2010 24th IEEE International Conference on Advanced Information Networking and Applications

Socio-Natural Thought Semantic Link Network

A Method of Semantic Networking in the Cyber Physical Society

Hai Zhuge
Knowledge Grid Research Group, Key Lab of Intelligent Information Processing
Institute of Computing Technology, Chinese Academy of Sciences, 100190, Beijing, China
zhuge@ict.ac.cn

***Abstract*—Humans have been recognizing, establishing and making use of various relations consciously and unconsciously since the formation of human society. Waving and maintaining various relations accompany everyone's life. Humans' social behaviors create or emphasize relations. Various networks evolve with the development of society. Some relational networks gradually become independent of individuals' life during evolution so that they become a part of knowledge and culture sharable cross generations. The study of social relations trace back to the age of Laozi (576–BC), Confucius (551–479 BC), Thales (624 BC–546 BC) and Socrates (469 BC–399 BC). The formal definition of general relation traces to the invention of set theory in 1874. Humans have intelligence to observe and participate in social processes, to think, and to know the effect of establishing a relation. Humans can also actively select appropriate relations and persons according to requirement, situation and social rules. Machines are obviously limited in these abilities. Various graph-based models have been used to connect resources in the cyber space. Two issues are fundamental: (1) machines know little relation in human society and the nature, data structures in machines are for machines to process not for humans to read, so it is not realistic to expect machines to discover social and natural laws and resolve relevant issues without human instruction; and, (2) machines are hard to know the effect of establishing and making use of relations, and to explain computing result according to society and nature. The cause is that machines do not have any worldview. Connecting various networks and machines with nature, society, and even human minds can create a new world where individuals have semantic images that can enhance mutual understanding. The semantic images can be constructed by a Semantic Link Network SLN consisting of nodes with rich semantics, semantic links between nodes, and rules for reasoning, influencing and evolving the network. Waving semantic link networks in the cyber physical society and exploring the laws of semantic networking are challenge issues.**

Keywords- cyber physical society; cyber physical system; human-level AI; semantics; semantic link network.

I. A BRIEF SURVEY ON LINKS

A. Hyperlink

Vannevar Bush foresaw hypertext and hyperlink in 1945 [5]. He introduced the notion of memex, which can browse and make notes in an extensive on-line text and graphic system, can contain a very large library, personal notes, photographs and sketches, and had several screens and a facility for establishing a labeled link between any two points in the entire library.

Hypertext pioneer Douglas Engelbart proposed a conceptual framework for the augmentation of man's intellect in 1963 [10]. He pointed out that a number of reference links could be established between statements within files and between files. He envisioned the future information system as an automated external symbol manipulation. He designed the system H-LAM/T (Human using Language, Artifacts, and Methodology, in which he Trained). In 1968, he created NLS (oN Line System) as the early hypertext system with three features: a database of nonlinear text, view filters for selecting information from the database, and views that structure the display of information for the terminal.

Ted Nelson coined the term hypertext with the goal of placing the entire world's literary corpus online [15]. According to his vision, hypertext can store and retrieve linked and windowing texts, documents can have windows to other documents, the evolving corpus is continually expandable without fundamental change, and, new links and windows can continually add new access pathways to old materials.

Randall Trigg describes the Textnet system as supporting nonlinear text-text where documents are organized as primitive pieces of text connected with typed links to form a network similar to the semantic net. The work focuses on specific link types that support literary criticism [16]. The Textnet can be regarded as the prototype of the current World Wide Web and e-science.

The typed link in hypertext system is a link to another document or part of a document that includes information about the character of the link. The CREF (Cross-Referenced Editing Facility) system supported four kinds of links: references link for cross-referring, summarization link for summarizing, supersedes link for versioning, and precedes link for ordering. The Guide system used three kinds of links: replacement link for replacing the texts in the current window, note link for displaying text in a pop-up window, and reference link for bringing up a new window with the destination text [4]. A 5-tuple typed link (link type, source node, destination node, a set of structured link attributes, and a free text annotation to the link) is given [11]. The motivation is to integrate the hypertext browsing with information retrieval. They suggest restrict authors and users to a few link types to facilitate mutual understanding.

In hypertext, hyperlink has the following characteristics:

Keynote at IEEE AINA 2010, Perth, Australia, 20-23 April 2010.

1550-445X/10 $26.00 © 2010 IEEE
DOI 10.1109/AINA.2010.186

IEEE computer society

- It enables reference texts immediately available for readers.
- It does not support reasoning.
- It does not concern networking rules. This is due to three causes: humans determine the browsing path, reasoning is the responsibility of humans, and it is not necessary to study reasoning between links.
- Its construction relies on humans (programmers of hypertext).

Although the typed hyperlink was called semantic link sometimes, e.g. in [11], the semantics of the semantic link lacks in-depth study.

Machine supported links within and between documents were regarded as a new opportunity to improve the ability of information systems at the early stage of hypertext research.

B. Semantic Net

Semantic Net SN was a directed graph for knowledge representation, where nodes are concepts, and edges are the relationships between concepts. It was firstly used in natural language processing, and then developed by Allan M. Collins etc [7]. It was adopted as knowledge representation method by some expert systems.

Hyperlink and semantic net SN are developed in parallel with different focus. Concepts in SN are meaningfully connected, while hyperlinks can arbitrarily point from one node to the other. It has been considered to extend SN to construct hypertext, such as typed nodes, semi-structured nodes (frames), and inheritance hierarchies of nodes and link types. SN aims at machine reasoning and interpretation, while hypertext is for humans to read. The common point is that the construction of both relies on humans (programs and knowledge engineers). Comparisons were also given in [8].

C. Linked Structures and Semantic Web

Various data structures like the linked list and tree can be regarded as a kind of link for machine processing not for humans to read. In database area, Bachman's network database model is a linked structure [1]. Two important links were used in relational database model: the functional dependence relation among attributes and reference relations between tables [6].

Many relations like inheritance were defined in object-oriented method for modeling the real world [3]. Linked Data is to connect related data on the Web based on URIs, HTTP, RDF (Resource Description Framework) and metadata.

Much effort has been made on the Semantic Web since Berners-Lee initiated this vision [2]. The key idea is to make machine understandable semantics. Logics, proof and trust are at the high level in the Semantic Web stack. Efforts include the development of various Web languages like RDF and OWL, RIF, ontology, and query languages like SPARQL. Semantic Web research has formed a research community, although there are some different opinions [13], for example, the logic-based semantic web technologies cover only a fraction of relevant phenomena related to semantics, RDF is similar to SN and to the classic conceptual modeling approaches such as entity-relation model and class diagrams in object-oriented method.

Hyperlink, SN, and RDF are graph-based model in general. Hyperlink is mainly for humans to browse, while SN and RDF are for machines to process.

II. SEMANTIC LINK NETWORK

The following are initial motivations of SLN:

- Support semantics-aware applications by extending hyperlink to semantics-rich link and enabling relational, analogical and statistical reasoning on semantic links.
- Explore the laws of semantic networking. It pursues diversity and experience in semantic networking with less emphasis on correctness. A system based on SLN is expected to have some preliminary intelligence such as answering queries on relations and guided browsing.

A. Definition

Semantic Link Network is an open system described as follows: $SLN=<N, L, Rules, OP>$, where

- N is a set of semantic nodes. A semantic node can be a concept, structure, or specific object such as text, image, video, and audio. A semantic node has a class c and attributes att, indicated by n or $n[c, att, exp]$, where exp is the explanation of n.
- L is a set of semantic links. A semantic link indicates a relation between two semantic nodes. A semantic link takes the following form: $n—\alpha→n'$ or $n—\alpha[c, exp]→n'$, where α is the indicator of the relation, and c and exp are the class and explanation of α respectively. Some semantic links reflect the relationships between attributes (called attribute-based semantic link), e.g., *olderThan* and *sameColor*. Some semantic links reflect behaviors of semantic nodes (called behavior-based semantic link), e.g., *friend* relation reflects the interaction relation between semantic nodes. The behavior-based semantic links cannot be derived from the attributes of semantic nodes.
- *Rules* is a set of rules on L such that new semantic links can be appropriately added between semantic nodes as the effect of reasoning, influence or evolution. For α, $\beta \in L$, if there is a rule $\alpha \cdot \beta \Rightarrow \gamma$, then γ can be added to L.
- $OP=\{AddLink, DelLink, AddNode, DelNode, AddRule, DelRule\}$ is a set of basic operations on SLN. Users can add semantic nodes, semantic links and rules to or delete them from SLN, and can also add themselves to the SLN as semantic nodes.

If there is a behavior-based semantic link l between semantic nodes A and B, there exists a semantic node C (artifact or event) where A and B co-occur, and l can be derived from the relation between A and C, and the relation between B and C.

Since the basic operation set is fix [17], SLN can be simplified as $SLN=<N, L, Rules>$. In some applications, we need to distinguish different types of nodes because some relations only exist between nodes of particular type. So SLN can be represented as follows:

$SLN=<N, \varphi, L, Rules>$, where φ is a mapping from N onto concept hierarchy $<C, \leq>$, $\varphi: N \rightarrow C$, $\leq$ is subclass relation, for

n_1, $n_2 \in N$, the instance of n_1 is the instance of n_2 if $\varphi(n_1)$ is the subclass of $\varphi(n_2)$, i.e., $\varphi(n_1) \leq \varphi(n_2)$. Usually, humans can be separated from other passive node types.

B. Semantics of Semantic Link Network

Hyperlink represents a kind of reference relation. The successor is the reference of the predecessor. There is no restriction for users to add a hyperlink to a hypertext. On the other hand, the label is given by humans when he/she establishes a link between concepts or documents, or adds a concept or document to existing network. Moreover, a label itself does not enough to express semantic relation between objects. For example, a hyperlink from a researcher's homepage to the website of the journal is only a reference. It cannot express that the person published a paper in this journal or is served as an editor or editorial board.

A set of semantic links such as *implication*, *subtype*, *cause-effect* and *reference* as well as a set of reasoning rules were suggested [19]. Semantic links such as *southOf*, *northOf*, *eastOf* and *westOf* were used to lay out wall-paintings. It assumes that users have commonsense on these links. SLN is to enable both machines and humans to understand its semantics.

The semantics of SLN depends on network structure and semantic space [25]. *The minimum semantic cover represents the structure of an SLN* [19]. *The semantic space consists of the classification hierarchy of concepts and rules*. Humans understand the semantics of an SLN by simple structure, class hierarchy and commonsense. The super-class concepts and the subclass concepts determine the semantic range of concept. The classification hierarchy of concepts reflects the consensus of people who build the network. The concept hierarchy contained in online resources created by many users like Wikipedia can help create such a hierarchy. The advantages are that explanations on concepts are available and the classification hierarchy can keep update with the expansion of online resources.

The semantics of a semantic link is determined by the following aspects (ARCR):

- *Attributes.* The attributes of two ends.
- *Relations.* The semantic link triangle that includes the semantic link.
- *Class.* The class in the concept hierarchy corresponds to the semantic link indicator.
- *Rules.* The rules that can derive it.

The semantics of a semantic node is determined by the following five aspects (ARCNI):

- *Attributes*. The attributes of the semantic node.
- *Relations*. The semantic link triangle that includes the semantic node.
- *Class*. The class of the semantic node.
- *Neighbors*. The semantics of its neighbor nodes.
- *Instances.* Its instances.

Semantic Link Network is an open system consisting of a *structure* (N, φ, L), a *primitive semantic space* (C, *Rules*), and an *operation set OP*, described as follows:

$SLN = <(N, \varphi, L), (C, Rules), OP>$.

Any semantic link γ indicated by the concept hierarchy C can be added to L if it can be derived from L according to *Rules*.

Establishing a meta-model for SLN is another way to define the semantics of semantic link network.

C. Characteristics

SLN has the following distinguished characteristics:

- *Open system*. New semantic nodes, semantic links, rules and even users will be added to SLN from time to time.
- *Dynamicity*. Operations on SLN may have little or great influence on the network due to different roles of nodes and links. The addition of new semantic links and rules may trigger new reasoning or influence.
- *Diversity*. Diversity lies in the diversity of semantic nodes, semantic links, rules and users. This leads to diverse semantic communities and complex network evolution.
- *Self-organization*. There is no central control on the construction of SLN. Any semantic node can link to any semantic nodes with a semantic link when necessary.
- *Autonomous reasoning*. Reasoning on semantic links is different from traditional reasoning on production rules due to the diversity of semantic links and rules. Reasoning can carry out locally because it is not necessary to derive out all relations, which overload storage. A semantic node can trigger reasoning when necessary according to neighbor semantic links and relevant rules. More importantly, SLN supports multiple reasoning such as relational reasoning, analogical reasoning and inductive reasoning.
- *Integrated structure, classification hierarchy and rules into semantic space*. The rules guide semantic networking, enable reasoning, and restrict the semantics of semantic links. The reasoning characteristic leads to the dependence between semantic links and between operations.
- *Sensitive operation order*. The result may be different if different order of operations is applied to an SLN. An SLN may be changed when deleting a previously added semantic link. As adding a semantic link may derive new semantic links, which may derive other links. If we remove the previously added link, the SLN may not go back to the original SLN. This relies on the definitions of addition and removal operations. So, $SLN \neq SLN \cup L' - L'$, and $SLN \neq SLN \cup Rule' - Rules'$, where $\cup$ and $-$ are graph operations. Generally, $SLN \neq SLN \cup SLN' - SLN'$, where $SLN \cup SLN' = <N \cup N', L \cup L', Rules \cup Rules'>$, and $SLN - SLN' = <N - N', L - L', Rules - Rules'>$. The semantics of an SLN is determined by the minimum semantic cover of the network and the

rules. With adding a certain number of semantic links, different semantic covers on different topics may emerge, therefore, the semantics of the SLN changes.

- *Complex.* A semantic node can be a semantic link network. For example, $f=m \cdot a$ indicates the equivalence between the abstract concept *f* and a complex semantic node consisting of concepts *m* and *a* as well as the multiplication relation "·". The whole formula can also be a semantic node.
- *Humanized.* SLN is not only a symbol model but also a humanized model. Semantic link and semantic node include rich content so that an SLN is not only for machine processing but also for human to read and think. The entity of a semantic node can be image, video, audio, and text. A semantic link is indicated by the subclass and superclass of the relation as well as its *use case*, an example of semantic link.

D. Example

Fig.1 shows an SLN waved during unearthing an ancient Tomb. The unearthed sculpture indicates that it was used by Wei Wu King (i.e., Chao Chao) who was the king of country Wei in three kingdoms dynasty of China (155-220).

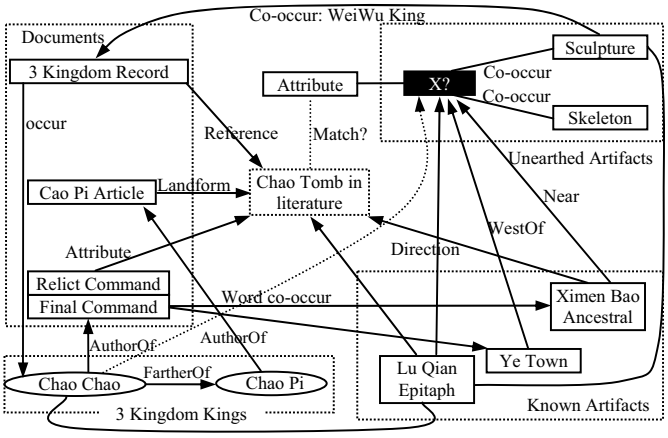

Fig.1. A semantic link network for archeological discovery.

The SLN can help indicate the relation between Cao Cao and the Tomb X through the following semantic paths:

- X —*co-occur*→Sculpture — *occur*→ WeiWuKing — *occurIn*→ 3KingdomRecord —*occur*→ ChaoChao ⇒X—*about*→ChaoChao.
- X —*co-occur*→Sculpture — *occur*→ WeiWuKing— *occurIn*→LuQianEpitaph—*occur*→ChaoChaoTomb ⇒X—*about*→ChaoChaoTomb.
- ChaoChao —*authorOf*→ FinalCommand —*indicate*→ ChaoChaoTomb —*near*→ XimenBaoAncestral ⇒ ChaoChao —*near*→ XimenBaoAncestral.
- ChaoChao —*authorOf*→ FinalCommand —*indicate*→ ChaoChaoTomb —*westOf*→ YeTown ⇒ ChaoChao —*westOf*→ YeTown.
- CaoCao—*is*→WeiWuKing—*occurIn*→ LuQianEpitaph—*near*→CaoCaoTomb⇒CaoCao —*near*→CaoCaoTomb.

The semantic nodes and the relations *about*, *near*, and *westOf* jointly indicate the semantics of node X. The relation can be enhanced by matching the attributes of the unearthed tomb and the attributes of the tomb in literature. This SLN helps human-level reasoning since machines are hard to understand the unearthed artifacts.

For online resources, it is possible to automatically discover semantic links among resources [24], and let machines do some light-weight reasoning.

E. Interface layout

Fig.2 shows the interface layout for displaying an SLN and its components. By using the zooming mechanism, an SLN can become a semantic node and a semantic node can become an SLN. So, the zooming mechanism can display the contents in the blocks at multiple abstraction levels and facets.

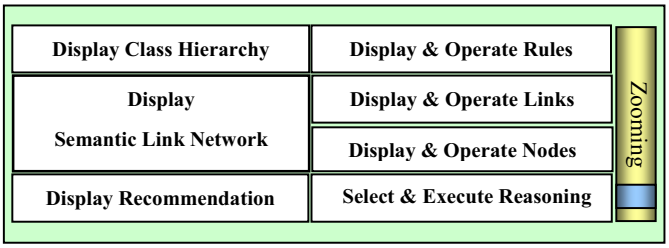

Fig.2 The interface layout for displaying and operating SLN.

Fig.3 shows three types of human-level reasoning:

- Determining the semantics of a node according to the neighbor semantic nodes and semantic links;
- Determining the semantic link between two semantic nodes according to the surrounding semantic links and semantic nodes; and,
- Adding or deleting a semantic link to observe the influence.

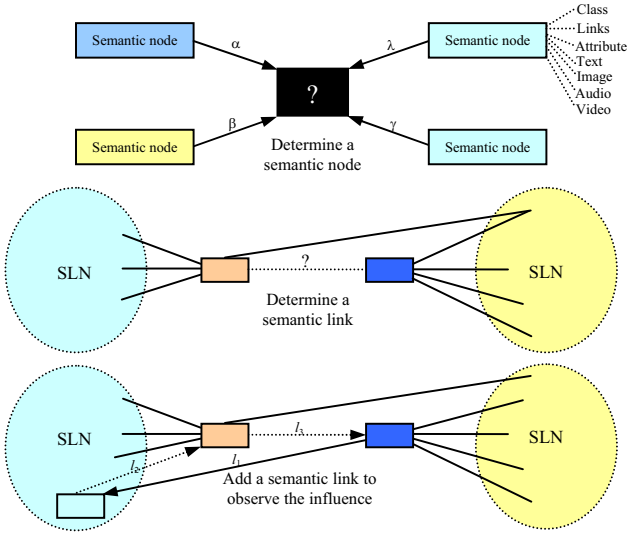

Fig.3 Three types of human-level reasoning.

What are the characteristics of the SLN-based interface?

The interface of hypertext and webpage has explicit text and implicit link structure. Its text priority is for humans to read rather than for humans to think. Reading hypertext has no big difference from reading text in paper although different front sizes and colors are used to attract readers' attention. It also has the problem of getting lost when browsing.

The SLN interface has explicit semantic link network and implicit contents in semantic nodes (entity may be multimedia). This structural priority enables users to know the general relation first, and to know the general structure when viewing a specific semantic node. The human readable SLN provides rich semantic relevant contents for humans to reason.

F. Method and Problems

SLN is a model and method for semantic networking, reasoning and analyzing rather than only a software tool for building a semantics-rich network. The implementation of SLN in cyber space can adopt SLN + X strategy. X refers to information techniques, such as Semantic Web, semantic P2P overlay [22], and data mining, which can help build a semantic link network in cyber space.

Semantic nodes are entities or abstract concepts, while semantic links are abstract relation. When the semantics of semantic node is hard to express, the semantic relations become more important. The following are the causes of linking semantic nodes:

- Relationships between the attributes of semantic nodes.
- Relationships between the classes of semantic nodes.
- The semantic link networks where the two semantic nodes reside, especially the neighbor semantic nodes and links. For example, two semantic nodes share some attributes or classes if they connect the same node with relations.
- Direct or indirect human interaction behavior.

Different from previous models such as semantic net and RDF, SLN can support not only machine reasoning but also human reasoning. SLN research concerns the following problems:

- Can we formalize SLN as a self-organized semantic data model to support network applications? How do we normalize SLN to efficiently support query, especially, query on relations?
- How do we enable SLN to deal with uncertainty?
- How does SLN evolve? How do semantic links and semantic nodes influence each other?
- How do we find appropriate semantic nodes and links according to time or the influence between semantic nodes and between semantic links?
- How can the semantic link between two seemly irrelevant objects be discovered? This is a challenge, even for documents, the similar relation can be automatically detected by using information retrieval approaches such as the Latent Semantic Analysis (SLA) and the Vector Space Model (VSM) [14]. An idea of automatically discovering semantic relations between Web pages are suggested in 2002 [18].
- How can a query be efficiently routed in a large semantically linked network? Similarity between documents has been used to raise the efficiency of query routing in P2P network [22].
- How does an SLN support automatic query answer? and the explanation?
- How does an SLN recommend appropriate content to users through semantic links?
- How do different reasoning processes influence each other when multiple links are added to an SLN?
- What is the relationship between SLN and the other models? Can SLN be integrated with other models? Human intelligent behaviors rely on two basic semantics: *link semantics* and *classification semantics*. Integrating SLN with the Resource Space Model based on multi-dimensional classification can form a semantic image [23]. The single semantic image is an effort to simulate the structure to support intelligent behavior.

Adding a semantic link would influence or incur reasoning on semantic link network, which may have global effect due to the following causes:

- Propagation of reasoning or influence.
- Similar reasoning conditions are satisfied in other part of the network.
- Influence of reasoning may happen between abstraction levels. Reasoning on one part may influence reasoning on other parts through semantic link paths.

From above discussion, we can see that SLN is different from previous work about link in goal, model, method, and research issues.

III. SLN 2.0: Towards a Self-Organized and Adaptive Semantic Data Model

SLN 2.0 aims at a self-organized data model to manage resources. SLN schema is to regulate semantic link networks by specifying node types, link types, and reasoning rules [26]. Resources and semantic link instances are regulated by their types. Reasoning on instances is based on reasoning rules defined in the schema. A global SLN schema reflects consensus on the basic semantics of domain. Users can define SLN instances by instantiating the global schema, or define a sub-schema first and then instantiating the sub-schema. Usually, schema is designed by designers.

An important issue is how to automatically generate a schema from a set of SLN instances. This concerns the clustering of semantic nodes according to their attributes, and then determining the semantic links between clusters. A method of integrating statistic approach and multiple reasoning mechanisms will help find the semantic links. A key issue is to make the schema adaptable to the change of instances. Current clusters may need adaptation when new instances come. A concept abstraction hierarchy can help generalize semantic links.

SLN 2.0 concerns the semantic peer data management to support decentralized data management. The key is to establish and maintain the semantic relation between neighbors according to their schemas, and to develop routing strategies that can make use of semantic relations. P2P SLN will be a decentralized and self-organized data model that can realize resource sharing regardless of heterogeneity between peers.

IV. SLN 3.0: Through Socio-Natural Thought

A. SLN in Five Worlds

With the development of society, artifacts continuously expand and gradually form an artifact world, which is relatively independent of humans. The future cyber physical society will involve in five worlds: the nature, human society, artifact space, cyber space, and mental space [23]. SLN 3.0 is a method for semantic networking in the five worlds.

SLN in nature reflects objective relation between objects. Scientific research is to unveil various relations and rules of the nature. Semantic nodes are natural objects with physical attributes and geographical location. One object links to the other by physical attributes or geographical location. The most common semantic link in nature is symbiosis relation and resource flow (material flow).

Artifacts record history, events and thought. SLN in the artifact space reflects classification, reference, or rendering relations between artifacts.

SLN in society reflects social relations. Semantic nodes not only represent resources but also humans and events. An event has start time and end time, and involves in humans, artifacts, and natural space. Attributes of semantic nodes reflect social attributes, related to classes. One semantic node may belong to several communities.

In the mental world, semantic nodes are classes (abstract concept) and instances (images of natural or social individuals). A class may link to another class. Human thoughts are in the mental world, but thoughts can be indicated by artifacts. Humans are connections between worlds. The movement of the networks forms and evolves centrality.

SLN in the cyber space records and indicates relations in the five worlds, so it enables humans to know the relations in the nature, society, artifact space, and mental space.

The separation of the five worlds clarifies the types of SLN and the subjective and objective characteristics of SLN, therefore will help SLN research focus on specific characteristics in different worlds.

B. Characteristics

SLN 3.0 has the following characteristics.

- *Semantic Flow*. It is a flow of content through semantic links. An instance of semantic flow is the emails from one person to the other during a period of time. A simple description of the relation could be *friend* or *cooperator*. But in-depth relation could be found according to the contents they communicated, which differentiate them among friends or cooperators.
- *Emotions*. A semantic link may express positive or negative attitude on the other node, e.g., comment through citation between papers could be positive or negative. A node may also express happy or unhappy emotion about interaction with the other node through semantic links.
- *Metaphor*. Semantics of a semantic link is implicitly indicated by some other semantic links.
- *Time*. SLN in society and minds concern time. A semantic node with lifetime $[t_0, t_n]$ and current time t is indicated by $n_i[c, att, exp, t, (t_0, t_m)]$. A semantic link α added to SLN at time t can be indicated by $\alpha[c, exp, \tau]$ where $\tau \le t$.
- *SLN as context*. An isolated interaction cannot reflect the real meaning. A self-contained piece of semantic link network can be as the context of interactions.
- *Service as node*. A service has its function, parameters, and description. Semantic links or potential semantic links between services or between parameters wave a service network that enables effective services.
- *Recommendation*. SLN 3.0 can recommend appropriate friends to improve the current status.

In SLN 1.0 and SLN 2.0, rules are mainly for reasoning, reflecting the influence between semantic links, and determining the semantics of semantic links. In SLN 3.0, rules can play the following roles:

- Guide the establishment of semantic links. It could recommend the best candidate when one node is going to establish a semantic link with the other nodes.
- Evaluate the status of semantic nodes, links and communities.
- Estimate the evolution of a semantic community.
- Predict the behavior of a semantic node.

C. Through Spaces

Humans have the ability to reflect various semantic link networks in the nature, and to create thought during interacting with each other and with the nature. Humans wave their SLNs in minds and reflect each other through interactions. SLNs in minds are indicated by artifact space, society, and cyber space.

The following interactions connect the five spaces as depicted in Fig.4:

- Interaction between humans establishes semantic links between semantic nodes and between SLNs, and can build the semantic images of thoughts in the mental space.
- Interaction between humans and the nature establishes semantic images of the nature, and semantic links between the nature and society.
- Humans can interact with the nature, society and artifacts directly or through the cyber space, establish semantic links between society, nature, artifact space and the cyber space, and leave semantic images of their thoughts.
- Interaction between the nature and the cyber space through sensors establishes links between the nature and cyber space.

- Creating artifacts will connect humans to the artifact space (humans will use or read the artifacts), link the new artifacts to existing artifacts, and link the SLN in the mental space to the world of artifact space.

The cyber space will store various SLNs. Connections between spaces enhance understanding through spaces. Flows in different spaces have different forms.

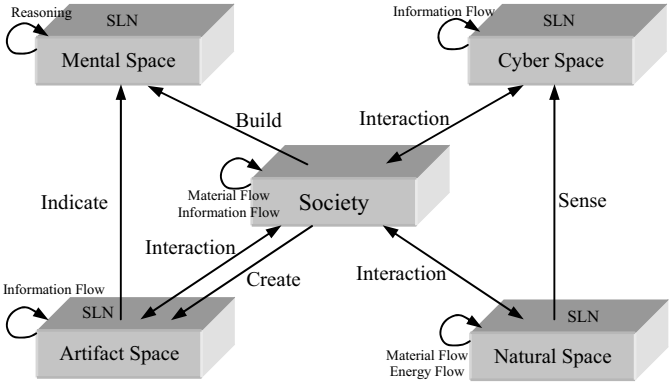

Fig.4. Interaction between spaces.

D. Explanation cross Spaces

Connecting the five spaces enables an SLN to explain *what*, *where*, *why*, *when*, and *how* through multiple spaces as follows.

- Society can explain: How it is related to humans? Who is relevant? Who can help? Which community involves in? What are the relevant social rules? What social resources can be used? What are its social and economic effects?
- Natural space can explain: How it is related to natural resources, phenomena, characteristics and laws? When and where it happens?
- Artifact space can explain: When and where they are created? Which are relevant? How are their values? Who are the authors or owners? Who are interested in them?
- Mental space can explain: Why? Which category it belongs to? What does it imply? What are the similar cases? What are relevant methodologies? How people like it?
- Cyber space can explain: How it is stored? How it is executed? How it is displayed? Why it is recommended? What models are used?

The cyber space will be able to capture attributes of individuals in society, nature, artifacts and even minds through sensors. The attributes can help establish the semantic images for the spaces in the future cyber physical society [27]. The semantic image of a space executes with the rules specific to the space. SLN can be the model of the semantic image.

E. Thought SLN

When a relation emerges, humans will recall the instances of the relations, and link these instances to experiences. Experience includes events, the interaction process, and the effect of establishing relations in the mental world. When SLN are used to wave personal semantic images in the cyber space, personal experience should be attached. When events and experiences are recalled, they will recall the participated resources and semantic links.

In the future cyber physical society, *thought is a process of raising questions, finding answers, and selecting appropriate semantic nodes and links to form SLNs*. Different from stimulus-response, thought SLN has the following basic characteristics:

- Emerge processes that have corresponding process instances in society or nature.
- Emerge cause from effect, or emerge effect from cause.
- Route a question to an answer through SLN.
- Find similarity and implication, and inspire process.

Different from the orthogonal latitude and longitude used to locate surface objects, human memory network uses a kind of triangle-based grid cells for navigation [9]. Coincidently, the basic relational reasoning of SLN is a triangle semantic link network.

V. PHILOSOPHY OF SLN

Laozi respected nature rather than action as he thought that unnatural act will break the natural balance. Confucius emphasized the morality, correctness, justice and sincerity of social relationships. He argued that particular duties arise from one's particular situation in relation to others, and the individual stands simultaneously in multiple relationships with different people. The idea is also significant to explore the social relationships in the future cyber physical society.

Thales explained natural phenomena via a rational explanation with reference to natural processes. Socrates believed the importance of friendships and community in human life. He and Plato believed that the world we observe is not the real one, but only a shadow of the real world.

The semantic image can be understood as the model of the shadow [25]. Individual and community have their own semantic images. Different individuals may have different individual semantic images, different communities may have different community semantic images, and the images may change from time to time.

There are two ways to link semantic images: *semantic links between attributes* and *interaction between semantic nodes*.

Kant believed that passive experience is not the beginning of understanding, and that there are some categories that humans actively use to make sense of the world. So, the semantic image integrates the classification-based resource space and the relation-based semantic link network [27].

A semantic link network may show some centrality and will change its centrality during evolution. The evolution of centers can be regarded as continuous competition between individuals (semantic nodes).

Semantic images are forms of reality in society and nature. Bio-sense is extended to sensors. Subjective and objective existence will extend to the cyber existence. The scientific

pursuit of the Socio-Natural Thought SLN (SNT-SLN) brings challenge philosophical issues.

VI. SUMMARY

Many research areas follow the visions of pioneers of IT and philosophy. The development of IT and society raises many new challenges.

SLN is to establish a model and method for networking versatile individuals in cyber physical society, to study the law of networking and evolution, and to support harmonious development of thought, society and nature. The following are three pursuits of SLN research.

- SLN 1.0 is to extend the hyperlink network by introducing the semantic space into nodes and links. SLN 1.0 has reasoning ability including relational reasoning, inductive reasoning, and analogical reasoning. SLN is dynamic in nature due to the reasoning ability. Semantics and centrality of SLN emerge and evolve with operations.
- SLN 2.0 is to establish a complete theory, model and method for establishing a self-organized semantic data model to support decentralized intelligent applications. Its distinguished features are self-organization, decentralized semantic networking, emerging semantic community, semantic community discovery, and the effect of semantic networking.
- SLN 3.0 (i.e., SNT-SLN) studies semantic networking method and the laws in society, nature, cyber space, and artifact space. It will be the method for establishing semantic images for individuals, communities and systems of the future cyber physical society.

Jim Gray proposed the notion of personal memex and world memex. The personal memex can record everything a person sees and hears, and quickly retrieve any item on request. The world memex can answer questions about the given text and summarize the text as precisely and quickly as a human expert in that field [12]. This notion is close to the ideal of SLN 3.0. SLN is also the semantic networking method of the Knowledge Grid [19].

The future interconnection environment goes beyond the scope of the Cyber Physical System (CPS). It concerns not only the cyber space and the nature but also humans and society [20, 21]. So it is called Cyber Physical Society. SLN is a method and model for semantic networking in the natural physical space, cyber space, social space, and thought space of the Cyber Physical Society.

ACKNOWLEDGMENT

This work was supported by the International Cooperation Project of Ministry of Science and Technology (2006DFA11970), National High Technology Research and Development Program of China (2007AA12Z220), National Science Foundation of China (60773057 and 60703018), and National Basic Research Program of China (2003CB317001).

REFERENCES

[1] C. W. Bachman, Data Structure Diagram, *ACM SIGMIS Database*, vol.1, no.2, 1969, pp.4-10.

[2] T. Berners-Lee, J.Hendler and O.Lassila, The Semantic Web, *Scientific American*, vol.284, 2001, pp.34-43.

[3] G. Booch, Object Oriented Design with Applications, Redwood City, Calif.: Benjamin/Cummings Pub. Co., 1991.

[4] P.J. Brown, Interactive Documentation, *Software: Practice and Experience*, March, 1986, pp.291-299.

[5] V. Bush, As We May Think. Atlantic monthly, July 1945, pp.101-108.

[6] E. F. Codd, A Relational Model of Data for Large Shared Data Banks. *Communications of the ACM*, vol.13, no.6, 1970, pp.377-387.

[7] A. M. Collins and M.R. Quillian, Retrieval Time from Semantic Memory. *Journal of Verbal Learning and Verbal Behavior*, vol.8, no. 2, 1969, pp.240–248.

[8] J. Conklin, Hypertext: An Introduction and Survey. *Computer*, vol. 20, no.9, 1987, pp.17-41.

[9] C.F.Doeller, C.Barry and N.Burgess, Evidence for Grid Cells in a Human Memory Network, *Nature*, Jan, 2010. doi:10.1038/nature08704.

[10] D. C. Engelbart, A Conceptual Framework for the Augmentation of Man's Intellect, In Vistas in Information Handling, vol.1, Spartan Books, London, 1963.

[11] H. P. Frei and D. Stieger, The Use of Semantic Links in Hypertext Information Retrieval, *Information Processing & Management*, vol.31, no.1, pp.1995, pp1-13.

[12] J. Gray, What Next?: A Dozen Information-Technology Research Goals, *Journal of ACM*, vol.50, no.1, 2003, pp.41-57.

[13] C. C. Marshall and F.M. Shipman, Which Semantic Web?, in: *Proceedings of the 14th ACM Conference on Hypertext and Hypermedia*, Aug 26-30, UK, 2003, pp. 57-66.

[14] A. A. Macedo, M. G. C. Pimentel, J.A. Camacho-Guerrero, An Infrastructure for Open Latent Semantic Linking, in: *Proceedings of the 13th ACM conference on Hypertext and hypermedia*, 2002, pp. 107-116.

[15] T. H. Nelson. Getting Out of Our System. Information Retrieval: A Critical Review, G.Schechter, ed. Thompson Books, Wash. D.C. 1967.

[16] R. H. Trigg, A Network-based Approach to Text handling for the Online Scientific Community. PhD. Thesis, University of Maryland, 1983.

[17] B. Xu and H. Zhuge, The Basic Operations of the Semantic Link Network and Its Completeness, in: *Proceedings of the 5th International Conference on Semantics, Knowledge and Grid*, Zhuhai, China, Oct.2009.

[18] H. Zhuge, L. Zheng, N. Zhang, and X. Li, An automatic semantic relationships discovery approach. *WWW2004*, pp.278-279.

[19] H. Zhuge, The Knowledge Grid, World Scientific Publishing Co., Singapore, 2004, (2nd edition, 2010).

[20] H.Zhuge and X. Shi, Toward the Eco-grid: A Harmoniously Evolved Interconnection Environment. *Communications of the ACM*, 47(9)(2004)78-83.

[21] H.Zhuge, The Future Interconnection Environment, *Computer*, vol.38, no.4, 2005, pp.27-33.

[22] H. Zhuge and X.Li, Peer-to-Peer in Metric Space and Semantic Space, *IEEE Transactions on Knowledge and Data Engineering*, vol.19, no.6, 2007, pp.759-771.

[23] H.Zhuge, Y.Xing and P.Shi, Resource Space Model, OWL and Database: Mapping and Integration, *ACM Transactions on Internet Technology*, vol.8, no.4, 2008, article no.20.

[24] H.Zhuge and J.Zhang, Automatically Discovering Semantic Links among Documents, in: *Proceedings of the 4th International Conference on Semantics, Knowledge and Grid*, 2008, pp.149-156.

[25] H. Zhuge, Communities and Emerging Semantics in Semantic Link Network: Discovery and Learning, *IEEE Transactions on Knowledge and Data Engineering*, vol.21, no.6, 2009, pp.785-799.

[26] H.Zhuge and Y.Sun, The Schema Theory for Semantic Link Network, *Future Generation Computer Systems*, vol. 26, no. 3, 2010, pp.408-420.

[27] H. Zhuge, Interactive Semantics, *Artificial Intelligence*, vol. 174, 2010, pp.190-204.