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# Thing Relation Modeling in the Internet of Things

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***Abstract*—The Internet of Things (IoT) technologies enable connections among things with wider ranges. The development of such technologies in cyberspace promotes the convergence of physical space and cyberspace. The research on social attributes (e.g., relationships and social existence) that currently exist and on interactive behavior of physical things from the convergence of those two spaces can help to efficiently address certain social problems such as food safety, medicine source tracking, and traffic adjustments. This research on social attributes can also help to improve the serviceability of the IoT. At present, research on social attributes in the IoT has not modeled the relations of things in the IoT. In this paper, we formulate social attributes of thing, analyze the role of relations that is one of important social attributes in the IoT, and use super network architecture to present the complex relations among physical things. Based on these relations and relation architecture, we use an ontology-based approach to model the relations of things. Finally, we use a case to interpret the concrete application process of relations in smart home.**

***Index Terms*—Internet of Things (IoT), smart home, social attributes, relations**

## I. Introduction

The Internet has contributed to the emergence of cyberspace, which led to changes in the existing modes of physical things. A physical thing in traditional physical space can be mapped into cyberspace, thereby generating a new peer entity existing in cyberspace, called a cyber entity[1]. Similar to physical things, each cyber entity has a life cycle: birth, growth and death. The cyber entity starts to exist in cyberspace in the birth phase and changes as a result of situations in the growth phase. The death phase includes two conditions: partial death and full death. The former refers to the cyber entity transforming from a dynamic entity into a static entity when it stops growing, while the latter is the deletion of the cyber entity from cyberspace.

The widespread use of the IoT in various fields, such as transportation[2], medicine[3, 4], and manufacturing[5], and other fields, has facilitated the development of related research that has influenced our lives. For example, we can use IoT technologies to help control devices easily, to care for patients or elderly people and even to address certain emergencies better and more conveniently. As the next generation of information and communication technology, the IoT has realized ubiquitous sensing through sensors with supercomputing ability[6]. These characteristics of ubiquitous sensing, connection, control and supercomputing for the IoT have contributed to the convergence of physical space and cyberspace, where more physical things have established interconnections with cyber entities through physical connections and network protocols. Undoubtedly, it is necessary to model physical things to gain information about them in cyberspace and to acquire more knowledge from this information to control physical things with cyber commands. The modeling of physical things usually refers to the birth and growth of corresponding cyber entities, which can be complemented by data descriptions.

Each physical thing has natural attributes, which refer to its characteristics. In addition, the perception, interconnection and interworking among physical things make their existing states and inter-behaviors (e.g., relationships and social existence) complex social attributes. For example, a desk has the natural attributes of color, length, width and height, but when it belongs to someone, it has the social attributes of a possessive relation with the person. For each physical thing, there are distinct or implicit social attributes. (1)Distinct social attributes can be acquired through things' social exist, e.g. production or flow information. The sensor is produced by a manufacture. Then it may be bought by a person or a social institution, be installed by a person, and then be managed by another person. In this process, the object has associations with some social institution or persons, these associations are distinct social attributes of physical thing. (2)Implicit social attributes usually can be acquired through the change of physical things characters, or data mining technology. For example, by observing the damage of the different point of view for a chair, you can judge a person's posture habits. Through the sale records of the physical things, person's interest can be inferred. Person's habits or interests are implicit social attributes of physical things.

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In the IoT era, considering the social attributes of things is beneficial for (1) helping to address certain social problems efficiently, such as food safety, medicine source tracking, and traffic adjustment, and (2) helping to improve the serviceability of the IoT. Currently, research on social attributes is at an initial stage in which the ways to precisely describe and model the relations among things existing in the IoT have not yet been explored [7-9].

Various relations exist among physical things because one physical thing is usually related to others. These relations are important social attributes that need to be formalized according to the life circles of cyber entities to establish relations in cyberspace. These established relations will be updated with sensing data to provide new knowledge and generate further wisdom. Relationship modeling is a also data-information-knowledge-wisdom (D-I-K-W) process[10]. With the development of AI, many smart systems have been developed, smart grid[11], smart home[12], *et al.* Therefore, some cues are provided for our work on thing relation modeling. First, the concrete relations among physical things must be clear. We may be familiar with certain concepts about relations, such as social relations, space relations, and time relations, but their role in the IoT is often ignored. Therefore, it is necessary to recognize the relations among physical things in the IoT and their role in IoT applications. Second, the network should be used for precise descriptions of relations, therein considering the complex architecture of the relations in the IoT. In this way, the role of relations in the IoT will be analyzed, a network structure for the relations among things will be provided, and an ontology-based approach will be used for the final modeling.

The papers' contributions are: (1) formulating social attributes of things in the IoT, especially relations which are one of important social attributes; (2) putting forwards a network architecture for the relations among things; (3) building an ontology model for thing which can model social attributes and natural attributes of things.

The remainder of this paper is organized as follows. In section II, we review related work on IoT modeling and social attribute research related to the IoT. In section III, the role of relations in the IoT is analyzed, and the super network architecture of the relations among things is described. Section IV describes the ontology-based approach to thing relation modeling, and use a case to interpret the concrete application process in smart home. Finally, we conclude our work.

## II. RELATED WORK

### A. *Thing modeling in the IoT*

In the IoT, physical things include physical objects, behaviors, tendencies and physical events. Physical objects (e.g., people, vehicles, tables, and birds) refer to concrete things with tangible bodies. Physical events (e.g., a tornado occurring in a certain place) involve something that occurred and that was triggered by certain conditions in physical space. Such events generally consist of objects, behaviors and causes[13].

To ensure the consistency of the mapping between physical space and cyberspace, identification modeling and attributes modeling of physical objects are necessary.

In the IoT, identification modeling gives the physical object an appropriate identifier so that it can be recognized uniquely. There are two primary types of identification schemes: ID and nID (non-ID)[14]. ID identification can be used alone based on an object's ID or combined with nID identification. Generally, ID identification applies unique strings of letters or numbers as identifiers to represent objects' identities so that the description is accurate and readable. ID has been widely used in multiple IoT applications, such as logistics and supply chain management, with the purpose of making objects globally identifiable. There are various code standards for ID identification; the electronic product code (EPC) [15] and ubiquitous ID (uID) [16] are the two most influential solutions for the universal unique identification of physical objects. The EPC is a code standard expressed in the form of an Internet uniform resource identifier, which we call the "Pure Identity EPC URI" [17]. The uID is expressed by uCode, a typical type of 128-bit fixed-length identification number. nID identification is used when an object's ID does not exist. Such identification usually applies some biometric characteristics, including face characteristics, fingerprints, and iris, as the identifiers to identify an individual. Face identification and resolution in the IoT have been achieved[18].

Some researchers are aware of the importance of semantic web technology in the development of the IoT and have applied it to IoT modeling[19]. Semantic computing has been used to address the heterogeneity challenge facing the IoT and further to enhance the interpretation of IoT data[20]. The central idea of semantic web technology is to use metadata for the semantic description of the content of Web information resources so that a computer can understand and process the content of the resource based on the semantic information and create multiple higher knowledge-based applications. As an important role in semantic web technology, ontology is a method to express complex concepts and relations. There are two popular ontology description languages: RDF (Resource Description Framework) and OWL (Ontology Web Language). Compared with RDF, OWL is applicable because of its advantage in supporting complex semantic expressions. In addition, SWRL (Semantic Web Rule Language) combines the sublanguage of OWL with RuleML (Rule Modeling Language), which can be used to achieve strong deductive reasoning[21].

To model an object's attributes considering temporal and spatial characteristics, logical and ontological frameworks for objects have been proposed, in which the object and its properties are expressed as predicates and its attributes are expressed as predicates of predicates[22]. Physical makeup language (PML) based on the XML (Extensible Markup Language) markup language is another popular method of describing physical objects, which can also be used for descriptions of physical things, processes and enticements. Generally, a PML document can be built through application programming and information added to this document.

Most modeling work is currently focused on physical objects, especially for natural attribute modeling, and seldom considers the social attributes of things in the IoT.

### B. *Social research related with the IoT*

In recent years, social attributes in the IoT have attracted increased attention. Liu proposed the idea of perceived social theory with an emphasis on the important position of social attributes in the IoT, which includes network socialization, coordinated socialization and service socialization[7]. Ning proposed the U2IoT architecture, which consists of a Unit Internet of Things similar to the human neural system and a ubiquitous IoT similar to a social organization framework[8]. This work supplies an insightful description for the architecture of the IoT and clarifies the logical and organizational relations among all types of IoT. They studied the social attributes of physical objects, such as state, behavior, and relations, and the social attribute (dimension) concept for the IoT.

Based on the concept of the social relationships among objects, Luigi introduced a novel paradigm of "social network of intelligent objects", namely, a social Internet of Things (SIoT). Relations in the SIoT include parental object relations, co-location object relations, co-work object relations, ownership object relations, social object relations, etc.[9]. Integrating social network concepts into the IoT gives the SIoT the advantages of (1) guaranteeing network navigability, (2) establishing trustworthiness, and (3) addressing IoT-related issues. The SIoT was considered the next evolutionary step of the IoT[23]. The relationships between the IoT and social networks (SNs) allow people to be connected to the ubiquitous computing universe, which contributed to the development of some related research. In particular, this facilitated works on semantic web service environments, the realization of socially aware services in both online social networks and peer-to-peer social networks, location-based awareness, the analysis of social network graphs and trust management[24].

Dina researches the dynamic social structure of things in CPSS[25]. Kazi has identified the social structures of SIoV components, their relationships, and the interaction types. SIoV is a vehicular instance of the Social IoT (SIoT), where vehicles are the key social entities in the machine-to-machine vehicular social networks [26].

These works explored social research related to the IoT from different aspects. This paper will study social attributes in terms of thing relations modeling in the IoT.

## III. The Role of Relations in the IoT and Their Network Architecture

In human society, social relations are various associations among people. For example, friend, relatives, colleagues, et al. In IoT era, social relations exit among physical objects and have important role. Each object which is connected into IoT is mapped into cyberspace. Because their joining and working in the IoT, there are various social relations among them. Some social relations which are distinct can be directly acquired according to simply observation, comparison or thinking. Some social relations which are implicit can be acquired according to data mining method [27, 28].

In IoT, except for social relations among people, there are other relations among things. Then, we will discuss these relations among things, and puts forward network architecture of relations.

### A. *The role of relations in the IoT*

What relations exist among physical things? What role do relations have in the IoT? Objects and events are the main types of physical things; therefore, their relations are important in the IoT. We will discuss three types of relations—object-object relations, event-event relations, and object-event relations—and interpret the role of relations in the IoT.

(1) Object-Object relations

Humans are special physical objects; therefore, other objects, except for people, are marked as non-people object (*NPO*). We will discuss object-object relations from three aspects: people-people relations, *NPO-NPO* relations and people-*NPO* relations. Because of the special nature of humans, they are characterized by different relations compared with *NPO*.

① People-People relations

When people are the objects, we call these relations social relations. For example, friendship is a social relation. Sociology distinguishes the types of social relations from multiple angles, which are complex. Here, we only mention personal relations. For example, depending on the closeness of an interaction, social relations usually can be divided into primary and secondary relations. The former refer to the established social relations on the basis of feelings, and they reflect the extensive, in-depth and direct contacts between people such as conjugal relations and friendship. The latter are based on events, such as peer relations and leader-member relations. In addition to social relations, there are spatial relations which can represent the position relation among people. Spatial relations among people include front_of, back_of, top_of, bottom_of, left_of and right_of[29].

In the IoT, these relations can be used in relation identification. For example, in a smart home situation, when a person wants to enter a home, the smart home system can confirm the identification of this person by searching the family members' social relations so that the gate will open depending on the result of the person's social relation identification; for example, if this person is the house owner's friend, then the door will open automatically.

② *NPO-NPO* relations

In the IoT, there are many relations among *NPOs*. Parent relations mean that an *NPO* is built in the same period by the same manufacturer (the role of family is played by the production batch). Co-located relations are determined whenever things (e.g., sensors, actuators, and RFID Tags) constantly reside in the same place. Social relations are established when things come into contact, sporadically or continuously, for reasons purely related to relations among their owners[9]. The above relations are similar to social relations among human, and these social relations can be used to complete specific tasks. There are many other relations. Reaction relations (or risk relations) mean that two *NPO*s may produce a chemical reaction if they are mixed. Same function (SF) relations mean that these *NPOs* have the same function. For example, they are temperature sensor, pressure sensor, or vision sensor. Perceiving same object (PSO) relations mean that some perceive devices perceive the same object. For example, several vision sensors sense the same object-house. Spatial relations can represent the position relations among *NPO*. Spatial relations among *NPO*s include inside_of and outside_of relations. Outside_of relations include front_of, back_of, top_of, bottom_of, left_of and right_of relations.

These relations are important in the IoT. For example, in a smart home, the system will usually produce a warning about

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some risk. When a phone is near a fire source, an explosion may occur. If the risk relation has been modeled and the above event occurs, warning information can be sent once the relation is identified.

③ People-*NPO* relations

Relations between people and *NPO* are possessive relations and usage relations. Possessive relations are established when someone owns something or a thing possess some other things. Usage relations mean that someone has used something. In certain specific cases, there are some specific relations. For example, for a manufacturer, productive relations involve the products produced. There are also spatial relations between people and *NPO*.

In the IoT, these relations have many applications. For example, possessive relations can be used to solve authorization problems. In a smart home, for child safety, a domestic appliance cannot be used by children under a certain age. Therefore, the possessive relations can only be set for an adult.

(2) Event-Event relations

An event may cause the occurrence of another event. In addition, an event may be part of another event. There are complex relations among events. From the perspective of modeling, an event is abstracted as a class, and each event class has many instances. The relations are different between event classes and event instances[30].

*E1* and *E2* are two events classes. Then, a binary relation R (*E1*, *E2*) between *E1* and *E2* is called an event-class relation; *e1* is an instance of *E1*, and *e2* is an instance of *E2*.

Event instance relations:

① If *e1* causes *e2*, then the two event instances have causal relations ($e1 \rightarrow_{cause} e2$). According to the temporal relations, event instance relations are divided into disjoint, continuous, overlapping and partial causal relations.

② If *e1* occurs after *e2*, then the two event instances have a next-event relation ($e1 \rightarrow_{next} e2$).

③ If *e1* temporally includes *e2* and *e1* occurs in a spatial part of *e2*, then the two event instances have an event part of relation ($e1 <_{part\ of}\ e2$).

Event class relations:

① If *e1* and *e2* cannot occur simultaneously, then the two event classes have an event disjoint relation ($E1 \| E2$).

② If *e1* belongs to *e2*, then the two event classes have an event-subclass relation ($E1 \sqsubseteq E2$).

③ If each instance *e1* of *E1* and each instance *e2* of *E2* have the relation $e1 <_{part\ of}\ e2$, then the two event classes have a part-of relation ($E1 <_{part\ of}\ E2$).

④ If $e1 \rightarrow_{cause} e2$, then the two event classes have a causal relation ($E1 \rightarrow_{cause} E2$).

In the IoT, relations among events have an important role. The event subclass relation can be used to define the hierarchy of events. For example, traffic accident⊑natural accident ⊑event. The next and part of relations among event instances need to be distinguished; this is helpful in certain situations. When a fire occurs, a smart home system will call 119(in China). The event of calling 119 is the next event of a fire event. The event class disjoint relations can help to make some inferences, and further conclusions can be acquired. Now, there are some works related with event in the IoT[31-33].

(3) Object-Event relations

Usually, time, space and objects (people or *NPO*) are related to an event. An object has causal relations with an event. For example, if John sets fire to a house, the cause of the fire is John. Then, the relation is John$\rightarrow_{cause}$ Fire.

Except for the relations between object and event, objects' attributes also have complex relations with things. In the IoT, with the help of sensing data, some concrete causes of an event can usually be discovered. The causes of an event are usually natural attributes, social attributes of the object or context. For example, weather, years of driving experience and ages have relations with traffic accidents.

## *B. The network architecture of relations*

From the above description of relations in the IoT, we can see the complex relations among events, people and *NPO*; their relations act as a network, and thus, we can use super network knowledge in this paper to describe these relations. Super network is a special complex network. Since the appearance of small-world network theory [34], the research of complex network is related many fields: gene, sociology[35] , Internet of Things [36], et al.

In a super network, the system includes many nodes and networks inside a network. A super network is defined from different perspectives but still lacks a generally accepted definition. C. Berge proposed a hyper graph theory in 1970 [37]; if a network can be described by a hyper graph, then the network is a super network.

Definition (Super network): Assume that $V = \{v_1, v_2 \dots v_n\}$ is a finite set. If (1) $e_i \neq \varphi (i=1,2,\dots,m)$ and (2) $\cup_{i=1}^{m} e_i = V$, then the binary relation $SN=(V, E)$ is a super network. The element $v_1, v_2, \dots, v_n$ of $V$ is the vertex of the super network, $E=\{e_1, e_2, \dots, e_m\}$ is the edge set of a hyper network, and set $e_i=\{v_{i_1}, v_{i_2}, \dots, v_{i_j}\} (i=1,2,\dots,m)$ is the edges of a hyper network. The super network is shown in Fig.1. In the figure, $V = \{v_1, v_2, v_3, v_4, v_5, v_6, v_7\}$, $E = \{e1 = \{v_1, v2, v3\}, e_2 = \{v_2, v_3\}, e_3 = \{v_3, v_5, v_6\}, e_4 = \{v_4\}\}$.

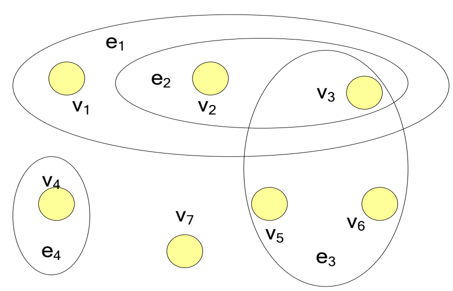


Fig.1. The super network

Super networks offer a new perspective for the architecture of relations. A node corresponds to things, and an edge corresponds to all types of relations among things.

We use *SAAM* to represent the architecture of relations. In the following, the construction of *SAAM* will be given. We select three types of things—people, *NPO* and events—to construct *SAAM*. Relations among people, relations among *NPO*s and relations among events respectively form a network.

An *NPO-NPO* network is formed according to relations among *NPO*. The node of the network is *NPO*, and the edge

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represents relations between *NPO*. The network model of (*NPO-NPO*) can be represented as $G_{NPO}=(NPO, E_{NPO\text{-}NPO})$. $NPO=\{NPO_1, NPO_2 \ldots NPO_n\}$ is the set of *NPO*, and $E_{NPO\text{-}NPO}=\{(NPO_i, NPO_j) \mid NPO_i, NPO_j \in NPO\}$ is the set of edges between *NPO*.

A people-people (*P-P*) network is formed according to relations among people. A node of the network is people, and an edge represents the relations between people. The network model of (*P-P*) can be represented as $G_P=(P, E_{P\text{-}P})$. $P=(p_1, p_2 \ldots p_n)$ is the set of people, and $E_{P\text{-}P}=\{(p_i, p_j) \mid p_i, p_j \in P\}$ is the set of edges between people.

An event-event (*E-E*) network is formed according to the relations among events. A node of the network is an event, and an edge represents the relations between events. The network model of (*E-E*) can be represented as $G_E=(E, E_{E\text{-}E})$. $E=\{e_1, e_2 \ldots e_n\}$ is the set of events, and $E_{E\text{-}E}=\{(e_i, e_j) \mid e_i, e_j \in E\}$ is the set of edges between events.

As we know, there are complex relations among people, *NPO* and events. A person can own many *NPOs*, e.g., Mary owns a phone, a pad and a sports watch. Mary has possessive relations with these *NPO*s. An event is related to certain people and *NPO*. Therefore, these complex relations are represented as super network architecture. The super network architecture for relations is shown in Fig.2. Except for the above networks, super network includes three new networks: People-*NPO* network, *NPO*-Event network and People-Event network.

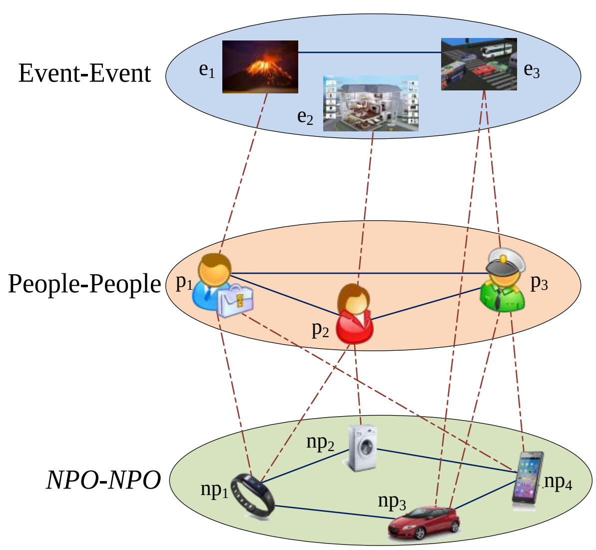


Fig.2. Super network architecture of relations

A People-*NPO* (*P-NPO*) network is formed by relations between people and *NPO*. This type of relations indicates the types of *NPO* that a person owns or is related with or who is related with an *NPO*.

An *NPO*-Event (*NPO-E*) network is formed by relations between events and *NPO*. This type of relation indicates the types of *NPO* that are related to the events.

A People-Event (*P-E*) network is formed by relations between events and people. This type of relation indicates who is related to the event.

$p_i \in P$, $npo_j \in NPO$, and $e_l \in E$ denote a node in a *P-P*, *NPO-NPO* and *E-E* network. $S(x, y)$ represents the connection. $S(p_i, npo_j)=\{0\|1\}$, $S(p_i, e_l)=\{0\|1\}$, and $S(npo_j, e_l)=\{0\|1\}$. When the value is 0, this means that there are no relations between the nodes of different layers; otherwise, there are relations between nodes of different layers. The architecture of relations can be defined as ①.

$$SAAM=f(G_P, G_{NPO}, G_E)=G_P+G_{NPO}+G_E+E_{P\text{-}NPO}+E_{NPO\text{-}E}+E_{P\text{-}E} = (P, NPO, E, E_{P\text{-}P}, E_{NPO\text{-}NPO}, E_{E\text{-}E}, E_{P\text{-}NPO}, E_{NPO\text{-}E}, E_{P\text{-}E}) \quad ①$$

$E_{P\text{-}NPO}=\{(p_i, npo_j) \mid s(p_i, npo_j)=1\}$, $E_{P\text{-}E}=\{(p_i, e_l) \mid s(p_i, e_l)=1\}$ and $E_{NPO\text{-}E}=\{(npo_j, e_l) \mid s(npo_j, e_l)=1\}$ represent the sets of edges among three types of physical things.

The *SAAM* model represents the complex relations among people, *NPO* and events. These relations can be stored, searched, and shown by a graph; therefore, they are intuitive and easy to understand. When we search for an event, the related people and related *NPO* can also be searched.

The people related to an event can be represented as ②.

$$E(p_i)=f(e_l, p_i)=\{p_i \mid p_i \in P, s(e_l, p_i)=1\} \quad ②$$

The *NPO* related to the people can be represented as ③.

$$P(npo_j)=g(p_i, npo_j)=\{npo_j \mid npo_j \in NPO, s(p_i, npo_j)=1\} \quad ③$$

*SAAM* can help us to distinctly see the complex relations among people, *NPO* and events. This hierarchical network is easy to realize when relations are mapped from the physical space to cyberspace. In the next section, according to the above relations and the network architecture of relations, an ontology-based approach will be used for thing relation modeling.

## IV. AN ONTOLOGY MODEL OF THINGS IN THE IOT

The ontology-based approach includes class declaration and property declaration (including data property and object property). In this section, the Protégé, one of the best ontology editing tools which creates ontology with a GUI, will be used for relation modeling. Generally, the Protégé includes parts of Pellet and other reasoning machines, with which class, data property and object property declarations can be obtained. Furthermore, relations will be declared in the object property.

### *A. The building of ontology model*

In ontology, classes correspond to different types of things. The top class thing can be classified into sub-classes including physical objects, event, etc. Physical objects has people and *NPO*. In a specific application scenario, more sub-classes can be defined. For example, the part of ontology class in smart home [38, 39] is shown in Fig.3. Device and furniture are the sub-classes of *NPO* class. Further, the sub-classes of device include communication device, meter, security equipment, entertainment equipment, home appliance, sensors, information device and lighting. And the sub-classes of people has guest, stranger and family members. The sub-classes of family member include adult, child and older. Except for class definition, Physical things' natural attributes and social attributes can be modeled as data property or object property. Data property is used to formalize things' natural attributes or some social attributes, which includes name, id, etc. Hereinto, ID is the unique identification of an object and can be represented by EPC or uID code standards. Object property is used to represent relations among classes or individual cases.

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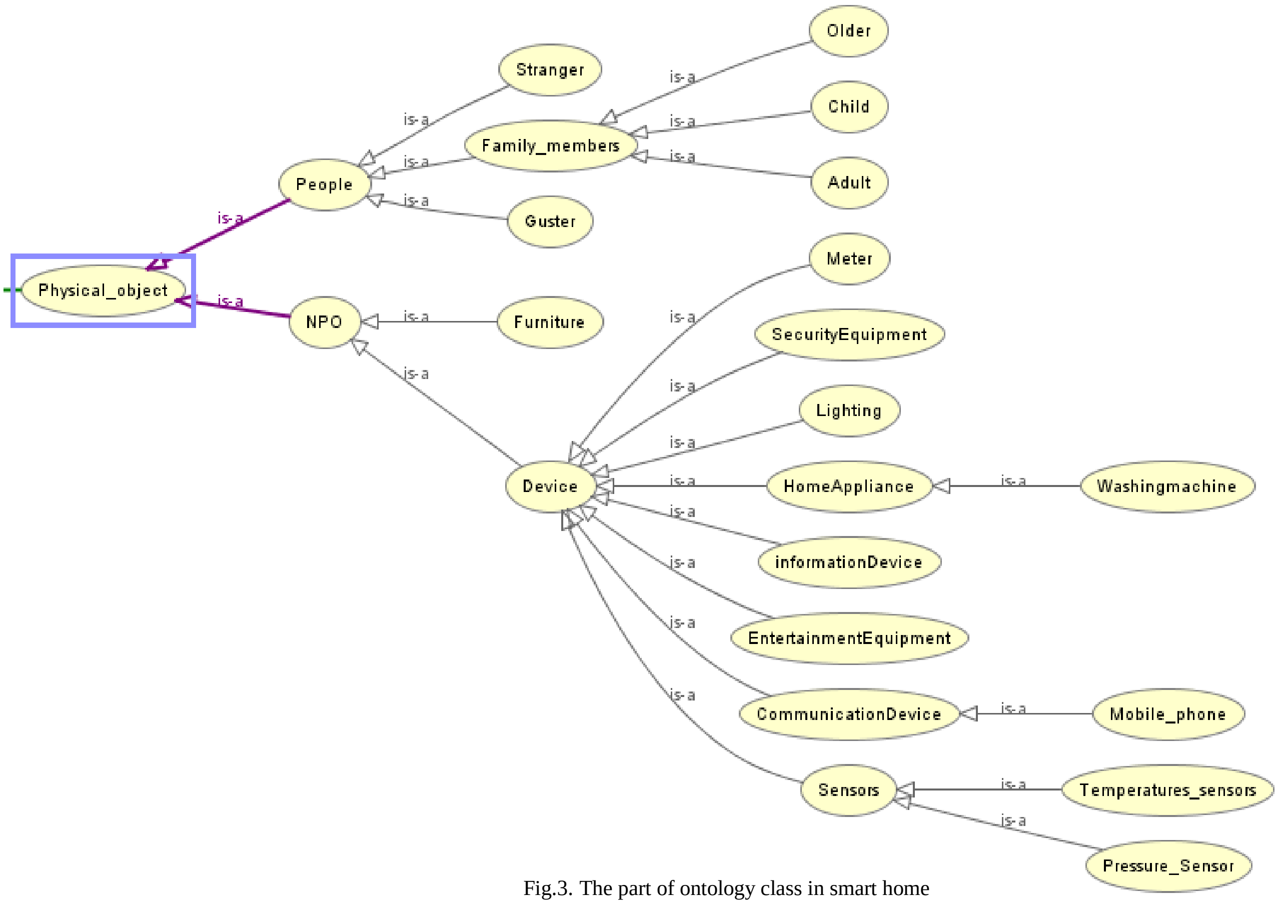


Fig.3. The part of ontology class in smart home

Some certain sub-relations have be described in section II. The definitions of relations are shown in Fig.4in which only part of them are given and more relations can be added according to the needs of a specific application.

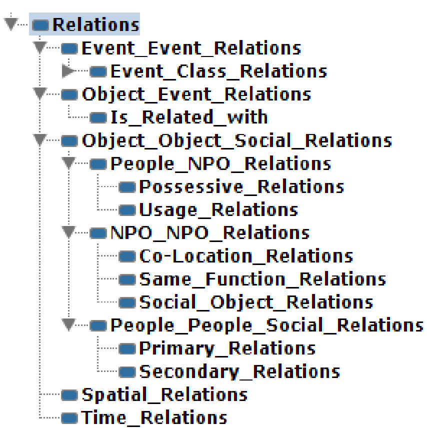


Fig.4. The definition of relations

A ontology model of things is created with the class, data property and object property being declared. Furthermore, cyber entities of individual cases of things can be declared according to the model and data. Individual cases of things, which are cyber entities, can be declared according to the model and data.

For example, a phone, a typical case of *NPO*, can be described in the JSON format as follows.

{"Identifier": { "id": "urn:epc:1:2.*.*"},
"Color" : { "co": "white"}
"Creator": { "name": "Huawei"},
"Relations ":{ "possessive relations": "Mary"},
}

Emily who is a case of people can be described as follows:

{"Identifier":{ "id": "3623*****"},
{"nid": "***"}
"Highest Education":{"Education"," Master"}
"Social role":{"Profession", "teacher"}
"Social relations":{ "Friend":"Rose"， "Smith"},
}

Relations are social attributes of cyber entities. They can be used in some scenes, but before that, the rules need to be set in advance. For example, in a smart home scene, some electrical appliances should not be used by a child considering security. When a person touches the electrical appliance, the system should judge the safe state for the people. The judgment of safe state can be expressed by SWRL rules. For example, *Person(?p)^contact(?c)^electricalappliance(?e)^attackedto(?c,?e)^isValue(?c,"on")^Usage_Relation(?p,?e)->safestate(?p).* In this rule, contact represents touch sensors, which are attached to the electrical appliance. This parameter takes on two values—"on" and "off"—which indicate whether the person has touched the electrical appliance. Usage_Relation (?p, ?e) is used to judge whether there is a usage_relation between p and e. Safestate (?p) means that the person is in the safe state.

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### B. *The discovery of relations based on SWRL*

An ontology-based approach also supplies an inference function through SWRL. The individual cases are instantiated according to an ontology model and raw sensor data. The individual cases have concrete attribute information, which includes existing relations among things. Based on the information of individual cases, new relations can be discovered through inference mechanisms or other data analysis methods. Here, we use inference mechanisms to interpret the discovery of relations.

As we know, an event is related to people, and *NPO* is related to time and space. Therefore, space, event, time, *NPO* and people classes are built. The time class has two sub-classes: interval and instance. Interval possesses the data properties begin_time and end_time. Individual cases are defined for each class. If two events occurred in the same place and the occurrence time had inclusion relations, things and people in two events may have certain relations. *I1* and *I2* are interval cases. *Inst1* and *inst3* are values of begin_time, *Inst2* and *Inst4* are values of end_time, *E1* and *E2* are event cases, *S1* is a space case, *P1* is a case of the people class, and *NPO1* is a case of the *NPO* class. The SWRL rule is shown in Fig.5. Through inference, the new relations of *P1* related to *NPO1* are discovered.

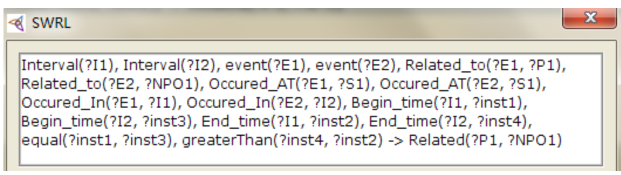


Fig.5. The SWRL reasoning rule

The above example shows the discovery of simple relations through an ontology inference mechanism. In addition to inference mechanisms, relations that involve social attributes of things can be discovered through data analysis methods.

### C. *An application case of relations in smart home*

In smart home, when a person stands at the doorway, the smart home system can confirm the identity of the person and his social relations. The service framework of smart home is show in Fig. 6. The sensors collect people's biometric characters, e.g. fingerprint and face images. The identification server is responsible for resolving the identity of person. The social relation server stores the social relations of the family, and is responsible for the searching of social relations.

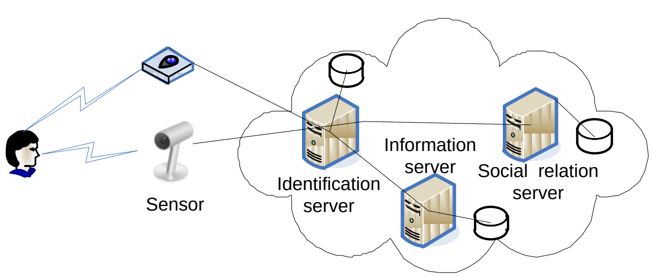


Fig.6. The service framework of smart home

When a guest of Mary visits her, the gate will automatically open. The whole process is as follows:

(1)The information of the guest is collected by sensors. For instance, a camera takes face photos of the person who is standing at Mary's doorway. Then the camera sends theses photos to the identification server.

(2)The identification server uses independent component analysis (ICA)[40], Gabor feature[41], LBP[42], and other face recognition algorithm to generate face identifiers from these face photos. Then the server can confirm the identity of the person with the face identifiers and some storage information.

(3)The identification server automatically sends the identity of the person to the social relation server. The server searches Mary's and her family members' social relations network. If the person is the guest of the family, the server will send a command to the gate controller. Then the gate in the physical space opens.

In the social relations network, all guests are set in the beginning. After that, the smart system with learning ability will automatically modify the social relations network according to the real situation. For example, a stranger can be turned into a guest according to his visiting times.

The above example interprets that considering things' social attributes can improve the serviceability of IoT.

## V. CONCLUSION

From the view of the social attributes of physical things, this paper focuses on thing relation modeling research. The work investigates the role of relations in the IoT and the architecture of relations and uses appropriate methods to realize thing relation modeling. First, we analyze three types of relations—object-object relations, event-event relations, and object-event relations, and discuss the role of relations in the IoT. Second, for complex relations, we use super network to describe the relations architecture among things. Third, based on these relations and their architecture, we use an ontology-based approach to realize thing relation modeling in the IoT. The ontology-based approach mainly includes class declarations, property declarations, individual case declarations, and inferences. The inference process uses SWRL rules. Finally, we use a case to interpret the concrete application process of relations in smart home.

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