Analyzing Human's Continuous Learning Processes with the Reflection Sub Task

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Abstract: This paper reports our learning support system for a human learner to visualize his/her mental learning processes with invisible mazes. The objective of this research is to bring the learning ability of the learning agent close to that of a human. To fill in the missing piece of reinforcement learning whose learning process is mainly behavior change, we add two mental learning processes, awareness as pre-learning process and reflection as post-learning process. To observe mental learning processes of a human, we propose a new method for visualizing mental learning processes by the reflection subtask with invisible mazes. As the experimental results, there is a strong negative correlation between the number of discovered solutions of the continuous learning task and the reflection cost. It suggests that subjects whose number of discovered solutions is upper do a very good job of the reflection subtask.

Key words: Cognitive simulation, reinforcement learning, learning process, awareness, reflection.

1. Introduction

Researches on learning process are divided into two fields. One is a learning agent in Artificial Intelligence [1, 2], the other is learning of a human in psychology [3]. For the learning agent, reinforcement learning is the major framework since it automatically learns after a learning goal is set in the learning environment. The main feature of it is that the learning goal is given by the human designer. On the other hand, researches on human learning ability have been performed in various research fields such as psychology, education, business, and so on. One of the main features of human learning ability is that it covers a vast territory of learning ability including discovery of learning goals, awareness [3], reflection [4], self-regulated learning [5], or continuous learning [6, 7, 8].

The objective of this research is to bring the learning ability of the learning agent close to that of a human. We focus on both reinforcement learning framework for the learning agent and the continuous

learning model of a human. However, there are two kinds of questions. First question is how to bridge an enormous gap between them. Second question is how to observe mental learning processes of a human. Previous methods of human learning researches mostly depend on observable behaviors or activities. On the other hand, a learning process of a human has a major difficulty in observing, since it is a mental process. Then a human learning process is yet-to-be-defined. So it is necessary to add a new twist to observe the human learning process.

To solve these problems, we propose a new method for visualizing mental learning processes with invisible mazes. We focus on continuous learning [9, 10], and aiming for modeling the unified continuous learning process model based on reinforcement learning framework for both a human and the learning agent. Our new approaches are following:

1. To fill in the missing piece of reinforcement learning whose learning process is behavior change, we add two mental learning processes, awareness as pre-learning process and reflection as post-learning process;

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2. The learning environment is the invisible maze consisting of invisible walls which are perceived as a sign that suggests the number of walls in the neighborhood;

3. We add the reflection subtask for expressing and summarizing something to be aware of learning from mistake or to be reflected on learning from experience. A learner can mark up his/her traces of the actions and signs for future success. It turns out to visualize his/her mental learning processes;

4. For continuous learning, we design the sequence of invisible learning goals which allows the learner to discover them according to the learning ability.

This paper reports our learning support system for a human learner to visualize his/her mental learning processes with invisible mazes for continuous learning. The paper is organized as follows: Section 2 introduces a theoretical background on continuous learning; Section 3 describes the way to design the continuous learning support system; Section 4 presents results and discussions; Section 5 gives conclusions and future work.

2. Background

First we summarize an overview of continuous learning and its learning process which is compared with that of reinforcement learning, then current usage of awareness and reflection in the Workshops on ARTEL is introduced.

2.1 An overview of Continuous learning

The concept of continuous learning comes from Industrial and organizational psychology. Smita and Trey [8] reviewed research on continuous learning. There are three levels, individual, group, and organizational level. At the individual level, it is self-directed; at the group level, it is collaborative. One of conceptual definitions of continuous learning is as follow: "Continuous learning at the individual level is regularly changing behavior based on a deepening and broadening of one's skills, knowledge,

and worldview" [7].

2.2 Continuous learning process model

A learning process model to achieve continuous improvement has been proposed [6]. Learning process is defined as a process that results in changed behavior. It consists of several mental processes. This model assumes a learner and the leader. The role of this leader is mentor or coacher rather than teacher [11].

There are two kinds of major learning methods, whether teacher-centered (Taught model) or learner-centered (Discovery model). The features of Taught model are extrinsic motivation, controlled and consistency. Its theoretical basis is behaviorism. On the other hand, the features of Discovery model are intrinsic motivation by the individual, empowered, autonomous, creativity and innovation. Its theoretical basis is Gestalt or cognitive psychology. Continuous learning seeks learner-centered rather than teacher-centered.

2.3 Comparison of Continuous learning with Reinforcement learning

Fig. 1 compares learning process between continuous learning and reinforcement learning. Fig. 1a shown the learning process of continuous learning. The major feature of it is that it circles each process and it has no end. The reason is that continuous learning is designed for an adult learner who is expected to spiral up along the endless learning cycle toward mastery of some professional skill. Thus it has commitment process to commit a learning goal. However, each process is mental process. In contrast with it, Fig. 1b shown the learning process of reinforcement learning. Its distinction is that its process has a start and an end. Since the objective of existing reinforcement learning is to find an optimal solution for the learning goal given by a human designer. Next section reviews Awareness and Reflection as important mental processes of continuous learning process.

Fig. 1 A comparison of learning process.

2.4 Awareness and Reflection on learning process

The concepts awareness and reflection are viewed differently across the disciplines among CSCW (computer-supported cooperative work), CSCL (computer-supported collaborative learning), psychology, business, educational sciences, computer science and so on. In the research field of TEL (technology-enhanced learning) for human learners, AR (awareness and reflection) is one of the active research issues [12, 13]. 2013 year's theme for Workshop on this field, AR-TEL 2013 is: "How can awareness and reflection support learning in different settings (work, education, continuing professional development, lifelong learning, etc.). What are the roles that technology can play to support awareness and reflection in these contexts?" [12]. We refer our meanings of Awareness and Reflection from these workshops papers.

The common feature of Awareness and Reflection is focusing experience of a learner on some information for future improvement. The main differences are that Awareness relates to the perception, Reflection mainly relates to the action or the behavior consisting of perception and action.

2.4.1 Awareness as pre-learning process

There are several meanings of awareness on learning. Closely related meanings to our research are as follows:

(a) Individual situational awareness is defined as

"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future [14]".

(b) Awareness is increasingly related to find appropriate learning objects, peers and experts or the 'right' learning path [15].

As pre-learning process, awareness plays an important part to trigger behavior change. Then we focus on the meaning of awareness as the need for distinction of indistinguishable perceptions or experience between future success and future failure. We assume that these indistinguishable perceptions occur by partially observable states [16].

2.4.2 Reflection as post-learning process

There are several meanings of reflection on learning. One of them is as follows: Learning through reflection is defined as "those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations [4]". We take to the concept of Reflective learning [17], which is "the conscious re-evaluation of experience for the purpose of guiding future behavior". As post-learning process, reflection plays a part to create some meaning out of behavior change or learning result. Then we focus on the meaning of reflection as creating the becoming explanation or interpretation toward the rule which can lead the learner not to failure but to success.

3. Designing the Continuous Learning Process

This section summarized the design concepts for the continuous learning process, then describes the way to design the continuous learning support system to guide a human to achieve continuous learning. Firstly, we describe the flow of the continuous learning process, secondly, designing the learning environment as an invisible maze model and how to visualize awareness and reflection processes are illustrated. After designing the continuous learning task by the maze sweeping, we describe designing the sequence of learning goals.

3.1 The flow of the continuous learning process

Fig. 2 showed the flow of the continuous learning process. This process consists of triple cycle. Innermost cycle is called a *trial*. A *trial* is defined as a transition sequence from start state to encountering either a goal state or a wall. In this cycle, a learner repeats an action and his/her mental process including awareness until he/she results in either success or fail of the task. Second cycle is called an *achievement*.

An *achievement* is defined as the learning of a maze sweeping task with the invisible goal. In this cycle, the learner reflects the trial by *the reflection subtask*, when the trial terminates by the encounter with a wall or a goal. If current trial is not accomplished, he/she

restarts the trial from the start state. Outmost cycle is *the continuous learning cycle*. When the learner accomplished current achievement, he/she can challenge next new achievement as he/she wants.

3.2 Designing the learning environment

Designing a learning environment for a human learner, we adopt a grid maze model from start to goal since it is a familiar example to find the path through a trial and error process [9]. A maze model is defined by five elements, state set, action set, a sign of walls, transitions and walls. For details, see Ref. [10].

3.3 Visualizing the awareness process by a sign

A sign is defined as the number of walls of four neighbors in each state. A learner can perceive a sign of current state as the presence of invisible walls, the perceived sign is displayed at the visited state to assist awareness until the end of the trial.

3.4 Visualizing the reflection process by the reflection subtask

We introduce the reflection subtask which is used to describe the awareness from a sign of the invisible walls to visualize his/her reflection process. The reflection subtask is defined to attach a marker on a state in the reflection map for expressing and summarizing a learner's mental learning processes. The markers are three kinds of colors, green, blue, and

Fig. 2 The flow of the continuous learning process.

red. They are distinguished by its color and the number of pieces, one green marker, four blue markers and four red markers.

At the end of a trial, markers can be attached on any state in the reflection map. Fig. 3 shows the initial reflection map of each stage. Fig. 4 shows an example of the reflection subtask of stage 1. Fig. 4a shows an example of the trial of Stage 1. In each state, whether visited or not is distinguished by its background color of the square either yellow (visited) or gray (not visited). Fig. 4b shows an example of the reflection map of Stage 1. The typical usage of them is to memorize the special event such as the encounter with an invisible wall or a goal, or to summarize the sign distribution in the searched maze. The reflection map are remained and displayed during a train of trials.

3.5 Designing the sequence of learning goals

Designing the learning goals, even the case of simple mazes may result in the difficulty of a partially observable state, it can be worked out by slightly broadening a learner's perceptual states to distinguish whether an invisible wall exists or not. The case of non-simple mazes results in more difficulty of partially observable states since they have various non- distinguishable states. This paper describes learning goals for the simple maze with a partially observable state.

Under simple and invisible mazes, the standard steps to master them are as follow:

1. Find a goal state if it is invisible;
2. If walls are invisible, estimate the borders of the current maze such like wall-following behaviors;

Fig. 3 The initial reflection map of each stage.

Fig. 4 An example of the reflection subtask of stage 1.

3. Search all maze sweeping paths from the start state.

We focus on learning goals for the second step to estimate the invisible borders of a simple maze. To solve this, the learner should try to consider the sequence of signs toward neighbor state. If the learner encounters either a wall or a sign 0 state, he/she can decide the direction of walls. In this case, an important learning goal to prevision an invisible wall is being aware of sign sequences as 0 → 1 or 1 → 2. Note that these increasing patterns for provisioning an invisible wall hold good only under simple mazes.

4. Experiment

To examine the effects our continuous learning support system, we conducted the continuous learning experiment by eight human subjects. We designed the continuous learning task as 54 stages in ascending order of difficulty.

4.1 Experimental setup

4.1.1 The learning environment

We prepare the sequence of invisible mazes consist of total fifty four stages. In each stage, there is one maze with two solutions to be found, total 108 solutions in all stages. The sequence of stages is arranged in order of increasing difficulty, first eight stages are simple mazes, 9th stage or later are all non-simple mazes. Note that a non-simple maze is surrounded by outside walls in concavo-convex shape, or it has an internal dividing wall.

4.1.2 The instruction for subjects

We show brief summary of the instruction for subjects.

- The objective of the task is to find two sweeping solutions in each maze.
- A sweeping solution is the longest path from the start state to the goal state.
- If you want to discontinue the experiment, you may terminate it at any time.
- The number displayed inside a grid is the number

of walls nearby.

- The method of operation in the maze and the reflection subtask

4.1.3 The measurement item

The measurements of the experiment are as follow:

- (a) The total time of the experiment
- (b) The number of challenged stages
- (c) The number of discovered solutions
- (d) The number of encounters with a wall
- (e) The total time of the achievements
- (f) The total time of the reflection subtask
- (g) The reflection cost

Note that the total time of the experiment (a) is the sum of the total time of the achievements (e) and the total time of the reflection subtask (f). Eq. (1) shows this relation. The reflection cost (g) is the total time of the reflection subtask (f) divided by the number of discovered solutions (c). Eq. (2) shows this relation, it is the index to evaluate the quality of the reflection process.

$$(a) = (e) + (f) \quad \text{Eq. (1)}$$

$$(g) = (f) / (c) \quad \text{Eq. (2)}$$

4.2 Experimental results

The experimental results show that seven subjects within eight continued to perform the experiment more than 60 minutes and they found more than 60 solutions within 108 solutions. Considering the number of found solutions as the continuous learning ability, we call these subjects as continuous learners.

To analyze, there are two kinds of interesting correlations on the number of discovered solutions (c). First one is a strong positive correlation with the number of failures encountering invisible walls (d) (the correlation factor is 0.88). Fig. 5 shows the correlation. This suggests that a continuous learner has a high tendency to accept failures. Second one is a weak negative correlation with the total time of the reflection subtask (f). This suggests that a continuous learner is efficient in his/hers reflection process. This means that the continuous learning ability depends on

Fig. 5 The experimental results 1.

Fig. 6 The experimental results 2.

not the length of reflection time but the quality of reflection. Then we define the reflection cost (g) as the measurement to evaluate the quality of reflection.

Analyzing the experimental results with the reflection cost (g), Fig. 6 shows that there is a strong negative correlation with the number of discovered solutions (c) (the correlation factor is -0.78). Note that there is a middle negative correlation with the number of encountering walls (d) (the correlation factor is -0.68). Therefore, the continuous learners truly work smart with a small reflection cost and a high tendency to accept failures.

In this experiment for the continuous learning task, subjects whose (c) is upper do a very good job of the reflection subtask as shown in Fig. 6, which means the reflection cost is small and they have a high tendency to accept (d) as shown in Fig. 5 which means the number of encounters with a wall is large.

4.3 Discussions

The meaning of the reflection cost and its usage are

discussed. Regarding the reflection cost as the level of proficiency on the reflection skill, as a learner gets more proficient at reflection, the reflection cost comes down then the learner becomes to solve invisible mazes more easily. Therefore, the learner discovers solutions in many stages and continues his/her learning.

Another issue is to calculate the incremental reflection cost during the continuous learning task, since it is possible to find a learner who has large reflection cost in early learning stages. Then selective support as the beginner learner becomes available. On the other hand, considering a learner who has small reflection cost as the advanced-level learner, it is possible to adjust the challenge level as harder.

5. Conclusions

We described the continuous learning support system. To support for awareness and reflection of mental learning processes, we proposed visualizing these processes by the reflection subtask. As the experimental results, the continuous learners truly work smart with a small reflection cost and a high tendency to accept failures. Future work is to design the collaborative continuous learning system between a human learner and the learning agent.

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