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Concept evolution analysis based on the Dissipative Structure of Concept Semantic Space

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HIGHLIGHTS

- Apply the thermodynamic theory to text semantic analysis.
- Propose two Discriminations of the Dissipative Structure of Concept Semantic Space.
- Analyze the concept semantic evolution based on the Dissipative Structure of Concept Semantic Space.

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ABSTRACT

In the domain of text semantic processing, concept semantic evolution is a common phenomenon involved in the lasting process of a concept's formation and development at different stages, which leads concept evolution analysis to be difficult in identifying concept evolution states. To solve the problem, the paper proposes a method of concept evolution analysis based on the Dissipative Structure of Concept Semantic Space (CSS). First, a CSS is constructed as surroundings where a concept forms and its semantic evolves. Second, an analogy is made with thermodynamics and the theory of Dissipative Structure is applied to CSS, which models the changing process of CSS from the disordered to the ordered. Third, the evolution of concept is analyzed based on the Dissipative Structure of CSS. Finally, the proposed method is verified by an application and experiments.

1. Introduction

In the domain of text semantic analysis and application, compared with a keyword, a concept has bigger semantic granularity and holds more semantic information [1,2], which is used in ontology construction [3], text semantic representation [4], text semantic annotation [5], semantic search [6], event detection and tracking [7], etc., in order to improve the efficiency of text semantic processing. In the above applications, the accuracy of concept analysis plays a crucial role in improving the precision of applications.

The accuracy of concept analysis is mainly reflected in the following aspects. (1) When a new concept appears, the system can detect it timely. (2) The system can express the current semantic of a concept accurately. (3) The system can perceive the change of a concept semantic timely. To achieve these goals, we have to analyze the phenomenon of concept evolution and its process from dynamic perspective.

Concept semantic evolution is a common phenomenon. Concept semantic, in the physical world or in the Web virtual space, is constantly evolving. Concept semantic evolution is a continuous process accompanying a concept's formation and development at different stages. Concept semantic evolution usually includes concept generation, concept disappearance, concept semantic transference, concept semantic diversity.

At present, concept learning methods can come down to three types: concept extraction in linguistics [8,9], concept extraction in statistics [10] and the combination of the two [11]. But these methods have their obvious deficiencies in analyzing the above phenomenon of concept evolution. It is difficult to determine whether concept semantic changes just by means of the changes of the attributive words or the relations between attributive words. It is also difficult to determine when concept semantic is comparatively stable and when it evolves.

Therefore, it is likely to analyze the process of concept evolution accurately from the global and dynamic perspective. The general process of a text semantic analysis system is constantly acquiring texts (i.e. web pages), extracting keywords of texts, mining semantic relations between the keywords and extracting concepts based

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on semantic relations between the keywords or syntactic analysis. In the above process, the continuous addition of texts leads to the constant changes of keywords and their semantic relations, which causes concept changes, namely, semantic evolution phenomena of concept semantic. Concept Semantic Space (CSS) can be regarded as surroundings where the above concepts evolve [12]. In CSS, concept evolutions are seen as the results of the interaction of the keywords by semantic relations.

Many similarities between CSS and thermodynamic system can found when we make an analogy. The keywords environment in CSS is analogous to the molecules in the thermodynamic system, the interaction between the keywords to the thermal operation of the molecules, the stable relation between the keywords to the ordered inter-molecules structure, concepts in CSS to subsystem of thermodynamic system. The theory of Dissipative Structure reveals the rules of molecule movement that the system mutates from the disordered state to the ordered state under the external influence. Concept Semantic Space (CSS) has a similar rule to molecule thermal operation, especially the process of keywords conversion from the disordered to the ordered, which is analogous to the Dissipative Structure of thermodynamics. So the theory of Dissipative Structure can be employed to study the Dissipative Structure of CSS. The ordered state of CSS is a macro-reflection of an ordered organization established by interactions of keywords and concepts in the CSS. The inter-conversion between the ordered state and the disordered state presents the concept semantic changes, namely, concept semantic evolution. Therefore, the paper proposes a method of studying concept semantic evolution by means of CSS evolution based on the theory of Dissipative Structure, which is expected to tackle the deficiencies in the above methods of concept evolution analysis.

The paper is organized as follows: the first section is introduction. Section 2 presents basic theories and related work. In Section 3, we construct a dissipative structure model of CSS and discuss discrimination of the Dissipative Structure of CSS. Section 4 analyzes concept evolution based on the evolution of CSS. In Section 5, the early detection method of emergency is introduced based on concept evolution analysis. Section 6 is mainly about experiments and conclusion is drawn in the last section.

2. Related work

2.1. Concept

The definitions of concept in philosophy, linguistics, logic, psychology, cognitive informatics, software engineering and knowledge engineering are not all the same [13]. Philosophically, concept is the basic unit of thinking. In artificial intelligence, concept is used to model the knowledge of human. In linguistics, concept is a noun or noun phrase as the subject of to-be structure [14]. In cognitive informatics, concept is an abstract structure with exact semantic of cognitive process, such as, thinking, learning, and reasoning [15]. In the above domains, concept is defined as the basic unit of thinking, learning and reasoning. A concept has intension and extension, namely its meaning (attribute words) and scope (example).

In the specific application area of the text semantic processing, the concept is dynamic and the amount of concept is very large. It is impossible to acquire all the intension and extension of a concept exactly, efficiently, and automatically. It is enough to acquire limited attributive keywords to describe a concept which could meet the practical requirement. Therefore in this paper a concept is a keyword of high semantic level, which can be described by several keywords or concepts at low semantic level [16].

Definition 1 (*Concept*)**.** A concept is a keyword which has higher semantic representation ability and can be described by k attributes, $C = \{kw_1, kw_2, kw_3, \ldots, kw_k\}$. In which, C is the concept and $kw_1 \sim kw_k$ are the k attributes of C which are acted as k keywords of lower semantic level.

2.2. Concept semantic space

Concept space is the semantic organization model of concepts, which have not had a uniform definition until now. Different definitions are proposed to fit the special research purposes and application scenarios [17–19]. In [18], concept space is formed by concepts and their semantic relation network. In [17], concept space is concepts and their semantic relations, among which concept is extracted and clustered from keywords of text several rounds. In the above definitions, concept space is used as a container to save concepts and their semantic relations, which is a static space and cannot make an automatic evaluation.

In our previous work [12], the Concept Semantic Space (CSS) is proposed to describe the dynamic process of concept changing. CSS is an open system composed of text set, semantic link network (SLN) of keywords (keywords and their semantic relations), and SLN of concepts (concepts and their semantic relations), which is not only the container of concepts and their semantic relations but also the space of all kinds of semantic activities, such as, the generation of new concepts, the disappearance of old concepts, the semantic changing of current concept, etc. In this paper, we directly consider CSS as the space of concept semantic analysis. The features of CSS are introduced briefly as follows.

(1) Multiple semantic granularities. The CSS describes the text set from multiple semantic levels, such as keyword, concept, and so on, in order to support services at different semantic levels.

(2) Multiple semantic dimensions. The CSS holds different kinds of semantic relations, such as association relations, similar relations and so on, in order to support services of different types of semantics.

(3) Dynamic. The CSS changes dynamically and automatically according to the changing of text database in order to support the service based on concept analysis.

(4) Macroscopic view. The CSS provides a global view of the text set in order to support the service based on global analysis of the set.

2.3. Dissipative structure

Under the effect of external environment, the thermodynamic system will sometimes produce a special development trend, the development process from disordered state to ordered state, such as the crystal structure, the laser phenomenon, which breaks the general law of thermodynamics. The dissipative structure theory proposed by Prigogine reveals the essence of the problem. A system, which is nonlinear, open which and far from equilibrium (whether physical, chemical, biological and social, economic system) exchanges material and energy with the outside continuously. Then it may mutate, that is, non-equilibrium phase change and the system changes from the chaos state into an ordered state in time, space or function. To maintain the ordered structure, the system needs to exchange matter or energy with the outside, which is called 'Dissipative Structure' [20].

The dissipative structure reveals the nature from junior to senior development pattern, has been widely used in biological evolution, city development, the social economy, information processing and other fields of research.

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