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The Interactive Computing Model for Cyber Physical Society

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***Abstract*—With the permeation of information technology into the physical world and human society, we are on the way to a Cyber Physical Society (CPSocio). A CPSocio inter-connects the nature, the cyber space, and the society, so as to provide human beings with a better living and working environment. Researches on CPSocio will lead to a new revolution of information science and technology. In realizing CPSocio, semantics is the most fundamental problem. It is the foundation of all the intelligent activities such as communication, interaction, and cooperation in CPSocio. We are facing various scientific challenges to understand and clarify principles and models of the computing in CPSocio. In this paper we focus on the interactive computing model of Cyber Physical Society, discussing a possible architecture and computing model that enable future intelligent distributed services in CPSocio. The proposed model focuses on the interactive computation emerged from self-interpretation, self-organization and interactions of individual objects. Self-interpretation enables objects to actively express their own semantic information to others. Interaction among objects will help achieving computing solutions in open, dynamic, limited and heterogeneous environments with partial available information and services. The model aims at providing a feasible framework for systematically tackling key problems and building intelligent services in CPSocio.**

I. INTRODUCTION

With the rapid permeation of information technology into the physical world and human society, new applications such as Internet of Things (IoT) [1], Cyber Physical System (CPS) [3] and new computing paradigms such as Cloud Computing [4] emerge rapidly. Promoted by the governments and industries, together with the effort of universities and research institutes around the world, a new revolution of information technology is on the eve. Internet of Things draws a colorful picture of future life: when people are connected with things equipped with identity and intelligence, the briefcase will remind his owner not to forget important documents, clothes will tell the washing machine her requirements for water temperature, and trucks will tell the porter the current vacancies for loading. From the micro aspect of view, a CPS is a set of physical objects which are integrated with computing resources, bestowed with identities and individual intelligence, and allowed man-machine interactions with physical process to provide intelligent services; from the macroscopical angel, a CPS is a complex network of physical devices with the functionalities of computation, communication, control, remote coordination and autonomy, which combines the participants' individual intelligence into a more powerful collective intelligence.

Beyond the philosophy of IoT and CPS and as their natural extension, a Cyber Physical Society (CPSocio) will come to birth during the continuous evolution of IoT and CPS and their integration with human society. CPSocio will bring to human beings new living spaces and development opportunities [19]. The CPSocio concerns not only the cyber space and the physical space, but also humans, knowledge, society and culture. It inter-connects the nature, the cyber space, and the human society [32-36]. We argue that the future interconnection environment should encompass these three different systems intelligently and seamlessly. The integration, interactions and evolution of the three worlds will lead to a CPSocio, where the physical world includes the nature, artificial materials, physical devices and networks, the virtual world is the digital interconnection environment constructed through perception of the physical world including mainly vision, hearing and to some extent touch, smell and taste, and the human word, which is composed of people, knowledge, culture and so on.

Figure 1 depicts the interactive computing scenarios in CPSocio. One can see that at least three systems are involved, and there are various interactions inside the systems and inter systems. In the computing services of CPSocio, semantics is at the core because it is the foundation for all the intelligent activities in CPSocio to understand and corporate with each other. Thus, it is a fundamental and challenging to find solutions to the following problems: what is the basic semantics of CPSocio? How can the semantics of one world be understood by other worlds? What is the appropriate computing model of CPSocio?

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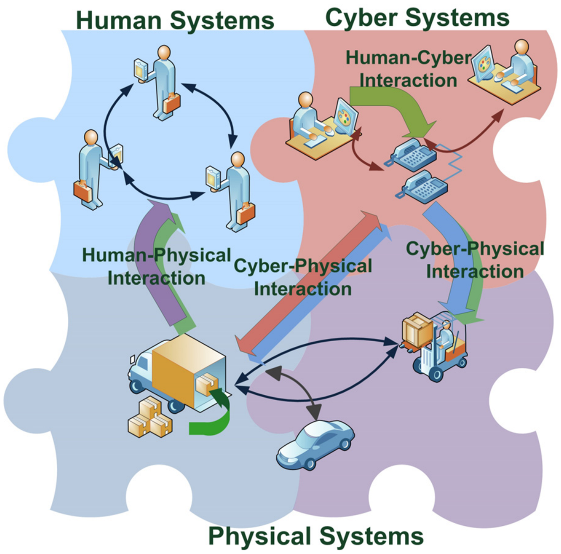

Figure 1. Systems in the Cyber Physical Society.

In this paper we present an interactive computing infrastructure for deploying scalable and intelligent services in CPSocio. The key idea behind the proposed model and infrastructure is to let the objects in CPSocio express and interpret themselves and interact with each other to accomplish the computing tasks. The computing infrastructure in CPSocio needs to deal with various difficulties including the dynamic and heterogeneous physical hardware environments, the open data view, the uncertainty of the communication and the partially available information. The proposed model is to cope with these challenges in a comprehensive way.

II. Related Work

With the development of communication and computing technology, Internet of Things (IoT) has become one of the most popular topics in recent years. The International Communication Union (ITU) [1], the US National Science Foundation (NSF) and the European Union etc have proposed their IoT roadmaps [2][3][6].

There is still no consensus on IoT. ITU's 2005 report pointed out that IoT makes possible the inter-connection and interaction between everyone and everything at any time and any place [1]. It was agreed in the report of the CPS (Cyber Physical System) Summit organized by the US NSF that CPS is a physical and engineering system that is monitored, coordinated, controlled and integrated through a computing and communication platform [3]. It was noted in the EU EPoSS (European Technology Platform on Smart Systems Integration) report that every object in IoT has its own identity and characteristics, communicates and interacts with each other in the information space consisting of society, environment and user through the interface in intelligence space. All these specifications of IoT share many common aspects with our analysis of the future interconnection environment in 2005 [5].

Researches on the underlying medium and communication technology have been carried out for years. Technologies such as sensor, RFID, kinds of wireless communication and near field communication are already mature and in the process of standardization. The IoT, as is expected, is the direct result of the development in chip and communication technology [18]. The real challenge in the next step is how to effectively utilize these underlying technologies to construct an intelligent and scalable distributed large-scale system to realize intelligent object-object interaction and to provide intelligent information services in CPSocio. The development of CPSocio at the application level lies in three aspects: object sensing, object-object interconnection, and object-object interaction.

A. *Object Sensing*

One of the research advances is to identify and sense physical objects using wireless and wired networking and communication technologies, as well as other intelligent information processing technologies. Now we can identify objects using RFID tags, perceive object status using sensors, and recognize objects using videos from monitoring cameras etc. Despite of lacking unified standards, there are already a bunch of usable mature technologies [1][2][21]. However it is not enough only to identify physical objects. The intrinsic attributes, information and knowledge carry abundant semantic information, which is even more important to the perception, control and interaction of objects. It is still under study how to represent physical objects' semantic information. It is not only a problem of standardization. It also needs to resolve the problems regarding the representative model, the interpretation model and the computing model of semantics.

In CPSocio, traditional data model and semantic representation model are unsuitable due to the heterogeneity, uncertainty, locality and dynamicity of physical devices, so it is a brand new research challenge to design a scalable model for representation and computation of semantics in CPSocio. Recent researches in wireless sensor networks and in CPS focus on adding an abstraction layer to physical objects for the purpose of representing different properties of objects under certain circumstances and providing corresponding computation tools [8][25]. But these work put the emphasis on the data representation and computation at server side. Information in a dynamic, heterogeneous and distributed networks have the dynamic, local and incomplete characteristics. Thus, it needs to study that which appropriate data models and semantic models for object descriptions in order to make physical objects self-organized, self-adapted and self-served to a certain degree.

B. *Object-Object Interconnection*

That is to make physical objects with identities connected into a network using wireless and wired networking technologies. We can solve the networking problem of wireless tags by near field communication technologies [26], and resolve network addressing problem using IPv6 etc [27]. An important problem in object-object interconnection is the integration of networks with heterogeneous structures, i.e. to provide a unified addressing and communication protocol in order to make physical objects in heterogeneous, dynamic and ephemeral networks connectable to CPSocio. The key of object-object interconnection is to support interconnection in semantic level. World Wide Web (WWW) offers us a nice resource identification and location mechanism. IoT shall in future be seamlessly interconnected and integrated with WWW, wherein the crucial point is the definition of existence of objects in WWW. Many Web base solutions have been proposed to integrate the IoT and CPS services with the Web framework [9][10][11][12][13][14].

Web-based interconnection solutions provide an extensible platform for computing systems to deploy in a standard data and service exchanging platform. It also provides opportunities for developing interconnection platform in a higher level of semantics, allowing the system to be integrated in an application level. However in a heterogeneous and dynamic distributed environment how to resolve the problem of lacking a central server becomes critical.

C. Object-Object Interaction

Once physical objects are networked, they can communicate, interact and cooperate with each other. This is the key to construct a scalable information system in CPSocio. Interaction and cooperation cannot be simply regarded as a problem of individual intelligence like pattern recognition, classification and reasoning concerns. Interaction is an intelligent process of collective work and evolution. Simply merging the objects in IoT using mashup [11] does not tackle the core of intelligent service. Considering Ambient Intelligence in the service integration is a step towards this goal [14]. In fact, intelligence can not only be reflected by any individual participant in the system but also emerges during the coordination and cooperation among a group of objects.

Interaction processes also have advantages in supporting intelligent services in dynamic, open and limited networking environments. Dealing with uncertainty, dynamic, and ephemeral events in sensor network now become more and more important [23][25]. There are also many platforms and frameworks that are presented for developing and deploying wireless sensor network applications [15][16][22][24]. Because it is difficult to obtain global information in CPSocio, interaction becomes a key process that helps acquire information in dynamic, open and limited environments. To study the emergence process of intelligence in a distributed environment is fundamental to realize intelligent object-object interaction.

III. Computing Elements in Cyber Physical Society

A. New Computing Environment

On the basis of interconnection and interaction between objects, a harmonically and organically evolving CPSocio will eventually turn up. The goal of the intelligent computing infrastructure in the CPSocio is to bestow physical objects the abilities of self-interpretation and perception, and the abilities to judge, response, decide and act according to their perception of environment, and incorporate the physical objects, machines, and human-beings into an intelligent interconnected network.

As we have discussed in the above section, the key step towards realizing CPSocio is to sense the objects. It is quite difficult to sense and recognize an object through one attribute of it. There still lacks feasible theories and techniques supporting a comprehensive recognition from multiple aspects. The reason is that features of objects and their representations cannot be unified and thus no single model is suitable for recognizing objects. For example, pattern recognition technologies for object shape and location are entirely different because of their entirely different data models. Even the properties of the same type require different recognition technologies due to different features, e.g. recognition technologies for face movement and body movement.

There are a large portion of objects in the real world whose properties and behaviours are controllable. If these controllable objects also own the ability to self-express and self-interpret, they will become much more intelligent. This idea distinguishes the CPSocio research from the traditional AI research in the following several points:

(1) If an object can express its properties and status actively and appropriately, many perception and recognition problems can be transformed into interaction problems and become easier to tackle.

(2) Traditional AI researches put more emphasis on the individual process of perceiving the surrounding environment and making reactions accordingly, such as planning, reasoning, recognition, and classification etc. The computation procedure, i.e. how input to an individual determines the output, lies at the core of the traditional AI research. Yet they do not focus much on the intelligence emerged in the process of self-interpretation, autonomous interaction, sharing and evolution of objects in a large, dynamic system, where human-beings, machines and physical objects are involved.

(3) Computation in CPSocio faces more challenges including dynamic networks, heterogeneous computing devices, limited resources, open data spaces, local data views, and many other problems like uncertainty.

The computing model in the CPSocio should bear at least the following features to cope with these challenges.

(1) *Scalability*. The computing model should scale with both the computing hardware capabilities and the network bandwidth. It should be able to run in both tiny computing devices and powerful servers. It can scale down its bandwidth consumption in limited networking environments.

(2) *Self-Adaptivity*. To scale down and up intelligently and automatically in dynamic and limited environments is another key feature of the computing model in the CPSocio.

(3) *Autonomy*. The computing model should be able to work in a server-less computing environment. That is, it should not depend on any pre-installed centralized services.

(4) *Openness*. The computing model should not assume a close world view on its data model and service model.

(5) *Fault-tolerance*. The computing model should be able to cope with uncertainties and failures, at least to some extent, to improve the survival rate of the services in limited and harsh environments.
(6) *Evolvement*. The computing model should be able to cope with the evolving environments in a dynamic way. To learn to optimize its computing routine, resource consumption, and solution finding.

B. Interaction As the Core of the Computing Model

To cope with these challenges, a new computing infrastructure is needed. We argue that the interaction is the core module of the desired computing model in CPSocio. As we have discussed in above section, the limits of current AI techniques drives us to seek to another roadmap to implement intelligent computing systems in CPSocio. Light-weight computation systems have been proposed to deal with these difficulties [7][17]. Interaction gives us a chance to achieve the solutions without much difficulty if objects can express their own semantic information, even in a very limited way.

For example, it can be more convenient to let an object tell us its location than to make decision through analysis of video clips, and an object can indeed decide its own location through exchanging location information with other surrounding objects, even with only partially available position information from those surrounding objects. For another example, a small set of nearing vehicles on the road can interchange their routes, destinations and available partial traffic information in a local small range to help make optimal route selection in an approximate way. It thus avoids using a central server to make a global route planning and optimization in a very large global data set, which is a hard computing problem. In a limited environment without powerful servers, the interaction can play even more important role in identification, optimization, planning, and controlling.

In above computing scenarios, the two basic features are shared:
(1) Objects can express their information and state for sharing, making the interaction based computing possible.
(2) Through the interactions of information of objects, computing goals can be approximated with local and partial information.

In fact, the computing model based on interaction has many merits that make it suitable as the underlying computing model for CPSocio:
(1) *Distributed*. The computing model based on interaction is naturally a distributed one.
(2) *Active*. The interaction among objects make the information access more flexible when objects can active publish and exchange their knowing.
(3) *Reciprocal*. The computing target can be achieved with other objects' help through interaction.
(4) *Peer-to-peer*. Objects are equally treated and assumed to be willing to provide their own partial information. And objects cannot assume that a powerful centralized server is available.

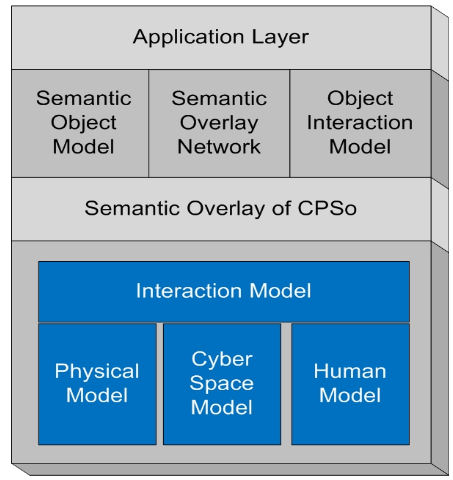

Figure 2. Computing Models for the CPSocio.

(5) *Open*. The computing model depending on interactions assumes an open-world semantics in its data view over the whole system. That is, since we are peers, if I do not know the solution, can I assume that other people know? I can try to ask them since they are active and our work is reciprocal.

These features correspond well to the requirements of the computing model of CPSocio proposed in previous section. Thus, we believe that involving interaction based computing model will help us realize the CPSocio. Then, the key question is that how to build a suitable computing infrastructure that can leverage interaction to provide intelligent computing services in CPSocio.

C. Interactive Computing Infrastructure

To incorporate the interaction into the computing model, we need to model the computing system in a more abstract level than previous any system. That is, we need to consider not only the cyber space, but also the physical world and the human world in a harmonic computing model framework. What we are facing is not only to databases, services, Web sites, but also to real physical objects and human-beings that interact with the physical world and the cyber-space world.

The computing model should not isolate any parts that play important roles in the system. Thus, the underlying part of our proposed model consists of the physical model, the cyber-space model and the human model, corresponding to the three subsystems in CPSocio. Figure 2 illustrates the basic infrastructure of the computing model in CPSocio.

Interactions among these three sub-systems are modelled in a synthetic framework, integrating three different parts in a unified way. Objects from different subsystems are mapped into one space where they can interconnect and interact in an abstraction level that mainly reflects the semantics of objects. We call this level a semantic overlay.

Semantic Overlay is just like another Web in the semantic level, interconnecting objects using URI in a semantic level. That is, each object in the system will be assigned with a semantic identification that is used to express its internal semantic information including identification, contents, status, services, and so on. We name such objects as the semantic objects. Semantic objects can connect each other either temporally or permanently to interact, coordinate and provide services to achieve the goals.

The computing model should focus on the logic level of interconnection among semantic objects, instead of the physical network level, make the high-level computing more adaptive to the underlying hardware platform. Thus, the semantic overlay level should be scalable and flexible in coping with the underlying dynamic, limited and large-scale physical network. Moreover, it should be able to support object location, message routing, and high-level distributed query processing in a fault-tolerant and efficient way.

Once the semantic objects can be connected on the semantic overlay, they will be able to interact with each other to perform tasks. How the interaction can be seamlessly supported over the semantic overlay needs to be further studied.

IV. Semantic Object

A. Semantic Object Structure

Semantic objects are the basic elements implementing various services on the semantic overlay. Semantic objects are the mapping of physical objects, cyber space objects and human-beings in the CPSocio. The self-interpretation is the core feature of the semantic objects, enabling the interaction in open, heterogeneous, dynamic, limited networking environments. That is, the semantic object should encapsulate the necessary information and computation information to make them autonomous to certain degree. They should not depend much on services from outside to perform information processing.

Figure 3 shows the basic structure of the semantic object. It consists of a set of object interfaces through which the basic interaction channels are setup with other objects. The semantic interpreter is to parse the interaction messages in the semantic context to distinguish different semantic interaction channels that have been setup with other objects. Inside the semantic objects, the semantic core plays the self-interpretation, interaction, action according to the current internal semantic states of objects and the semantic views on outside world. Semantic memory is for temporally storing the interaction contexts. Semantic identification is to represent the objects semantic content in a unified semantic representation language.

Taken the internal structure of a semantic object as a whole, the semantics of an object is reflected by not only attributes but also interactions. Self-interpretation can be regarded as the self-expression and self-illustration of the properties, functionalities, status and constraints of physical objects.

A semantic object can be viewed as a semantic tag attached to certain physical object, cyber-space object or even a human-being. The semantic expression, interpretation, and interactions of objects are treated in a unified semantic

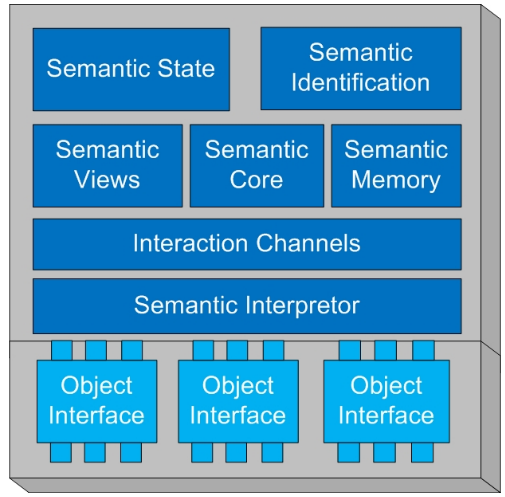

Figure 3. Semantic Object Model

computing framework that is encapsulated inside the object. That is, the semantic object model is not only a data model, but also a computation model. The interpretation of the semantics does not depend on outside computing modules that could not be available in limited environments. Instead, the object carries the interpretation computing procedures along with itself. In this way, the object becomes active and self-expressed. This object-oriented principle enables the whole system to be built with autonomous blocks in open dynamic environments.

B. Self-Interpretability

The key strategy of CPSocio in handling open, dynamic and limited heterogeneous environment is to put at the core the semantic expression of individual objects, making objects active, autonomous and self-interpreted. Semantic information of physical objects is identified by semantic objects. Intelligent interactions and cooperation between objects are based on the self-interpretation of semantic information beard in semantic objects.

In traditional definition, semantics is regarded as assignment and interpretation (computation) to strings. The semantic space is determined by the interpretation process. Usually, interpretation is isolated from the data carrying semantic information. In application scenarios of intelligent semantic tags, storing and publishing data with semantic information in semantic tags is not adequate for resolving the interpretation and computation problems of semantic tags in an open environment. That is, in an open environment, there’s no guarantee of an accurate semantic computing model to correctly interpret the semantic information beard in semantic tags. In this situation, a feasible solution is to allow not only semantic description information but also semantic computing information. However general script languages or binary executables will bring unresolvable difficulties to query, matching and integration of semantic information. Due to the undecidability of programming languages, we are unable to understand the computational semantics of one program using another program. So it is impossible to use a computing language equivalent to Turing machine as semantic information carrier and embed it into intelligent semantic objects. The key to this problem is to design a language model which partially supports the representation of semantic interpretation (computing) information and at the same time is decidable and has relatively low computational complexity. In fact, in most cases, we do not need a complete interpretation of the semantics of objects. That is, to some degree we can ignore the correctness, completeness or soundness that will make problem undecidable or hard. Rather, approximation can be made by using some semi-structured computing model to achieve an acceptable semantic interpretation accuracy.

C. *Self-Interpretable Semantic Description Language*

It is a key problem to design an intelligent semantic object language based on self-interpretable semantics. At the heart of the language is the representation of computational semantics. In an intelligent semantic object language, data semantics such as properties, status and contexts can be expressed using traditional semantic representation methods such as Semantic Web, while computational semantics can be regarded as a queryable and executable program. The expression and operation of computational semantics need to be integrated into the intelligent semantic object language. There are also a series of research problems concerning intelligent semantic object, including an intelligent semantic object storing and indexing platform, data structures for storage management of semantic objects and a corresponding light-weight operation language, compatibility with database storage schema, Web resource representation models such as Semantic Web and Web service.

To achieve semantic self-interpretation, we need to embed semantic computing information into intelligent semantic objects. In traditional computing models, data and program are isolated, such as database, Semantic Web etc. Despite of the advantages such as extensibility and optimizability, there are also many weak points, e.g. the heterogeneity problem. That is, we do not know the interpretation of data unless we get the interpretative program. If we don't store semantic computing information in intelligent semantic object we have to do the computation on other devices, which is very inconvenient to deal with in practice. If every semantic object needs a specific short interpreter, it means that every device that uses the semantic objects has to load a corresponding interpreter in advance. This is obviously infeasible.

The idea of our way to solve this problem borrows much wisdom from object-oriented programming languages, persistent object model and dynamic languages [20]. Our solution is a light-weight self-interpretable intelligent semantic object language. In recent years, the trend of integration of data and computation becomes a mainstream in the programming language domain. Examples of this trend include LINQ in C# and Active Record in Python etc. The essential idea is to transfer the query, representation and operation of data, which are traditionally separated from programs, to the language side. This combines data operation with program more tightly. The self-interpretable semantic model makes a further step to combine the semantic representation and computation together by defining a light-weight object-oriented semantic description language. OSLN is such an initial step [28]. In OSLN, both semantic representation information and semantic computing information are uniformly encapsulated in a semantic object. OSLN defines a unified interpretation and execution model for semantic computation, that is, to realize the self-interpretability of intelligent semantic tags through interpretative execution of semantic objects. Interpreters are stored in semantic object. Computing devices will fetch the embedded interpreters from semantic object. The encapsulation characteristic and interpretative execution architecture makes intelligent semantic object not only a carrier of data but also a carrier of computation.

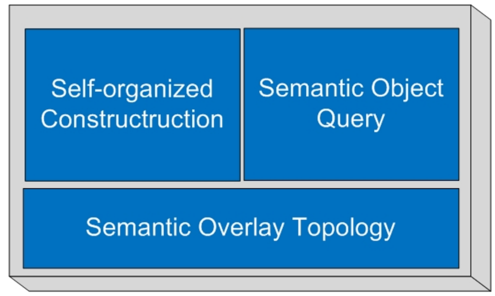

Figure 4. Semantic Overlay Model

Compared to LINQ in C#, OSLN puts more emphasis on semantic representation but not on data description. Different from the semantic representation languages for the Semantic Web such as RDF and OWL, OSLN at the same time supports descriptions of semantic computing while the former needs an interpreter written in another programming language such as Java.

V. SEMANTIC OVERLAY

The semantic overlay is formed by connecting semantic objects in an abstracted level. Each object for a certain physical object, or a cyber-space object, or a human being must be implemented in a physical level with physical ID and network connections. However, physical level identification and network connection is not the core problem for the intelligent services in CPSocio. Only connected in the semantic level can the CPSocio provide intelligent services. That is why we focus on the semantic overlay that is built upon the physical networks to support interconnection and interaction in the semantic space.

There are three major components in the semantic overlay model (see Figure 5). First, to cope with the dynamic physical environments, the semantic overlay should select an adaptive and robust network topology as the underlying networking platform. The topology of the semantic overlay is unstructured with constructed long links and short links among semantic objects to reflect the semantic relationships among objects.

The unstructured topology has better robustness and fault tolerance than structured topology, although the query routing efficiency may not that efficient as the structured ones. However, when the topology bears the small-world features, the message routing efficiency can be improved. In fact, many natural and social networks bear the small-world features [30].

Second, the construction of the topology should be in self-organized way. Building a small-world network topology can be done from different ways [30][31]. One can explicitly use some specific long link distributions to generate navigable small-world topologies. Evolving method such as BA model can be leverage to form scale-free network topologies that also bear small-world features. The inherent self-organization and evolvement of the small-world networks make it a promising solution for building the semantic overlay network in self-organized way.

Third, the semantic overlay should be able to support semantic object queries in a scalable and distributed way. Semantic object location is to query semantic objects according to the query conditions on the semantic contents on the semantic overlay. Since there is no guaranteed centralized server for query processing, a distributed semantic query processing mechanism is needed. There have been many distributed query processing methods proposed on ad hoc networks [29]. These methods can be leveraged to support complex semantic query processing on the semantic overlay.

VI. DISTRIBUTED INTERACTIVE INTELLIGENCE MODEL

Distributed interactive intelligence could be regarded as a self-exploration, self-optimization and emergence process of computation procedures through distributed interactions. Since information is incomplete and unpredictable in open and dynamic environment, traditional logic reasoning is not well applicable. In CPSocio, physical objects reflect their semantics through perceivable properties and interaction with the surrounding environment. Through interaction the target solution space can be approximated. For example locating an object can be accomplished through interactions of this object with multiple other objects. The underlying premise here is that we can deduce the target information in the semantic space composed of the local information of the individual objects, and an interaction could be deemed as a routing choice in the semantic space based on local information. Therefore, building the distributed interactive intelligence model could be regarded as routing in a certain semantic space based on incomplete information.

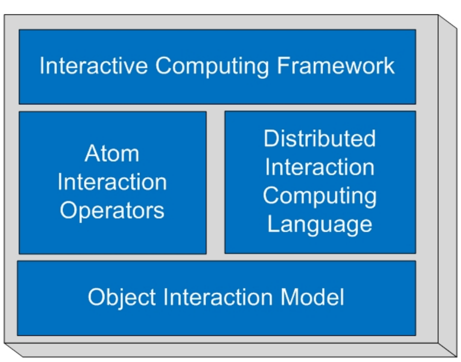

Figure 5. Interaction Model

Figure 5 illustrates the basic components in the interactive computing model. The underlying is the object interaction model, which consists of two main parts: atom interaction operations and distributed interaction computing language. Based on the interaction model, we need to build up a distributed interactive computing framework to support the application development, running, and maintenance.

A. Object Interaction Model

Atom interaction operators play the core role in the object interaction model. It defines the basic interactions both in syntax and in semantics for achieving information and performing computation over the semantic overlay. An interaction operator will encapsulate the normal processing schedule, the message routing process, the semantic schema of the operator as well as the uncertainty handling and exception handline process. The scheduling will determine the routine of the interactions to be issued in certain contexts. The message routing process determines the remote semantic objects that are to be interconnected and how the messages will be scattered or routed to the target semantic objects. The semantic schema defines the data to be sent or to be retrieved. The uncertainty and the exception handling will define what actions to be taken when the failures or uncertainties occur.

The atom interaction operators will encapsulate those complicated context handling processes so that the developers can easily develop and deploy the application logic using interaction operators. Thus, we also need a distributed interaction computing language that supports distributed programming and running based on the atom interaction operators. The programmed interaction protocols will be embedded in the semantic core of the semantic object to guide the interactive computing over the semantic overlay.

B. Distributed Interactive Computing Framework

Because semantic computing information, i.e. semantic program interpreter, is embedded in semantic objects, it is a critical to study how to utilize these light-weight semantic computing information to realize the dynamic interaction between semantic objects. A distributed interactive computing framework is required to provide the developing tool box, the runtime supporting environment, the middle-ware for integrating with Web, Internet, databases, and other data sources. With the framework, it is possible for users to develop and implement their own intelligent semantic objects tailored to certain interactive computing applications.

By virtue of the framework, system designers can make abstractions of the application scenario, model the intelligent computation problem, develop the corresponding semantic computing modules, and finally establish the distributed intelligent application based on interaction . The intelligent interactive computing developing platform should be compatible and seamlessly connectable to existing platforms, including information services on WWW such as semantic

Web and basic protocols such as SOAP and URI, which will allow seamless integration of intelligent semantic objects into Web computing and then the interconnection of the physical world and network space. On the other hand, the framework can provide specific intelligent semantic object banks against certain domains to describe, express and represent both the physical world and the network space in a unified way, and to interconnect the two worlds by intelligent semantic object integration.

VII. CONCLUSIONS

This paper proposes an interactive computing model that focuses on individual semantics and interactive semantics to cope with the dynamic, open, limited future interconnection environments. On the basis of the model, we can build the scalable intelligent applications for CPSocio and will eventually come to a harmonically evolving intelligent interconnection environment which links physical space, cyber space and society.

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