Towards an Ontological Representation of Memory Concepts through Theories and Models

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Abstract

Memory has been the subject of studies across various disciplines facing significant conceptual and terminological challenges. This paper introduces a multi-layered computational and reference ontology designed to represent memory models and theories. The Memory Ontology (Mem'Onto) is composed of two main levels: (i) a core level ontology generalizing memory concepts, including the concepts of models and theories, systems, processes, and representations, and (ii) a specialized level gathering memory concepts through models and theories in particular domain (Psychology). It is demonstrated how ten distinct psychological models and theories can be systematically mapped into a shared axiomatized structure. Mem'Onto promotes interdisciplinary interoperability, enabling a more comprehensive understanding of memory models and theories.

Keywords

memory, ontology, psychology, theory and model

1. Introduction

Memory has been a subject of reflection, and its study is part of a long intellectual tradition. First explored by philosophers [1, 2], it has become the focus of scientific inquiry. From the late 19th and early 20th centuries onward, it thus attracted growing interest from psychologists and neuroscientists [3, 4, 5], as well as historians and sociologists, to name a few. The concepts of memory, however, still lack formalization [6]. They often derive their meaning from the models and theories that underpin them. These scientific discussions focus either on memory in general or on one of its specific aspects (e.g., working memory, the consolidation of memories over time, or the organization of knowledge in semantic memory). Research on memory is today a particularly dynamic field of study. Recent efforts – notably the "Psycho Models" repository [7], which consolidates 21 computational models in psychology – underscore the growing need for well-grounded ontologies to systematically describe and organize such models.

This paper introduces a multi-layered ontology composed of a core level generalizing memory concepts, including models and theories as well as systems, processes, and representations, to name a few, and a specialized level gathering memory concepts through models and theories in Psychology. The fundamental goal of Mem'Onto is to represent memory entities (concepts and relations) at conceptual level as they are described by their authors in the theories and models they proposed. It demonstrates how ten well-known psychological models and theories can be systematically mapped into the shared axiomatized structure. This mapping not only clarifies discrepancies but also represents the conceptual borrowing across models and theories.

The rest of the paper is organised as follows. §2 discusses the main related work; the methodology for constructing the ontology is presented in §3, and the ontology itself is introduced in §4; the implementation of the ontology and its evaluation are presented in §5; finally §6 concludes the paper.

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2. Related Work

The main researches on memory representation draw on various levels of representation and disciplines (Table 1). Closer to this work, CoTOn [8] is an ontology representing working memory theories in the field of cognitive neuroscience. Based on UFO, it covers various working memory models. Mem'Onto borrows a number of concepts from CoTOn integrated into our core and domain ontology levels. However, several differences remain between the two ontologies: (1) ontology scope: CoTOn focuses uniquely on the working memory with the aim of annotating functional neuroimaging data, while Mem'Onto has a larger scope (where the core level can be extended to cover interdisciplinary views on memory); (2) instances vs. concepts: CoTOn represents domain entities as ontological instances; Mem'Onto concepts (abstract entities in a theoretical framework) aims at capturing the conceptual structure of the domain instead of concrete realizations of that structure (instances). For example, the procedural memory is used as a generalized category that can be referenced and specialized, rather than an instance; an instance would be a particular realization of the procedural memory (e.g., patient's procedural memory as assessed by a battery of neuropsychological tests); (3) linguistic layer: instead of using a new concept (Linguistic Term in CoTOn), Mem'Onto uses SKOS properties.

	Domain	Nb. Concepts	Specialized	Version	Reference
Cognitive Atlas	Cognitive Sciences	918	No	0.4	[9][10]
CogMemo	Cognitive Psychology	1511	Yes	2.6	[11][12]
MF	Mental Functioning	418	No	2025-07-08	[13][14]
BCIO	Behavioral Changes	> 1000	No	1	[15][16]
CogPO	Experimental Paradigms in Cognition	199	No	1	[17][18]
NBO	Behavioral Phenotypes	4548	No	2023-07-04	[19][20]
CoTOn	Cognition	7	Yes	1	[8][21]

Table 1
Resources on memory representation. *Specialized* refers to the resources dedicated to describing memory concepts.

3. Methodology

The overall ontology construction methodology was fully manual and followed an iterative process:

1. *Scope Clarification*: Firstly, the scope of the ontology has been defined, along with the scientific gaps it was intended to address. This has been guided by an identified conceptual need by the memory researchers from the French Memory Research Group[1] (GDR Mémoire). The scope definition involved as well the analysis of existing resources describing memory concepts. The definition of 5 competency questions (CQs) by an expert helped defining the scope of the ontology.

2. *First Ontology Version*: Once the scope has been defined, a first version of the ontology has been designed (described in [22]), which reuses several statements from CoTOn. This reuse follows the scenarios three and four (reuse and reengineering of ontological resources) of the NeOn methodology [23]. In this initial version, the representation choices were also guided by a mental model, highly influential and widely adopted in memory psychology: Tulving's SPI (Serial, Parallel, Independent) model [24]. Based on the literature describing it, the main concepts and relations were manually extracted to produce a domain ontological representation.

3. *Experts in the loop*: An expert in Psychology and terminology provided a preliminary evaluation on the first model. Based on this validated version, researchers from the GDR Mémoire have been contacted to provide input for integrating additional theories and models. Their answers have been gathered through a questionnaire[2]. Fifteen experts answered the survey from different domains such

[1] French Memory Research Group website: https://gdrmemoire.com/
[2] https://tinyurl.com/memonto-survey

as Psychology (11, 73.3%), Neuroscience (3, 20%), and one expert in Cognitive Science (6.7%). From the responses and the existing in CoTOn, we kept 10 models and theories: 2 that overlap between CoTOn and expert responses; 3 that are unique to CoTOn; and 5 that are exclusive to the expert responses (including the SPI model in the first version of the ontology).

4. *Incremental Ontology Augmentation*: For each selected model and theory, we reiterated the process of manually extracting information from the literature describing them. It involves incorporating the expert feedback within an iterative process. This process is inspired from the methodology proposed by [25], which describes a co-creation ontology approach in a multidisciplinary scenario.

5. *Ontology Implementation*: The ontology has then been implemented in Protégé tool and represented using the Web Ontology Language (OWL). This addresses an explicit requirement from experts (machine readable and searchable resource).

4. Mem'Onto

The notion of "Theory" and "Model" is not always clearly distinguished in the literature, in particular in Psychology, and in the existing ontology resources in general. For example, CoTOn groups theories and models under the concept of "cognitive theory" while the CogMemo thesaurus uses the term "scientific discourse" as upper-concept. In the philosophy of science, the terms 'Model' and 'Theory' have been widely used, repeatedly redefined and even more hotly debated. It appears that there is no consensus on the definitions of "theories" and "models". As stated by Frigg, "In some cases it is not clear where the line between them should be drawn, and whether something is a model or a theory" [26]. For these reasons, we have chosen to stay as close as possible to the researchers' usages of these concepts (we do not distinguished them by definition but rather according to the usage). However, we can state that, in our Mem'Onto, we consider models and theories as artifacts of scientific discourse used to explain and predict phenomena. Mem'Onto is structured in two levels (Figure 1), as detailed in the following.

Multi-layer structure First, the *core-level* structures the entire domain level, covering concepts commonly found in models and theories of memory. Figure 1 depicts how the core level of Mem'Onto (upper and purple level in the figure) covers the different generalisations of the domain level (lower and blue level in the figure). The terms used in the ontology are drawn from the terminology of memory researchers. Memory Processes (inherited from Process) commonly refer to actions performed on other memory entities (including the three main ones: encoding, storage, and retrieval). We then introduced the concept Memory Disposition (referred to as "Memory Concept" in previous versions of Mem'Onto). The sub-concepts of Memory Disposition are Cognitive Memory System (organized structures of more elementary operating components), Memory Phenomenology (how memories are experienced), Memory Phenomenon (empirical effects related to memory) and Mental Representation (linked to the preservation/reconstruction of an event, or referring to acquired knowledge or skills). Memory Representations (the mental encoding, organization, and storage of information about the world, oneself, or experiences) are types of Mental Representation. Our definition of Memory Theory and Memory Model correspond to the usage of each Author. Second, the *domain level* covers concepts and relations in ten psychological models and theories, as Episodic Memory, Recollection or Consolidation. Figure 1 depicts the domain level of Mem'Onto (bottom level), which are further described below.

Concept Evolution, Borrowing and Equivalences In science, researchers may rely on previous studies to support and position their advancements, i.e., reusing and deriving new models and theories from existing ones. For that reason, a tracking of concepts, including their reuse and modifications, is represented in Mem'Onto. For each concept derived from another concept, it is noted that the concept `isIntegratedIn` the target theory or model. In cases where this concept has undergone modifications between the `source` and `target` concept, we indicate whether the concept has been conceptually changed (i.e., changes in the definition of the concept) or whether it has changed terminologically

(i.e., the concept no longer refers to the same term). For each model or theory in Mem'Onto, every concept originating from another models or theories is listed, specifying the source theory or model as well as the type of inclusion – whether the concept was `integrated` as-is or whether it was `revised`, terminologically or conceptually, with respect to its original definition. Besides the reuse and modification of concepts, some authors state that multiple concepts are equivalent to a single preexisting concept. For example, the Self Memory Model stipulates that the combination of Event-Specific Knowledge (ESK) and General Event results in a representation equivalent to the concept of Episodic Memory [27].

Models and Theories at the Domain Level From the 10 models and theories selected (Step 3 in Section 3), 5 focus on working memory; they were adapted from CoTOn and modified to align with our conceptualization (i.e., the Early Decomposition Model [28], the Embedded-Processes Model [29], the Late Decomposition Model [30], the Modal Model [31], and the Multicomponent Model [32]). The other 4 were selected from among the models and theories most frequently mentioned in the answers of our survey to the researchers (i.e., the Self Memory Model [27], the Fuzzy-Trace Theory [33], the MNESIS Model [34], and the Time-Based Resource-Sharing Model [35]), in addition to the SPI Model [24] from the previous ontology version [22][3]. Below, the Time-Based Resource-Sharing Model (TBRS) is developed. TBRS is a model describing an architecture of working memory, introduced by *Barrouillet* and *Camos*.

5. Ontology Implementation and Evaluation

Mem'Onto has been implemented in the OWL2 language on Protégé. A permanent identifier has been assigned to the ontology: https://w3id.org/memonto. The ontology is described using different metadata in order to be compliant to the FAIR principles. The conceptual evaluation of the ontology was carried out iteratively with our expert; continuous modifications were made to the ontology throughout the addition of new models and theories. The logical consistency of the ontology has been checked via a reasoner integrated in Protégé (HermiT 1.4.3.456).

To verify the completeness of Mem'Onto, it was checked whether the ontology adequately addressed the defined competency questions (which can be found via our w3id). The corresponding SPARQL queries were written and tested using the Apache Jena Fuseki RDF store. To assess the model compliance to the FAIR principles, the FOOPS [36] online tool has been used. A score of 74% of FAIRness is obtained for Mem'Onto, thanks to its documentation using pertinent metadata and permanent ID. This score can be further improved by indexing the model in a searchable resource, such as the Linked Open Vocabularies catalogue[4].

6. Conclusions and Future Work

This paper has presented Mem'Onto, a multi-layered ontology that represents core memory concepts, theories, and models. This modular ontology supports the modelling of different approaches to memory in cognitive psychology as well as the borrowing and modification (studies evolution) of existing concepts. As future work, several perspectives remain: to extend and adapt Mem'Onto to other models and theories, particularly computational models of memory; to extend it to other memory-related disciplines, notably philosophy, in order to develop an interdisciplinary ontology; and finally, to validate the ontology by a large panel of experts.

[3]To clarify, the first version of Mem'Onto from 2025 was based on a single model: Tulving's SPI model. The second version of Mem'Onto presented here focuses on representing nine other theories and models in addition to the SPI model.
[4]https://lov.linkeddata.es/dataset/lov/

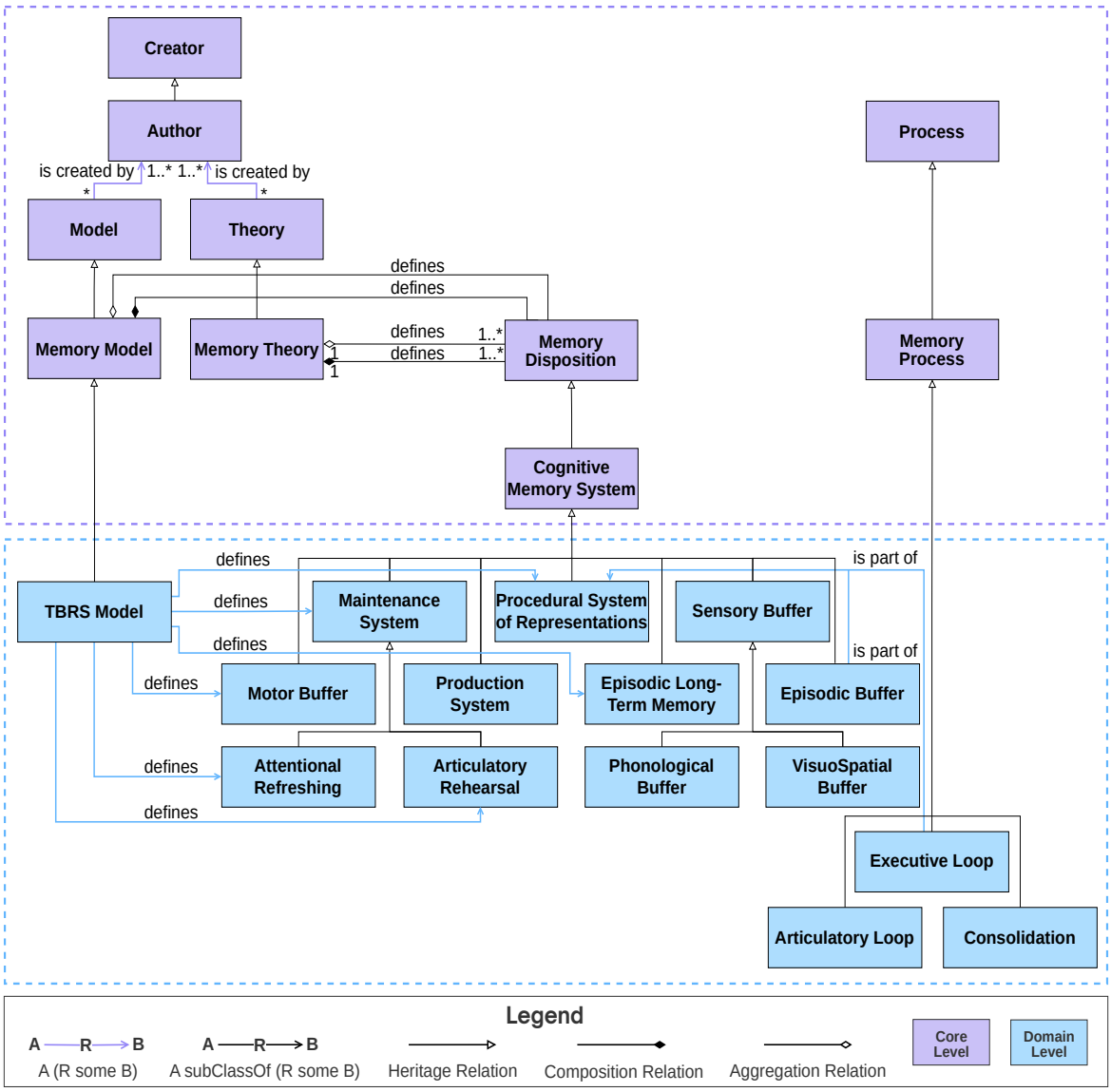


Figure 1: Representation of the Time Based Resource Sharing Model of Working Memory according to MemOnto with the core level concepts in purple and the domain level concepts in blue.

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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