REASONING WITH PLANS
INFERENCE OF SEMANTIC RELATIONSHIPS AMONG PLANS ABOUT URBAN DEVELOPMENT

BY

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Abstract

Plans have been considered the end products of planning activity, and research has focused on how plans are made. Careful thought has not been accorded to how plans are used, after they are made, in reasoning about and choosing how to act. In any given situation, various organisations make plans, some of which have overlapping scopes and intersecting intentions. As a result, the actions considered in these plans have semantic relationships such as substitutability, interdependence, and contingency with one another. The purpose of this dissertation is to identify and explain the semantic relationships between actions within and among plans to better understand how to reason with plans and about actions.

The thesis defended is that it is useful and possible to reason from multiple plans when deciding what to do. A plan contains information about interdependencies and uncertainties of multiple decisions and actions considered by an actor. These relationships are not limited to actions within one's own purview. One has to consider also the effects of others' actions and intentions on one's own. Since a single plan cannot account for all these interdependencies even for one actor, every actor should consider multiple plans–both plans of her own and those of others–in making decisions.

This dissertation examines the various plans made over time by various organisations in McHenry and Champaign counties in Illinois. Relationships between actions within and among multiple plans can be discovered using attributes of actions and the configurations of actions within a single plan so that they can be considered in future planning and decision making. It builds upon multiple disciplines and methodologies to represent actions, situations, intentions, and relationships among them.

Simple databases based on real situations were used to demonstrate that these relationships can be encoded and queried in reasoning with plans. The results demonstrated that previously discovered semantic relationships can be used to discover additional relationships across plans thereby enriching the decision making. The approach provides a systematic way of structuring the information in plans so that reasoning about relationships among actions across multiple plans is possible.

Keywords: Plans, Organisations, Intentions, Substitutability, Interdependence

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efforts there may remain some fallacies in reasoning or errors. The responsibility is mine.

Mark Twain once wrote, “For substantially, all ideas are second hand, consciously or unconsciously drawn from a million outside sources and daily use by the garnerer with a pride and satisfaction born of the superstition that he originated them.” I harbour no such pride or superstitions. Thanks to many unnamed, which made it possible.

In the spirit of sustaining the intellectual commons, this work is left in a restricted public domain. As Saul Bellow famously said, “If you have the strength to pick them up, take them with my blessing.”

Contents

List of Tables

List of Figures

List of Abbreviations

CATS	Chicago Area Transportation Study
CCRPC	Champaign County Regional Planning Commission
CMAP	Chicago Metropolitan Agency for Planning [1]
CTA	Chicago Transit Authority
CUMTD	Champaign Urbana Mass Transit District
CUUATS	Champaign Urbana Urban Area Transportation Study
EPSG	European Petroleum Survey Group
ETJ	Extra Territorial Jurisdiction
GIS	Geographic Information System or Science (as appropriate)
IDOT	Illinois Department of Transportation
INDOT	Indiana Department of Transportation
LEAM	Landuse evolution and Impact Assessment Model
KIF	Knowledge Interchange Format
LEED-ND	Leadership in Energy and Environmental Design - Neighborhood Design
LRTP	Long Range Transportation Plan
MPO	Metropolitan Planning Organisation
NIPC	Northeastern Illinois Planning Commission
OGC	Open GIS Consortium

[1] In 2007, NIPC and CATS merged into CMAP

OGP	Oil and Gas Producers, International Association of
PDM	Planning Data Model
PML	Planning Markup Language
RoW	Right(s) of Way
RTA	Regional Transportation Authority
SRA	Strategic Regional Arterial
SQL	Simple Query Language
TIF	Tax Increment Financing (District)
TIP	Transportation Improvements Program/Plan
WKT	Well Known Text
UCSD	Urbana Champaign Sanitary District

Chapter 1

Plans as Information

Gretel wept bitter tears, and said to Hansel: “Now all is over with us.” “Be quiet, Gretel,” said Hansel, “do not distress yourself, I will soon find a way to help us.” And when the old folks had fallen asleep, he got up, put on his little coat, opened the door below, and crept outside. The moon shone brightly, and the white pebbles which lay in front of the house glittered like real silver pennies. Hansel stooped and stuffed the little pocket of his coat with as many as he could get in. Then he went back and said to Gretel: “Be comforted, dear little sister, and sleep in peace, God will not forsake us,” and he lay down again in his bed. When day dawned, but before the sun had risen, the woman came and awoke the two children, saying: “Get up, you sluggards! We are going into the forest to fetch wood.” She gave each a little piece of bread, and said: “There is something for your dinner, but do not eat it up before then, for you will get nothing else.” Gretel took the bread under her apron, as Hansel had the pebbles in his pocket. Then they all set out together on the way to the forest. When they had walked a short time, Hansel stood still and peeped back at the house, and did so again and again. His father said: “Hansel, what are you looking at there and staying behind for? Pay attention, and do not forget how to use your legs." "Ah, father," said Hansel, "I am looking at my little white cat, which is sitting up on the roof, and wants to say good-bye to me." The wife said: "Fool, that is not your little cat, that is the morning sun which is shining on the chimneys." Hansel, however, had not been looking back at the cat, but had been constantly throwing one of the white pebble-stones out of his pocket on the road.

—from Hansel & Gretel; The Complete Grimm's Fairy Tales

1.1 What should Gretel do?

Hansel's predicament in light of his parents' intentions led him to formulate a series of actions–filling up his pockets with pebbles, walking in the rear, and throwing the pebbles on the road. These actions, and plans that informed them, were shaped by his intention to get back home, if and when they were left stranded in the forest (a contingent circumstance). They were further related to the stated and unstated plans of the parents and were made, used, discarded and modified when these circumstances changed. Bruce and Newman (1978), in their seminal paper on interacting plans, dissect this famous fairy tale to illustrate the concept of interacting plans of agents, whose actions are interdependent with other actions over which they have limited control. They touch upon the nature of devious or misleading plans so that real plans can work and how some of these real plans need to be kept secret and contingent on other plans. Each character not only has a plan, but also interprets the plans of others. Hansel overhears a plan believed by his parents to be secret, and then he creates his own plan and keeps it secret (successfully despite the parents' observation of his behaviour). In particular, Hansel does not accept his parents stated intent to return at the end of the day to the place they leave the children. Nor does Hansel reveal his plan to drop pebbles in order to mark a path home.

Adding to the mix is the curious indifference of the Grimms (and that of Bruce and Newman) to the actions and thoughts of Gretel[1]. She is aware of the secret plans of their parents. Hansel merely tells her about his intentions of getting back, not the methods and plans he chose to realise that intention. She chooses merely to follow her brother's actions in the hope that it will accomplish her own objective of getting back to the house. Even later in the story, when Hansel chooses bread crumbs instead of pebbles, she does not prepare for the contingency of the crumbs disappearing thereby impairing her own ability to accomplish her goals. Were Hansel to reveal his plans to Gretel, would she have chosen to prepare for such contingency in light of Hansel's and their parents' plan? This we do not know. However, this story illustrates the complexity of choosing ones own actions in light of others' actions, stated and secret plans, and intentions.

This dissertation addresses the question: How do and should we reason about what is to be done, in light of various kinds of plans that exist and are pertinent to a decision situation. In particular, the dissertation focuses on the uses of plans in urban development by various actors with distributed authority, bounded capability and endowed with imperfect foresight and other cognitive limitations. Like Donaghy and Hopkins (2006), it presupposes that resolution and identification of all the interdependencies between actions is futile and that there will be multiple and related plans one should consider in making decisions. Unlike Pollock (2006), this dissertation does not propose a formal account of thinking before acting, but

[1] Possibly because she is too young and incapable of planning.

relies on illustration from stylised examples from cases of planning in Illinois to argue for a method of using plans before acting.

1.2 Thesis

The central thesis of this work is that it is useful and possible to reason with multiple plans when deciding what to do. Plans contain information about intentions, contingencies and interdependencies considered by the actor who made the plan about a particular set of actions. When making one's own plan or using it to decide what to do when and where, interdependencies and contingencies of one's own actions or their outcomes may be affected by actions of others. Thus, it would be useful to consider the intentions of others that are made public in plans. It would, therefore, be advantageous to use the already discovered relationships between actions, to understand how else our actions are related to others' actions. In particular, this dissertation is focussed on two general types of relationships. One is 'Substitutability' and the other is 'Interdependence'. Some of these relationships are already clarified in making ones own plan. Since individual plans are limited in focus, they cannot consider all such relationships. The aim of this dissertation is to provide a framework to heuristically discover these relationships that are not already discovered, considered and accounted for.

Friend and Jessop (1976) describe the alternatives considered and a decision making process in the city council of Coventry and formulate methodologies to deal with uncertainty associated with the decisions. They further elaborate on the necessity of the planning process not only to formulate these alternatives but also to consider joint solutions to interdependent or otherwise linked decisions.

Extending this work, Friend and Hickling (2005) categorise the decision making process as incremental process under three different kinds of uncertainty-that of environment, that of values, and that of related decisions. They consider multi-organisational decision making and explicitly account for influence versus capability, however, without considering the availability of information within existing plans. This dissertation extends their work in this direction, to use the plans of various organisations in making one's own decisions in light of linkages with other decisions of one's own and those of others.

Alternatives are choices of actions that are possible and are available in a decision situation. Plans make these alternatives explicit for the purpose of the particular plan because the choice among the alternatives is partially evaluated and a subsequent choice is left for *ex post* plan reasoning.[2] Decisions can be made to winnow out alternative actions thus, restricting the set of available alternatives for later decision making.

Interdependence, on the other hand, is about decisions that are linked to each other. Choices in one decision affect the outcomes of the other decision and thus both these decisions are to be considered simultaneously. One of the reasons for planning (or thinking before acting) is to take a moment to consider these interdependencies rather than making decisions myopically. Interdependence that is considered in this dissertation includes unidirectional dependency (contingency), bidirectional dependency, priority, complementarity, and parthood relationships among actions. Contingent actions should have their functional prior actions already taken before the sequents are chosen. Two mutually interdependent actions must be chosen together when choosing one action. A temporal

[2]One can argue that there is no such thing as post-planning because planning is a continuous state of flux without a beginning or an end. I will defer this topic to a later work.

order between a set of actions provides clues about how actions are arranged in time. Choosing an action may make more sense only when it is chosen along with a complementary action. An action when chosen, involves choosing all the constituent actions that make up the action.

Prior work has demonstrated how information within a single plan is organised: Actions within plans are arranged into lists (agenda) , contingent actions (policies or strategies), or tightly integrated action sets (designs). Using these configurations is useful in determining which actions are substitutes or otherwise interdependent within a single plan or across multiple plans. Furthermore, the actions themselves have numerous attributes which also could be harnessed to arrive at possible relationships between actions. The central contribution of this work, is that information so arranged within plans can be used to infer other possible relationships across plans. Irrespective whether a data structure exists to formalise them in a computer based information system, reading plans and making plans in this fashion makes them possible to be effectively used in decision making of many. I consider multiple plans of different actors about related actions to discover previously unstated relationships between actions.

This dissertation is not concerned with the decisions that get made or what political, social and rational considerations play into decision making once this information is made available. Many decision theorists such as Simon (1982) and Keeney and Raiffa (1993) and planners concerned with the micro political environments in planning behaviour such as Forester (1999) and Healey (1997) have described these considerations in great detail. The elephant in the room is the presence of plans, which is largely ignored both by management and planning theorists. This dissertation is an attempt to refocus the discussion on plans and justify the many resources spent in making them.

1.3 A View of Urban Planning

Almost all scholars in urban planning domain view planning as a mechanism to reach consensus over goals (Innes and Booher 1999) or of state control over development (Webster and Lai 2003) or as advocacy for social, environmental, intergenerational and other kinds of justice (Davidoff 1965; Krumholz and Forester 1990). In all the rhetoric about justice, statism and participation a key component of planning is obscured. One of the outcomes of planning is that *plans get made*. The question then is, what is the purpose of those plans and how best to use them, once they are made.

Plans can be construed to be instruments that direct change and clarify an organization's own actions to itself. However, by the process of planning in public, the planner reveals the plan that then shapes the expectations of others. Thus, explicit plans can be viewed as instruments that are meant to reveal preferences so that others can adjust their actions accordingly. This view of planning as a method to combat costly information search, can find parallels in the arguments advanced for zoning in Hopkins (2001) and Barzel (1997) or for commitment described in Levin (1976). Planners should then consider plans of other strategically important actors, such as federations of governments, local developers, or environmental advocacy groups, and respond either in synergistic or antithetical fashion (Kaza and Hopkins 2006). One can view planning as a process that starts with an intention and makes plans to realise it and in the process of negotiating with oneself and with others, the process modifies intentions and plans simultaneously (Hoch 2007) . This planning process would be a continuous process, which adjusts itself in light of new information about what the world is and how other actors are responding to it. Plans are almost never fixed in time or in the formal documents that symbolise them. Urban planning discipline has largely been concerned with plans of governments and I consider this view too narrow. Whether or not the plan is a formal document adopted by the particular agency, is largely irrelevant to its use in decision making. One ought to view plans as a way to organise information about intentions, intended actions, their effects, and their interactions. Plans should be able to guide decisions and are worth making when the decisions about actions that are indivisible and interdependent and they have irreversible effects, and actors that make them face imperfect foresight (Hopkins 2001).

Suchman (1987) in her opening statement discusses two traditions of navigation as a metaphor for two types of purposeful action as they relate to planning: European and Trukese. The European navigator sets a course *a priori* and the major part of the rest of the effort is to correct any deviation from this course. On the other hand, the Trukese navigator only sets a goal and responds to uncertain situations in an *ad hoc* fashion without losing sight of the goal. Hopkins (2001) claims that the former is essentially 'error control' behaviour and the latter is 'goal directed' behaviour and are distinctly different from 'plan based action'. However, in both cases plans exist. The European navigator's plan is a detailed set of actions complete with reckonings, bearings and lines of position, as well as policies to correct course when the vessel goes off-course, a set of designs and policies. In the case of Trukese navigator, the plan is merely a goal and a loosely defined set of policies in anticipated situations (based on previous experience and learning) and improvisation in unanticipated situations (also a learnt skill). In the spirit of Suchman (1987) and Dewar (2002), this dissertation does not propose that formal plans ought to account for all information needed to deal with inherently uncertain futures. Instead, it merely presupposes that plans are made to deal with specific uncertainties and are modified as needed by the actor to whom the plan is useful.

Taking this view of plan as an organiser of fluid information about intentions and actions in changing and contingent circumstances as given, the dissertation sets out to explore the methods for reasoning with multiple plans. It is almost inevitable in a world of distributed authority, that different organisations engage in planning about different but sometimes contingent and overlapping issues. Most of these entities that make these plans in the public domain are typically government agencies at different levels of governance. However, voluntary groups also make and publish plans seeking to influence certain kind of choices about future with no real authority to make those choices themselves (e.g. Commercial Club of Chicago 2000). To plan and to act effectively, each agency or group that plans ought to consider at the minimum if not account for, the explicit plans of other groups.

Land use plans are about regulations and investments. Investments are changes to particular entities of the world, called assets. Regulations codify the rights of actors over these assets. For example, a subsidy is an investment, while a tax is a regulation. Information about assets, actors that hold rights over these assets and regulations or transactions that change those rights are necessary information for any planning situation. An ideal system would track these changes of assets, and changes of rights over these assets to arrive at 'plan ready information' (Carrera

2004). If we postulate that agents are planning continuously by amending old plans, updating them or discarding them in light of new information, relevant information needs to stay current.

Plans are inputs to decision making, because they have at least partially considered what courses of actions could be taken in what future and how such decisions affect the future itself. Since such thinking before acting is not possible on-the-fly due to limited capability of an agent, plans are made ahead of time for future decision making. Furthermore, plans consider the relationships of decisions that need to be taken now to actions that are to be decided upon later. On the other hand, while making these decisions plans do not dictate outcomes, because they are but one input, albeit an important one.

Plans are thus a product of cognitive activity, not of political capability alone. This claim is a radical departure from the standard account of planning by urban planning academics and practitioners. [3] Planning considers multiple decisions ahead of time before acting even when deciding on only one action. The degree of property rights or communicative capabilities of the planners are irrelevant to the justifications of plans and planning. They matter only when the substantive portions of plans deal with issues of property or when procedural justifications involve open communication. Not all plans of interest are about these issues.

A note about the word political is in order here. Political in this context refers to an ever changing social structure within which rights, responsibilities and norms are negotiated. The historical currents of these negotiations establish, perpetuate and at times demolish the structural relationships such as power and hierarchy.

[3] Save for a few exceptions such as Intriligator and Sheshinski (1986); Hopkins (2001). Even Hoch (2007) in making Bratman's contribution accessible to urban planners, minimises the cognitive dimensions of planning and focusses on Planning by the State (capitalisation in original).

While it is important that plans be cognisant of the political environment they are creatures of, many a planner view planning as a function that is organised in the collective realm or as Habermas puts it the 'public sphere'. While planning and the attendant plans benefit from engaging the political context they operate in, there is no reason why they exclusively should or ought to. Plans can occur because of their usefulness in decision making for a sole individual or happen because they are useful to make and use as a group. They can occur entirely due to ratiocination or through laborious process of communication, more likely through a combination of both. In either case, they serve specific purposes of clarifying to self about possible futures or clarifying to others about likely actions that I may take in those specific futures and likely responses I am anticipating from others. Unlike the technical view of planning that dominated the early part of twentieth century, this view does not presuppose that problems are solved devoid of the context. However, this view does not accept that there is no role for individual person or organisation in making and using plans. "Plans are not government regulation, centralized authority, or collective choice ... Plans make sense within and among organizations. If I control all decisions, I can benefit from plans; if I can influence only one decision, I can benefit from plans ... Plans make sense for individuals or groups. If I act alone, I can benefit from plans; concerted collective action can benefit from plans ... " (Hopkins and Alexander in review).

If we postulate that plans are not arrived at by agreeing to them as a group, but are intensely personal at the same time they are social, at any given time, then many actors are planning by building on earlier plans of their own and of others and modifying these plans. Some make their plans public or accessible to others for a variety of reasons (Kaza and Hopkins 2006). When such plans are available as information, how should it influence our own plans and decisions in so far as they are related? [4]

1.4 An Example

This brief section provides an illustration of why this question is interesting to study and is useful. This case was first described by Hopkins (2007) and is paraphrased in the paragraph below. For maps to provide the context to this and future examples please refer to appendix B.

A big box retail store, Meijers, has announced its plans to open a new store at the South-Eastern edge of Urbana in the fall of 2008. In part, the store's expansion action has been conditioned by a necessity of building a new warehouse that will serve the two stores in the metropolitan region (interdependence). The East-West connectivity in the metropolitan region had been increased substantially by completion of Windsor Road (the South edge of the Meijers site). Windsor now cuts through the University of Illinois' South Farms, which had previously blocked it, and has been upgraded to a four line road, in segments either built or scheduled all the way to Route 130. This plan of the County and the City to expand this road was contingent on the actions and plans of the University, which has completed the plan for relocating the South Farms to accommodate its growth. On the other hand, the city of Urbana in its comprehensive plan has not ruled out the interchange between Route 130 and I 74 making the intersection of Windsor Road particularly accessible, if that alternative gets chosen. However all the other

[4] Inferring plans from observed actions is a very important point but is not the focus of this dissertation.

alternatives in contention for the interchange also propose a connectivity with the Windsor Road for different segments (see figure 2.3).

In an exceedingly complex and rich example about the use of plans and their impact on actions described in Hopkins (2007) this is but a smidgeon. Nevertheless, this paragraph illustrates the complexities of relationships of three kinds of actors–firm, City, University. Each has plans that accounted for possible futures and their own likely actions in those futures. The plans of the City about the interchange are made public after Meijers made their own plans of expansion. However, the actions of the firm are dependent on the plans of the City and as such their reasoning about expansion would not only include their own plans but also plans of the City and the University. Similarly the plans of the city about the interchange and the extension of the Windsor Road are contingent upon the University's plans about South Farms but also its eastward annexation strategy. It is in this cacophony of interacting intentions and changing plans and circumstances that we must decide what to do when before we act.

As is argued in the § 1.3, plans are input to making decisions. Since each decision is concerned with choice of a particular alternative, focussing on alternatives is important. On the other hand, as Hopkins (2001) and Keeney and Raiffa (1993) have demonstrated, thinking before acting is quite useful when we pause to consider the effects of one choice of alternative in a particular decision over the choices of alternatives in linked decisions. One of the compelling reasons to make plans is to make interdependencies explicit, which are otherwise not in focus. These are the reasons to focus on these two types of semantic relationships in the dissertation.

1.5 Context

This dissertation follows the framing of planning as a way of thinking before acting (Pollock 2006) and in the case of urban development plans as artefacts of organising information and reflecting commitment (Bruce and Newman 1978; Hopkins 2001; Levin 1976). With few exceptions, reasoning with multiple plans is not considered in the literature. Bratman (1987) when considering plans as a means by which rational agents clarify intentions, beliefs and desires alludes to plans as being in flux and dependent on knowledge of others' plans and intentions. He, however, focusses on the issue of co-ordinating ones actions with others through the means of changing plans and intentions, without accounting for the reasoning that leads to these changing plans.

From an economics stand point, planning has become synonymous with regulation or essentially equivalent to the command and control economy as evidenced by the use of a 'social planner' as a contrast to a multitude of autonomous and rational agents interacting. However, plans appear in the economics disguised in other names such as decisions under uncertainty (Dixit and Pindyck 1994), strategic and mutual interdependence (Von Neumann and Morgenstern 1944) and satisficing (Simon 1982). Planning is essentially thinking before acting and as such even pure myopic optimisation could be considered planning when these optimisation leads to decision rules that consider the effects of the actions before the action has been taken. In all this literature, only effects of possible actions of others on ones own actions are considered, not the intentions and the changes in them as typified by plans. This dissertation's point of departure is at this bend.

Urban planners, taking a cue from the economists focussed on the planning by governments as a response to market failures (e.g. Webster and Lai 2003). Planning is presumed to happen in a communicative setting (Innes 1996; Healey 1997) and plans are that of a collective made for a public purpose. In contrast, Galbraith (1973) considers a collection of large firms as 'planning system' referring internal planning of organisations (including firms and governments) that allows them to be the producers and consumers of goods and services not only merely inter-organisational coordination.

Plans in this context have become an afterthought to the process, where the process is supposed to produce collective information and expertise that no written documents can carry (Innes 1998). However, there is a minority who argue that plans are important and useful objects of study (Hopkins 2001; Hoch 2007; Mastop and Faludi 1997; Hovey 2007; Kaza and Hopkins 2006) irrespective of whether a government makes them or not, or makes them publicly or not. Drawing from that tradition Hopkins, Kaza, and Pallathucheril (2005b), Kaza (2004), and Singh (2004) have demonstrated a data model to describe the information within the plans. Using these models, we have demonstrated that plans can be represented in a systematic framework from which inference is possible. Building on these, Hopkins et al. (2005a) demonstrate an application of using such a data model to drive the inputs of plans into multiple urban simulation models. Simultaneously, ontological representations for urban planning have been pursued by a multi disciplinary project, some of whose work is published in Teller et al. (2007). While this work lays foundation for the thesis described in this dissertation, none of them explicitly considers the phenomena of multiple plans.

In a Jamesian tradition of pragmatism Verma (1998) describes how connections and similarities could be used to reason about actions in planning without depending on reasoning from first principles (foundationalism). Verma argues that similarities between various explanations about how the world might work (theories) to form connections, which then become a basis for inquiry and action. In the same way, by seeking connections between various plans relevant to a particular decision, I seek to establish the utility of making plans to inform parts of these decisions of both oneself and others.

Most of the urban development happens in a world of distributed authority, many actors are planning, interacting, making and changing plans based on observed behaviours, expectations of what various futures might hold for them and other such information and knowledge. These actors make many plans over time, some of which supersede others but others which deal with completely different set of issues and linkages from earlier plans. Also, changing information about others' plans helps us to understand the impacts of ones own intentions and actions and thus leads to further changes in plans. It is this problem of reasoning with these plans in a structured environment that is addressed in this dissertation.

1.6 Methods

This dissertation uses two complementary methods: conceptual analysis of the semantics of reasoning with plans and construction of a prototype database and queries to demonstrate the feasibility of reasoning with plans in realistic situations. As can be evidenced by the references used in the dissertation, this work has drawn from multiple disciplines ranging from Artificial Intelligence, GIS, and Economics to Urban Planning. As such, the methods used to demonstrate the viability of the thesis draw from all of them to some degree. Nevertheless, this dissertation is about plans in urban situations. In support of the thesis, I use examples from two different planning cases in Illinois. One involves plans of various organisations and actors in the Champaign-Urbana metropolitan region and the other is about plans related to McHenry County. I use textual analysis to identify the relationships of actions within the plans in particular contexts, and stylised examples to illustrate the concepts of semantic relationships between actions apparent or deducible within and among plans. In many cases, I use these examples to back general claims about configurations of actions or attributes of actions in inferring certain relationships.

This research demonstrates an information system (human or computer supported) that is conducive to such planning processes. To prècis Innes (1998; p. 54), "When information is most influential, it is also most invisible. Thus, rather than saying that policy makers consciously apply information to make a choice, it is more accurate to say that information frames, or in other words limits the available choices in the first place. Information acts more as a lens than as a bottom-line finding." An information system of plans, adequately designed to work with experts who have institutional and contextual knowledge, would greatly expand the ways in which plans are used and efficacy of plans. This would further affect the way in which we make plans and make them public.

In addition to this exposition about information within plans, I also demonstrate the information system with illustrations operationalised in databases of multiple plans. These databases, while following the general logic of attribute and relationship configurations as described in Hopkins et al. (2005b) or in chapter 2, are relational databases, and appropriate modifications are made to account for these differences. A Querying tool was written in Java to query the databases, make appropriate inferences heuristically, and run other models and programs to determine the semantic relationships based on perceived effects of the actions.

The two approaches to defending the thesis complement each other. The conceptual explanation is more feature rich and expository. It is amenable to human interpretation of roles about information available in plans and a structured method of invoking them in decision situations. The database examples demonstrate the feasibility of building computer tools to support such an endeavour. The databases and tools are not meant to serve as a complete prototype of an information system; they serve only to demonstrate in concrete terms the feasibility of the concepts.

Couclelis (1991), argues forcefully that current GIS methodology is inadequate to the task of planning. To this end, I refocus the attention on entities central to planning–actions, actors, assets and activities (four As). Location is treated as one of the many attributes that may exist for these entities. In reading plans, with this perspective in mind, we get away from the location centric information systems and move towards action centric information systems, which are more appropriate for planning. Elsewhere, in Kaza (2004), I have described such an approach as being useful in describing rights, restriction of rights and permissions. The same concepts of actions, actor et al. divorced from underlying location and time can be used in describing plans.[5]

Finn et al. (2007) described a method of structuring information within multiple plans in the McHenry County in a web-based information system. I draw on this work considerably, however the focus of that work is the display of information to make a new plan. This dissertation, on the other hand, is interested in how

[5] Plans are distinct from regulations. Plans lack the backing of police power.

people would reason with plans similarly structured. It also extends their work by adding more complex relationships such as policies, strategies and designs within the plans that are being considered.

1.7 Structure of the Argument

This dissertation is arranged into three major parts. The first part comprises chapters 1 & 2, and provides a summary of the argument and definitions and explanations of the terms used throughout the dissertation. Chapter 2 illustrates the key points about descriptors of the state of the world (the four As) and the roles plans play in the world. More details are provided in appendix A. The configurations of actions within a single plan such as agenda, policies, designs and strategies are elaborated. Plans also have other functions such as goals and visions and may contain information about evaluation criteria . However, these aspects of plans are not central to the thesis in question and hence are only referred to in passing.

The second part, which is the main thrust of the dissertation, comprises chapters 3, 4, & 5. Chapter 3 explains the concepts of substitutability in various degrees (complete and partial) and identifies when they are made apparent within a plan. It then considers the use of configurations of actions, such as designs and strategies, to infer what actions can be substitutable and argues that substitutability is a relationship with respect to particular criteria. It then argues that capability restrictions of actors or location restrictions of actions can preclude one action from being taken when other actions are taken. It finally concludes with the distinction between the rational function of plans and the rhetorical function of plans and the effect on determining which actions are substitutable.

Chapter 4, deals with multiple semantic relationships such as complementarity, priority and parthood relationships between actions. In particular, it focusses on identifying these relationships within the plan first. To this end, it elaborates on the design function of plans and argues that once such relationships are identified in each plan we can use these relationships to identify further relationships among actions in different plans.

Chapter 5 opens with finding further relationships among actions by identifying the presence or pitfalls of transitive reasoning about substitutability relationships. In particular, it distinguishes the transitivity relationship of partial and complete substitutes. It then goes on to explain how we can find substitutes based on already existing interdependence relationships. Similar issues are explored in the context of various interdependencies and interdependence of substitutes.

The final part of the dissertation comprises of chapters 6 & 7. While each of earlier three chapters uses stylised examples and analytical reasoning as described in §1.6, chapter 6 demonstrates the feasibility of building an information system that can support this kind of reasoning by using pseudo code and results from queries. The demonstration is merely illustrative of the ideas and is only sufficiently refined and complete for the particular purpose of exposition. Chapter 7 recaps the ideas discussed, and lays out further work, and conceptual and technical obstacles that still need to be overcome before a working prototype of such an information system can be developed. The appendices provide some of the contexts already described elsewhere, more technical details of the demonstration database and queries.

Susan Hurley once described her style of work to Andy Clark as "patiently building a complex, coloured mosaic of many parts, rather than a single serial argument that moves like a freight train from one point to the next." It is in this spirit that various (and seemingly disconnected) parts of the arguments are assembled separately keeping in mind the larger picture and the thesis described in this chapter. In the final parts of the dissertation, hopefully it will be clear how they all hang together.

1.8 Contributions & Conclusions

The intention of this dissertation is to refocus the discussion of plans and their utility in urban development contexts. It is not a treatise in logic, information theory, economics, computer science, decision theory, or political philosophy. Its purpose is specific and narrow. While borrowing uninhibitedly from these disciplines, the dissertation remains focussed on reasoning with plans and the uses of such reasoning in decision making in urban development.

The contributions of this dissertation are specific. It provides a methodology to use multiple plans in a decision situation by making use of relationships among actions that are already discovered to make further inferences about relationships that are not apparent. It strengthens the view that plans are to be made to be used in decision situations and provides a framing for making plans in such a manner. It expands on previous work on the ontology for urban planning to provide for a structured, if not a very general, view of accounting for various aspects of plans and urban development and puts them in the context of recent advances in GIScience in representing non-locational objects.

Much of the dissertation could also be viewed, however, as a structured method of viewing plans, planning, and decision making in general. The model specified and discussed is at a sufficiently abstract level that human could act as a repository of information, lexical analyser, and a reasoning node all at the same time. Reasoning with plans is valuable for making sense of plans in practice, whether or not computer supported information systems are in place to support such reasonings.

Chapter 2

Semantic Relationships & Reasoning

Semantics is a branch of linguistics (semiotics) that deals with the relationships between a set of signs and the objects they represent. "In formal studies, a semantics is provided for a formal language when an interpretation or model is specified. However, a natural language comes ready interpreted, and the semantic problem is not that of specification but of understanding the relationship between terms of various categories (names, descriptions, predicates, adverbs ...) and their meaning"[1]. This dissertation interprets and analyses the semantic relationships among concepts in plans. To this end, we delve into the nature of plans and their uses in decision making and why these semantic relationships edify the uses of plans by various agents.

This dissertation does not attempt at rigourous formalism or automated inference based on such formalism. It uses ontology as an abstract way of describing things and relationships between things that are of interest. Sowa (1999; p. 493) describes the study of ontology as

> ...the study of the *categories* of things that exist or may exist in some domain. The product of such a study, called an ontology, is a catalog

[1]"semantics" The Oxford Dictionary of Philosophy. Simon Blackburn. Oxford University Press, 1996. Oxford Reference Online. Oxford University Press. University of Illinois - Urbana Champaign. 23 July 2007 `http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t98.e2147`

> of the types of things that are assumed to exist in a domain of interest D from the perspective of a person who uses a language L for the purpose of talking about D. The types in the ontology represent the *predicates, word senses,* or *concept and relation types* of the language L when used to discuss topics in the domain D. An uninterpreted logic, such as predicate calculus, conceptual graphs, or KIF, is *ontologically neutral*. It imposes no constraints on the subject matter or the way the subject may be characterized. By itself, logic says nothing about anything, but the combination of logic with an ontology provides a language that can express relationships about the entities in the domain of interest.
>
> An informal ontology may be specified by a catalog of types that are either undefined or defined only by statements in a natural language. A formal ontology is specified by a collection of names for concept and relation types organized in a partial ordering by the type-subtype relation. (emphasis in the original)

In this dissertation we are not concerned with complete formalisation of the all things related to urban development, but use them as a structured way of thinking about urban development. Unlike computer scientists who are interested in reasoning systems that mimic human reasoning, I aim to complement human reasoning capabilities with the use of computers. Since so little is specified about the uses of multiple and related plans in decision making, this dissertation's aim is not to formalise it but to break new ground in understanding the reasoning with and using plans.

This chapter describes the terminology used throughout the dissertation and sets out the basis and rationale for the thesis. It will first explain the notion of plans as intentions and commitments to particular actions. It will then elaborate descriptors of the state of the world and the relationships between them. Once they are identified, the elements of action configurations in plans as designs and strategies are elaborated. It will then briefly explain the semantic relationships we are interested in, such as substitutability, priority, and contingency and give reasons why they are useful in reasoning about what to do with existing plans.

2.1 Intentions, Actions and Plans

Urban planning is concerned with the choices of actions (or combinations of actions) situated in a spatio-temporal context and towards a set of goals in various plausible futures. When the definitions of choices, goals and actions are broadly construed, planning is about intentional decisions (e.g. Bratman 1987; Hoch 2007) taken prior to the fact, about possible relationships of actions. Plans are records of such decisions and relationships among them. Typically planning literature has focussed on the method of planning (e.g. Kaiser et al. 1995; Forester 1999; Davidoff 1965), the justifications for planning (e.g. Hopkins 2001) and the efficacy of planning (e.g. Flyvbjerg 1998; Webster and Lai 2003). However, we are interested in plans as information about intentions that can be harnessed to make decisions. Hopkins (2001) claims that plans are useful to make when these decisions satisfy the 4 Is – Interdependence, Imperfect foresight, Indivisibility and Irreversibility.

Bratman suggests that intentions are distinct from desires and beliefs and they form the basis for plans. The fact that Hansel desired not to be left alone in the forest gave reasons to intention of getting back to his house, which suggested a course of action of throwing the pebbles to mark the route. The act of considering inter-related decisions and actions to match them to intentions and further to particular goals is the process of planning. A planning process may not completely match intentions and actions to circumstances; for it is prohibitively costly do so.

Plans are not predictions of a future. They merely specify likely actions to take in different considered contingent circumstances on the basis of intentions and other interdependencies. Hansel's plan did not account for a future in which the bread crumbs are eaten away by the birds even when his intentions and desires remained the same. In other words, a planner and, therefore, a decision maker should recognise not only various actions that may lead toward the goal to satisfy the intent, but also various uncertainties that hinder or complement such actions. It is useful to think about these actions, effects, and intentions in various interesting, but not all, combinations of them ahead of time before acting. These are plans of individuals, which are made to be used. There are other plans whose function is rhetorical, in that they are made to convince other people what their intentions ought to be. In some cases, plans provide subtle directions to choices of actions as well as intentions and in others they provide vociferous rhetoric. These distinctions play an important part in understanding the semantic relationships between actions in these plans.

Bratman further characterises that intentions involve *volitional commitment*. Levin (1976) argued that different stages of planning provide varying degrees of commitment to a proposal. The commitment itself does not guarantee the proposal being realised, much less in any particular form, but does provide information to others about how they might modify their own plans to suit the new information. Plans are made explicit *a priori*, to provide a clue to others as well as to oneself about expected actions (Mastop and Faludi 1997). If a transit authority has a plan for operational maintenance of a railway system, for example, this plan lays out the sequences of actions (closing links, re-routing trains, etc.) that it intends to pursue in various futures. In other words, this plan is useful to make even if no one else wants to know about it. It is useful to make my plans public in some cases, however, because it reduces the strategic uncertainty of other actors about my actions, and such knowledge by them may be beneficial to me. A transit agency might make some parts of its operational plan public to affect the travel behaviour or residential location choices of commuters. Such publication of plans is intended to influence choices of actions (both over which one has control and no control) in a decision situation when they are inter related. To this end, we should use plans as a way to edify our own actions in light of others' known commitments .

To use these plans, especially in the context of urban development, we need to formulate an acceptable terminology that is generalisable and sufficiently rich. In the next sections, I briefly describe the concepts in the terminology to use them in the rest of the dissertation. Key concepts are also summarised in the glossary of terms.

2.2 Key Concepts about State of the World

The state of the world is an all encompassing view of the world we live in. The name itself is a misnomer because of the dynamic nature of the state. It includes activities, which are flows essentially, on assets by actors and changes in those activities and assets are decisions or actions by actors. These ideas have been discussed in (Hopkins 1999; Hopkins, Kaza, and Pallathucheril 2005b) and are necessary to set the stage for elaborating the semantic relationships. A complete description of the state of the world as a representative model of the state of affairs of existence is not useful, and not possible. The aim is to account for a general structure of the relationships which pertain to land use planning and representing only portions of the state that are useful in a particular context. Much of the following section is already described in Hopkins, Kaza, and Pallathucheril (2005b) and Kaza (2004) and is summarised here for completeness and comprehensibility of later chapters.

Guttenberg (1993; p. 17) argues, “For planners with a physical design background (engineer, architects), the city consists of land, buildings and other physical facilities, that is, material objects and their subject relationships. For those with a background in law, education, economics, and psychology, it consists of non-material objects, beliefs, values, attitudes, rules, and habits of thought and behaviour.” To reconcile these notions we should be able to define constructs that will encompass these entities to completely describe the different views of urban planning.

For the purposes of this dissertation, we are concerned with four types of entities that populate the state of the world. Assets , are things that persist and over which various actors can act to change their characteristics. An action is an *occurent* which may persist at an instant of time or may happen over an interval of time. An action’s purpose is to change assets or to change capabilities. Rights are subsets of capabilities, which circumscribe what actor may do. A decision is a type of action that precedes action and plans inform these decisions. Alternatives frame the choices of actions, in decision situations. Planning is fundamentally about interdependence of various decisions. An activity is an aggregation of behaviour that occurs on assets. An activity is not fundamentally different from action but is useful to account for it separately as behaviour in aggregate as opposed to individual actions that make up these changes. An actor is a fundamental decision maker who plans, takes decisions and acts. More details of these are given in appendix A.

It is useful to note that plans are encompassed within the state of the world. Each actor has an interpretation of how these plans are related her interpretation of relationships, and hence we do not presume any uniqueness of representation that is available devoid of the user. Each actor (possibly constituent actors that make up these actors) can represent these plans in their information system (computer or otherwise) in the way they see them fit using these categories. These categories are by no mean complete but they are extensible.

2.3 Key Concepts about Plans

Plans are useful to make to alleviate decision making by considering multiple interdependent actions.[2] For example, in a game of squash, two opponents play against each other with the objective to hit the ball towards the wall in such a fashion that the opponent cannot return. Each player is constrained by the set of shots he or she has based on the position of the player on the court and the po-

[2] There are other reasons we may plan. In this dissertation, we focus on the usefulness of plans in decision making.

sition of the other player on the court. That is to say, options are constrained not only by individual choice of location but also dependent on the choices of others. Further the player has to choose a best possible shot only after figuring out the trajectory of the ball based on the opponent's play. If the player is supremely rational, then figuring out the best possible shot should involve computational time, which should be less than the time of the ball in air before hitting the ground. If the time is not suficient, the player would be the epitome of a rational fool to paraphrase Sen (1978) if she tried to formulate the course of action on-the-fly.

Now let us turn what an actor can do to alleviate the dilemma of choice. Simon (1982) provides a seminal explanation: the agent instead of optimising, satisfices . There is, however, another explanation that is pertinent to planning, which draws from Simon's observations. It is that the agent plans 'ahead'. For example, a player might decide ahead of the game that she is going to occupy the centre of the court as much as possible. Or, she might decide to play to her opponent's backhand if he is cornered on the left and to her opponent's forehand if he is cornered on the right given the knowledge that her opponent is right handed. These decisions prior to the game take the dimensions of plans. Though these situations may not be realised exactly, the player can build on these 'plans' to satisfice for the variations on these situations without starting to optimise from first principles. Thus, the act of planning has to do with understanding which situations are likely to occur and what are reasonable courses of action in each situation. It could also be that the plan would be dynamic in nature, that is the plan ahead of the game would be to decide to decide when the difference in the score is greater than 3 points in the opponent's favour to change the plan. If the situation is realised at moment Υ, only then is the decision taken about which portion of plan to follow.

In arriving at decisions, we should evaluate multiple alternatives and their usefulness towards multiple goals. Plans construed broadly provide different alternatives suitably ordered for particular decisions. Since plans are continually changing, the alternative set, or the order relations they provide for a particular decision situation, may expand, shrink or otherwise change. We are concerned with actions, or configurations of actions in designs and strategies, that can produce the same effect or otherwise cannot be executed simultaneously.

While planning, we start with existing knowledge of what the intentions are and how these intentions interact with other plans. However, plans are much more than intentions–they may be prescriptions of actions. They provide information about what decisions to take under various contingent futures before these futures actually materialise. Such information is useful to the extent it helps us decide what to do now. Also plans[3] at best have incomplete characterisations of information required for decisions.

The tyranny of small choices as described by (Kahn 1966) and (Schawrtz 2004), and by extension the paralysis of decisions that arises from it, is alleviated by planning to some extent. Plans provide directions for decisions that come after them. Clearly dominated alternative actions are taken out of consideration in future decision making to reduce choices in a decision situation. For example, an interchange on an interstate highway and a zoning change to commercial in the adjoining areas are interdependent actions. A good plan would recognise these relationships ahead of time. When the decision to change the zoning category of a particular parcel in the neighbourhood arises, the plan would point to the

[3]What can be construed as a 'single plan' could in fact be multiple plans and be categorised as agenda, policies, strategies and designs. Even a traditional comprehensive plan has a multiple of these within it.

interchange question.

The object classes above can be used to describe states of the world, the content of plans, and the decision situations in which plans are used. The current state of urban development can be described with these entities, including dynamic descriptions of current trends or mechanisms of change. These descriptions can be data about reality or states as expressed in urban development models. Plans contain intended changes to assets, or changes to capabilities and provide information about configuration of actions. In particular, plans can contain configurations of actions arranged into agendas, strategies, policy and designs (Hopkins 2001). These configurations are elaborated below.

2.3.1 Configuration of Actions

Actions or decisions that precede them are arranged into different categories based on the usefulness of their relationships. It is in these relationships that the information in plans is encoded.

An agenda is a list of actions to be performed by actors . The list itself has no internal relationships; it is unordered. However, items in an agenda may have attributes that could create order, such as date of completion or a priority rank. Agendas could also account for constraints, such as cumulative costs relative to a budget constraint.

A policy is an if-then statement, which is applied repeatedly given a situation (Kerr 1976; Hopkins 2001) . The given situation (the 'if' clause) may be attributes of states of the world, action, or a collection of these. The action prescribed (the ‘then’ clause) is taken by an actor and thus depends on capabilities of the actors to whom the policy is intended to apply. The actor to whom the policy applies may be different from the actor who created the policy.

A decision tree can be construed as a strategy. Strategy involves uncertain outcomes and contingent actions. The initial node of the strategy is an action contemplated by the actor. Because of uncertainty of expected consequences of the action, planning would necessarily involve considering various unrealised but possible consequences. At a decision node the actor can list a choice of actions that will be available to be taken and the uncertain consequences for each of those choices. A preferred choice of action based on preferred expected consequences from each decision node can be identified based on issues, goals, and criteria. Listing all possible outcomes is unrealistic, however, so a strategy is always incomplete at best. See figure 3.4. However, unlike a decision tree, which is a methodological object to choose a particular path based on quantifiable objectives and probabilities, the tree structure of strategy is intended to postpone decisions about choices of action until after the contingent situation actually occurs.

Design is a collection of pre-specified relationships among actors, actions, assets, activities, and the relationships that bind them. Hence, design could be considered a collection of metarelationships. Design for urban systems is not elaborated as a situation that needs to be solved, but as a solution that has already been worked out. Designs could be about actions of actors or expected outcomes of those actions. Rowe (1991) has argued that design has to be cognisant about relationships between entities that are not physical. On the basis of the above, we can classify the relationships between action and their consequences into three types: spatial, temporal, and functional (figure 4.1). A proximity relationship between schools and residential land use is a spatial relationship. Adjacency is another example of a spatial relationship. A construction-management plan for a highway project is a design consisting primarily of temporal relationships about actions. Temporal relationships can include collections of sequences of actions or consequences that are, or need to be, realised. Functional relationships could be about interdependent consequences or actions. Compatibility of activities is a functional relationship. A transit-oriented design would include relationships of travel and wait time to the density of population it serves and the extent of service. A bubble diagram of circulation corridors and functional spaces is a design representation of a set of functional relationships.

Some elements of plans may be represented in multiple ways. Since we are interested in interpretation of a plan by various actor, no uniqueness is posited. For one, a set of actions may just be a list and for others they may be intricate steps that need to performed in sequence in consideration of circumstances. For example, particular investments in roads might be represented as an agenda in a capital-improvements program and as a design for a network in a transportation plan. Plans also incorporate indicators, including issues, goals, and criteria, which serve to assess consequences. A strategy might be expressed in relation to goals that are responsive to issues and measured by criteria. The indeterminacy of uniqueness of relationships of all actions in plans, provides useful opportunities to expand on existing plans. It is imperative to acknowledge that, to consider and encode 'all' possible contingencies and interdependencies between various sets and subsets of actions is an unreasonable expectation of plans and planners. The plans specify only relationships between specific combinations of actions that are of particular interest to the decision maker. As and when some alternatives and other related decisions recede from the decision situations, they provide opportunities to add or reconsider other actions and decisions and how they might relate to decisions that are being considered and yet to be taken.

Plans also contain other information such as goals and criteria, which are statements about characteristics of the preferred state of the world and not necessarily about actions or configurations of actions. These other types of information are omitted from the discussion in this section.

2.3.2 Multiple and Related Plans

Different actors have concurrent plans, some of which are interdependent. An example is presented in figure 2.1.[4] In the Champaign and Urbana region, different actors participated in the different planning processes of the cities, counties and other agencies at various times. For example, in the long range transportation planning of Champaign Urbana Urbanized Area Transportation Study (CUUATS), all the major actors such as the University, City of Champaign, City of Urbana, Illinois Department of Transportation (IDOT) and other interested parties have participated. The City of Urbana went ahead and unveiled its own comprehensive plan a few months later and did not mention the major ring road proposal of the Long Range Transportation Plan (LRTP). See figures 2.2 & 2.3. Champaign's current planning process, 'Champaign Moving Forward', also does not explicitly mention the ring road proposal.

[4]Source: `http://www.champaignmovingforward.com/pdf/concurrentTransStudies.pdf` –Accessed July 21, 2007

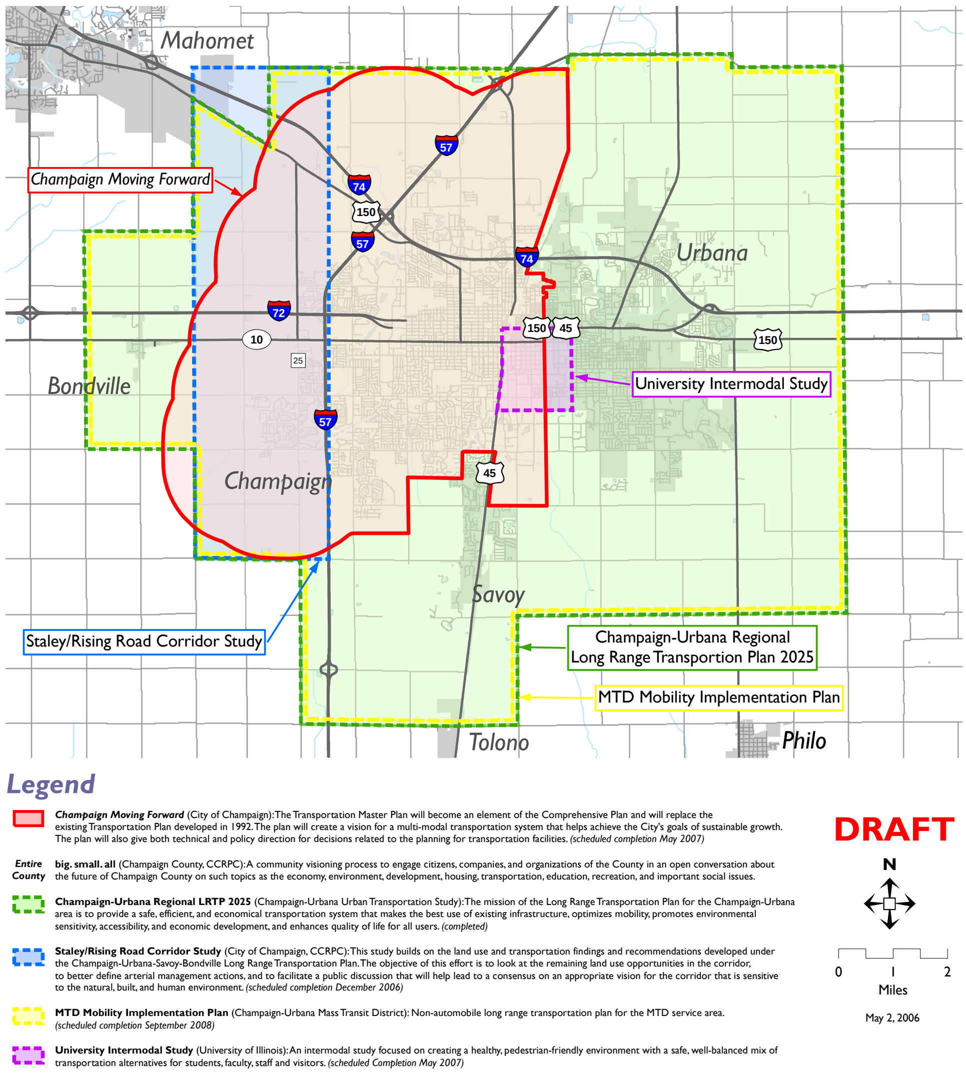


Figure 2.1: Concurrent Transportation Plans or Studies in Champaign County

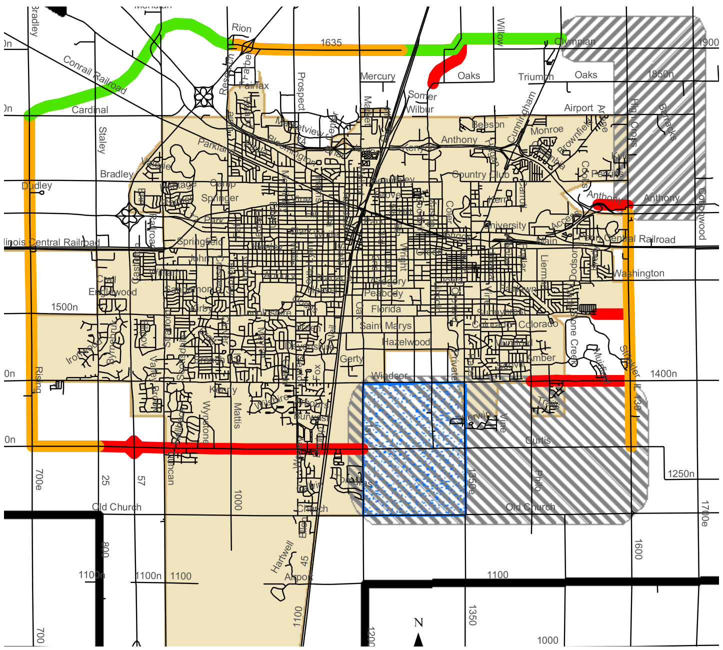


Figure 2.2: Long Range Transportation Plan –Champaign Urbana Urbanized Area Transportation Study (2004)

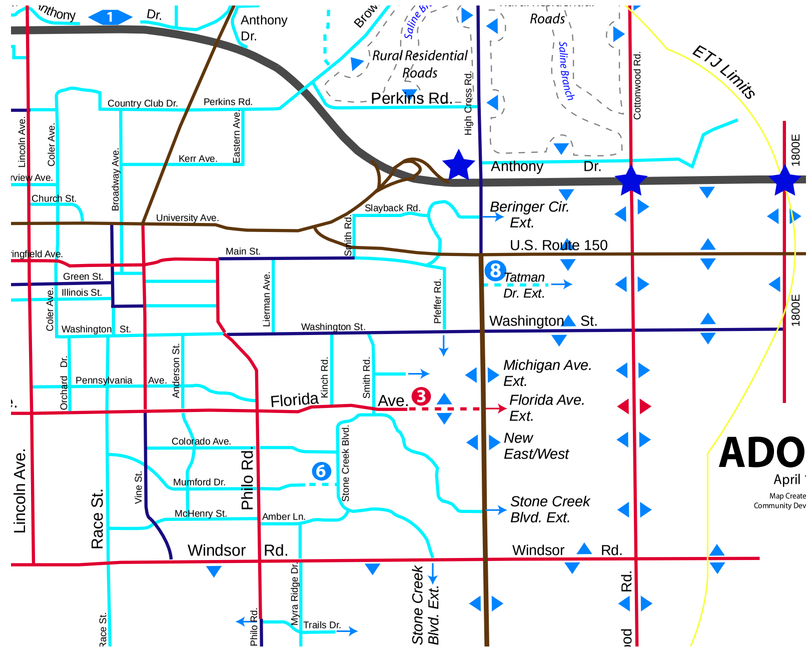


Figure 2.3: Mobility Map –Urbana (2005)

The University of Illinois Campus Area Transportation Plan published in 1999 (University of Illinois 1999) argues for enhancing multi-modal transportation access in and around the campus. Some tactics, however, extend well beyond the spatial extent of the campus. On page 74, the plan suggests widening Springfield Avenue where it connects the southern tip of downtown Champaign to the Northwest portion of campus between Neil and Wright Streets. "In order to widen portions of Springfield Avenue," the plan notes, "it would be necessary to replace the existing viaduct at the railroad tracks to accommodate additional travel lanes and semi trucks. The City of Champaign and the University should work with [Illinois Department of Transportation] regarding the replacement of this viaduct." To increase multi-modal access within the campus, the University's plan is contingent on the plans and actions of other actors well outside the campus; this is not an unusual situation.

Actor `University`[5] has a plan which identifies `Widen Road`as decision contingent on `Replace Viaduct`. However, the actor who is responsible, or has the capability to replace the viaduct is the group of actors consisting of the `City` and the, `Department of Transportation`. If either actor balks at replacing the viaduct, then the University cannot expand the road. This has a cascading effect on other plans of the university which were contingent on the expansion of the road, such as if and where to build a parking structure or transit transfer station. Thus, the decision by the Department of Transportation, indirectly changes the plans of the University.

Likewise, actors may make plans that directly attach their own future actions to existing or planned actions of other actors. The Champaign Police Department,

[5]Whenever it is appropriate that the terms are part of the structured data model described in § 2.2 and in Hopkins et al. (2005b), they are in `Latin Modern typeface.`

for instance published a Five Year Community Safety Plan in 1995 (Champaign Police Department 1995). The first goal in the plan was to address the issue of "Total Crime" in the community; the first strategy to address that goal was, "To comprehensively address infrastructure and service needs in threatened areas," (p. 28). The actions under this goal are to "Combine efforts between police and planning departments in the on-going evaluation of neighbourhoods in which to begin to develop specific improvement plans," (p. 28), and to "Integrate neighbourhood needs into the multi-year strategy for infrastructure improvement included in the [Capital Improvements Program] and public works maintenance programs throughout the city" (p. 28). By integrating land use and service provision within a policing and safety plan, the Police Department illustrates the utility of being able to track the plans and decisions of other actors when making a plan; the police department is relying on the actions of the planning department as a way to combine these two currently unconnected activities in order to serve their own needs.

In analysing cases of metropolitan regional planning in Australia, Abbot (2005) identifies the issue of credible plans. Even Bratman acknowledges such distinctions for plans meant to inform commitments to oneself. What one intends does not necessarily mean that the action that naturally follows the intention *will* be taken, but for the same person to believe that the action that directly contradict these intentions will be taken, is irrational. However, others may discount these stated intentions as misrepresentation of true intents. It is thus important in many contexts to develop a better understanding of the strategic nature of decisions to make plans, to share them, and to use them. We argue that, rather than pursue the implausible task of ensuring that complete and "true intents or likely actions" will be included in plans, we should learn to be savvy about strategic use of plans (Christensen 1999). We should be savvy about inferring strategic use by others and strategic use for ourselves.

2.4 Relationships among Actions

Plans are constantly subject to revisions and modifications based on changing intentions and circumstances, so some decisions about actions are left for future decision making. Plans specify some of these relationships among decisions. A decision situation usually involves considerations of alternatives that need to be considered and contingent and other interdependent decisions that need to be accounted for. Furthermore, the decisions are restricted by the capability restrictions and the previously considered relationships with other decisions already accounted for in the plans (figure 2.4)

The two main types of relationships among plans we are concerned with in this dissertation are substitutability and interdependence. Sometimes they are explicitly mentioned in the plans and at other times they can be inferred from the configuration of actions specified in the plans. They are elaborated in chapters 3 and 4.

A commitment to a goal of 'equality of housing opportunity' is not a commitment to a particular subsidy or a specific regulation. A subsidy and regulation are alternatives to achieve the same goal. When a plan for a city publicly declares such a commitment, it leaves vague the question of which particular action will achieve this goal. The commitment to intentions allows flexibility in choosing particular

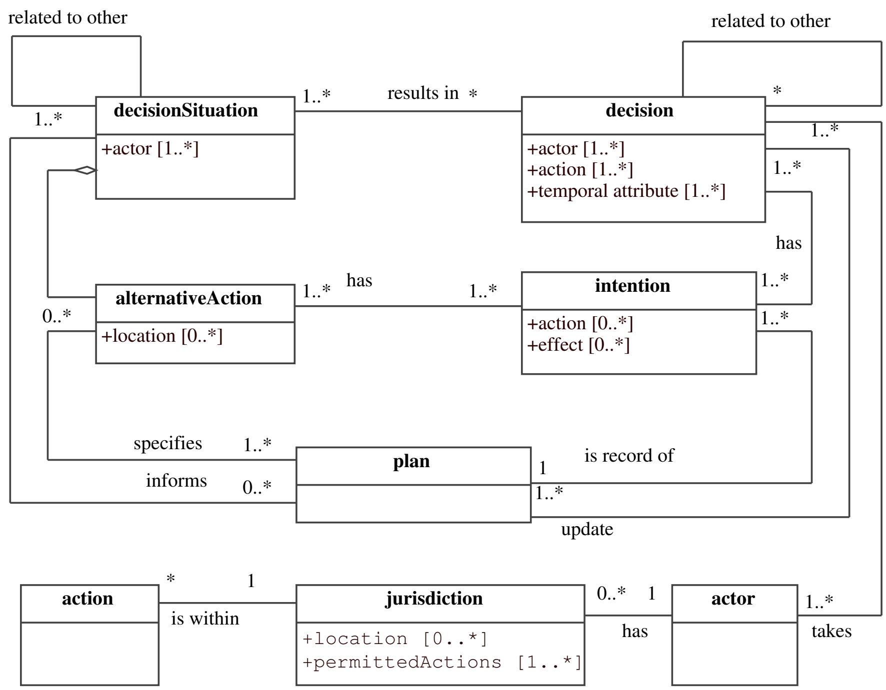


Figure 2.4: Plans, Decisions, & Actions –Kaza and Hopkins (2007)

actions or sets of actions as the situation demands. However, committing only to intentions postpones the decisions and commitment to actions, which may be advantageous or not, or advantageous to some and not others.

A planner can consider the relationships of her own actions with other actions she may have authority over. She may also consider the actions and decisions she may not have control over. In the case of the squash player, the policy of occupying the centre court could also be related to ones own speed of movement and strengths as a player. However, the player may also decide that occupying the centre of the court is contingent on displacing the other player from that centre through drop shots, and thus the play of drop shots is contingent on the opponent occupying the centre court over which the player has limited control. When plans of one organisation make these relationships clear, then they are considering relationships of ones own decisions with other actions over which someone else has authority, but are nevertheless important to realise for ones own sake. Thus, each action is tagged with the responsible actor.

While these actions may figure in different plans of different actors, contingencies are incompletely specified in all these plans. Looking at these relationships from multiple plan perspectives gives us a better way of formulating our own action paths.

2.5 Discovering & Using Relationships among Actions

The contingencies and relationships among various actions are clarified in a plan, and thus relationships included in a plan are more likely to be apparent than relationships among actions that are not considered in any one plan. The thesis of this dissertation is that it is feasible to discover these relationships given a sufficiently general framework to describe plans and the state of the world (e.g. Keita et al. 2004; Kaza and Hopkins 2007). The dissertation also provides examples and illustrates the utility of such an endeavour and to confirm its feasibility in practice.

In many cases, the actor responsible for the decision is an attribute of the decision situation. If one plan specifies a decision is subsequent to or otherwise interdependent with decisions of other actors, and if such other actors identify other contingencies between those actions, then we can begin to reason about further interdependencies between decisions of one actor and actions of another. These

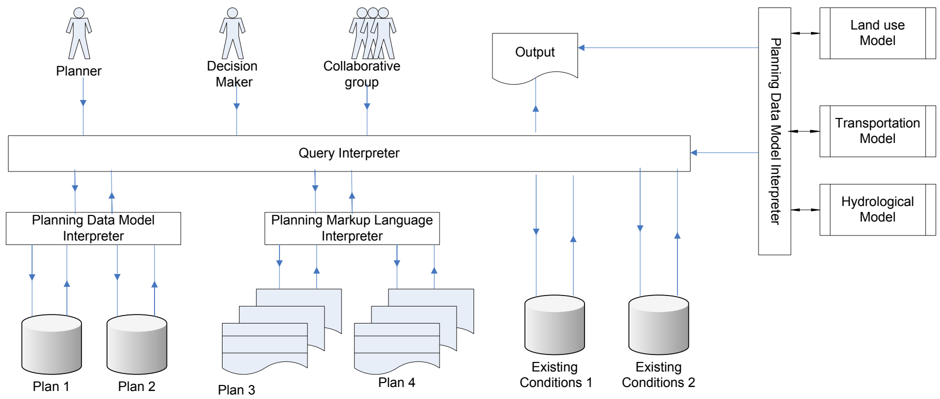


Figure 2.5: Schematic Diagram of a Reasoning System

other decisions may have alternative actions associated with them in different plans. Representing plans in an ontological framework helps us make those connections.

A schematic diagram of how the system would work is presented in figure 2.5. Ideally, when plans are represented in a structured representation either as a relational database or as tagged documents, they can interact with different representations of existing conditions and urban models that project different effects of actions based on these intentions and current conditions. A completely transparent system is a long ways away. Based on experience with GIS, however, we can begin to imagine how this system might interact in demonstration databases that are set up exclusively for the purposes of this dissertation.

The known relationships between attributes are specified and the intent of the demonstration is to identify the ways in which the system may interact with the user. A completely coherent information system that automates the process of reasoning is neither the intent nor the claim, even in the limit. The information system has to interact with users, who make targeted queries, select particular models to identify effects and use heuristic reasoning to arrive at likely relationships to be considered in decision making.

2.6 Setup of Demonstration

For the purposes of demonstration of the ideas presented in this dissertation, two computers with similar PostgreSQL (v.8.1) (Momjian 2001) databases are set up. The geography information is stored using PostGIS (v 1.2) extension, which spatially enables the PostreSQL databases. One of the databases comprises information in the McHenry County Unified 2020 Plan[6] and the other comprises the information in other relevant plans such as the North Eastern Illinois Planning Commission's (NIPC) Common Ground Plan, the plans of the cities within the county, the conservation district's plans, etc. The idea is to illustrate the concept of distributed information, which could be parsed into a consistent data structure. In a real world case, these plans would be tagged documents residing in multiple locations, building upon the concepts illustrated in Hopkins et al. (2005b); Open GIS Consortium (1999); Heflin (2001).

As detailed in appendix C, each database consists of an agenda table, which is essentially a list of actions with relevant attributes such as location, responsible actor, etc. Other tables within the database are tables that describe design relationships and contingent relationships within a strategy. To illustrate the idea of effects, a land use simulation model, LEAM is previously run to simulate possible changes in allocation of residential and commercial development. More details about this simulation model can be found in Deal and Schunk (2004) and Fang et al. (2005). Application of this model to McHenry County case is discussed in

[6]This plan was never adopted but the information in this database is from the draft version.

Pallathucheril et al. (2005). The choice of the model is largely irrelevant to the justification of arguments made in this thesis, but does matter in determining the semantic relationships based on effects. When models can write and read inputs, which are within the framework of a Planning Data Model (PDM), the models could automatically be run to illustrate the concepts of substitutability and interdependence with respect to effects.

On a different computer, a querying tool was set up in Java to connect to these multiple databases and query according to the heuristic rules to identify the interdependence and substitutability. The client recognises different kinds of attributes (e.g., different types of geography) of the action items and their configurations and prompts further queries to the databases. While it is not the intention of the system to automate the process of recognising semantic relationships of actions across plans, this provides a mechanism for the user to identify further relationships. These relationships are temporarily stored on the client computer to assist in identifying further relationships as described in chapter 5. Ideally, the querying tool would be a program that crawls the web to identify these semantic relationships within the tagged documents.

The purpose is merely to demonstrate the effectiveness of this approach. No claim is made about the efficiency of this client or the database structures. More details of the schema and the query client are given in appendices C & D.

2.7 Conclusion

In this chapter, I have described a particular take on plans and their relationships to actions and intentions. I use these categorisations to claim that plans are useful in making decisions at a later point in time and thus should be used as a source of such information. In particular, I argue not only that there are multiple relationships among actions within a plan described to various levels of detail, but also that decision situations benefit from looking at multiple related plans. It is the endeavour of this work to identify how to identify these relationships among actions in various plans.

The chapter also describes the terminology used throughout the dissertation, which was described in great detail in previous work. It then explains the ideal approach envisaged by this work and describes the setup used to demonstrate why such an ideal approach is helpful.

The next three chapters give detailed descriptions of the relationships of substitutability and interdependence and describe how to use them to discover further relationships between actions among plans. They form the substantive core of the dissertation.

Chapter 3

Substitutability

To make a decision in a particular situation, we may consider multiple alternatives from which one or none may be chosen. To paraphrase Sartre, to decide not to decide is also a decision. In any given decision situation, trivially, two alternatives always exist. Alternatives are characterized by their substitutability with respect to criteria. The purpose of this chapter is to identify the substitutes, when they are not explicitly identified or are non-trivial, so that they can help us in making decisions. To this end, we use the information within plans and the ways plans are used in urban development to tease out the substitutability relationships.

Plans can contain explicit alternatives, where decisions have not yet been made about which alternative is to be chosen. Furthermore, an actor can commit only to goals, but not commit to any one of the different actions that may achieve them. Plans may indicate sets of actions that can be considered towards achieving such goals. In either case, prior planning by an actor has winnowed out some alternatives as preferable to, or more relevant than, others. Thus, the remaining alternatives are to be considered in the decision situations. The decision to choose an alternative is postponed until a later date, and plans provide some support and bases for such decisions.

In this chapter, I explore various types of substitutability and the criteria required for assessing whether two actions are substitutable. First I characterise the notion of degree of substitutes borrowing from the concepts of economic goods. Then I examine the implicit substitutability evident within a single plan in strategies and use other configurations of actions to decide on the criteria for substitutes. Furthermore, attributes of actions could be used to tag actions as substitutes. I then, discuss the use of these implicit characterisations in determining the idea of substitutes across plans. I conclude with the deficiencies of these methods and provide indications of further directions in examining this relationship.

3.1 Perfect and Imperfect Substitutes

Traditional economics literature has been preoccupied with the idea of an agent deriving utility from the consumption of various goods. Two goods are considered substitutable if they provide similar utility for a similar purpose, regardless of other differences. Goods are perfect substitutes if they provide exactly the same utility for the same purpose and imperfect if they are perfectly substitutable with respect to some attributes and not with others. I shall employ similar distinctions with respect to actions.

Two actions are perfect alternatives with respect to the specified criteria if they satisfy the criteria to exactly the same extent. The criteria can be intents, effects, constraints, utility, or any number of other measures. Further, I stipulate that the alternatives are perfect if an actor perfectly trades-off the performance of each action with respect to a particular subset of criteria the alternatives do not agree upon. Note that I do not invoke the traditional economic concept of a representative agent. The concepts of neo-classical economics such as elasticities are not relevant to this exercise. We are interested in actions and values of individual actor and plans are particular to each actor, and therefore two actions are alternatives when deemed so by individual actors.[1]

Imperfect or partial substitutes are two or more actions that perform equally well with regard to particular criteria and fare differently or are not comparable with regard to other criteria. Two actions can be imperfect substitutes if they share the same intent but produce different effects, or are spawned by completely different intents but are considered substitutable due to restrictions on capabilities. For example, budgetary constraints may force a choice between upgrading an existing road versus laying a new road; they are substitutable with respect to the constraints even if they share neither the intent nor the effects such as realised traffic or development patterns.

To this end, I differentiate between two major criteria of the substitutability relationship. Two actions may be substitutable (completely or otherwise) because

- Effect Criterion – Same effect (state of the world) is generated as an outcome of different actions.
- Intent Criterion – Two actions share the same intent irrespective of the effects.

To cause an effect can be considered as an intent. I differentiate between these two to distinguish intended effects from the unintended ones. For example, while an emission control regulation and pollution credit program could be considered substitutes with respect to the intent of reducing the pollution level, they may

[1] Nevertheless, we can infer which two actions are considered alternatives by another actor. Indeed it may be the case that during the planning process, in the act of convincing others, we infer these relationships and make requisite arguments.

have many other effects depending on the frames of analysis of these actions (such as distributive and economic effects), which may make them incommensurable. Further, two actions, even when backed by different intents, may produce similar effects within a particular frame of analysis causing them to be labelled as alternatives.

Furthermore, of particular interest for urban planning purposes are the following criteria that differentiate planning from other activities.

- Occurrence Criterion – Different entities may not occur simultaneously in a situation and the 'Same' entity cannot happen in multiple instances.
- Location Criterion – Multiple things may not happen at the same place. This can be seen as a particular instance of the occurrence criterion.
- Capability Criterion – Two actions are alternatives because they are mutually exclusive with respect to capability of the actor irrespective of intents and effects.

One reason to differentiate these criteria is because they distinguish between attributes of relationships between assets and actions that are spatial, temporal, intentional, and causal. Without claiming to be exhaustive or representative, I will elaborate on these in later sections.

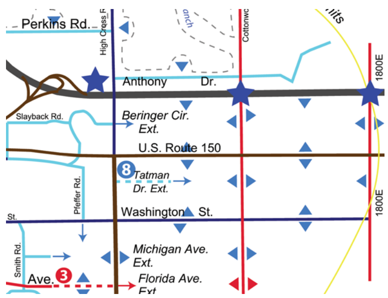
It is fairly obvious that these criteria individually and in combinations do not completely specify whether a pair of actions are substitutable and the degree to which they are. For example, there may not be any restriction on different 'roads' being built in multiple places. The same pathway can be considered both a bike path and a pedestrian path way, thus violating the location criterion. Further, *overlap* and *underlap* topological relationships (see Casati and Varzi 1999) befuddle the location criterion.

Nevertheless, these distinctions are important to conversation of planning and hence distinguishing between them helps us in reasoning about what to do. To get at substitutability, we may have to rely on intuition and on previous cases in which substitutability was recognised and established, which is called 'Case Based Reasoning' (see e.g. Haigh and Veloso 1995; Shi and Yeh 1999). To this end, discovering substitutability is based on reasoning about actions, effects, and intents.

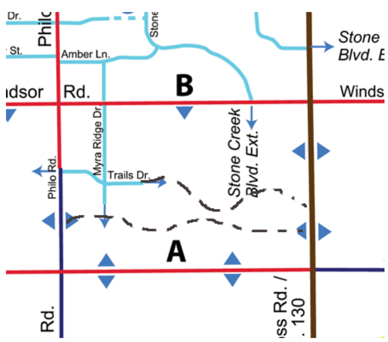
In the next few sections I discuss, with illustrations, the types and degrees of substitutability and how they occur in the context of urban development and how they are manifested in plans. Subsequently, I elaborate on what kinds of substitute and interdependence relationships within plans can be harnessed to reason about substitute actions among plans.

3.1.1 Perfect Alternatives

The Comprehensive Plan of Urbana adopted in 2005, (Urbana 2005) specifies that at the time of adoption, the final location of the interchange on I-74 in the North East of Urbana has not been completely decided. It leaves the decision to a future time, but specifies which alternatives have not been winnowed out. The three alternatives, represented by stars in figure 3.1(a) are expansion of the current interchange at High Cross Road, a new interchange at Cottonwood Road, or a new interchange at 1800 East. Since the location and occurrence criteria mandate that the same interchange cannot occur at multiple locations; the three different locations of "I-74 interchange" are alternatives with respect to each other.



(a) Alternatives for Interchange



(b) Policies for Sub-collector Streets

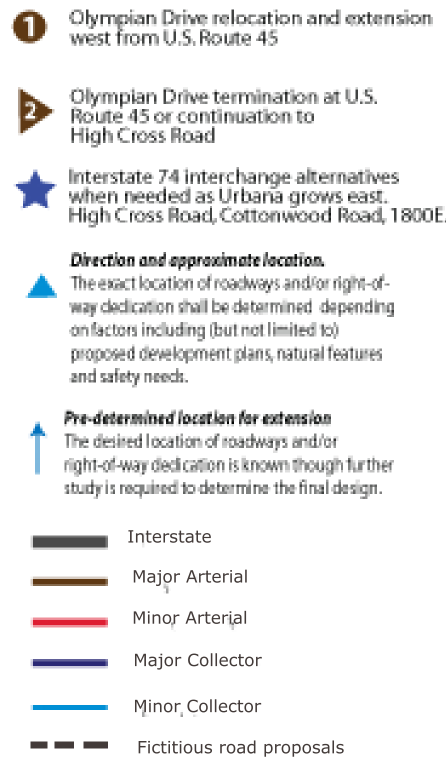


Figure 3.1: Perfect Alternatives - Excerpted from Urbana (2005)

Figure 3.1(b) specifies a policy about the connectivity of the sub-collectors. The exact locations of the sub-collectors are not specified. Instead, the Urbana Comprehensive Plan specifies a policy of having two sub collector streets between two parallel collector streets more than a mile apart. With respect to this policy any two sub collectors (defined by location and configuration) between the collectors are alternatives with each other. However, it is fairly obvious that the two road proposals illustrated by dashed lines in the figure 3.1 are unlikely due to their unorthodox configurations.

As illustrated by both these examples, alternatives are perfect with respect to particular aspects of the state of the world. Nevertheless, the different options for the location of the interchange or the configuration of the sub collectors are not perfect substitutes with respect to every conceivable intent they are supposed to satisfy and effect they bring about. For example, a sub-collector too close to the parallel collector is not desirable and hence cannot be substitutable with another sub-collector location that is more desirable and that satisfies the same policy about connectivity. Also, if the interchange at High Cross road is built, then the distance considerations between interchanges do not preclude building another interchange at 1800 E at a later date as the City expands Eastwards. With respect to desirability as specified by other policies or guidelines about the minimum distance from collectors, these alternatives are only partially substitutable. Thus, for the most part, almost all sets of actions are partially substitutable; however, it is useful to consider them as complete substitutes at various stages of the plan making and plan using processes depending on the restrictions on frames of analysis.

3.1.2 Partial Substitutes

Partial substitutes differ from alternatives in that the actions are substitutable with respect to some purposes, not all. A policy of subsidy for pollution abatement programs or a tax on pollution volume are partial substitutes because they share the same intent of pollution reduction but produce different effects with respect to distributive justice considerations.

To illustrate an example of partial substitutability where projects of similar nature compete for approval, consider proposals A, B, C, and D in different plans as also

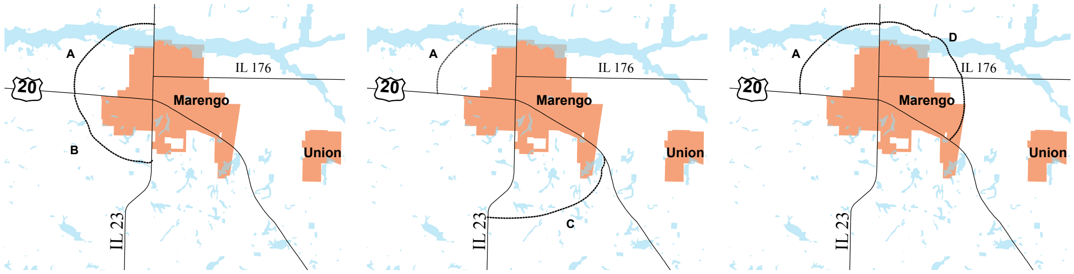


Figure 3.2: Partial Substitutability of Actions

depicted in figure 3.2. The intent of *A* and *B* is to create a bypass for the traffic on IL 23. *D* and *A* create a bypass for US 20 both east and west of Marengo to IL 23, but not a bypass for IL 23. To the extent in which the action sets both have *A* included in them, they are substitutable through the effects of bringing about *A* and diverting some traffic from IL 23, but they are not substitutable with regards to intents. In a similar fashion *B* and *C* are partially substitutable with *A* because they divert some traffic from US 20 onto IL 23. Even when, as in the more interesting cases, actual location of *B* is different from that of *A*, they are partially substitutable with each other. To recognise the substitutability of the two designs one has to abstract the network of roads into a network of links and nodes with traffic patterns and query if both proposals accomplish at least some of the same purposes. Consider the following stylised example (see appendix A for definitions of terms).

```
Background data

Plan1:  Agenda 12:  Improve B
Plan2:  Design 1:  Build A.
Plan3:  Design 4:  Build D and C
Plan4:  Design 3:  Improve B and Build C
⋮
```

```
Heuristically determining substitutes

Query1:  Find proposals that link IL 23 and US 20
Response
Plan1:  Agenda 12
Plan2:  Design 1
Plan3:  Design 4
⋮

Query2:  Find proposals that will reduce the traffic on IL 23 in
Northern part of the City
Response
Plan1:  Agenda 12
Plan4:  Design 3
Plan2:  Design 1
⋮

Query2:  Find proposals that will increase the traffic on US 20
Response
Plan3:  Design 4
Plan4:  Design 3
```

To get at the semantic relationship of partial substitutability among the bypass links, queries 2 and 3 trigger a traffic simulation model for each of the available transportation projects and check if the traffic on IL 23 would be reduced. However, if query 1 were to be asked, the recognition of topological relationship of connectivity is sufficient to recognise the substitutability. Thus, the question of substitutability becomes a question of substitutes with respect to a particular attribute. If mere connectivity is the issue, then all the proposals are partial substitutes. However, if the intent is to find substitutes of an action that result in a state, in this case volumes of traffic on particular links, then we arrive at different results. Alternatively the query could also be about the development pattern instead of traffic volume. In this case, land use simulation coupled with a traffic model should be triggered. As can be readily seen, the results of the queries would be heavily dependent on the assumptions of the models. In such cases, multiple model frameworks and model triangulation are useful (Beer 1962).

On the other hand consider another case illustrated by figure 3.3. The ring roads 1 and 2 are alternatives because they differ only in locational attribute of the intention of City 1. However, the intentions that support the building of ring roads 1 and 3 are different, and as such they are partially substitutable. If City 2 also intends to divert its traffic away from the existing road B to A , then ring road 3 would be a partial alternative with respect to diversion of traffic to both road 1 and road 2. However, road 1 and 2 could also be partial alternatives to each other with respect to cost of construction if one of them involves significant costs while acquiring the right of way.

In this dissertation I do not seek to resolve the question of degree of substitutability with respect to which kinds of attributes explicitly enables us to classify actions as perfect substitutes. In fact, such resolution is inimical to reasoning in a planning framework. Instead, I take the approach that for a particular set of attributes that are of interest to the planner at a particular time, in a particular frame, with particular ideas about how the world works (models), and relying upon particular measures, the effects and intents will determine which actions are substitutable with regard to which attributes. These framings are constantly subject to revision

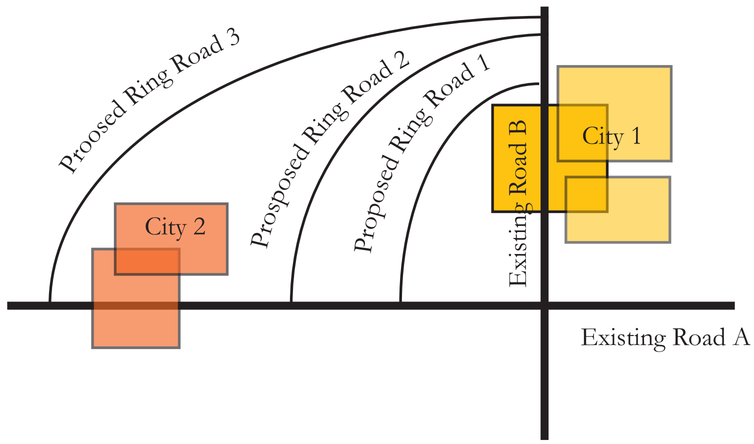


Figure 3.3: Alternative Ringroads

even for a single individual.

3.2 Using Action Configurations within a Plan

Prior planning by actors may indicate which sets of actions are substitutable for another. These may be recorded in plans. To illustrate, we consider elements of plans, such as designs, policies and strategies as elaborated in § 2.3.1. Once actions are configured into designs and strategies based on various relationships among actions, then these relationships along with the intent and effect criteria could be used to discover substitutable actions and configurations.

3.2.1 Strategy

The most complicated and useful exercise of planning is to recognise uncertainty of outcomes of actions and plan strategically with respect to goals and criteria. Thus in a particular plan, strategies specify to sufficient depth possible outcomes as well as possible actions in response to those outcomes (figure 3.4) (Friend and Hickling 2005). Once two actions are considered substitutable, they are a part of strategy. In other words, if two actions (or sets of actions) are considered substitutable, then the resolution of which action to pursue has been left for a future time. These actions are in response to an uncertain situation which characterises the decision situation.

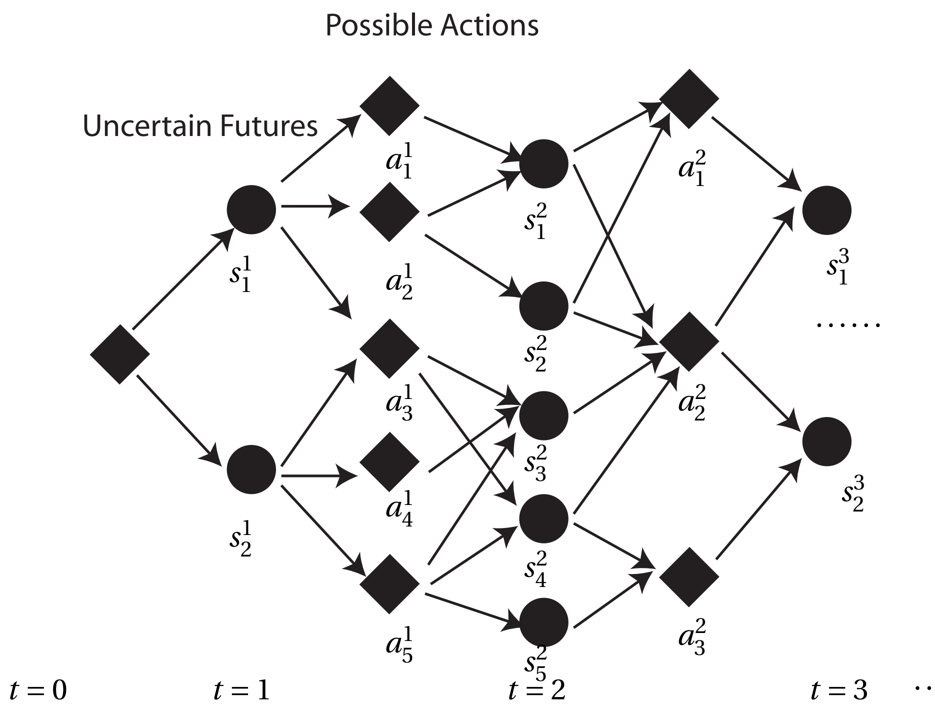


Figure 3.4: Inferring Alternatives from Strategies

The strategy could thus be represented as a directed (bipartite) graph delineated by events and actions as nodes.[2] In such cases, alternative actions are actions that share the same neighbours from edges coming into them with respect to the particular uncertain state. Actions a_1^1, a_2^1 and a_3^1 are alternatives with respect to each other in response to state s_1^1. Actions a_1^2 and a_2^2 are alternatives to each other but not with a_3^2 in response to s_2^2 (because a_2^2 is substitute for a_3^2 in response to s_4^2). It

[2]The representation in figure 3.4 uses time as opposed to events. Passage of time is one kind of event. The occurrence of any state could be an event. See Worboys (2005).

is fairly obvious that the transitivity property does not hold for inferring alternatives: a_3^2 is alternative to a_2^2 but not to a_1^2 . However, if three actions are pairwise substitutable because they are responses to the same state, then transitivity holds, however this inference is trivial because the substitutability is automatically inferable because they are responses to the same state.

In the case of strategy, we can deduce not only whether two actions are substitutable, but also whether two paths of actions are substitutable. In this particular example, we can infer that the set of actions $\{a_1^1, a_1^2\}$ and the set $\{a_3^1, a_2^2\}$ are substitutable sequences of actions because they both are paths from the states s_1^1 to s_1^3. In the event of the realisation of the state s_1^1 both these paths are possible options available to the decision maker. Substitutability in strategies must take into account the relationships among actions and outcomes in the strategy,

3.2.2 Policy

Policy, on the other hand, could be considered a simple if-then rule (see Hopkins 2001; Kaza 2004). For more elaboration see § 2.3.1. As such, it is structurally similar to a strategy with one uncertain event (If clause) and one consequent. More often than not, the consequent does not specify a single action. Rather, it specifies an attribute of the state of the world the action should bring about or an attribute of the action itself. In such cases standard rule checking should determine if two actions bring about the same effect or have the same attribute. For example, a policy of requiring LEED-ND[3] certification for a new neighbourhood development is an example of a policy that requires performance measures.

[3] Current certification process is still in the pilot project stage. See `http://www.usgbc.org/DisplayPage.aspx?CMSPageID=148`–Accessed January 10, 2008.

In figure 3.1(b), the two different configurations of the sub collector fit the connectivity of collectors policy prescription. Thus, constructing either one of the roads is an alternative to constructing the other. In fact, there are infinite such alternatives possible. The main collector streets, or the rights of way, are specified in the city official maps. The preservation of connectivity relationships between these collectors is also important, but to represent them at a specific location perpetuates the idea of certainty about the alignments of these sub collectors. Instead, the plan merely specifies that the locations should be decided later on and specifies rules about how the connectivity should be preserved. However, other policies and guidelines winnow out alternatives based on minimum lot sizes and the restrictions on sewers. Thus, although each policy is a relatively simple structure, it is still important to consider interactions among policies.

3.2.3 Design

Design relationships are primarily about interdependence relationships. As such they do not have information about actions that are substitutable . However, it is possible to use designs to discover if two actions are substitutable within a design. Designs are substitutable perfectly or partially when their intents are the same or their effects are the same. Other criteria can be used to discover the substitutability of designs by discovering whether the actions that compose the design can be substituted. However, such substitution of the parts of a design should preserve the relationships within the design. That is, if `Precedes(`A,B`)` (i.e. if A precedes B) is a part of a design, then as long as the change in the attributes of A (Say change from $A_{(t_1,actor_1)}$ to $A_{(t_2,actor_2)}$) does not affect the precedence relationship with B, then the two A's are substitutable with respect to the design.

However, when the relationships within the design are altered, if the effect remains the same, then the designs are substitutable to each other with respect to effects.

I shall postpone this discussion of reasoning with design. The next chapter will elaborate on the interdependence relationships and hence the design relationships will be given adequate treatment. The elaborations of these different types of interdependence relationships are used in the subsequent chapter on reasoning with partial orders . That chapter will touch upon reasoning with both interdependence and substitutability to recognise each other.

3.3 Using Attributes of Actions

Thus, action relationships in plans can be used to identify, discover and represent alternative actions within a single plan. However, we can still use the attributes of the actions themselves to reason about alternatives. A few attributes of actions that are of independent interest for urban planning purposes are illustrated next.

3.3.1 Location

Urban planning is concerned with spatially focussed decision making. The location attribute is, thus, an important attribute that is persistent in almost all entities of interest. The preponderance of geographic-centred information systems for planning purposes is a testimonial to its importance. In this section, I discuss the peculiar characteristics of location that enable us to identify whether two actions are mutually substitutable.

Figure 3.5: Olympian Drive relocation – Excerpted from Urbana (2005)

In this work, we follow the Newtonian characterisation of space as opposed to Liebnitzian: We can consider location independently of the objects that inhabit it (Galton 2001). This is a pragmatic choice, not a technical one. An action can be defined divorced from location. More often than not, however, the location is vaguely defined. To illustrate this state of affairs, refer to figure 3.5. The relocation of Olympian drive is deferred and by the virtue of it being a decision (not an action), it does not have a certain location.[4] Notwithstanding the appearance of exactness in the plan, Olympian drive is potentially located somewhere in the band as shown in figure 3.5. This could be represented as a probability field centred on the configuration as shown in the map. Unlike many debates in GIS (Campari 1996; Worboys and Duckham 2004), this vagueness is not an error of measurement or representation, but inherent fuzziness that accompanies information about possible future states. Plans are intended actions set in future; they always have uncertainty associated with actions, and in particular the location

[4] For legend please refer to figure 3.1(c)

attribute is typically not crisp.

When the location attribute of an intended action is not crisp, then any derivative of the action for which the location attribute falls within the parameters of the fuzziness of the original action is an alternative with respect to another action that falls within the same parameters. Depending on the scale of the plan, this vagueness has local effects. While the various configurations of Olympian drive within the tight parameters specified by the band may not provide any useful information, consider the figure 3.6.[5] A joint proposal by IDOT and INDOT to connect Interstates 57 and 65 is considering the location described by the band in the figure. A configuration of the connector that goes north of the city of Beecher and one that goes south of Beecher are alternatives for the agencies concerned. These alternatives, along with the new regional airport that is proposed close by, have very different implications for Beecher in terms of the traffic patterns.

Note that the above examples are manifestations of the occurrence criterion. That is, two Olympian drives cannot occur at approximately the same location, nor can two connectors to the interstates occur. The two connectors taken together can still provide a connection between the two interstates. They cannot, however, occur together due to perceived redundancy of one when the other is built. Thus the occurrence criterion is tempered with the capability restriction of the responsible actor and the intents they are supposed to satisfy.

However, we can also use the location criterion explicitly to identify alternatives. Situating an action at a particular location may prevent other actions from occurring at that location. Building Olympian drive at a particular location prevents zoning a parcel that overlaps it as residential zone. Thus, the rezoning and build-

[5]Source: `http://www.in.gov/dot/projects/illiana/` – Accessed January 15, 2007

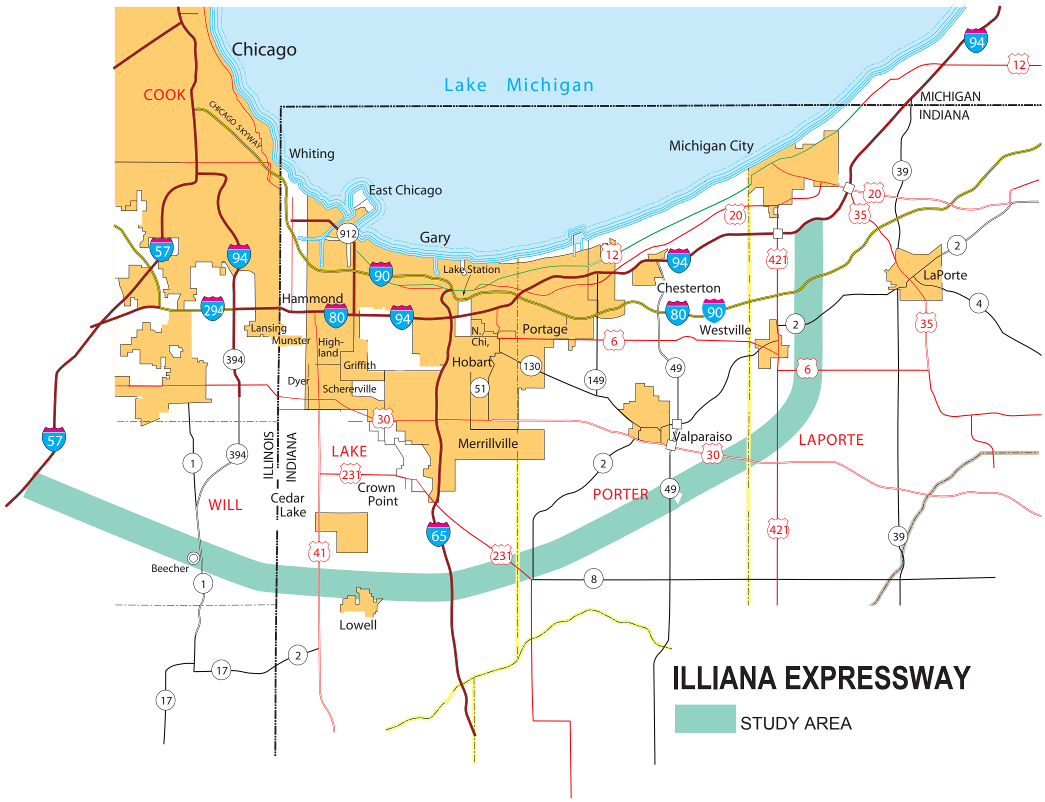


Figure 3.6: I-57 - I-65 Connector Study Area

ing Olympian drive are alternatives with respect to location criterion. It is important to note that an action, or a decision, does not have an inherent location attribute associated with it (see figures A.2, A.3 & A.4). It derives its locational attribute from the asset it changes or the jurisdiction to which it applies. Two assets cannot exist at a location at a time if there are inherent restrictions. In general, we assume the default restriction is 'forbidden' deontic operator: Unless explicitly permitted, two assets compete for a specific location. Actions that bring these assets into being are thus alternative actions. However, there are other characteristics of space that complicate the issue. Some of them are 'overlap' and 'underlap'. Again these issues are addressed with explicit permission with the default being forbidden, i.e., a bike path cannot occupy a foot path unless explicitly identified as doing so. Thus proposals to build either one of them at a location are considered alternatives to each other.[6]

3.3.2 Actors & Capabilities

Actions are carried out by actors and are, thus, restricted by what actors are able to do (refer to §2.2). When explicit ownership of an action is assigned to actors, then capability restrictions force a trade off between actions that can be performed by the same actor. Thus, if two actions share the same responsible actor, then the pair is tagged to be potential substitutes. Even, when the effects of the pair in question are not the same, doing one may preclude the other, and hence it is worth recognising these trade-offs.

From this list of actions that share the same actor, we can weed out actions that are interdependent with each other. Thus, presence of a design relationship between the two actions overrides the capability restriction in this setup. For example, if IDOT is responsible for both `Acquiring Land` and `Building Interchange`, then it is clear that both actions have to be accomplished to build an interchange. In this case, these actions are not substitutable for each other. Design relationships are discussed further in chapter 4.

Finding actions that have the same attribute for the responsible actor is reasonably easy with actor as an attribute. It is reasonably hard, however, for a non-expert to recognise whether a combination of actions falls beyond the capabilities of an actor, and if so what kinds of trade-offs are warranted. Automatic recognition of such combinations would require an exhaustive listing of continually

[6] A counter example is a multi use path, which is both a bike path and a foot path.

changing capabilities of each actor. Prudent reasoning with plans would involve humans to make such judgements.

3.4 Across Plans

In the earlier sections I have identified how substitutability is implicit in plans. In this section, I will identify how such discovery of substitutes within one plan can help us discover substitutes in other plans about the same issues. Typically, if a plan of a business group specifies a course of action contrary to that of the city's own plan, then both action sets could be considered alternatives. Whether they are perfect or imperfect substitutes will depend on the attribute characteristics they are measured upon. It is fairly common that plans are made by a group explicitly acknowledging that its plan is a 'counterplan' to some other group's plan, and thus the issue of substitutability is made explicit. Trivially, if two actions are substitutes for each other within a single plan and another actor proposes another action as a substitute for either one of them, then it is also substitutable for other. In other words, the transitivity property applies for substitutability when the substitutability is identified either through effects or intents or other attributes.[7] Note that transitivity is violated when we consider partial substitutes, especially when there are tradeoffs between performance on attributes. However, we are also concerned with situations in which one plan does not recognise the other. Political expediency and human cognitive limitations make these situations all the more frequent.

Plans are owned by different actors and they are made for different purposes and

[7] As noted earlier, substitutability is not transitive when we consider strategies.

we need to be careful about how these different purposes inform the relationships. Therefore, I distinguish between two views of plans. One is that of plans that are made for one's own 'internal' use and the other is plans that are used as a rhetorical device to help convince others what their plans should be. Each view has distinct ideas about what plans are meant to accomplish and has different implications for determining the question of alternatives.

The Metropolis 2020 plan, which is authored by the Commercial Club of Chicago (a collection of private actors), recommends not expanding the "CATS proposal for adding two lanes to the thirteen-mile segment of I 90 (at a cost of $130 million)" (Commercial Club of Chicago 2000; p. 80) . In other words, the Commercial Club is suggesting to the regional planning agency what its intentions ought to be. Instead it recommends that "that right-of-way should be used for a new transit line that would extend the CTA Blue Line to Elk Grove, Schaumburg, Rolling Meadows, and beyond." The Commercial Club does not have any direct capability to extend the CTA line, only to advocate for its views. Nevertheless, its plan makes apparent that its own proposal should be considered as an alternative to the CATS proposal. While the CATS proposal to expand I 90 is typical of a Metropolitan Planning Organisation planning for a region, the responsibility of expanding the interstate lies with IDOT and a number of other agencies. However, the MPO's plan and study is prerequisite for the IDOT to act on such a proposal. Thus the CATS plan is a plan that has direct implications for decision making whereas the Metropolis 2020 plan has a rhetorical function, to persuade others not to implement projects as specified in the CATS plan. In many cases plans serve both internal and rhetorical functions simultaneously.

3.4.1 Plans for Oneself

In plans that are meant for the one's own use in decision making, substitutes are often recognised through the interdependence relationships. Consider an example in which a Sanitary District has a plan to expand sewer trunks and a city has two alternative locations for allowing new commercial development. The sewer trunks are better utilised if they are placed to serve the commercial development that may result. The Sanitary District, in making its decision about the trunks, will have to recognise and acknowledge the City's expansion plans, and thus the expansions of sewer trunks at these two locations become alternatives to each other. Unlike Knaap et al. (1998) we do not need to consider this as a leader-follower Stackelberg equilibrium. If a neighbourhood group wants to force the city not to permit new commercial development near their own neighbourhood, they could persuade the Sanitary District to commit to expanding the sewer trunks at a location different from their neighbourhood, thereby limiting the choices of the city of Urbana.

In the above example, each actor such as the City, Sanitary District, and neighbourhood group made plans for itself. However, each of them explicitly recognised the interdependency of it own plan with respect to others' plans and made this interdependence apparent in its own plan. Thus, alternatives for one particular actor were recognised in its own plan. Through interdependence relationships within and across the plans, individual actors can generate alternative actions for themselves. The Sanitary District's actions being interdependent with the City's actions forces the two locations of expansion of sewer trunks as alternatives. The neighbourhood group's plan then recognises these alternatives of the Sanitary District and formulates alternative courses of action for itself in each case.

An actor may belong to different groups that are owners of different plans. In such cases, if one plan requires one action in the same space time situation (Worboys 1994) as the other plan, then they may be substitutes to each other for the purposes of the actor. More specifically, in cases when each plan requires a different action from the same actor in a particular situation (decision or space-time) then the actor when making a decision has to consider both actions as alternatives informed by different plans. To discover these relationships, simple attribute matching queries suffice at least to discover them from the stand point of heuristics. Searching for all actions that are proposed in a particular location (with a buffer) and actors responsible for these actions from various plans will identify a subset of actions that need to be closely investigated for substitutes. The same approach can be applied to temporal locations.

This approach, in principle, could be extended to rules about the attributes of actions (policies). Two policies are substitutable if their intents are the same or the effects are the same irrespective of the actions they spawn. The pairs of actions from these different policies specified in different plans would then be substitutes for each other.

3.4.2 Plans for Others

Rhetorical plans, on the other hand, are made to influence others' actions by suggesting to them courses of action different from those they otherwise would have taken. These plans explicitly identify which actors should pursue what and in relation to which other events. They may or may not make explicit reference to the actors' original plans, but nevertheless imply them.

Such plans are routinely made and used. The classic Flyvbjerg (1998) study of business group's counterplan to the proposed relocation of the integrated modal transit stop or the Commercial Club of Chicago (2000) plan in direct contrast with the Chicago Area Transportation Study (2003) serve as examples. In plans for others, intended actions of others are identified with the alternatives proposed. As such, any negation of such proposed actions would be considered an alternative for the actor to whom the plan applies. To build or not to build is the question that needs to be decided upon by CATS and IDOT.

When an actor A proposes to do an Action a_1, and another actor B proposes that action a_2 be done by A, alternatives can still be recognised by the earlier methods even when B does not acknowledge the substitutability relationship between a_1 and a_2. Since the responsibility for the action a_2 still lies with actor A, the capability constraint used for recognising substitutes flags this pair of actions for further evaluation. If on the other hand, when B does not identify the responsibility of A with action a_2, then other characteristics such as location and temporal attributes can be used to evaluate the substitutability relationship.

Thus, the metadata of a plan should include both potentially different owners and authors. In addition, each element of the plan (actions, intentions , goals etc.) should have an attribute of a responsible actor who may be different from both owners and authors. In addition, each configuration of actions, such as designs and strategies, would have a responsible actor. While the responsible actor of the configuration is inherited by default by the actions that compose it, they can be overridden by the individual action's attribute. Thus, Metropolis 2020 is authored and owned by the Commercial Club, while the action of `extending transit line` is a design whose responsible actor is CTA. Individual atomic actions that compose this design, while not yet identified, can have different responsible actors.[8]

3.5 Conclusion

Different configurations of actions and their attributes in a plan can be used to determine substitutability of actions and the degree of substitutability. Two actions are potentially substitutable if they satisfy the same intent or cause similar effects. They can be substitutable with respect to policy, strategy, or design depending on the configuration of actions. They are also alternatives if taking one action precludes the other due to a variety of restrictions such as capability and location.

In this chapter, I have described and illustrated the ways in which different actions or collections of actions within plans can be viewed in combinations as potential substitutable actions. The question of substitutes is useful to determine because substitutes are inputs to decision making by actors. In the next chapter, I describe the other kind of semantic relationship that is evident within and among plans, interdependence.

[8]For the purposes of this dissertation, responsible actor is an actor with the authority or capability to perform the action and is charged to do so. The finer distinctions between authority, capability and responsibility are glossed over.

Chapter 4

Interdependence

Interdependence is a semantic relationship when two actions are dependent on each other. For the purposes of this dissertation, I include relationships such as explicit uni/multi-directional dependencies, parthood, and complementarity. In this chapter, I explore the different types of interdependence relationships and how intuitive notions of these relationships will get us sufficiently further along in discovering other relationships.

Actions are interdependent when the states they generate are related. This tautological statement seems frivolous, but is important to state at the outset because we distinguish between actions and effects. An action of subdividing a parcel and an action of providing access to these parcels are interdependent, not in the least because provision of the access determines the spatial relationships between the sub-divided parcels. Considering the provision of access without considering the subdivision or vice versa is meaningless. On the other hand, actions may also be related to other actions through their attributes. For example, A may be prior to B. On the other hand, A and B may expand roads that are connected, and from a traffic management perspective they are interdependent due to their complementarity. Each action may be considered and taken independently without any restrictions, but considering them both would generate a better outcome. Thus, both outcomes and attributes of the actions help us determine the interdependence between actions.

Following the structure of the previous chapter, I first discuss the interdependence relationships that are apparent in a single plan. Primarily, designs serve to make the interdependencies explicit. I then argue how both the attributes of the actions as well as the states they generate (or are presumed to generate) could be used to discover further interdependencies in plans. Since further interdependence can be discovered from already noted interdependence relationships between actions, discovering these interdependencies between actions across plans is viable. Once we discover these interdependencies within a plan and across plans, the next chapter deals with using substitutes and mutually dependent actions to discover further semantic relationships between actions.

By no means are the interdependencies discussed here exhaustive. They are merely representative and are postulated to be of interest to planners. Nevertheless, by laying out these specific relationships, I hope to make the case that explicitly recognising interdependencies is useful for planners in general.

4.1 Within a Plan–Design as a Set of Interdependent Actions

In this section, I elaborate on the concepts of interdependence of actions within a plan. After all, one of the key reasons for planning is to address the question of interdependence of multiple decisions ahead of time. As such, we focus on that aspect of plans that is primarily concerned with interdependence, namely designs.

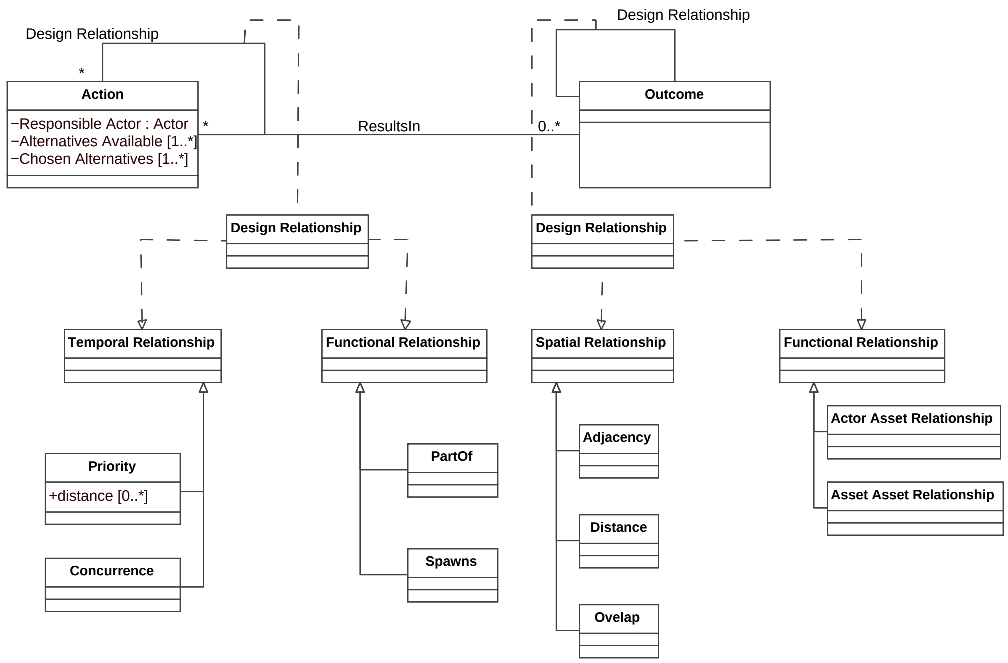


Figure 4.1: Incomplete Description of Design Relationships

Fundamentally, design is a tightly worked out set of actions that sit in relation to other actions and when taken together achieve a desirable result. Design can thus be thought of as an intentional action set whose member actions are related to each other, deliberately assembled, and to be taken in concert to bring about a particular state of the world. In this thesis, I arbitrarily limit[1] the relationships to those among actions or among outcomes (see figure 4.1). Such relationships that are of particular interest in urban planning are spatial relationships such as adjacency and distance, functional relationships such as connectivity, actor-asset relationships such as owneğğrship, or other actor-action relationships such as responsibility.

A familiar example of a design is a design of a building. It can be viewed as an out-

[1]The only compelling reason for this is to differentiate between a design and a strategy. If we consider the contingency relationship between actions and outcomes as a design relationship, then every relationship is a design relationship.

come, where the constituent parts fit together coherently. A key point, however, is that the design could be a building or, more elaborately, could be the actions that bring into being the constituent parts. In other words, a construction management plan of a building is, for example, also a design, as are the architect's conceptual relationship diagrams or the detailed construction diagrams. On the other hand, we are also interested in designs that can draw from a social science perspective. Excellent examples for such a design are the hierarchical structure of an organisation (e.g., firm). A division of labour in a group working on a project, coherently specified, is a design. Lest it be taken that designs are necessarily static in nature, it need not be so. Any process can be viewed as a state or an outcome and thus specified relationships between outcomes could be relationships between processes.

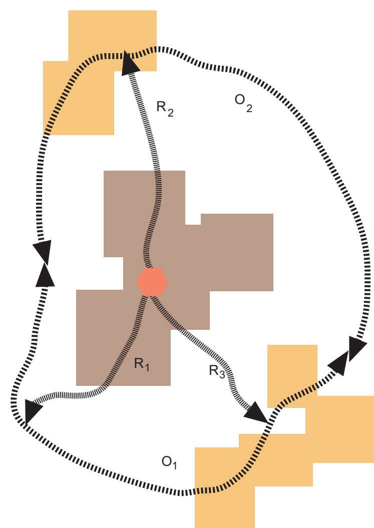


Figure 4.2: Infrastructure Investments as a Design

The transportation improvements plan in figure 4.2 could be modelled as a Design. In this case, the three radial links would be considered together because they would only be effective in strengthening the core if all links were built. And the two ring road links would be considered together because they would only be effective in improving peripheral access if both were built. The response or anticipation of developers would then consider the construction or anticipated completion of combinations of links rather than individual links. This is a very simple instance of design relationship.

A design, however would be that the combinations of R_1, R_2 and R_3 has to be built in conjunction with the O_1 and O_2

```
ActionSet1(R1,R2,R3),
ActionSet2 (O1,O2)
NetworkConnect(R1,R2,R3)
...
NetworkConnect(O1,O2)
Precedes (ActionSet1, ActionSet2)
Connect(ActionSet1, ActionSet2)
```

As the preceding paragraphs make clear, all actions that constitute a design are by definition interdependent, more specifically complementary, with respect to the outcome envisaged by the design. The main work of this chapter is to recognise what kinds of interdependencies help us to reason about other semantic relationships.

Broadly construed, we are concerned with the design relationships, which are spatial, functional, temporal, and mereological in nature. Spatial relationships include distance or qualitative spatial relationships such as front and back (Freksa 1992). Functional relationships are the actor-asset relationships such as ownership, or asset-asset relationships such as connectivity. (See Kaza 2004; for more complete characterisations.). Temporal relationships are modelled after interval logic of Allen and Ferguson (1997). Mereological relationships such as parthood or membership and subset relationships are treated naively without references to the topological issues raised by Casati and Varzi (1999). They are further elaborated in the context of multiple plans in later sections.

Since actions are events, the relationships between events (whether intentional or not) are discussed in the next section. To discuss them as events can also help us formulate the relationships between states in futures, we do not have any control over but nevertheless, need to be considered to formulate responses.

4.2 Event Relationships

Just as we need to divorce the notions of Assets and Actors from location, we also need to divorce events from inherent underlying framework of time. Since plans are made for contingent futures, the occurrence of a particular future (or non-occurrence) is an event that the plan is supposed to address, irrespective of its location on the temporal axis. The temporal location of the event is useful only for the purposes of discerning relationships to other events. Thus, an event set can comprise temporal relationships such as `before`,`lag`, and `temporal adjacency` as primitives, without inferring them from the locations of actions on the temporal scale. As I have mentioned earlier, actions are intentional events and thus inherit the same relationships as non-intentional events.

Furthermore, these relationships are ephemeral and particularistic. For example, a plan of city government may suppose event A is prior to B (building the ring road first and expanding the connectors to the centre later in the figure 4.2) and choose to plan for such a future (by scheduling the capital improvements plan and budgets accordingly). However, the suburban villages at the fringes may suppose the opposite precedence relationship. It may be useful to get to the employment centre in the city first, than to connect to other fringe development. Especially, when the issue is who gets to act on which subset of actions in the design, plans of multiple agents may presume incongruent event relationships. Furthermore, different plans of the same agent may prescribe different sequences of actions, depending on which futures the plans account for.

Actions being intentional events are related to each other and other entities in the world. I classify the event relationships as Spatial, Temporal and Functional relationships. All of these relationships are present in designs if they are intentionally so arranged. All of these relationships require slightly different elaboration about reasoning with them and are described as follows.

4.2.1 Temporal Relationships

Grenon and Smith (2004) and Worboys (2005) distinguish two different modes of representing event relationships. One is SNAPshots of states arranged on the temporal axis, and the other is primarily focussed on the processes (existence, modification etc.) that occur in a SPAN of time. Both kinds of representation are useful, and in fact this reasoning system considers both modes of representation without too much emphasis on the rigorous and exact translations between the two. Activities, such as shopping, travel, or residing, are processes and the level of activity, such as volume of sales transactions or traffic count on a link, are also

Snapshots of states. Thus, an action A_1 can occupy an interval of time (t_1, t_2) whose purported outcome S_1 may occupy (t_3,∞) with $t_3 \geq t_2$. If on the other hand A_2 has to precede A_1 and occupies an instant of time, then it should occur before A_1. If on the other hand A_2 brings about S_2, which is a prior for S_1, then A_2 has to occur before t_3. It may be the case that the only information available is that A_1 takes two years to complete, irrespective of the start date. The precedence relationship of the A_1 and A_2 is still valid and useful.

The key temporal attributes of and relationships between events are `precedes`, `lag`, `succeeds`, `simultaneity`, `occupies`, and `overlaps`. Actions individually may have attributes such as `beginTime`, `endTime`, and `requiredTime` from which the temporal relationships between actions can be deduced. Keeping in mind the adequatist, fallibilist and particularlist model of reasoning and representation (to use the words of Grenon and Smith (2004)) adopted and defended in this dissertation, reasoning with partial orders is sufficient for most purposes of planning. In other words, all the events need not fit in the event plane and all the relationships need not be immediately apparent or deducible. For example, `precedes (A, B)` and `precedes (C, B)` taken together make no claim about the precedence or any other relationship of A and C. If we postulate that priority relationship usually implies contingency (see §4.3.2) then an action X that is contingent on occurrence of B is also contingent on occurrence of A and C. For example, `prior(Acquire RoW, build Road)` often implies that the acquisition of RoW is necessary to building the road.

If the precedence relationship between two actions is not deducible from the partial order, then the actions may be simultaneous or not. However, the requirement of simultaneity is a much stronger relationship than an absence of precedence order. Simultaneity often indicates complementarity, but not vice versa. Building the interchange and the ring roads in figure 4.5 are complementary, but they need not be simultaneous. On the other hand, actions such as ceding the RoW and rezoning the right of way consistent with the neighbouring parcel can be simultaneous and often are complementary actions.

4.2.2 Spatial Relationships

Much work has been done in spatial reasoning (Galton 2001; Egenhofer 1991; Laurini 2001; Alexander et al. 1977; etc.) both from an information system standpoint and a human standpoint. Thus, most of them need no further elaboration except in the context of how the spatial relationships are apparent in the context of interdependence.

While actions themselves can have spatial attributes, most of the cases we are interested in are the spatial relationships[2] between the outcomes. For example, in figure 4.3 the village centres, the resource management areas and preservation areas are arranged in space to account for intents about preservation and resource protection around the Kishwaukee river and its tributaries. Land is designated either as protection areas or preservation areas contiguous to the river. This in turn limits the urban development to compact chunks around the major roads.

Such arrangements of future land uses are not uncommon as shown in another case in figure 4.4. The commercial and light industrial land uses are arranged to take advantage of the presence of the interchange, which provides regional access. Furthermore, the industrial uses are also arranged so that they are adjacent

[2] I include topological relationships to be abstract spatial relationships

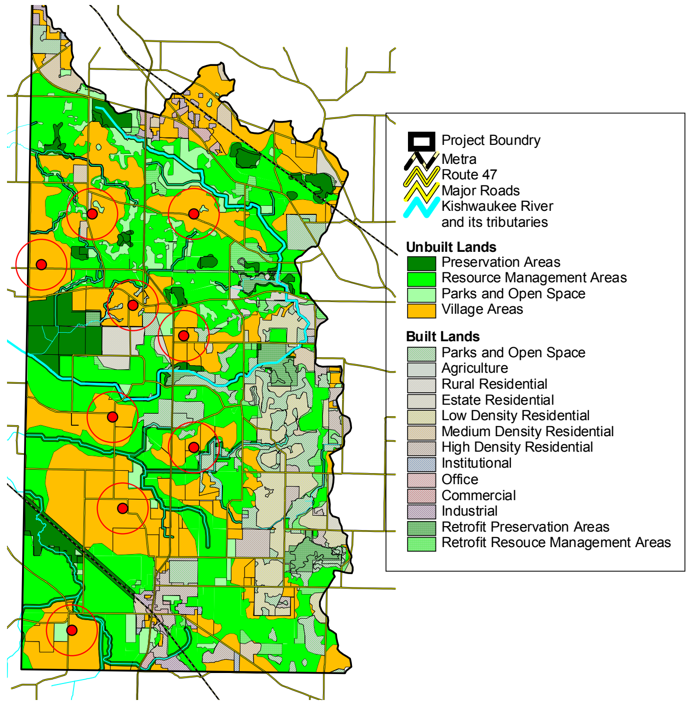


Figure 4.3: Future Land Use Scenario as a Design –Conservation Design Forum et al. (2002)

to the rail line on the West. In addition, it intends to protect the stream corridor. Of course, the City does not own any property in this area and neither does it intend to develop the area with such configuration of land uses. The city mentions these in its plans to provide backing for any future decision making on zoning changes, variances, roads and sewers, and permits it may grant to other actors who seek to develop these parcels of land.

Thus, the intent of this future land use map is to provide indications of what spatial relationships between outcomes of actions of others the City would prefer and would encourage. The spatial relationships of `adjacency`, `location`, `distance`, `along`, `between`, `within`, `underlap`, and `overlap` are useful to represent interdependence.

There are number of other useful spatial relationships such as `connectivity` on

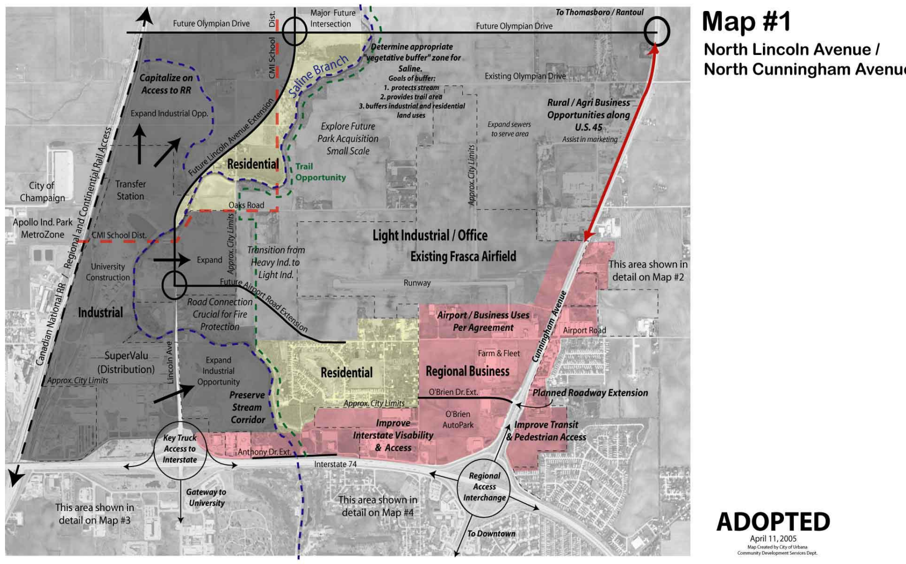


Figure 4.4: Spatial Relationships in Future Land Use in North Urbana–Urbana (2005)

a network, which are glossed over in this dissertation, but remain important. The limitation is due to the choice of PostGIS, which supports only limited topological and network operations.[3] Conceptually, however, there are no inherent limitations, and I have discussed these various points in other chapters. In chapter 7, I will elaborate on them again.

Spatial mereological relationships such as `intersect` and `contained in` provide clues to interdependent actions. Suppose, an action A_1 requires an outcome, which has a spatial attribute of L_1 and A_2, an outcome with spatial attribute L_2. If L_1 and L_2 intersect or are otherwise related, then there is a potential interdependence between A_1 and A_2. For example, in figure 4.4, if an action that permits industrial activity would fall spatially within preservation of the stream buffer, any permit should be cognisant of the preservation action.

[3]As of fall 2007.

4.2.3 Functional Relationships

Functional relationships are relationships between Assets, Actions, Activities and Actors that are apparent in the State of the World. They can be actor-asset relationships such as `ownership` or actor-actor relationships such as `member of` or action-action relationship such as `contingency`. We are concerned with all of these, as in the case of spatial relationships, because if the outcomes have relationships such as asset-asset relationship, then the causal actions may be interdependent.

For example, building a new Olympian drive as referred to in § 3.3.1 requires that the old Olympian drive be dismantled, new RoW acquired, old RoW ceded back to the adjacent property owners, and funding be secured to construct the new road. In other words, destroying an asset, transferring rights from one actor to another, and acquiring capability by an actor are all related to constructing the new road. Some of these actions are functional priors; some of them require changes in capabilities of actors. If these relationships are specified in designs, then the actions that bring them about are interdependent.

4.3 Discovering Interdependencies across Plans

Once we have identified the crucial interdependent relationships among actions within a plan, our next task is to turn to interdependent relationships that have not yet been identified across plans. While some of these relationships may be present within the same plan, this section presents them as found across plans because it is a more generic case than interdependencies within a plan. A plan *A* may thus identify a set of actions as being complementary due to the enhanced effect they are supposed to have as a combination. However, another plan *B* of another actor may identify an action as being complementary to a set of actions specified in *A* and thus should be pursued only in the event that actions in *A* materialise. To identify these interdependence relationships across plans, even when they are not completely congruent with each other, gives us important information about how different plans and thereby different actors view the importance of different relationships.[4]

In the subsequent sections, I lay out the modes for inferring some design relationships from other apparent design relationships, which may help us in identifying the other semantic relationships such as complementarity and parthood. In this process, I draw from the reasoning systems that are already in place and will elaborate upon them as and when it becomes necessary.

4.3.1 Complementarity

Two actions are complementary with respect to an effect if they enhance the effect together more than either action when pursued alone . A set of actions are complementary both with respect to intents and effects. In other words, a set of actions may be tagged complementary to each other or we could discern if they are complementary based on the state of the world they generate. For example, in figure 4.5, if the intent is to divert traffic onto IL 23 passing through Marengo, then the interchange proposal between IL 23 and I 90 (shown as *I* in the figure 4.5) and the ring roads *A* and *B* are complementary. However, the combination of build-

[4] I still maintain the distinction between plans for oneself and rhetorical plans as alluded to in §3.4

ing roads *A* and *C* together, with *I* are not complementary. On the other hand, *A* & *C* are complementary actions, when expanding the interchange between US 20 and I 90 outside the county .

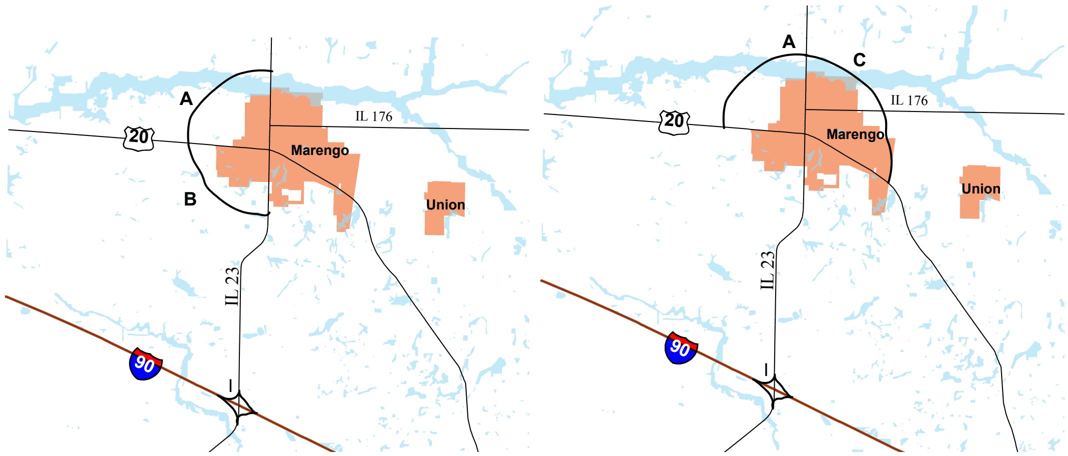


Figure 4.5: Complementary Actions — Interchange and Peripheral Road

The decision to build either interchange, does not necessarily consider the configuration of the ring road. The location of the ring road on the other hand is also not entirely dependent on which interchange gets built and when. If it is likely that both the interchanges are built in near succession, then pursuing the construction of all three segments of the ring road makes sense. However, if one interchange is an alternative to the other with respect to budgetary constraints, then choice of the segments to suit the desired traffic patterns is useful.

A short explanation of the context is in order. The city of Marengo is in the Southwest quadrant of McHenry County, IL and is served by only one interstate, I 90. This explains the enthusiasm of the County to get the interchange *I* built. The Kishwaukee River runs north of Marengo and is considered a significant natural resource. Hence the plan by the conservation district seeks to preserve the river area by acquiring rights to the parcels and thereby precluding incompatible development and uses. One of the large portions of contiguous high quality farmland in the county is located south of the interchange. Hence, a non-profit group whose interest is soil conservation appeals for preserving this swath of land from development and lobbies for its protection. The question of which interchange should be built is complicated by the fact that I 90 is a toll way. The construction of a full interchange, therefore, also requires construction of toll booths with sufficient distance between two points of toll collection.

Complementarity of two actions is thus a semantic relationship, which can be recognised only in respect to the outcome envisaged. Since outcomes, or effects in other words, are structurally similar to intents, two actions may be complementary to the desired intent. The complementarity may be explicitly declared in the prior planning process, or it may have to be discovered based on incomplete understandings of how the world behaves. Such understanding could be generated through modelling.

The ring road is depicted in the local plan of the City of Marengo. The plan of the neighbouring Kane County (to the South) includes the expansion of the interchange *J* between US 20 and I 90 (not shown in the figure), and upgrading of the toll booths associated with that interchange. For the city of Marengo to decide which segments of the ring road need to be built, it has to understand the commitment of various actors to building which interchange and thus be able to represent these expectation in its 'knowledge base'.[5] The following is a schematic representation of major relationships of actions in different plans.

[5]This does not belittle the benefits of human knowledge that is not easily encoded in a logical system. The knowledge base is presumed to conceptually include both human expertise as well as computer databases. The argument here is merely for a computer supported system to help human reasoning.

Marengo Plan

Agenda 1: Build (A)

Strategy 1: If Interchange I gets built then build (B)

else build (C)

Desgin 1 : Connect $(A \wedge (B \vee C))$(Connect A with either B or C)

⋮

Mchenry Conservation District Plan

Design 1: Acquire contiguous parcels along the Kishwaukee river

Design 2: Acquire land before Marengo commits to building A or C

⋮

McHenry County Plan

Agenda 1: Support DoT plan to build Interchange I

⋮

McHenry Soil Conservator's plan

Goal 1: Preserve the high quality farm land, south west of I 90

⋮

Kane County Plan

Agenda 1: Support DoT plan to expand interchange J

⋮

IL DoT Plan

Alternatives (Expand (J), Build (I))

Strategy 1: If (funding is X ∧ favourable recommendation of study) then build I, else if the funding is Y then expand J

⋮

As noted in the schematic representation, Marengo's plan explicitly recognises the alternatives put forth in the DoT's plan and situates Marengo's actions in strategies to enhance the intended effect of traffic diversion. However, the conservation district only recognises the plan of the city to build the ring road. If the plans of the neighbouring Kane and McHenry counties are available along with a reasoning system, a simple query would determine that the conservation district's decisions are dependent on the city's plan, which is further dependent on the State DoT's plan and the counties' plans. Similar reasoning can be followed by the soil conservation group in McHenry County in their decision to support the interchange J in Kane County. By reasoning that the conservation group would support building the interchange J to the detriment of building the interchange I, McHenry County might enact regulations and provide incentives to preserve farmland.

4.3.2 Priority & Dependency

An action is prior to another either temporally or functionally. If action A occurs before or after B, then they share a temporal relationship . Allen and Ferguson (1997) discuss the representations of temporal events and relationships and reasoning with them. In this section, we are primarily concerned with the functional priority relationships of actions. An action A is functionally prior, if it is necessary before the occurrence of B. In other words, if we decide to do B, we have implicitly decided to do A. Thus, functional priority is dependency or otherwise called contingency . An action A is functionally prior if it is necessary before the occurrence of B .

These functional relationships should be generated from the local and legal context . If we decide to build an airport, we then have also committed to acquire the land and zone it appropriately. Similarly, building of a road requires that RoW be in place, trunk sewers be extended, and utility easements be in place. These functional relationships between actions are well understood by planning experts and should be easily translatable into ready references for access, not unlike existing reference books such as American Planning Association (2006) or Watson et al. (2003). On the other hand, standard land use planning texts such as Kaiser et al. (1995) could also be used to crystallise existing professional knowledge to identify the functional relationships. For example, Kaiser et al. (1995; p. 349) state, "Churches, community centres, clubs, and other local community serving institutions will have land reserved in convenient locations, on circulation networks." Thus, the functional relationship of access of the community service facilities translates into a spatial relationship between circulation networks (bus routes, roads , etc.) and the land reserved for them.

In the earlier example (figure 4.5) of the decision situations of various actors in McHenry County, the interchange I can be built only after a Federally mandated study is completed that produces a favourable recommendation. The study thus is a functional prior to the building of the interchange I. On the other hand, building the interchange I is not prior to building roads A, B, or C because it is not a necessary action. The construction of either ring road is not necessarily dependent on the conclusion of the study even when a complementarity relationship holds.

If the soil conservation group recognises the priority of the study and its recommendations as necessary for building of interchange I, and if it believes that building I is inimical to its goals, then it could reason that lobbying for strong representation of its concerns during the study process would produce an unfavourable recommendation. Such an unfavourable recommendation would serve its intent to oppose the interchange. This course of action, if it were made explicit in their negotiations with McHenry County, which favours the interchange, could lead to the county enacting regulations that conserve farmland to assuage the concerns of the conservation group.

Sometimes priority and dependency are also explicit in strategy (and policy). Urbana, according to its comprehensive plan, has a policy of providing at least two sub-collectors between collectors that are a mile apart. The policy, which applies to the citiy's extraterritorial jurisdiction (ETJ), can be represented as

```
If
  Request for subdivision permit within ETJ ∧
  Site encompasses two collectors more than a mile apart
then
  Require (Build (Two subcollectors between collectors by
Developer))
```

This policy can also be represented as another decision making rule, when the site does not encompass both collectors, but falls between the collectors that do not have connecting sub-collectors.

```
If
```

```
  Request for subdivision permit within ETJ ∧
  Site intersects land bounded by two collectors more than a
mile apart
then
  Require( Build(One or Two sub-collectors between collectors by
Developer))
```

The requirement to build the subcollectors is thus contingent on application for a subdivision permit. In many cases, the antecedent involves an attribute of the state of the world. If the attribute (or a measure of it) can be brought about by an action, then the action causes the state, which is in turn prior to the consequent clause. Thus the causing action is also prior to the consequent. In the above example, the attribute of the collectors being a mile apart has no such immediate causal actions. In the second version of this policy, the choice of requiring to build one or two sub collectors is left till a later stage when the actual site location and characteristics determine such decision.

The interchange between I 90 and IL 23 (named I in the figure 4.5) is supported by McHenry County. It can be deduced from Marengo's comprehensive plan that the configuration of the ring road that should be built is dependent on whether this interchange gets built or the interchange between US 20 and I 90 (named J in the figure) gets expanded. Marengo has neither any authority nor any capability to build these interchanges, but its own actions of choosing the configuration of the ring road is dependent on IDOT's actions. This is specified as dependency in the strategy of Marengo. Since Marengo explicitly recognises these actions of IDOT and prepares for various contingencies, dependency between the plans of these two actors is apparent.

4.3.3 Composition

Actions can be compositions of other actions. A `Create TIF District` action can be viewed as a single action or as a collection of `Certify Tax Base` → `Notify Public` → `Adopt Redevelopment Plan` → `Sell Bonds` . The granularity of actions (Worboys and Hornsby 2004) is important in reasoning with plans and thus it is important to recognise these part-whole (mereological) relationships.

One way to look at the composition relationship is to view it as a design relationship among multiple actions. In other words, the functionally sequential actions such as `Certify Tax base` etc., are present in a design of creating the TIF district. Once the design is specified, we can encapsulate the lower order actions and specify the relationships between higher order actions. If, however, there is an interdependence relationships between lower order actions and some other actions, encapsulation loses information. But such encapsulation preserves tractability of reasoning without resorting to decomposition to atomic actions and relationships.

Mereological relationships are studied in the abstract representations of geography in Casati and Varzi (1996). Similar reasoning could be applied to actions and events in understanding the relationships between them. Parthood relationships are typically considered partial orderings; reflexive (A is a part of itself), antisymmetric (If A is a part of B and vice versa then A is B) and transitive (If A is part of B and B is part of C, then A is part of C). We argue that recognising actions in the urban development context as parthood relationships, among other design relationships such as spatial, temporal, and functional, will help us in uncovering relationships among actions. For example, if action A is part of B and B is temporally prior to C, and if D is part of C, we can conclude that A is temporally prior to D.

As discussed in the earlier sections, multiple representations of the same action are useful for different purposes; i.e. `Create TIF district` can viewed as an element of an agenda or as a design, which is a composition of other actions arranged in a sequence. If an action is a composition of others, we could reason that any interdependence relationship the higher order action has with other actions may be directly inherited by the lower order actions. That is, creating a TIF district is contingent on the availability of jurisdictional authority to create such a district. In the context of the creation of the TIF, all the actions that compose it, are contingent on the legislation by the state granting authority to create a TIF. It should, however, be noted that the capability to sell bonds and certify tax base may be available to the City for other purposes, even when there is no enabling legislation that grants the capability of creating a TIF.

4.4 Conclusion

In this chapter I have described the interdependence relationships between various actions of various actors and some ways to identify them when they are not already identified in a plan as a design. The presence of spatial relationships between outcomes; functional relationships between actions, actors and assets; and temporal relationships between events and actions gives us some clues about the complementarity, composition and directional dependence of one action over another. Furthermore, if an actor identifies another's action as a prior (or any other interdependency) to her own action, then such interdependencies lead to concerted effort to co-ordinate such actions. Identifying these interdependencies also lets us resolve decisions, even when decisions within our own capability are held up because of contingency of other decisions over which we have no authority. In such cases, only rhetorical action is possible to convince the responsible actor.

In the next chapter I use relationships of substitutes and interdependence that are already apparent to discover relationships between other actions. In particular, I will demonstrate when reasoning via transitivity and distributivity is appropriate for different combinations of interdependent and substitutable actions.

Chapter 5

Heuristic Reasoning with Semantic Relationships

Earlier chapters have dealt with semantic relationships such as interdependence and substitutability within and among plans. In this chapter, I will demonstrate heuristic methods to arrive at further relationships based on the relationships already discovered or made explicit. To reason with plans, one needs to understand not only what is said in the plans themselves, but also what is left unsaid to make judgements about the usefulness of such reasoning in informing decisions and actions. Thus, the methods described here are heuristic and idiosyncratic, and judgement about their usefulness is reserved for particular circumstances.

Once substitutes (partial or complete) are recognised, if either of the alternatives is interdependent with another action, then the other alternative is likely to be interdependent with that other action. If two actions are interdependent, then the substitutes of these two actions are likely to be interdependent. In this chapter, I examine these claims in detail. Under specific conditions, where interdependence and substitutability are apparent, they are likely to be passed on to other actions. In particular, we are interested in the transitive and the distributive properties of these semantic relationships. Furthermore, we also look for substitutes and interdependent actions in the spatial, temporal and functional sense, and how each is different from the other in reasoning about further semantic relationships. The table 5.1 provides a succinct view of how the relationships are discovered. However, it should be noted that the absence of any value in the particular cell is as indicative as a presence. Detailed explanations of these are given in subsequent sections.

5.1 Fishing for Substitutes

Substitutes across plans are easier to discover when the actions in the plans have some commonly specified attributes. These attributes include, but are not limited to, location, intent, actor, and time. They can also include the attributes of assets they change. In chapter 3, I have argued that intents, effects and location are useful ways to discover actions that are substitutable. In this chapter, we focus on discovering more substitutability relationships among actions between which some other relationships have already been discovered.

As I have mentioned earlier, substitutability makes sense only with respect to particular evaluative attributes. Whenever the claim of substitutability is made in this chapter, it is implicitly assumed that such a set of evaluative attributes is defined, known and apparent. When needed, the substitutability with respect to *what*, is explicitly stated.

5.1.1 Complete Substitutes

Substitutability is a binary relationship (a relationship between two entities). Trivially, an action is substitutable for itself. Furthermore, if an action A is an alternative to B then it follows that B is an alternative to A. Complete substitutability is transitive if the two pairs of actions are substitutable for the same reason. It is not transitive if they are substitutable for incompatible reasons. Suppose building a bike path and a footpath are substitutes due to locational constraints. If the footpath and expanding a fire station are substitutes due to budget constraints, then the bike path and fire station may not be affected by a budget constraint. Clearly, they are not affected by a locational constraint and hence may not be considered substitutes. However, transitivity is maintained when the attributes over which the substitutability is evaluated, stay the same. A bike path, footpath and a road lane expansion are pair-wise substitutable if they are alternatives due to the locational constraint.

This example, brings us to a point that is central, if not always emphasised throughout. While, one cannot automatically determine if the fire station and the footpath are substitutable, a human makes judgement on the substitutability of these actions taking into account conditions beyond the union of the attribute set on which the substitutability of the two pairs of actions has been evaluated. The tagging of these elements as possible candidates for substitutes is useful in and of itself in order to make further judgements. Thus, heuristics serve to highlight possible candidates for further evaluation by humans, rather than displacing human reasoning completely.

The claim about the binary nature of the relationship needs further exposition. An action is alternative to another. A set of actions are alternative to another set. The sets of actions that do not have either interdependence or contingency relations between them are substitutable if as a set they are substitutable to the other with respect to intents, effects, capabilities or other criteria. An arbitrary set of actions contains a farm subsidy and a downtown TIF and another set contains price supports and a downtown improvement plan. These sets are substitutes because the constituent actions are substitutes for each other due to their purported effects. Suppose the downtown TIF is an alternative to annexation of properties in downtown by a State agency due to the location criterion. The set of actions containing TIF and farm subsidies is alternative to the set that consists of price support and annexation.

As in the case of illustration in §6.2, extending the Milwaukee District West line and extending Union Pacific North West line (both to be operated by Metra) are tagged as potential substitutes due to budget constraint of Metra. If there is another project such as Suburban Transit Access Route (or STAR line, between Joliet and O'Hare), which is limited by the budget constraints of Metra [1], then each of these projects is mutually substitutable for the other.

On the other hand, the presence of a contingent (or mutually dependent) relationship between actions helps us to identify substitutability with more sophistication. The building of an interchange at High Cross road (figure 4.2) and expanding the road are interdependent with each other to improve the traffic on High Cross Road and Windsor Road. On the other hand, the interchange at Cottonwood is interdependent with extending Cottonwood Road to improve the traffic conditions on Windsor Road. These two sets of actions are substitutable because they produce similar effects with respect to the conditions on Windsor. Further, the interchanges themselves are alternatives. However, it does not follow that expansion of Cottonwood and expansion of High Cross Road are substitutable with respect to traffic conditions on Windsor Road unless the respective interchanges are also built. Thus, as combinations, the actions may be substitutable, while they may not individually be substitutes. The interdependence creates peculiar inter-

[1] This project is described in Regional Transportation Authority et al. (2007; p 48). Especially, due to budget cuts for Metra, this is the case as of July, 2007.

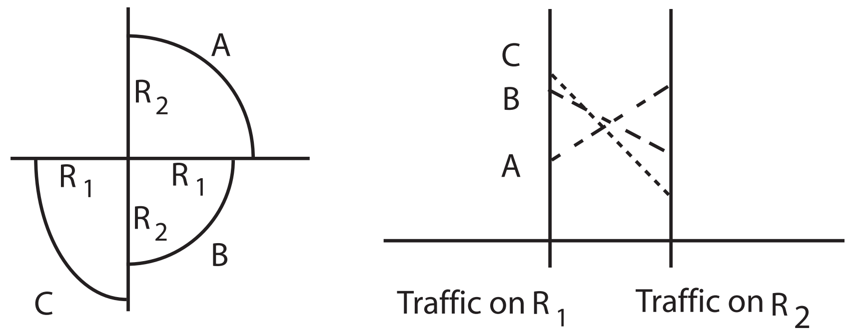


Figure 5.1: Intransitivity of Partial Substitutes

actions between the elements of the action set, which makes them substitutable as a set but not individually.

When we consider actions as atomic without any relationship with other actions, an arbitrary collection of these actions can be substituted by another arbitrary collection of actions, if each of the elemental actions is substitutable with the original actions. However, when a collection of actions has interdependence relationships, such as complementarity and priority, among the component actions, then only that collection of substitute actions that preserves the interdependence relationships is substitutable to the original collection. In other words, while the substitutability inherits upwards from elements to collections, the inheritance downwards is questionable. A design may be substitutable to another design—a light rail is alternative to increased bus service—without any of the constituent actions that compose either design being individually substitutable.

5.1.2 Partial Substitutes

Transitivity does not normally hold for partial substitutability even when the attribute set over which it is evaluated stays the same. This can be viewed as a simple extension of the triangle inequality. Two actions could be considered partial substitutes if the effects they are purported to generate are not exactly the same but fall within an acceptable level of each other. For example, in figure 5.1, ring roads A and B are partially substitutable because the amount that A compared to B reduces traffic on R_1 is the same as the amount that B compared to A reduces traffic on R_2. The user may make the judgement that the composite effect of either ring road on traffic on R_1 and R_2 is roughly the same and hence the ring roads are substitutable. By following the same reasoning one may conclude that B and C are also partially substitutable by the same criteria. However, by the same criteria, A and C may not be partial substitutes. To deduce partial substitutability, a transportation model has to be able to evaluate the effects of these actions on the criteria specified by the user.

When actions in a pair are completely substitutable, then partial substitutability is transitive provided the evaluative set remains the same. If a subsidy and a regulation are perfect substitutes for each other with respect to a particular environmental effect, then any action that is partially substitutable to either is partially substitutable to the other with respect to the effect. However, caution is recommended for this mode of reasoning. Consider the case of a combination of figures 3.2 and 3.3 as described in figure 5.2. While A and B as a pair are partially substitutable to A and D due to the intent of creating a bypass around the Marengo area, D and E are alternative locations for the same project. The combination of actions of A and E is partially substitutable to the combination of A and

D. However, the presence of the connectivity relationship between A and D and the absence of connectivity between A and E make them poor substitutes. Such judgements can only be made if there is an explicit record of the connectivity relationships between A and D as a design.

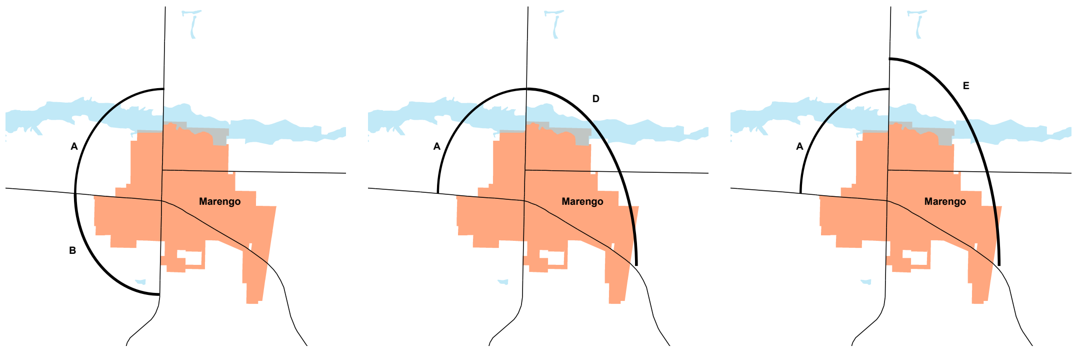


Figure 5.2: Partial Substitutability of Alternatives

When two actions are partial substitutes that are complete substitutes on a restriction on the criteria set, then tagging more pairs based on transitivity is a tenable strategy. On a particular restriction on the evaluative set, the partial substitutes are complete substitutes. Thus, by restricting the evaluative attributes, we can use the reasoning presented in the earlier paragraph to discern more candidates for partial substitutability. It will then become incumbent on the user to investigate further to determine the substitutability characteristics.

5.1.3 Contingent Actions

Contingency is unidirectional dependency between actions. When the antecedent action cannot be identified (or may not be useful to identify), the consequent action can be contingent on a particular manifestation of effect in the state of the world, however such effect is generated. In either case, one claim is that two such consequent actions could be identified as substitutes if they share the same antecedent condition. However, even if the antecedent condition remains the same in two different policies, of even the same actor, substitutability is questionable unless the policies themselves are substitutable with respect to intents or effects.

For example, consider two policies: a policy of the Urbana Champaign Sanitary District to provide sewer connections to individual lots only after annexation by the city and a policy of expanding the sewer trunk capacity only after annexation. Provision of sewer connections to individual lots and expansion of trunk capacity are not substitutable actions even though they are dependent on the same contingent action, the annexation of the parcel by the city. In fact, in this particular case, they are interdependent actions because the second consequent is functionally prior to the first consequent. On the other hand, alternative policies, such as provision of public sewer connections or provision of oversight for on-site waste water systems in the event of annexation by the city, contain substitutable consequent actions.

It then becomes important to determine how policies are substitutable with respect to each other. In fact, any set of actions with a particular configuration of relationships between them (Designs, Policies and Strategies) could be deemed a higher order action. The same criteria, such as effects and intents, should be used to judge if the action sets are substitutable as elaborated in chapter 3. Such encapsulation of actions into higher order actions is necessary to reason about relationships.

If two policies are substitutable, say with respect to intent, and the antecedents are alternatives, then the consequents are alternatives with respect to that intent.

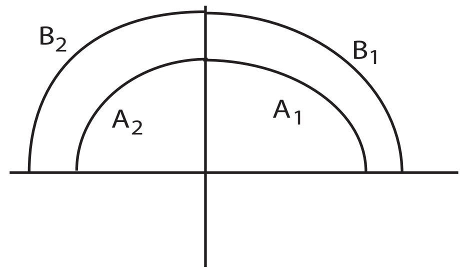
For example, a policy of requiring two sub-collectors to be built when the collectors are a mile apart (refer to §3.1.1 and figure 3.1(b)) is an alternative to a policy that requires three sub-collectors. Since the intent is to ease mobility, these policies are substitutable, and choosing to apply one precludes the choice of the other. The antecedent condition, that the collectors are a mile apart, is also the same. Hence, the action of requiring two sub-collectors is substitutable to the action of requiring three.

This may be a trivial example; however, policies have the same structure as a set of actions and their functional priors and sequents[2]. Thus, if those sets are substitutable and the priors are substitutable then the functional sequents are substitutable.

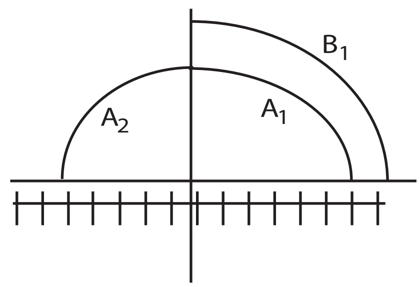
5.1.4 Other Interdependent Actions

One can also examine the distributive nature of substitutability of actions that are otherwise interdependent. When two sets of actions A and B, which have complementary actions (A_1, A_2) and (B_1, B_2) contained in them, are substitutable with respect to an effect, and A_1 is substitutable for B_1 with respect to the same effect, then A_2 and B_2 are also partially substitutable. This case is illustrated in figure 5.3(a), where the two ring road pairs (A_1, A_2) and (B_1, B_2) are partially substitutable as wholes and A_1 and B_1 are partially substitutable as parts with respect to reducing the traffic on radials. This leads to the recognition that A_2 and B_2 are also partially substitutable. In figure 5.3(b) A_1 is complementary to A_2 due to con-

[2]Policies have a different role and justification. They are meant to be used as a rule for repeated application and hence have general descriptions of actions in antecedents and consequents. However, application of a policy to a particular instance results in action sequences, which can be ordered functionally into priors and sequents.



(a) Inheritance of substitutability downwards



(b) Non substitutability of some complementary actions

Figure 5.3: Substitutability of Complementary Actions

nectivity and A_1 is equivalent to B_1. However, A_2 is probably not complementary to B_1 . The rail line while being substitutable to the set (A_1, A_2) is not substitutable to (A_2, B_1) because the complementarity is not preserved, even when A_1 and B_1 are partially substitutable.

Interdependent action sets can be substitutes if each of the constituent actions are substitutes and the relationship of interdependence is still preserved. In cases, where constituent actions are not individually substitutable, action sets, as a whole, could still be substitutable when the intents, effects and other restrictions makes them substitutable as a set. Enacting a TIF district may be substitutable for provision of small business grants due to budgetary restrictions if the intent is to develop the downtown. However, selling bonds for creating the TIF district is not necessarily substitutable in intent or in effect to any of the actions that characterise the small business grant program.

If we consider interdependent actions as designs, even when the design includes collections of actions by different actors, then a design is substitutable for another deign. The tight relationships between one set of actions and the other are easily broken by merely replacing some of the actions that constitute the design. It is this kind of tightness that allows designs to function as they do.

Parthood relationship is transitive and typically considered a partial order. However, the questions of substitutability of constituents raise serious philosophical questions about the identity of the collection. Imagine all a ship's components are substituted with otherwise identical components. Is it still the same ship? Without wading too deeply into this debate, best left to abstract thinkers (e.g. Wiggins 1980; van Inwagen 1994; Bottani et al. 2002), we can consider the whole action set as a design in which the constituent parts have no relationships between them. Thus, only relationship between a set of actions and the constituent actions is a membership relation. We can use the membership relationship of the set theoretic notions to reason about subsets and other collections arising out of such membership relations. In such a case, replacing one subset of such a design with another substitutable subset, while still affecting the composition of the whole design, does not affect the usefulness of recognising the substitutability of the collection of actions with respect to intents and effects by which the action subsets are substitutable. Substitutes of the sub-actions thus provide ways to generate substitutes of the action sets by merely replacing the substitutable sub-actions.

5.2 Interdependence of Substitutes

In the earlier section, I have described how we can use some of the interdependencies to discover substitutability and how the substitutability distributes over interdependency. In this section I will explore the possibilities of discovering interdependencies based on available substitute relationships. In general, the same interdependence is not preserved when we substitute the elements of the set. For example, if action A is a part of B and B is substitutable with C, it is unlikely that A is a part of C. However, when A is substitutable with A', then the new composition B' derived from substituting A with A' is substitutable with B when they are evaluated with respect to the same attributes by which A and A' are evaluated. These claims for different kinds of substitutes and interdependencies are examined in the subsequent sections.

5.2.1 Complements

Complementarity of two actions is due to the specific configuration of actions, so that the effects they generate are super-additive. Thus, if substitutes of these actions are considered, then it is unlikely that they retain the same configuration of relationships as between the original actions. This makes the complementarity between substitutes likely. In general, complements can be recognised by the criteria described in §4.3.1. In figure 5.2, while D is substitutable for E, A and E are not complementary by the virtue of non-connectivity. This suggests that a particular configuration of relationships between A and D (in this case connectivity) is a necessary prior for complementarity. When these particular configurations are explicitly identified, we can use substitutable parts to preserve interdependence of the whole, when the configuration is not disturbed. When the location of A is shifted to A' so that A' connects to E then (A, A') and (D, E) are pairwise substitutes and A' and E are complements.

When the intent is to reduce traffic on the horizontal collector, as shown in the schematic figure 5.3(b), if a rail line along the collector can be substituted for either set of ring roads, then the constituent parts of the ring road are not individually substitutable for parts of the rail line. This is due to the indivisibility of the rail line. The rail line is substitutable as a whole to the set of ring roads.

In the example given in §4.3.1, interchange I and J are alternatives due to functional constraint of distance between toll booths and probably due to budget constraints of IDOT. The ring roads A and B together are complements to I, whereas A and C are complements to J (figure 4.5). One can then tag these sets of actions as potential partial substitutes. They can already be recognised as partial substitutes due to an intent criterion. Such recognition is enhanced by their interdependency relationship with alternative interchanges. However, as noted in §5.1.1 (an analogous condition for the case of Champaign Urbana), neither of the ring roads serves its purpose unless the appropriate interchange is also built.

5.2.2 Priors

On a similar note, functional dependence (unidirectional such as priority) is not necessarily retained. If acquiring a RoW has to occur prior to building a road at a location L_1, which is substitutable to another location L_2, then acquiring RoW at L_1 is not useful to build a road at L_2. However, such recognition may prompt questions about the degree of substitutability and the attributes over which the substitutability is evaluated. That is if RoW is already acquired at L_2, then building a road at L_2 may become more attractive in comparison to building a road at L_1.

However, it is possible to infer some interdependencies that are not already discovered. If an action A is equivalent to another B, (i.e. A is the same as B but for a translation in a space time plane) then all the functional priors of A similarly translated are priors to B. As repeated often, the intent of this exercise is to discover ways of using plans because logical omniscience is neither desirable nor practical from the philosophical standpoint of planning. If the priors of B are not explicitly recognised, then the planner should be prompted to do so or give sound reasons why such is not the case. Both functional and temporal priority relationships endow partial orders among actions. Since translation as an operation in a space time plane is uniquely invertible, the same partial order is preserved in the translated plane.

Functional priority then is preserved between equivalent actions. If, however, two actions are substitutable due to other constraints, such as capability or intent, then the functional priors of each may not be priors of the others. Similar reasoning holds for temporal priority. If `succeeds with lag`$_t$`(A, B)` and B is substitutable for C with respect to effects, then it may be the case that `succeeds with lag`$_s$`(A,C)`. With respect to the precedence relationship to A, B and C are not substitutable; they are not substitutable with respect to the design. Expansion of High Cross Road succeeds the construction of the interchange at High Cross Road (figure 3.1(a)). Construction of the interchange at High Cross Road is alternative to the construction of interchange at Cottonwood. No precedence relationship exists between the expansion of the High Cross Road and construction of the interchange at Cottonwood.

5.2.3 Composition

Similarly the composition relationship does not distribute over substitutes. Issuing bonds and developing a plan for providing street lighting could be parts of creating the TIF, which intends to beautify a certain city neighbourhood. Usually, issuing bonds can be substituted for other kinds of borrowing, such as borrowing from the Federal government. However, such borrowing cannot be a part of creating a TIF.

However, when the substitutes are equivalent actions, the equivalent of the part action is contained in the equivalent of the whole action. Creating a TIF in a central business district now and creating a TIF in the peripheral business corridor 3 years from now are equivalent actions. As such, issuing bonds three years from now is a part of creation of the TIF three years from now.

5.3 Transitivity of Interdependence

In earlier sections, I have identified the distributive properties of substitutes and interdependent actions. This section deals exclusively with transitivity property of interdependence. For the most part, the transitivity property holds for interdependent actions, so they can be represented as posets . I explore these relationships further in the following paragraphs.

In the figure 5.2 the ring road A is complementary to B. Further, A is complementary to D due both to connectivity relationships and to the intent to reduce the traffic within the Marengo urban area. However, B is not complementary to

D due to the absence of the connectivity relationship. With respect to the intent or the effect of reducing the traffic within the metropolitan area of Marengo, they can still be complementary. Thus, the recognition of complementarity between the pairs (A, B) and (A, D) is not sufficient to recognise the complementarity between (B, D). This leads to a conclusion that complementarity is not transitive.

Expanding Cottonwood road is dependent on the building of the interchange at Cottonwood. Committing Urbana's share of the budget for the building of the Cottonwood interchange along with the IDOT's share and the County's share according to the current budgeting formula is prior to the construction of the interchange. Thus the expansion of the Cottonwood road is dependent on these commitments. A developer who is trying to speculatively develop the area around Cottonwood, would have to be cognisant of these dependencies and invest when such budgetary commitment by all the three actors is evident. Thus functional priority may be transitive.

Temporal priority, being a partial order, can be represented with a directed acyclic graph. The entire chain in the poset could be used to determine the precedence relationships between actions. Thus, on a chain in a poset, actions are well ordered. However, posets also have antichains. As noted earlier, the indeterminacy of precedence relationships between two actions can point to the feasibility of concurrence relationship between them. Acquiring a RoW precedes building the road. When two roads are to be built in different locations, there is no determination of the precedence relationship between acquisition of each RoW and thus no preclusion of their being acquired simultaneously. However, when there is a precedence relationship between the building of these roads, RoW becomes a part of the chain and other precedence relationships can be deduced.

Mereological relationships, on the other hand, are transitive. Especially in the naíve sense we are interested in, these relationships can be represented as another partial order. A is a part of B, which is a part of C, and thus A is a part of C. Exceptions to these rules and more sophisticated analysis of mereological relationships are left for further work.

5.4 Caveats

This chapter discusses the use of already discovered relationships of substitutability and interdependence to discover further relationships. The mode of reasoning is the discovery of semantic relationships over time, which builds on earlier discoveries and other changes in contextual knowledge. No claim is made about the infallibility or completeness of these discovered relationships.

The concept of logical omniscience both in the formal logical system and cognitive reasoning agents is frustratingly obdurate. This chapter makes no such claims. Nor does it imply that such omniscience, even in the limit, would be useful. The arguments made and defended in this chapter are fallible and context sensitive and therefore heuristic. Furthermore, the thesis presumes a cognitively limited, boundedly rational, and learning agent who is interacting with an information system both in making and using plans.

More often than not, the relationships of substitutability and interdependencies between a pair (or a set) of actions can be deduced through criteria described in chapters 3 and 4. The reasonings described in this chapter can be used mainly to either supplement discoveries or use them as potential candidates to be checked against the criteria described in earlier chapters, or evaluated through further investigations. They are not meant to supplant reasoning about semantic relationships by human judgement, or provide sufficient conditions to determine the relationships.

Taken together with this chapter, the previous chapters provide coherent methods of discovering semantic relationships. Even within a plan, some actions are recognised *a priori* as alternatives and interdependent actions. Thus, the ideas discussed in this chapter can be used to discover further such relationships within the plan and then they can be used across plans to discover more.

	Relation (A, B)	Substitutes		Interdependent			
Relation (B, C)		Partial	Complete	Prior	Complements	Contingent	Part of
Substitutes	Partial	Non-Transitive	A is partially substitutable with C if the evaluative criteria are the same				
	Complete	Possible partial substitutes when B & C are equivalent	Alternatives when using effects or attributes	Not determined when using relationships in policies or strategies	Under certain conditions, A is prior to C	Under certain conditions, A & C are complementary	C is contingent on A' when B & C are equivalent [a]
Interdependent	Prior			A is prior to C			
	Contingent		Possibly, A is prior to C		A is contingent on C		
	Part of		C" which is generated from (C\B)∪A could be substitutable to C				A is part of C

Table 5.1: Distributive and Transitive Properties of Semantic Relationships

[a] Equivalent in this context refers to translation in space-time.

Chapter 6

Demonstration

Through database and query prototypes, this chapter demonstrates that the ideas from the preceding three chapters can be implemented in computing tools that would assist a human in reasoning with plans. It provides a concrete implementation of the data model and the reasoning process. This chapter provides a succinct view of how a properly structured data model of information within plans and intelligent queries by the user of the information can get at some of the semantic relationships that are not identified. The task then is to record these semantic relationships in a fashion that is available to others, or future self, to draw more inferences from.

I first describe the pseudo code (`Latin Modern font` in the subsequent sections) that is used to represent the queries and responses from the database. I then elaborate on examples that discover alternatives and interdependent relationships from already existing plans using the ideas elaborated in chapters 3 and 4. Towards the end of the chapter, I also illustrate a mechanism to discover further relationships using heuristic reasoning as described in chapter 5.

6.1 Setup

The demonstrations are based on queries to a set of spatially enabled databases in PostGreSQL as explained in §2.6. Two fairly simple databases, whose schema is described in appendix C are on different computers. They are meant to mimic the real world in which the information within the plans is located in various places and access is selectively granted. These databases are action centric. One contains actions and relationships from McHenry County's 2020 Unified Plan[1], whereas the other database consists of actions and relationships from plans other than the unified plan. So for example, action items from various collections of plans by Metra are all stored in the same database for simplicity. Similarly for the case of Champaign County, one of the databases is about actions from the Urbana Comprehensive Plan and other is about other relevant plans. Furthermore, existing complementarity and substitutability relationships within a plan as present in designs and strategies are also stored in the databases. On the local computer that hosts the query client, the discovered relationships such as temporal priority and complements are stored in a database to simulate persistent storage and use of previously discovered relationships in making further inferences.

The databases concerning McHenry County include101 action items, 50 from the 2020 unified plan and 51 from 10 other plans. The unified plan includes three designs and all the other plans in the databases include another three deisgns. Furthermore, the relationships in designs such as complements and parthood are identified. For the case of the Champaign County, the database consists of the ac-

[1]Though the McHenry 2020 Unified plan has never been adopted by the County, it does not undercut its use in this case as I have defended the position that plans provide information about a particular actors' view of intentions, actions and their relationships with changing circumstances and other future decisions irrespective of their official adoption status.

tion list of two plans (that of Urbana and the MPO), which are described in §6.2.3. The database contents are by no means intended to be complete or randomly selected. A Simple Query Language (SQL) dump of the databases is provided in the CD-ROM attached as appendix C.

As noted in chapter 2, the query client connects to these databases and extracts relevant information based on the search on attributes and the relationships that are stored in the databases. It then uses the rules described in the earlier chapters to eliminate actions from the result set or to do additional queries based on these rules. After it exhausts the relevant rules applicable it returns the result set for the user to make further judgements and store the information about relationships on the local computer so that they can be used in making more queries later on. Essentially, the role of the query client is to build a SQL query string multiple times.

The queries are given first, then the results and the responses from the databases are given under their own headings. In the responses, only the information pertinent to the example is mentioned. Usually, this includes the id of the row as well as the textual information that describes the action (description) and the other attributes of the action, such as the plan it belongs to and the geographic information (if available). A note about the geographic information is in order. Locational attributes need two distinct pieces of information: the co-ordinate system and the collection of co-ordinates that make up the geometry. Spatial Reference IDs (SRID) in this case are the geographic projected co-ordinate systems as standardised in the European Petroleum Survey Group (EPSG) codes.[2] Though the

[2] EPSG is now a defunct organisation and is absorbed in International Association of Oil and Gas Producers' (OGP) Surveying and Positioning Committee. See `http://www.epsg.org/` – Accessed Dec 27, 2008.

database stores the spatial attributes in binary format, they can be output in Well Known Text (WKT) format as specified by the Open GIS Consortium[3] (OGC). This WKT representation is a human readable format of the database storage, presented here as a long string. Hence all the points, lines, polygons, multilines, and geometry collections are so defined. Also, the advantage of the PostGIS is that, since we are not limited by a particular geometry type, different actions in the same table can have different geography attributes (i.e., can be points, lines, multilines, polygons or any arbitrary collection of these). The attributes are mentioned for reference only and are truncated for readability. As and when required, a visualisation of the responses to the queries is in the figures.

6.2 Finding Alternatives

In this section, I illustrate by concrete examples from McHenry County and Urbana how we can use reasoning with plans to discover substitutes. As mentioned in chapter 3 one of the ways to get at substitutability is to see if actions are substitutable with respect to capability (doing one action precludes doing another because there is no capacity to do both) and with respect to location (doing one action at a place may preclude doing something else at the same place). Furthermore, I will illustrate schematically how to use the configurations of actions within plans (such as designs and strategies) to infer whether the actions are substitutable.

[3] OGC defines these in its Simple Feature Access and Coordinate Transformation Service specifications. See `http://www.opengeospatial.org/standards/sfa` & `http://www.opengeospatial.org/standards/ct` – Accessed December 27, 2008.

6.2.1 Capability Restriction

If action items have an attribute of actor or a locational attribute, then a simple attribute matching query flags the sets of items as potential substitutes. For example, checking for various projects in different plans where the responsible actor is Metra results in the following list of actions, which are thus flagged as substitutes. Note that the query results in actions from different databases as described in §6.1.

```
Query: Actor Metra as an attribute of actions that are not
complementary in all plans
```

Response[4]:

```
Id: 1; Description: Extend Metra Milwaukee District West line
from Elgin to Huntley with a corridor continuing to Marengo,
with stations at Huntley and Marengo
Plan: McHenry County 2020 Unified Plan
```

Geographic Attribute: SRID:26916 [5] ;

```
MULTILINESTRING((383327.9122157367
4667812.589445614,382171.70987572847 4669293.422432616,...))

Id: 12; Description: Enhance Metra UP-Northwest Line by adding
expanded coach yard at Johnsburg, improving signaling,
relocating the Crystal Lake Coach Yard to Woodstock, and
improving track materials
Plan: Metra Collection of Plans
```

[4]Although two more results are

[5]SRID 26916 is UTM NAD83, Zone 16N projected co-ordinate system.

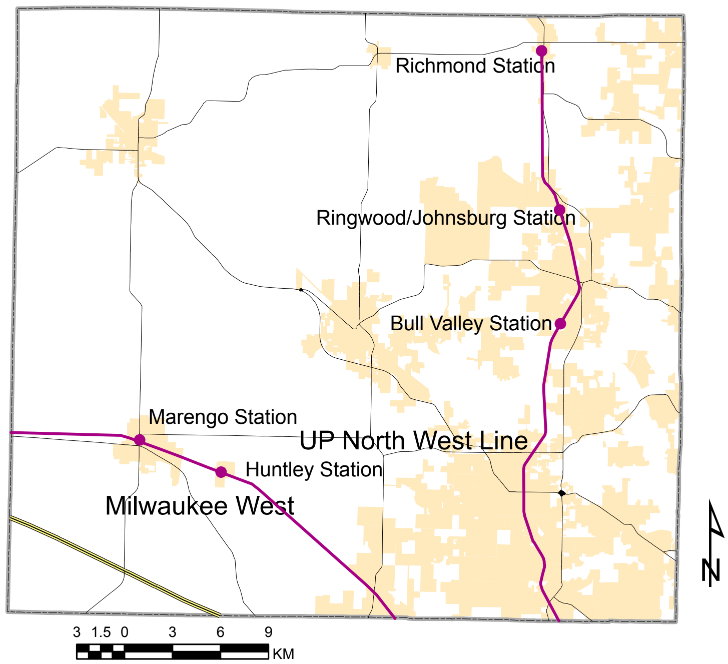


Figure 6.1: Actions by Metra in Various Plans

```
Geographic Attribute:  SRID=26916;
MULTILINESTRING((393580.89151034685
4667662.819333007,392564.53859803395 4669599.05776253,...))
```

In figure 6.1 the enhancements of Union Pacific North West Line are complementary to building the stations at Bull Valley Road, Johnsburg, and Richmond and are identified as complements in the databases *a priori*. Though they have Metra as responsible actor, they are not returned as responses to the query even though their locational attributes intersect and have the same responsible actor. The query client removes them from the result set that is being returned and stations are not tagged as substitutes to the extension of the Metra Milwaukee District West line. The query system recognises the already identified complementary actions and removes them from the responses. Also note that this is an artefact of the sequence of the result set. In other words, if the action

```
Id:26; Description:  Extend Metra Union-Pacific Northwest Line
North Branch to Richmond, with stations at Bull Valley Road,
Ringwood/Johnsburg and Richmond
Plan:  McHenry County 2020 Unified Plan
```

was returned in the result set prior to the action id 12, then action id 26 would have been returned as potential substitute to action id 1. This defect can be corrected by querying for complementary actions to the result set returned and finding out more substitutable actions as described in §6.4. Thus, only the extension of the West line and the enhancements of the Union Pacific Northwest Line are considered by the query program as potential substitutes due to capability restriction of Metra. These projects have different intents and are specified in different plans by different actors (McHenry County and Metra), even though the responsible actor is the same (Metra). However, it is unclear that Metra has the capacity to pursue both. They are left for further investigation by the user to determine if they are indeed alternatives or if Metra does have the capacity and inclination to pursue both projects.

Similar queries on any attribute of the action table can be used to determine if actions are substitutable because they share the same attribute. One important kind of query that is of interest to planners is if actions are substitutable because they are slated to occur on the same location. This is described in the next section.

6.2.2 Location Criterion

The use of the location criterion can help us identify the potential substitutability relationship between actions. A simple geographical intersect query can find all actions whose locational attributes intersect or fall within a particular polygon as shown in the dotted line in the figure 6.2

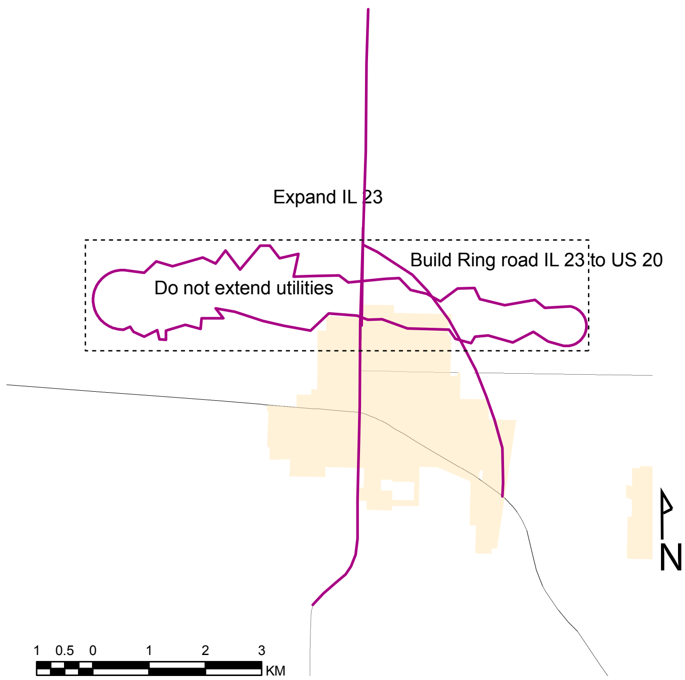


Figure 6.2: Actions by Various Actors at a Location

```
Query:  Actions in all plans that have geographical attribute
that intersects POLYGON((362579.5 4679802,362579.5
4681585.5,...))
```

```
Response:
```

```
Id:  33; Description:  Expand IL 23 to four lanes between south
of Harvard and north of Downtown Marengo, as far south as
Pleasant Grove Road
Plan:  McHenry County 2020 Unified Plan
Geographic Attribute:  SRID=26916; POLYGON((366483.1875 4675197,
...))

Id:  38; Description:  Build a new two lane roadway bypassing
Marengo to the northeast from IL 23 to US 20
McHenry County 2020 Unified Plan
Geographic Attribute:  SRID=26916; POLYGON((367383.84375
4677128,...))

Id:  39; Description:  Do not extend utilities to serve flood
hazard areas
Plan:  City of Marengo Comprehensive Plan
Geographic Attribute:  SRID=26916; POLYGON((362579.5
4679802,362579.5 ...))
```

While Marengo's own comprehensive plan restricts utilities in flood hazard areas (id 39), the County's plan proposes to extend a road (id 33), which runs through it and build a new ring road (id 38).[6] A planner with expert prior knowledge of 'utilities follow roads', is able to conclude from the results of this query that either of the first two actions conflicts with the third. These actions are thus alternatives because the third cannot be carried out if either of the first two is carried out.

[6] The above query reports envelope information of the geographic extents.

6.2.3 Using Configuration of Actions

The above two examples use the attributes of actions to identify potential substitutes. In the next case I use the configuration of actions within a plan to identify the substitutability relationship. As noted in appendix C a strategy in a database is represented as a bipartite acyclic graph with uncertain nodes leading to two possible actions and actions having two uncertain nodes.[7]

In this example, I use the interchange example in the Urbana Comprehensive Plan as first described in § 3.1.1 and figure 3.1(a). The case is stylised in figure 6.3. Urbana's Comprehensive Plan specifies three alternative locations of the interchange for I-74 at I, J and K in the figure. In its Long Range Transportation Plan, the MPO proposes to build a ring road R around the Champaign Urbana area in its LRTP. It intends to use the opportunity of expanding link D, provided by building the interchange at I, so that the ring road includes the expanded D. (see figures 2.2 & 2.3)

Action	**Uncertain Effect1**	**Uncertain Effect2**
Expand on D and A	K is built	
I is built	Expand D, Expand A	
I is not built	J is built	
K is built	Expand F, Build C, Build B	

Uncertain Node	**Possible Action1**	**Possible Action2**
	I is built	I is not built
Expand D, Expand A	K is built	
J is built	Expand E, Build G	Expand E, Expand A, Build B

Table 6.1: Representing a Strategy in a Relational Database

[7] The choice of binary tree is merely a matter of convenience to illustrate the example.

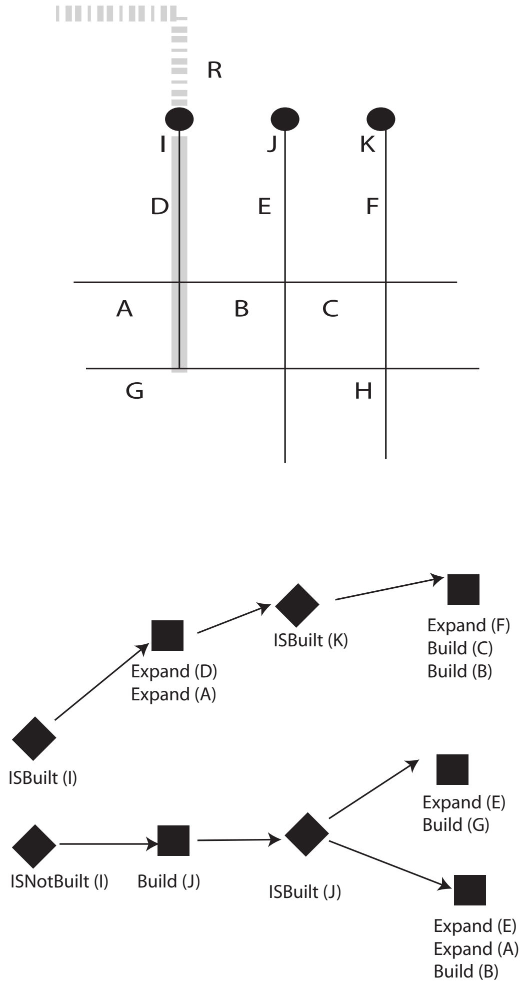


Figure 6.3: Strategy about interchange and expansion of roads

```
Query:  Potential substitutes based on the strategy id 1
Response:
{Build I, Not Build I}
{{Expand A, Build G}, {Expand E, Build B, Expand A}}
```

In table 6.1 the strategy is represented as diagrammed in figure 6.3.[8] The possible actions are linked to action table and the uncertain effects are linked to uncertain

[8]This is not the actual representation of the tables in the database, which have only ids as values to the columns as described in appendix C.

nodes. Since two actions are substitutes if they are contingent upon the same uncertain node from the table, an easy way to get at substitutability is by simply checking for values that have non-null values in both possible action columns of the uncertain node table. A planner from the MPO is using the information in the strategy as described by the City of Urbana in the following way. By querying for substitutable actions based on the strategy the planner finds that {`expand(A)`, `build(G)`}and {`expand(A)`, `expand(E)`, `build(B)`}(collections of actions) follow possible choices of actions to the uncertain node of `build(J)`. These collections of actions are potential substitutes. Based on the heuristic rules described in chapters 3 and 5, since `expand(A)`is part of both the action sets, the subsets {`build(G)`}and {`expand(E)`, `build(B)`} are flagged as being potential partial substitutes by a query. The planner can then query for all actions in all plans that are contingent on the actions described in the strategy and the response gives the planner the following already encoded contingencies.

```
Query: Functional Prior actions in all plans to all actions in
the strategy id 1

Response:
{
Action1: Expand D
Plan: Urbana Comprehensive Plan
Action2: Build R
Plan: MPO LRTP
}
{
Action1: Expand D
```

```
Plan:  Urbana Comprehensive Plan
Action2:  Build I
Plan:  Urbana Comprehensive Plan
}
```

Building R is dependent on expanding D, which is in turn dependent on building I, and so building R is also dependent on I.[9] This transitivity of functional priority is explored in chapter 5. Based on the earlier query about alternatives the user knows that building I is alternative to not building I and she can populate a potential strategy for the MPO of using E as a ring road in the contingency that J gets built. Thus she can further surmise that, R including D and R including E are partial alternatives to each other. Many such relationships can be inferred from this very simple strategy.

6.3 Interdependence Relationships

In this section, I illustrate how interdependence relationships are represented in designs within one plan and how such representations can help us uncover further interdependencies.

Mchenry's 2020 Unified Plan suggests that various projects be implemented to expand IL 47 from I 90 to Woodstock. Even though the interchange between IL 47 and I 90 falls outside the county jurisdiction, the county has a legitimate interest in expanding the access to the city of Woodstock and other neighbouring

[9] As described in the schema, Action1 is considered prior to Action2 since priority is a binary relationship as opposed to a n-ary relationship.

villages from the only Interstate that connects them to the City of Chicago. Various projects are then suggested as part of the overall design, whose intent is to expand access to Woodstock.

In querying for such an intent, the composition of the following actions in a design with an intent to provide access to Woodstock is returned as a design. This design is a part of McHenry County Unified Plan. It is also illustrated in figure 6.4. All these actions have IDOT as their responsible actor, but they are present in McHenry County's plan. The query first returns the design and then, based on the actions that compose the design, returns the attributes of the actions from the action table. Actions within a design are necessarily complementary to each other even when they may have other design relationships. After that, any actions that are complementary to the actions based on the intents and previously recognised complementarities are returned as a response to the query.

```
Query:  Intents related to access to Woodstock in all plans

Response:
Design:
Action1 Id:  34
Action2 Id:  48
Action3 Id:  16
Plan1 Id:  1
Intent:  Expand access to Woodstock from I 90;

Actions that compose the design:

Id:  16; Description:  Expand IL 47 to four lanes between I-90
and IL 176;
```

```
Plan: McHenry County 2020 Unified Plan;
Geographic Attribute: MULTILINESTRING((381662.651827734
4667801. ...
Id: 34; Description: Expand IL 47 to four lanes between IL 176
and US 14 on the southern edge of Woodstock;
Plan: McHenry County 2020 Unified Plan;
Geographic Attribute: MULTILINESTRING((381846.094192691
4683548.27260841,381839....))

Id: 48; Description: Expand IL 176 to four lanes between US 14
and Dean Street, and between IL 31 and US 12, build four way
intersection at IL 176 and IL 47;
Plan: McHenry County 2020 Unified Plan;
Geographic Attribute: POINT(382675.13724609 4677973.63427922)

Complementary actions:

Id: 46; Description: Build a full-directional interchange at
IL 47 and I-90;
Plan: McHenry County 2020 Unified Plan;
Geographic Attribute: MULTILINESTRING((381598.651099117
4664509.18150359,...)) Intent: Expand access to Woodstock from
I 90;
```

A user can further deduce that a new action 'expansion of IL 47' comprises two actions, which are complementary because they expand IL 47 in links that are connected (ids 16 & 34) and can encode them as a separate design. With respect to the intent of expanding the access to Woodstock, taking one action or the other

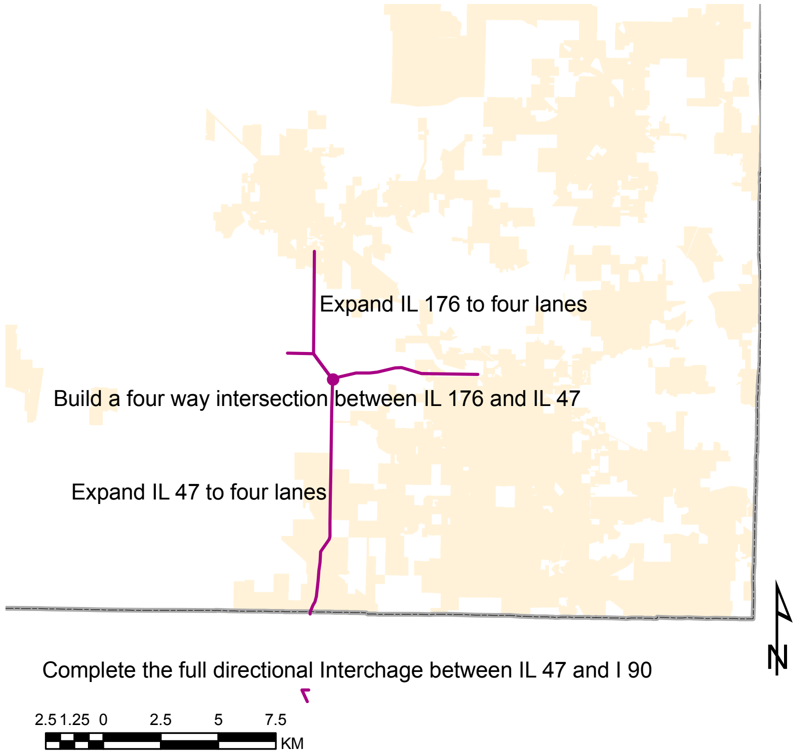


Figure 6.4: Design Relationships between Actions regarding IL 47

is not sufficient. Furthermore, expansion of IL 176 (id 34) is necessary to provide access to Crystal Lake, which is towards the East of IL 47. Also, the county's plan specifies that a full directional interchange (id 46) be built between IL 47 and I 90, even when it lies outside the county's jurisdictional boundary and is not part of the design to expand access to Woodstock. Nevertheless, the full directional interchange is important to the expansion of IL 47 and IL 176, which fall within the county's authority to expand. Note that since these two actions share the same intents they can come up as potential substitutes in a naive query on intent to expand access to Woodstock. However, since complementarity is explicitly identified, they are not identified as substitutes because, as argued earlier, complements and substitutes are mutually exclusive. The county specifies the interchange in its plan so that it can persuade IDOT to undertake the expansion of the interchange, probably in conjunction with the neighbouring Kane County.[10] Nevertheless, as noted, all these relationships are specified within a single plan of McHenry County.

Now that the user has information about the complementary actions from a particular actor, she can check for geographic overlap between the location of the IL 47 expansion project and others to find that various other actors have actions in their plans that overlap with the IL 47 expansion. They are noted in figure 6.5

```
Query:  Geographic overlap with IL 47 project
Response:
Id:  18; Description:  Extend Ackman Road from Haligus Road to
IL Route 47 with intersection improvements;
Plan:  McHenry County 2004-2008 Highway Improvement Program;
Responsible Actor:  McHenry County
Geographic Attribute:  MULTILINESTRING((383662.981075311
4673435.68281845, ...))

Id:  20; Description:  Expand Algonquin Road to five lanes west
of Randall Road to IL Route 47;
Plan:  McHenry County 2004-2008 Highway Improvement Program;
Responsible Actor:  McHenry County
Geographic Attribute:  MULTILINESTRING((382091.550786849
4670245.2472585, ...))
```

[10]A subtlety, not directly pertinent to this illustration, has to be noted for the purposes of planning. I 90, being a tollway, needs the construction of toll booths for interchanges. While I 90 as of today is an open access tollway, building three full interchanges at IL 47, US 20 and IL 23 as intended by various plans (IDOT, Kane County, and McHenry County) within a distance of 15 KM has implications for toll collection and equity considerations.

```
Id:  33; Description:  Require a 100-foot wide landscaped buffer
along IL 47;
Plan:  Village of Huntley Comprehensive Plan;
Responsible Actor:  Huntley
Geographic Attribute:  MULTIPOLYGON(((382467.759585828
4671058.3233238, ...)))

Id:  34; Description:  Adopt the 100-foot building setback along
Route 47 established by the Villages of Huntley and Lakewood;
Plan:  Lake In the Hills Comprehensive Plan;
Responsible Actor:  Lake in the Hills
Geographic Attribute:  MULTIPOLYGON(((382463.300351794
4671056.23116261, ...)))

Id:  40; Description:  Adopt a historic downtown zoning
classification and more careful land use and design review
process for redeveloped sites in this area;
Plan:  Village of Huntley Comprehensive Plan;
Responsible Actor:  Huntley
Geographic Attribute:  MULTIPOLYGON(((381660.48897198
4670079.25413187, ...)))
```

The villages of Huntley and Lake of the Hills require a 100' buffer along the highway and the Village of Huntley intends to adopt a historic preservation ordinance in its downtown, which is intersected by the expanded IL 47. These actions are related to the expansion of the highway if the user has prior knowledge that expansion of a highway usually causes a particular pattern of development along

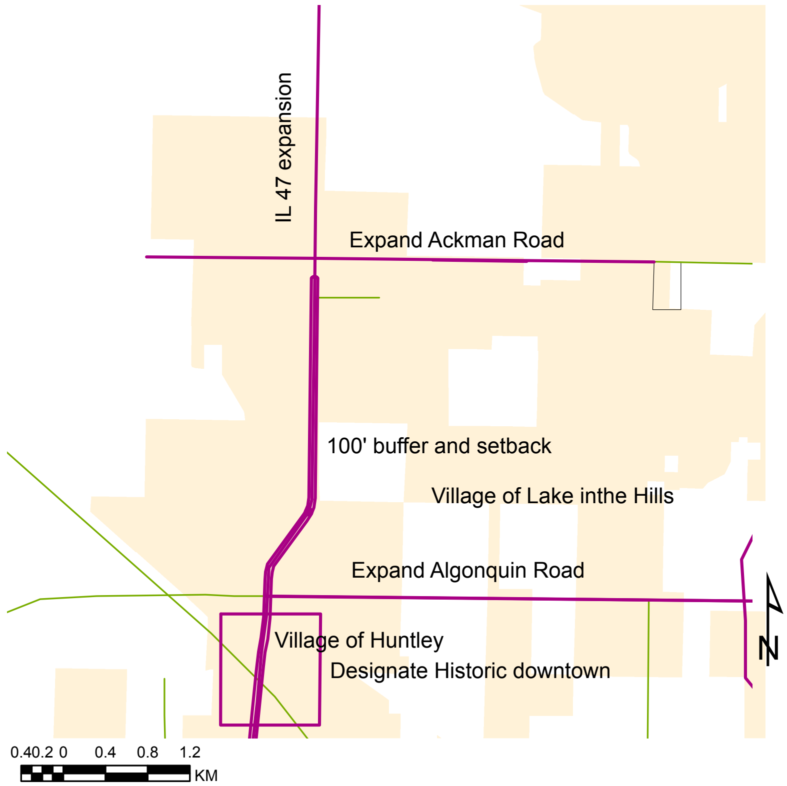


Figure 6.5: Actions in Other Plans related to IL 47

it. In fact, the buffer and the downtown historic preservation ordinance could act as offsetting actions (negative complementarity) to the expansion of the highway, and user has to make such deductions based on the results of the query and other institutional knowledge. Furthermore, the Transportation Improvement Program (TIP) of the county also specifies expansion projects (Ackman and Algonquin Roads) that intersect IL 47. While IDOT is responsible for the IL 47 expansion project, the County and village of Lake in the Hills are responsible for the expansion of these roads. They have to co-ordinate their actions to bring about the enhanced effect of taking both actions. Hence interdependence of these two actions of different actors is identified by the user based on the results from a location query.

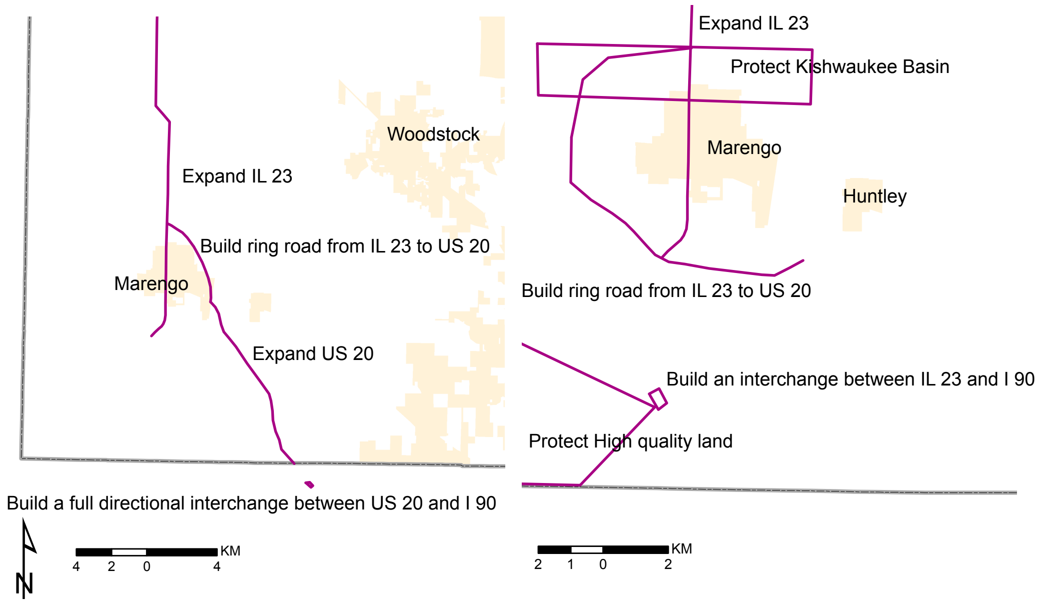


Figure 6.6: Heuristic Reasoning with Interdependence and Substitutability

6.4 Discovering More Relationships

In this section, I will briefly illustrate, using examples from earlier chapters and sections, how we can heuristically reason further relationships from already discovered relationships.

In preceding chapters, I have identified that the interchange between US 20 and I 90 and that between IL 23 and I 90 are substitutable because of considerations of distance, capability of IDOT, the responsible actor, etc. We have also discovered that connectivity relationships between the interchange of US 20 and I 90, US 20 and IL 23, and the ring road that connects the latter on the east of Marengo make them complementary actions and therefore interdependent. Furthermore, the ring road west of Marengo, expansion of IL 23 and the interchange between IL 23 and I 90 are also interdependent (see figure 6.6). The interchange at IL 23 and I 90 also adversely impacts the soil conservation group's plans of protecting

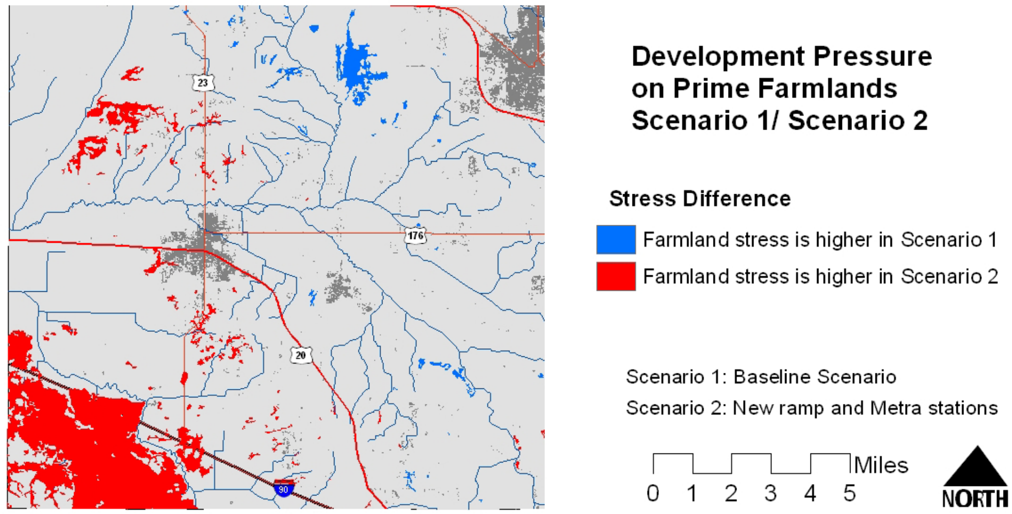


Figure 6.7: Effect on Farmland in a LEAM Simulation

the high quality farm land south west of the interchange (figure 6.7)[11]. Thus, the soil conservation group would view the interchange between US 20 and I 90 as a potential complementary action to its own designs of protecting the farmland from development.

The following is known from different kinds of queries to the databases as described in earlier chapters and sections. These are also shown in figure 6.6. These discovered relationships are stored in a database to allow for further inferences. For the city of Marengo, building a ring road on the east of Marengo from US 20 to IL 23 and expanding US 20 is an alternative design to building ring road west of Marengo from US 20 to IL 23. If the city has not deduced this already from other sources, it can deduce this from the interdependence relationships between these expansions and interchanges and the substitutability relationships between the interchanges as shown below.

[11]This graphic was produced by Dongjun Kim using the data generated during the course of McHenry County project at LEAM

In the following representation the user finds the alternatives about the interchange as a set discovered using queries based on intents and capabilities.

```
Query: For all plans find actions with Actor 'IDOT' and Intent
'Access to I-90'

Response: Alternatives
{
Id: 47; Description: Build a full directional interchange at
US 20 and I-90;
Plan: Kane County TIP;
Intent: Access to I-90
Geographic Attribute: MULTILINESTRING((375248.038701926
4666857.51932545,...))

Id: 50; Description: Build a full directional interchange at
IL 23 and I-90;
Plan: McHenry County 2020 Unified Plan;
Intent: Access to I-90
Geographic Attribute: MULTILINESTRING((366099.862303183
4671006.58163019,366403.45222792 ...))
}

Query: Complementary Actions to action Id 47

Response: Complements
{
```

Id: 39; Description: Expand US 20 to four lanes between the eastern edge of Marengo to the Kane County border, ensure compliance with IDOTs SRA design standards;
Plan: McHenry County 2020 Unified Plan;
Intent: Improve capacity on US 20;
Geographic Attribute: MULTILINESTRING((369845.586957555 4677133.96248372, 370126.723946259 ...))

Id: 38; Description: Build a new two lane roadway bypassing Marengo to the northeast from IL 23 to US 20;
Plan: McHenry County 2020 Unified Plan;
Intent: Reduce traffic on IL 23 within Marengo;
Geographic Attribute: MULTILINESTRING((367383.844720509 4681600.26495372, 367630.629979408 ...))

Id: 33; Description: Expand IL 23 to four lanes between south of Harvard and north of Downtown Marengo, as far south as Pleasant Grove Road;
Plan: McHenry County 2020 Unified Plan;
Intent: Improve access to Harvard from I-90;
Geographic Attribute: MULTILINESTRING((367268.465400159 4695269.58404303, 367177.37555276...))
}

Query: Complementary Actions to action Id 50
Response: Complements
{

```
Id:  33; Description:  Expand IL 23 to four lanes between south
of Harvard and north of Downtown Marengo, as far south as
Pleasant Grove Road;
Plan:  McHenry County 2020 Unified Plan;
Intent:  Improve access to Harvard from I-90;
Geographic Attribute:  MULTILINESTRING((367268.465400159
4695269.58404303, 367177.37555276...))

Id:  46; Description:  Build a ring road on North west of
Marengo from IL 23 to US 20;
Plan:  Marengo Comprehensive Plan;
Intent:  Reduce traffic on IL 23 within Marengo;
Geographic Attribute:  MULTILINESTRING((363704.875119147
4678906.66611613, 364055.690143287 ...))
}
```

Since expansion of IL 23 (action id 33) is complementary to either interchange and since interchanges, themselves are alternatives, the user can investigate the nature of substitutability between the action items of sets {39,38} and {46}. Since building of the ring roads 38, and 46 have the same intent of diverting traffic from the city of Marengo, they can be potential substitutes.

Once the user has access to this information, she can reason as follows. The acquisition of the parcels along the Kishwaukee River by the McHenry Conservation district is offsetting the potential growth along the IL 23 corridor that falls within the Kishwaukee basin. Irrespective of which interchange gets built, the parcels along the IL 23 corridor will be provided with a higher access to a transportation network. Hence, the conservation district would prefer to speed up the acquisition if either interchange is to be built. However, if the user also identifies that an interchange at IL 47 and I 90 (not shown in the figure 6.6; Refer to figure 6.4) is an alternative to either of these two interchanges, then since Kishwaukee basin is not affected by the building of that interchange, the conservation district may want to view it as a complementary action to its own conservation efforts. From this reasoning, the conservation district might decide to advocate for the interchange at IL 47 because this interchange would not have a direct effect and would reduce the likelihood of the other interchanges being built because they are substitutes from the perspective of IDOT.

6.5 Conclusions

This chapter illustrates the kinds of queries and the databases that are needed to support the queries to discover semantic relationships between actions among various plans of various actors. The illustrations here are only tip of the iceberg of the kinds of relationships described in earlier chapters and are here only to demonstrate the feasibility of building such an information system as well as a reasoning mode. These instances demonstrate that plans contain useful information to reason with, not just statements of fact that can only be found in "a cellar in the bottom of a locked filing cabinet, stuck in a disused lavatory with a sign on the door saying Beware of the Leopard." [12]

Furthermore, these cases also demonstrate that relationships already discovered and recorded in plans (configurations of actions, alternatives , etc.) are useful in

[12] I could not resist this quote about plans from Douglas Adams' Hitchhiker's Guide to the Galaxy.

determining further relationships that are not immediately evident. The nature of reasoning about inherently uncertain futures with inherently uncertain values about how actions are related makes it impossible to be logically omniscient. It is useful to reason piece-meal as and when a particular decision about an action is made in light of available information in plans about its relationships with other actions that have been taken, that will be taken, and that others are likely to take.

Chapter 7

Conclusion

The contributions of the thesis to the field of planning inquiry are particular and several. It demonstrated the effectiveness of thinking of plans as useful information in decision making. It built upon the previous work in Hopkins, Kaza, and Pallathucheril (2005b) and focused on the relationships between actions as a key to understanding and uncovering more relationships. In this process it demonstrated that multiple plans adequately structured can be used to discover more relationships that are ripe to be considered in a future planning and decision making exercise. By focussing on use cases to demonstrate the feasibility and applicability of the approaches, it built upon multiple disciplines and methodological approaches to understand and represent actions, situations and relationships among them. The dissertation then demonstrated the use of already discovered semantic relationships to discover more relationships thereby enriching the decision making process. In this process, it argued for a systematic way of writing plans so that they can be useful as opposed to mere reports that gather dust. Toy databases based on real situation demonstrated that some of these relationships can be encoded and queried to assist planners in reasoning with plans. These accomplishments are detailed in §7.1.

This is but one of the first steps to describe the content and structure of information within plans and methods of using such information. Various obstacles lie in front of us that will need to be overcome before a system including computing databases and human reasoning skills can be operationalised. I briefly describe these obstacles in §7.2.

7.1 Accomplishments

This dissertation demonstrated the complexity of the semantic relationships between actions. Specifically, it focussed on the broad categories of substitutability and interdependence of actions. These relationships are useful because they affect one's own choice of actions and one should consider the consequences of one's own actions against the tapestry of inter-related actions of others and how they may or may not fit. Wherever appropriate, I distinguished between two different functions of a plan—a tool to organise information about my own intentions and actions that follow for myself, which is a contrivance to inform others of my intentions and proposed actions, versus a rhetorical device to convince others about their intentions, actions and the relationships between them. These distinctions are important in discerning the relationships of actions that occur in multiple plans. When I make a plan to have breakfast, it is to figure out how to get to a nearby coffee shop. When I inform others of my plan, it is to make sure that my plans influence their choices of actions, so that they can co-ordinate their actions with my intentions and actions. When I suggest a plan to have a breakfast with others, it is to shape their intentions and actions as well as my own based on their own plans.

Two general semantic relationships between actions are the focus of this dissertation: Substitutability and Interdependence. A set of actions are substitutable with each other if they produce (or are purported to produce) the same effect or choosing one precludes choosing the other. Fundamentally, all decisions are about choices between substitutable actions. It is then important to identify the choice set of any decision situation. Interdependent actions are important to identify because choice of an action affects future choices that are interdependent on it and past choices over which it depends. Fundamentally, planning is about figuring out these interrelationships so that we are not myopic. Thinking carefully before we act (without being paralysed by thinking) is in essence the act of planning.

To this end, I followed earlier work on distinctions between intents, plans, decisions, and actions. While not taking for granted any linear temporal ordering between these intents, plans and decisions, I posited that plans are about actions arranged in particular configurations to make sure that inter-related decisions get considered even when deciding to act on one decision. When multiple plans are available as information, then the inter-relationships identified are much more rich and varied because other actors are identifying these relationships. So we need to augment the relationships identified in our own plans with information from other plans to make more informed decisions. Two artefacts are available to make these kinds of reasoning. One is the inherent attributes of the actions themselves and other is the relationships that are already identified between actions.

Actions within plans have attributes such as time, location and responsible actor that can be used to identify relationships between them. Furthermore, intents and effects are recorded either in the databases or linkages to external models to determine if two actions are related. We can tease out how they are related (whether they are substitutable or interdependent) based on the attributes of actions. For example, if two actions occur at the same time at the same place then they are likely to be substitutes. If two actions share the same intent or cause the same effect, they are likely to be substitutes. If two actions have temporal attributes then they can be ordered on a temporal scale. Many such relationships can be posited for further investigation. Note that I do not claim that substitutability or interrelationships are guaranteed by the overlap of these attributes.

Furthermore, configurations of actions within one plan can also be used to identify the substitutability and interdependence relationships between actions listed among plans. The dissertation posited that some of these relationships are already identified and noted in individual plans. These configurations of actions that are of interest are agenda, policy, design and strategy. These configurations can be considered higher order actions and thus can be related in the same ways as described in the previous paragraph through their attributes. However the actions that compose these configurations could also be related. When two policies are substitutable because of the effects they generate, then the consequent actions are substitutes if the antecedent conditions are the same in the two policies. Designs specify the interdependent relationships such as temporal and functional priority, complementarity and parthood relationships. Strategies provide clues towards both contingency relationships as well as substitutable paths of actions. Transitive and distributive properties of these relationships are also examined and heuristics are given. Thus, this dissertation gave an account of configurations of actions available within a plan to identify semantic relationships within a single plan. It then demonstrated in a sufficiently general way that these relationships within a plan can be used to identify relationships between actions across plans.

In particular, I argued that an information system that supports planning should account for these multiple plans, relationships across plans, learning, and discovery over time. I demonstrated in a heuristic sense with toy databases and particular queries how this might be accomplished in a real application. The databases, being relational in nature, are not particularly amenable to represent complex datatypes and relationships that are necessary for planning. Temporal relationships are not fully supported in the standard database packages, but nevertheless do not hinder conceptual reasoning with temporal attributes. The emphasis of the dissertation is on plans and not on constructing efficient infrastructure for information systems. Much of the work described in the dissertation should be viewed as a method to interpret and use plans whether or not this process is computer supported.

7.2 Remaining Obstacles to Overcome

The main issues that remain to be addressed before an information system to reason with multiple plans can be implemented are categorised into Organisational, Conceptual, and Technical issues. I believe the urgency of addressing the issues follows this order. Each of these is related to the others in ways described below.

7.2.1 Organisational

The intent of the dissertation is not to provide an organisational account of information sharing and using. However, plans are products of organisational [1] cogni-

[1] A person is a unitary organisation.

tive activity and thus, we have to account for organisational and inter-organisational culture in sharing, and using these plans in decision making.

Information sharing

The dissertation assumes that some plans of organisations would be public. This assumption is widely supported by empirical observations in urban settings. However, some plans of organisations are also necessarily secret, as described in Kaza and Hopkins (2006). The willingness to share the information in a plan, let alone in a structured way, is dependent not only on the strategic nature of the purpose of information, but also on the charge and culture of the organisation involved.

The structure described in this dissertation is for accessible plans. In other words, no consideration is given to the degree of accessibility, to whom the plans are accessible and control of such. One can only look at other information systems such as spatial data infrastructure and management information systems to acknowledge the trials of getting organisations to share and use information. However, none of the concepts described in the dissertation is invalidated by the strategic behaviour of information sharing among organisations. One of the key components that needs to be addressed in future work is the question of granting privileges to particular information to particular kinds of actors.

Accuracy and Timeliness

Even when such information is accessible, the timeliness of the information within the plans is always questionable. Plans do not record actions that are already taken. They portend possible action, and thus, there is inherent uncertainty about whether the actions will be taken or not. Plans are continually changing due to changes in circumstances, planning processes that never stop, and modifications to account for interdependencies discovered after a plan is authored. The proposed data structure does account for these changes by encoding plans not as monolithic documents but as a web of relationships that can be woven and rewoven as and when it becomes necessary.

However, the particular organisation whose plan it is always has a strategic advantage as to whether the relationships specified in the plan still hold. It may or may not be in the organisation's interest to make this information widely available. Nevertheless, the dissertation sidesteps the question of whether organisations have incentives to maintain the timeliness of the information over which they have control. Furthermore, it does not address the question of how one should account for the relevance of information. Is a plan made a few months ago more relevant and more accurate information about current intentions than a plan made a few years ago?

7.2.2 Conceptual

Many conceptual questions about plans, intentions, and actions are left unresolved or not considered in this dissertation. A few of them are briefly discussed below.

Interpretation of Plans

While plans may be made public by the author or the owner of the plan, one can also observe others' actions and infer their plans. In such cases, I can identify particular relationships among decisions, actions, and intentions of others and interpret them. Such interpretations depend on the cognitive capacity and organisational ability of the interpreter.

Structurally such interpretations and inferences of plans are no different from the plans that are made public. Nevertheless, added uncertainty about interpretation to represent 'true'[2] intentions, should figure into the need to qualify the discovered relationships of substitutability and interdependence based on these interpretations as opposed to owner published and maintained plans. Irrespective of whether the plan-owner makes the relationships explicit or one infers these relationships (substitutes, interdependence etc.) between actions through interpretations, the relationships are still useful in deciding what one should do and how these decisions are affected by the actions, or possible decisions of others.

Changes in Assets

Subdivision of land creates new parcels. Annexation by the city changes the boundary of the city while giving some rights to the owner of the parcel about services. Reconfiguration of lots by merging two lots changes title information. Annexation or subdivision of the lots may require, by regulation, the necessity to provide

[2] It is unclear true intentions are useful anyway because, intentions, actions, and plans could be obfuscated, or are likely to change without reasonable notice.

for utility easements, which changes the surface and sub surface rights characteristics.

This dissertation though it identifies the need to account for changes in assets over time, brackets this topic for future work. GIS and philosophy of identity have long been interested in changes over time. Since actions in plans are fundamentally about changes to assets and changes to rights, a clear account is needed of how these changes, when made, affect plans. This segues to the next topic on changes in plans.

Changes in Plans

In Kaza et al. (2007), we have begun to address the question of changes to plans that happen over time. These changes can be tracked by observing which decisions get taken and which actions are carried out. The historicity of plans and decisions provides a useful way to keep track of the efficacy of plans in informing decisions and decisions in updating plans. Currency of plans should be ensured so that they can be used effectively in urban decision making.

By observing the decisions that are made and their situatedness in plans, we archive some portions of the plan material as irrelevant to future decision making. This allows us to explore further relationships between decisions and their outcomes, which may not have been envisaged in the previous versions of the plans. There are also situations in which a subsequent plan completely overrides a previous plan due to fundamental changes in the perceived importance of the relationships and other values, which are inherently political. These need to be accounted for if heuristic reasoning is to work effectively.

7.2.3 Technical

The other category that needs to be addressed, about which a lot of research is being done elsewhere, is primarily technical in nature. Representations of Geography (e.g. Galton 2001), distributed information (e.g. Decker et al. 1999; Heflin 2001), descriptive frameworks (e.g. Singh 2004), representation of time, and multiplicity of such representations, translations among them (e.g. Worboys 2005; Frank 1998; Gerevini 1997; Peuquet 1994) are all part of an ongoing effort to make sense of information quickly and effectively. In particular, since plans have traditionally relied on natural language to express ideas, a structured method of identifying relationships among plans is a novel one and would be controversial as early development in GIS and its attendant critique shows.

The choice of relational databases to demonstrate the feasibility of the ideas set forth in this dissertation is pragmatic one. The databases to represent spatial information are fairly well developed and are sufficient for most purposes. However, the inherent structural nature of the relational databases forces complicated representations of even simple relationships such as temporal attributes and trees. Object oriented databases are more amenable in this regard.

The construction databases required significant interpretation effort on my part from the reading of the plans as published and thus, may be disputed by the authors and owners of the plans. Nevertheless, such interpretation is not going to disappear from planning and plans. Ways should be explored to represent multiple interpretations of the same actions and plans and make them available.

7.3 Finis

Plans are made to be used. Their uses are numerous and are not limited to the specific reasons described in this dissertation. However, in reasoning about intentions and possible actions, plans provide useful insights. It is to this end the dissertation provides useful contributions. What possible actions of others' and other intended actions of my own are related to an action I am considering is a question pertinent to making and using plans.

Without any presumption of an all unifying tool or a data model that will account for all relationships, we should strive not only to develop suites of tools that will be helpful, but also to develop the temperament of planners and the public in using these tools so that plans can be made more efficiently and used more effectively.

Appendix A

The Four As

This appendix is taken almost verbatim from Hopkins, Kaza, and Pallathucheril (2005b) and included here for easy reference because the dissertation work builds directly on this conceptual data model.

The state of the world consists of entities that can be categorised into Actors, Actions, Activities and Assets. There are relationships between these entities such as ownership, responsibility, capacity etc. Actors are beings that have capability to take a decision, act upon it and have particular interest in the state of the world. Assets are either artificial or natural entities that are fundamental to realisation of utility. Activities are behaviours of actors that occur on these assets. Actions, to take a linguistic analogy are "verbs", that deal with either changes or decisions to change of actors and activities. There are other entities that are identified later on such as roles, capabilities etc. But these entities are defined only in conjunction with those described above. The elaborations of the characteristics of these entities are described below.

Figure A.1 represents actors as persons, organisations, or populations of persons or organisations. A group of persons organised in roles, responsibilities, and decision rules is an organisation. So, for examples, households, firms (in the economic sense), neighbourhood groups, government agencies and city councils are organisations. Populations are collections of actors without organisational struc-

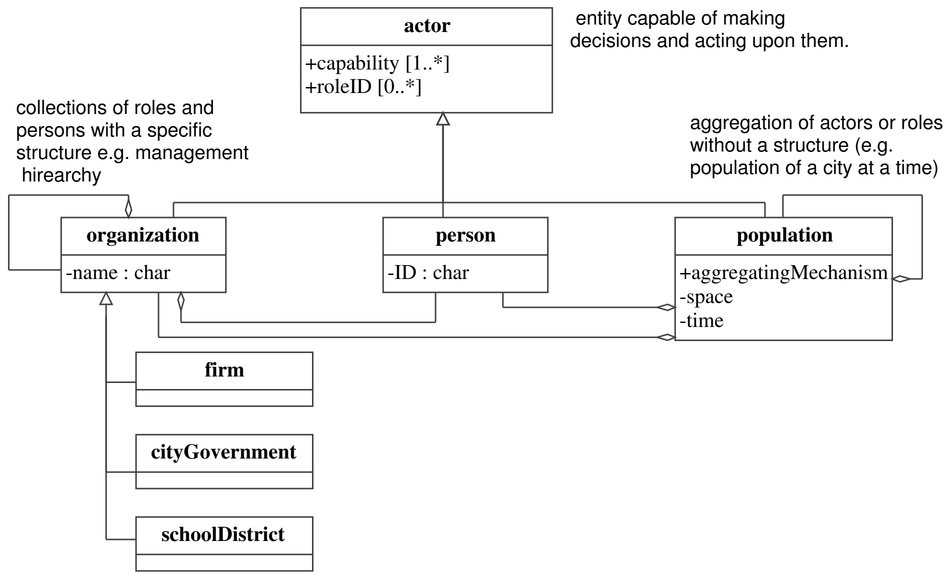


Figure A.1: Actor Class Diagram –Hopkins, Kaza, and Pallathucheril (2005b)

ture, such as the population of persons in a census tract or the population of firms in a municipality. Actors have Roles and many of the capabilities of Actors are associated with Roles rather than directly with Actors. For example, the Authority of a mayor goes with the Role, not the Person. Also Roles can exist without an Actor associated with them, so that the authority of a Mayor is defined regardless of the Person holding the office, but the influence a particular mayor may have depends both on the Role and the Person. Similarly an Actor can have multiple roles whose combination will determine the set of capabilities the actor possesses.

Activities occur on Assets and are performed by Actors. They are aggregates of behaviour occurring on assets performed typically by a populations of actors. Traffic flow on a street network (commuting), shopping by a Person, and retail services in a building are activities. Activities are different from actions in that Activities describe aggregates of behaviours that are not fundamental changes to the system of Assets and Capabilities and for which Decisions to Act are not explicit. Activities are also constrained by capabilities of actors but it might not always be possible to identify a one to one relationship between Activities and Actors. Activities may be considered loosely coupled with the notion of Actors. An Activity may have effects on Assets, notably depreciation. Activities are also subject to capacity constraints and congestion relative to Assets

Assets can be Facilities, Equipment, Consumables or Intangible. See figure A.2. Facilities are Physical objects such as building Structures or Networks, such as streets. They can also be Virtual Networks such as microwave networks or Designated Areas such as land zoned for development or protected habitats. Assets are related to other assets. For example, equipment may be assigned to a particular facility. Land or water in a river could be defined as an asset from which resources are used. Buildings could be located on a site or a dam on a river at a location at a time or for a period of time. Actors in their roles can own, lease, hold government jurisdiction over, have maintenance responsibility for, or have other use rights in Assets. Assets may or may not have a location attached to them.

Actions, not to be confused with Activities, change Assets themselves or their relationships to Activities or Actors. Actions are central to the planning domain and include decisions and realized actions. Decisions are commitments to actions that have not yet been realized (figure A.3). Thus a decision by a city council to invest in a road project is distinct from the realization of that project on the ground. Decisions and realized actions include regulations, investments and transactions. Actions can also change capabilities of Actors and include changing rights and responsibilities. It is useful to distinguish between realized actions and decisions as commitment to actions, because responses to actions by other actors may be based on decisions or expected actions before an action is realized. Actions have

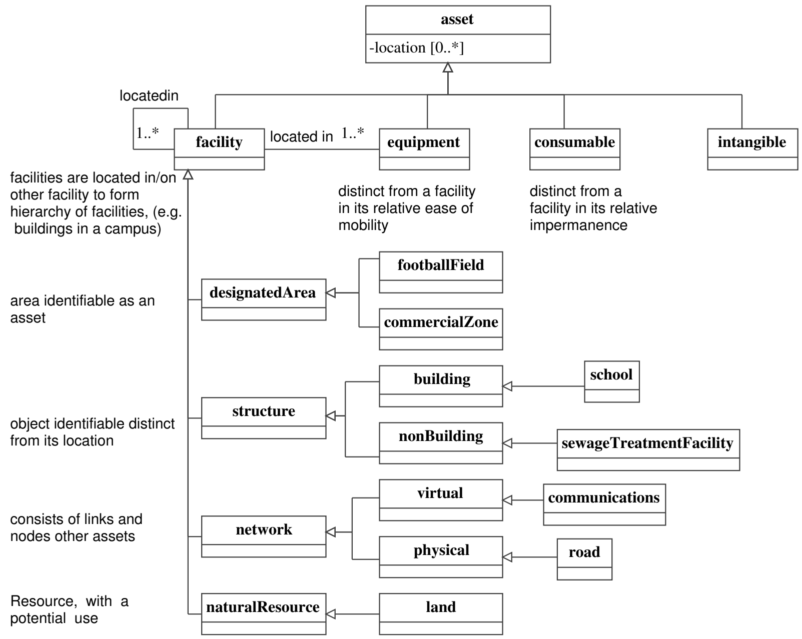


Figure A.2: Asset Class Diagram
–Hopkins, Kaza, and Pallathucheril (2005b)

consequences either realized or expected, which are generally distributed over space as well as time. The consequences themselves are represented as states of the world.

Actions are a class of events, *occurrents* to use the typology of Worboys and Hornsby (2004). A difference between actions and events that is crucial for urban planning purposes is that actions are intentional events. They are precipitated by an intentional system (actor) deliberately. To distinguish, a flood is an event, whereas flood relief effort is an action or a collection of actions. For urban planning purposes, we are concerned with both actions and events. Plans, however, are necessarily relationships between actions that are contingent, interdependent, complementary or substitutable. For example, a design is either a temporally contingent system of actions (a construction plan), or a functionally interdependent system (a building with circulation spine and functional space) that can exhibit spatial or topological characteristics, or a collection of mixed spatio-temporal relationships (trip management on a rapid transit system).

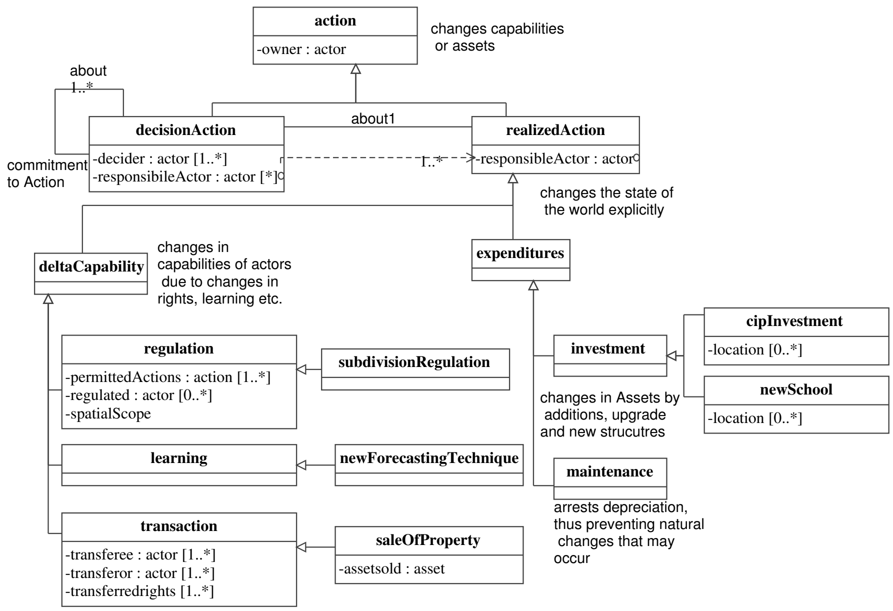


Figure A.3: Action Class Diagram –Hopkins, Kaza, and Pallathucheril (2005b)

Actions change either Activities or Assets. Actions change activities due to change in Capabilities of Actors. That is to say, an Action may result in change in preferences of a set of Actors, which will then result in change in an aggregate behaviour occurring on an Asset. Imposition of a Toll tax on a bridge might change the volume of traffic on the link of the Network. Actions also are directly related to change in Assets as in the case of investments. An enactment of a regulation, its enforcement, both are actions about a particular state of the world. Actions are taken by Actors who have the Capability to take them, which includes Authority. The authority itself is defined through regulations, mandates, and norms. It should, however, be noted that just because the capability to take the Action exists, the Action itself need not be taken. Therefore, Capabilities are defined only in conjunction with the Action, as it will not be useful to describe exhaustively all the possible Actions that can be taken under a Capability of a particular role.

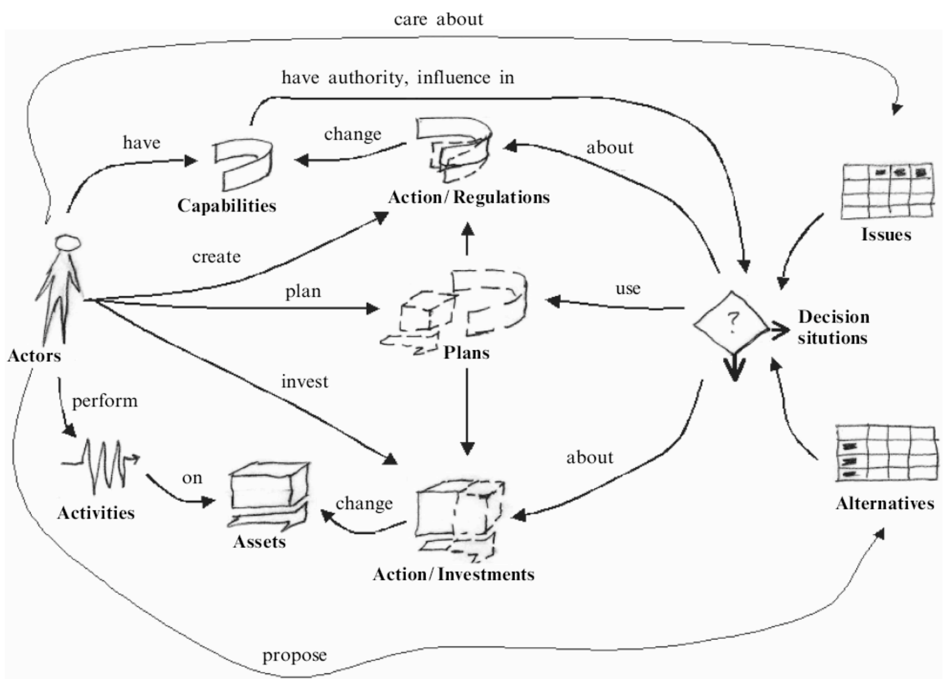


Figure A.4: State of the World –Hopkins, Kaza, and Pallathucheril (2005b)

Entities and relationships are used to describe the state of the world. Changes in entities occur through other entities such as actions. Changes in relationships are typically defined through regulations or norms. Actors perform activities on assets. They have capabilities to take actions and such actions can either in the form of investment change assets or through Regulation. Thus the relationship is cyclical however not portrayed adequately in figure A.4. Assets include buildings, networks (such as streets), and designated areas such as land zoned industrial. Investments change the state of assets, creating, destroying, expanding, or contracting them. Actors ”do” activities such as residing, producing, and recreating in or on assets. Activities are one way of defining land uses to be allocated in space.

Actors have Capabilities, including Preferences, Authorities or Rights, Skills, Financial capacity, and Behavioural Norms. Learning, Regulation, and Transactions change capabilities of actors. Plans are primarily about Investments (changing assets) and changing Capabilities. Actors make plans, perceive particular issues, make proposals for action, and have authority and influence in decision situations. Decision situations use plans, confront issues and weigh alternatives, and may result in decisions for action.

Appendix B

Base Maps

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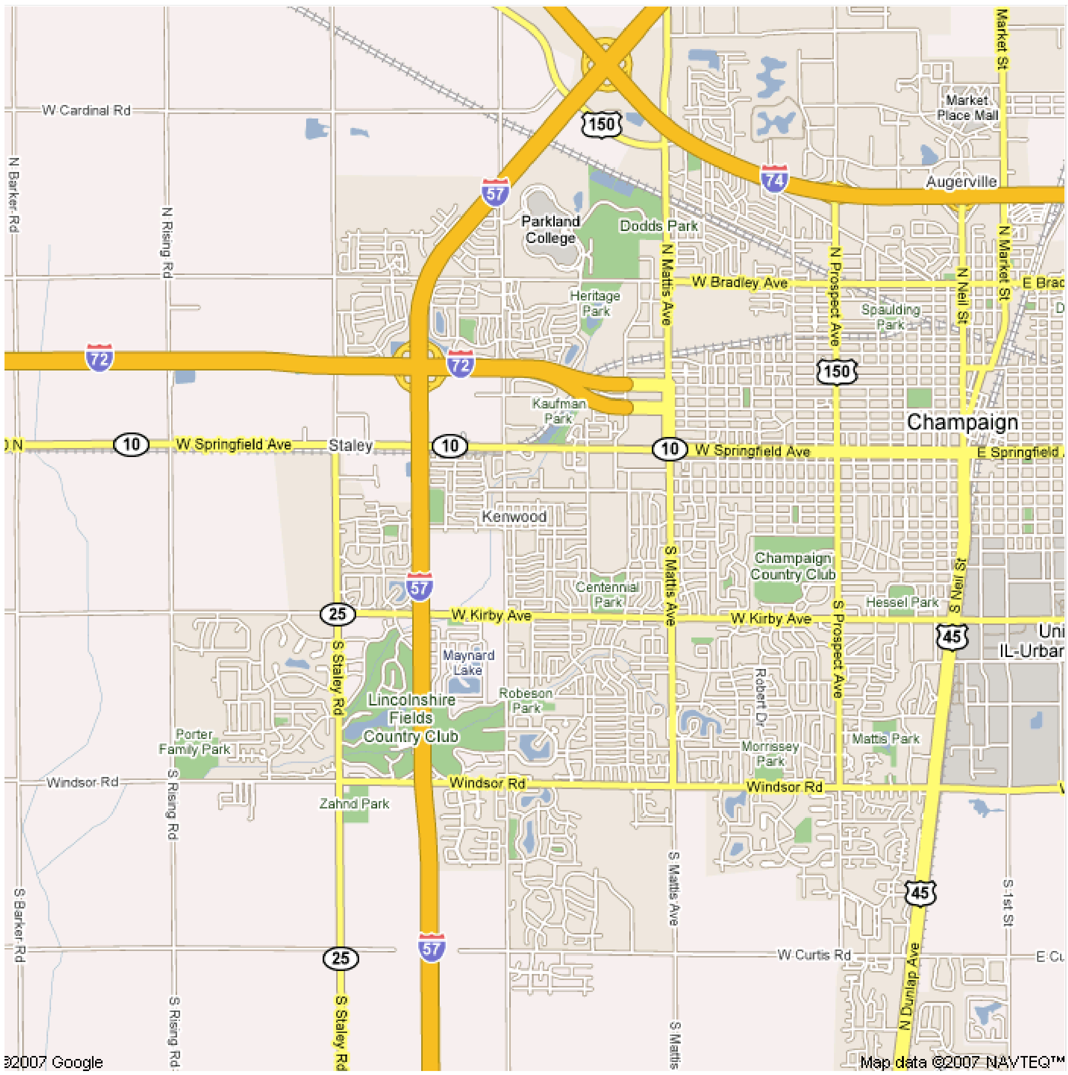

Figure B.1: Base Map of Area around City of Champaign

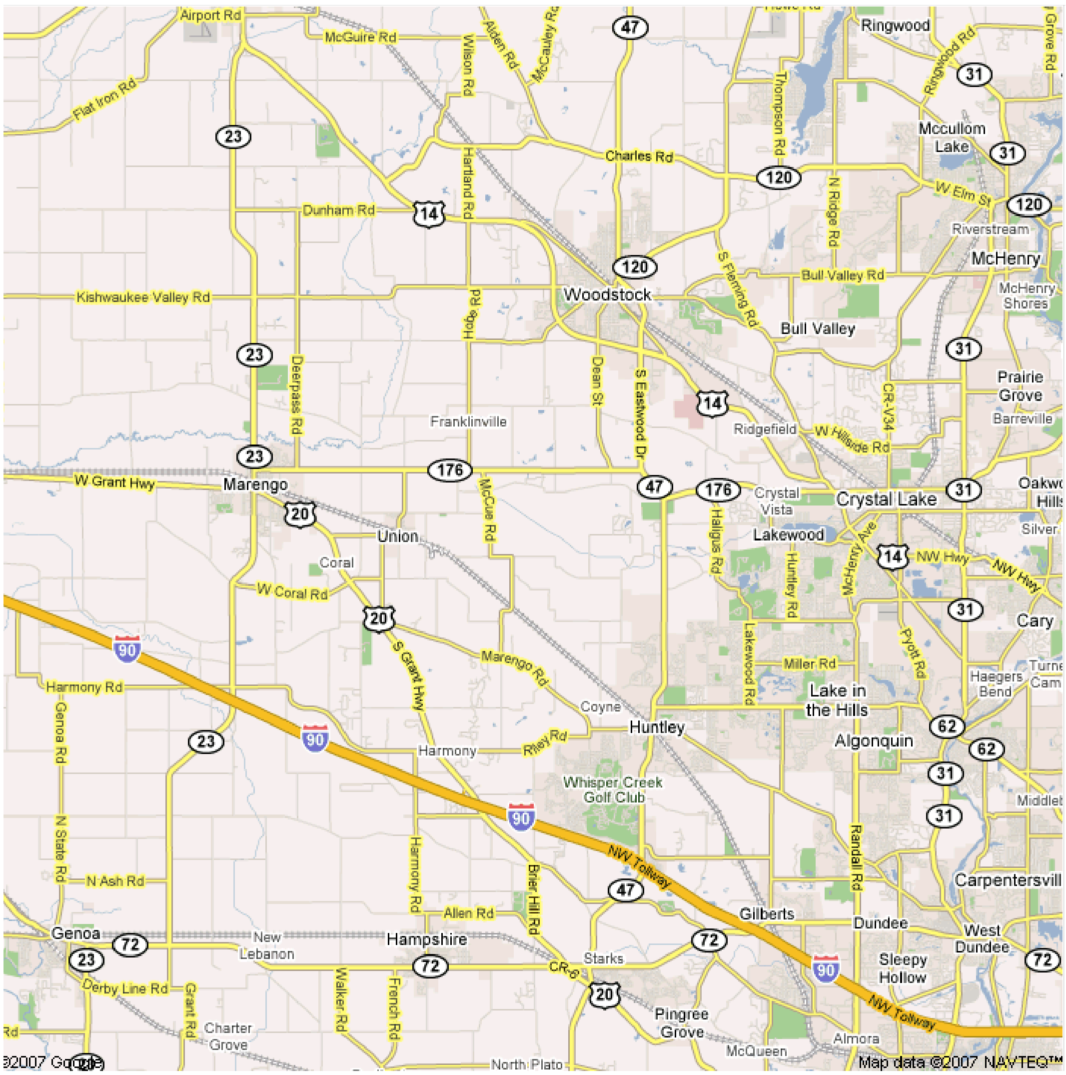

Figure B.2: Base Map of Area around McHenry County

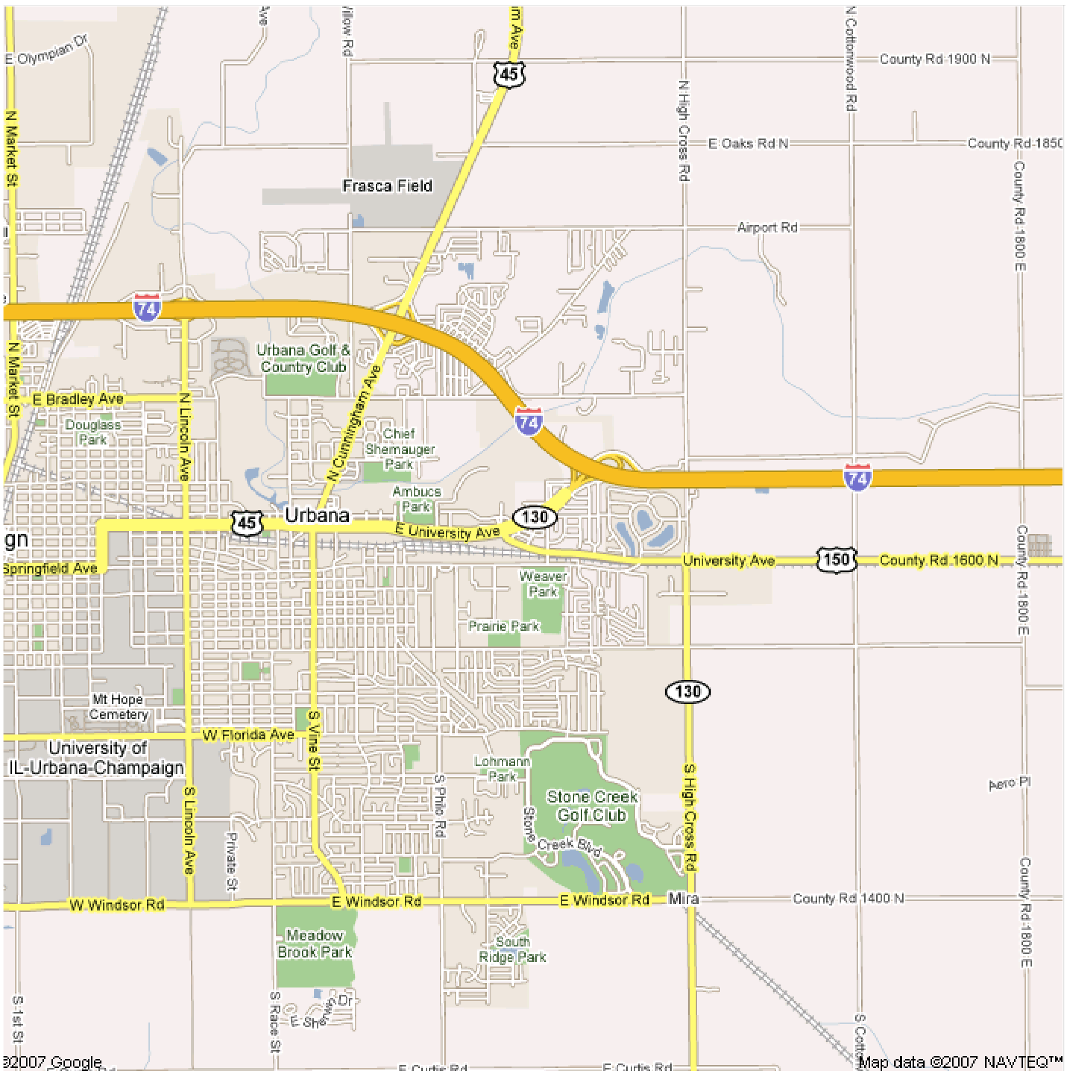

Figure B.3: Base Map of Area around City of Urbana

Appendix C

Schema & Tables

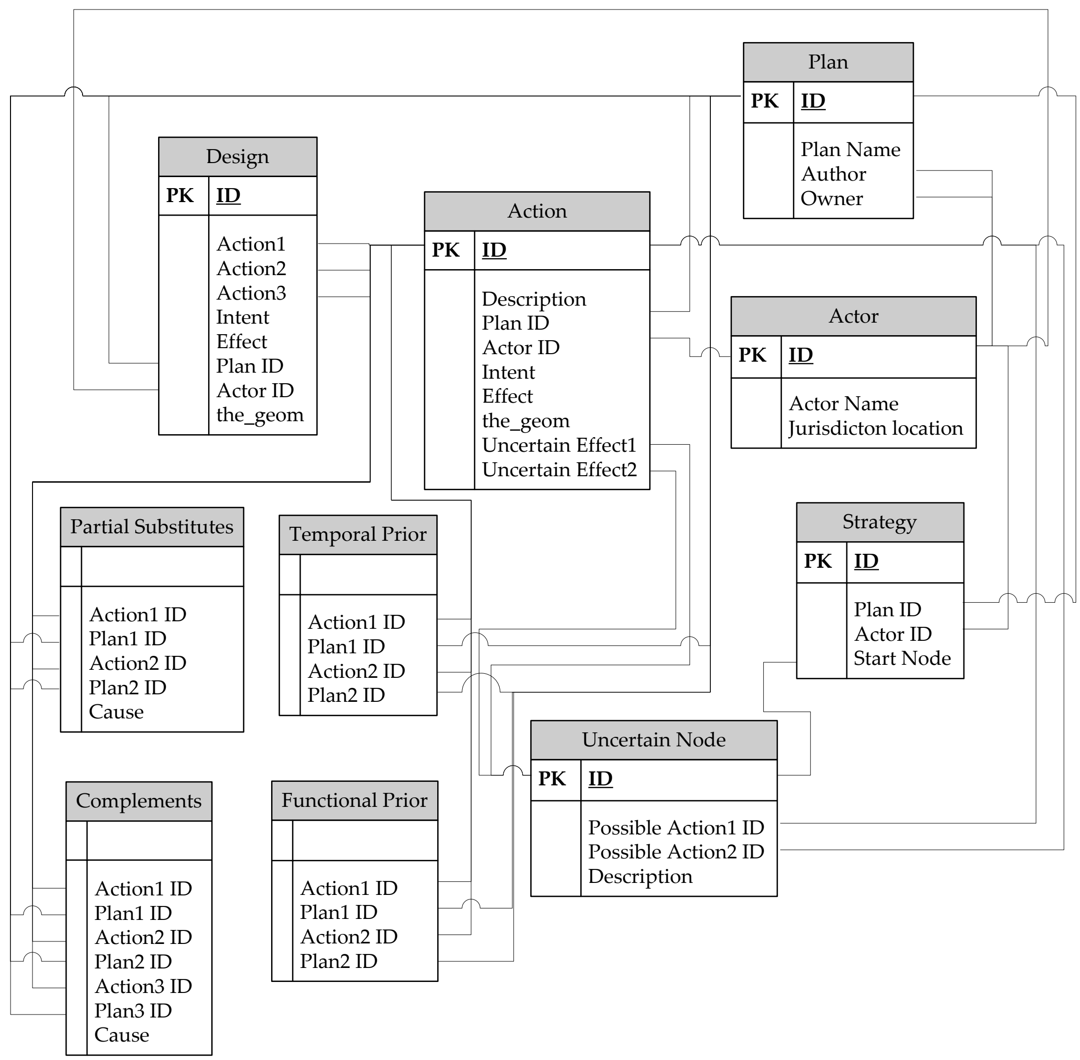

Figure C.1: Database Schema

The relationships show in the figure C.1 are standard joins on IDs in a relational database while querying. Furthermore since functional and temporal priority is a binary relationship, Action 1 is considered prior to Action 2.

The following tables give a glimpse into the information used in the databases to demonstrate the task of identifying the semantic relationships. For the purposes of the demonstration only a stylised version of information in Urbana's comprehensive plan and the MPO's LRTP is used and thus is not listed in the following tables.

The plans populated in the databases with their ids are given below. Not all the information in each of these plans is used.

ID	**Name**
1	McHenry 2020 Unified Plan

ID	**Name**
2	Pace 2020 plan
3	Village of Algonquin Comprehensive Plan
4	Lake in the Hills Comprehensive Plan
5	Fox River Grove Comprehensive Plan
6	Marengo Comprehensive Plan
7	McHenry County 2004-2008 Highway Improvement Program
8	McHenry County Conservation District Plan
9	Kane County TIP
10	Metra Collection of Plans
11	Huntley Comprehensive Plan

Table C.1: List of Plans in Two Databases

The following is a sample of the agenda tables in the databases. Note that not all attributes are listed for the sake of readability.

ID	Plan ID	Description	Intent
1	1	Extend Metra Milwaukee District West line from Elgin to Huntley with a corridor continuing to Marengo, with stations at Huntley and Marengo	
2	1	Extend Metra Union-Pacific Northwest Line North Branch to Richmond, with stations at Bull Valley Road, Ringwood/Johnsburg and Richmond	
4	1	Expand Randall Road to six lanes between IL 31 and the Kane County border	Expand access to Algonquin and Crystal Lake
38	1	Build a new two lane roadway bypassing Marengo to the northeast from IL 23 to US 20	Reduce traffic on IL 23 within Marengo
46	1	Build a full-directional interchange at IL 47 and I-90	Expand access to Woodstock from I 90
47	1	Build a Metra station in Ridgefield along the current Union Pacific-Northwest Line Service Route, including parking	
50	1	Build a full directional interchange at IL 23 and I-90	Access to I-90

Table C.2: Sample Action Items in One Database

ID	Plan ID	Description	Intent
12	10	Enhance Metra UP-Northwest Line by adding expanded coach yard at Johnsburg, improving signaling, relocating the Crystal Lake Coach Yard to Woodstock, and improving track materials	
22	2	Build a Community Transportation Center near IL 31/IL 62 in Algonquin to provide Pace service	
33	11	Require a 100-foot wide landscaped buffer along IL 47	Protect Kishwaukee basin
34	4	Adopt the 100-foot building setback along Route 47 established by the Villages of Huntley and Lakewood	
36	3	Build a community park adjacent to Jacobs High School, Woods Creek, and the future extension of Marnish Drive	
46	6	Build a ring road on North west of Marengo from IL 23 to US 20	Reduce traffic on IL 23 within Marengo

Table C.3: Sample Action Items in Another Database

Appendix D

Software Used and Query Client

The following software and versions are used to illustrate parts of the dissertation.

Java v1.6.0_1 by Sun Microsystems. See http://java.sun.com/javase/6/webnotes/version-6.html

LEAM (Landuse Evolution and Impact Assessment Model) Landuse simulation model.See http://www.leam.uiuc.edu

PostGreSQL v 8.1.9. A database program. See http://www.postgresql.org/ftp/source/v8.1.9/

PostGreSQL JDBC v.8.1.409jdbc3. A Java Database Connection (JDBC) library for PostGreSQL. See http://jdbc.postgresql.org/

PostGIS v1.1.3 Spatial Extensions of PostGreSQL. See http://postgis.refractions.net/

PostGIS JDBC v1.2.1.Spatial extensions for PostGreSQL JDBC. See http://postgis.refractions.net/

PROJ v.4.5.0 Projection library. See http://proj.maptools.org/

GEOS v.2.2.3. Geometry Engine Open Source. See http://geos.refractions.net/

GDAL v.1.3.2. Translator library for raster geospatial data formats. See http://www.gdal.org/

R v.2.5.1 Software environment for statistical computing and graphics. See http://www.r-project.org

StarSpan v0.998 See http://starspan.casil.ucdavis.edu/–Rueda et al. (2005)

Due to limitation of the page size and to maintain readability the sample query client code is included in the cd-rom attached.

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Glossary

Action is a type of occurrent. It is a deliberate event by a particular actor towards a specific goal. Refer to Hopkins et al. (2005b); Worboys and Hornsby (2004), 126

Activity is an aggregate of behaviour that can be measured in terms of levels on a particular asset. Refer to Hopkins et al. (2005b), 125

Actor for the purposes of this dissertation is an intentional entity, that has capabilities about actions and has limited foresight., 124

Agenda is a list of actions with no inherent relationships between them. It is a trivial design. (Hopkins 2001), 28

Alternatives are a set of actions which achieve the same goal, satisfy the same intent, or otherwise mutually exclusive actions. Interchangeably used with Substitutes, 42

Antichain is a set of pairwise incomparable elements in a poset P. Antichains are also called Sperner systems, 100

Asset is an entity that persists. This could be facilities(immobile in location), equipment(mobile in location), consumables (mobile in time) or intangible. This is different from actors who have capabilities. Refer to Hopkins et al. (2005b), 126

Attribute is a property of an entity that is readily knowable, 10

Belief is individuated by agents psychological state about conviction about truth of a case, 22

Chain is a set of pair wise comparable elements in a finite poset, 100

Commitment ties intention and action that follows. See Cohen and Levesque (1990), 23

Criteria is an attribute of the state of world against which the semantic relationships are determined. For example, criteria could be level of traffic on a link, density of urban development, or just mere existence. See also Attribute, 16

Design is a collection of actions that are related by priority, interdependency and complementarity and parthood. (Hopkins 2001), 29

Desire is a preference for a state of the world, whether or not such state is achievable within the agent's capability. Used synonymously with goal, 22

Imperfect Substitutes are two actions that perform equally well with regard to particular criteria, and fare differently or are not comparable with regard to other criteria. The criteria are particular and specified by the user. Also used interchangeably with partial substitutes and imperfect alternatives, 43

Intentions form the basis for plans as distinct from desires. Perhaps best described by Davidson (1963) as, "syncategorematic and cannot be taken to refer to an entity, state, disposition, or event. Its function in context is to generate new descriptions of actions in terms of their reasons" (see Bratman 1987). Intention provides reasons for actions over which the agent has some control, desires may provide reasons for intentions., 22

Overlap Two objects overlap if there exists another object that is a part of both. Similar to Intersection relation of Sets, 45

Partial Order is a binary relationship that is reflexive, antisymmetric, and transitive. A partial order is an antisymmetric preorder. See Poset, 97

Policy is a conditional rule, which specifies what action to take in response to a contingent occurrence(Kerr 1976); a trivial strategy. Similar to formation of habit to overcome tyranny of small decisions., 29

Poset is a partially ordered set where order between *particular* elements of the set is known, as opposed to well ordered set where order between *any* two elements can be determined. See partial orders, 99

Satisficing is a type of rational behaviour distinct from optimising in also considering the cost of optimisation in a capability restricted agent. Coined by H. Simon, 26

Strategy is a conditional tree, which specifies what action to take in response to a contingent occurrence and various outcomes that may result from such an action. Unlike decision trees, one path is not chosen. (Hopkins 2001), 29

Tyranny of small choices is a condition where routine choices of actions become problematic if the agent is continually trying to optimise. Boundedly rational agents try to overcome this tyranny, among other things, by forming habits. Coined by A. E. Kahn, 27

Underlap Two objects underlap if there exists another object that both objects are parts of. Similar to Union relation of Sets, 45

Index

Author's Biography

Nikhil Kaza was born in Vuyyuru, Andhra Pradesh in India, on October 15, 1978. He graduated from the Indian Institute of Technology at Kharagpur in 2001 with a degree in Architecture. He relocated to Champaign, Illinois to pursue graduate education. He completed Master of Urban Planning in 2004 and Master of Science in Applied Mathematics in 2007 both from the University of Illinois. He is currently working as a Faculty Research Assistant at the University of Maryland at College Park.