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Ontology-based Systemization Approach to Capture Meta-level Thinking Processes from Gaze Behaviors

Yuki HAYASHI[a*], Kazuhisa SETA[a] & Mitsuru IKEDA[b]

[a] *Graduate School of Humanities and Sustainable System Sciences, Osaka Prefecture University, Japan*

[b] *School of Knowledge Science, Japan Advanced Institute of Science and Technology, Japan*

*hayashi@kis.osakafu-u.ac.jp

Abstract: It is difficult to capture a person's thinking processes because of the invisible, shapeless, complex structure of thought. In order to approach implicit thinking processes, we propose a framework for capturing a portion of meta-level thinking processes from gaze behaviors. Here, we focus on the meta-level thinking processes in the dissolution of belief conflicts, and introduce the concept of *semi-metacognitive-level thinking*, which allows us to make assumptions about the monitoring/control cycle based on gaze behaviors toward externalization objects of base-level thinking. In this paper, we discuss a framework for capturing metacognitive thinking processes from gaze behaviors and propose an ontology to embody the concept of the framework.

Keywords: Metacognitive skill, meta-level thinking, critical thinking, thinking-gaze ontology, gaze behaviors.

1. Introduction

In daily life, we face many difficult social issues that may have various viewpoints, making it difficult to find a proper solution in such situations. In this case, an aspect of metacognitive skill, or "thinking about thinking," should be exerted as an internal self-conversation that serves to explain our thoughts in a logical manner. While thinking activity is the essence of human existence, it is difficult to train thinking skills because this is essentially a cognitive activity and implicit behavior unobservable by others (Rana and Upton, 2013).

In order to grasp the implicit thinking processes of internal self-conversation, the thinking aloud method, which requires subjects to talk while solving a problem or performing a task, is often used (Jaspers et al., 2004). However, this method has some limitations; for example, unconscious processing is inaccessible and high cognitive load can hinder verbalization by utilizing all available cognitive resources (Jääskeläinen, 2010). To tackle this problem, there are several studies that use an eye-tracker to analyze thinking; for example, verbalization processes (Guan et al., 2006) and the difference between normal and mindless reading (Reichle et al., 2010). Bondareva et al. analyzed relations between students' learning performance and eye-tracking data in self-regulated learning (Bondareva et al., 2013). However, there is little research that focuses on revealing the metacognitive processes in the context of internal self-conversation.

The objective of this research is to make the implicit and chaotic metacognitive processes clear using eye-movement information. In internal self-conversation, metacognitive monitoring and control refer to higher order thinking that targets base-level thinking. In this study, we hypothesize that some meta-level thinking processes can be captured from gaze behaviors on the assumption that an application allows a user to externalize his or her base-level thinking into a designed interface component. As the term "metacognition" is used in many different ways in different situations (Kayashima et al., 2005), as a first step in validating our hypothesis, it is essential to clarify the conceptual connection between meta-level thinking and gaze activities in order to determine the meta-level thinking processes that may be captured through eye movements. To approach this objective, we introduce an ontology that systematizes the concept of meta- and base-level thinking activity,

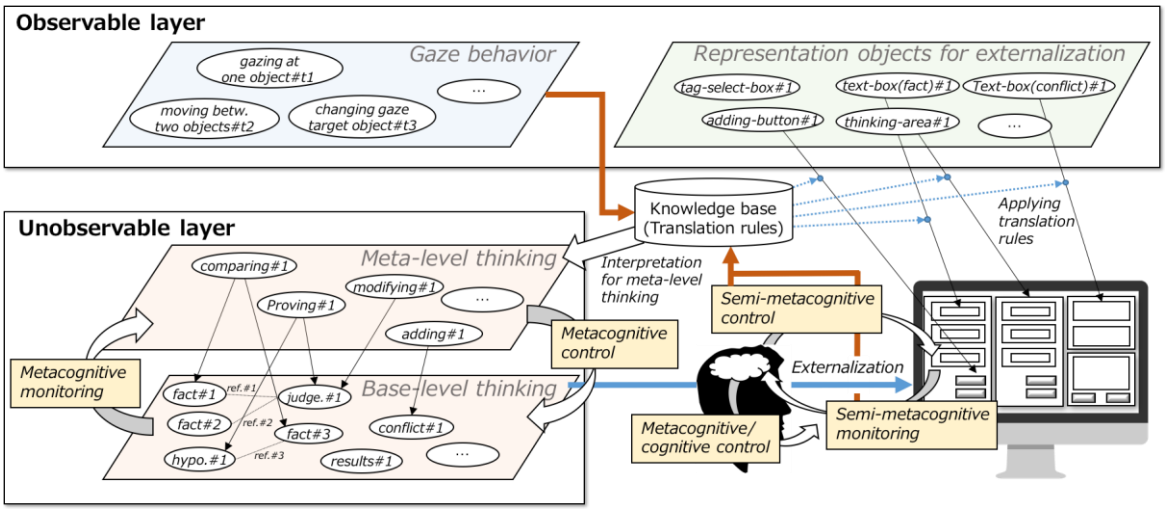

Figure 1. Framework for Capturing Meta-level Thinking Processes from Gaze Behaviors.

representation component for externalization of cognitive thinking, and gaze behaviors. In this paper, we discuss the concept and applicable scope of gaze-thinking ontology. We then introduce an example of thinking recognition application (Hayashi et al., 2016) that can capture the sequence of user's gaze information during his or her meta-level thinking processes.

2. Approach for Developing an Ontology

2.1 Target Thinking Processes

We focus on the critical thinking processes in internal self-conversation. More specifically, we focus on meta-level thinking processes in the dissolution of belief conflicts. These thinking processes require the creation of new knowledge by identifying meaningful conflicts between one's own thinking and that of others.

In order for learners to train themselves in the critical thinking processes involved in internal self-conversation, Chen et al. proposed a thinking training environment called Sizhi (Chen et al., 2011). This tool is designed to encourage meta-level thinking processes by clearly verbalizing one's own thinking and that of others' processes in a logical manner, and reflecting on the thinking processes to find meaningful conflicts for fruitful knowledge creation. While Sizhi allows learners to externalize their base-level thinking, the thinking processes in meta-level monitoring and control (e.g., proving or comparing the validity of externalized statements and finding conflict) are still implicit. The idea behind this research is to approach the implicit and chaotic meta-level thinking processes using clues from gaze behaviors to externalize base-level thinking processes.

2.2 Capturing Meta-level Thinking Processes

Figure 1 represents a framework for capturing meta-level thinking processes from gaze behaviors. The thinking processes include base-level and meta-level thinking, where meta-level thinking monitors (metacognitive monitoring) and controls (metacognitive control) the base-level thinking processes. In the case of internal self-conversation about the dissolution of belief conflicts, to think about *fact*, *conflict*, *hypothesis*, *decision*, *results*, etc. corresponds to base-level thinking activities; for example, "Eri was bullied because she changed her attitude when she interacted with boys" (*fact*), and "I was bullied because I got along well with Eri" (*results*). Meta-level thinking targets the base-level thinking; for instance, "comparing certain fact with the reason" and "proving a hypothesis," are components of metacognitive monitoring while, "modifying the conflict" is an aspect of metacognitive control. As we know, thinking processes cannot be observed from the external world (as shown in the lower left of Fig. 1).

As it is an observable activity, we can capture a user's gaze behaviors using eye-tracker devices. In reading, the eye moves continuously along a target, running through short rapid movements (saccades) and short stops (fixations). Of course, we need to note duration times of eye movements carefully, so that we can track gaze behavior such as "gazing at certain object at #t1" and "changing gaze target object at #t3" (as in the upper left of Fig. 1) based on the series of saccades and targets of fixations. Here, we introduce the concept of representation objects (see the upper right of Fig. 1), which allow a user to externalize his or her base-level thinking. The objects include areas, text-boxes, buttons, and select-boxes, at the software application level. These objects are observable; hence, we can capture the processes of eye movements to the base-level thinking representation objects.

On the assumption that a user enables to externalize base-level thinking onto the appropriate representation objects, gaze behaviors toward the objects imply a portion of his or her meta-level thinking. That is, we assume isomorphism between the cycle of metacognitive monitoring and control in meta- and base-level thinking and the cycle of gaze behaviors and externalization of base-level thinking to the representation objects. As externalized base-level thought is a portion of base-level thinking and may be added to or modified through the externalization of internal self-conversation processes, we regard the latter cycle as *semi*-metacognitive monitoring and control. Here, the targets of fixations affect the consciousness that what he or she wants to focus on, so that we mind the semi-metacognitive monitoring is controlled by metacognitive and cognitive activities (as depicted in the lower right of Fig. 1).

In meta-level thinking processes, the way to monitor and control base-level thinking is different depending on the thinking strategy for dissolving belief conflicts. For example, one thinks the case externalized by another (e.g. correction strategies), he or she needs to recognize and understand the other's case. In order to deal with this aspect in the semi-metacognitive level, we introduce a knowledge base (translation rules) that defines the correlation between possible meta-level thinking and the gaze behaviors according to the thinking strategies (middle of Fig. 1). As it is possible to interpret several meanings from some gaze behaviors in meta- and base-level thinking, we take the position that the translation rules do not determine a unique interpretation for each gaze behavior. By setting an appropriate translation rule based on the objective of the thinking strategy and adapting it for representation objects, we assume that the thinking processes in semi-metacognitive monitoring and control are captured.

This study develops an ontology to systematize the above concepts of thinking processes in the dissolution of belief conflicts. Explicitly defining these concepts as machine-readable operational forms is important for researchers who wish to share a common understanding and to develop applications that allow us to capture semi-metacognitive-level thinking processes based on the target objective. In addition, the ontology includes the potential to allow developers to construct novel thinking training applications by capturing learners' internal conversation processes, which is practically impossible in conventional applications.

3. Gaze-thinking Ontology

3.1 Overview of GT-ontology

In this section, we explain the current state of the gaze-thinking ontology (GT-ontology), which systematizes the concept of (i) semi-metacognitive-level thinking processes; (ii) representation objects for externalization; and (iii) gaze behaviors, as discussed in Section 2, using an ontology development environment[1].

3.1.1 Semi-metacognitive-level Thinking Processes

Figure 2 shows a part of thinking activities in GT-ontology and systematizes the concepts of critical thinking processes in the dissolution of belief conflicts. Thinking activities include base-level thinking (BL-thinking), semi-metacognitive-level thinking (semi-ML-thinking), and meta-level thinking (ML-thinking).

[1] Hozo -Ontology Editor-, http://www.hozo.jp

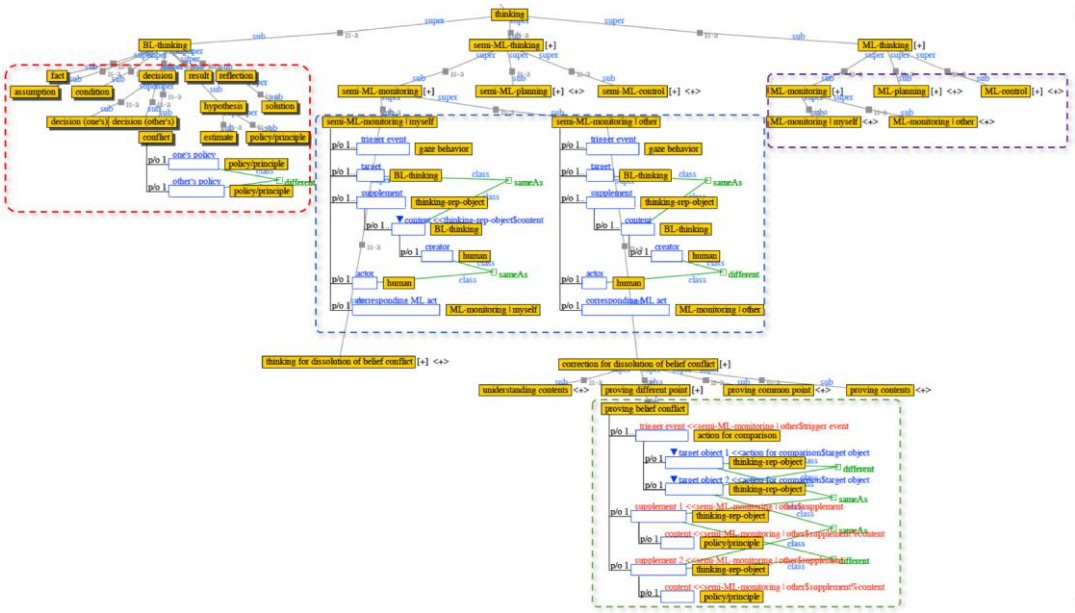

Figure 2. A Subset of Thinking Activity Concepts.

The concepts of base-level thinking are systematized under BL-thinking (the red dotted-area in Fig. 2). For example, as the root of conflict arises from different policies and principles, the concept "conflict" is defined as a concept composed by one's and other's policies, and they must be "different". ML-thinking specifies three concepts: meta-level monitoring, planning, and control as "ML-monitoring," "ML-planning," and "ML-control," respectively (the purple dotted-line area in Fig. 2). BL-thinking and ML-thinking are unobservable activities from the external world.

Here, we define the concept of semi-ML-thinking activity under the assumption mentioned in Section 2.2. This concept includes semi-meta-level monitoring, planning, and control as "semi-ML-monitoring," "semi-ML-planning," and "semi-ML-control," respectively, similarly to ML-thinking. Each concept has a "corresponding-ML-act" to clarify the isomorphism between ML-thinking and semi-ML-thinking. In order to systematize the difference between thinking targets and strategies, we consider the thinking processes regarding a dissolution of belief conflicts of himself/herself and that of other's as another concept; the case of semi-ML-monitoring includes "semi-ML-monitoring | myself" and "semi-ML-monitoring | other" (the blue dotted-area in Fig. 2). Both of the concepts have the "target" denoted as BL-thinking, the "actor" of the thinking, and "trigger event" played by "gaze behavior" for capturing semi-metacognitive-level thinking processes. Additionally, we define as a "supplement" the representation object ("thinking-rep-object"), which signifies the objects for externalizing contents of base-level thinking linked to a "target" with a "same-as". The difference in thinking targets is defined by linking the "actor" and "creator" of each supplement with a "same-as" (semi-ML-monitoring | myself) or "different" (semi-ML-monitoring | other).

Specific semi-ML thinking activities are systematized under the concept of "thinking for the dissolution of belief conflicts" and "correction for the dissolution of belief conflicts." For example, actions for proving the validity of belief conflicts ("proving belief conflicts") are defined under the concept of "semi-ML-monitoring | other," which does not appear under the concept of "semi-ML-monitoring | myself" (the green dotted-area in Fig. 2).

3.1.2 Representation Objects for Externalization of Base-level Thinking

Figure 3 shows some of the representation objects in GT-ontology. Under the concept of "concrete object" we define a "representation object" as a concept which has "content" and "media" (the red dotted-line area in Fig. 3), and a "medium" which serves as the media of the representation object. Under the representation object, we define "thinking-rep-object" for externalizing contents of base-level thinking, whose content is specialized as being played by "BL-thinking." As the medium, we systematize the concepts of "interface components" in the software application that include areas, panels, buttons, text-boxes, etc. Each of these has a specialized software function, e.g., text-boxes allow a user to input characters (the blue dotted-line area in Fig. 3).

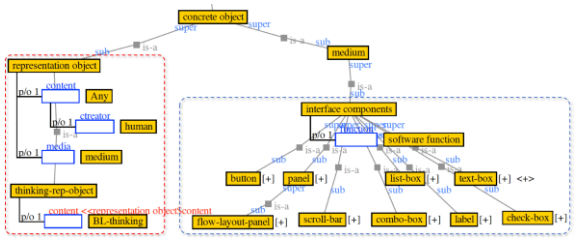

Figure 3. A Representation Component for Externalization.

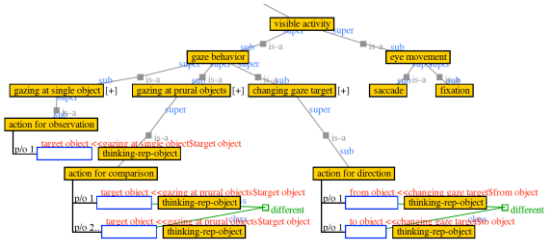

Figure 4. Gaze Behavior Concepts.

3.1.3 Gaze Behaviors

Some gaze behaviors are shown in Fig. 4. We systematize general classes of gaze behavior such as "gazing at a single object" and "changing gaze target." Under the general concepts, gaze behaviors toward the representation objects, as defined in the previous section, are systematized. For example, "action for comparison" has two gaze target objects that are "thinking-rep-objects," and they must be "different."

3.2 Discussion

In GT-ontology, the concept of gaze behaviors plays the role of event trigger in semi-ML-monitoring activities. For instance, "action for comparison" is defined as a trigger event of "proving belief conflict." In this case, in order to represent the correspondence relation between gazing at "target objects" and the "supplements," they are linked with "same-as" and "different." Here, "content" of each supplement is specialized as played by policy or principle defined in BL-thinking to represent the concept of proving belief conflicts (the green dotted-area in Fig. 2).

In this manner, the ontology allows us to develop a specific application that can explicitly express what sort of semi-ML-activities are captured by what types of gaze behaviors toward what kind of base-level thinking representation objects. Note that researchers need to set actual translation rules according to the objective of thinking strategies outside of the ontology. While the ontology is not completely described at this stage, and meta-level thinking itself is still externally unobservable, we believe this ontology serves as a basis for common understanding for researchers who approach the invisible, shapeless, complex structure of thinking processes.

4. Example of a Meta-level Thinking Capturing Tool

We have developed a tool to analyze the meta-level thinking processes of user's internal self-conversation that we intend to reflect the concept of GT-ontology. Figure 5 demonstrates the interface. This tool follows the design principle of Sizhi, as explained in Section 2.1. The interface depicts four thinking areas: "A's thinking" denotes one's own thinking, "B's thinking" denotes opponent's thinking, "conflict" denotes the difference between A's thinking and B's thinking, and "knowledge-building" denotes dissolving the root of conflict.

A screen-based eye-tracker is introduced to track users' gaze behavior in internal self-conversation processes. The tracker determines which area in the interface the user is looking at by setting area of interest (AOI) regions based on the four thinking areas discussed above (A's thinking, B's thinking, conflict, and knowledge-building) and distinguishes each statement object and its included components (areas of thinking-tags, references, and statement textboxes), conflict textboxes, and edit buttons. The tool records the user's gaze activity as well as other actions in detail, which includes user's gaze events and thinking externalization action (i.e., keyboard and mouse events).

As an initial analysis to investigate the utility of gaze data in understanding the thinking processes, we conducted an experiment for analyzing the data of trainers' correction processes. In the experiment, we mainly focused on comprehensive features, such as the gaze time in thinking areas. From the results, we confirmed that there is some possibility for interpreting the context of a trainer's monitoring and control processes (see Hayashi et al., 2016 for more information).

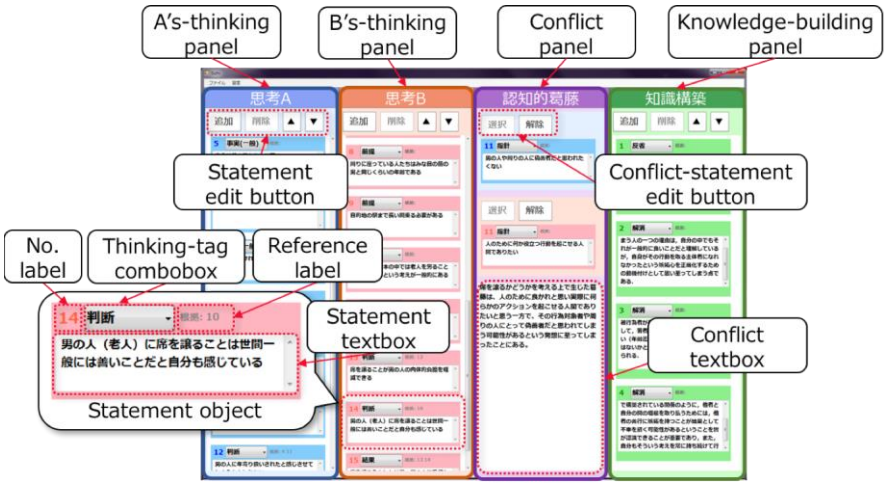

Figure 5. Interface of Eye-Sizhi (Hayashi et al., 2016).

5. Conclusion

In this paper, we proposed a framework to capture meta-level thinking processes based on gaze behaviors and introduced the GT-ontology. This ontology systemizes the concepts of meta- and base-level thinking processes, representation objects for the externalization of base-level thinking, and gaze behaviors. In addition, as a practical application based on our systematized ontology, we introduced a tool to capture learners' and trainers' semi-metacognitive-level thinking processes.

For future work, we are continuing to develop and expand GT-ontology (e.g., defining a number of specific semi-ML thinking activities according to thinking strategies). In addition, we need to define the notation of translation rules used to implement an application for capturing the metacognitive-level thinking processes.

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References

Bondareva, D., Conati, C., Feyzi-Behnagh, R., Harley, J. M., Azevedo, R., & Bouchet, F. (2013). Inferring learning from gaze data during interaction with an environment to support self-regulated learning. In *Proc. of the 16th International Conference on Artificial Intelligence in Education (AIED2016)*, pp.229–238.

Chen, W., Fujii, M., Cui, L., Ikeda, M., Seta, K., & Matsuda, N. (2011). Sizhi: Self-dialogue Training Through Reflective Case-Writing for Medical Service Education, In *Proc. of Workshop on Skill Analysis, Learning or Teaching of Skills, Learning Environments or Training Environments for Skills in conjunction with ICCE2011*, 551–559.

Guan, Z., Lee, S., Cuddihy, E., & Ramey, J. (2006). The Validity of the Stimulated Retrospective Think-aloud Method as Measured by Eye Tracking, In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 1253–1262.

Hayashi, Y., Seta, K., & Ikeda, M. (2016, to appear). Gaze-aware Thinking Training Environment to Analyze Internal Self-conversation Process, In *Proc. of 18th International Conference on Human-Computer Interaction (HCII2016)*.

Jääskeläinen, R. (2010). Think-aloud Protocol. *Handbook of Translation Studies*, 1, 371–373.

Jaspers, M. W., Steen, T., van Den Bos, C., & Geenen, M. (2004). The Think Aloud Method: A Guide to User Interface Design. *International Journal of Medical Informatics*, 73(11), 781–795.

Kayashima, M., Inaba, A., & Mizoguchi, R. (2005). What Do You Mean by to Help Learning of Metacognition?. In *Proc. of the 12th International Conference on Artificial Intelligence in Education (AIED2005)*, pp. 346-353.

Rana, D., & Upton, D. (2013). Thinking, Reasoning and Problem Solving. *Psychology for Nurses*. Routledge, 51–58.

Reichle, E. D., Reineberg, A. E., & Schooler, J. W. (2010). Eye Movements During Mindless Reading, *Psychological Science*, 21(9), 1300–1310.