey, *A Brief History Of Neoliberalism*.

<sup>7</sup> A parallel story could be told for collateralized debt obligations (CDOs) – one of the major contributors to the 2008 financial crisis – as the models which made them possible share a similar history to the derivative pricing models analysed here.

<sup>8</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 6.

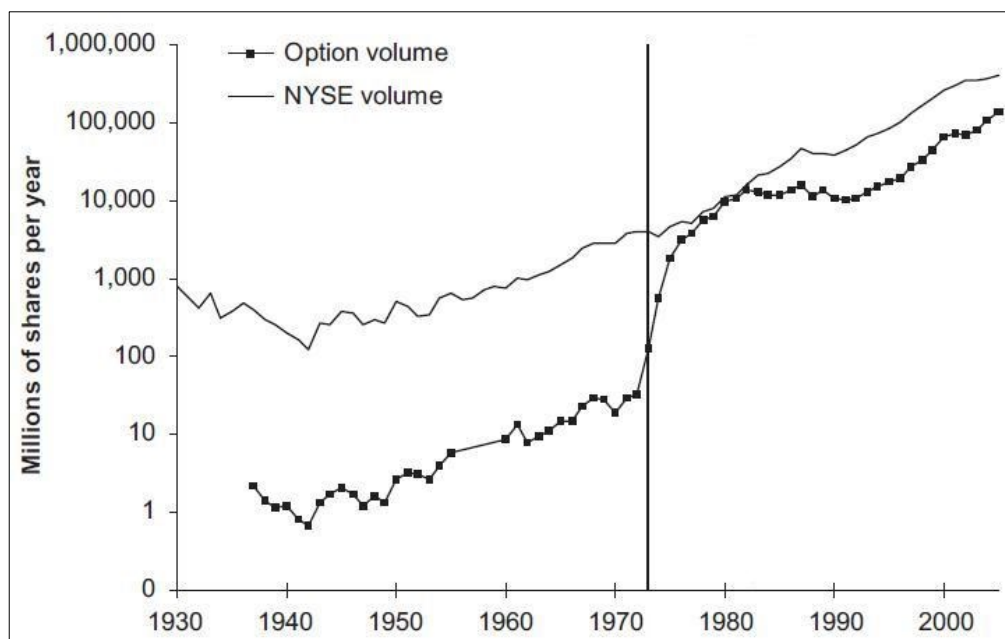


Figure 7: The rise of options trading in the 1970s<sup>9</sup>

Options, like their name suggests, are the option to purchase or sell an asset at a specified price (the ‘strike price’). A call option allows the option buyer to purchase an asset, while a put option allows the option buyer to sell an asset. A further distinction can be made between European and American options, neither of which references a geographical specification but instead refers to when an option can be exercised. European options can only be exercised at one specified date (the ‘maturity date’); whereas American options can be exercised at any point up to the maturity date. Options, at least in one use, are a means to hedge against the risk of an asset value fluctuating too wildly. A seller of a good (e.g. farmers selling wheat) may buy a put option in order to guarantee a minimum price at which they can sell a good, thereby minimizing the risk in asset volatility. Similarly, a buyer of a good (e.g. airlines buying jet fuel) may buy a call option in order to set a ceiling to the price they pay for an asset in the future.

<sup>9</sup> This graph is a modified version of that found in Mixon, “Option Markets and Implied Volatility: Past Versus Present,” 172. Note that this is a logarithmic scale, which visually minimises the actual leap in options trading. The solid vertical line marks the year 1973, when the Black-Scholes-Merton formula was published and when the first centralized exchange devoted to options (the Chicago Board Options Exchange) opened up.

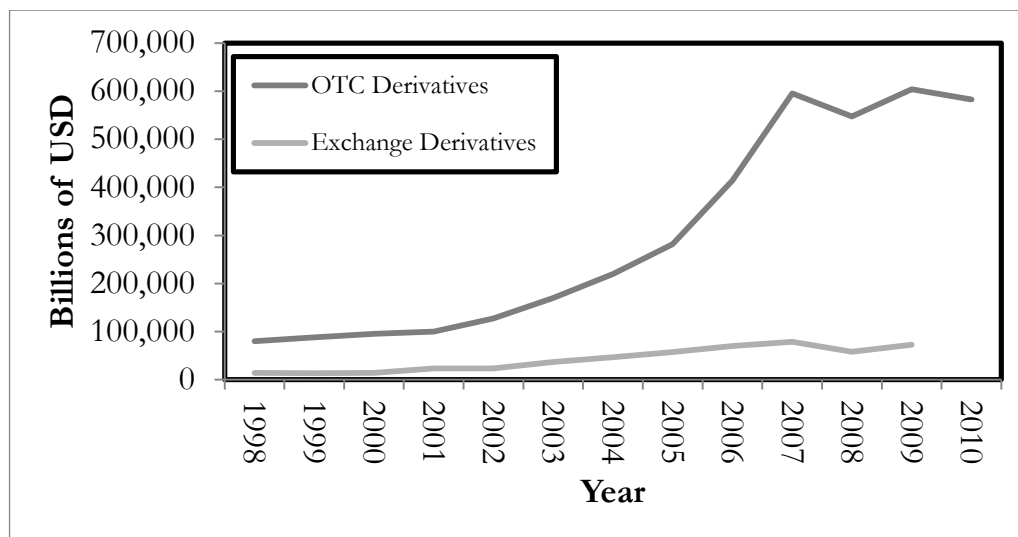


Figure 8: Notional outstanding amounts of derivatives, 1998-2010<sup>10</sup>

Options also have a speculative use by virtue of the leverage they can provide. For instance, the buyer of an option, crucially, is not buying the underlying asset itself, but only the right to possibly own (or sell) it in the future. Typically, only collateral has to be paid up front, which is a small percentage of the actual asset value under consideration. Leverage can therefore be created by using a relatively small amount of capital to purchase options on the movements of a relatively large amount of assets. Furthermore, derivatives are off-balance sheet entities, meaning they are not subject to the capital requirements that on-balance sheet entities are regulated by. Banks and other investment bodies do not need to set aside capital in order to trade in derivatives markets, thereby leaving more capital for use in the markets. Options, as a result, are extremely popular as a tool of speculation.

Futures are similar to options, though they do not allow for the choice of buying or selling the underlying at the expiration date.<sup>11</sup> Instead, they are agreements to buy or sell an underlying at a predetermined price and at a

<sup>10</sup> Source: Bank for International Settlements (BIS). Note that these numbers are not inflation-adjusted. These numbers are also drawn from their second-half reports – so 2008, for instance, includes the effects of the financial crisis. BIS began thorough record-keeping in 1998, which marks the start of this chart. Prior to then, the International Swaps and Derivatives Association (ISDA) kept records of market value and activity, but only on currency and interest-rate derivatives and only from 1987.

<sup>11</sup> Forwards are another type of derivative, though they are largely equal to standardized, exchange-traded versions of futures.



predetermined time. They are less flexible than options, though as a result, there is no premium paid for having a choice.

Swaps are a more recent invention and consist fundamentally in the exchanging of income streams between parties. Oftentimes these are used to manage the volatility of currency exchanges or interest rates. For instance, one party may want a stable (fixed) interest rate, while another party is willing to accept the volatility of interest rates in the belief that they will provide greater returns. The excess gains that may come from the variable rate are exchanged for the security of knowing the future interest rate in advance and being able to plan around it.

These three instruments provide the basis for all the ensuing derivatives that will be referred to in this chapter. The more complex derivatives (e.g. exotic options and structured products) are typically comprised of variations and combinations of options, futures and swaps. The focus point for this chapter – where technology, practitioners, complexity and representation all meet – will be in the realm of options traders. It is here that the complexity of the market, its perception as a global entity, and actions focused on these representations of global finance, all arise.

The story here will focus on a few key moments in their history. After a brief historical overview of financial quantification, we will look at the origins of pricing models with Fischer Black, Myron Scholes and Robert Merton. We will then examine the shift in the use of pricing models that occurred as a result of the 1987 stock market crash, showing how volatility came to be the prism through which much market activity was perceived by options traders. Third, we will look at the proliferation of models as a result of debates over the nature of ‘volatility’ and the overcoming of various material frictions. Fourth, we will focus on how these models came to frame options markets in terms of volatility as a simplifying heuristic. Fifth, we will then argue that these models have made possible a variety of new behaviours in the markets, which have contributed to making possible the rise of global finance.

## The Complexity of Finance

Global financial markets are complex both in the technical sense of a complex system and in the intuitive sense we give to the term. In the more mundane everyday sense, markets are comprised of thousands of traders carrying out billions of transactions every day. With the incorporation of algorithmic trading recently, these volumes are surging ahead. The average daily volume of the New York Stock Exchange (NYSE) increased 300% over the period of 2005–9, while the number of daily trades increased 800% over the same time.<sup>12</sup> This surge in volume has been matched by a surge in the variety of financial products available as well. The traditional equities and bonds have been joined by increasingly exotic derivatives and increasingly abstract products (as we will see, even derivatives of the volatility of volatility are now being traded).

In response to this expansion of products, volumes, and market participants, a variety of tactics have been developed to simplify this complexity. A mass of information is produced in an attempt to try and make intelligible the dynamics of the market: corporate financial reports, scores of analysts' reports, and organisation's own proprietary analyses, to name just a few. In addition, organisations set up trading desks devoted to specific securities and specific regions, and traders make use of various heuristics all the time in an attempt to make sense of the mass of information (e.g. profit/earnings ratios, credit default swap costs, and bond spreads).

Global financial markets are also complex in the technical sense: subject to critical phase transitions, sensitivity to initial conditions, self-organising, and capable of generating emergent phenomena. Prices in markets tend to follow a random walk pattern, but under certain conditions produce significant critical events (i.e. crashes) that can be modelled as a phase transition in the market.<sup>13</sup> Various patterns in financial markets (e.g. the existence of power laws) all suggest their nature as a properly complex system.<sup>14</sup>

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<sup>12</sup> Beunza et al., *Impersonal Efficiency and the Dangers of a Fully Automated Securities Exchange*, 5.

<sup>13</sup> Sornette, *Why Stock Markets Crash: Critical Events in Complex Financial Systems*, chap. 3.

<sup>14</sup> Gabaix, "Power Laws in Economics and Finance."

It is as a result of these sorts of complexities that financial actors have turned towards various representational technologies in order to make it possible to intervene in the market. In particular, this chapter will examine option pricing models as tools which condense an immense amount of information about these complex systems into an actionable representation that allows traders to trade.

### **A History of Financial Quantification**

Despite the recent popularity of these products, financial derivatives have been around for millennia. Since this chapter is concerned broadly with the effects of financial quantification, it is worth briefly examining the history of such quantification. In particular, we will demonstrate the basic steps that were required for the worldview presupposed by modern derivatives to emerge.

The link between finance and mathematics has a long history, harking back to at least ancient Sumerian and Babylonian laws on interest rates in the third century BC.<sup>15</sup> This was a very rudimentary sense of financial quantification though, as while interest was calculated on various loans and debts, this relied only on basic arithmetic and was predominantly subject to the whims of moral and legal arguments rather than any sort of quantitative reason.<sup>16</sup> When interest was paid, it was typically paid through the same substance that had been lent out. Repayment was given ‘in kind’<sup>17</sup> for most of history, or eventually through money (though money understood as a means of exchange and not as self-generating capital). Early finance also neglected any numerical distinguishing of maturities on loans beyond a basic ambiguous distinction between short-term and long-term.<sup>18</sup>

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<sup>15</sup> Lo and Hasanhodzic, *The Evolution of Technical Analysis*, 5; Homer and Sylla, *A History of Interest Rates, Fourth Edition*, Kindle Location 372-378.

<sup>16</sup> Kaye, *Economy and Nature in the Fourteenth Century: Money, Market Exchange, and the Emergence of Scientific Thought*, 80-87.

<sup>17</sup> The term ‘in kind’ has remained with us in the present era, and suggests the historical separation of different kinds of substances, values and magnitudes. This is a remnant of medieval mathematics, where ‘numbers’ were based upon incommensurable units of substances, leading to incommensurable series of numbers. There was no conception of a general number. (Hadden, *On the Shoulders of Merchants: Exchange and the Mathematical Conception of Nature in Early Modern Europe*, 68-71.)

<sup>18</sup> Homer and Sylla, *A History of Interest Rates, Fourth Edition*, Kindle Location 276-285.

*Early Derivatives Pricing*

Similarly, while options and futures had existed even during Aristotle's time, until recently there was no market for such items and no procedure for pricing them. A number was affixed to these entities, but based on qualitative reason rather than quantitative calculation. As Joel Kaye argues, the basic problem was this:

“Since [the lender's] profit is in the future he has no way of making a rational decision as to whether or how much he will benefit from the [lending], and both equality and rationality are essential to proper, non-usurious economic transactions.”<sup>19</sup>

What was necessary for financial quantification to arise was the ability to quantify and price a projected future. Finance being intrinsically temporal, this was a necessary condition. In the late medieval origins of quantification it is the work of the thirteenth century Franciscan monk Peter John Olivi where the idea of quantifying the future explicitly occurs for the first time.<sup>20</sup> The crucial step of this shift was Olivi's argument for the reality of probability in issues of pricing.<sup>21</sup> Importantly, Olivi based this argument on his claim to be rationally transcribing existing economic practices. Since merchants already estimated a discounted real value to the probability of future profits, in practice merchants were therefore implicitly giving reality to probability and future value. Despite the largely qualitative justification of pricing interest rates on loans, merchants were nevertheless suggesting in their actions the potential to quantify future value and probability. It was a form of quantification without metrology, or an application of numbers without measurement or calculation. Instead of the real abstraction of

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<sup>19</sup> Kaye, *Economy and Nature in the Fourteenth Century: Money, Market Exchange, and the Emergence of Scientific Thought*, 120.

<sup>20</sup> Olivi's work was spread primarily through the sermons of St. Bernadino of Siena, who often took directly from Olivi's writings without referencing them. (Ibid., 118.)

<sup>21</sup> Ibid., 121. Note that Olivi's argument pre-dates the origins of probability theory in the seventeenth century. It was crucial that probability be established as a real and measurable phenomenon first, before it could ever become the focus of sustained mathematical attention by the likes of Blaise Pascal and Pierre de Fermat.

commodity exchange,<sup>22</sup> what was taking place was the real abstraction of discounting future profits – an abstraction as crucial to capitalism as exchange. On the basis of this practice, Olivi would go on to argue that the moral necessity of equality between capital lent out and capital returned was based not simply on an arithmetical calculation as had previously been thought. Rather, the equality of future value with present value was a geometrical concern, with a degree of latitude given to randomness and the intrinsically probabilistic nature of the future.<sup>23</sup> With Olivi then, the idea of rationally justifying and quantifying future value and probability comes to be explicitly posed for the first time. This was the conceptual shift required for perceiving time and possibility as commensurable with quantification, and the entire history of financial quantification since owes its origins to this revolution in thought.

From this point, the history of stock pricing (and prediction) has been an eclectic mix of individual expertise, heuristics, and analysis of company information. The modern strategies for those actively involved in the market (i.e. not including passive ‘buy and hold’ strategies) have been broadly divided between technical analysts (‘chartists’) and fundamentals analysts. The latter involves the slow and patient analysis of a company’s operations in order to determine its likely future. As Wall Street historian Peter Bernstein writes, fundamentals analysts “pour over accounting data, interview managements, scrutinise industry trends, consult economists, probe into political forces, and worry over interest rates.”<sup>24</sup> The belief here is that there is a real value to a company that can be discerned with close scrutiny. Investors using this strategy seek to find mispriced securities on the basis of what they estimate the real value to be.

On the other hand, there are the technical analysts (or chartists). They seek to examine the history of stock market prices in order to uncover patterns in the seemingly random fluctuation of the market. Distinctive patterns like the ‘head and shoulders’ are presumed to occur because of market psychology, and the belief

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<sup>22</sup> Sohn-Rethel, *Intellectual and Manual Labour: A Critique of Epistemology*.

<sup>23</sup> Kaye, *Economy and Nature in the Fourteenth Century: Money, Market Exchange, and the Emergence of Scientific Thought*, 124.

<sup>24</sup> Bernstein, *Capital Ideas: The Improbable Origins of Modern Wall Street*, 134.

is that they can give astute traders a relatively accurate forecast of the immediate future (see Figure 9).<sup>25</sup> The practice, while denounced by some as no better than astrology, has existed in some form since the Babylonian era and today continues to find many practitioners – particularly in the commodities and currency markets.<sup>26</sup> Modern-day technical analysts use computers, pattern-seeking algorithms, and a wide array of indicators and measures to determine the existence of trends and turning points, all in order to derive the near-term future of stock prices.<sup>27</sup>

As is clear from this discussion, both methods rely heavily on the experience and expertise of individuals, and the use of heuristics to simplify the massive amount of information involved in either analysis. (The most well-known is the price-to-earnings ratio, or P/E, which is believed to offer a rough estimate of whether a stock or index is over- or under-priced.)

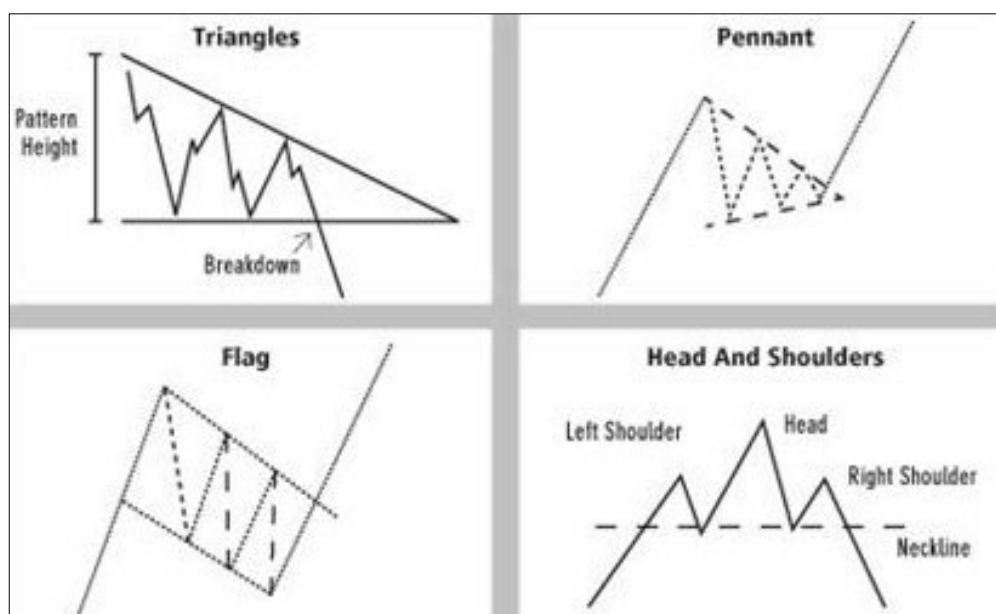


Figure 9: Common patterns in technical analysis

By contrast, a third group that has come to dominate the past fifty years of financial thinking rejects the idea that price movements can be predicted in

<sup>25</sup> The reliance on market psychology has resonances with behavioural economics today – if economic actors are cognitively biased, there may be good psychological reasons for the existence of market patterns.

<sup>26</sup> Lo and Hasanhodzic, *The Evolution of Technical Analysis*, viii.

<sup>27</sup> *Ibid.*, 156–157.

advance – basing this conclusion upon the random walk hypothesis.<sup>28</sup> Unlike technical analysts or fundamentals analysts, the random walk hypothesis argues that stock pricing is entirely random and produces no stable patterns. The consequence of this argument is that consistently beating the market becomes impossible since any predictable price movement is already incorporated into the price.

The random walk hypothesis points to both the fundamental difficulty and the subsequent solution to pricing options. Take, for example, a call option with a strike price of £40 on a stock currently worth £45 and with an expiration date in six months. This option gives you the opportunity to buy that stock at £40 in six months. To buy this option now will cost a minimum of £5 (the difference between the current stock price and the option strike price). But there is also a premium to be paid as well, which is dependent on the amount of time the stock price has to grow and how volatile it is. The longer the time period until expiration, and the more volatile the stock price, the higher the premium for the option will be. The problem is, given the six month period before the option can be exercised, how to precisely price the possible variation in the stock price?

This is the essence of the problem that the Black-Scholes-Merton (BSM) equation solved. Prior to their 1973 publishing of the Black-Scholes (and later, Merton) equation, the problem was resolved using rough rules of thumb on the basis of past experience. It was generally acknowledged that the longer until the expiration date and the higher the current interest rates, the more the option would cost for buyers.<sup>29</sup> There was little theoretical backing for this, and no precise equation for determining the prices, with the result being that options pricing was often affected by personal relations as well as by profit considerations. “Each person set his own fair price.”<sup>30</sup>

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<sup>28</sup> For an extensive overview and critique of the random walk and related ideas, see: Fox, *The Myth of the Rational Market: A History of Risk, Reward, and Delusion on Wall Street*.

<sup>29</sup> Bernstein, *Capital Ideas: The Improbable Origins of Modern Wall Street*, 206; MacKenzie and Millo, “Constructing a Market, Performing Theory: The Historical Sociology of a Financial Derivatives Exchange,” 123.

<sup>30</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 144.

It was in this context that Black, Scholes and Merton made their revolutionary contribution. Since the immediate precursors for the BSM equation have been well covered in other works, the story will be taken up at its crucial juncture: the BSM equation itself.<sup>31</sup>

### *Black-Scholes-Merton*

In contrast to previous pricing practices, the BSM equation provided a clear and standardised means to price options. It does so by, counter-intuitively, abstracting from the particularities of the underlying asset and instead relying on inputting only a few variables: the risk-free interest rate, the volatility of the asset, the current asset price, and the time until expiration (see the Appendix for the precise equation). The risk-free interest rate is simple enough to calculate and the underlying's price and the time until expiration are immediately given quantities. As we will see, however, it is the unobservable volatility variable which has plagued option pricing models. The BSM model nevertheless stands as the foundations for all subsequent models. It is, as Donald MacKenzie notes, akin to a Kuhnian paradigm within the financial world – while it has been surpassed in the details by more advanced models, the basic approach that it takes to pricing options is fundamental for the models we will examine shortly.<sup>32</sup> Therefore, it is essential to grasp its conceptual implications before moving on.

Black and Scholes argument relied on the conjunction of two previous advances. The first was initially formulated by a French mathematician, Louis Bachelier, in his 1900 PhD thesis.<sup>33</sup> Bachelier's work argued that changes in stock growth could be modelled with arithmetic Brownian motion – effectively, that at each time period, stock prices would follow the EMH's random walk and grow (or contract) randomly according to a normal Gaussian probability distribution.

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<sup>31</sup> For this earlier history, see: Fox, *The Myth of the Rational Market: A History of Risk, Reward, and Delusion on Wall Street*; Bernstein, *Capital Ideas: The Improbable Origins of Modern Wall Street*; MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets*.

<sup>32</sup> MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets*, 139.

<sup>33</sup> Bachelier, "Theory of Speculation". While Bachelier is an important figure in the history of option pricing, there are even earlier predecessors such as Jules Regnault's 1863 attempt at applying probability calculus to price movements, and Henri Lefevre's 1874 use of geometric modelling for price movements. (Preda, *Framing Finance: The Boundaries of Markets and Modern Capitalism*, 97-105.)



However, the use of the normal distribution made it theoretically possible that a stock price could become negative, which is an empirical impossibility. So in 1960 Case Sprenkle revised the work to model stock prices according to geometric Brownian motion, which follows a log-normal probability distribution instead (see Figure 10).<sup>34</sup> This modelling of stock growth volatility made it possible to estimate the probable future values of a given stock – crucial for understanding what the value of an option based on that value should be.

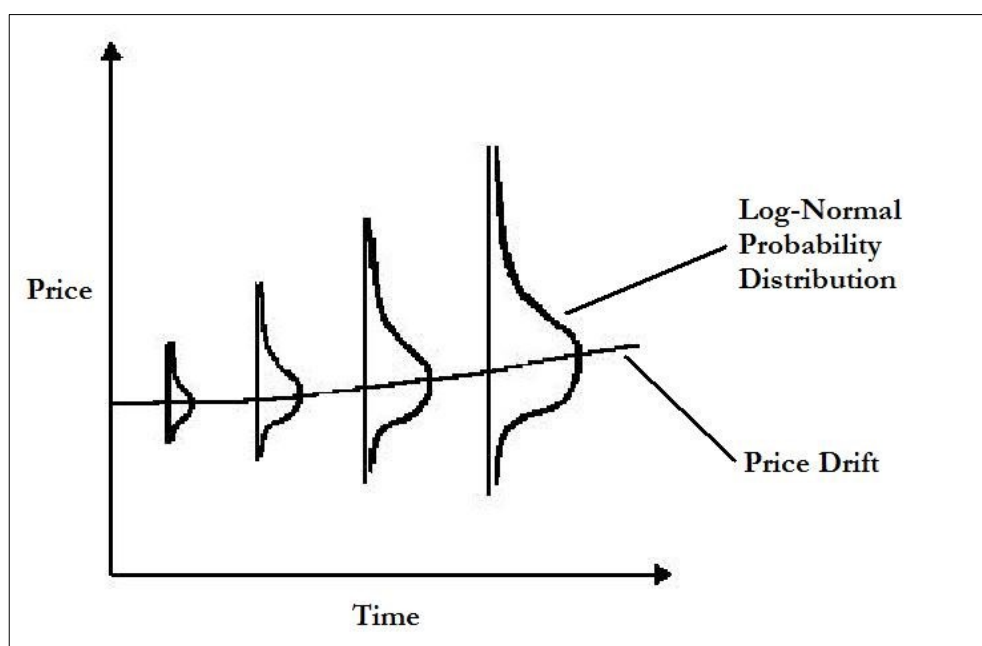


Figure 10: Log-normal probability distributions

The second advance upon which Black and Scholes relied was the capital asset pricing model (CAPM). In essence, CAPM provides a quantification of how risk should be valued – it gave a precise definition to the sense that more risky assets should have higher returns in order for investors to be interested in them. Risk, moreover, was a relative concept and not an absolute measure. Since some risk can be diversified away, this risk has no premium. What cannot be diversified away, however, is the riskiness of the entire market itself.<sup>35</sup> Thus the riskiness of a particular stock was dependent on how correlated it was with the entire market. Stocks that are uncorrelated with the market can have their risk diversified away;

<sup>34</sup> Sprenkle, “Warrant Prices as Indicators of Expectations and Preferences.”

<sup>35</sup> MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets*, 129.

stocks that are heavily correlated cannot and thus require higher returns by investors (the level of correlation came to be symbolised by the Greek letter ‘beta’). CAPM also allowed for an arbitrage argument to be made about risk – stocks with the same beta must have the same expected return otherwise they could be arbitrated to make a risk-free profit (an act which would itself eventually eliminate the discrepancy).

The essence of the Black-Scholes argument relied on these consequences of CAPM. They argued first that the price of an option can be equated through comparison with an equivalent entity – a ‘replicating portfolio’ consisting of various stocks, bonds, cash (and/or more liquid options). The European vanilla options that Black-Scholes originally examine can be dynamically hedged through time by buying or selling the appropriate ratio of stocks.<sup>36</sup> The resulting portfolio has zero beta, meaning all of its risk can be diversified away according to CAPM. In this case, the returns on the entire hedged portfolio are known in advance – since it is perfectly hedged, it is riskless, and must therefore provide the risk free rate of interest.<sup>37,38</sup> Therefore, the option, plus its replicating portfolio, must provide a risk-free rate of interest (see Figure 11). This is the basic conceptual argument that leads to the BSM equation. Setting this known rate of return against the changes in the value of the hedged position ultimately provides Black and Scholes with a partial differential equation (PDE)<sup>39</sup> that models how the price of the option varies over time and with changes in the stock price (see the Appendix). Once this general equation is established, setting the boundary conditions<sup>40</sup> allows for the PDE to be

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<sup>36</sup> This ratio is known as ‘delta’ and is symbolized by  $\partial V/\partial S$ . It is the sensitivity of the option’s price to changes in the underlying’s price.

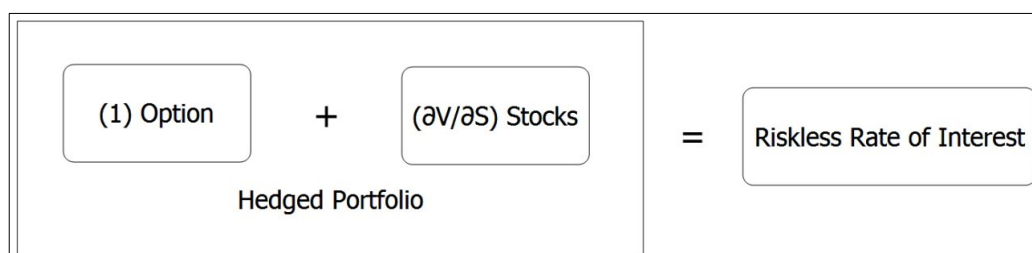
<sup>37</sup> Black and Scholes, “The Pricing of Options and Corporate Liabilities,” 641–643.

<sup>38</sup> The risk-free rate of interest is often taken to be either the rate of interest on US Treasury bonds, or the London Interbank Offered Rate (LIBOR). The importance of this rate for pricing options reveals a major reason why rate changes are followed with such attention in the financial world. For a fascinating sociological study on how the LIBOR is set, see: MacKenzie, *Material Markets: How Economic Agents Are Constructed*, 78–83.

<sup>39</sup> It is a ‘partial’ differential equation because it models the rate of change for three variables, which must be solved while holding one variable the same over time.

<sup>40</sup> The ‘boundary conditions’ are the limits on the function. For instance, if the strike price of a call option is higher than the stock price at the date of maturity, then the option is worth zero. Otherwise, at maturity the option is worth the strike price minus the stock price.

solved as the option pricing formula for calls or puts – that is to say, what has now become the famous Black-Scholes formula.<sup>41</sup>



*Figure 11: The Black-Scholes conceptual argument*

What is particularly notable about the final equation is what it does not include. It does not take into account the expected return on the stock, individual investor preferences for risk, information on the individual stock itself, or information about supply and demand for the option or for the stock.<sup>42</sup> None of these elements play a role in determining the price of an option. Instead, it is the short-term interest rate (a known value), the stock price (a known value), the exercise price (a known value), the time to maturity (a known value), and the volatility of the stock's growth (an assumed value), that provide the components for pricing.

Black and Scholes innovation was to provide a standardised pricing formula for options, based upon a relatively simple argument that employed CAPM's conclusions about diversification. Simply put, since the hedged portfolio is riskless, it must provide the risk-free rate of interest. Yet while Black and Scholes showed what the price must be, it took Robert Merton to show how to achieve a perfectly hedged position – it is his contributions which have made the equation known by the Black-Scholes-Merton name.<sup>43</sup>

Merton's advances were twofold: first, to provide a more general argument than Black and Scholes had provided (one not based upon CAPM assumptions). Second, and related, Merton transitioned from a discrete-time equation to a

<sup>41</sup> Black and Scholes, "The Pricing of Options and Corporate Liabilities," 644.

<sup>42</sup> In practice, however, options are determined partially by supply and demand. (Haug, "Option Pricing and Hedging from Theory to Practice," 57.)

<sup>43</sup> Merton, "Theory of Rational Option Pricing."

continuous-time equation. This latter shift involved a move from standard calculus to stochastic calculus, arguably inaugurating the true mathematisation of modern finance. Using the continuous-time model, Merton was able to develop truly dynamic hedging – where hedging occurs at every instant – and this made it possible that “you could get rid of the risk, but not just the systematic risk, all the risk.”<sup>44</sup> Thus, Black and Scholes were right that the hedged portfolio returned the riskless rate of interest – but in Merton’s work this was because of continuous hedging and not because of CAPM. As we will see later, one of the most important consequences of Merton’s derivation of the BSM equation was to introduce the idea of continuous dynamic hedging into finance.

#### *Inverting BSM and the Volatility Surface*

The BSM equation was and is a paradigmatic success, and arguably the most important contribution of quantitative finance. As Donald MacKenzie has demonstrated, BSM had performative effects on option pricing and eventually brought market prices in line with theoretical prices.<sup>45</sup> At this stage, BSM operated as a representational technology that produced knowledge of option prices – though a representational technology that also shaped the empirical referent in conformity with the representation. Yet October 1987 inaugurated the emergence of a phenomenon that dramatically changed the way in which the assumptions of the model were conceived.<sup>46</sup> This month saw the biggest one-day stock market drop ever, with the Dow Jones Industrial Average crashing 22.6% on 19 October. Since then, options prices began to systematically diverge from the theoretical prices constructed by BSM. This was the emergence of the ‘volatility smile’ (or skew) which became evident when traders realised that the market prices were consistently deviating from the model’s proposed prices. What was according to

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<sup>44</sup> MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets*, 136.

<sup>45</sup> *Ibid.*, 174–177.

<sup>46</sup> The options trader Elie Ayache notes that in fact the volatility surface could be seen to emerge a few months before October 1987, when traders started to ask about the prices of deep out-of-the-money puts. BSM models produced a price of zero when these were input, yet this was nonsensical. The result was that these options were given a minimal price of one cent, thereby implicitly introducing the volatility smile. (Ayache, *The Blank Swan: The End of Probability*, 355.)

BSM an apparently risk-free arbitrage opportunity that should be quickly eliminated, instead persisted. Rather than BSM being an idealised attractor around which market prices could fluctuate, BSM had now become a model that systematically mispriced options.

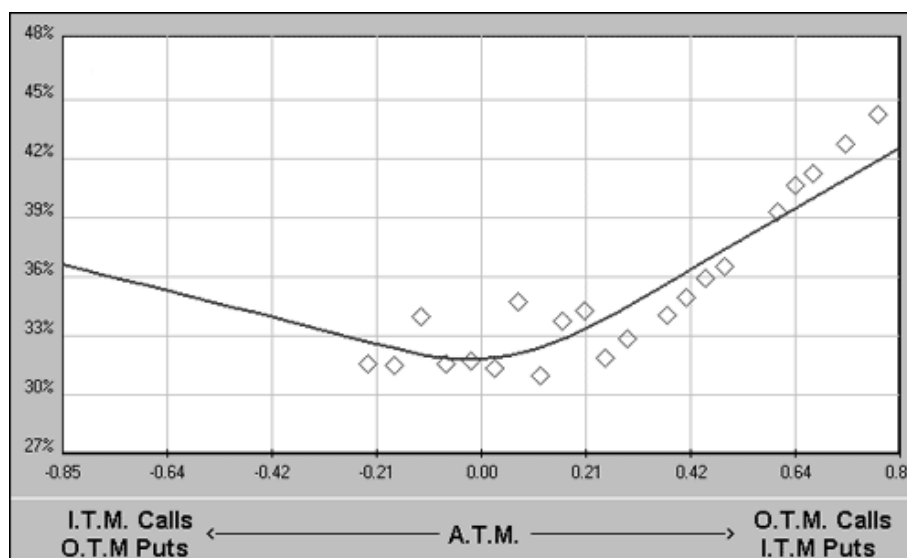


Figure 12: The volatility smile

The essence of the shift was from the assumed constant volatility parameter in the BSM model to the non-constant volatility of the market. In Figure 12, the distinctive shape which gives the volatility smile its name is clearly visible. The diagram shows the variation of the volatility implied by the market prices for options (on the vertical axis) with the strike price of the option (the horizontal axis). As strike prices get further away from the current stock price ('at-the-money', or ATM), the implied volatility rises. In the standard BSM model, this line should be straight across – volatility should not vary with strike price. What was occurring in the markets was that options which the model deemed to be highly unlikely to be exercised (options with strike prices far from the current stock price, i.e. far 'out-of-the-money', or OTM) because of the unlikelihood of the stock price reaching this point, were in fact being valued in the market at a significantly higher price than expected. Fundamentally, the market price was taking into account the possibility of statistically "impossible" situations like the October 1987 crash. If such extreme events occurred more than the model assumed, then the likelihood

of exercising such far-OTM options was higher than assumed, and therefore their value was higher than estimated.

Taken together, the volatility smile and the term structure of volatility comprise the ‘volatility surface’: a three-dimensional surface that plots how volatility varies with both the maturity of the option and with the strike price of the option (see Figure 13). Each particular market has its own unique and dynamic volatility surface. The particular shape of the surface in any given asset class depends on the historical volatility of the asset – indexes, for instance, tend to drop greater percentages than they gain, and so the smile is skewed towards that end. By contrast, individual stocks and foreign exchange are more symmetric and therefore the smile is more balanced.<sup>47</sup>

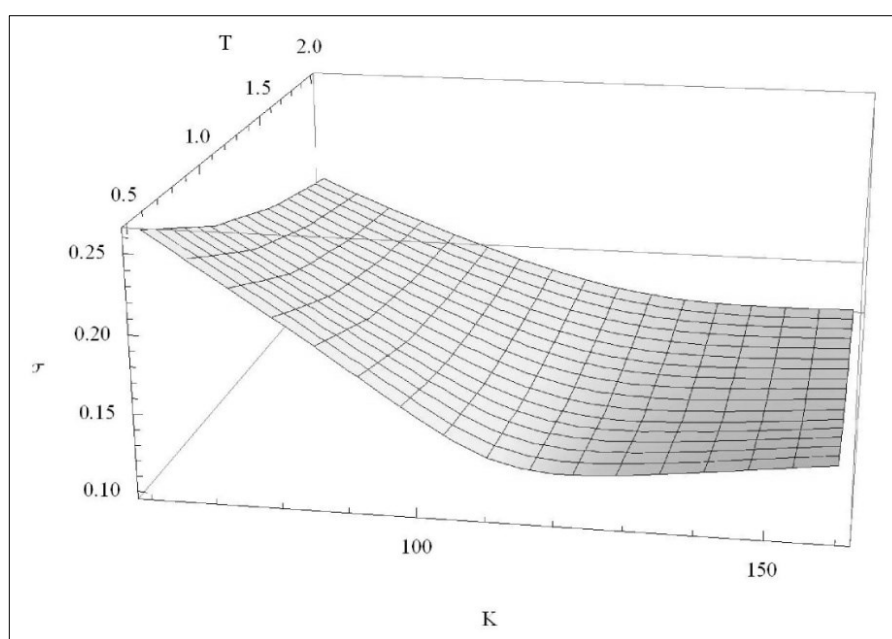


Figure 13: The volatility surface

With these complications in the volatility surface, traders have moved away from the intended use of BSM to price derivatives, and have instead taken to using the representational technology in a radically different way. Rather than derive a theoretical price, traders gradually began to use the equations to derive the ‘implied volatility’. That is to say, given the market price, what level of volatility will solve the BSM equation? The reasons for this shift were twofold: first, since the volatility

<sup>47</sup> Derman, “Laughter in the Dark: The Problem of the Volatility Smile.”

variable was unobservable, traders used the market prices for liquid options to generate the appropriate volatility for the option pricing model. They could then input this derived constant back into the equation and extrapolate from liquid prices in order to price more illiquid options. The second reason for the shift was the conceptual simplification that volatility brought about. As a theoretically produced entity, volatility managed to act as a common denominator behind the multiplicity of derivatives, strikes, maturities, and sectors. Quoting derivatives in terms of volatility rather than price allows traders to quickly determine whether a derivative is mispriced and how it may be used to hedge their own position. Volatility quickly became the language of traders. As MacKenzie relates,

“Gradually, what was being bought and sold in an options market was re-conceptualised: it was the Black-Scholes-Merton model’s free parameter, *volatility*. If stock volatility increased, options became more valuable; if it decreased, they became cheaper.”<sup>48</sup>

While money has been conceptualised by Marx as a general equivalent that manages to bring together otherwise heterogeneous commodities, with implied volatility we find an even more abstract general equivalent. Price, for derivatives traders, was still too relative to time (i.e. maturity) and possibility (i.e. strike price). What was needed was an abstract equivalent that could make comparisons between price, time, and possibility. Implied volatility came to serve this purpose.

The significance of this is the re-purposing of the BSM technology that it brought about. BSM was no longer a simple tool to construct a price, but instead a representational technology to filter out the massive amount of information contained within the market in order to infer the market’s collective expectation of future volatility. This was, properly speaking, a complete inversion of the original BSM model. BSM was meant to price options, not to imply volatilities from market prices. What we see here is an important instance of a technology creating new and unintended capacities through its very existence. This inversion shows definitively

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<sup>48</sup> MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets*, 168.

why BSM was not merely an extension of existing capacities – it was the unintentional creation of entirely new capacities that augmented previous practices.

Thus in practice, when trading on the basis of implied volatility, traders would analyse the market's pricing of implied volatility against the theoretical price presented by BSM (or some other functionally similar model). Comparisons can then be made across similar derivatives<sup>49</sup> – for instance, if one has a lower volatility than the other then there may be an arbitrage opportunity.

However, in implying volatility there are a number of complications involved. In the first place, oftentimes the pricing equations cannot be analytically inverted and must instead be numerically calculated.<sup>50,51</sup> In other words, the equations are not as simple to solve for a variable as something like ' $A+B=C$ , therefore  $B=C-A$ ', making numerical calculation a computation-heavy method. In addition, there are multiple ways to derive the level of implied volatility: using either a weighted approach over the different strikes and maturities, or a minimised-square pricing error approach, or simply selecting a single option that will represent the implied volatility to be used.<sup>52</sup>

The volatility surface adds further challenges to the practice of implying volatility. Most significantly, implied volatility is no longer set against a theoretical volatility, but rather against statistical (historical) volatility. If implied volatility is greater than the recent historical volatility, the option is often considered to be overvalued. Option pricing software, such as OptionVue, can immediately present this material together on one screen (see Figure 14). Yet it is not as simple as matching up a given volatility against historical or expected volatility. In addition to the earlier difficulties with implying volatility, the use of historical volatility adds another impediment. In order to compare it with implied volatility, historical

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<sup>49</sup> The process of determining which derivatives are similar enough to be subject to arbitrage (e.g. the companies may be from the same industry) is itself a product of a specialized socio-technical arrangement. See: Beunza and Stark, "How to Recognize Opportunities: Heterarchical Search in a Trading Room"; MacKenzie, Beunza, and Hardie, "The Material Sociology of Arbitrage."

<sup>50</sup> Mayhew, "Implied Volatility," 8.

<sup>51</sup> This is achieved by "by iterating the BSM analytical formula in a root-finding routine." (Ayache, Elie. Personal communication, 4 May 2011.)

<sup>52</sup> Mayhew, "Implied Volatility," 9-10.



volatility requires selecting a sample size that is representative – which raises questions of how far back in time, which maturities and strikes are included, etc. Complications like this are resolved in large part through a function of experience and context, further demonstrating that representational technologies are always situated in a specific cognitive assemblage.

Even the market prices one employs are not as simple as they may seem:

“What one thinks of as ‘market data’ are often prices filtered through another model or calculation. Yields are extracted from collections of bond prices. Volatility is calculated from historical returns. Each year, as markets mature, products become more liquid and traders calibrate their quotes to greater numbers of related securities, sometimes so many that their prices must be obtained via electronic price feeds. All of this involves software.”<sup>53</sup>

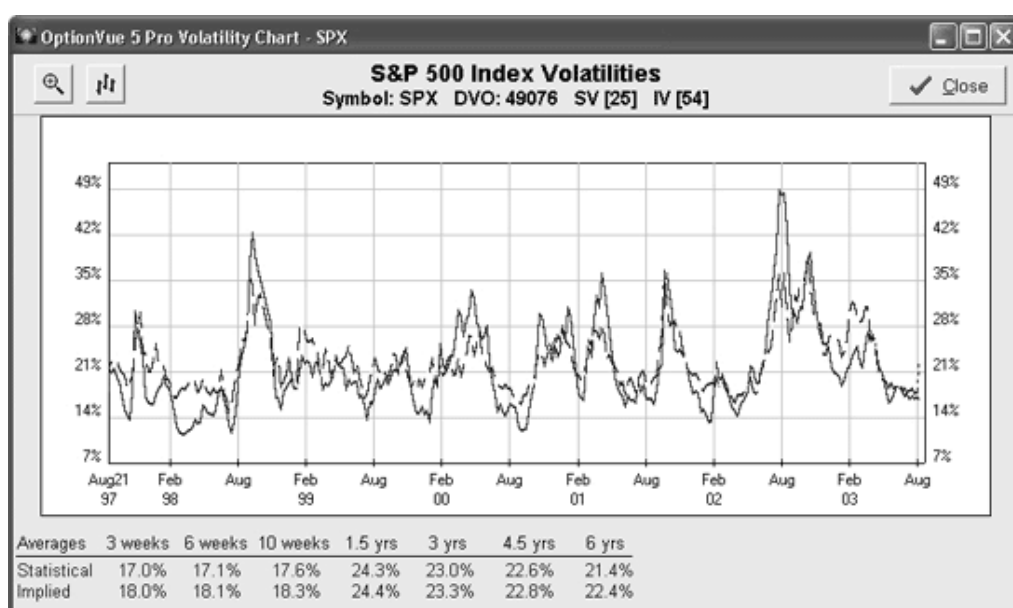


Figure 14: OptionVue – statistical vs. implied volatility

In the Chicago Board Options Exchange (CBOE), this model-dependency of derivatives prices has even been embodied in the exchange’s autoquote system. This system functions as a universal provision of quotes for all the listed options,

<sup>53</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 165.

which are then distributed to the CBOE's trading floor and around the world.<sup>54</sup> As with all options, these market prices are generated on the basis of a particular model, in this case the Cox-Ross-Rubinstein model (which will be examined briefly later). Further complicating the picture, while CBOE provides a public autoquote system, individual traders can and do employ proprietary quoting systems to gain an edge over the competition.<sup>55</sup> The end result of this is that, quite literally, market prices do not exist without option pricing models.

In addition to these difficulties, the use of BSM to imply volatility surfaces also entails a practical contradiction insofar as BSM assumes a constant volatility while the market presents non-constant volatilities. Implied volatility could still be *quoted* and used as an abstract measure, via BSM. However, using BSM to *price* options on the basis of more liquid securities is impossible if the model cannot even reproduce the existing market prices.<sup>56</sup> Even prior to the volatility surface, BSM was incapable of pricing products like American put options.<sup>57</sup> Clearly something new was necessary.

The next section will examine how this transformation of volatility generated a proliferation of competing representational technologies, but with the technicalities of implying volatility covered it is worth stepping back and explicitly resituating the argument in the context of the overall thesis. The idea implicit within the act of implying volatility is that *the prices of options contain within them a wealth of information that is only accessible via the use of specialised technology*. To be sure, the idea that prices are the aggregate of all information on a particular product is a commonplace in economics (see the earlier discussion of EMH). Yet what is occurring in derivatives valuation is an unbinding of that aggregate and the selection of only a portion of that information. The technologies of derivative valuation are in this sense a means to extract and make perceptible an aspect otherwise hidden within price dynamics – an aspect which suggests the future expectations of volatility and risk, as well as an aspect that can then be used

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<sup>54</sup> MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets*, 201.

<sup>55</sup> *Order Granting Approval to Proposed Rule Change Relating to DPM Obligations for Maintaining Backup Autoquote Systems*.

<sup>56</sup> Derman and Kani, *The Volatility Smile and Its Implied Tree*, 3.

<sup>57</sup> Durbin, *All About Derivatives, Second Edition*, 172.

to leverage larger trades through hedging. In this regard, derivatives valuation technology is not merely an extension of existing human capacities, but instead a proper augmentation of them. It makes something visible which is otherwise invisible to the isolated human mind. It transforms volatility from an imperceptible medium into a perceptible representation. As will be shown in the next section, the role of volatility was only going to become more essential.

### **A History of Option Pricing Models**

As a result of BSM's failings, the technological developments in quantitative finance have been generating models that have more complex representations of underlying price changes. The general problem is well understood – BSM volatility no longer matches up to market volatility – yet there are different interpretations of how this problem should be resolved. This has led to a proliferation of different approaches, and a proliferation of new models.<sup>58</sup> The construction of these new representational technologies has been essential to the everyday trading of the dealers and market makers that perform global finance. Without it, actors are incapable of determining a rational price and incapable of determining the proper hedging position. In other words, without financial models, risk (e.g. credit risk, delta risk, market risk, etc.) increases and the dynamics of the market shift.

As a means of coping with the spread of the volatility smile, many firms now have different trading desks (dealing with different asset classes) and the overall risk management team, all creating models to grapple with volatility.<sup>59</sup> The massive proliferation is in part an attempt to create proprietary models that give an edge over the competition. Yet despite the proliferation, the basic premises of derivatives pricing contained within the BSM framework have been maintained as they spread not only through geographical space, but also through theoretical space in terms of different underliers.

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<sup>58</sup> It is worth noting that unlike many technological innovations, development in pricing models has often been created within heavily institutional frameworks rather than outside of the establishment. (Bijker, Hughes, and Pinch, "Introduction," 13). Many models came from the research wings of the largest financial institutions, such as Goldman Sachs or Barclays Global Investors which has a research department of over one hundred people. (Bernstein, *Capital Ideas Evolving*, 139.)

<sup>59</sup> Derman, "Laughter in the Dark: The Problem of the Volatility Smile," 4.

Like the representational technologies examined in other chapters, the development of pricing technologies has been channelled by the material nature of the technologies. The pure abstractions of mathematical finance have had to face up to the material constraints and possibilities of the real world – often finding itself expressed as a tension between the speed necessary to trade in the market, and the sophistication of the volatility variable, all while remaining bound within the conceptual framework established by BSM. In the early days of financial modelling, computers were massively limited by memory constraints and computing power. The result was anaemic user interfaces that functioned within the restrictions imposed by the state of computer technology, but at a major loss of efficiency. Derman relates his experience of first working in finance:

“Each time a salesperson needed to value an option for a potential trade with a client, he or she had to type in, on one line after another, the bond’s current price, maturity, and coupon as well as the option’s expiration and strike; then the salesperson had to enter the current short-term interest rate and the bond’s assumed future yield volatility. One more tap on the return key and the program computer the model’s theoretical price and told you how to hedge it with the underlying Treasury bond. If you wanted to compute the option value for a variety of volatilities, expirations or strikes, you had to repeat the same sequence, entering items and hitting keys all over again.”<sup>60</sup>

In an industry premised upon speed and efficiency (particularly to grasp fleeting arbitrage opportunities), such tedious routines were a major hindrance to the adoption of models. The result was that one of the first areas to be developed in quantitative finance was proprietary trading systems that simplified the interface. Today, the production of software (either as components, or entire trading systems)

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<sup>60</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 134.

is a major industry within the financial world, and essential to the smooth operations of global finance.<sup>61</sup>

Yet computational frictions still exist today, to the point where sometimes even the inventors of complex models may avoid them and rely instead on simpler models.<sup>62</sup> The complexity of some models simply outstrips their usefulness in practice. Such a rationale is only intelligible within a framework where models are not aiming at realistic dynamics (and more complex models), but instead where models are used to *do* things. In being used to accomplish new practical capacities, models must face up to the concrete realities involved in their implementation. The attempts to resolve these frictions have come to focus upon a few basic areas of research and innovation. First, there are those which make volatility itself a stochastic (i.e. ‘volatile’) variable. Second, there are those which make volatility subject to ‘jumps’ in the asset price. There are also combinations of these, along with more advanced models which will be briefly covered.

#### *Constant Volatility*

From their beginnings, option pricing models faced up to computational and data frictions, and much of their development has been guided by attempts to overcome these frictions while maintaining the usability of the technology. The publication of the BSM model occurred only a month after the opening of the Chicago Board Options Exchange (CBOE) – the first exchange devoted to trading options on leading stocks. The BSM model quickly spread within traders involved in the CBOE and soon became the industry standard.<sup>63</sup> The famous investor Edward Thorp had even programmed his own options pricing formula into a handheld calculator prior to the opening of the CBOE – a formula that he admitted was largely similar to Black-Scholes equation.<sup>64</sup> Within six months of the equation being published, Texas Instruments had created and begun marketing a handheld

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<sup>61</sup> Ayache, *The Blank Swan: The End of Probability*, 173.

<sup>62</sup> Wilmott, *Frequently Asked Questions in Quantitative Finance, Second Edition*, 250–251.

<sup>63</sup> Das, *Traders, Guns & Money: Knowns and Unknowns in the Dazzling World of Derivatives*, 195.

<sup>64</sup> Thorp, “On Gambling and Trading,” 28.

calculator pre-programmed with the BSM equations.<sup>65</sup> As Merton recalls, “Such a complete and rapid adoption of finance theory into finance practice was unprecedented.”<sup>66</sup> The desire to spread the material embodiments of BSM was clearly a force in the early stages of the CBOE.

Yet in the beginning the equations remained too difficult and computationally intensive – computers at the time were too cumbersome to bring on the trading floor and even calculators with algorithms pre-programmed took too long to be useful.<sup>67</sup> Sheets of prices (introduced by Black in 1975) became the initial way in which the equation entered into trading pits – effectively constructing a distributed cognitive system in action.<sup>68</sup> The advancement of computer technology overtook these initial constraints, to the point where by the 1980s financial models were being taken up in practice as soon as they could be created.<sup>69</sup> This rapid uptake of new models demonstrates clearly how central they were to the practices of financial firms. The 1980s also saw the point where computing technology finally allowed nearly real-time prices and hedging ratios, allowing the technology to become a seamless component in trading routines.<sup>70</sup>

In the context of these computing developments, an important advance in constant volatility models was made by John Cox, Stephen Ross and Mark Rubinstein.<sup>71</sup> It was particularly an improvement on BSM by virtue of being more easily implemented on a computer, and for allowing the possibility of numerically solving the equations with relative ease.<sup>72</sup> It was applicable to stocks which paid dividends and to American options as well, rather than just the European calls and puts that BSM had quantified. Eschewing the advanced mathematics used by Black and Scholes, and Merton, the Cox-Ross-Rubinstein model also presented the basic valuation approach in a manner easily understandable by traders without a

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<sup>65</sup> Bernstein, *Capital Ideas: The Improbable Origins of Modern Wall Street*, 227.

<sup>66</sup> Merton, “Influence of Mathematical Models in Finance on Practice: Past, Present and Future,” 454.

<sup>67</sup> MacKenzie and Millo, “Constructing a Market, Performing Theory: The Historical Sociology of a Financial Derivatives Exchange,” 124.

<sup>68</sup> MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets*, 160-162.

<sup>69</sup> Merton, “Influence of Mathematical Models in Finance on Practice: Past, Present and Future,” 455.

<sup>70</sup> *Ibid.*, 456.

<sup>71</sup> Cox, Ross, and Rubinstein, “Option Pricing: A Simplified Approach.”

<sup>72</sup> *Ibid.*, 230.

mathematical background.<sup>73</sup> J. Michael Harrison and David Kreps went on to turn BSM into a more general theorem<sup>74</sup> – they developed a pricing equation for any option or other derivative on an underlying. They also introduced ‘martingale theory’ which helped further bridge the mathematics realm with the finance realm, setting the stage for implementing financial models deeper into computer software.<sup>75,76</sup>

Yet despite the technological advances made, the constant volatility assumptions limited the flexibility of their use in certain situations. Under particular circumstances, these models would systematically produce incorrect prices and incorrect implied volatilities. As a result, modellers turned towards relaxing the constant volatility assumption.

### *Stochastic Volatility*

The first generation of post-volatility smile models loosened the restrictions on volatility by attempting to directly model the volatile nature of volatility. With stochastic volatility (SV) models, volatility itself was largely unbound from its assumption of constancy. Volatility instead followed a random-walk pattern: the volatility of volatility. In particular models other factors enter into determining the path as well, such as stock price variations (itself stochastic), and the tendency of volatility to revert to a mean. Yet the essence of these models is the parameter designated for the volatility of volatility itself. The reversion to a mean factor is notable, however, in that it entails these models have implications for the *dynamics* of the volatility surface, and how it is likely to evolve given current prices.

Crucial to using these models is the necessity of calibrating the parameters of the model to the prices of the market. The problem of calibration is a ubiquitous one in option pricing – ranging from setting the parameters for one variable (e.g. volatility in BSM) to setting tens of parameters (e.g. interest-rate

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<sup>73</sup> Ibid.

<sup>74</sup> Harrison and Kreps, “Martingales and Arbitrage in Multiperiod Securities Markets.”

<sup>75</sup> Martingale theory is the mathematical theory of ‘fair games’ – that is to say, games in which you are as equally likely to win as you are to lose. The application of this to financial markets is premised on the efficient markets hypothesis idea that the markets cannot be consistently beaten.

<sup>76</sup> MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets*, 141.

models).<sup>77,78</sup> As with climate change models, financial models do not admit of clear answers to what parameters should be set at. Model calibration in finance is often done against relatively liquid securities – their prices are used to orient the model (this is ideally done against stocks, bonds *and* options, thereby providing the most thorough calibration). It is a matter of making sure the model(s) reproduce the existing market prices for the more liquid securities. These liquid products have clear markets, and they can then be used to calculate prices for more illiquid securities. Since the market determines the base level from which other options are priced, this entails a constant re-calibration of the models as well.<sup>79</sup> A problem with calibration, though, is that while it produces a converging (i.e. non-arbitrage) price for the liquid securities (this is the essence of calibration), it necessarily produces diverging prices for the more illiquid options. The different parameters of different models produce different outcomes of the pricing process.<sup>80</sup> Each model has a different means of calculating a price, and while the models can be calibrated to all produce the same price for liquid securities, once calibrated they will all be extrapolated to produce different prices for illiquid securities because of their different calculations. In addition, as with climate change models, calibration error can occur here and mistakes can be made in estimating the proper parameters.<sup>81</sup> In part, this is why practitioners will sometimes use several models simultaneously to price derivatives – this helps to narrow down the range of acceptable values and highlight any blatant calibration errors. In using different models, though, some are too difficult to calibrate, making them again impractical for everyday use. They simply contain too many parameters to fit to the existing data. The problems with

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<sup>77</sup> Wilmott, *Frequently Asked Questions in Quantitative Finance, Second Edition*, 204.

<sup>78</sup> There have recently been developments in non-parametric models as well. Rather than having preset parameter variables for the price dynamics of the underlying asset (e.g. lognormal diffusion, volatility and drift), these models try to directly derive the price dynamics from representative data. Since these models stand outside the work here and require much more complex mathematics than can be elaborated in this space, they will be left aside. The interested reader can find more information here: Campbell, Lo, and MacKinlay, *The Econometrics of Financial Markets*, 498–523.

<sup>79</sup> Elie Ayache's book *The Blank Swan* is a philosophical elaboration of this and other points, which argues that despite the most advanced use of probability mathematics and stochastic calculus, the very idea of probability remains incommensurable with what he calls 'contingency'.

<sup>80</sup> Ayache, "Can Anyone Solve the Smile Problem? A Post-Scriptum," 11.

<sup>81</sup> For a discussion of various estimating methods and their intrinsic capacities for error, see: Campbell, Lo, and MacKinlay, *The Econometrics of Financial Markets*, 356–369.



calibration are compounded by the fact that calibration has different uses when used by different users. For market makers, an accurate calibration is important since their profit derives from the spread in bid and ask offers. For proprietary traders, on the other hand, their profit derives from discovering mispriced securities – something which is impossible to do if the model is calibrated to simply return existing market prices.<sup>82</sup> While calibration is therefore a ubiquitous data friction for this representational technology, with stochastic volatility models this calibration process tends to be particularly computationally complex and difficult to fit to market prices.<sup>83</sup> This hindrance is one of the primary reasons more simple (though less realistic) models have arisen.

The Heston SV model has nevertheless garnered popularity in practice through its ability to overcome computational frictions. While other stochastic models have more accurate representations of the diffusion process, it is the Heston model which first established a ‘quasi-closed-form’ solution to its equation.<sup>84</sup> By contrast to equations that require numerical solutions, a closed form analytic solution is a very straightforward procedure that requires little computational power. “An analytical solution is one in which you plug factors into a function and get a result.”<sup>85</sup> Equations that need numerical solutions do not admit of such a straightforward method of solution and instead require a sort of brute-force approach to solving them. As a result, they are much more computationally-intensive and much slower to process. Solutions to these equations involve a variety of methods, such as binomial and trinomial trees, finite difference or Monte Carlo methods. Despite their differences, each involves working through a variety of solutions, and using trial-and-error to approach an approximate solution. In the high-speed world of financial trading these computationally-intensive solutions make some models impractical, since they provide a valuation far too slowly to be actionable. The alternative solution is to use closed-form solutions only, but this can produce mispricings of options

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<sup>82</sup> Carr, “The Wall Street Wizard of Option Symmetry and Volatility,” 123.

<sup>83</sup> Gatheral, *The Volatility Surface: A Practitioner’s Guide*, 7-8.

<sup>84</sup> Heston, “A Closed-Form Solution for Options with Stochastic Volatility with Applications to Bond and Currency Options.”

<sup>85</sup> Durbin, *All About Derivatives, Second Edition*, 172.

too.<sup>86</sup> As a result, there's a delicate balance between the two mathematical choices. With the Heston model producing a quasi-closed-form solution, the result was that while other models were "computationally expensive" to achieve a solution, the Heston model provided the crucial speed necessary for becoming an operative model.<sup>87</sup>

While SV models are theoretically elegant in their more accurate representations of volatility, their material embodiment has produced a number of frictions. First, they remained computationally intensive, though as we saw the Heston model partly resolved this and has become a popular choice as a result. Second, their calibration to present market prices proved to be difficult and time-consuming.<sup>88</sup> They also relied on a number of factors affecting the volatility of volatility, most of which were difficult to estimate accurately.<sup>89</sup> Some models even have parameters that remain the same over time, meaning they cannot be calibrated to market prices for options near expiration.<sup>90</sup> Perhaps most worryingly for traders, stochastic volatility tends to make hedging positions increasingly difficult to accomplish, thus introducing new sources of risk and exposure to large market changes.<sup>91</sup>

### *Local Volatility*

In an attempt to move beyond these material frictions, the next generation of models set itself a more modest goal. Rather than re-think the entire diffusion process (the volatility of volatility), local volatility models attempted to derive the market's volatility from the market prices, in a sort of ad hoc manner. A number of models were developed along these lines, with Emanuel Derman and Iraj Kani formulating the most concise and clear version.<sup>92</sup> All these models share the presumption that given the market prices of options, a unique diffusion process

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<sup>86</sup> Shaw, "How I Became a Quant," 233.

<sup>87</sup> Gatheral, *The Volatility Surface: A Practitioner's Guide*, 24.

<sup>88</sup> *Ibid.*, 7.

<sup>89</sup> Derman and Kani, *The Volatility Smile and Its Implied Tree*, 3.

<sup>90</sup> Gatheral, *The Volatility Surface: A Practitioner's Guide*, 39.

<sup>91</sup> Derman, "Laughter in the Dark: The Problem of the Volatility Smile," 10.

<sup>92</sup> Derman and Kani, *The Volatility Smile and Its Implied Tree*; Rubinstein, "Implied Volatility Trees"; Dupire, "Pricing with a Smile."

can be derived that accurately fits the given price distribution. In other words, it is possible – for each maturity date and strike price – to extract and extrapolate the market’s expectation of short-term (local) volatility. This local volatility is the market’s expectation of volatility over a short time-step, rather than over the entire life of an option.<sup>93</sup> Summing these local volatilities together, the visual result is represented as a binomial tree diagram (see Figure 15) with underlying price and option maturity as the axes, and the level of volatility being measured by the shape of the grid. It can be seen in Figure 15 that the implied volatility tree shifts its volatility over time, whereas the constant volatility tree (by definition) maintains the same volatility for every point. The advance made by local volatility models was that they could be used to generate a rational implied volatility for any node in the tree, provided there were three given nodes. Through a process of triangulation, the entire tree could be reverse engineered from the market’s prices and then used to price more illiquid derivatives.<sup>94</sup>

Similar to the way in which the original BSM made possible the rational pricing of options, the new local volatility models also made possible a rational determination of volatility. “From this tree you [could] calculate both the distribution and the volatility of the index at future times and market levels, as implied by options prices.”<sup>95</sup> These local volatility models made possible the capacity to extrapolate from given volatilities in order to generate prices and volatilities for more illiquid securities – and ensuring that they were consistent with each other. In particular, they were crucial for calculating rational prices for barrier options, and static hedges for exotic options.<sup>96</sup> Such derivatives were incapable of being modelled by BSM and could only be priced and hedged through local volatility models.<sup>97</sup> Effectively, these models corrected the hedging strategies and pricing mechanisms that were systematically wrong in the BSM model.

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<sup>93</sup> Rubinstein, “Implied Volatility Trees,” 797.

<sup>94</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 241.

<sup>95</sup> Derman and Kani, *The Volatility Smile and Its Implied Tree*, iv.

<sup>96</sup> *Ibid.*, 15.

<sup>97</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 245.

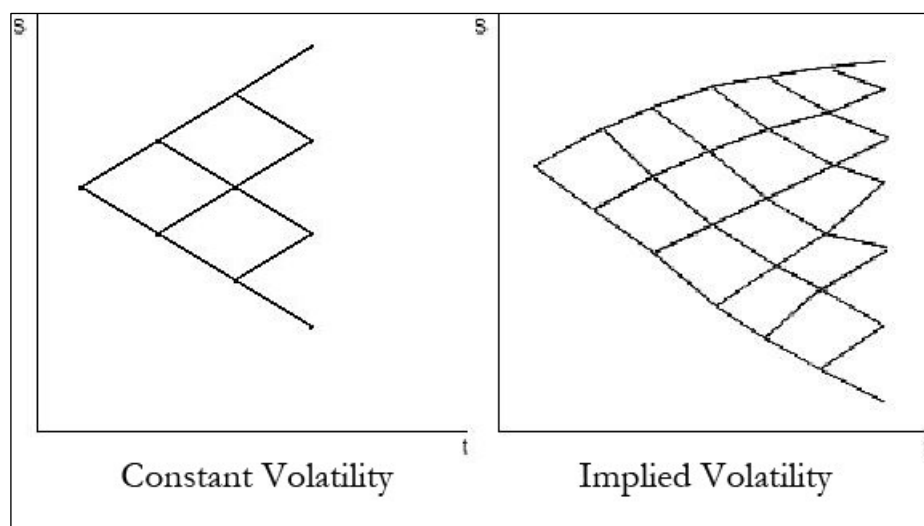


Figure 15: Examples of binomial trees

By taking volatility to fluctuate with the level of the underlying's price, they take volatility to be both stochastic *and* deterministic. The fluctuations in volatility are taken to be a simple function of the underlying's stochastic price volatility. There are no additional sources of volatility beyond this, meaning that while local volatility ends up being stochastic, it is fully determined by the underlying's stochastic process – marking off an essential conceptual difference between local and stochastic volatility models.

Local volatility models ran into data frictions though. Since they generated implied volatility on the basis of a few discrete options, they necessarily left out the implied volatility surface *between* options that were missing from the market (i.e. between strike prices and maturity dates). As with climate change models, local volatility models had to face up to the problem of using discrete parameters to model a continuous phenomenon. The solution was the same as with general circulation models – to use mathematical methods to interpolate the missing data. Yet this is a computationally intensive process and one that could produce disconcerting results.<sup>98</sup> The models were also theoretically unsatisfying. The attempt to derive local volatility from empirical prices, rather than provide a theoretical explanation for the changes in volatility reminded some of the pre-

<sup>98</sup> Derman, “Laughter in the Dark: The Problem of the Volatility Smile,” 8; Derman, *My Life as a Quant: Reflections on Physics and Finance*, 247.

Copernican attempts to add variables to account for celestial movement.<sup>99</sup> Thus while local volatility models served as an intuitive and computationally efficient attempt to incorporate the volatility surface, under certain circumstances they returned mistaken hedge ratios and implied volatilities.

### *Jump Diffusion*

Even with stochastic volatility, new models were incapable of modelling the very short-term smiles involved in actual market pricing. Prices for near-expiration options were significantly higher than the models supposed, and were being valued according to a much larger change in underlying price than could be accounted for by existing probability distributions.<sup>100</sup> What was necessary was to introduce jumps – literally, discontinuities in the price diffusion process – where massive shifts in prices could occur in very short time periods.

While historically first, jump-diffusion models constructed specifically for the volatility surface were the third generation.<sup>101</sup> In constructing these models, one of the primary questions to be answered is the size of the jump. Often, models will provide a variety of different jump sizes that may occur, each of which has a particular probability of occurring.<sup>102</sup> In Merton's original model, this distribution of jumps followed a lognormal distribution. In addition to the jump-size probability, the models also give a probability for a jump in any given time period. Together, these models tend to produce volatility smiles that raise the price of near-expiration options as the probability of a major jump makes far OTM options more likely to be exercised. Jump-diffusion models tend to under-value far-from-expiration options, as the price is assumed to revert to a mean, and the initial effects of any jump end up dissipating.<sup>103</sup>

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<sup>99</sup> Ayache et al., "Can Anyone Solve the Smile Problem?," 79.

<sup>100</sup> Gatheral, *The Volatility Surface: A Practitioner's Guide*, 51.

<sup>101</sup> Robert Merton was responsible for the first jump-diffusion model, as far back as 1976 - but this was developed for more accurate diffusion representations, and not for reasons of the volatility surface. (Merton, "Option Pricing When the Underlying Stock Returns Are Discontinuous.")

<sup>102</sup> Gatheral, *The Volatility Surface: A Practitioner's Guide*, 54.

<sup>103</sup> *Ibid.*, 65.

The problem with jump-diffusion models is that they ultimately break down the possibility of replicating them. Each possible jump size requires a different hedge, and since the jump size is unpredictable and can take on an infinite number of sizes, there is no way to hedge for all the possibilities.<sup>104</sup> As with all the post-volatility smile models, the very essence of BSM – the dynamic replication of an option – appears to be severely curtailed in its effectiveness.

### Seeing Markets

Despite their divergences over how to model volatility, each of these models represents options markets in terms of this theoretical variable. While it is often forgotten due to the naturalisation of talking about ‘global markets’, there is no empirical referent for such a term. No one has ever seen a ‘global financial market’ in the flesh – such an entity exists only in and through local situations and constructed perspectives. The first such perceptions were created through the medium of price charts in the 1830s. These charts abstracted away from the particularities of companies and made clearer the patterns of stocks that comprised a market.<sup>105</sup> Through their composition in chart form, these patterns made perceptible something like the ‘market’ as a whole. In the words of one broker at the time, the chart provided “the bird’s eye view of the stock market.”<sup>106</sup> In other words, charts constructed a ‘panorama’ – a (local) overarching view of a (global) totality which obscures its own production and mediation.<sup>107</sup> The visualization of the market took on temporal qualities with the introduction of the stock ticker in the 1870s. This technology came to replace the discontinuous publicizing of prices that had previously occurred on whiteboards. Before the ticker, prices had also been plagued by variation in the quotes – different brokers would present different stock prices, and errors were rampant. With the advent of the stock ticker, “instead

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<sup>104</sup> Derman, “Laughter in the Dark: The Problem of the Volatility Smile,” 11; Gatheral, *The Volatility Surface: A Practitioner’s Guide*, 55.

<sup>105</sup> Lo and Hasanhodzic, *The Evolution of Technical Analysis*, 39.

<sup>106</sup> Preda, *Framing Finance: The Boundaries of Markets and Modern Capitalism*, 165.

<sup>107</sup> Latour, *Reassembling the Social: An Introduction to Actor-Network Theory*, 187-190.

of multiple, discontinuous, heterogeneous, and unsystematically recorded prices, we now have single, continuous, homogeneous, nearly real-time price variations.”<sup>108</sup>

The market, as the complex system comprised of a multitude of actors with billions of transactions a day therefore has always required a representational technology in order to make the market perceptible and capable of being acted upon. While not a completed project, the tendency of modern markets has been towards screen-based trading and away from floor-based exchanges.

“Most FX trading takes place through the medium of the screen and electronic booking systems. Most information also comes through the screen – through proprietary services (and especially Bloomberg) or through email and bulletin boards to which all the traders on the floor can contribute – and through telephone conversations on open lines with company dealers in other locations.”<sup>109</sup>

Similarly with day traders, ethnographic research suggests the vast majority of their time is spent on price observation – the acts of trading are themselves a relatively small portion.<sup>110</sup> As such, much of the modern trading environment is constituted in and through computer representations. Such representations ‘frame’ the financial environment and set boundaries upon relevant and irrelevant information.<sup>111</sup> The models and computer software that produce the frame can obscure certain aspects, while bringing other aspects to light.<sup>112</sup> Phenomenologically, such representational technologies extend the temporal nature of experience beyond immediacy (via the use of historical data and economic forecasts), while simultaneously abstracting from individual trades in order to produce a global overview. In other words, framing provides the material basis upon which traders, brokers and market makers’ decisions are subsequently

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<sup>108</sup> Preda, *Framing Finance: The Boundaries of Markets and Modern Capitalism*, 142.

<sup>109</sup> Clark and Thrift, “The Return of Bureaucracy: Managing Dispersed Knowledge in Global Finance,” 243.

<sup>110</sup> Preda, *Framing Finance: The Boundaries of Markets and Modern Capitalism*, 242.

<sup>111</sup> Callon, “An Essay on Framing and Overflowing: Economic Externalities Revisited by Sociology.”

<sup>112</sup> Beunza and Stark, “How to Recognize Opportunities: Heterarchical Search in a Trading Room,” 94.

made. It orients attention towards itself, and coordinates activities amongst its users.<sup>113</sup> It is not simply a representation of the market – for all intents and purposes, it *is* the market.<sup>114</sup> While this framing process is never fully completed (i.e. excluding all external factors), it nevertheless can give rise to a sense of ‘the market’. At a fundamental level, therefore, the global financial market is first materially produced as an object of cognition via the mediation of databases, computer-programmed algorithms, and data visualization tools. Such technology standardises and normalises the market, producing both a common language and a common perception of the market and its relevant factors. It allows “economic actors to rationalise their future courses of action and to project the outcomes of these actions, a process which establishes boundaries between efficient and inefficient actions.”<sup>115</sup>

With option pricing models, one of the most unique aspects of this material construction of global markets has been the language of volatility that has come to dominate in practice. While BSM and other derivative pricing models have lost some of their uncritical acceptance, the terms they introduced into the derivatives world have remained fundamental. The ability to ‘see’ volatility is now a reality for traders. In the same way that the smallest particles of the world can only be visualised through specialised instruments, so too is volatility only perceivable through the use of specialised financial models. This use of options pricing models to perceive an aspect of market prices that is otherwise imperceptible is now a standard practice. Options and derivatives are routinely quoted in terms of their volatility, and an entire index (the VIX) has arisen in order to trade volatility.

A significant reason for the dominance of this perception of the market in terms of volatility was the conceptual simplification that it brought about. As a theoretically produced entity, volatility managed to act as a common denominator behind the multiplicity of derivatives, strikes, maturities, and sectors. Quoting derivatives in terms of volatility rather than price allows traders to efficiently

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<sup>113</sup> Cetina, “How Are Global Markets Global? The Architecture of a Flow World,” 40.

<sup>114</sup> Ibid., 45.

<sup>115</sup> Preda, *Framing Finance: The Boundaries of Markets and Modern Capitalism*, 117.



determine whether a derivative is mispriced and how it may be used to hedge their own position. Volatility quickly became the language of traders.

### **The Rise of Volatility**

On the basis of these new ways of seeing the market, new capacities have become available to market actors. Contrary to liberalism's analysis of technology in IR, the introduction of technologies does not simply speed up or reduce the costs of otherwise unaltered market relations.<sup>116</sup> Rather, these representational technologies have expanded the capacities of individuals to act in the world and think about the world. Foremost among these new capacities is the production of new financial products, the innovative capacities to hedge and speculate using derivatives, and the construction of a market for the model-based variable 'volatility'.

In determining what the technology allowed market participants to do, it is crucial to make precise who the market participants in question are. There are essentially four types of participants in derivatives markets: speculators, hedgers, arbitrageurs, and derivative producers.<sup>117</sup> Speculators are those who believe they can predict the future and use derivatives to place bets on outcomes. Hedgers are those who are looking to limit losses by purchasing derivatives that stabilise future outcomes. Arbitrageurs are those who seek out discrepancies in prices between similar assets and look to make 'risk-free' profit from exploiting these differences. Finally, derivative producers profit from actually constructing the derivatives, particularly with complex structured products and exotic options.

Similarly, there a wide variety of bodies involved in derivatives markets: investment banks, commercial banks, hedge funds, pension funds, mutual funds, municipalities, corporations, and high-worth individuals, among others. For our purposes here, we will be looking primarily at the dealers and 'market makers' within banks: those who create, buy and sell derivatives, and who profit through a combination of derivative production and arbitraging.

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<sup>116</sup> MacKenzie, "Opening the Black Boxes of Global Finance," 93.

<sup>117</sup> Valdez and Molyneux, *An Introduction to Global Financial Markets, Sixth Edition*, 381.

*The Proliferation of Financial Engineering*

The constant revolution of derivatives modelling has led to a unique state of the field today. Whereas BSM originally gained its reputation as an accurate representation of reality (and indeed, is still taught as such in most universities), today most practitioners accept that there are inevitably multiple models. Models of the volatility smile are no longer considered just *representational* measures, but also as practical *tools* that allow traders to enter into the market: “When options traders invert the Black-Scholes formula, they don’t care about the *knowledge* of implied volatility; they care about the delta hedge to execute in the market. [...] It is the trader’s way into the next market movement.”<sup>118</sup> Curiously, this use of models as tools into the market has meant the reintroduction of all the experience, context, and rules of thumb that were initially banished by the BSM model. Correctly judging whether a model is right, whether volatility is high or low, and whether two products are similar enough to be an arbitrage opportunity, are all functions not just of mathematics but also of social organization, expertise, and luck. Today, traders will often employ multiple models, sometimes aligning their different valuations into spreadsheets to provide an immediate sense of how sensitive pricing is to different inputs and different models.<sup>119</sup> Firms will compete with each other, looking to generate models that will allow them to profit off of the mispriced products of others.<sup>120</sup>

Quants also continually develop new customised products for clients, in order to secure a profit for the production process and for the uniqueness of their product.<sup>121</sup> While the earlier years of derivatives trading were dominated by vanilla options, by the 1990s exotic options were beginning to emerge and become

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<sup>118</sup> For Ayache, whether the underlying probability distribution exists or not is irrelevant (distinguishing him from those who seek more accurate probability distributions and those like Taleb who argue there are epistemological limits to knowing the distribution). Ayache argues instead that the probability distribution is important only insofar as it allows the market maker to re-enter into the market - in other words, completely rejecting the representational view of financial models in favour of a pragmatics of models. Ayache, “Option Trading and Modeling,” 251.

<sup>119</sup> Haug, “Practical Valuation of Power Derivatives,” 209.

<sup>120</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 8.

<sup>121</sup> For more on the process of financial innovation, see: Lepinay, *Codes of Finance: Engineering Derivatives in a Global Bank*.

popular.<sup>122</sup> After the collapse of Long Term Capital Management in 1997, volatility and variance swaps proliferated.<sup>123</sup> Yet the profit advantages of these new products only last momentarily, as competitors will dissect new derivatives in order to reverse-engineer them. The result is a decrease in profit levels, and the ensuing search for ever more complex and structured products.<sup>124</sup>

While the 1970s and 1980s saw the mathematical formulas emerge for some of the more exotic options, it was not until the 1990s that such products became widely used within the financial world – in no small part due to the fact that the technological means to produce such derivatives were at the time non-existent.<sup>125</sup> Even some of the most widely used models – such as the binomial model created by Cox, Ross and Rubinstein – required lengthy calculations that were hindered by the existing state of technology. As the options trader, Satyajit Das, has noted, “as the availability of computers increased, the ability to handle more complex types of options rapidly increased.”<sup>126</sup>

Other factors played a motivating role in the development of the wild derivatives found today (e.g. options on the VIX, which are essentially derivatives of derivatives). As competition spread in the options markets, the profits to be made from simple derivatives decreased, and financial institutions were spurred on toward the production of more complex derivatives and structured products (under the marketing banner of ‘customised risk’). At the same time, new regulations produced an incentive to move liabilities off balance-sheets by using derivatives, which then allowed for leveraging and liquidity at an unprecedented level. As MacKenzie makes clear, the invention of novel derivatives is like any other invention in that it requires a keen sense of meeting users’ requirements. Details such as the option sizes, margin requirements, and the risks that can be hedged by a new instrument all play a part in designing these instruments.<sup>127</sup> Yet these

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<sup>122</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 209.

<sup>123</sup> Gatheral, *The Volatility Surface: A Practitioner’s Guide*, 137.

<sup>124</sup> Das, *Traders, Guns & Money: Knowns and Unknowns in the Dazzling World of Derivatives*, 41.

<sup>125</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 221.

<sup>126</sup> Das, *Traders, Guns & Money: Knowns and Unknowns in the Dazzling World of Derivatives*, 197.

<sup>127</sup> MacKenzie, *Material Markets: How Economic Agents Are Constructed*, 69–70.

advances were only made possible through the modes of action opened up by the development of new technologies and models.

Technology also played a role in making markets ‘complete’. Most markets are incomplete in the sense that there are gaps in the maturity or strike prices available.<sup>128</sup> The development of abilities to hedge risks, and the proliferation of models, has made it cost effective to provide derivatives in areas that were previously untenable. The result has been a proliferation of products in a different sense: not the creation of entirely new products, but the expansion of existing products into covering previously overlooked risks.

The general dynamic in derivatives markets has therefore been that new products call forth models to price them, and new models prefigure products to use them.<sup>129</sup> Central to this proliferation is a ratcheting dynamic: first-level derivatives (i.e. vanillas) are priced on the basis of more liquid underliers (e.g. stocks and bonds), which then allows a market to emerge in the first-level derivatives. These first-level derivatives can then be used as the more liquid derivative to price second-level derivatives (i.e. exotics). Such a dynamic points to what Merton calls the ‘financial innovation spiral’:

“The proliferation of new trading markets in standardised securities such as futures, options, and swaps makes possible the creation of a wide range of new financial products, many custom designed and sold OTC by financial intermediaries to meet selected needs of investors and corporate issuers. Next, volume in the new markets expands further as the intermediaries themselves trade simply to hedge their own exposures from the products they sold. Such increased volume in turn reduces marginal transactions costs and thereby makes possible the further implementation of new products and trading strategies and this, in turn, leads to still more volume. New markets also evolve as some successful products become

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<sup>128</sup> Merton, “Applications of Options Pricing Theory: Twenty-Five Years Later,” 333.

<sup>129</sup> Derman, *My Life as a Quant: Reflections on Physics and Finance*, 221.

standardised and their source of distribution moves from intermediaries to markets. Success of these trading markets and custom products then encourages investment in creating additional markets and products, and so on it goes, spiralling toward the theoretically limiting case of complete markets and zero marginal transactions costs.”<sup>130</sup>

In other words, once the models and technology are in place, the economic dynamics of the situation take on an autopoietic nature. These dynamics produce incentives for further development of derivatives, which produce ever greater needs for advances in technology and model production. At its limit, even the speed of light becomes a technological issue for financial trading.<sup>131</sup> At such extreme points, the physics of materiality that comprise the infrastructure become all important.

#### *Trading, Hedging, and Speculating*

As we saw earlier, prior to 1987 the most important first effect of BSM was to provide a rational and universal means to quantify the value of options. While there were previously a series of rules of thumb used to pragmatically determine the boundaries of prices for options, these were still subject to individual whims. BSM initiated a sort of ‘attractor’, to borrow a term from complexity science. The price generated by the BSM equation did not need to precisely match up to the market price, but it provided an idealised point around which market prices were presumed to fluctuate. Deviations from this idealised point were considered opportunities for arbitrage and were quickly exploited and eliminated for profit.

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<sup>130</sup> Merton, “Influence of Mathematical Models in Finance on Practice: Past, Present and Future,” 456.

<sup>131</sup> Wissner-Gross and Freer, “Relativistic Statistical Arbitrage”; The importance of the speed of light here is the opportunity to use a particular trading strategy (statistical arbitrage) in order to profit off of the price differences between two markets. Those with access to the information quicker are able to profit over those with access to the information later (even if this ‘later’ is measured in microseconds). Thus the physical location between two markets can become of crucial importance. Fundamentally though, this is nothing new in finance as such strategies have been employed even during the American Civil War. Upon the South’s defeat, one American financier chartered the fastest boat possible in order to travel across to Europe and profit off of the news before the information reached anyone else. (Freedman, *Introduction to Financial Technology*, 10.)

While the role of option pricing models as a representation of an objective price did not last long, the capacities it made possible for hedging positions are among its most significant consequences. Through their argument<sup>132</sup> linking together a portfolio made of stocks and bonds, with that of an option, BSM made it possible to both price the option (which the CAPM no-arbitrage argument deemed must be equivalent to the portfolio), and to hedge the option (i.e. returns could be precisely managed by taking their opposite position).<sup>133</sup> What is called ‘static hedging’ can work perfectly when it is possible to buy an inverse replica of the derivative sold (e.g. buy a put option when selling a call option, or vice versa). The problem is that in practice such perfect matches are rarely possible – in which case, it becomes important to find suitable alternatives. Thus, the perhaps most distinctive advance made possible by BSM was that of ‘dynamic hedging’.<sup>134</sup> ‘Static hedging’ entails taking an opposite position once, and then holding both positions until expiration. Dynamic hedging, by contrast, is a constant manipulation of one’s position by altering the mixture of options, stocks, and riskless bonds in the replicating portfolio. The shift from static to dynamic hedging also allowed for market-makers to more easily trade derivatives, as their hedge no longer had to remain until expiration in order to work. Through BSM and other models, it also became possible to conceptualise the various types of risk that an option is exposed to, and hedge against each individually. (The sensitivities to these risks are known as ‘the Greeks’ since each has a Greek letter associated with it (except for ‘vega’).) Most crucially, dynamic hedging made it so that option sellers (primarily dealers) could mitigate the risks of their positions – a virtual impossibility beforehand. The result was a significant decrease in the amount of risk that a dealer had to take on. Since dealers and market makers are the primary sources of liquidity and volume

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<sup>132</sup> In fact, it was the argument provided by Black and Scholes – and not the equation – that was their primary advance. The formula itself had already been produced in various forms by previous scholars. It was their linking of the no-arbitrage rule along with the CAPM, which allowed them to demonstrate the price was independent of risk-return. (Haug, “Option Pricing and Hedging from Theory to Practice,” 40.)

<sup>133</sup> This function continues today, despite the modern inconsistencies between theoretical and market prices. (Ibid., 55.)

<sup>134</sup> In the words of one options trader, “the probability distribution that underlies the pricing tool serves *only* the purpose of putting in place the dynamic replication [i.e. hedging] strategy of derivatives.” (Ayache, *The Black Swan: The End of Probability*, 82., emphasis added.)

within markets, the sheer growth of the derivatives market is hard to imagine without this capacity for them to minimise risk.

The original impetus for derivatives was for them to be used to hedge and minimise risk. But their mathematical valuation simultaneously allowed the construction of a speculative market for them (an example of how technology opens up new capacities and not merely expanding existing possibilities). The result was a massive expansion of the set of possible actions that could be carried out by those who create global markets.

The capacity to hedge, in particular, is essential to dealers and market makers for derivatives. Both are heavily involved in buying and selling derivatives and are exposed to numerous risks as a result. Dealers, for instance, predominantly sell options to clients, which leaves them holding the opposite end of the deal. Since the buyer of an option is limiting their downside risk, it is the dealer who is left covering that risk. The result is that they are placed in a precarious position. Hedging is therefore a crucial component of dealers' work since it is what allows them to offset their short positions. Dynamic hedging – made possible solely by derivatives valuation models – is one of the primary ways in which modern dealers hedge their position. In dynamic hedging, as the underlier's price changes, so too must the hedging of the position, and it is the models alone which provide the proper ratios of stocks, bonds, and cash to replicate the option payoff. This requires not only the model itself, but also “appropriate position-keeping and risk-management tools”.<sup>135</sup> As Mark Davis and Alison Etheridge write,

“In earlier days there was no way to hedge an option contract: markets were illiquid, costs too high and information too scanty. Effective management of option risks depends on having a ‘deep’ (implying large) market and trading on a sufficiently fast timescale.”<sup>136</sup>

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<sup>135</sup> Neftci, *Principles of Financial Engineering, Second Edition*, 189.

<sup>136</sup> Davis and Etheridge, “From Bachelier to Kreps, Harrison and Pliska,” 97.

More generally, derivatives made it possible for all investors to hedge what was once considered unavoidable risks (e.g. currency devaluation, among others). It was now possible to hedge against and protect against these possibilities, meaning corporations and institutional investors could mitigate their risk in new ways. The result was that the management of risk has now become a massive and important part of corporations.<sup>137</sup> (Albeit, the main risk management systems such as Value-at-Risk (VAR) are massively simplifying despite their complexity.<sup>138</sup> If one distinguishes between ‘risk’ as a known unknown, and ‘uncertainty’ as an unknown unknown, it is not clear that risk management has come to terms at all with the latter.) Regardless, the expansion of hedging that occurred as a result of derivatives valuation models is an important way in which complexity and volatility are managed. Through their management of complexity, these technological objects have allowed for the creation of today’s global financial markets.

There is a flipside to this management of complexity however, and it was made clear in the 2008 financial crisis. As with all of the representational technologies examined in this thesis, they are open to multiple uses and they have unintended consequences beyond their creator’s intentions. As a component of a larger assemblage, these technologies have their own set of capacities that vary from assemblage to assemblage. In the deregulated world of the 1980s onwards, derivatives valuation models became a tool of speculation.

In the first place, as we saw above, derivative valuation models provided a new way to estimate profitable trades via implied volatility. This opened up new means for professional arbitrageurs to compare heterogeneous assets against each other. This also opened the space for a shift in how investment banks profited – from mergers and acquisitions, underwriting, initial public offerings, and other traditional services, to proprietary trading and arbitrage hunting.

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<sup>137</sup> Das, *Traders, Guns & Money: Knowns and Unknowns in the Dazzling World of Derivatives*, 89.

<sup>138</sup> VAR is another instance of computer modelling being used in the financial world. It often employs simulations based on Monte Carlo methods, which repeatedly simulate random possible losses to a position and generate a likelihood of each loss (or gain). (Durbin, *All About Derivatives, Second Edition*, 194.)



Pricing models simultaneously made possible the ability to hold large and complex positions across markets, since such moves were beyond cognitive capacities beforehand.<sup>139</sup> In the words of one options trader,

“I’ll stand in a pit with [options on] 16 stocks that each trade two [expiry] months and five strike prices and I’ll take anybody on: turn off the lights, I want to trade with no electronics. But when you get to multiple expirations, strike prices, higher volatility stocks . . . well, volatility changes by 10%, Arco goes from a 15 to a 13.5 [annualised percentage implied volatility], I can do that math in my head. [With a high volatility stock] 150 to 135 seems like it ought to be similar but . . . I’ve got too much money at risk if I’m wrong in my mental calculations.”<sup>140</sup>

The sheer size of the markets massively increased as a result of computing as well. This was assisted in part by dynamic delta hedging – traders no longer had to hold onto a portfolio until expiry in order to secure their hedge. Instead, now they could consistently (and, indeed, were forced to) manipulate their positions in the market, thereby opening up new buyers and sellers. It was also assisted by the shift away from ‘block trading’, where large transactions are made all at once. The risk in this traditional strategy was that the price could shift as a result of that very transaction, or that transaction costs (e.g. commissions, bid-ask spreads) of multiple trades will rise, eliminating the profit potential from a trade. By contrast, today computers make such large trades possible (and profitable) by automatically optimizing trading strategies in order to effectively space out the trade over time.<sup>141</sup> Through a combination of varying the volume, timing and sequencing of trades, these programs inaugurated the first developments in algorithmic trading.<sup>142</sup> These technological innovations have all contributed to making possible the explosion in

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<sup>139</sup> MacKenzie and Millo, “Constructing a Market, Performing Theory: The Historical Sociology of a Financial Derivatives Exchange,” 125–126.

<sup>140</sup> *Ibid.*, 126.

<sup>141</sup> Schulman, “How I Became a Quant,” 76.

<sup>142</sup> Chriss, “How I Became a Quant,” 127.

derivatives trading that this chapter began with. Today, on large stock exchanges like the NYSE, there can be over a billion transactions occurring in a single day of trading. There is no physical way for this to occur without the assistance of computers and automated trading programs:

“Such volume would be impossible without the computer. Many complex securities could not even be priced without the computer’s speed and mathematical capabilities. So-called DOT transactions automate small trades on the New York Stock Exchange and transmit them instantaneously from the customer’s broker to the post where the order is executed.”<sup>143</sup>

The size, speed, and liquidity of modern markets has therefore been made a possibility through the computational and mathematical innovations first introduced by derivative pricing models.

### *The VIX*

One market in particular is a direct result from the rise of options pricing models: the Chicago Board Options Exchange Market Volatility Index (VIX). First proposed in 1993 and launched in 2004, this index relies on the shift to implied volatility, and measures the implied volatility that is hidden in the S&P 500’s index options.<sup>144</sup> By measuring the market’s expected volatility in the next 30 days, the VIX effectively represents how risky the market believes that period will be. In times of crisis, the VIX shoots up (see Figure 16). As a result, the VIX has now become a widely used indicator of ‘fear’ in markets. In other words, a market based on products produced by theoretical models, is now being used as a symptom of market emotions. This level of second-order abstractions has led to a situation where there is no consensus about what the index fully means.<sup>145</sup> (A situation

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<sup>143</sup> Bernstein, *Capital Ideas: The Improbable Origins of Modern Wall Street*, 5.

<sup>144</sup> Whaley, “Derivatives on Market Volatility: Long Overdue Hedging Tools.”

<sup>145</sup> Tett, “Vix Volumes Rise Could Drive Investor Trends.”

complicated further by debates over how to calculate the index and how to weight different options.)

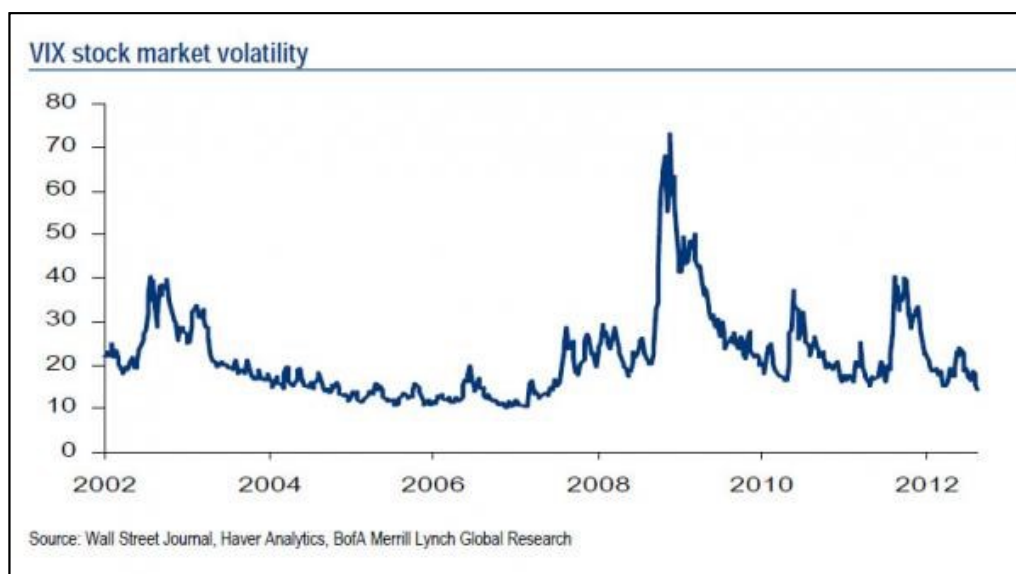


Figure 16: The VIX

Despite these difficulties, the VIX has been a success as attested to by its rapid growth in volume.<sup>146</sup> Its success goes beyond its general function as a fear index, and speaks to the capacities it makes possible for hedging risks. In particular, it is significantly easier to dynamically hedge against future volatility changes if there is a market for volatility itself. For instance, vega is the variable for how the price of an option changes with respect to changes in the underlier's volatility and can be hedged through volatility options. Products based around the volatility index make it possible to accomplish such hedging gestures. This is indeed what has occurred: with the theoretically-constructed VIX index of implied volatility, a range of new VIX-based products (futures and options) have been engineered. The significance of this is that it makes possible a range of new options for hedging and trading. In the words of one trader,

“The medium of options actually changes the kinds of messages it occurs to you to express. This is really the reason why I think options

<sup>146</sup> Kaminska, “VIX Futures: Why the Most Hideous Forecasting Record?”.

are so interesting and valuable. If the only three words in my financial vocabulary were buy, short, or hold, I might not bother thinking my way to a thesis that could only be expressed with optionality.”<sup>147</sup>

The volatility index and the volatility products that surround it literally extend the conceptual and perceptual possibilities of traders. Again, it should be emphasised that trading volatility products is entirely model-dependent – volatility only exists as an exchangeable asset by virtue of the models that produce it.

### **Conclusion**

With an understanding of option pricing models, what they do, and how they have developed, we can now summarise their role in the material construction of global finance. The construction of the global through these representational technologies has occurred in a number of ways. These technologies have, first, made it possible to ‘see’ the volatility assumed within market prices – a possibility which has given rise to the VIX and the transactions and products that circulate around it. Secondly, option pricing models have opened up new possibilities to hedge and trade, expanding the language within which positions in the market can be taken up. These technologies have generated a wide variety of new products and been at the basis of entirely new markets.

At all levels of the global financial world, models have become embodied in the technological objects used routinely every day. They provide the basic material infrastructure without which today’s massive derivatives markets simply would not exist – transforming the ‘gentlemanly’ capitalism of earlier markets into the increasingly computational markets of today.<sup>148</sup> Yet the built-up nature of this infrastructure imposes certain constraints and possibilities for any future development. For instance, high-frequency trading (HFT) is bumping up against the limits of exchange’s abilities to log and time-stamp trades – a problem that

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<sup>147</sup> Woodard, “What Options Are Good For.”

<sup>148</sup> Pardo-Guerra, “Computerising Gentlemen: The Automation of the London Stock Exchange, c. 1945-1995.”

becomes essential when trying to discern how crashes occurred.<sup>149</sup> Instituted decades ago, the Network Time Protocol (NTP) is what synchronises computer clocks together – yet it is limited to synchronizing with an accuracy of  $10^{-2}$  seconds.<sup>150</sup> Relative to the nanoseconds that some HFT occurs in, this is an eternity. This infrastructural path dependency is placing limits on how fast trades can be completed, and forcing alternative means to escape this constraint.

Similarly, with the financial models themselves, the various component pieces (algorithms, equations, computer code, data visualization, graphics processors, data servers, etc.) produce a series of likely possibilities for any future development. For instance, the limitations of current processing power lead the development of new models to aim for closed form solutions, or to only employ manageable probability distributions (avoiding the ‘monstrous’ distributions of Benoit Mandelbrot).<sup>151</sup> Other possible paths of development are neglected as a result of the nature of the representational technology.

Yet despite this ongoing automation of financial markets (which one UK government report envisions as the eventual ‘depopulation of trading floors’), social and political factors remain.<sup>152</sup> Historical research on options trading is illuminating here, highlighting how various social conventions were capable of supporting a minimal market for derivatives. The historical data from market prices suggests that early options markets employed a variety of basic rules of thumb in order to produce a relatively rational system of market prices.<sup>153</sup> Implied volatility was systematically related to realised volatility, and overt arbitrage opportunities were typically minimised thus making options correctly priced relative to each other. Evidence from personal accounts and news stories suggests the existence of some conscious awareness of the factors involved in pricing options, and also suggests a minimal existence of static hedging. What does not

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<sup>149</sup> Millo, “High Frequency Trading and Techno-Political Path Dependency.”

<sup>150</sup> Freedman, *Introduction to Financial Technology*, 66.

<sup>151</sup> Mandelbrot and Hudson, *The (Mis)Behaviour of Markets: A Fractal View of Risk, Ruin & Reward*.

<sup>152</sup> Cliff, Brown, and Treleaven, *Technology Trends in the Financial Markets: A 2020 Vision*, 36.

<sup>153</sup> Kairys and Valerio III, “The Market for Equity Options in the 1870s”; Mixon, *The Foreign Exchange Option Market, 1917-1921*; Mixon, “Option Markets and Implied Volatility: Past Versus Present”; Moore and Juh, “Derivative Pricing 60 Years before Black-Scholes: Evidence from the Johannesburg Stock Exchange.”

exist, though, is accurate pricing – the data suggests systematically overpriced options. The most thorough comparative study of pre-BSM markets therefore is correct to say that the qualitative factors are highly similar between periods.<sup>154</sup> This is due to the existence of basic financial rules of thumb concerning arbitrage and the likely volatility of stocks. However, the post-BSM era shows a noticeable increase in the accuracy of pricing. Likewise in terms of hedging, pre-BSM strategies relied on basic (though important) ideas of put-call parity in order to hedge their positions when buying or selling options. Importantly, all the evidence suggests this remained at a level of static hedging – a hedge established at the beginning of a position and then held to expiry. Dynamic hedging, a primary act of modern derivatives markets, was only an idea at the time.

What these historical studies do show though is that particular social conventions can sustain a minimal level of option pricing. Principles of arbitrage, including put-call parity, and heuristics to take into account factors like volatility (i.e. ‘market conditions’ as one 1914 treatise put it) all functioned to give some consistency to pricing between options and their variations. These exist in a social world, and while the introduction of BSM appeared to initially negate the social factors, the emergence of the volatility smile and the proliferation of option pricing models has made social factors increasingly significant.

In addition to this explicit return of social aspects involved in derivatives trading there are the often implicit political decisions that have gone into the construction of models. Foremost here are the technical decisions embedded in technologies such as option pricing models, credit default swap models, Value-at-Risk (VAR) models, and macroeconomic models. Such technologies were constructed initially to create representations of various complex phenomena: volatility, correlation, risk, and economies.<sup>155</sup> The ease with which their constructions could be communicated and replicated lent these numerical

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<sup>154</sup> Mixon, “Option Markets and Implied Volatility: Past Versus Present,” 183.

<sup>155</sup> For an overview of these technologies, their limitations, and their consequences, see: Li, *On Default Correlation: A Copula Function Approach*; Triana, *The Number That Killed Us: A Story of Modern Banking, Flawed Mathematics, and a Big Financial Crisis*; Keen, *Debunking Economics - Revised and Expanded Edition: The Naked Emperor Dethroned?*; MacKenzie and Spears, “The Formula That Killed Wall Street? The Gaussian Copula and the Material Cultures of Modelling.”

representations a sense of objectivity and, hence, a sense of authority.<sup>156</sup> This authority was then employed to justify wild speculation in financial markets, leading to excessive risk-taking, massive leveraging, and the eventual breakdown of the global financial system. As always, the issue is not that the technology *caused* this bubble and its subsequent burst; rather the technology altered the behavioural landscape and made over-leveraging and excessive risk-taking to be increasingly less costly (and in fact, often profitable) actions. The well-known limitations of these technologies (e.g. their incapacity to model realistic probability distributions, their reliance on past data, and their dismissal of long tail events) were set aside and lost in the rush to make profits. Being situated in a larger sociotechnical assemblage (that of capitalism), these representational technologies performed an array of functions with both useful and disastrous results. While some have taken this as evidence of an overreliance on mathematics and technology, as will be argued in the final chapter, such an approach neglects the extent to which the contemporary world requires such technologies. The politics of representational technologies and cognitive assemblages are not something to be banished by fiat, but instead a problem to be faced up to.

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<sup>156</sup> Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*, ix.

## APPENDIX: THE BLACK-SCHOLES EQUATION

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There have been a number of conceptual ways to derive the BSM equation, with Paul Wilmott citing the existence of at least 14 different ways. The derivation of this equation is taken from Wilmott's *Frequently Asked Questions in Quantitative Finance*.<sup>1</sup> Note that this is the equation that shows how the price of an option varies with time and stock price changes. For the price of a particular option at a particular time, we need to input the boundary conditions (i.e. the characteristics of the particular option, such as expiration date, call or put, and when it can be exercised).

$$\frac{\partial V}{\partial t} + \frac{1}{2} \sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + rS \frac{\partial V}{\partial S} - rV = 0$$

Where,

$V$  = option price

$t$  = years until expiry

$\sigma$  = volatility of the underlying's returns (i.e. growth)

$S$  = underlying price

$r$  = current annualised risk-free rate of interest

$\frac{\partial V}{\partial t}$  : the rate of time decay, i.e. the loss of option value as the expiration date approaches

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<sup>1</sup> Wilmott, *Frequently Asked Questions in Quantitative Finance, Second Edition*, 129-131.



$\frac{1}{2}\sigma^2S^2\frac{\partial^2V}{\partial S^2}$  : convexity term, i.e. the rate at which a hedged position varies on average from changes in the stock price

$rS\frac{\partial V}{\partial S}$  : price drift, i.e. the growth of the stock price at the risk-free rate of interest

$-rV$  : the discounting of the future value to the present time (at the risk-free rate of interest)

This equation is formed by setting a riskless portfolio proportioned between options and stocks on one side, against the riskless rate of interest on the other side. Rearranging the terms produces the above equation.

Yet this PDE does not yet tell us what the price of an option should be; it only shows us how the option price varies with stock price and volatility. In order to get a pricing formula, what is necessary is a second step whereby certain boundary conditions on the function are set.<sup>2</sup> These are dependent on the type of option, the strike price of the option and the price of the underlying. Given these, particular formulas can be derived that provide a means of computing the price of particular options.

Finally, the particular formulas can have the relevant numbers inputted in for the variables, which can then be computed, providing a solution to the equation.

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<sup>2</sup> For this derivation, see: Black and Scholes, "The Pricing of Options and Corporate Liabilities," 643-645.

## 6 / SEEING CRISES

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“With Ushahidi, you have the big picture immediately.”<sup>1</sup>

-anonymous activist

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In contrast to climate change and financial markets, humanitarian crises are less likely to be noted as particularly complex. Yet the logistical networks and coordination that go on behind the scenes of a major humanitarian operation are among the most complex acts of cooperation that occur today:

“Imagine the planning involved in an event like the Olympics. Now imagine planning the same event but not knowing when or where it will take place, how many spectators will attend, or how many athletes will compete. The near impossibility of the task gives some insight into what humanitarian logisticians are up against.”<sup>2</sup>

In the wake of the 2010 Haitian earthquake, the devastating 2004 tsunami in the Indian Ocean, and other major humanitarian disasters, increased global attention has been paid to the ways in which actors involved in humanitarianism can and should evolve to deal with these emergency situations. Media, international organizations, and non-governmental organizations have all reflected on the implications and path forward for managing crises, with a wealth of reports emerging in the wake of this decade’s crises.<sup>3</sup>

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<sup>1</sup> Meier, “Ushahidi as a Liberation Technology,” 105.

<sup>2</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, inner flap.

<sup>3</sup> For example, see the UN’s *Global Survey of Early Warning Systems* and the International Red Cross and Red Crescent’s *World Disasters Report 2005: Focusing on Information in Disasters.*, and the massive mobilization of the media for Haitian disaster relief.

A similar set of complex crisis situations has become significant recently with the political events surging across the Arab world. While analytically distinguishable from humanitarian crises, these political crises share many common aspects and often blur at their boundaries. Political crises typically produce humanitarian crises, while humanitarian crises often stretch the capacities of political systems. The result, in either case, is a situation characterised by its complex and fast-moving nature. Moreover, in both instances there is often a dearth of reliable information. If effective political action is premised upon the conceptual representations of a situation, then rational action becomes nearly impossible in crisis situations. In this regard, the new technologies involved in crisis mapping can be seen as a means for political actors to overcome this cognitive deficiency. Through this case study it will again be demonstrated how political actors are in fact constructed not only socially, but also through material technology. The very perceptions of actors is altered by technological extensions, and “map-based ‘mashups,’ through the use of frequently updated data from multiple sources, allow us to ‘see’ microbehaviour spatio-temporally.”<sup>4</sup>

The next section will make precise the various complexities involved in humanitarian crises, demonstrating that it is often a system beyond the cognitive capacity of any group of non-augmented minds. The third section will outline the early history of crisis mapping, focusing on its pre-history in various attempts to map crises after the fact, as well as the shift to predictive modelling attempts in the second half of the twentieth century. The fourth section will articulate the development of contemporary crisis mapping, from its origins with a Kenyan blogger to the rapid and sophisticated international technology it has become today. Important here are the various frictions internal to the technology: particularly the tensions between the functional demands of the technology and the limitations imposed by the materiality of the software. The penultimate section argues that crisis mapping software has changed the capacities of actors in significant ways, and undertakes to demonstrate these effects through a variety of

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<sup>4</sup> Liu and Palen, “The New Cartographers: Crisis Map Mashups and the Emergence of Neogeographic Practice,” 70.

recent humanitarian crises. It will show how this technology has enabled humanitarian actors to see crisis in a new way.

### **The Complexity of Crisis**

The traditional history of humanitarian action traces its origins back to Henry Dunant and his efforts to eventually create the International Committee of the Red Cross (ICRC).<sup>5</sup> Yet its origins in fact lie further back in the cultural changes that arose in the late eighteenth century. Behind this shift was a combination of new religious interpretations that placed salvation in individual's control, increasing confidence in the ability of scientific knowledge to change things for the better, and technological changes that made the scope of communities geographically wider. All of these came together to foster a novel humanitarian sense amongst people – expanding empathy beyond the traditional local borders and into new imagined communities.<sup>6</sup> Since this time, the humanitarian desire has come to embody itself in an array of institutions, laws, practices, and technologies. The contemporary humanitarian landscape is a diverse mixture of public and private, local and global, formal and informal actors.

A first source of complexity is therefore the fact that the “actors in the humanitarian world are often uncoordinated, spontaneous, unsolicited, and disparate.”<sup>7</sup> The Haitian earthquake, for instance, had over 900 aid organisations that were registered with the UN – plus all those who had not registered.<sup>8</sup> Humanitarian operations are typically put together incredibly quickly and it is often unclear precisely which actors will be responsible for what. The logistics of humanitarian operations involve a number of different levels, ranging from the international to the national to the local. A variety of different components also need to be coordinated to produce an effective humanitarian assemblage: materials, information on the ground, finance, people, and knowledge from past

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<sup>5</sup> Barnett, *Empire of Humanity: A History of Humanitarianism*, 1.

<sup>6</sup> *Ibid.*, 49–56.

<sup>7</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, 9.

<sup>8</sup> Barnett, *Empire of Humanity: A History of Humanitarianism*, 3.

experiences.<sup>9</sup> These crisis responses entail coordinating a variety of agencies: international institutions, local relief agencies, national governments, individual volunteers, privatised logistics corporations, and in situations with poor security, even privatised military contractors.<sup>10</sup> This linkage to conflicts (as many humanitarian situations are) increases the complexity of the situation and the necessary sophistication of the response.<sup>11</sup>

A second major source of complexity is the uncertainty and lack of information in most humanitarian crises. “Information is the foundation upon which the humanitarian supply chain is designed, formed, and managed.”<sup>12</sup> At the most general levels, crises are plagued by uncertainty over the size, the tendencies and the nature of a crisis.<sup>13</sup> These contemporary crises often embody incalculable risks – meaning preventative measures are incapable of sufficiently dealing with them.<sup>14</sup> In addition, there is uncertainty about what will be available (in terms of labour, capital, and existing infrastructure). The needs and supplies of resources can frequently fluctuate, and the very infrastructure and environment that the relief work is operating in is typically altered by the crisis (the devastation wrought by an earthquake, for instance).<sup>15</sup> There is not only a requirement to know what the local needs are, but also to know what the local supplies are. As procurement is one of the most difficult tasks for humanitarian relief, being able to find supplies locally saves both in terms of costs and time. Key pieces of information are often not well understood. The demand for resources, for instance: what precisely is needed for a successful operation in the circumstances? (Experience helps, but is insufficient.)<sup>16</sup> Conversely, data about supply is needed: from where are resources (food, money, blankets, labour) going to come from? Therefore, unlike a standard business supply chain, humanitarian supply chains are much more uncertain about

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<sup>9</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, 48.

<sup>10</sup> Singer, “Strange Brew: Private Military Contractors and Humanitarians.”

<sup>11</sup> Keen, *Complex Emergencies*.

<sup>12</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, 90.

<sup>13</sup> Marsden, “Determining the Role of Geospatial Technologies for Stigmergic Coordination in Situation Management: Implications of the Wireless Grid,” 1.

<sup>14</sup> Jasanoff, “Beyond Calculation: A Democratic Response to Risk,” 16.

<sup>15</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, 12–13.

<sup>16</sup> *Ibid.*, 13.

the basic parameters of what is required. There are difficulties both in assessing *who* is in need of assistance, and *how* they can be helped. The latter ranges from understanding what is needed to understanding how to get it there (a process which can involve unorthodox means such as air-drops and loading elephants).<sup>17</sup> Gathering data is therefore one of the key challenges and those in the field have the best access to this information.<sup>18</sup> Yet these sources are often uncoordinated, making centralising data into a single overarching vision of the crisis more difficult. Moreover, this information can and often is politicised by the various actors involved.<sup>19</sup> Aid agencies may portray situations as worse than they actually are, while governments may downplay the crisis in order to avoid international attention. The different incentives to manipulate data add to the uncertainty and complexity of the situation.

The final source of complexity is the dynamism of the situation. Humanitarian crises are constantly evolving situations that surpass the capacity of static information systems to respond. Instead, a dynamic information management network is necessary to equal the dynamism of the situation. In addition, these contemporary situations comprise complex networks of social, economic, and political relations between a variety of heterogeneous groups. The effects of any humanitarian action in such a complex system are necessarily multiform and unpredictable to some degree.<sup>20</sup> Combined with the urgency of responding to a humanitarian crisis, and the inevitably political nature of every intervention, the complexity of organizing a response quickly becomes very complex.<sup>21</sup>

All of these complexities are tied together in the logistical requirements of humanitarian operations. In particular, the initial stages of a crisis are the most crucial and the most intense for establishing the logistical structure for a humanitarian operation. At this point, operations need to be set up and established as quickly as possible in order to get relief out to the affected

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<sup>17</sup> Ibid., 15.

<sup>18</sup> Ibid., 103.

<sup>19</sup> Keen, *Complex Emergencies*, 156-162.

<sup>20</sup> Duffield, *Global Governance and the New Wars: The Merging of Development and Security*, 252.

<sup>21</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, 9-10.

communities. There is also a plethora of issues to be handled at this point, “such as obtaining visas, negotiating landing rights, getting customs clearance, [and] arranging licenses for vehicles.”<sup>22</sup> Collecting information about the situation, about the affected population, about the available resources, and the means to bring all these aspects together – this forms the crux of the complexity issue for humanitarian agencies. The importance of logistics for humanitarian situations was recognised in a McKinsey report in 2000, which went on to instigate widespread changes in the International Federation of Red Cross and Red Crescent Societies (IFRC). The logistics of humanitarian relief and disaster response were given their own department, in recognition of their importance for effective humanitarian action.<sup>23</sup> The focus here will not be on the entire logistical network that goes on behind the scenes of a humanitarian response. Rather, the focus here will be on the immediate coordination of resources and how the technology of crisis mapping allows both humanitarian organisations and affected populations to change the way they approach a crisis situation. This is the particularly crucial hinge upon which much of the success of the aid operation hangs. As one expert notes, “for those organising the immediate response, one of the biggest challenges [is] getting information (assessment) about the situation on the ground. They [need] to know what [is] affected, what [is] needed, what resources [are] available, and, as aid [begins] to arrive spontaneously, what [is] coming and when.”<sup>24</sup>

### **A History of Crisis Response**

With the complexity of modern crisis situations, the primary demand is therefore some means to ‘see’ the crisis. Some means, in other words, to quickly gather, collect, organise, and analyse data about the real-time fluctuations in the wake of a crisis. Historically, the technology of mapping has played a key role in providing and organising this information. (There is evidence, in fact, that maps existed before language as a means of communication.)<sup>25</sup> Yet, as will be shown, it is only

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<sup>22</sup> Ibid., 81.

<sup>23</sup> Ibid., 53.

<sup>24</sup> Ibid., 89.

<sup>25</sup> Marsden, “Stigmergic Self-Organization and the Improvisation of Ushahidi,” 10.

recently that crisis mapping has taken on a form conducive to effective assistance in the midst of a crisis. For the most part, the historical use of maps has been to aid post-hoc assessments. Today's crisis mapping technologies are the first to function as real-time visualisations of the situation, thereby allowing actors to more fully see a crisis.

Initial attempts to map crises were done after the events, to provide the public with a geographical representation of what had occurred, and to provide organisations with a different perception to analyse. Oftentimes, crisis mapping represented riots, with the 1863 draft riots in New York and the 1967 riots in Detroit both being mapped for local media.<sup>26</sup> Perhaps the most historically famous case of crisis mapping though was John Snow's use of geographical patterns in determining the source of cholera in mid-1800s London. Countering the then dominant miasma theory (which argued cholera spread through bad air), Snow plotted the cases of cholera on a map and found support for the germ theory of cholera and correctly pinpointed the source in a nearby water pump. The spatial analysis and geographical representation played no small role in justifying Snow's claims, and the local council prohibited usage of the pump as a result.

Later efforts at crisis mapping began to incorporate some ostensibly predictive aspects - using conceptual models to articulate the spatial and temporal dynamics of disasters.<sup>27</sup> For instance, aid organisations in the 1970s employed models to represent ecological dynamics. These were used in an effort to systemise the relationships involved in drought situations. How were pastoral practices related to international trade regimes related to weather patterns? The models provided the agencies with some means of systematically thinking about how interventions within the humanitarian situation would affect the rest of the system.<sup>28</sup> Yet most of these efforts at crisis mapping were for early warning systems,<sup>29</sup> creating, for instance, geographical models of how a drought would likely generate a particular spatial distribution of famine. More recent projects have

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<sup>26</sup> Toscano, "Icon Index Insurrection, or, On the Fascinating Futility of Riot Mapping."

<sup>27</sup> Powell, *An Introduction to the Natural History of Disaster*; Dynes, *Organized Behavior in Disaster*.

<sup>28</sup> Jasanoff and Wynne, "Science and Decisionmaking," 65.

<sup>29</sup> Druke, *New Humanitarian Partnerships with Technological Communities*.



coded and visualised civil wars in an effort to disaggregate country-level data and make clearer the relationships between conflict, resources, and ethnicities.<sup>30</sup> More recent crisis mapping software is also being used prior to disasters – to catalogue the existing infrastructure of schools, water pipes, and hospitals. In developing countries, where this information is often scarce, it can be crucial for responding effectively to disasters.<sup>31</sup> These more recent crisis maps were significantly aided by the emergence of remote sensing technology – inaugurated by the launching of the first remote sensing satellite in 1999.<sup>32</sup> These technologies generated the geo-referenced data that today’s crisis maps rely upon, and were quickly developed with military applications, particularly as part of the counterinsurgency effort in Afghanistan.<sup>33</sup>

The current stage of crisis mapping technology arose in the last decade. The possibility of this crisis mapping relies upon the technological platform provided by the recent spread of mobile technology throughout the developing world. The last ten years have seen a rapid and pervasive diffusion of technologies – significantly, not only at an elite level, but also at the most general levels. As of 2010, there were over 4 billion mobile phones in operation, at a level of 78 for every 100 people.<sup>34</sup> Over a billion people now have access to the internet, and both of these numbers are continuing to grow rapidly.<sup>35</sup> More importantly, they are spreading quickest in developing countries – areas that are now leaping over the need for large fixed infrastructural systems.<sup>36</sup> What this has meant is that technology now permeates many everyday social relations to an unprecedented degree. The world we live in can no longer (if it ever could) be considered a solely social sphere, disconnected from the materiality of the physical world and the implication of technological objects in the organization of human relations.

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<sup>30</sup> Weidmann and Kuse, “WarViews: Visualizing and Animating Geographic Data on Civil War.”

<sup>31</sup> Anstey, “Empowering Citizen Cartographers.”

<sup>32</sup> *Mapping the Maps: A Meta-Level Analysis of Ushahidi & Crowdmap*, 6.

<sup>33</sup> Beck, “Remote Sensing and GIS as Counterterrorism Tools in the Afghanistan War.”

<sup>34</sup> *Measuring the Information Society 2011*, 1.

<sup>35</sup> Coyle and Meier, *New Technologies in Emergencies and Conflicts: The Role of Information and Social Networks*, 6.

<sup>36</sup> Kolodzy, “Wireless Telecommunications.”

As such, there has been a revolution in social interaction and capacities with the rise of mobile phone technology. Their distributed infrastructure has been used to monitor election results in real-time, to chart medical inventories, track mosquito net distribution, provide mobile banking, and other important services.<sup>37</sup> With the simultaneous rise of Geographic Information Systems (GIS), there came a push for more user-centric and interactive mapping technology. This 'neogeographic' school emerged in the 2000s and formed one of the key steps towards modern crisis mapping.<sup>38</sup> In its broadest form, neogeography refers to "a blurring of the distinctions between producer, communicator and consumer of geographic information."<sup>39</sup> The expansion and incorporation of users into the creation of maps was an important practical and theoretical step towards the generation of crisis mapping software.

### **A History of Crisis Mapping**

Today's crisis mapping technology brings real-time information together in order to produce geographical representations. Instead of text, which can be fairly time-consuming to cognitively digest in urgent disaster situations, maps have been recognised for some time as useful mediums for communicating information to those in the field. "Maps not only create a common language but can also be loaded with information about the resources available along the way. Maps can identify in advance information that needs to be regularly updated and invite the users to also become a source for those pieces of information."<sup>40</sup> As research has shown, maps can also act as a computational tool - easily carrying out spatial calculations that would be otherwise laborious.<sup>41</sup> In trying to efficiently set up logistics operations and distribute resources along often improvised transportation networks, these visual representations are immensely helpful. Part of their capacity to assist in this is through their bird's-eye view perspective that they provide: the

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<sup>37</sup> Livingston, *Africa's Evolving Infosystems: A Pathway to Security and Stability*, 12-14.

<sup>38</sup> Liu and Palen, "The New Cartographers: Crisis Map Mashups and the Emergence of Neogeographic Practice."

<sup>39</sup> Goodchild, "NeoGeography and the Nature of Geographic Expertise," 82.

<sup>40</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, 109.

<sup>41</sup> Hutchins, *Cognition in the Wild*, 61-65.

map “presents the world in a perspective that can never be achieved from any actual viewing point.”<sup>42</sup> From here, new relations and new patterns emerge, shifting the way in which the crisis is seen.

The information that is visualised varies from crisis to crisis, but encompasses a wide range of events. The Libyan crisis map, for instance, included “updates on military actions, evacuations, movement of refugees, and street fighting.”<sup>43</sup> A simulated earthquake exercise aggregated information on food, water, shelter, health and medicine resources, people trapped and the location of functioning hospitals, among others. One key question is over what data should be collected.<sup>44</sup> As with any map, there are political choices about how to represent the reality of the situation.<sup>45</sup> The pragmatic character of crisis maps is clear here, insofar as what is needed for aid agencies is not a complete and total representation of a crisis – but instead, a simplified yet accurate representation of the most relevant elements.

While the focus here will be on the technological aspects, to be clear, crisis mapping also involves the efforts of numerous individuals (for instance, an institutionalised volunteer grouping has recently been established).<sup>46</sup> The approach here, however, is to examine technology as it is implicated within these social networks. As with the other case studies, the question is what function does this representational technology carry out, and how does it produce new capacities for cognition and action that are unthinkable without the introduction of this new technology? As opposed to the other technologies examined in this thesis, crisis mapping’s advantage over human cognitive capacities lies primarily in its ability to collect, filter, and organise mass amounts of data rapidly and efficiently – as opposed to providing calculative abilities beyond human means.

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<sup>42</sup> Ibid., 108.

<sup>43</sup> Ungerleider, “Here’s a Map of the Humanitarian Crisis Hotspots in Libya (Don’t Tell Gaddafi).”

<sup>44</sup> The PLoS Medicine Editors, “Digital Humanitarianism,” 1.

<sup>45</sup> Pickles, *A History of Spaces: Cartographic Reasoning, Mapping and the Geo-coded World*, chap. 2.

<sup>46</sup> Meier, “Changing the World One Map at a Time.”

### *Aggregation Technologies*

Initial efforts to try and leverage the new technologies and new conceptualisations of mapping in order to assist in humanitarian situations were made over the period of 2000-2010. A large number of examples exist from this time period, but one will suffice to show the level of development and how the technologies of crisis mapping were shifting in the latest generation. The focus in this period was on aggregating information and employing it as a shared, static representation amongst humanitarian actors.

The institutional origins of this experiment began during the eastern Zaire crisis of 1996, when the UN created the United Nations Joint Logistics Centre (UNJLC) in order to coordinate and manage the incoming humanitarian resources.<sup>47</sup> The specific mandate of the UNJLC was not to act as another UN agency, but instead to function as a coordination mechanism between existing humanitarian agencies.<sup>48</sup> In this regards, the staff worked both to develop new means to coordinating logistics and to make the most efficient use of limited resources. In 2002, in the wake of the American invasion of Afghanistan, a website was established for the UNJLC, designed specifically for assistance in coordinating logistics in Afghanistan. The website included information and was constantly,

“...updated and made more comprehensive to reflect planned regional and strategic airlifts, status of transportation corridors, availability of warehousing, rates for commodities and transport, and details like the status of border crossings.”

The goal of the website was relatively straightforward: to provide a centralised hub for useful information that humanitarian agencies could use in their logistics planning.<sup>49</sup> The UNJLC Chief Information Officer, Nigel Snoad, states that the aim was to anticipate the needs of the humanitarian groups and to

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<sup>47</sup> Clark, Fernandez, and Zhang, “Technology and Humanitarian Actions: A Historical Perspective,” 17.

<sup>48</sup> Tomasini, *Managing Information in Humanitarian Crises: The UNJLC Website*, 1.

<sup>49</sup> Kaatrud, Samii, and Van Wassenhove, “UN Joint Logistics Centre: A Coordinated Response to Common Humanitarian Logistics Concerns,” 12.

put this data up on the website for everyone to access.<sup>50</sup> Maps were also provided – particularly of roads – but most were out-of-date and inaccurate after years of conflict and weather had made some roads impassable.<sup>51</sup> Notable here is that the UNJLC was largely a passive aggregator of information, rather than an active coordinator. (Though on the odd occasion it also did this – negotiating between local transport businesses and the humanitarian community, for instance.)

Yet the surprise of 9/11 and the speed of the ensuing Afghanistan invasion meant that the UNJLC website had to be constructed quickly by a local programmer.<sup>52</sup> The earliest versions of this site were too slow, constrained to particular browsers, and in later generations, were quickly overloaded with too much information coming in.<sup>53</sup> Data frictions and computational frictions were adding up. Collecting data typically required establishing trusted contacts with organisations on the ground and relying on military intelligence in order to generate up-to-date information.<sup>54</sup> Both were difficult and time-consuming, and presented a real limit on the speed and breadth of the information the UNJLC could accurately access. With later developments in crisis mapping, we will see that one of the most unique features becomes the ability to very easily collect data from many individuals on the ground, thereby overcoming the data frictions of this logistics information system. For those in the field (as opposed to regional headquarters), most found the website usage was too slow and too intermittent to be of much use. Internet connections were spotty, and the technology was not available to make the website a ubiquitous tool. It took the rise of mobile phone technology in the past decade to make web access pervasive. With it, the threshold of usability was passed for web-based information hubs in the field. In later iterations of the website, the UNJLC began to take on a forecasting role – researching and producing projections for concerns about fuel prices, for instance.<sup>55</sup> The website began to incorporate a variety of maps for all sorts of

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<sup>50</sup> Tomasini, *Managing Information in Humanitarian Crises: The UNJLC Website*, 2.

<sup>51</sup> *Ibid.*, 4.

<sup>52</sup> *Ibid.*, 3.

<sup>53</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, 110-1.

<sup>54</sup> *Ibid.*, 112.

<sup>55</sup> Tomasini, *Managing Information in Humanitarian Crises: The UNJLC Website*, 7.

relevant data. In the words of one researcher, “These smart maps with embedded data quickly found their way to the walls and desks of the entire humanitarian community in one of the world’s largest humanitarian relief efforts.”<sup>56</sup> Yet for all its innovation in digital humanitarian logistics, the UNJLC remained oriented towards providing government agencies and NGOs with information. With the emergence of later generations of crisis mapping, this would be transformed to include multi-way communication and integration of the local populations.

### *Interactive Technologies*

A major shift towards greater interactive capacities occurred with a suggestion from a Kenyan blogger. In the midst of post-election violence there in 2007-2008, Ory Okolloh blogged a small question: “Guys looking to do something - any techies out there willing to do a mashup of where the violence and destruction is occurring using Google Maps?”<sup>57</sup> From this suggestion, 15-20 volunteers worked to produce a program called Ushahidi (meaning ‘testimony’ in Swahili) and the website was operational within a week. During the period of violence, over 45,000 people participated and hundreds of accounts of violence were posted.<sup>58</sup>

The software of contemporary crisis mapping (Ushahidi being the most famous) allows individuals to submit reports to a centralised computer system. It aggregates real-time information from SMS text messages, Twitter reports and other social media into a Google Maps-based geographical representation. In addition, it distinguishes itself from other crowdsourcing initiatives by mandating a geolocation of any information received.<sup>59</sup> From its initial development in 2007, Ushahidi has “since been used in Afghanistan, Colombia, the Democratic Republic of the Congo (DRC), Gaza, India, and Lebanon, and [...] Mozambique.”<sup>60</sup> More recently, crisis mapping has manifested in Liberia, Sudan, Egypt, and the

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<sup>56</sup> Ibid., 11.

<sup>57</sup> Okolloh, “Update Jan 3 11:00 Pm.”

<sup>58</sup> Marsden, “Stigmergic Self-Organization and the Improvisation of Ushahidi,” 3.

<sup>59</sup> Munro, “Crowdsourcing and the Crisis-Affected Community,” 14.

<sup>60</sup> Coyle and Meier, *New Technologies in Emergencies and Conflicts: The Role of Information and Social Networks*, 23.

Libyan revolution.<sup>61</sup> Rebels in Libya made use of mapping software to orient their mortar fire and target government tanks.<sup>62</sup> It has been “used in South Africa to track xenophobic violence against immigrants. A more advanced version of the software was deployed to monitor violence in the Eastern Congo in 2009.<sup>63</sup> Al Jazeera-International used it during the Israeli invasion of Gaza in 2009. Furthermore, the Ushahidi platform has been used to coordinate relief efforts following the devastating earthquake in Haiti and the wildfires in Russia.”<sup>64</sup> By 2012, Ushahidi had been used to produce maps in 140 countries.<sup>65</sup>

The essential reason behind crisis mapping’s rapid diffusion is that, as we have seen, information is crucial to any humanitarian operation. Traditionally, the means for generating information about a crisis has relied on painstaking and labour-intensive processes:

“A network of people collects information by going into communities. They compile readily available data by speaking with the locals and observing the situation. For example, staff members in the field would report about fuel prices, exchange rates, security and distances, and transportation costs. All this assumes there are reliable means of communication for them to share the data with analysts.”<sup>66</sup>

Crisis mapping radically transforms the nature of information gathering and the production of situational awareness. Rather than a top-down search for information, real-time data on the situation can be built from the ground-up. More than this though, modern crisis mapping moves beyond just aggregating knowledge about a situation, and instead functions to represent a situation and provide the capacity to interact with it. As one Egyptian activist stated, “With Ushahidi, you

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<sup>61</sup> <<http://libyacrisismap.net>>

<sup>62</sup> Coghlan, “Google Points Way for Libyan Rebel Artillery in Fight Against Gaddafi.”

<sup>63</sup> Diamond, “Liberation Technology,” 11.

<sup>64</sup> Livingston, *Africa’s Evolving Infosystems: A Pathway to Security and Stability*, 21.

<sup>65</sup> Meier, “Ushahidi as a Liberation Technology,” 95.

<sup>66</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, 105.

have the big picture immediately.”<sup>67</sup> A meta-level analysis of recent crisis mapping invokes a similar shift:

“While these professional actors were, for many decades, most often confronted by an information vacuum following a crisis, which meant that they were tasked with providing initial assessments,, they are now confronted with a deluge of multi-media, user-generated content shared on multiple social media channels, often in real-time.”<sup>68</sup>

The potential benefits of contemporary crisis mapping are therefore clear. Foremost is its ability to allow for real-time coordination – not only of organizations and their relief efforts, but also of individuals in the affected communities. In terms of existing humanitarian organizations, it allows for a clearer picture than ever before of the situation on the ground. This means a more effective and efficient use of finite resources, as well as a potentially quicker response to the situation. The accuracy of matching needs to supplies and the rapidity of the response are both key qualities of effective humanitarian relief.<sup>69</sup>

As a piece of software, the original crisis mapping technology was grounded upon a merging of the geographical software of Google Maps and OpenStreetMap (OSM) with the text-messaging software of Frontline SMS. The former provided the malleable geographic representations, while the latter created the capacity for users to input data themselves (rather than centrally by an administrator). As opposed to climate change modelling, crisis mapping requires nimble, cheap, and minimal hardware in order for it to be effective in a disaster situation. Frontline SMS software, in particular, is designed to be run on a single computer even without an internet connection, thus making it well-suited in areas of poverty and destroyed infrastructure.<sup>70</sup> Google Maps, on the other hand, was coded in such a

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<sup>67</sup> Meier, “Ushahidi as a Liberation Technology,” 105.

<sup>68</sup> *Mapping the Maps: A Meta-Level Analysis of Ushahidi & Crowdfunder*, 5.

<sup>69</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, 95.

<sup>70</sup> Marsden, “Stigmergic Self-Organization and the Improvisation of Ushahidi,” 15.



way as to be eminently open to modification by users, and this ease was eventually institutionalised as such in its Application Programming Interface (API).<sup>71</sup> Frictions between computational requirements and the demands of speed remain though, and have led to developments in the basic crisis mapping software. The original Ushahidi software required installation on a server, necessitating relatively large and expensive equipment and the time to set up the software. This meant that Ushahidi was largely too slow to respond to the immediate needs of a humanitarian crisis. In response, a cloud-based crisis mapping program was made available (Crowdmap) as well as a downloadable and upgraded version of the original crisis mapping software (SwiftRiver). In all these developments, the driving force has been the friction between the demands of, on the one hand, the computational and data requirements of the software versus, on the other hand, the demands of easy access and mobility of the service. The former requires some degree of material embodiment (even cloud-based services require internet access), while the latter seeks to minimise this physical footprint as much as possible.

Yet while the software and hardware components are important, by far the most significant technological infrastructure of crisis mapping is the global dispersal of mobile phones. As mentioned earlier, mobile phones have rapidly spread throughout the world, and are particularly gaining widespread dispersal in developing countries. Most of these countries are seeing exponential growth in mobile phone usage. This spread of mobile phones has led to two shifts: the dispersal of means of communication (via mobile phones and wireless internet) and the decentralisation of creators of information (towards the affected populations).<sup>72</sup> The result is a surge of information that can potentially overwhelm traditional organisational means of handling data. Therefore, one of the key data frictions with the new crisis mapping has been the emergence of mass amounts of information that is (and will be) employed in relief operations. By virtue of opening up information supply to a much wider range of actors than is typical of humanitarian agencies, crisis mapping's most serious problem has become how to

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<sup>71</sup> Dalton, "Mashing-up Maps: Google Geo Services and the Geography of Ubiquity," 89-92.

<sup>72</sup> The PLoS Medicine Editors, "Digital Humanitarianism," 1.

ensure the validity of incoming information. This leads to one of the major computational frictions within crisis mapping, which is the need to balance out the speed of information with the accuracy and trustworthiness of information. Rumours and deliberate lies can be just as easily spread as accurate information, and the often anonymous nature of reports makes verification difficult.

More frictions with crisis mapping's knowledge production arise in certain crisis situations where there is the issue of information being used against the sender – the Sudanese and Iranian governments, for instance, have used technology to trace back and arrest people sending information.<sup>73</sup> To counter this, Libyan crisis mapping information was open in real-time to only a select group of people, with information becoming publically available only after a 24-hour delay. Between the risk of information being misappropriated and the difficulty in verifying information, a number of tensions arise that are in fact intrinsic to the nature of crisis mapping. In other words, they can be mitigated, but never eliminated. Specifically, there is a tension in crisis mapping between the necessary publicity of the information, the secrecy of the sender, and the simultaneous need to verify the validity of the sender. A further complication arises with the tension between the need for real-time information, and the delay it takes to verify information.<sup>74</sup> Taken together, any one of these tensions can be resolved to some degree, but not all three at the same time. The very functions of this technology create a necessary impasse which guides future development. A number of means have been created to lessen this impasse, including the use of photographs as visual evidence, the use of multiple reports to corroborate claims, and the use of consciously bounded sets of information producers.<sup>75</sup> In this latter case, rather than allowing anyone to submit, only specific individuals are allowed by virtue of being trustworthy sources. The reputational status of actors becomes a key variable here – that is to say, the linkages within a social network.

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<sup>73</sup> Coyle and Meier, *New Technologies in Emergencies and Conflicts: The Role of Information and Social Networks*, 14.

<sup>74</sup> *Ibid.*, 15.

<sup>75</sup> Bock, *The Technology of Nonviolence: Social Media and Violence Prevention*, chap. 9.

### *Automated Technologies*

The data frictions involved in this surge of information are compelling development towards increased automation. The raw data provided by crisis mapping requires analysis in order to be employed usefully, and speed is of the essence here.<sup>76</sup> Typically this is done by trained individuals, though increasingly automated analytics are being implemented as well. Crisis mapping software is moving beyond just a raw presentation of incoming data, and instead supplementing this with a filtered, calculated, and organised presentation of the influx of information. In other words, beyond acting as a mere repository of information, crisis maps are beginning to take on a properly adjunctive function for cognition. The necessity of this automation can be seen in, for instance, the fact that twenty million Hurricane Sandy-related tweets were generated over the course of that storm.<sup>77</sup> Such quantities of data simply overwhelm even well-trained teams of disaster responders. This quantity of data not only necessitates some form of automated analysis, but also makes it possible. Earlier attempts at pattern recognition relied on relatively few data points, making it difficult (if not impossible) to extract useful information.<sup>78</sup> With the large datasets emerging now, meaningful relationships are becoming possible to unearth.

Further developments in crisis mapping software are therefore increasingly automating specific functions and making use of computing power to achieve actions unattainable by humans alone. For instance, the data from crisis mapping is now being combined with data analytics software and data visualization programs included in the upgraded program SwiftRiver.<sup>79</sup> At its base,

“SwiftRiver is designed to accomplish three tasks: structure unstructured data, conditionally filter and prioritise real time content, and provide context, especially location. SwiftRiver accomplishes these tasks through applications for natural

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<sup>76</sup> Ibid., 106.

<sup>77</sup> Meier, “The Problem with Crisis Informatics Research.”

<sup>78</sup> Bock, *The Technology of Nonviolence: Social Media and Violence Prevention*, 106.

<sup>79</sup> <<http://swiftly.org>>

language/artificial intelligence processing, SMS and Twitter data-mining, and information source verification.”<sup>80</sup>

Part of the automation developments stem from the tension mentioned earlier between the quantity of data and the veracity of data, with analytics and tagging being employed in order to automatically compare incoming (unverified) information with previous (verified) reports – allowing for some mitigation of the accuracy problem. This involves distributed cognition, i.e. the outsourcing of calculative processes to some sort of technology. In this case, the initial analysis of the accuracy of a new piece of information is being automated and judged by a piece of software rather than a human user. This is not to discount the continued role of individuals in verifying information though, as other features of this software include a simple voting system that allows users to collectively judge accuracy. Other systems are looking to automate the process of translation, bypassing the expensive and relatively rare resource of human translators.<sup>81</sup> Yet this automation brings its own biases in, as most machine translation has been focused on dominant languages and languages in developed countries (where economic incentives exist to develop the translation algorithm).<sup>82</sup> As a result, developing countries and minority languages suffer from less effective automated translation processes.

Further developments allow for this data analysis to be combined with software that automatically determines the location focused on by news stories, as well as sentiment analysis which monitors emerging trends in news stories and user reports. Other technical advances are automating the categorization of incoming reports, and the translation of material as well.<sup>83</sup> Bayesian modelling is being employed in order to automatically sort incoming information, and categorise it according to the type of event under discussion.<sup>84</sup> All of these technical developments are applications of statistical techniques that uncover otherwise

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<sup>80</sup> Marsden, “Stigmergic Self-Organization and the Improvisation of Ushahidi,” 3.

<sup>81</sup> Carbonell et al., “Language Technologies for Humanitarian Aid.”

<sup>82</sup> Ibid., 120.

<sup>83</sup> Meier, “What Is Crisis Mapping? An Update on the Field and Looking Ahead.”

<sup>84</sup> Bock, *The Technology of Nonviolence: Social Media and Violence Prevention*, 110.

imperceptible patterns in the real-time flow of data. With this automation, crisis mapping is not simply a replacement of existing human capacities, nor is it reducible to human interpretations of it. Instead, crisis mapping is an independent factor in its own right which is now altering how crisis situations are perceived and responded to. It is transforming the sociotechnical assemblages of humanitarian crises.

Yet this overcoming of incoming data frictions creates its own significant computational frictions in crisis mapping: the need to have accurate and quick information versus the computational demands of analysing this data. Techniques like machine learning, natural language parsers, automated translation, semantic analysis, etc. all require intensive levels of computation (or do not even exist yet).<sup>85</sup> In the Haitian situation, obsolete browsers, old computers, and even the internet usage policies of humanitarian organisations, all fundamentally constrained how crisis mapping could be used.<sup>86</sup> A further tension exists within the balance between computing power (of smartphones, for instance) and battery power.<sup>87</sup> While computing power has increased exponentially, battery power remains a fundamental constraint. Increasing the former means decreasing the latter – an important consideration for areas with widespread power outages. The combination of outdated technology, with the demands of some of the new automated features will form one of the key tensions for further development in crisis mapping.

A current trend in developments though is towards incorporating additional mechanisms for generating a clearer picture of crisis. For instance, recent research has used mobile phone data to track population movements in the wake of crisis situations. Initial estimates suggest a real-time accuracy that surpasses existing methods of tracking data and that can match up to reconstructive surveys after the crisis.<sup>88</sup> However, such methods of data collection include notable political

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<sup>85</sup> Meier, “The Problem with Crisis Informatics Research.”

<sup>86</sup> Morrow et al., *Independent Evaluation of the Ushahidi Haiti Project*, 5.

<sup>87</sup> Carbonell et al., “Language Technologies for Humanitarian Aid,” 133.

<sup>88</sup> Bengtsson et al., “Improved Response to Disasters and Outbreaks by Tracking Population Movements with Mobile Phone Network Data: A Post-Earthquake Geospatial Study in Haiti,” 5.

biases insofar as they underestimate the movements of those without mobile phones (youth, the elderly, and the poor).<sup>89</sup>

### **Seeing Crises**

With the advances made possible by this technological platform, crisis mapping software is increasingly being employed by a variety of actors in humanitarian crises in order to extend their cognitive capacities. Unlike climate modelling (which makes nonlinear complex systems intelligible) and financial modelling (which created a general equivalent to simplify a variety of market transactions), crisis mapping primarily extends cognition by aggregating, sorting, and analysing mass amounts of real-time data.

In the midst of a crisis situation, information is one of the most significant resources. While the traditional problem has been the dearth of information and the effort necessary to recover some overarching view, today the problem is of the abundance of information and the effort necessary to filter this incoming real-time stream into actionable knowledge. While crisis mapping remains relatively new in comparison to the other representational technologies in this thesis, it is nevertheless already showing a consistent shift towards greater automation, towards wider informational inputs, and towards mitigating the material frictions involved in computation.

As both the computational infrastructure expands (via diffusion of mobile technology and eventually smartphones) and as the social habits of inputting data via social media are incorporated (a process well underway in developed countries), crisis mapping's data requirements and frictions are consistently growing. Increasing automation is the likely result, with a number of recent experiments highlighting the possibilities. The combination of machine learning algorithms along with monitoring of internet and infrastructure data has been demonstrated to be capable of alerting international organisations about troop movements in conflict zones as well as violations of ceasefire agreements. "In this way, rapid deductive cycles made possible through technology can contribute to rapid

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<sup>89</sup> Ibid.

inductive cycles in which short-term predictions have meaningful results for actors on the ground.”<sup>90</sup> Similarly, post hoc studies of the Haitian earthquake showed that the 2010 cholera outbreak could have been detected significantly earlier via analytics of the large quantity of social media data.<sup>91</sup> Such incipient developments in the computational realm are likely to continue transforming the ways in which crises are perceived by actors. The data frictions involved in the rise of big data for humanitarian situations are being slowly overcome through developments upon the computational platform.

Yet for all these technological advancements, problems still exist in translating ‘sensing into shaping’, as actionable information is not always employed.<sup>92</sup> The collection of data is progressing quickly, and the analysis of such data is rapidly following on this progress, yet the take up of this information by relevant actors often still remains within its infancy.<sup>93</sup> Nevertheless, a number of examples show how this technology is already being employed to generate shifts in how crises are perceived – by both international organisations and by crisis-affected communities themselves.

### **The Rise of Situational Awareness**

In outlining the main effects that this representational technology is having, one must distinguish between two groups. The first is the institutional perspective: how humanitarian organisations are employing this cognitive adjunct in their operations. The second is the local community’s perspective: how crisis mapping is shifting their perceptions of the crisis they find themselves in. For the former, crisis mapping is primarily about the production of situational awareness for their organisations – a (potentially) real-time overview of the crisis. For the latter, crisis mapping primarily changes their perception of the crisis by allowing them to extricate themselves out of their local situatedness, and take a wider and common perspective on the crisis. Crisis mapping here allows for stigmergic behaviour: the

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<sup>90</sup> Robertson and Olson, *Sensing and Shaping Emerging Conflicts*, 13.

<sup>91</sup> *Humanitarianism in the Network Age*, 27.

<sup>92</sup> Robertson and Olson, *Sensing and Shaping Emerging Conflicts*, 43.

<sup>93</sup> *Ibid.*, 14.

ways in which “actors can affect the behaviour of other members of the community through the traces that their activities leave in shared artefacts”<sup>94</sup> – in this case, the collectively produced representation of the crisis situation. As a rapidly evolving technology, there is also the future potential for crisis mapping to take on predictive functions. The example of Ushahidi’s use in the wake of the Haitian earthquake will illustrate where these future developments may head.

#### *Situational Awareness*

The primary novel capacity of crisis mapping, and its deployment by emerging cognitive assemblages, is to generate situational awareness of an ongoing crisis. As one researcher aptly describes it,

“Ushahidi’s technology can be used by organisations to map what is happening, not unlike what one sees in World War II movies, where generals smoke cigars and pipes and push what appear to be toy tanks, planes, and ships to different locations on huge map tables as their strategy evolves over time. Ushahidi provides a digital version of such a map table, but it works even better in combining textual information with pictures and videos, along with an ability to communicate quickly with large groups of people who submitted the information posted onto the map.”<sup>95</sup>

In achieving this, crisis mapping makes use of a number of tools of cartographic visualisation in order to make a wide variety of knowledge available to the user at a glance. Techniques like query (where clicking on something leads to more information), reexpression (allowing the user to alter what information appears according to categories like medicine or violence), and linking (where non-spatial graphics are attached to objects), have all been employed in crisis maps.<sup>96</sup> These tools help generate the subtleties of situational awareness, which is

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<sup>94</sup> Marsden, “Stigmergic Self-Organization and the Improvisation of Ushahidi,” 5.

<sup>95</sup> Bock, *The Technology of Nonviolence: Social Media and Violence Prevention*, 123.

<sup>96</sup> Hallisey, “Cartographic Visualization: An Assessment and Epistemological Review,” 353–354.



increasingly mediated by computer representations – and the visual interfaces of crisis maps.<sup>97</sup> As was shown earlier, at least some organisations are already altering their internal structures in order to take into account the influx of data coming from crisis mapping.<sup>98</sup>

Crisis mapping's effects are not only technical but also shaping possible behaviours.<sup>99</sup> For instance, the clearer the information about relief work is, the easier it is to maintain the humanitarian principle of neutrality by clarifying how aid is being distributed. (This is a problem even in the response to natural disasters, since there are always existing political divisions in these areas.) The entire logistical chain can be made more efficient by having a clearer sense of the different roles and needs required. In addition, the information also assists with donors and the media – making it more transparent how relief is being distributed.

This raises the important issue (to be discussed more in the concluding chapter) that crisis mapping, in its visual form, elides representational and non-representational functions. A crisis map purports to provide an accurate image of an on-going crisis, yet these maps are also social and political by virtue of being constructed in such a decentralised manner. This tension gets partially played out, as was shown earlier, in discussions over the validity and accuracy of incoming data. Particularly when crisis mapping is employed in the midst of conflicts, there are serious political concerns about data-gathering, accuracy, and manipulation.

Lastly, these crisis maps are making possible not only the spatial analysis of disasters, but also the temporal analysis as well. By representing the information in these novel visual forms, they are making it easier to discern the patterns involved in crises and thereby making it easier to prepare and respond to future crises.<sup>100</sup> Different temporal representations in Ushahidi, for instance, have focused on selecting particular slices of time to present simultaneously, and on providing a dynamic movie-like overview of the entire crisis.

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<sup>97</sup> Marsden, "Stigmergic Self-Organization and the Improvisation of Ushahidi," 9.

<sup>98</sup> *Mapping the Maps: A Meta-Level Analysis of Ushahidi & Crowdmapping*, 17.

<sup>99</sup> Tomasini and Van Wassenhove, *Humanitarian Logistics*, 100-101.

<sup>100</sup> Liu and Palen, "The New Cartographers: Crisis Map Mashups and the Emergence of Neogeographic Practice," 82-86.

### *Stigmergic Coordination*

In both its organisational adoption, and its use by crisis-affected communities, crisis mapping extends cognition as well by carrying out a stigmergic function: “the phenomenon of indirect communication mediated by modifications of the environment”.<sup>101</sup> In particular, crisis mapping provides a shared – and importantly, modifiable – geographical representation around which actors can coordinate, plan, and communicate information. Through this cognitive extension, crisis mapping provides the medium for the creation of ‘virtual organisations’<sup>102</sup> which are effectuated primarily via some form of online mediation. These maps “function as an interface or index to additional information’ in a way that facilitates an up-to-date, dynamic, and interactive presentation and dissemination of geospatial data to many more users at a minimal cost.”<sup>103</sup>

Whereas the production of situational awareness primarily assists organisations in managing humanitarian logistics, the stigmergic functions of crisis mapping assist local communities as well. Sociological research on crises has found that in these situations, individuals will converge together for a variety of reasons – ranging from assistance to curiosity to anxiety.<sup>104</sup> In many ways, crisis mapping is supplementing this often physical convergence with a digital convergence online. Crisis mapping establishes the material conditions for a shared awareness of a situation.<sup>105</sup> With this spatial representation available, crisis mapping software becomes about self-organising coordination amongst a large group of dispersed actors. It alters existing behaviours by providing a platform for this coordination, via the construction of shared representations.

Communities can and have used these maps for real-time, collective problem solving. One study of a post-crisis situation found social media was crucial for individuals to ascertain and become aware of the immediate situation they

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<sup>101</sup> Marsh and Onof, “Stigmergic Epistemology, Stigmergic Cognition,” 136.

<sup>102</sup> Cogburn, Santuzzi, and Vasquez, “Developing and Validating a Socio-Technical Model for Geographically Distributed Collaboration in Global Virtual Teams.”

<sup>103</sup> Liu and Palen, “The New Cartographers: Crisis Map Mashups and the Emergence of Neogeographic Practice,” 70.

<sup>104</sup> Hughes et al., “‘Site-Seeing’ in Disaster: An Examination of On-Line Social Convergence.”

<sup>105</sup> Meier, “Theorizing Ushahidi: An Academic Treatise.”

found themselves in.<sup>106</sup> While crisis mapping was not specifically involved in this situation, similar functions of collating and organising information were employed. After the immediate effects, social media was then used to solve various problems, particularly related to the sequencing of events and discerning information about various people involved in the crisis.<sup>107</sup>

Crisis mapping is therefore creating new possible behaviours by shifting away from typical top-down humanitarian assistance and towards ground-level self-organised assistance.<sup>108</sup> Individuals within the affected communities can be matched up with medical resources nearby, with food and energy supplies lost in the confusion of a crisis, and with family members and friends who have been separated by the crisis. With crisis mapping information usually available publically, there is a new resource for those in the midst of the crisis to organise themselves. Rather than information traveling up from those on the ground to those at the highest levels of humanitarian groups, with crisis mapping information travels horizontally amongst the community members. Crisis mapping can also close the circle between sender and receiver by allowing coordinators to send out information to those who subscribe to its free service via text, email or RSS feeds.<sup>109</sup> At the same time, many crisis maps are made public online and can be visited by any interested parties.

### *The 2010 Haitian Earthquake*

Despite some early difficulties and after some initial hesitations, there has been a quick acceptance by humanitarian agencies of the role of crisis mapping in providing information. By the time of the Libyan uprising, requests for crisis mapping were coming from the UN Office for the Coordination of Humanitarian Affairs (OCHA) itself.<sup>110</sup> Crisis maps have also been used to prioritise the use of resources, as well as to map out possible health centres in the midst of disasters like

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<sup>106</sup> Palen et al., "Crisis Informatics: Studying Crisis in a Networked World," 6-7.

<sup>107</sup> Ibid., 8.

<sup>108</sup> *Humanitarianism in the Network Age*, 15-17.

<sup>109</sup> Bock, *The Technology of Nonviolence: Social Media and Violence Prevention*, 108.

<sup>110</sup> Meier, "Crisis Mapping Libya: This Is No Haiti (Updated)"; Munro, "Crowdsourcing and the Crisis-Affected Community," 6.

the Haiti and Japanese earthquakes.<sup>111</sup> Software similar to Ushahidi was employed for disaster relief after Hurricane Sandy, giving organisers a real-time overview of the situation which allowed them to efficiently send out volunteers to help where they were most needed.<sup>112</sup> Over 150,000 crowdsourced photos were used by the US Federal Emergency Management Agency (FEMA) to aid in relief efforts.<sup>113</sup> The added value of crisis mapping as seen by these humanitarian agencies comes from the capacities it permits for communication and coordination in the midst of a crisis.

To date, the most extensive and significant use made of Ushahidi and crisis mapping software was in the wake of the 2010 earthquake in Haiti. The quake measured 7.0 on the Richter scale and is estimated to have killed over 300,000 people, with it affecting a total of 3 million people. In the days after, Ushahidi provided the only map which aggregated incoming information – making it a key technology for generating a representation of the crisis.<sup>114</sup> This role was made possible in part by the infrastructure that remained standing: 70-80% of mobile phone towers, and over 70% of the population owned a mobile.<sup>115</sup> It should be made clear that Ushahidi played a role alongside many other actors, but it had a particularly visible presence in the relief efforts (including praise from the then US Secretary of State Hilary Clinton).<sup>116</sup> Most of the incoming texts were handled through the separate Mission 4636, and only a portion of these reports were ever placed on the crisis map.<sup>117</sup> Throughout the course of the immediate crisis, 40-60,000 reports were passed through the overall crowdsourced information system (which included a number of other initiatives), with about 3,500 reports ultimately being placed geographically on the Ushahidi crisis map.<sup>118</sup>

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<sup>111</sup> Lohr, “Online Mapping Shows Potential to Transform Relief Efforts.”

<sup>112</sup> Neu, “When Nerds Cross the Rubicon: How Military Veterans Are Revolutionizing Disaster Response Networks through Better Technology.”

<sup>113</sup> Heaton, “How Emergency Managers Can Benefit from Big Data.”

<sup>114</sup> Morrow et al., *Independent Evaluation of the Ushahidi Haiti Project*, 5.

<sup>115</sup> Munro, “Crowdsourcing and the Crisis-Affected Community,” 6.

<sup>116</sup> Meier, “Haiti: Taking Stock of How We Are Doing.”

<sup>117</sup> Munro, “Crowdsourcing and the Crisis-Affected Community.”

<sup>118</sup> Morrow et al., *Independent Evaluation of the Ushahidi Haiti Project*, 5.

The Haitian crisis provides a good example though since as well as being the largest deployment of the technology, it is also the most thoroughly studied case. The aim here is to draw upon this research and examine how the representations of crisis mapping are being integrated in practice. The evidence from various studies points to crisis mapping being incorporated into humanitarian organisations as a means for situational awareness at the upper levels, rather than as a rapid response to immediate events in the field.<sup>119</sup> Both the US military and smaller NGOs were known to have used the maps to strategically determine the best areas to place their resources, but individual reports from the crisis map were not used as frequently.<sup>120</sup> The aircraft carrier USS Carl Vinson, for instance, requested Ushahidi's assistance in pinpointing coordinates,<sup>121</sup> and the US Federal Emergency Management Association (FEMA) stated that it “provided the most comprehensive and up-to-date information available to the humanitarian community.”<sup>122</sup> It was used to map out possible health centres in the midst of the disaster,<sup>123</sup> and crowdsourced crisis maps became “the de facto source for Haiti map data within most UN agencies and the EC Humanitarian Unit.”<sup>124</sup> As these examples demonstrate, responders looking for the broad overview of the situation found the maps highly useful. For these situational awareness purposes, “Visualisation was a key aspect. [For instance, t]he clustering of reports on the map closely matched the mandate of the Marines to identify centres of gravity.”<sup>125</sup> The significance of this is that crisis mapping was being used precisely as a cognitive adjunct – a technological means to provide situational awareness of local conditions which was otherwise unavailable. While the evidence remains anecdotal, the independent report on Ushahidi’s use in Haiti also found that those involved believed that crisis mapping did directly help save lives.<sup>126</sup>

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<sup>119</sup> Morrow et al., *Independent Evaluation of the Ushahidi Haiti Project*, Munro, “Crowdsourcing and the Crisis-Affected Community,” 12.

<sup>120</sup> Morrow et al., *Independent Evaluation of the Ushahidi Haiti Project*, 13.

<sup>121</sup> Munro, “Crowdsourcing and the Crisis-Affected Community,” 49.

<sup>122</sup> *Mapping the Maps: A Meta-Level Analysis of Ushahidi & Crowdmap*, 22.

<sup>123</sup> Lohr, “Online Mapping Shows Potential to Transform Relief Efforts.”

<sup>124</sup> Druke, *New Humanitarian Partnerships with Technological Communities*, 15.

<sup>125</sup> Morrow et al., *Independent Evaluation of the Ushahidi Haiti Project*, 15.

<sup>126</sup> *Ibid.*, 6.

This is not to say that the construction of a cognitive assemblage was smooth or without problems. A lack of standardisation between the event data on the crisis maps and the event data typically used by humanitarian organisations was a primary barrier to fully integrating these technologies into a cognitive assemblage.<sup>127</sup> The types of information were often simply incompatible, though the crisis mapping team did attempt to accommodate this during the crisis. Translation remained difficult as well, though Ushahidi appeared to have served a productive function in that regard. The software was used to translate messages between the multiple languages being used by civilians and emergency workers. This representational technology made possible the quick mobilisation of translators who were effective enough that “the average turn-around from a message arriving in Kreyòl to it being translated, categorised, geolocated and streamed back to the responders was 10 minutes.”<sup>128</sup> Geolocating texts remained another hurdle in Haiti because at times mobile providers or users did not supply information about where a text had been sent. In response, crisis mappers successfully used the social networks of Haitians in order to calculate where texts had come from.<sup>129</sup>

Finally, highlighting the future of crisis mapping, mobile phones were used to track patterns of migration after the earthquake had devastated the country. This phone data was used not only to track migration after the earthquake, but also to assist in deciding where and how to distribute medicine after a cholera outbreak.<sup>130</sup> After the crisis, research on 1.9 million mobile phone users in Haiti found that the mobility patterns after the crisis were highly predictable when one knew normal travel habits.<sup>131</sup> Combining this data with crisis mapping can and will allow future deployments of the cognitive assemblage to provide an even more in-depth look at the dynamics of the crisis.

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<sup>127</sup> Ibid., 5.

<sup>128</sup> Munro, “Crowdsourced Translation for Emergency Response in Haiti: The Global Collaboration of Local Knowledge,” 2.

<sup>129</sup> Bock, *The Technology of Nonviolence: Social Media and Violence Prevention*, 119.

<sup>130</sup> Tett, “Big Data Is Watching You.”

<sup>131</sup> Lu, Bengtsson, and Holme, “Predictability of Population Displacement after the 2010 Haiti Earthquake.”

## Conclusion

This chapter has attempted to demonstrate the emerging cognitive assemblages being built by the humanitarian community. In many ways, crisis mapping embodies the transformations occurring here: the shift to decentralised information-gathering, the rising use of mobile phones and social media, the growing glut of usable data, and the adoption of technologies to sort, analyse, and spatially represent all this in an actionable interface. In Haiti, these cognitive assemblages saw their first significant – if tentative – deployment, and ad hoc use was made of these technologies by a variety of actors.

Crisis mapping is also part of an ongoing transformation in humanitarianism to a decentralised form of information-gathering (akin to the volatility shift in finance, and the adaptation shift in climate modelling). At least some humanitarian organisations have shifted their internal structures in order to better process the flood of information coming from crisis mapping.<sup>132</sup> One of the major ongoing developments is a process of standardization, with attempts to bring together all the sources and users of humanitarian information into a common framework. Further attempts at institutionalisation and professionalisation include the creation of a volunteer taskforce for crisis mapping, with established skills and experience in dealing with the information. Others have called for a metadata standard, which would allow data from various crises and sources to be more easily compared and used.<sup>133</sup> This is all in an attempt to overcome ‘information fragmentation’ – the gaps, inconsistencies, and lack of communication that exist between different information repositories.<sup>134</sup>

This transformation of crisis management is extending to the United Nations system as well, where the UN Secretary-General has put forth a plan for a Global Impact and Vulnerability Alert System (GIVAS) which would construct a “system that provides decision makers with real-time information and analysis to ensure that responses to global crises take appropriate account of the needs of the

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<sup>132</sup> *Mapping the Maps: A Meta-Level Analysis of Ushahidi & Crowdfunder*, 17.

<sup>133</sup> The PLoS Medicine Editors, “Digital Humanitarianism,” 2.

<sup>134</sup> Harvard Humanitarian Initiative, *Disaster Relief 2.0: The Future of Information Sharing in Humanitarian Emergencies*.

most vulnerable populations.”<sup>135</sup> These monitoring and early-warning functions are intended to be supplemented with a crisis management system, the Emergency Preparedness Information Centre (EPIC), which mimics in many ways the functions of crisis mapping. Its aims are to aggregate a wide variety of data (real-time and structural) and present them in “a single place that will present decision makers with a simple and efficient way to access all operational emergency information.”<sup>136</sup>

While it is only in the initial stages, these developments all show that humanitarian organisations are turning themselves into cognitive assemblages which use technological adjuncts to expand their capacities to perceive a crisis. The future only points towards a solidification of these tendencies and the creation of more stable and professional cognitive assemblages.

Yet as the critical geographer John Pickles reminds us,

“What is geography if it is not the drawing and interpreting of a line? And what is the drawing of that line if it is not also the creation of new objects? Which lines we draw, how we draw them, the effects they have, and how they change are crucial questions.”<sup>137</sup>

Every drawing of a line, every production of a map, is not only a representation, but also a pragmatic injunction with political biases. There remain, as with every technological representation, political and technical choices about the source of the input data. These range from public data, private and commercial data, journalistic information, and crowdsourced data.<sup>138</sup> Public data often involves more scientific and standardised information. The resources of the state can provide both the means to produce scientific data, and the capacity to impose a standard on information formats. Private and commercial data often tends towards more

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<sup>135</sup> Coyle and Meier, *New Technologies in Emergencies and Conflicts: The Role of Information and Social Networks*, 20.

<sup>136</sup> *Ibid.*, 21.

<sup>137</sup> Pickles, *A History of Spaces: Cartographic Reasoning, Mapping and the Geo-coded World*, 3.

<sup>138</sup> Liu and Palen, “The New Cartographers: Crisis Map Mashups and the Emergence of Neogeographic Practice,” 78–82.



frequent and specialised information, while crowdsourced information is more amenable to real-time interactive data. The choice between these information sources carries its own implicit political decisions. Other users have raised concerns about the technology over-representing not only those with mobile phones, but also those who know about the service.<sup>139</sup>

Furthermore, what this geographical mode of visualisation particularly leaves out are the structural relations between different entities in a crisis situation (especially significant in conflicts). In this regard, the choice to focus on spatial information is at the expense of network information.<sup>140</sup> These latter forms of visualisations would “give additional information about indirect ties (e.g. enemies of enemies), density, complexity, and structure of the actors’ network environment.”<sup>141</sup> There is also the constant threat of intentional manipulation of crisis maps in order to further political ends. Rumours and inaccurate information, for instance, have been shown to contribute to increased violence in past crises – the 2007 post-election violence in Kenya was partly fuelled by radio broadcasts announcing false information, and similar spoiler effects occur in many conflict situations.<sup>142</sup>

Despite these technical and political challenges, this chapter has attempted to show that the humanitarian community is coming to realise the significance of generating a geographical representation of ongoing crises. Such technologically produced entities allow actors to gain situational awareness and make possible a variety of new capacities. The next chapter turns away from the details of the case studies in these previous three chapters, and steps back to draw out some general conclusions about the politics of cognitive assemblages, and about the changing nature of power with regard to such technologies.

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<sup>139</sup> Morrow et al., *Independent Evaluation of the Ushahidi Haiti Project*, 18.

<sup>140</sup> Brandes and Lerner, “Visualisation of Conflict Networks.”

<sup>141</sup> *Ibid.*, 170.

<sup>142</sup> Livingston, *Africa’s Evolving Infosystems: A Pathway to Security and Stability*, 3.

## 7 / THE POLITICS OF COGNITIVE ASSEMBLAGES

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“Technology is the source of our options. Options are the basis of a future that keeps us above the level of pawns. Those who condemn technology, properly applied, eliminate our options. They commit the worst of all pollutions – the pollution of our future.”<sup>1</sup>

-Krafft Ehrliche

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In its case studies, this thesis has concerned itself with a specific subset of technology – namely, the material technologies that are being used to think about complex situations. Yet the most important effects of these technologies will only be felt by a wider perspective – in the sociotechnical systems that are becoming ubiquitous aspects of contemporary life. In this regard, the case studies reveal particular condensations of much broader and more dispersed trends; trends which appear bound to continue. Even over the course of researching this work, new cognitive assemblages have been constantly introduced by government agencies. Technology is increasingly intertwined with cognition and politics, and this tendency is only continuing to accelerate.

In this concluding chapter we intend to step back from the technical details of the individual case studies and attempt a synoptic view of what these developments might mean. This thesis began with the problem of cognitive mapping: how does an individual situate themselves conceptually in the midst of a complex system? The answer proposed was that it is technology which allows individuals to accomplish this by becoming a necessary adjunct to our internal cognitive processes. On one level, this is banal – electronic calculators, for instance, have been used for decades now in order to solve problems that evade our inherent

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<sup>1</sup> Ehrliche, “The Extraterrestrial Imperative.”

mathematical talents. Technology simply is an adjunct to humans (indeed, the two have co-evolved throughout history). Yet what is occurring now is different in at least two ways: one is that these new technologies are now capable of modelling dynamic and complex global systems for the first time in human history. As the case studies have attempted to show, these technologies are providing representations of these cognitively intractable systems in such a way that they become amenable to our finite abilities for thought and action. Secondly, these technologies are being massively diffused throughout the social fabric. They are beginning to emerge everywhere - ranging from the grand supercomputing of climate change models to the mobile phone app that tracks a social network. Our phenomenology of the world is increasingly being mediated by these digital representations and this pervasiveness is itself a novel phenomenon. The problematic to be examined in this concluding chapter can therefore be articulated as what are the likely consequences of off-loading and expanding thought processes about complex global systems into machines? And what are the consequences if the global can only be made intelligible via digital representations? And what does it mean for world politics if the ways we think about global problems are increasingly filtered through a computational medium?

In their own way, each of the case studies has attempted to outline how these representational technologies are situated in larger cognitive assemblages, how the materiality of technology acts as a platform for society and a platform for technological development, and how these technologies are constructing new modes of perception, cognition, and action. With climate change modelling, major material frictions emerge with the significant computational and data requirements of the GCMs. Yet on the basis of this infrastructure, new ways of seeing nature have been constructed and new political practices have been made possible. The ability to see long-term climate changes at local levels has made adaptation policies a much more opportune political choice. With financial modelling frictions arise between the speed requirements and the complex mathematics employed to model options markets. The spread of derivatives valuation models has however constructed the possibility of seeing markets in terms of volatility, and has made

possible a variety of new financial engineering that has opened up the space for new behaviours in the markets. In particular, the capacity to see volatility has created an entire market devoted to this theoretically derived variable, and new modes of hedging market positions have emerged as a result. Lastly, with crisis mapping software the major material frictions have arisen between the speed demands of the software and the computational limitations of mobile technology. However, despite the relatively recent emergence of this technology, it has been quickly recognised as an important means to seeing crises in real-time. This overarching perspective on various crises has allowed humanitarian organisations to generate situational awareness of the crisis, and for affected communities to use stigmergic coordination to mobilise their own relief efforts in a decentralised fashion.

A shift to new climate change policies; a transformation of financial speculation; and a move to decentralising relief efforts – all of these demonstrate ways in which representational technologies are orienting specifically political possibilities in the world today. These technologies do not simply alter behavioural landscapes, but instead exert a facilitating force on the ways in which political worlds of environmental policy, financial markets, and humanitarian relief are practiced.

The remainder of this chapter attempts to draw out some generalisable propositions about the political implications of representational technologies and cognitive assemblages more generally. The next section outlines a brief historical narrative of different global technologies. While recognizing the overlapping and co-existing nature of these different technological types, it is nevertheless argued that they can be productively periodised according to which technology is dominant at a particular time. The third section argues for a first political quality of these technologies: their capacity to expand and alter possible behaviors and thoughts. The three case studies examined in this thesis are used as illustrations of how representational technology can change political actors' abilities to represent, augment, and respond to events. The fourth section demonstrates a second political quality of these technologies – their ability to obscure and highlight

different aspects of the world via both (invisible) algorithms and (visible) interfaces. Lastly, the final section concludes by examining the distinct role that representational technologies are being used for in order to construct macro-actors and construct conduits of power.

### **Building, Destroying, and Representing the Global**

It was shown in Chapter 2 that IR as a discipline has largely ignored technology as an independent factor in world politics, yet in practice world politics and technology have interacted in a number of significant ways. Drawing upon this existing literature – both in IR and elsewhere – these interactions can be schematised in three broad and overlapping waves that each contribute to materially constructing the global: connection, destruction, and representation. While the types of technologies overlap and co-exist, their relative prominence in each period allows us to draw out a broad schema. In the contemporary world, with connective technologies having already established a closed system,<sup>2</sup> and the utility of destructive technologies in a period of relative decline, it is representative technologies which appear to be quickly rising in significance.

#### *Connection*

The first era of global technology emerges properly in the nineteenth century with the rise of connective technologies. This refers to the capacities available to move goods, people, and information around the world.<sup>3</sup> As with the other technological eras, what was crucial here was not just the quantitative shift between earlier connective technologies and the contemporaneous ones. More important was the qualitative shift invoked by these quantitative advances: these technologies passed crucial thresholds of usability which allowed European empires to connect their territories in significantly new global ways. In principle (and in practice), societies had been capable of trading goods around the world for some hundreds of years

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<sup>2</sup> Mackinder, “The Geographical Pivot of History.”

<sup>3</sup> This idea closely mirrors Buzan and Little’s idea of ‘interaction capacity’ – though we here distinguish between constructive/connective technologies and destructive technologies. Buzan and Little, *International Systems in World History: Remaking the Study of International Relations*, 80.

before the nineteenth century. Even by the thirteenth century, the Eurasia region was nearly spanned by a series of regional trading subsystems connected at their edges.<sup>4</sup> Yet what shifted during the nineteenth century was the level of usability – the costs (economic or otherwise) associated with such connections were significantly reduced to a point where connection took off.

This connective capacity meant, above all else, the capacity to transport goods and people. Paradigmatic among these technologies was the invention of the steam engine which made possible the rise of steamships and railroads. Steamships provided a new capacity to travel inland and upstream into Africa and Asia, setting the logistical basis for the imperialism of the nineteenth century.<sup>5</sup> While ocean-faring steamships remained unworkable for some time, areas such as the Mississippi River and the Ganges River were quickly populated with steamships travelling up and down them. The opening of the Suez Canal in 1869 drastically increased the connective capacity across the world system, as steamships became considerably more usable in the Europe-Asia route. Similar diffusion of technologies occurred with the railroad systems. Locomotives emerged in 1814 and by the end of the century over 800,000 kilometres of railroads had been planted around the world.<sup>6</sup> All of these technologies played a major permissive role in the expansion of the European imperialism (and the British Empire in particular), with a number of cases being built explicitly for controlling the territory.<sup>7</sup> All together, these technologies are estimated to have reduced travelling times by 80% over the course of the century, making travel accessible to a much wider audience than ever before.<sup>8</sup>

Yet it was not just the connection of physical objects, but also informational content, that was important for this time.<sup>9</sup> Particularly significant here was “the

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<sup>4</sup> Abu-Lughod, *Before European Hegemony: The World System A.D. 1250-1350*.

<sup>5</sup> Headrick, *The Tools of Empire: Technology and European Imperialism in the Nineteenth Century*, chap. 1.

<sup>6</sup> Buzan and Little, *International Systems in World History: Remaking the Study of International Relations*, 282–283.

<sup>7</sup> Darwin, *After Tamerlane: The Rise and Fall of Global Empires, 1400-2000*, 188.

<sup>8</sup> Buzan and Little, *International Systems in World History: Remaking the Study of International Relations*, 278–279.

<sup>9</sup> For a later example of the significance of information technology in constructing imperialism, see: Yang, *Technology of Empire: Telecommunications and Japanese Imperialism, 1930-1945*.

separation of information from paper for the purposes of transporting it.”<sup>10</sup> In this regard, the nineteenth century saw the invention of the telegraph and submarine cables which made possible the ability to communicate easily and quickly over vast distances.<sup>11</sup> As one historian writes,

“The rapid spread of the telegraph (carrying commercial information, especially prices) and the steamship (at first mainly for mail and passengers) helped to unify the whole vast region from the Mississippi to the Urals from the 1830s and ‘40s onward.”<sup>12</sup>

By the 1860s, Europe was connected with India and China by telegraph as well.<sup>13</sup> Over the course of the century, the speed of communication between Britain and India had dropped from approximately 5-8 months to the same day.<sup>14</sup>

Lastly, there were the technologies which opened up the capacity specifically for humans to travel into novel territories. This was the technology which mitigated the extremes of different environments. Much like the spacesuit made it possible for humans to establish a route to the moon in the twentieth century, so too did medicine like quinine make the interiors of Africa possible to traverse by Europeans in the nineteenth century.<sup>15</sup> Until this point, the inland expansion of European imperialism had been greatly hampered by the various strands of malaria, making attempts to connect with these areas a virtual suicide mission. The discovery of quinine and the procedure for its effective use significantly expanded the habitable area for European imperialism to travel within.<sup>16</sup>

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<sup>10</sup> Buzan and Little, *International Systems in World History: Remaking the Study of International Relations*, 287.

<sup>11</sup> Darwin, *After Tamerlane: The Rise and Fall of Global Empires, 1400-2000*, 188.

<sup>12</sup> *Ibid.*, 239.

<sup>13</sup> *Ibid.*, 249.

<sup>14</sup> Buzan and Little, *International Systems in World History: Remaking the Study of International Relations*, 287.

<sup>15</sup> de Monchaux, *Spacesuit: Fashioning Apollo*.

<sup>16</sup> On the importance of technology for habitat, see: McLuhan, *Understanding Media: The Extensions of Man*, chap. 13.

These three forms of technology – transportation, information, and environmental – all contributed to a major increase in the connective capacities of the nineteenth century world.

### *Destruction*

The second era of global technologies overlapped with the first, but emerged primarily in the twentieth century with the newly developed capacities for destruction across the globe.<sup>17</sup> As opposed to the constructive technologies of the earlier era, these technologies were solely means to enact violence on people and infrastructures around the world. Moreover, these destructive technologies no longer relied as heavily on existing connective technologies to traverse the globe. In the previous era, destructive capacities such as soldiers and gunboats could be transported around the world (given enough time) but only by following constructed paths (e.g. railroads) and natural paths (e.g. riverways). In this new era, destructive technologies were separated from this connective foundation and began to act directly as global technologies in themselves.

The most obvious of these technologies was the nuclear bomb, which heralded the possibility of immediate and devastating destruction around the world. In terms of the global violence, just as significant as its pure destructive power was the speed and range with which it could be launched around the world. Its mere existence shifted the strategy of security from mobilisation to deterrence.<sup>18</sup> The importance of a front in a war declined as nuclear bombs could be delivered across national boundaries and frontlines. As important as the nuclear bomb though, was the intercontinental ballistic missile (ICBM) which made possible its ability to traverse the globe. The V-2 rocket of WWII heralded this new approach to warfare, and its use against Britain demonstrated the novel capacity to wreak devastation across increasingly large expanses.<sup>19</sup> The continued development of

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<sup>17</sup> This section is closely mirrored by the idea of ‘violence interdependence’ developed in Deudney, *Bounding Power: Republican Security Theory from the Polis to the Global Village*.

<sup>18</sup> Herrera, *Technology and International Transformation: The Railroad, the Atom Bomb, and the Politics of Technological Change*, 184.

<sup>19</sup> McNeill, *The Pursuit of Power: Technology, Armed Force, and Society Since A.D. 1000*, 367.



missile technology (combined with the driving force of the Cold War) soon led to the first proper ICBM and the subsequent envelopment of the entire world within striking distance of the superpowers.<sup>20</sup> While the ICBM was arguably a transportation technology, it broke free of the need to rely on artificial and natural pathways and could immediately be delivered to any space. At this point, the global had not only been constructed via connective infrastructures, but also by destructive capacities.

Thus, whereas the earlier connective age had heightened the interactive and constructive possibilities between different areas of the world, the new destructive era made it possible for violence to be dealt across the globe without the medium of a connective technology.

### *Representation*

Today sees the surfacing of a new era of global technologies – the representational technologies which have been the focus of this thesis. As has been demonstrated, they represent large-scale complex phenomena by employing sophisticated models to track and generate a representation of the system in question. Unlike the earlier industrial technologies that operated primarily on nature, these technologies tend to operate immediately on culture – on texts, images and other representations.<sup>21</sup> As the focus of this thesis, three technologies have been taken as emblematic of this representational era: general circulation models, option pricing models, and crisis mapping software. Each of them in their own way models and produces a human-sized representation of a complex global phenomenon. To be sure, representational technologies have played important roles prior to the twenty-first century.<sup>22</sup> Modern maps, for instance, arose in fifteenth and sixteenth century Europe<sup>23</sup> and went on to play a significant role in articulating and forming the basis

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<sup>20</sup> For a fascinating take on missile development, see: MacKenzie, “Missile Accuracy: A Case Study in the Social Processes of Technological Change.”

<sup>21</sup> Poster, “An Introduction to Vilém Flusser’s ‘Into the Universe of Technical Images’ and ‘Does Writing Have a Future?’,” x.

<sup>22</sup> Jens Bartelson points out that a transformation of the cosmological worldview was first necessary to conceive of ‘the global’: Bartelson, “The Social Construction of Globality.”

<sup>23</sup> Pickles, *A History of Spaces: Cartographic Reasoning, Mapping and the Geo-coded World*, 96–99.

for territorial authorities in the early modern era.<sup>24</sup> Yet truly global and accurate representations remained obscure for some time. As late as 1774, for instance, the most sophisticated maps in existence still referred to Alaska as an island.<sup>25</sup> In addition, contemporary representational technologies distinguish themselves from previous technology by introducing new possibilities of mapping dynamic and complex global phenomena. Such technologies find no parallel in the early modern era. Most significantly though, today's representational technologies are capable of being manipulated in a wide variety of ways, thereby allowing individuals to experiment and reason with them.<sup>26</sup> They here take on the characteristics of an extended cognitive system, and begin to augment individual and institutional capacities for thinking and perceiving.

The origins of the contemporary shift can be seen to have developed out of the demands of the Cold War, the requirements of industrialised economies, and the cybernetic revolution of the time.<sup>27</sup> It was the Vietnam War which saw the use of one of the first real-time computer-mediated representations of a warzone.<sup>28</sup> Here was a situation where computers were being used not simply to *calculate*, but instead to act as a *perception* on a complex situation. Sensors were placed along the Ho Chi Minh Trail (disguised as natural artefacts) and used to track movement, sound, body heat, and distinct odours. All of this data was filtered into a computer system and predictions were automatically generated about the future path of the abstract entity that appeared on the operators' screens. It did not, in other words, construct the system in question – but it provided a representation of it that had been unavailable before the rise of the technology.

Today's global representations follow in the path set by these military applications – yet they are both quantitative and qualitative differences from these immediate predecessors. In the first place, they are simply significantly more accurate: in their explanations of past events, in their tracking of real-time events, and in their forecasting of future events. While earlier systems had authority solely

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<sup>24</sup> Branch, "Mapping the Sovereign State: Technology, Authority, and Systemic Change."

<sup>25</sup> Darwin, *After Tamerlane: The Rise and Fall of Global Empires, 1400-2000*, 164.

<sup>26</sup> Morgan, *The World in the Model: How Economists Work and Think*, 13.

<sup>27</sup> Beniger, *The Control Revolution: Technological and Economic Origins of the Information Society*.

<sup>28</sup> Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America*, 142.

by virtue of being labelled ‘scientific’ approaches, the contemporary models often have a long track record of success to back up these claims. In addition, early representational technologies remained almost entirely tied to static formations and simple systems. It is only with the late twentieth century that the capacities to represent dynamic, complex, and nonlinear systems start to emerge in widespread ways. Finally, there is the emerging trend of ‘big data’ – where massive new datasets allow for a transition from deductive models to inductive inferences, i.e. from modelled assumptions to empirical data.

In summary, the era of global representational technology is the latest in a series of global technologies. Whereas the first era made possible the construction of a truly global world, the second made possible its destruction, and it is the contemporary era which is beginning to make possible its widespread representation.

### **Expanding Political Possibilities**

With the increasing ubiquity of representational technologies, two broad political implications emerge. This section examines the first of these (the expansion of possible thoughts and actions), while the next section will highlight the second political aspect (the implicit and explicit biases built into digital representations). As has been shown, technology determines society not by making specific outcomes or behaviours or social formations inevitable; instead it determines the general landscape of possible actions and thoughts that actors are capable of carrying out. The focus in this section is therefore to supplement the diverse literature on how quantification and similar forms of technical representation help to govern and regulate people and things,<sup>29</sup> with a focus on how digital representations determine the behavioural landscape in particular ways. This section will draw upon the case studies to illustrate that digital representations have three functions which form the basis for expanding the behavioural landscape: their primary function as (1)

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<sup>29</sup> Miller and Rose, *Governing the Present*; Desrosières, *The Politics of Large Numbers: A History of Statistical Reasoning*; Dean, *Governmentality: Power and Rule in Modern Societies, 2nd Edition*; Tooze, *Statistics and the German State, 1900-1945: The Making of Modern Economic Knowledge*; Foucault, *Security, Territory, Population: Lectures at the College de France 1977-1978*.

representational, and two supplementary functions as (2) augmentative, and (3) pragmatic. While not every representational technology participates in every aspect to the same degree, the scope of the new capacities being made available can be suggested through these examples.

### *Representational*

The most obvious function of representational technologies is to represent some entity or system in the world, and in this regard, contemporary technologies are greatly expanding what it is possible to represent.<sup>30</sup> The case studies have shown that nonlinear systems, massive datasets, obscure correlations, and newly quantifiable social interactions are all expressions of this expanded capacity to represent the world in knowledge. These tools are subsequently being used in order to construct new objects, subjects, and relationships for manipulation.<sup>31</sup> With these emerging conceptual objects in knowledge, emerge new political possibilities to act upon those entities. Not merely to regulate or govern them, but also to shape them, intervene in them, interact with them, and support them. As representational technologies expand to encompass these new areas, they are simultaneously expanding the realms which actors can have control over. Insofar as politics is the art of shaping and controlling others, these representational technologies are producing the political via expanding what it is possible to shape and control.

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<sup>30</sup> It is worth noting that in the case of models and simulations (each being a particular type of digital representations) there is some debate within philosophy of science about what it means to say that they ‘represent’ something outside of themselves. (Knuuttila, *Models as Epistemic Artefacts: Toward a Non-Representationalist Account of Scientific Representation*) With their internally closed worlds, modelling appears to construct its own world and risks measuring the validity of its propositions against the model itself rather than against the external data. Even the idea of matching the outcome of a model up against an empirical phenomenon is problematic once the issue of ‘fitting the data’ is raised. The response we accept here is that models are capable of representing by virtue of the explanatory irrelevance of lower-level phenomena. DeLanda, *Philosophy and Simulation: The Emergence of Synthetic Reason*, 14. In such situations, there is a real emergent phenomenon (e.g. temperature) that is indifferent to small variations in the components that make it up (e.g. individual molecules). Modelling the lower-level components is therefore irrelevant to explanation, and a model can gain cognitive traction on real phenomena by virtue of simplifying assumptions.

<sup>31</sup> This is similar to how words and numbers also operate, but is both more general (incorporating alternative visual modes of representing as well), and more specific (embodying the material qualities cited in the section above). See also: Hansen and Porter, “What Do Numbers Do in Transnational Governance?,” 410.

In this regard, the general circulation models used to study climate change provide one of the clearest examples of how the representational function of digital representations makes new political behaviours possible. Recall that these massive and intricate computer models form the material infrastructure for all of our knowledge about how the earth's climate will be modified over the coming decades.<sup>32</sup> Their successful adoption and use is also almost entirely dependent on how well they represent the climate system. While pragmatic and material limitations are always necessary considerations, nevertheless the normative goal of these particular models is to accurately represent a complex system. As chapter 4 showed, in the last decade the pursuit of this goal and the technological development of GCMs have made local-level forecasting increasingly possible – both by incorporating elements of the climate system relevant to the local level, as well as by increasing the resolution of the models.<sup>33</sup> With this new capacity to represent how climate change will affect local levels has come the capacity to react and plan for it. In other words, with today's GCMs, regional and local climate adaptation has become a meaningful possibility. The sorts of representational knowledge necessary to adequately respond to and adapt to local climate change were simply unavailable prior to the development of this technology, despite the political desire for it (seen as early as the 1970s).<sup>34</sup> The representational function of these knowledge producing technologies has been expanded, and with it has come an expansion of possible political behaviours. Climate change policy and the constraints that actors face up to are partly shaped by the material infrastructure which expands the capacity to control, intervene, and manipulate a complex system like nature.

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<sup>32</sup> Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*.

<sup>33</sup> Dahan, "Putting the Earth System in a Numerical Box: The Evolution from Climate Modeling Toward Global Change."

<sup>34</sup> Charney et al., *Carbon Dioxide and Climate: A Scientific Assessment (Report of an Ad Hoc Study Group on Carbon Dioxide and Climate)*, 2-3.

### *Augmentative*

Since digital representations can *generate* in addition to *representing*, they also have a supplementary capacity to augment our world with new images. With this function, instead of representing something else, they come to fully replace that ‘something else’. They construct a world, instead of representing a world. In the works of Jean Baudrillard and Vilém Flusser, ‘simulation’ and ‘technical images’ are taken to efface the classical distinctions between the real and the fake, the true and the false, the artificial and the natural.<sup>35</sup> Whereas traditional images emerged from the depiction of an object, digital images instead operate by creating the object itself.<sup>36</sup> As Baudrillard famously writes,

“The territory no longer precedes the map, nor does it survive it. It is nevertheless the map that precedes the territory – *precession of simulacra* – that engenders the territory, and if one must return to the fable, today it is the territory whose shreds slowly rot across the extent of the map.”<sup>37</sup>

In this ‘hyperreal’ world, the problem is not how to go from the real to modelling it in a simulation, but instead how to start from simulation and install a sense of the real.<sup>38</sup> Rather than represent new objects, subjects, and relationships, the augmentative function seeks to create them.

With contemporary technologies, the representational function typically has primacy over the augmentative function. Yet, the world of option pricing demonstrates how this supplementary function operates. As chapter 5 revealed, today’s option pricing models seek to generate a perspective on derivatives markets in terms of ‘volatility’ – a theoretical entity originally intended as a constant in the equations underpinning these models. The vagaries of the markets and traders led to this unassuming element in an equation coming to instead be the focus of the

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<sup>35</sup> Baudrillard, *Simulacra and Simulation*; Flusser, *Into the Universe of Technical Images*.

<sup>36</sup> Flusser, *Into the Universe of Technical Images*, 10.

<sup>37</sup> Baudrillard, *Simulacra and Simulation*, 1.

<sup>38</sup> *Ibid.*, 124.

option pricing models. Its usefulness in providing a general language with which to compare across asset classes, strike prices, and expiry dates, led to volatility become a key medium of perception for options markets. Today, while having a tenuous basis in a real phenomenon, what options traders are concerned with are primarily the visual representations of three-dimensional volatility surfaces and how they correspond to the rapidly fluctuating prices on their screens.<sup>39</sup> The reality of the model is their focus, or in other words, the technology has provided an augmented version of the markets. On the basis of this augmentation of financial markets, it has become possible to trade and hedge volatility itself – leading to the recent creation of a market for products based on the Volatility Index. The VIX, in addition, has become a primary indicator of market sentiment, commonly referred to in the press as an important gauge of fear.<sup>40</sup> The rise of global volatility markets finds its condition of possibility in the vision of options markets constructed by the various derivative valuation models. Yet throughout this, volatility remains a theoretical entity, one found only in the models used by traders. It is a construction of models, an augmentation of reality, yet its effects have been widespread in allowing a variety of new economic behaviours in global markets.

The significance of the augmentation function is therefore to highlight ways in which digital representations can have autonomy above and beyond their representational functions. Images are projections onto an environment – they are not just representations, but also overlays. In this sense, one must reject the ‘digital dualist’ thesis which argues that the digital world is in opposition the ‘real’ physical world.<sup>41</sup> As the augmentation function reveals, they are both real – digital representations simply add a new layer to the world. They augment reality by constructing new worlds and objects without any necessary reference to a physical process. Once one recognises their reality, one also recognises their effects as well. For example, once one is informed that gait recognition software codes pacing up

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<sup>39</sup> MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets*; Ayache, *The Blank Swan: The End of Probability*; Gatheral, *The Volatility Surface: A Practitioner’s Guide*.

<sup>40</sup> Tett, “Vix Volumes Rise Could Drive Investor Trends.”

<sup>41</sup> Jurgenson, “Digital Dualism Versus Augmented Reality.”

and down subway platforms as ‘suspicious’, one is likely to change one’s behaviour as a result.<sup>42</sup>

### *Pragmatic*

The final function of digital representations is their pragmatic function: the ways in which representations can encode orders and responses into themselves. Beyond just representing a phenomenon, and beyond constructing an augmentation, digital representations also *do* things. “Technical images signify models, instructions about the way society should experience, perceive, evaluate, and behave.”<sup>43</sup> In this way, algorithms can have agency delegated to them; they carry out some series of actions.<sup>44</sup> Moreover, given a computer-mediated representation, we are often predisposed to act in accordance with what it represents – and neglect what it does not represent.

At the most basic level of coding this pragmatic function is embodied in the fact that algorithms *are* instructions.<sup>45</sup> As one software theorist succinctly puts it, “code is the only language that is executable.”<sup>46</sup> While natural language also contains orders, the orders of a software code pass directly through the physical world without requiring the mediation of a human mind.<sup>47</sup>

At the more intuitive, everyday level, the pragmatic force of digital representations can be seen to operate by virtue of ‘order-words’.<sup>48</sup> These words “do not concern commands only, but every act that is linked to a statement by a ‘social obligation’.”<sup>49</sup> They are akin to a generalised speech act; a demand made by the representation as a result of its being embedded in a social world. They effectuate not only transformations in the social standing of that which is modelled (placing it under a category, for instance), but also impart demands on the user of the model. Insofar as models construct a world, they project a series of behaviours and

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<sup>42</sup> Hale, “Identity Crisis: Facial Recognition Technology and the Freedom of the Will.”

<sup>43</sup> Flusser, *Into the Universe of Technical Images*, 50.

<sup>44</sup> Berry, “The Social Epistemologies of Software,” 380.

<sup>45</sup> Mackenzie, *Cutting Code: Software and Sociality*, 32–33.

<sup>46</sup> Galloway, *The Interface Effect*, 70.

<sup>47</sup> Hayles, *My Mother Was a Computer: Digital Subjects and Literary Texts*, 49–50.

<sup>48</sup> Deleuze, “Postscript on Control Societies,” 180.

<sup>49</sup> Deleuze and Guattari, *A Thousand Plateaus*, 79.



interactions that would be properly adapted to that world. Even the seemingly transparent interface of contemporary technologies shapes the way we act.<sup>50</sup> It can also include the imperatives of action, particularly in situations with little reaction time (as in emergencies).

In these regards, crisis mapping software provides a good illustration of this function. As was shown, this is software which is being employed to produce real-time maps of resources, emergencies, and events in crisis situations, thereby giving international humanitarian organizations an unprecedented perspective on these situations.<sup>51</sup> Yet insofar as the representations produced are situated in a social context of urgency and finite resources, the crisis maps simultaneously impose demands on the humanitarian agencies and individuals using them. These demands can range from (relatively rare) cases of immediate emergency needs to (more common) cases of situational awareness revealing where resources need to be distributed and what may need to be coordinated.<sup>52</sup> It is on the basis of these representations that crisis mapping software has made it possible for international humanitarian agencies to gain an increasingly god's eye-like perspective on rapidly changing crisis situations and to therefore delegate relief workers and resources as efficiently and effectively as possible. The massive and difficult effort of getting relief agencies into the field to gather information about the disaster situation has been greatly simplified by this new representational technology. Simultaneously, this technology has opened up new capacities for local individuals affected by a disaster to interact with relief agencies, giving new self-organising power to those on the ground. While this capacity has existed beforehand, what is novel is the ability to do so immediately and with near real-time multi-way communication between the relevant actors.<sup>53</sup> In particular, crisis mapping provides a shared and -

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<sup>50</sup> Recent expensive litigation between Apple and Samsung over the gestural basis of interfaces demonstrates the significance of this. Wingfield, "Jury Awards \$1 Billion to Apple in Samsung Patent Case."

<sup>51</sup> Coyle and Meier, *New Technologies in Emergencies and Conflicts: The Role of Information and Social Networks*.

<sup>52</sup> Morrow et al., *Independent Evaluation of the Ushahidi Haiti Project*.

<sup>53</sup> To be sure, there are many issues that remain with the accuracy, validity, and biases of these new forms of communication.

importantly – modifiable geographical representation around which a variety of actors can coordinate, plan, and communicate information.

In summary, representational technologies have representational, augmentative, and pragmatic functions. Any particular technology will combine each of these functions to different degrees: for climate modelling, representation is primary. For option pricing, augmentation is primary. And for crisis mapping, pragmatism can be considered the main purpose. Yet each of them are expanding the possible thoughts and actions of what political actors can do, thereby demonstrating how technology determines society by shaping behavioural landscapes.

### **Obscuring Political Possibilities**

Beyond the explicit shaping of political possibilities, these technologies also come with various implicit political consequences – the origin of which can be found in digital representation’s augmentative capacity. The model becomes the reality, and in doing so, it effaces its representational function and sharpens the force of its pragmatic function. This contributes to the immense power of digital representations – the global becomes immediately visible via a glance at a screen.<sup>54</sup> Yet it also raises an inevitable problem of the model – the active forgetting of the disjuncture between the model and the modelled. This, however, is an aspect inherent to digital representations: they require that the processing and mechanisms which produce a visual to disappear into the background. A webpage which foregrounded the source code, for instance, would be illegible to all but specialists. Similarly, a graphical representation of local climate change effects would be incomprehensible if it attempted to include every individual data point behind it. This section aims to shed light on this obscured quality and highlight some of the ways in which the algorithms and interfaces of digital representations are encoding political assumptions, values, and demands.<sup>55</sup>

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<sup>54</sup> Latour, “Visualization and Cognition: Drawing Things Together.”

<sup>55</sup> For a look at the related political aspects of databases, see: Ansorge, “Digital Power in World Politics: Databases, Panopticons and Erwin Cuntz.”

*Algorithms: The Invisible*

Beyond the superficial appearance of the interface – the visible component of the digital representation – lies the software that encodes an algorithm. Algorithms, at their most basic, are simply sets of rules to be followed – with an input leading deterministically to a corresponding output. At this abstract level, algorithms have existed in some form for as long as recorded human history (the Babylonians used them in their system of law, for instance).<sup>56</sup> Yet today’s algorithms are embedded into machines rather than the flesh of a human body, and they are vastly more complex than these early algorithms. As one recent summary of the state of algorithms puts it,

“[Today], algorithms have already written symphonies as moving as those composed by Beethoven, picked through legalese with the deftness of a senior law partner, diagnosed patients with more accuracy than a doctor, written news articles with the smooth hand of a seasoned reporter, and driven vehicles on urban highways with far better control than a human.”<sup>57</sup>

Algorithms now permeate nearly every aspect of our lives, yet most attention on the politics of a digital world has been given to the issue of data privacy and ensuring the transparency of what information has been collected by governments and companies. Much less attention has been paid to its necessary correlate: the opaqueness of the algorithms, predictive analytics, and statistical work that is turning this raw data into meaningful indicators. This is particularly significant as increasing amounts of political decisions are being shaped and even made by these obscured sets of technical instructions.

By definition, “an algorithm selects and reinforces one ordering at the expense of another. [As a result,] they affect what can be said and done.”<sup>58</sup> Encapsulated in this quote is the notion that, at their most general level,

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<sup>56</sup> Steiner, *Automate This: How Algorithms Came to Rule Our World*, 54.

<sup>57</sup> *Ibid.*, 7.

<sup>58</sup> Mackenzie, *Cutting Code: Software and Sociality*, 44.

algorithms are responsible for the translation of raw (and often complex and massive) data into amenable representations. They, in other words, form the basis for how we know things about complex systems. The algorithms act as the mechanisms to produce knowledge from data, making them a form of ‘software epistemology’.<sup>59</sup> Digital cameras, for instance, have built into themselves algorithms to sharpen edges, heighten contrasts, and reduce blurring.<sup>60</sup> The image that emerges on the screen is not the image that entered into the lens of the camera. This small, everyday example encloses within itself the fact that today – via algorithms – much of what we take as immediate perception is in fact heavily filtered through a particular digital mode of constructing knowledge. While data exists essentially as number, its translation into an amenable visual form always involves technical, aesthetic, and political choices that are often invisible – and it is algorithms where these decisions are being played out.

Some of these political issues are quite obvious, as with the coding of human individuals. Iraqis who self-identified as Iraqi, for instance, were surprised to be coded in the US biometric system as Sunnis, Shiites, and Kurds.<sup>61</sup> While categorizing individuals has always occurred (and always been a political gesture), the significant difference from previous attempts to collect and analyse data is the automation of the procedures now.<sup>62</sup> This quantitatively expands the possibilities of analysis. Today, “modern data-mining techniques abstract, represent and calculate population groups that cannot be observed directly; which may therefore only exist in the imagination of the sovereign and the columns of databases.”<sup>63</sup>

This is especially prevalent with predictive algorithms in the field of security. In these cases, automated learning algorithms hunt through the wealth of data available today about the public. Financial transactions, travel patterns, phone interactions, goods shipped, and so on, are all examined in an effort to find distinctive ‘threat’ patterns.<sup>64</sup> Invisible to the human eye, the algorithms alone are

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<sup>59</sup> Manovich, “Image Processing and Software Epistemology.”

<sup>60</sup> Ibid.

<sup>61</sup> Ansorge, “Digital Power in World Politics: Databases, Panopticons and Erwin Cuntz,” 73.

<sup>62</sup> Ibid., 71.

<sup>63</sup> Ibid., 82.

<sup>64</sup> Amore, “Algorithmic War: Everyday Geographies of the War on Terror,” 51.

capable of finding these patterns within a huge amount of data and visualizing them for their human operators. On the basis of this, predictions are made about likely future behaviours. And as technologies to disperse this knowledge are constructed, the everyday becomes permeated with increasingly constant surveillance and analysis. The surveillance of the border is abstracted from its particular location and becomes extended to wherever credit cards, mobile phones, subway cards, and CCTVs are being used. Algorithms not only make visible particular relations, they also act as imperceptible censors. Certain words can be automatically filtered, or simply made more difficult to access (try typing a profanity into Google and see how few are autocompleted).<sup>65</sup>

Algorithms therefore encompass within themselves a number of actions that are easily recognised as political: they encode, sort, categorise, calculate, draw out patterns, and establish regimes of what is visible and invisible. Most significantly, unlike previous classification mechanisms they sort knowledge according to engineered principles rather than through expert judgments,<sup>66</sup> and they do so in an obscured fashion. Yet they remain political through and through, even when the representational function dominates in a particular technology.<sup>67</sup>

### *Interfaces: The Visible*

For most actors though, algorithms remain hidden and their interaction with digital representations centres on the interface. From this perspective, models turn the messy reality of the world into a smooth image. Despite this advantage, the gradual adoption of simulations and models into various areas has been met with suspicion. Worries continuously arise that such technologies effectively distance the user from the reality of the phenomenon, by leaving the mediating steps opaque.<sup>68</sup> Users rarely know precisely how the models work, let alone how the hardware works or the physics of computer screens and processors. As a result, the

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<sup>65</sup> Morozov, "You Can't Say That on the Internet."

<sup>66</sup> Gillespie, "The Relevance of Algorithms," 26.

<sup>67</sup> In such cases where representation reigns (as in climate change modeling), distinguishing between what is a valid algorithm and what is a politically-charged algorithm must be done on a case-by-case basis.

<sup>68</sup> Turkle, *Simulation and Its Discontents*, chap. 2.

inevitable errors, simplifications, limits, and biases of the mediating model are left obscure. Yet the black-boxing of computer models is a necessary step. The advantage *and* limitation of digital representation is that it black-boxes such intermediary steps, allowing human cognition to extend chains of inferences beyond what is possible with the naked mind.

The risk is that digital images distance the viewer from the effects which are not modelled. One can know perfectly well on an abstract level that the model is imperfect, yet still be persuaded by the constructed reality on the screen. Despite the acknowledgement that machines make errors, that the simulations are not real, and that garbage in means garbage out, digital representations still take on a reality of their own whereby they appear more real than what they are supposed to represent.<sup>69</sup> Precision can be mistaken for validity, and the digital model mistaken for the reality.<sup>70</sup> Debates over the distributional effects of climate change have sometimes hinged on whether a particular factor is included in the general circulation model.<sup>71</sup> Architects have made major engineering errors by mistaking the simulated image for the reality of the project.<sup>72</sup> In our era of nuclear test bans and highly sophisticated simulations of nuclear explosions, the sense of the destruction wrought by these weapons is being lost in a flurry of flashy interactive simulations of molecular constituents.<sup>73</sup> In the financial world, the demands for tractable probability distributions (and not the ‘monstrous’ probability distributions that Benoit Mandelbrot discovered) and usable technologies meant that the long tail of risks were erased from the models’ outputs.<sup>74</sup> In crisis mapping, the technical questions of how data is verified lead to different representations of the situation – representations that can be manipulated by parties with a desire to confuse international humanitarian agencies. And perhaps the most pertinent

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<sup>69</sup> Ibid., chap. 3.

<sup>70</sup> Masco, “Nuclear Technoesthetics: Sensory Politics from Trinity to the Virtual Bomb in Los Alamos,” 364.

<sup>71</sup> Forsyth, *Critical Political Ecology: The Politics of Environmental Science*.

<sup>72</sup> Turkle, *Simulation and Its Discontents*, 51–52.

<sup>73</sup> Masco, “Nuclear Technoesthetics: Sensory Politics from Trinity to the Virtual Bomb in Los Alamos,” 365.

<sup>74</sup> Triana, *The Number That Killed Us: A Story of Modern Banking, Flawed Mathematics, and a Big Financial Crisis*.

example is the widespread ignorance of a coming financial crisis by the economic mainstream.<sup>75</sup> A reliance on general equilibrium models and an absence in modelling the effects of banks on the credit system meant that the most popular economic models all failed to forecast a coming crisis.

In response to these tendencies to mistake the model for the modelled, some modellers play with the authority of digital representations: some intentionally degrade a representation in order to highlight its ambiguities, while others will improve images in order to hide uncertainties.<sup>76</sup> In any case, political possibilities of what is visible and invisible are being shaped by the intentional use of such representations. Yet regardless of these disruptive practices, there remains a tendency towards naturalizing the cognitive aspects of machines – they go from being contentious adjuncts to our thought processes, to being internalised and necessary components. In addition, digital images come to project authority by virtue of being easily transportable without any informational loss as well (what Latour calls an ‘immutable mobile’).<sup>77</sup> Their autonomy means they take on a life of their own and they can emanate a form of authority that appears to be beyond political intrigue.<sup>78</sup>

Yet what is at issue here is more than just the delegation of authority to experts; it is the delegation of authority to nonhuman technological systems. This acceleration of technological development is generating a progressive erasure of the space for human decision.<sup>79</sup> This is perhaps one of the most novel aspects of this new regime of technological governance: whether it is in the form of autonomous drones, algorithmic traders, automated surveillance techniques, or the automation controlling urban flows. The question that this all raises is “what does *govern* mean when no decisions need to be made and where administration is automatic?”<sup>80</sup> The trust we tend to delegate to these representations risks closing off political options rather than expanding them.

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<sup>75</sup> Keen, *Debunking Economics - Revised and Expanded Edition: The Naked Emperor Dethroned?*.

<sup>76</sup> Turkle, *Simulation and Its Discontents*, 79.

<sup>77</sup> Latour, “Visualization and Cognition: Drawing Things Together,” 7–13.

<sup>78</sup> Hansen and Mühlen-Schulte, “The Power of Numbers in Global Governance,” 458.

<sup>79</sup> Berardi, *After the Future*, 57.

<sup>80</sup> Flusser, *Into the Universe of Technical Images*, 123.

Many have taken a look at the issues raised above and argued that the problem is with modelling itself. An over-reliance on economic models is what led to the crisis. An over-reliance on a particular type of risk modelling obscured the real risks. Yet the argument of this thesis is that modelling is a *necessary* correlate of a technologically advanced world such as our own. The infrastructures which sustain our standards of living are far too complex for an un-augmented human mind to deal with. There is a large body of literature which has established human individual's poor capacity to think about nonlinear phenomena. Even our mathematics - the most systematic form of thought - has only recently incorporated nonlinear equations. Yet in a complex system like the climate system, nonlinearities are prevalent and prominent. It is models which, again, give us the capacity to recognise how small shifts can produce large effects, and how interacting mechanisms can offset or accentuate each other. Moreover, a ratcheting effect emerges from these technologies; they are used to make complexity intelligible, but they then allow for more complexity to emerge, which then calls forth the need for more technology, and so on. The answer to these issues is not to reject advanced representational technologies, but to make explicit their political implications and their openness to manipulation.

### **Power and the Material Construction of World Politics**

As is hopefully clear by now, the politics of representational technologies are increasingly significant, ubiquitous, and invisible. As big data analytics, neural networks, machine learning, and computational social science grow and expand, they also function to efface their own operations. The user interface becomes the sole medium of interaction for most, and the political question of how representations are constructed is hidden beneath the shiny veneer of a screen. The specifically political question of by whom and for whom these modes of perception are being created is increasingly cloaked in technical jargon.

This veneer of seemingly authoritative technical jargon is particularly deceptive once the limits of these new representational technologies are accounted for. With any representational medium there are certain benefits and certain



limits: language, mathematics, images, and models all have their own specific constraints in representing the world.<sup>81</sup> While the latest representational technologies have made significant advances into modelling new phenomena, they nevertheless run into inherent limits.<sup>82</sup> In particular, limits exist in the ability to solve differential equations, and in the ability to model randomness. With the former, many differential equations remain impossible to find a solution for, forcing researchers to discretise a continuous function into a finite difference equation.<sup>83</sup> In doing so though, a gap is introduced between the discrete model and the continuous reality – a gap which can be ameliorated to some degree, but which can never be fully eliminated. For linear systems (i.e. simple systems), these ameliorations may not be a problem, yet for nonlinear systems (i.e. complex systems) this gap can lead to significant uncertainty about the future trajectories of the system.

In a second limitation, the problem stems from the very nature of algorithmic modelling. In a real complex system, the outcome is unpredictable as the system is sensitive to initial conditions. The limits of measurement mean that there will always be an element of chaos and unpredictability to the system. So if one were capable of exactly replaying the real system over and over again, the outcomes would vary. By contrast, with models the outcome is deterministically decided in advance by the model itself: replaying the same system with the same initial conditions results in the same outcome. This limitation stems from the discrete nature of computation: whereas the initial conditions are a continuum and a variation, the translation into the digital medium entails turning them into discrete elements that lose this intrinsic variation.<sup>84</sup> In order to overcome this problem various ad hoc solutions have been developed: modelling complex systems now usually entails adding in pseudo-random generators or ‘perturbed’ physics

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<sup>81</sup> van der Ree, “The Politics of Scientific Representation in International Relations.”

<sup>82</sup> Also see: Harel, *Computers Ltd.: What They Really Can't Do*.

<sup>83</sup> Winsberg, *Science in the Age of Computer Simulation*, 7-9.

<sup>84</sup> Longo, “Critique of Computational Reason in the Natural Sciences,” 7.

after the fact, or blocking ‘monstrous’ probability distributions.<sup>85</sup> Yet at this point, “the causal structures differ profoundly, even if the imitation is excellent.”<sup>86</sup>

These limitations – fundamental or contingent – are nevertheless secondary when it comes to the question of how representational technologies are being used to construct power. Power is not something that pre-exists, nor is it a natural property of some actor, nor is it a self-generated cause. Power is an effect of construction – both material and social. The significance of actor-network theory is precisely to highlight this entanglement of the material and the social. Without the stability, resiliency, and objectivity of material elements, social relations fluctuate and become difficult to navigate:

“Although in order to stabilise society everyone – monkeys as well as men – need to bring into play associations that last longer than the interactions that formed them, the strategies and resources may vary between societies of baboons or of men. For instance, instead of acting straight upon the bodies of colleagues, parents and friends, like baboons, one might turn to more solid and less variable materials in order to act in a more durable way upon the bodies of our colleagues, parents and friends. In the state of nature, no one is strong enough to hold out against every coalition. But if you transform the state of nature, replacing unsettled alliances as much as you can with walls and written contracts, the ranks with uniforms and tattoos at td reversible friendships with names and signs, then you will obtain a Leviathan.”<sup>87</sup>

With a material infrastructure though, social relations become sedimented, locked into hierarchical and materialised patterns. In the same way that contemporary

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<sup>85</sup> For example: Heintzenberg and Charlson, *Clouds in the Perturbed Climate System: Their Relationship to Energy Balance, Atmospheric Dynamics, and Precipitation*; Mandelbrot and Hudson, *The (Mis)Behaviour of Markets: A Fractal View of Risk, Ruin & Reward*.

<sup>86</sup> Longo, “Critique of Computational Reason in the Natural Sciences,” 9.

<sup>87</sup> Callon and Latour, “Unscrewing the Big Leviathan: How Actors Macrostructure Reality and How Sociologists Help Them To Do So,” 284.

societies rely upon a material infrastructure in order to take on their consistency and stability, so too does power require a material infrastructure. As Michael Mann's exemplary work has thoroughly demonstrated, power is reliant upon networks of allied entities in order to be exercised.<sup>88</sup> Different social formations can be distinguished by the differing capacities for how quickly, how far, and how intensively commands can be issued. Each of these capacities is in turn transformed by the technological platform in existence for that society. As the technological platform develops, it eventually becomes possible for global actors to exist: those actors who can affect more or less directly social relations around the world. What is missing in Mann's analysis (and similar approaches towards the infrastructures of power) is an analysis of the *ways* in which actors can control others. Technology here alters not only the spatial diffusion of commands, the speed of commands, and the intensity of the commands; it also alters *what* commands can be issued. This is one of the primary contributions of representational technologies – they alter and augment the possible points of intervention into a sociotechnical world. In this way, representational technologies are appendages for power.

With the technologies examined in this thesis, the focus has been on ones which have extended the power capacities of already powerful actors: national politicians, financial traders, and international organisations. Indeed, many of the emerging representational technologies are being embedded within sociotechnical assemblages that are oriented towards intensifying divisions of power capacities. Bioinformatic algorithms coexist with a view of life as patentable pieces;<sup>89</sup> high frequency trading algorithms are embedded in an economic system premised upon cunning;<sup>90</sup> and crisis mapping algorithms exist alongside a humanitarian system oriented towards a contested paradigm of liberal peace.<sup>91</sup> In an age where automated surveillance, climate reengineering, and large-scale data tracking are

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<sup>88</sup> Mann, *The Sources of Social Power, Volume 1: A History of Power from the Beginning to A.D. 1760*, chap. 1.

<sup>89</sup> Mackenzie, *Cutting Code: Software and Sociality*, 65.

<sup>90</sup> Srnicek and Williams, "On Cunning Automata: Financial Acceleration at the Limits of the Dromological."

<sup>91</sup> Campbell, Chandler, and Sabaratnam, *A Liberal Peace?: The Problems and Practices of Peacebuilding*.

already occurring, the question of which actors are being constructed and augmented via these technologies is highly significant.

The issue of resistance arises here. If representational technologies are necessary for complex societies, if they have a ratcheting effect that tends towards greater complexity, and if they augment the power capacities of political actors, then the risk is that they simply exaggerate existing political hierarchies. An important research question that this thesis leaves open is precisely how can these technologies be employed by those without power in order to transform society in a progressive manner? It is obvious that there are severe hurdles in the critical appropriation of these technologies though. One of the more important effects of such technologies is to accelerate a ‘proofs war’ whereby the amount of effort going into producing a piece of knowledge must be (typically) matched by an equal effort to overturn it.<sup>92</sup> Yet the amount of resources required to mobilise and produce counter-knowledge against dominant models is immense and poses a serious problem for any critical approaches. In James Scott’s terms, “not every actor can ‘see like a state’ because the wherewithal to impose such simplifying order on complex masses of humanity lies, for better or worse, outside the competence of most social actors.”<sup>93</sup> Yet knowledge of these technologies is increasingly crucial for understanding the modern operations of power. Regardless of whether one seeks to compete with these technological prostheses or limit and regulate them, it still requires comprehension of the intricacies of the technical details in order to contend with the changing modes of representing the ‘global’.

A satisfactory answer to the question of resistance would require an entire book in itself, yet a direction can be provided here for further research. As was argued in Chapter 1, there is an important distinction to be made between global actors who build networks of power and global actors who manipulate existing networks of power. While the former typically require intense amounts of resources in order to build and sustain, the latter instead become powerful via manipulating existing networks. Rather than competing on the basis of sheer force

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<sup>92</sup> Latour, “Visualization and Cognition: Drawing Things Together,” 12; Latour and Woolgar, *Laboratory Life: The Construction of Scientific Facts*.

<sup>93</sup> Jasanoff, “Ordering Knowledge, Ordering Society,” 26.

(a losing proposition for any resistance), competition here occurs on the basis of cunning and strategic action.<sup>94</sup> These are akin to weapons of the weak – tools used to subtly shift social situations to the advantage of those without institutional power.<sup>95</sup> With representational technologies, such tools have the potential to generate cognitive maps of complex situations in such a way as to *create* leverage points within an existing hierarchical order. The barriers facing these projects should not be underestimated (particularly for those with a lack of monetary resources), yet they are examples that these technologies can be used for resistance and change, as well as power and structure. Technology, it must be remembered, is not a means to overcoming social conflicts; it is rather a tool that is employed by political struggles. Technology is no panacea, but by transforming the material platform of society it shapes how conflicts are carried out and what potentials there are for progressive changes.

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<sup>94</sup> I owe this point to Benedict Singleton.

<sup>95</sup> Scott, *Weapons of the Weak: Everyday Forms of Peasant Resistance*.

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