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Cyberentity and its consistency in the cyber-physical-social-thinking hyperspace ☆

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ABSTRACT

The Internet of Things (IoT) computing paradigm and its variants, such as the Social Internet of Things (SIoT) and the Internet of People (IoP), have enabled the interconnection of billions of devices with existing computing systems like the social networking platforms. Such interconnection allows IoT applications to offer large-scale context-aware services. On the other hand, the pervasive integration of the IoT and the Cyber-Physical Systems (CPS) have posed many new challenges on the cyber modeling of physical, social and thinking entities. After mapping all the basic elements that form the physical, social and thinking spaces, these elements will be represented in the cyberspace as cyber entities, which are the most elementary particles of the cyberspace. Cybermatics was proposed as a holistic field for the systematic study of cyber entities in the cyberspace and their functions, properties, and conjugations with entities in conventional spaces. In this paper, we emphasize the temporal parts, life cycle and inter-relations of the cyber entities. The potentials of endurance and perdurance cyber mapping are also discussed. Furthermore, a mapping model that incorporates the cyber entity evolution and temporal parts consistency is proposed and presented using a smart home as a use case scenario.

1. Introduction

The Internet of Things (IoT) has become an attractive computing paradigm that realizes ubiquitous services with large-scale ambient intelligence. The IoT facilitates the massive integration of billions of devices allowing for dynamic and seamless interconnections across heterogeneous smart applications [1]. Moreover, in the last few years, we have witnessed the emergence of many IoT variants, these variants emerged due to the convergence of IoT and other computing systems. The Social Internet of Things (SIoT) has emerged as a result of the convergence of IoT and social computing systems such as social networking platforms. Similarly, the Internet of People (IoP) and the Internet of Thinking (IoTh) are the results of the

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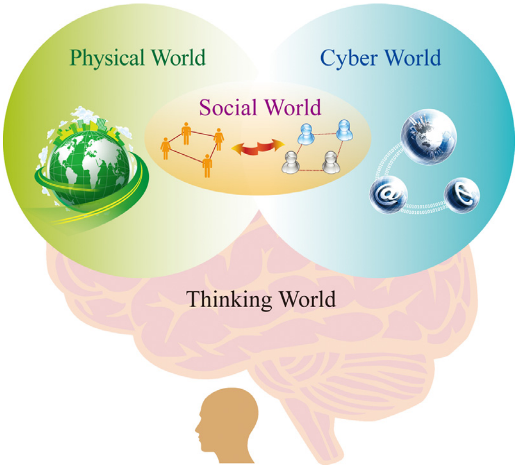

Fig. 1. Cyber-Physical-Social-Thinking hyperspace.

convergence of the IoT and human-centric computing and affective computing respectively. In addition to that, many computing paradigms are closely related to the IoT, such as Fog and Edge computing [2], and the Internet of Vehicles (IoV) [3]. The social computing systems such as personality computing and social signal processing emerged as new fields that focus on the user's social context to achieve social-aware services. On the other hand, brain informatics, affective computing, and other brain-related fields are advancing every day, aiming to represent human thoughts and emotions in the cyberspace. The consolidation of IoT, social computing, affective computing, brain informatics and Cyber-Physical Systems (CPS) yielded the Cyber-Physical-Social-Thinking hyperspace (CPST) [4] (see Fig. 1).

The CPST hyperspace represents the combination, communication, and inter-relation of multiple spaces, including the cyber, physical, social and thinking spaces. In addition to billions of connected physical entities, the CPST also incorporates social entities and thinking entities. The mapped entities will have a digital representation in the cyberspace known as cyber entities, they represent the most elementary particles of the cyberspace. The Cybermatics was proposed as a holistic field for the systematic study of cyber entities in the cyberspace and their functions, properties, and conjugations with entities in conventional spaces (i.e. physical, social, and thinking space). The vision of the smart world has been proposed recently, in which ubiquitous computing is an essential requirement for ambient intelligent environments. The smart world will realize the CPST hyperspace that encompasses the total integration of the physical perception, the social correlation, the cyber interaction and cognitive thinking in every aspect of our daily lives. The CPST hyperspace will be composed out of a tremendous number of interconnected smart devices, networks, and applications. The CPST hyperspace will change the form of existing for entities in the physical, social and thinking spaces; these entities will have a cyber representation in the cyberspace, that exist simultaneously along with its conventional counterpart.

Physical entities have well defined physical properties, and these properties change continuously over time, these changes should be reflected on the cyber counterpart, thus realizing an accurate mapping where all the changes of the physical entity's properties are well preserved in the cyberspace and managed by the cyber entity's evolution model. One of the obstacles we face when correlating the change of a physical entity to its corresponding cyber entity is known as the problem of change. Due to the data explosions that occurred following the interconnection of the IoT, SIoT, and IoTh, the cyber modeling of the mapped physical/social/thinking entities might pose many challenges related to the management of cyber entities' evolution, consistency, and life cycle. Moreover, the cyber mapping model should consistently preserve the spatial and temporal attributes of the mapped entities. The number of internet-connected devices will exceed the number of people by 2020, with seven devices for each person on average. With the enormous number of connected devices, the generated data from these devices will lead to numerous data explosions. The challenge is how to effectively process such a tremendous amount of data generated by the interconnection of the physical, social and thinking entities and preserve the property change of these entities. In this paper, we emphasize on the cyber entities' temporal parts, life cycle, and their inter-relations, we discuss the potentials of endurance and perdurance cyber mapping. Furthermore, a mapping model that incorporates the cyber entity evolution and temporal parts consistency is proposed.

The rest of the paper is organized as follows. Section 2 reviews the recent advances and related works. Section 3 defines the basic entities of the three conventional spaces and cyber entities. The problem of change during cyber mapping and a cyber mapping model is presented and discussed in Section 4. Section 5 presents a cyber-enabled smart home as a use case. Finally, we conclude the paper in Section 6.

2. Related works

Many works have studied the IoT and its variants (SIoT, IoP, and IoTh) and the convergence between these systems and the CPS that leads to the emergence of the CPST hyperspace. Ning et al. [4] established a CPST hyperspace architecture to explain the Cybermatics, in which they focus on three main features: intelligence, interconnection, and greenness. The Interconnected Cybermatics is considered as the variability and dynamics of the Internet of Anything, indicating that the physical things could establish seamless connectivity based on the physical perception, cyber interactions, social correlations and thinking communications. The Intelligent Cybermatics refers to the super-mechanisms that harmoniously address the CPST hyperspace. Finally, the Green Cybermatics aims to discuss the energy issues to guarantee effective communication and networking in the hyperspace. Ning et al. [5] presented an architecture for the IoT, in which they proposed the Unit IoT and Ubiquitous IoT architecture. The Unit IoT architecture is inspired by the human neural network, namely man like neural network (MLN) model. While the Ubiquitous IoT refers to the universal IoT that integrates multiple heterogenous Unit IoTs, the Ubiquitous IoT architecture employs Social Organization Framework (SOF) model. Ma et al. [6] discussed the trend of cyberization that has followed the computerization and the informatization. The authors explained the necessity and significance of the field of Cybermatics, what it is and what it encompasses, and how it is related to other research fields and areas. The Cyberlogic refers to the basic logical facts that establish a bridge from cyber philosophy to cyberscience. In [7] the authors presented the concept and methods of Cyberlogic, and the role of Cyberlogic in the CPST hyperspace is demonstrated. While the General Cyberspace (GC) is the outcome that has yielded from the cyberspace based on the deep convergence of spaces and ubiquitous connections between conventional entities. In [8] the GC was investigated from three main aspects: existence, interactions, and applications/services, in terms of philosophy, science, and technology perspectives respectively.

The security of the cyber entities in the CPST hyperspace has been discussed in many works [9–11], Ning and Liu [9] proposed a cyber-physical-social based security architecture (IPM) that deals the Information, Physical, and Management security perspectives, they have also presented how the architectural abstractions support Unit IoT and Ubiquitous IoT (U2IoT) model. Along the same vein of IoT security, in [10] they designed an aggregated-proof based hierarchical authentication scheme (APHA) for the layered networks, the proposed scheme is also based on the architecture of U2IoT. Liu et al. [12] reviewed the works related to the field of the smart world. They discussed the smart world evolutions through four phases, the smart world elements and its driven applications are discussed in the context of the CPST hyperspace. The authors studied the potentials of web intelligence, brain informatics, and ubiquitous intelligence as enabling technologies to realize the smart world vision. The intensive interconnection of the conventional (physical/social/thinking) spaces' entities will lead towards human-centered computing systems, thus exposing users to many health risks due to the extensive interactions with the cyberspace. Similarly, in [13] the evolution of the smart world is introduced, and the physical-based coordination, social-inspired interactivity, brain-abstracted cooperativity, and cyber-enabled homogeneity are, respectively, discussed as the main characteristics of the smart world.

Zeng el al [14] surveyed the advancement of cyber-physical-social systems (CPSS) through cyber-physical systems (CPS), cyber-social systems (CSS), they have reviewed the previous system-level designs in different application domains and compared their performance characteristics and feasibility for CPSS. Zheng et al. [15] have discussed the disastrous effects of the intensive interaction with the cyberspace, a condition known as Cybersyndrome, a group of physical, social, and mental disorders that affect users due to the massive interaction with the cyberspace. While in [16] they have presented the classification, formation stages, prevention, and recovery methods of Cybersyndrome, they also explored the impact of Cybersyndrome in physical, social, and thinking spaces. Dhelim et al. [17] proposed a cyber-enabled human-centric smart home architecture. The proposed architecture is based on smart home residents' social and thinking entities. The home residents are the center of the proposed architecture, where the smart home control and all the offered services are based on the behaviors, habits, actions, and even emotions and thoughts of the residents. Similarly, Zhu et al. [18] proposed a spatial-temporal-logical framework to manage the relationships that connect the physical objects in IoT scenarios and map their interconnection to the cyberspace. Moreover, the authors have discussed the cyber mapping methods that properly capture the objects' properties.

The works in [19–21] discussed the cyber-individual (Cyber-I). Cyber-I is a cyber entity that represents the counterpart of a person in the cyberspace, which is a unique, digital, comprehensive description for every person in the physical world. In [19] Ma et al. studied the impact of Brain Informatics to realize the potentials of Cyber-I, through the collection of brain data using advanced technologies such as electroencephalography (EEG) and functional magnetic resonance imaging (fMRI). The collected data are then processed with a long-term global vision and holistic view toward understanding the principles and mechanisms of the Human Information Processing System (HIPS). In [21] the authors presented a dynamic growth model for Cyber-I, aiming to: (1) schedule a Cyber-I's growth according to data and time, (2) manage the quantity of raw data that is involved in a specific growth process, (3) generate the Cyber-I model data with appropriate growth forms, and (4) keep the update records of a Cyber-I model's growth process into a log file in personal database. However, none of the above-mentioned works have discussed cyber entities' consistency and the mapping of the property changes and the resulting temporal parts consistency, we classified the related works in Table 1.

3. The CPST hyperspace and entities

Many things/entities can be observed using our consciousness and senses, nonetheless, these entities differ in many aspects and properties, some of them have physical properties, while others may not have a representation in the physical space. In this section, we will discuss the existence of entities in the three conventional spaces (physical, social, and thinking) and the emerging cyberspace. The resulting hyperspace is depicted in Fig. 1.

Table 1
Related works classification.

Work	Topic	Space
[4,6]	Cybermatics	Physical/Social/Thinking/Cyber spaces
[19–21]	Cyber-I	Cyberspace
[12,13]	Smart world	Cyber-Physical-Social-Thinking hyperspace
[15,16]	Cyber-Syndrome	Physical/Social/Thinking/Cyber spaces
[7]	Cyberlogic	Cyberspace
[8]	General cyberspace	Cyberspace and cyber-enabled spaces
[11]	Cyberentity security	Cyberspace
[14]	CPSS	Cyber-physical-social
Current work	Cyberentity consistency	Cyber-Physical-Social-Thinking hyperspace

3.1. Physical entities

The concept of a physical entity has been extensively discussed in classical and modern philosophy. The ontological studies about the physical entity discuss the existing and the categories of being, what is known as the ontological distinction. In this regard, many fundamental questions are raised about the existing physical entities. What is said to be a physical object? Can we consider all the physical entities as physical objects? And what are the different modes of being of entities? The basic feature that distinguishes the physical entities from other ontological categories of existing is that the physical entities have spatial properties that characterize their mode of existence in the physical space. From the computing point of view, the vision of IoT is to empower the physical object with a certain level of computational capabilities and connect them to the internet. Like the above-mentioned questions about the ontological studies of the physical entities, similar questions are raised during the conceptual modeling of the IoT. What is the most elementary entity of such a system? How to digitally represent and maintain the spatial-temporal properties of the physical entities? The accurate spatial-temporal modeling of the physical entities' features and properties will help the IoT to offer pervasive context-aware services. All the nodes of the IoT network are considered as physical entities that reside in the physical space and may have other representations in other spaces, that includes individual nodes, such as a smart device or a control device, or a group of objects that all together form another node, like a smart home for instance. To digitally represent and maintain the spatial-temporal properties of physical entities, we need to rely on a wide variety of sensors. The physical entity is embedded with multiple sensors that map the spatial-temporal characteristics of the attached physical entity to the cyberspace.

3.2. Social entities

Another form of existing that took place in our daily lives is the social relationships that hold among physical entities. The social space is mirroring to the social connections that interconnect the physical entities in the physical space. A social entity is a reflection of a connection or a relationship between two physical entities. The edges of the social graph, used by social networks is a typical example of a social entity that connects physical entities (people in this case). The relationship that a social entity represents is not limited to only human social relationships, but also includes other forms of social relations, such as human-object, object-object [22], human-animal, plant-plant. The SIoT extends the IoT network to incorporate the social relationships among objects to establish a navigable social network. While the IoP is established by combining the IoT with the social network graphs to enable the smart object to offer social aware services by connecting them to the social networks. The social space can be modeled as a graph structure, where the vertices represent the physical entities and the edges represent the social entities that connect the physical entities.

3.3. Thinking entities

The existence from the ontological view is not limited to only the physical entities. Non-physical entities can exist despite the fact that they do not possess any spatial properties. Entities such as memories, emotions, thoughts, ideas, dreams, feelings, preferences and personality traits exist although they are not physically present in the physical world. These entities are known as thinking entities, they are the most elementary particles of the thinking space. At the physical level, the thinking entities are the result of chemical reactions within our brains. However, there are some key differences between thinking entities and physical entities. Firstly, they do not exist in a physical form, in other words, they have no spatial dimension. Secondly, the way humans perceive thinking entities is totally different, mostly through visual representations. Lastly, their physical existence is different from their content, for instance, a mental image of a circle does not exist as a circle in one's head. With the advances of neuroscience and affective computing, we are closer than ever to reveal the human mind's inner status, which will enable us to include the users' thinking entities in the computing system, what is known as IoTh [23].

3.4. Cyber entities

In addition to the conventional spaces (physical/social/thinking), a new space known as the cyberspace has emerged and continue to expand, similarly, it is composed of entities, the digital things that function in cyberspace can be termed as cyber entities, which are the digital things that function in the cyberspace. "We may generally define a cyber entity as anything that exists digitally in cyberspace, either purely synthesized by a computer, or closely correlated to and further conjugated with a real entity in physical, social and thinking spaces" [6]. A cyber entity is the digital representation of either a physical/social/thinking entity with only partial attributes and features of the conventional entity, or entity that exists only in the cyberspace and does not have a counterpart in the other conventional spaces. A synthetic cyber entity may or may not have a counterpart in any of the conventional spaces. A conventional entity is mapped as a cyber entity in the cyberspace by capturing its properties using various types of cyber-physical-social-thinking mapping systems, a cyber entity may have multi-identity status (including the basic identity and other temporary or assistant identities). A cyber entity might be the cyber representation of an existing physical entity, thus the changes that take place in the physical space will be reflected in the corresponding cyber representation. Similarly, a cyber entity can represent a social or thinking entity.

Entities in the conventional spaces follow a life cycle mechanism that governs the existing status of these entities in their living spaces, similarly, the cyber entities follow such a mechanism. Mainly, creation, evolution, and termination phases. The creation is the first phase of a cyber entity, if the corresponding cyber entity is a digital representation of a conventional entity, the cyber entity and the conventional entity will have the same time of creation, in other words, the cyber entity will start to exist in the cyberspace when the corresponding conventional entity is created. For example, connecting a new node to the existing IoT network will lead to the creation of a new cyber entity related to that node. Unlike the evolution and termination phases that can be exempt for some specific cyber entities, the creation phase is common to all cyber entities. The evolution is the main and the longest phase in the cyber entity's life cycle, after its creation, the cyber entity will grow according to predefined evolution model that can handle and reflect the changes of the corresponding conventional entity. Some cyber entities might be exempt from this phase and would be considered as static cyber entities. The termination phase is the final step of a cyber entity's life, here we distinguish two kinds of termination, partial and full termination, the first takes place when a cyber entity stops evolving, turning it from a dynamic entity into a static one, while the full termination is deletion of the cyber entity from the cyberspace. The end of a social relationship between two friends and its representation in the social space is an example of partial termination, as the cyber entity that represents their relationship would stop growing but it is not completely deleted, while the deletion of a webpage is considered as a full termination of its corresponding cyber entity.

4. Entities and consistency

Physical entities have well defined physical properties, these properties change continuously over time, these changes should be reflected on the cyber counterpart, thus realizing a true mapping where all the changes of the physical entity's properties are well preserved in the cyberspace and managed by the cyber entity's evolution model. One of the obstacles we face when correlating the change of a physical entity to its corresponding cyber entity is known as the problem of change [24].

4.1. Endurance-based mapping

Based on the endurance theory, the property changes that take place in the physical world does not affect the fact that it is the same entity, in other words, despite the property changes, the physical entity is the same physical entity that had existed in the past and the same physical entity that will exist in the future. However, to explain the problem of change, the endurantists clam that the relations between the physical entities and time are causing the property changes. This theory looks logical and intuitive. However, the chronological changes of a physical entity should be continuously captured by the cyber entity's evolution model, thus, preserved in the cyberspace. As shown in Fig. 2, the lined circle represents only the current cyber representation of the physical entity's properties, which is not the case with perdurance based mapping, that preserves all the temporal parts of the physical entity. In Fig. 2, the cyber entity is represented inside the striped circle, because the mapped cyber entity usually has only partial properties and attributes of the physical/social/thinking entities [6].

4.2. Perdurance-based mapping

The other theory of persistence and identity is the perdurance theory, which claims that all the physical entities are spread out through time as they are spread out in space, thus a given physical entity could not be present as a whole in a given moment, and only a temporal part of that physical entity is present in that moment. Therefore, when a property change happens, the resulting entity is another temporal part of that physical entity. Likewise, a successful sequence of cyber temporal parts represents the corresponding cyber entity, with only one of them being the cyber entity of that conventional entity at a specific time (see Fig. 3). This differentiation between different cyber temporal parts come in handy in managing the relations between cyber entities using the temporal part management unit of the cyber mapping model. For example,

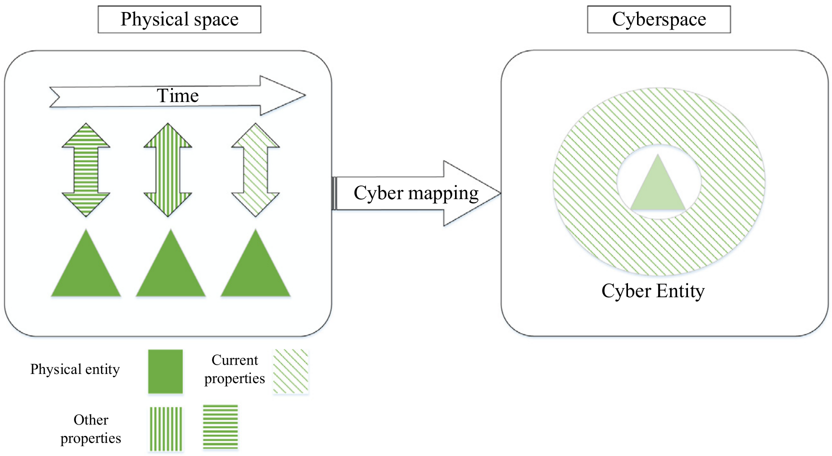

Fig. 2. Endurance-based cyber mapping.

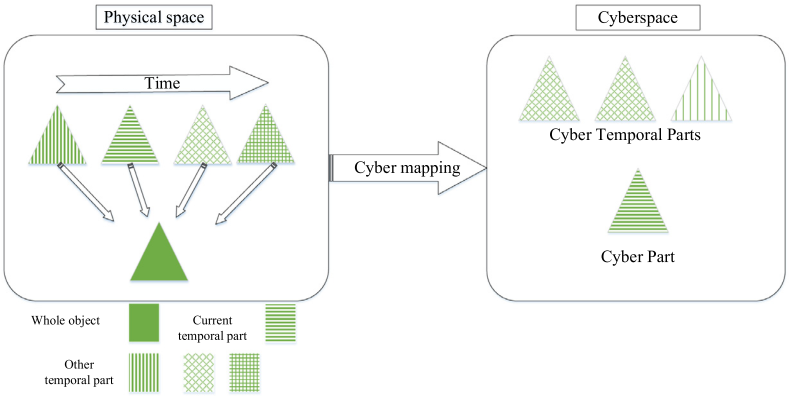

Fig. 3. Perdurance-based cyber mapping.

during a suicide case investigation, the investigators might be interested to determine all the cyber entities that have a relation with the last cyber temporal part of the cyber entity that represent that person (Cyber-I).

4.3. Cyber entity mapping model

To properly capture the conventional entity's properties and manage the mapped cyber entity temporal parts changing. We propose a cyber mapping model that manages the cyber entity's temporal parts, as well as its relation with the other cyber entities in the CPST hyperspace. Once the cyber entity is created, it must be able to change to reflect the mapped entity's properties change. The cyber entity changes are controlled by a cyber mapping model that preserves the spatial-temporal consistency during cyber mapping. The cyber mapping model must be dynamic with adaptive methods to reflect the property changes of the conventional entity, the main components of the cyber mapping model are shown in Fig. 4.

The cyber entity growth model, such as the one presented in [21], is responsible for the acquisition, classification, organization, storage, and management of the vast amount of data related to the conventional counterpart of the current cyber entity. For example, in a smart home environment, the residents may generate a huge amount of data. After prepossessing and classifying the generated data into physical, social, and thinking data respectively, the growth model correlates the cyber entity with the newly acquired data and the cyber entity's properties will change accordingly. The relations management interface is responsible for managing relationships with other cyber entities. It works in parallel with the growth model and provides all the information that relates to the current cyber entity with other cyber entities. Most of the relations among cyber entities are the cyber representation of social entities, a reflection of the social relationship between two conventional entities. In the social relations literature, many theorems have been proposed, the most prominent one is known as "the six degrees of separation" theorem, proposed by Frigyes Karinthy in 1929, the theorem claims that “all living things and everything else in the world is six or fewer steps away from each other”. Moreover, the cyber entities are even more connected since they incorporate the three conventional spaces, for instance, a person's anger feeling might be connected and related with other person's physical presence, even though they may not know each other but they are connected in the thinking

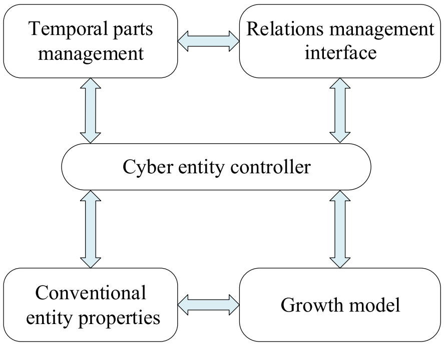

Fig. 4. Cyber entity mapping model components.

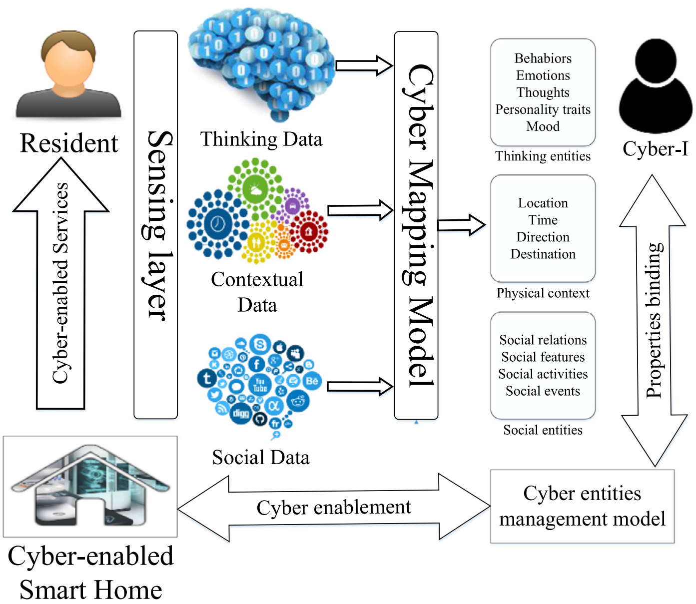

Fig. 5. Cyber-enabled smart home.

space and not only through the conventional social relation. As mentioned earlier, mapping an entity from the conventional spaces to the cyberspace is considered as mapping all the associated temporal parts of the corresponding entity. Only one of the resulting cyber parts will be present at any specific moment, and the role of the temporal parts management unit is responsible for managing the cyber temporal parts, as well as preserving and maintaining the properties of the mapped entity. The data flow that is fed to the evolution model will definitely change the cyber entity's properties, thus a change in the current temporal cyber part will take place. Other than that, property changing will potentially lead to a change in the relations with other cyber entities, being the main component in the cyber entity, Cyber entity controller is to coordinate these changes and synchronize it with the other units.

5. Smart home use case

In the context of a smart home scenario, the management, and control of the cyber-enabled smart home depend on the physical-social-thinking status of the smart home residents and their corresponding cyber entities. As shown in Fig. 5. Different types of data are generated by the smart home sensors, mainly thinking, social and physical (contextual) data. All the data that are related to the brain, emotions, cognitive, personality and habits are classified as thinking data. The social data is generated from social interactions between the home residents with their social circle, such as social network data, phone calls, and physical interaction. All other spatial-temporal or contextual data are classified as physical data. Multiple cyber entities are created as a result of mapping the aforementioned data to the cyberspace. In this context, the resident is represented in the cyberspace as a Cyber-I, which is a cyber entity that represents the counterpart of the person in the cyberspace, where Cyber-I is a unique, digital, comprehensive description for the smart home resident [20].

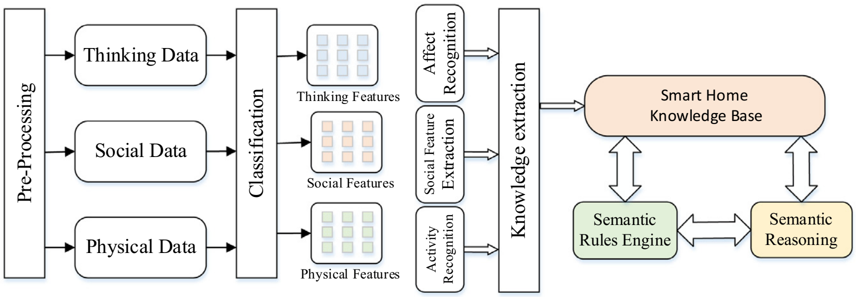

Fig. 6. Semantic reasoning on smart home data.

Such an architecture for the smart home can help to manage the residents' social and thinking context more effectively. The smart home is empowered by a knowledge graph that incorporates the home residents' personal ontology domains that organize their physical, social and thinking data. After processing the data generated by the pervasive home sensors. The features are classified into either a physical, social or thinking feature, and the representing information is merged with the smart home's knowledge base. Knowledge related to the residents is extracted and represented according to the ontology, and from that, the new knowledge is deduced using semantic reasoning along with the semantic rules engine, as shown in Fig. 6. For example, if the physical context of a resident is watching TV, and the body-attached sensors' emotion recognition system detected that his current emotion is sad, based on this knowledge along with his profile (personality traits, watching history and other profile information), the appropriate content is suggested, this can be expressed using SWRL rules as:

Resident_In (?x,TV_Front) ^ Thinking_Entity(?x, ?te)^ Current_Emotion(?e)^ Has_Trait(?x,t) → Recommand_Content(?x, ?e,t,c)

A plethora of applications could be implemented by manipulating the resident's physical, social and thinking cyber entities, in this context we illustrate some to the possible application scenarios

A. Smart food ordering system

In the aforementioned cyber-enabled smart home architecture, the residents' thinking entities are mapped into corresponding cyber entities. In this application scenario, the resident's feelings are recognized by analyzing the data generated by the body area network sensors implanted in the resident's body. The resident's current mental statues and feelings are represented as cyber entities within the knowledge graph. As mentioned early, the knowledge graph grows by adding a new fact from the extracted sensed data, and each node that represents a cyber entity is managed by a cyber entity mapping model that controls the property changes of the mapped entity. For example, after analyzing the features of the body area network sensors, the smart home deduces that the resident starts to feel hungry, at that moment the resident is not even consciously aware yet that he is hungry. The smart home checks the connected smart fridge, which is empty at the moment, the smart home deduces the most suitable meal for the resident at this time using semantic reasoning over the related cyber entities related to the context of the resident and current temporal parts of these entities, such as diet program, history logs and medical condition. In addition to the resident's current physical, thinking status and contextual information, the reasoning process also includes other information about the ordering process, such as the resident's previous restaurant ratings and delivery time.

B. Social aware smart home

The IoT is expected to be improved by incorporating a social dimension to its connected nodes, which is known as the SIoT network. The nodes of the SIoT are connected through one or more degrees of social relationship. In the context of a smart home, to offer social aware services, the smart home is interconnected with the residents' social networks as well as their social context, the outcome of such integration is that the smart home's knowledge base will be able to infer the residents' social activities and events and customize its service accordingly. The above proposed general mapping model can be utilized to realize the integration of social network services with the IoT objects, which will enrich the IoT with a customizable structure that will ensure the network navigability and service discovery, and merge the IoT with the human social network. Giving the smart home a social dimension might result in a plethora of social aware applications and services. For example, the smart home is connected to the residents' social networks account. After analyzing the posted content by a resident, the smart home through semantic reasoning infers that the resident is planning for a trip tomorrow at 6 am, the smart home makes the necessary preparation for the trip accordingly.

C. Thinking-aware smart home

In addition to its interconnection with the residents' social networks, in the IoTh, the smart home's knowledge base might include the residents' preferences, habits, behaviors and even their personality types [25]. This can be achieved by the continuous analysis of the residents' data and the recognition of the residents' activity based on the sensed data from the deployed sensors. For instance, if a resident is used to make a cup of coffee every morning during the weekdays at 7:30 am, the smart home will automatically learn this habit by classifying the data gathered from the water boiler and the cup attached sensors. After the learning phase, the event “drink coffee” is automatically triggered. Another example of the thinking enabled smart home application is content delivery customization, where the smart home recommends a customized content base on the residents’ current thinking status, without the need for explicit control. All of the delivered content, such as music, movies and radio channels to play is selected based on the resident’s current emotional and thinking conditions and his preferences, in other words the smart home will make the most enjoyable experience for resident, the home devices may play romantic content when the resident’s in love, motivational songs/movies when he is disappointed or depressed, and so on and so forth. The content is selected not only by considering the bio-signals of the body area network for emotion recognition, but also by including the current physical and social contexts, and the resident’s personality traits.

6. Conclusion and future work

According to the endurance theory, the property changes that take place in the physical world do not affect the fact that it is the same entity, and that the relations between the physical entities and time are causing the property changes of these entities. On the other hand, perdurance theory claims that all the physical entities are spread out through time as they are spread out in space, thus a given physical entity could not be present as a whole in a given moment, and only a temporal part of that physical entity is present in that moment. Perdurance-based mapping is favorable when conventional entities are mapped to the cyberspace because it preserves the chronological changes of the conventional entities’ property changes. Perdurance cyber mapping model can properly capture the conventional entity’s properties and manage the mapped cyber entity temporal parts changing, as well as its relation with the other cyber entities in the CPST hyperspace. There is much work left to further study the consistency of cyber entities, giving a holistic mathematical representation for endurance and perdurance cyber mapping is our next research direction.

Declaration of Competing Interest

The authors declare no conflict of interests

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