CHAPTER 1

Semantic Computing

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We define semantic computing as a field that addresses the derivation and matching of the semantics of computational content and that of naturally expressed user intentions to help retrieve, manage, manipulate, or even create the content, where "content" may be anything including video, audio, text, process, service, hardware, network, community, and so on. It brings together those disciplines concerned with connecting the (often vaguely formulated) intentions of humans with computational content. This connection can go both ways: retrieving, using, and manipulating existing content according to user's goals ("do what the user means") and creating, rearranging, and managing content that matches the author's intentions ("do what the author means").

1.1 CONNECTIONS BETWEEN CONTENT AND INTENTIONS

The connection between content and the user can be made via (1) semantic analysis, which analyzes content with the goal of converting it to a description (semantics); (2) semantic integration, which integrates content and semantics from multiple sources; (3) semantic services, which utilize content and semantics to solve problems; and (4) service integration, which integrates different kinds of service to provide more powerful services; and (5) semantic interface, which attempts to interpret naturally expressed user intentions (Fig. 1.1). The reverse connection converts descriptions of user intentions to create content of various sorts via techniques of analysis and synthesis.

Note that as most of the information is sent and received through a network, security is needed at multiple levels including data-level [1], communication level [1], database level [2], application level [3] and system (community) level

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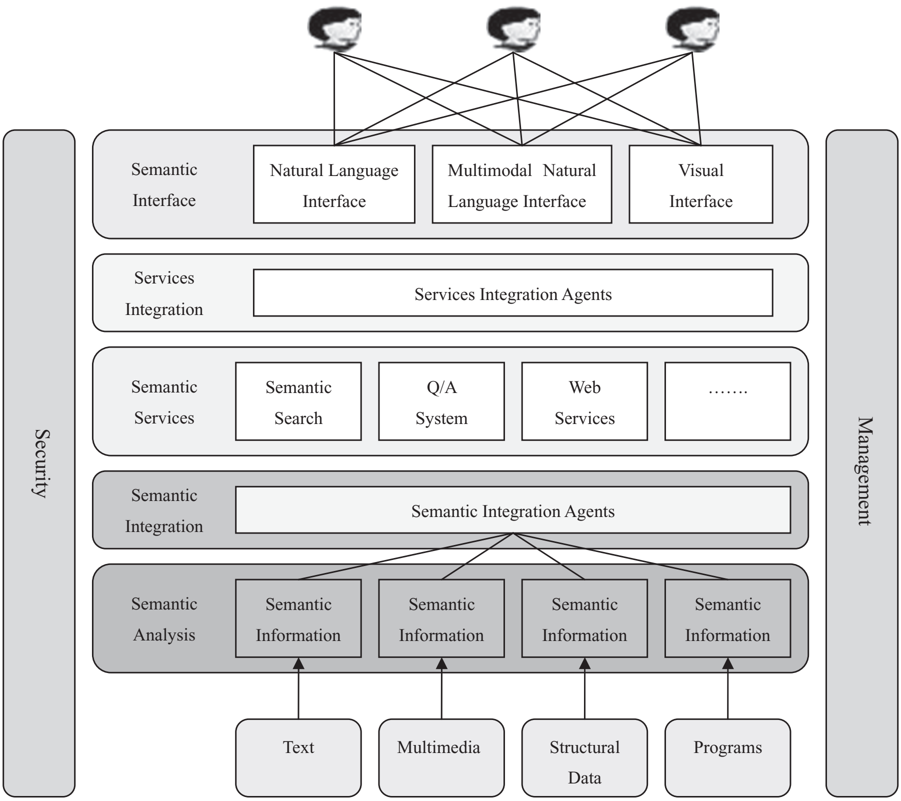

Figure 1.1 Architecture of semantic computing.

[4]. The flows of information are controlled both horizontally and vertically to assure desirable properties including QoS (quality of services) [5, 6] and integrity.

1. *Semantic Analysis*—analyzes and converts signals such as pixels and words (content) to meanings (semantics).
2. *Semantic Integration*—integrates the content and semantics from different sources with a unified model; it also includes languages and methodologies needed for developing semantic applications.
3. *Semantic Services*—utilize the content and semantics to solve problems, and some applications may be made available to other applications as services.
4. *Service Integration*—integrates different services to provide more powerful service.
5. *Semantic Interface*—allows the user intentions to be described in a natural form.

1.2 SEMANTIC ANALYSIS

"Semantic analysis is the process of relating syntactic structures, from the levels of phrases, clauses, sentences and paragraphs to the level of the text as a whole, to their language-independent meanings, removing features specific to particular linguistic and cultural contexts, to the extent that such a project is possible. The elements of idiom and figurative speech, being cultural, must also be converted into relatively invariant meanings."[1] Semantic analysis is the foundation of semantic computing; it provides the information resource for semantic integration and semantic services.

The research areas related to semantic analysis include but are not limited to:

1. Natural language understanding and processing
2. Understanding and processing of texts and multimodal content
3. Understanding of texts, images, videos, and audios
4. Speech recognition
5. Web mining
6. Data mining
7. Process mining

Semantic analysis may be the most developed part among the five layers of semantic computing, but it still has a lot of limitations. Most research on semantic analysis has focused on multimedia data analysis [7–9], text analysis (including shallow semantic parsing [10], latent semantic analysis [11, 12], as well as probability latent semantic analysis [13]), structural data analysis [14], and web analysis [15]. Early attempts at semantic analysis addressed complex problems such as semantic understanding, knowledge representation, and reasoning, and some progress has been reported on the understanding of certain domain-specific stories [16, 17]. The success, however, largely depends on domain-specific knowledge. A more robust approach is yet to be developed.

The output of semantic analysis is a description of content. To be useful, the description has to be machine processable. Several languages have been proposed to support such descriptions, including keywords, ontology, Moving Pictures Experts Group (MPEG), and others. In the case that automatic semantic analysis is difficult, descriptions may be generated manually in the form of annotations.

1.3 SEMANTIC INTEGRATION

Semantic integration considers the descriptions derived from the semantic analysis layer that is presented in different formats and integrates such information before it can be used. Existing work on semantic integration includes:

[1] http://www.wikipedia.org.

- *Database Schema Integration* [18, 19] Database schemas may have different structures. Schema integration aims at unifying the matching elements. Various data sources are integrated into a data warehouse.
- *Data Exchange* [20, 21] To enable data exchange, applications need to convert messages between the formats required by different trading partners.
- *Ontology Integration (or Merging)* [22–24] Given two distinct and independently developed ontologies, it produces a fragment that captures the intersection of the original ontologies. This area is similar to that of schema integration but is more difficult in nature due to the rich and complex knowledge representation structures found in ontologies.
- *Ontology Mapping* [25, 26] Ontology mapping could provide a common layer from which several ontologies could be accessed by multiple applications. Ontology mapping is different from integration and merging because it does not try to combine several ontologies into a single, complete one.
- *Semantic Conflict Resolution* [30] This is needed to ensure semantic interoperability among heterogeneous information sources.

1.4 SEMANTIC SERVICES

A major goal of semantic computing is providing more powerful computing services for all kinds of users. Semantic services have been developed in several forms:

- *Web search*, including automatic question answering (Q/A) [32, 33] and information retrieval (e.g., Google[2] and Windows Live[3]). Both have attracted significant amount of attention in the past and at present.
- *Multimedia databases*, with a primary focus on content-based retrieval [34].
- *Domain-specific applications*, designed to support interoperable machine-to-machine interactions over a network for specific applications.[4]

1.5 SERVICES INTEGRATION

Although semantic services are useful for different kinds of users, sometime they are limited or insufficient for applications requiring several services working together.

A prerequisite for a set of services to collaborate is their ability to understand the mental model, often described in the form of ontology, of each other

[2] http://www.google.com.
[3] http://www.live.com.
[4] http://www.w3.org/TR/ws-arch/.

and communicate with each other. Mapping between ontologies is a major area of interest where automated and scalable solutions are also sought due to the vast number of services. Service integration [27–29, 31] provides the interoperation methods between different services involved in practical scenarios.

On the other hand, for service integration, a significant gap still exists between specialists and nonspecialists, or among specialists focusing on different aspects of a problem. Traditional web services provide a protocol UDDI to perform resources description, discovery and integration. However, this protocol can only be used by experienced specialists. Automatic composition of services hence is strongly desired.

1.6 SEMANTIC INTERFACE

To achieve the goal of providing more powerful computing services to all kinds of users, a portable and friendly user interface is required. This is especially important when cell phones become more capable. Standard graphical user interface (GUI) techniques such as browsing, menu trees, and online help may be far less appealing for the next-generation applications. Therefore new standards of interface, such as natural language interface, multimodal interface, and visual interface, are becoming increasingly important.

A *natural language interface* allows people to interact using a form of a human language, such as English, as opposed to a computer language, a command line interface, or a GUI. Natural language interfaces may be designed for understanding either written or spoken texts. Attempts have been made to replace command lines and database queries with some form of natural language queries and to use some natural language syntax for programming languages. The most common problem of a true natural language interface is ambiguity: The same sentence may have multiple interpretations. Another problem is that users often assume that computers can reason as a human being and has the full knowledge as a human being.[5]

A *multimodal natural language interface* combines natural language input with other forms of input such as gesture. There are several strong reasons for creating an interface that allows voice to be combined with gesture as the input [35]:

- Expression is easy.
- Voice and gesture complement each other and when used together create an interface more powerful than either modality alone.
- Combining speech and gesture may improve the accuracy of recognition and reduce the length of speech, resulting in faster task completion compared to using speech alone.
- Users work more efficiently by using speech and gesture together.

[5] http://www.usabilityfirst.com/glossary/term_755.txl.

In addition to understanding user intentions, a semantic interface should be able to present the result produced by a semantic application in a form that can be easily understood by the user. In online analytical processing (OLAP), for example, it is important to provide a reporting tool on top of the server. Research on visualization allows the user to effectively visualize complex systems of information/data; it is particularly useful for decision making, training, simulation, virtual reality, augmented reality, and wearable computing applications [36].

Semantic programming is essentially another aspect of semantic interface: It allows users to express, in a natural way, their intentions when creating content which may be a program, a video, a process, a document, or others.

1.7 SUMMARY

Some areas of semantic computing have appeared as isolated pieces in various fields such as computational linguistics, artificial intelligence, multimedia, software engineering, database, and services computing. As shown in Figure 1.2, the field of semantic computing *glues these pieces together into an integrated theme and addresses their synergetic interactions*. For example, it addresses how retrieval of multimedia content may be facilitated by natural language annotations, how embedded texts may be extracted from images, how software may be derived from requirements described in natural language, how security can be added based on contexts, how Web search can be accomplished effectively with a cell phone, and so on.

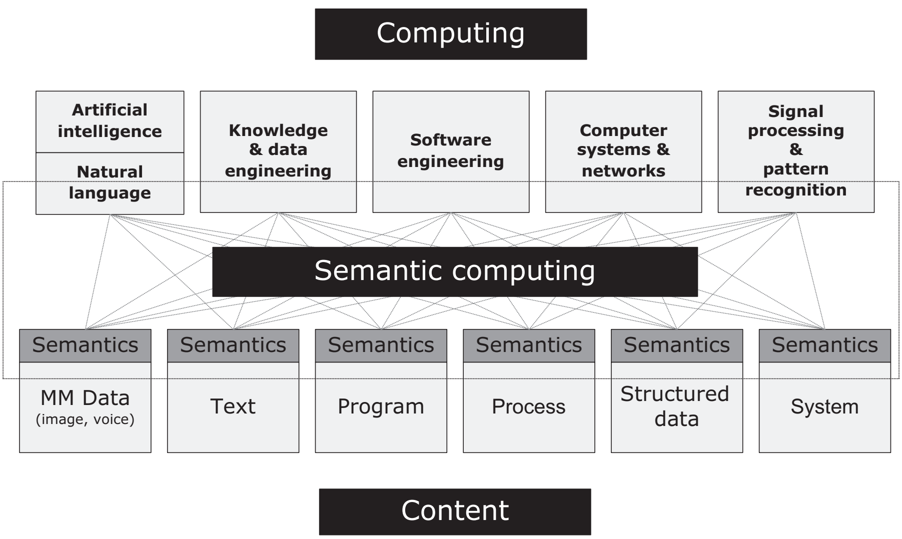

Figure 1.2 Technical coverage of semantic computing.

This may be the first book ever that attempts to introduce semantic computing as an integrated discipline. While researchers in the past have focused on their individual fields, considering semantic computing as an integrated discipline has the advantage that people may share their approaches in solving common problems. More importantly, more applications require the integration of different types of content and their corresponding tools to address complex requests from the user.

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