Consciousness and Automated Reasoning

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Abstract

This paper aims at demonstrating how a first-order logic reasoning system in combination with a large knowledge base can be understood as an artificial consciousness system. For this we review some aspects from the area of philosophy of mind and in particular Baars’ Global Workspace Theory. This will be applied to the reasoning system Hyper with ConceptNet as a knowledge base. Finally we demonstrate that such a system is very well able to do conscious mind wandering.

1 Introduction

Consciousness and Artificial Intelligence (AI) is an old and still ongoing debate. The question whether an AI system is able to understand in a conscious way what it is doing was very prominently raised by Searle’s chinese room experiment [Searle, 1980]. This is based on a symbol processing system, the Chinese room, which is a kind of production rule system. There also is a thread of this discussion, using sub-symbolic arguments, by dealing with artificial neural networks as discussed together with various other arguments in [Cole, 2019].

Embedding the discussion of AI systems and consciousness in a larger context, it is worth noting that it is a topic since the mind-body problem raised by Descartes. He postulated that mental process are properties of the mind only — the body has to be considered separately. The discussion since Descartes has resulted in a constant change of naturalistic (or physicalistic) and idealistic positions.

The naturalistic position received a lot of impetus by the successes of neuroscience in connection with the ambition of artificial intelligence to model neural networks in artificial systems. In this position the spiritual dimension of the human being is subordinated to the physical dimension, the spiritual is derived from the physical, in short: We are only a bunch of neurons [Crick, 1994] and our ego is only an illusion, as postulated by Metzinger [Metzinger, 2019].

In contrast to this naturalistic view there is a long tradition of approaches which aim at understanding consciousness by taking body and mind into account. These approaches can be summarized by the notion of panpsychism, which will be discussed in Section 2.

McDermott is commenting in [McDermott, 2007], that AI researchers “tend to shy away from questions about consciousness... The last thing most serious researchers want is to be quoted on the subject of computation and consciousness.” In this paper we aim at demonstrating that an AI system, in our case Hyper [Baumgartner et al., 2007], an automated reasoning system for first-order logic, can be very well interpreted as a conscious system according to the Global Workspace Theory (GWT) from psychology [Baars, 1997].

GWT, also called Baars’ theater, is an approach to consciousness which is mainly motivated by the need for handling the huge amount of knowledge in memory. The reasoning system Hyper resembles this model in astonishing ways, without having been specifically developed that way. Its development was driven only by the need to be used in the area of deep question answering [Furbach et al., 2010; Furbach and Schon, 2016].

The first part of the paper contains a general review of issues on consciousness: The discussion around physicality and panpsychism is depicted in Section 2 and Section 3 focuses on information theoretic approaches to consciousness. The second part instantiates these approaches by looking at the Hyper reasoner through the glasses of the GWT (Section 4) and by introducing mind wandering with Hyper in Section 5.

2 Physicalism versus Panpsychism

In this section we discuss an approach to consciousness that allows us to attribute it to artificial systems as well. We follow the argumentation of Patrick Spät [Spät, 2010], who introduced a so called gradual panpsychism, which is contrasted to physicalism. Spät argues against physicalism by stating that it cannot really clarify what the physical is, although it claims that all phenomena of the world are based on purely physical properties: If physicalism is based on the state of knowledge of contemporary physics, the definition must inevitably be incomplete, since contemporary physics does not yet provide a complete description of all phenomena occurring in the cosmos. In addition, contemporary physics may prove to be wrong. Also reference to a future, complete physics, which is equivalent to a “theory of everything”, is not helpful because it cannot be specified further. A physicist resembles Baron Münchhausen, who claims that he can pull himself out of a swamp by his own hair. For while the Baron needs an external point of reference at which he finds support and by which he can pull himself out, the physicist needs his subjective perspective in order to have access to the world at all. Since only
phenomena that can be objectively verified and formulated in the language of mathematics are to flow into the scientific description of reality, the subjective perspective is faded out. There are facts that go beyond the explanatory models of physicalism. In order to know what conscious experiences are and how they feel, a subjective, i.e. “inner” perspective of experience is required. This is what Thomas Nagel’s question aims at: What is it like to be a bat? [Nagel, 1974] The physicist can cite all kinds of physical facts about the bat, but she cannot take its perspective or experience. She cannot take it because she is not a bat and does not have the body she needs to experience the bat’s consciousness. However, as a result of Descartes’ separation of body and mind (cogito, ergo sum), the body was isolated from the mind and regarded as an object. This dualistic division does not take into account the fact that one experiences one’s environment through and with one’s body. The body is therefore not an “illusion” of the brain. Rather, the brain needs the body in order to experience its environment. Maurice Merleau-Ponty describes the conscious experience and physical “immersion” in the outside world using a footballer who does not perceive the ball, the boundaries of the playing field and the goal as representational or analytical — rather, the football field is “present as the immanent target of his practical intention” by actively acting in the football field [Merleau-Ponty, 1976]. When we communicate with other people, we can — or we try to — read from their gestures and facial expressions how they are doing. Consciousness is entangled with the body and our experience shows that we can approach the consciousness of other beings, but this becomes more and more difficult the further we genetically distance ourselves from each other (see the bat above).

Spit introduced the concept of “gradual panpsychism” by assuming a fundamental connection between mind and matter. He is arguing that a specificity of mind goes hand in hand with the complexity of matter or organisms. He assumes a very simple rudimentary form of mentality, namely mind as an ability to process information. It is based on Bateson’s concept of information: A “bit” of information is definable as a difference which makes a difference [Batson, 1972]. Information is a difference that changes the state of a system, i.e. creates another difference. As soon as several differences exist in a system, a selective operation is necessary, i.e. a decision must be made. Following Whitehead’s demand “that no arbitrary breaks may be introduced into nature” [Whitehead, 1967], panpsychism is assuming that not only humans and animals, but also cells, bacteria and even electrons have at least rudimentary mental properties. It is extremely difficult to draw a dividing line between mentally gifted and mindless entities. Single-celled organisms such as bacteria show unconscious intentionality due to their purposeful behaviour. According to [Spät, 2010] research shows that even bees, rats and coyotes have a distinct mental inner life.

3 Information and Consciousness
This section discusses two information-based approaches to consciousness, which are defined along the lines of panpsychism from the previous section. One is the information integration theory of Tononi [Tononi, 2004] and the other, the global workspace theory of Baars [Baars, 1997], can be seen as an instance of Tononi’s theory.

Information Integration
Information integration theory of Tononi [Tononi, 2004] avoids the necessity of a neurobiological correlate of consciousness. It is applicable to arbitrary networks of information processing units, they need not to be neural or biological. Tononi is proposing a thought experiment: Assume you are facing a blank screen, which is alternatively on and off and you are instructed to say “light” or “dark” according to the screen’s status. Of course a simple photodiode can do exactly the same job, beep when the light is on and silence when it is off. The difference between you and the photodiode is the so called “qualia” — you consciously experience “seeing” light or dark. This is a partially subjective process, a first-person feeling, which we are not able to measure or compare with that of other persons (a prominent treatment of this topic is in [Nagel, 1974]). One difference between you and the photo diode is, that the diode can switch between two different states, on and off, exclusively whereas your brain enters one of an extremely large number of states when it recognizes the light. But it is not just the difference in the number of states, it is also important to take the degree of information integration into account. If we use a megapixel camera instead of a single photodiode for differentiating light from dark, this technical device would also enter one of a very large number of possible states (representing all possible images it can store). According to Tononi the difference between you and the camera, is that the millions of pixels within the camera are not connected to each other. Your brain, however, integrates information from various parts of the brain. (For example it is hard to imagine colours without shapes.) Tononi gives in [Tononi, 2004] a formal definition of information integration by defining a function $\Phi$, which measures the capacity of a system to integrate information. This function is used to find subsets of elements of the system which have a high $\Phi$-value, so-called complexes. They are responsible for integration of information within the system, Tononi is considering them as the ‘subjects’ of experience, being the locus where information can be integrated.

Based on this understanding of consciousness, one can try to test the theory by considering several neuroanatomical or neurophysiological factors that are known to influence consciousness of humans. Tononi is doing this in great detail in [Tononi, 2004], others are developing new Turing tests for AI systems based on this theory (e.g. [Koch and Tononi, 2008]).

In the following we will depict another approach to consciousness, which can be seen as a special case of the information integration theory, namely the global workspace theory developed by B. Baars [Baars, 1997].

The Theater of Consciousness
One motivation for Baars global workspace theory (GWT) [Baars, 1997] is the observation, that the human brain has a very limited working memory. We can actively manipulate about seven separate things at the same time in our working memory. This is an astonishing small number in con-
contrast to the more than 100 billion neurons of the human brain. Another limitation is that human consciousness is limited to only one single stream of input. We can listen only to one speaker at a time, we cannot talk to a passenger during driving in heavy traffic and there are many more examples like this. At the same time there are numerous processes running in parallel but unconsciously. GWT is using the metaphor of a theater to model how consciousness enables us to handle the huge amount of knowledge, memories and sensory input the brain is controlling at every moment.

GWT assumes a theater consisting of a stage, an attentional spotlight shining at the stage, actors which represent the contents, an audience and some people behind the scene. Let’s look at the parts in more detail:

The stage. The working memory consists of verbal and imagined items. Most parts of the working memory are in the dark, but there are a few active items, usually the short-term memory.

The spotlight of attention. This bright spotlight helps in guiding and navigating through the working memory. Humans can shift it at will, by imagining things or events.

The actors. The actors are the members of the working memory; they are competing against each other to gain access to the spotlight of attention.

Context behind the scene. Behind the scenes, the director coordinates the show and stage designers and make-up artists prepare the next scenes.

The audience. According to Baars, the audience represents the vast collection of specialized knowledge. It can be considered as a kind of long-term memory and consists of specialized properties, which are unconscious. Navigation through this part of the knowledge is done mostly unconsciously.

It is important to note, that this model of consciousness, although it uses a theater metaphor, is very different from a model like the Cartesian theatre, as it discussed and refused in [Dennett and Kinsbourne, 1992]. A Cartesian theater model would assume, that there is a certain region within the brain, which is the location of consciousness, this would be a kind of humunculus. In Baars theater, however, the entire brain is the theater and hence there is no special location, it is the entire integrated structure which is conscious. This is in very nice accordance with Tononis information integration theory, described above. And indeed Baars and colleagues developed an architecture based on GWT, which they call LIDA "a comprehensive, conceptual and computational model covering a large portion of human cognition" [Baars and Franklin, 2009]. LIDA consists of a number of software modules, which implement a cognitive cycle which is derived from the GWT. Baars gives a detailed justification of LIDA by modeling aspects of human cognition within his model.

In the following we will follow a very different road — instead of designing a new architecture based on GWT, we will show that an existing automated reasoning system for first-order logic, namely the Hyper-System [Baumgartner et al., 2007] as it is used within the Corg project [Schon et al., 2019], can be seen as an instance of GWT.

4 Automated Reasoning and GWT

We briefly depict an automated reasoning system and comment on particular problems that arise if it is applied in the context with large knowledge bases. In Subsection 4.2 we interpret the system along the lines of Section 3 as a Baars’ theater and hence a model of the GWT.

4.1 Reasoning with large Knowledge Bases

Hyper is an automated theorem prover for first-order logic [Baumgartner et al., 2007]. First-order theorem proving is aiming at the following task: Given a set of formulae \( F \) and a conjecture (sometimes called query) \( Q \) the question is, whether or not \( Q \) is a logical consequence of \( F \), written as \( F \models Q \). For first-order logic formulae this is an undecidable problem, but it is semi-decidable, meaning that if the logical consequence holds, the prover will stop after finite time stating that it is a consequence. Hyper, like most of the high performance provers today is a refutational prover, which means that the question whether \( F \models Q \) holds, is transformed into the equivalent question asking if \( F \cup \neg Q \) is unsatisfiable. Before trying to prove the unsatisfiability of \( F \cup \neg Q \), Hyper transforms \( F \cup \neg Q \) into a normal form, a so-called set of clauses. Figure 1 shows an example for a refutation of a set of clauses. Hyper is a prover which is based on a tableau calculus, this has the nice property that it is manipulating one single proof-object, the tableau, in order to demonstrate the unsatisfiability of the problem at hand. The upper part of Figure 1 shows such a tableau, which is essentially a tree that was developed branch by branch. This means, that an inference step selects a branch and then tries to extend this branch by using a clause from the clause set together with an inference rule specified by the calculus. The technical aspect of the calculus on how to extend the tree in detail are not important here. We want to point out, however, that at any stage of the construction of a tree, a branch represents one interpretation of the given formulae. E.g. the left-most branch in our example corresponds to the (partial) interpretation \( \{ r(a), p(a) \} \), which cannot be extended to a model of the clause set, because the latter contains the negation of \( p(a) \) (in our notation: \( \leftarrow p(a) \)) which results in closing the branch by adding the leaf-node \( \perp \). A proof is found if there is a tableau which contains only closed branches, as it is the case in our example from Figure 1.

Hyper has been used in many different application areas, reaching from commercial knowledge based systems to intelligent book development [Baumgartner et al., 2004]. Recently Hyper was used as the main reasoning machinery in natural language query answering [Furbach et al., 2010] and for cognitive reasoning, in particular answering commonsense questions [Furbach and Schon, 2016].

In all of these applications Hyper very rarely managed to find a proof within the given constraints — in most cases there was a timeout and Hyper’s result was a branch that represents a partial interpretation of the formulae at hand.

For the rest of this paper we use a running example from a commonsense reasoning benchmark [Maslan et al., 2015]. Those problems are researched in the above mentioned Corg project — here we use it as a kind of showcase of an application of a reasoner together with a huge knowledge base.
above triple has been translated into the following formula:

\[ \text{ConceptNet as background knowledge, we have translated most} \]
\[ \text{ConceptNet is stored in the form of triples such as} \]
\[ \text{edge. ConceptNet is a semantic net structure with 1.6 million} \]
\[ \text{reasoning system the problem has to be translated from natural} \]
\[ \text{language to a formal language — in our case this is} \]
\[ \text{automated language to a formal language — in our case this is} \]
\[ \text{first-order logic. This translation is done in a fully auto-} \]
\[ \text{curated way based on the Boxer-System [Basile et al., 2016;} \]
\[ \text{Curran et al., 2007]. Hence, we can start the reasoning pro-} \]
\[ \text{cess for finding the appropriate answer to the question at hand by} \]
\[ \text{invoking the Hyper prover with the formula which results} \]
\[ \text{from the Boxer-translation. For one alternative in the problem} \]
\[ \text{description of Example 65 given in Figure 2 Boxer outputs the} \]
\[ \text{following first-order logic formula:} \]
\[ \exists A(dog(A)) \land \exists B, C(rAmn(C, B) \land bone(B)) \]  
(1)
\[ \land rAgent(C, A) \land chew(C)) \]

It is obvious that for reasoning with this formula knowledge about the world is necessary; e.g. about food intake of dogs or about the composition of meat and bones. This knowledge of course cannot be added by hand, it is necessary to use a knowledge base, where all possible facts and relations about the world are available. If this knowledge is not restricted to a single domain, if it is general enough to be used for questions from different areas it gets very large and hence difficult to handle. In the X-project among other sources ConceptNet [Speer et al., 2017] is used as background knowledge. ConceptNet is a semantic net structure with 1.6 million edges connecting more than 300,000 nodes. Knowledge in ConceptNet is stored in the form of triples such as (dog, hasA, fur).

To allow the first-order logic reasoner Hyper to use ConceptNet as background knowledge, we have translated most of the English part of ConceptNet to first-order logic. The above triple has been translated into the following formula:

\[ \forall x(dog(x) \rightarrow \exists y(hasA(x, y) \land fur(y))) \]  
(2)

The resulting knowledge base consists of 2,927,402 axioms and is therefore far too large to be completely processed by reasoners. Hence, it is necessary to select parts of this huge knowledge base which might be appropriate to solve the problem at hand. Note, that this situation is very different from a classical automated reasoning problem, as it is given in Figure 1, where all the necessary formulae to find a proof are given. They can be used all together by the reasoning system, without the necessity to guess parts of it to be loaded into the system.

This situation is depicted in the left part of Figure 3. There is the logical representation of one of the sentences from the problem given in Figure 2. The knowledge base, ConceptNet, is displayed in the middle of the figure. The task is to select those parts from the knowledge base which might be helpful for reasoning about the logical representation. To this end there are two selection methods sketched: The first one uses syntactic criteria exclusively for the selection [Hoder and Voronkov, 2011]. Depending on the symbols occurring within the logical representation those parts of the knowledge base are selected, which contain one of these symbols (additionally this selection takes the number of occurrences of a symbol into account in order to prevent that very frequent symbols like isA lead to the selection of the whole knowledge base). The second method uses additionally semantic criteria for the selection. The semantics of a symbol is given by a word embedding, which is used to find semantically similar symbols for the selection process. As a result not only formulæ containing the symbols dog, chew and bone are selected, but also those containing similar symbols like for example mandicate and remasticate. This method is described and evaluated in detail in [Furbach et al., 2019].

For commonsense reasoning problems like the examples shown in Figure 2, Hyper is not able to find a proof for one of the alternatives, even with the appropriate background knowledge. This is because the problem often do not represent a logical consequence in a given situation, but rather statements have to be compared with respect to plausibility. This kind of reasoning is also called cognitive reasoning.

Therefore after a certain amount of reasoning the system developed in the Corg project analyses the inferences performed by Hyper (see the green path in the right part of Figure 3).

4.2 Looking through the GWT-Glasses

In the previous subsection we briefly explained how the theorem prover Hyper is adapted and used within the area of cognitive reasoning. We now show that Hyper in combination with large knowledge bases can be interpreted as an architecture that implements the GWT as introduced in Section 3.

The stage. The working memory is the branch of the tree which currently is expanded. In the right part of Figure 3 this is the green path of the tree — it contains the context in which the next reasoning step will be performed.
Logic representation of COPA problem:

\[
\exists A (dog(A) \land \exists B, C(rion(C, B) \land bone(B) \land ragent(C, A) \land vlchew(C))).
\]

Figure 3: On the left: Syntactic selection uses symbols from the problem to select parts of the background knowledge, depicted with black arrows and regions. Similarity selection takes the meaning of symbol names into account by additionally selecting formulae containing symbols which are similar according to a word embedding (depicted by blue arrows and regions). On the right: A snapshot during a Hyper run. The (green) path of the tree, Hyper is working on, corresponds to the working memory.

The spotlight of attention. This bright spotlight selects and highlights those parts of the (green) branch together with the formulae from the problem or the selected parts of the knowledge base which are used for the next reasoning step.

The actors. The actors correspond to the application of inference rules on the set of clauses currently processed by the theorem provers. The result of the actors’ actions correspond to new formulae derived by an inference step.

Context behind the scene. Behind the scenes, the reasoner and its control act as a director.

Audience. According to Baars, the audience represents the vast collection of specialized knowledge. It can be considered as a kind of long-term memory, namely the knowledge base.

Altogether we have a complete Baars’ theater of consciousness consisting of the reasoning system Hyper, together with its control and its background knowledge — we have a system which can be interpreted as a conscious system according to the ideas presented above. In the following section this will be deepened by discussing mind wandering.

5 Mind Wandering

Mind wandering is a process in which people do not stick to a single topic with their thoughts, but move in chains of thoughts from one topic to the next. In doing this the border between conscious and unconscious processing is continuously crossed, and in both directions. Hence studying mind wandering certainly contributes to a better understanding of consciousness. Mind wandering often occurs in less demanding activities. A study [Killingsworth and Gilbert, 2010] shows that up to 40% of the time a human mind is wandering around.

Mind wandering also has interesting positive effects, which is investigated in [Mooneyham and Schooler, 2013] where it was shown that mind wandering can be helpful in finding creative solutions to a problem. In this section we show, that a control system of Hyper is very well able to invoke mind wandering for Hyper. We will first give a rough overview of the system and then go into detail about the individual steps.

Overview of the System

The mind wandering process is started from an initial formula, such as Formula (1). In the first step, the system performs a semantic selection as described in the previous section to select suitable background knowledge for this formula. The formula together with the selected background knowledge — we have a system which can be interpreted as a conscious system according to the ideas presented above. In the following section this will be deepened by discussing mind wandering.

1Picture of network: [Gibson and Vickers, 2016], CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/). Visualization of Word Embedding: Euskara: Hitz batzuen errepresentazioa by Aelu013, CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0/deed.en) (word removed).
process is repeated until Hyper’s inferences no longer provide new information compared to the previous round. A detailed description of the individual steps of the system follows.

The Audience – Background Knowledge and Selection

The selection from the knowledge base starts with a set of symbols called the current context, which consists of the symbols from a starting formula like for example Formula (1) and similar symbols.

Selecting all formulae from the knowledge base in which one of the context symbols occurs results in a large set of formulae. Using all these formulae would be too unfocused w.r.t. the considered formula, so a filtering step removes all formulae in which other predicate symbols occurring in the formula are not within a certain range of similarity to the symbols in the context. To measure similarity, cosine similarity in a word embedding is used. The interval in which the similarity must fall for a formula to be selected is passed to the system by two parameters. With the help of these parameters it is possible to control how far the background knowledge is allowed to move away from the context symbols. With a suitable interval it is possible to select a formula like (2) while preventing to select a formula like

\[ \forall x (\text{poodle}(x) \rightarrow \exists y (\text{relatedTo}(x, y) \land \text{dog}(y))) \]  

(3)

Currently, the system can use either the ConceptNet Numberbatch [Speer et al., 2017] word embedding or a word embedding learnt on personal stories from blog entries [Roemmele et al., 2011].

Actors and Context behind the Scene — Reasoning

The selected set of formulae together with Formula (1) is passed to the Hyper reasoner. Hyper is started with a time-out of 30 seconds and calculates during this time a possibly partial model for the input formulae. This model represents knowledge that can be inferred from Hyper’s input. In the next step, the system analyses Hyper’s output. Since the input formulae are still very broad despite the filter methods mentioned above, the (partial) model also contains a very broad knowledge inferred from Hyper’s input. First the system extracts all predicate symbols from Hyper’s output and removes from this set all symbols from the current context to prevent the mind wandering process from getting stuck. Hyper’s model produced for the running example contains 122 predicate symbols which are thematically widely spread: from ears, skin, flesh, wolf, calcium, animal, collar and vertebrate to woof and barking, many terms are represented.

Spotlight of Attention — Finding a Focus

To determine a focus in the multitude of these terms, the system performs a clustering on these terms using KMeans and the cosine similarity of a word embedding as similarity measure. Currently, the number of clusters created corresponds to the number of predicate symbols in the model divided by 4. In future work, different values for the number of clusters will be considered. Next, the systems orders the resulting clusters by their cosine similarity to the predicate symbols in the current context and chooses one of the clusters as the focus. For the experiments, the cluster in the middle of the sorted sequence is chosen as the focus in order to allow the mind wandering process to move away from the current context. In the running example, this led to selecting the cluster consisting of the symbols animal and animals as the new focus. Other choices for the focus cluster are possible and can be selected with the help of a parameter. Next, the system creates a simple formula from the symbols in the focus cluster and selects suitable background knowledge as described above. In this selection, the symbols from the focus cluster together with similar symbols are used as new context symbols. The described process is repeated a desired number of times or until the process does not deliver any new symbols.

Experimental Results

Starting from the symbols in the initial formula, the symbols in the selected focus clusters represent the result of the mind wandering process. Starting from Formula (1) containing the symbols dog, chew and bone the described system provides for example the following sequence of sets of focus symbols:

\{animal, animals\} → \{gardening\} → \{garden, horticulture, farming\} → \{mowing, lawn, yard\} → \{outside, front, outdoor\} → \{weather\} → \{thunder, lightning\} → \{cloud, sky, clouds\} → \{water\}

This corresponds to a mind wandering chain which focuses on animals leads to gardening and finally addresses weather aspects which leads to water.

It should be noted that the system has many parameters to control this mind wandering process. For the experiments, different parameter combinations were automatically tried out and the sequences of focus symbols generated in this way were manually inspected. Different parameter values led to a different chain which finally ends at fashion:

\{furry, tail, fur\} → \{coats, wool, coat\} → \{fur\} → \{animal, pet, hair, coat, pelt, wool\} → \{sleeves, robe, braided, leather, fur, garment, buttoned, styled, pockets, strand, woven, cloth, wearable\} → \{coats, covering, pattern, textile, fastened, worn, wool, coat, material, pelt\} → \{wearing, robe, suit, shirt\}

6 Conclusion and Future Work

In this paper we tried to connect work from research on consciousness with work on formal reasoning. We depicted an implementation of a mind wandering process within a logical reasoning system, which can be interpreted as the action of a consciously reasoning system. Further work has to be done for finding a way to determine what knowledge is interesting enough to be kept within the focus of the system and how the knowledge base should be modified according to the results of mind wandering. Currently, only one path of the proof tree is considered for the mind wandering process. In future work we plan to extend the approach to consider multiple open branches for mind wandering.
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