Towards Granular Reasoning on the Web

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Abstract. Granular reasoning describes a way of thinking that relies on the human ability to perceive the real world under various levels of granularity. It would have a significant impact on problem solving at a Web scale. The paper reports some preliminary ideas on how to study granular reasoning for humans and for the Web in a unified way. Firstly, we investigate human granular reasoning related functions, such as human declarative memory organization and retrieval with multiple information granule networks. Secondly, we develop a granular reasoning system to demonstrate the proposed method. Thirdly, we try to combine the results from the previous two for the implementation of a cognition-inspired computing platform on the Web.

1 Introduction

Humans can perceive the real world under many levels of granularity (i.e., abstraction) and can also easily switch among different granularities. Consequently, we can abstract and consider only things that serve a specific interest and ignore things that are irrelevant [12, 23, 26]. By focusing on different levels of granularity, one can obtain different levels of knowledge, as well as an in-depth understanding of the inherent knowledge structure. Granular reasoning is thus essential for human intelligence and would have a significant impact on problem solving and reasoning at a Web scale. The main purpose of the paper is to explore this direction of research. We plan to study human and Web granular reasoning in a unified way by considering granular reasoning on the Web as an application of human-inspired granular reasoning.

ACT-R, a computational cognitive architecture [4], is used to analyze, examine and validate our studies. It provides a good framework by considering the interaction among different modules of information processing in the human brain. To understand human problem solving based on the ACT-R architecture, we take two steps. First, we will perform a series of experiments on heuristics and granular reasoning in human problem solving that involves memory retrieval (such as retrieving heuristic rules) in multiple information granular networks and visual attention that involves checking the representation of the problem state. We will develop ACT-R models to predict when and how long the brain areas corresponding to memory retrieval and visual attention are active during the processes of problem solving, how the brain areas change when retrieving different information sources in different information granular levels. We use data from fMRI recordings to test these models.

Second, we will use the chunk structure in the declarative memory of ACT-R to build the plug-in systems for the organization of multiple information granule networks. ACT-R's declarative chunk representation provides a good way for modeling granular reasoning [1, 2]. In every chunk, there is a special slot, called IS-A, which connects the current chunk to its category, which is also a chunk. During retrieval, both the probability to be retrieved and the retrieval time for each chunk are based on its activation, which is computed by adding the base level activation and associative activation from the context. In other words, whether a piece of information is retrieved or not is determined by not only the frequency and recency, but also the context elements. According to the spreading activation theory of memory, declarative knowledge is represented in terms of chunks and associative pathways between chunks, which forms a semantic network of concepts. A hierarchical structure is also present in this network, classifying concepts into more general and more specific ones. We will use ACT-R to represent multiple information granule networks.

As a demonstration for our methodology, we plan to develop a multi-resolution granular reasoning scheme and implement a granular reasoning system on the Web. They include an information organization structure called multiple information granule networks and implement a trade-off algorithm for selecting and retrieving such networks based on the understanding of the question under constraints.

The rest of the paper is organized as follows. Section 2 discusses the background and related work. Section 3 describes how to investigate human granular reasoning strategy and design related cognitive experiments for understanding the principles and mechanisms of information organization, retrieval and selection in human memory. Section 4 presents a preliminary Web granular reasoning framework and a case study on travel planning services to demonstrate the usefulness of the proposed framework. Finally, Section 5 gives concluding remarks.

2 Background and Related Work

Reasoning in practical situations is always under certain constraints such as space, time, incomplete or uncertain information, and limited knowledge. It is necessary to draw reasonable conclusion under such constraints. This leads to studies of various practical, and perhaps not 100% sound reasoning methods.

Granular computing [22–24, 26, 27], variable precision logic [21], and ripple-down rules [7, 10] offer such reasoning strategies.

Variable precision logic may be viewed as a logic implementation of the general ideas of granular computing. It concerns reasoning with incomplete information and under time constraints. More specifically, it is based on a trade-off between precision of inferences and the computational cost in deriving them. The building block of the variable precision logic is a rule of the form "if A then B unless C", where C is an exception. If we do not have sufficient time, we can simply draw a conclusion B if A holds, although we know that when C also holds, we cannot conclude A. If we have more time, we can examine the condition C and draw new conclusion. In general, we can associate measures to such rules so that we can perform quantitative inference.

Ripple-down rules offer a slightly different organization of rules. A rule is typically associated with another rule of exceptions, and the latter may also have another rule of further exceptions, and so on. Ripple-down rules can be used to organize general and not 100% correct knowledge with another modification rule, and so on. Thus, it offers a reasoning method, similar to variable precision logic. One can stop a reasoning process in the middle of a ripple-down rule, if time constraints must be met. Although the conclusion we draw may be incorrect, the structure of ripple-down assures that we would make few mistakes.

"Rule + exception" strategies work in a similar way. We can construct a general rule that may not be 100% correct. To remedy this, we add exceptions to rules [16, 25]. Under time constraint, we can simplify inference using rules without considering the exceptions. If more accurate conclusions are needed, we can take more time to examine the exceptions.

In summary, the three heuristics trade precision for time under time constraints. They have, in fact, been effectively used by everyone in daily problem solving. These three heuristics share a common feature, namely, representations of knowledge under different level of granularity. It seems that the consideration of multiple levels of knowledge may be one of the keys for designing practical reasoning methods. In particular, we need to organize the data, information and knowledge on the Web at multiple levels.

Another typical feature of Web reasoning is the need to combine rule-based reasoning with case-based reasoning [14, 15]. Some Web information cannot be represented explicitly as rules, but cases, due to the complexity and variety of Web information and Web service provisioning. Moreover, the experience gained from the cases can be used to improve the modeling and in turn to improve the rules. Based on this observation, we can develop a hybrid reasoning method on the Web at multiple levels.

3 Human Granular Reasoning

Artificial Intelligence (AI) has been mainly studied within the realm of computer based technologies. Various computational models and knowledge based systems have been developed for automated reasoning, learning, and problem solving.

However, there still exist several grand challenges. The AI research has not produced major breakthrough recently, due to a lack of understanding of human brains and natural intelligence [24]. In addition, most of the AI models and systems will not work well when dealing with large-scale, dynamically changing, open and distributed information sources on the Web [8, 9, 28, 30].

Ignoring what goes on in human brain and focusing instead on behavior has been a large impediment to understanding complex human adaptive, distributed reasoning and problem solving [28, 30]. In order to develop a new cognitively inspired Web reasoning and problem-solving systems, we need to better understand how humans perform complex adaptive, distributed problem solving and reasoning. Understanding the principles and mechanisms of information organization, retrieval and selection in human memory aims to find more cognition-inspired methods of information memory system, problem solving and reasoning at the Web scale.

Based on many investigations on information retrieval and selection in human memory system, we can view the human brain as a huge distributed knowledge base with multiple information granule networks. In the light of the brain inspired methodology, we need to investigate specifically the following issues:

- Why humans can give a good answer within a reasonable time by exploring variable precision when receiving a question (i.e., a reasoning problem)?
- How humans select a suitable level of information granules and retrieve in single or multiple information sources, which is based on a trade-off between user needs and certain constraints?

As a result, the relationships between biologically plausible granular reasoning and Web reasoning need to be defined and/or elaborated.

From the viewpoint of granular reasoning, data, information, and knowledge are arranged in multiple levels according to their granularity as multiple information sources [23, 30]. A higher level contains more abstract or general knowledge, while a lower level contains more detailed or specific knowledge. Reasoning and retrieval can be performed on various levels in single or multiple information sources. Results from a higher level may be imprecise but can be obtained faster. In contrast, one can move to a lower level to obtain more precise conclusion if more time is allowed. Hence, granular reasoning offers a multi-resolution reasoning scheme, which may choose a proper level of granularity to draw a desirable conclusion under certain constraints. Such a reasoning and retrieval scheme is commonly used by human for practical and real-time problem solving and decision-making.

As part of a long-term effort to address the above two issues, we will first carry out two series of cognitive experiments to investigate the mechanism of information retrieval and selection in a variable precision fashion in human declarative memory.

Experiment 1 aims at answering the question of how human selects a suitable level of information granules (IGs) and retrieves from single or multiple information sources (ISs), which is based on a trade-off between user needs and certain constraints. The experiment is divided into four cases by making different types of questions (tasks), namely, participants need to:

1. use single IS and search for an answer on single IG level in the IS,
2. use single IS, but search for an answer on different levels of IGs in the IS,
3. use multi-IS, but search for an answer on single IG in each IS, and
4. use multi-IS and search for an answer on different levels of IGs in the ISs.

The behavioral patterns and activities of the brain under these cases will be evaluated to understand the neural mechanism of information retrieval and selection in a variable precision fashion. The results will inspire us to develop an information organization structure with multiple information granule networks and a trade-off algorithm for selecting and retrieving on such networks based on the understanding of the question under constraints [5, 13, 30].

Experiment 2 is related to retrieval strategy and visual attention during problem solving. Different information has its own role in the problem solving process. For example, information with respect to a goal guides the search direction and information with respect to a situation is essential to solve a problem. This experiment will use Sudoku to illustrate the role of different types of information granules during problem solving. In this experiment, memory load is also considered. Different memory loads affect the sufficiency of information maintenance and integration. With different memory loads, participants either retrieve information respecting to a goal or a situation. Based on the results, different behavior patterns and brain activities will suggest the mechanism of information granular types in problem solving, and provide evidence to support the relationship between an information granule retrieved and a task/problem when facing an unsettled situation [20].

For these cognitive experiments, a broadly used empirical methodology, functional magnetic resonance imaging (fMRI) will be used to investigate the neural mechanism of memory organization and information retrieval and to measure the dynamic change of BOLD effect in the brain. In addition, ACT-R will also be used to explain human's behaviors, as well as to clarify the relationship between cognitive modules and the brain [4, 3].

4 A Granular Reasoning Platform

The main ideas of granular reasoning are to organize data, information, and knowledge in multiple levels, i.e., hierarchical structures, and to draw a desirable conclusion under certain constraints at particular information and/or knowledge levels. A granular reasoning platform may be built based on these ideas.

The platform must provide an information organization structure with multiple information granule networks and implement a trade-off algorithm for selecting and retrieving on such networks based on the understanding of the question under constraints [13, 29]. Information relevant to solve a problem is collected from global Web based distributed information sources, and these sources are organized by using ACT-R declarative memory representation under the need of granular reasoning. Furthermore, declarative knowledge is selected and retrieved based on the spreading activation theory of memory according to ACT-R.

In what follows, we use a travel planning system to demonstrate how granular reasoning works for real-world problems by using the platform. The travel planning system is shown in Fig. 1. Firstly, we will design a multi-level granularity structure for information organization over large-scale semantic repositories. Secondly, we will implement a trade-off algorithm to switch between different levels of granularity, which is inspired by human intelligence in the problem solving process.

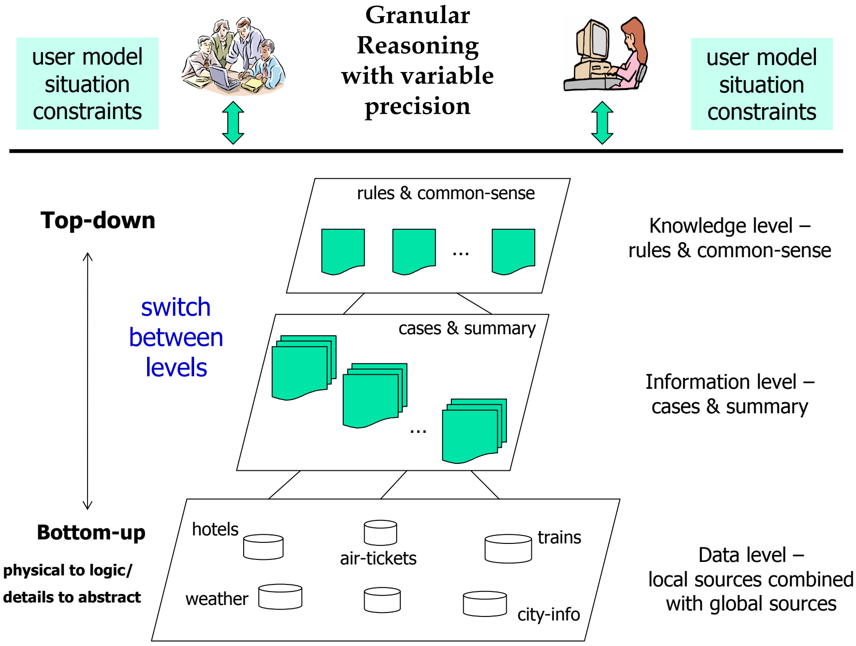

Fig. 1. Travel planning system design with multiple information granule networks

The information sources are organized in three levels, namely data level, information level, and knowledge level as shown in Fig. 1. Although the information sources can be organized in more than three levels for real-world needs, the three-level model may be enough to demonstrate our idea.

The data level is built by coupling global semantic Web/social networks with local information sources, which is at the bottom of the information organization structure. The data sources can be represented as a set of RDF triples (or RDB) with activation weights, which are revised dynamically. In specific cases, the data level has the data stored in an organized way, such as air-ticket, hotel, weather, city-information, and so on.

Basic granules in the information level are cases, which are formed by abstracting and summarizing multiple data sources in the data level [14]. One or more cases can be classified/grouped and represented as chunk(s). Furthermore, the cases/chunks in the information level are managed and changed according to associative and base level activations. For example, the plans for a business trip and for a tourist trip are different. For a business trip, exact schedule is always the first priority. For a tourist trip, such as for a student trip, the budget may be the first priority. In the case of a family trip, comfortability is a major concern, besides the budget. Therefore, in the difference cases, the way of abstracting and summarizing is different. The activation and weight for the multiple sources are also different. The algorithm of locating and selecting corresponding data sources is a challenge.

Basic granules in the knowledge level are rules, which are learned from cases in the information level and/or from the data sources in the data level directly. One or more rules can be classified/grouped and represented as chunk(s) as well.

In order to carry out granular reasoning in a variable precision fashion, user related information needs to be prepared by learning personalized user models. Based on the preparation stated above, we can implement a trade-off algorithm for selecting and retrieving on such multiple information granule networks based on the understanding of the question under constraints.

As shown in Fig. 1, both bottom-up and top-down processing are involved, as information selection and retrieval will switch among levels based on the query from users. With support of the multiple granular structure and trade-off algorithm, the system can combine rule-based and case-based reasoning methods and choose the proper granularity level and then locate the necessary data sources effectively for the specific query and customer. More importantly, the results from the cognitive experiments may help us to understand the human problem solving mechanism deeply, and the principles can also be used to improve the system.

5 Concluding Remarks

The capabilities of human brain, e.g., thinking in image and handling the uncertain issues, depend on something more than logic and exact mathematical computing. Many problems have been reported to be hard for computers, while easy for humans [24]. The study of Web intelligence (WI) must be connected with cognitive neuroscience. It has been advocated to develop WI in combination with brain informatics [30].

The new breakthrough from merging the research of WI and cognitive neuroscience is expected to provide the neural basis for the study of AI and WI. Some researches [17, 19] using fMRI on probability reasoning revealed that probability reasoning is mainly executed by language-specific network. Anderson [2] reported that humans always search for related empirical evidence with uncertainty by commonsense to make a smooth reasoning. Different emotional feelings influence the process of human thinking [18, 6], which embodies the human uncertainty of thinking. A neural imaging study [11] showed that reasoning task with emotional contents mainly activates ventral medial prefrontal cortex (VMPFC) and reasoning task with neutral contents activates more lateral/dorsal lateral prefrontal cortex (L/DLPFC).

The information processing mechanisms of human approximate reasoning obtained from the field of cognitive neuroscience could be used in the development of intelligent systems [16]. It is possible to study human intelligence together with the achievement of intelligent systems by cognitive approaches, and then make an intelligent system, which can deal with open, dynamically changing and uncertain information at the Web scale. Granular reasoning seems to offer a good solution for reasoning on the Web.

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