Towards a Semantic Representation of Memory Entities

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Abstract
Different disciplines have been studying human memory and related issues for thousands of years. However, the definitions of the concepts relating to memory vary depending on the discipline or theory. In order to conciliate these variations and ambiguities, a solution is to formally define the concepts studied through ontologies. This paper presents Mem'Onto, a Memory Ontology which gather concepts related to memory, based on the Tulving's SPI model. This theory corresponds to a model of memory organisation and brings together various central elements of memory according to Tulving, whether in Memory Systems (e.g. Episodic Memory, Semantic Memory, Procedural Memory), in Mnesic Processes (e.g. Encoding, Storage, Retrieval) or in the level of consciousness of these subsystems during Retrieval (Implicit and Explicit). Mem'Onto is adapted from an existing ontology, CoTOn, a Cognitive Theory Ontology designed from a working memory use case.

Keywords
memory, domain ontology, FAIRness, CoTOn, UFO

1. Introduction

Memory is a concept that has been studied in various disciplines since Antiquity where it was the subject of study by many philosophers [1, 2] before neurocogniticians and psychologists [3, 4, 5] developed an interest in it in the early 20th century.

It refers to a cognitive mechanism that allows humans to acquire knowledge about the world, to remember their personal experiences, and to imagine episodes in the future, influencing their identity and interpersonal relationships [6]. However, depending on the theory that studies memory, concepts may have a common referent (i.e. 'an entity in reality' [7]) but different linguistic terms to refer to it, or may share the same term corresponding to distinct notions. For example, in some schools of philosophy, memory is considered necessarily true and reliable (a normative phenomenon), and constitutes itself a form of knowledge [8] while it has a descriptive nature [9] according to psychology.

Although several reflections have been carried out in those disciplines in the last years [10, 11, 12, 13, 14, 15], there is a lack of conceptual formalisation of the memory concepts, which are the building blocks of scientific theories, models and discourses. This hinders both intra- and interdisciplinary studies on the topic. First, conceptual and terminological heterogeneities within the same community directly affect the results of their scientific research. For example, it is hard to assess the benefits of working memory training when there is no consensus definition of working memory among psychologists. Secondly, conceptual and terminological problems affect the communication between different communities.

This need for conciliate these variations and ambiguities appears to fall within the widely used definition of an ontology as 'a formal, explicit specification of a shared conceptualisation' [16]. Thus, an approach would be to exploit the knowledge representation capabilities of ontologies to accommodate definitions and terms from different fields and theories, in order to propose a conceptual representation that includes the different perspectives of the various memory sciences, thereby highlighting both their differences and their similarities.

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A close effort is the CoTOn ontology on working memory [17]. This ontology, aligned with the UFO foundational ontology [18], represents concepts intended to describe the different parameters defining a theory or a cognitive concept (e.g., **Cognitive Concepts**, **Author** or **Cognitive Theory**) while its instances refer to their respective entities (e.g., Working memory, Baddeley & Hitch or Multi-component model). However, this representation is rather intended to focus on working memory (cognition) and does not cover important aspects of memory such as the notion of process. Furthermore, for representing models such as Tulving's SPI model [19], a fine grain level of representation is required.

This paper presents Mem'Onto, a Memory Ontology which gathers concepts related to memory. It provides a first fine-grained representation that generalises CoTOn in order to be able to represent other concepts than working memory ones. This generalisation aims at accommodating both a cognition-oriented model and a psychology-oriented theory (Tulving's SPI model). This theory corresponds to a model of memory organisation and brings together various central elements of memory according to Tulving, whether in Memory Systems (e.g. **Episodic Memory**, **Semantic Memory**, **Procedural Memory**), in Mnesic Processes (e.g. **Encoding**, **Storage**, **Retrieval**) or in the level of consciousness of these subsystems during Retrieval (e.g. **Implicit** and **Explicit**).

The rest of this paper is organised as follows. Section 2 discusses the main related work. Section 3 introduces the proposal model, its multi-level structure and its underlying model (CoTOn). Section 4 details how Mem'Onto has been implemented and Section 5 presents the evaluation of the ontology. Section 6 discusses some design choices and finally, Section 7 concludes the paper and presents the perspectives for future work.

2. Related Work

This section overviews the main related work on memory representation, from different levels of representation and disciplines. Table ?? summarises such works.

In cognition, hierarchical knowledge representation is one approach to representing cognitive neuroscience through the prism of the field. Among those representations, the Cognitive Atlas [20, 21], is a collaborative project aimed at developing a knowledge base that reflects current views in the field of cognitive science. In particular, this knowledge base contains 'concepts' (915 entries) and 'tasks' (853 entries) which can be related to each other by `is a part of` and `is a kind of` relationships (and their inverses) associated with a definition adopted by the cognitive neuroscience community. Among the 24 memory-related concepts, we can find **working memory**, **retrieval** or **primary memory** for example.

A terminological resource with an in-depth interest in memory is the Thesaurus in Cognitive Psychology of Human Memory [22]. This is a bilingual (French-English) terminological resource covering concepts from the cognitive research on human memory (memory systems and processes, empirical effects, memory disorders, study methods and measurements, theories and models). This thesaurus contains 1459 concepts (e.g. **causal theory of memory**, **semantic memory**, **hippocampus**) organized in the form of hierarchical (generic and specific terms), equivalence (synonyms) and associative relationships, most of which are provided with a definition and bibliographic references. The following properties specifying the semantic relationships are included: `is diagnostic tool of`, `is disorder of`, `is measure of`, `is study method of`, `is model of`, `is theory of` and `is component of`, and their inverses.

The Mental Functioning Ontology [23] is a domain ontology that considers the ontological representation of memory, dedicated to document mental diseases and grounded on BFO (Basic Formal Ontology). This ontology is structured around 418 classes, 4 of which relate to memory. This ontology considers the memories as a **Mental Disposition**, itself a sub-concept of **Bodily Disposition** realized in a **Mental Process**. It is a procedural and disease-oriented representation, which deviates from our representation of memory.

Some ontologies consider the concept of memory from a behavioural sciences perspective. For instance, the Behaviour Change Intervention Ontology (BCIO) [24] aims to provide a common conceptual framework in the field of behavioral sciences and is built on the Basic Formal Ontology. This ontology contains more than 1000 entities with 6 memory related concepts such as **associative memory**, **iconic memory** or **procedural memory**.

The Neurobehavior Ontology (NBO) [25] represents behavioral processes and phenotypes. Its foundationnal ontology is BFO, and it is composed of more than 4,548 concepts. In particular, 42 concepts are directly related to memory (e.g. **autobiographical memory**, **eidetic memory** and **topographic memory**).

A more experimental oriented ontology is CogPo [26] that represents experimental cognitive paradigms in the functional neuroimaging community. It does this by representing experimental behavioral paradigm conditions and by contrasting experimental behavioral paradigm conditions. The Cognitive Paradigm Ontology is a collection of 199 concepts, but none specifically around the concept of memory.

Finally, close to our work is CoTOn [17], a cognition ontology based on cognitive neuroscience theories. It aims to represent objectifiable knowledge about observable entities in the experimental setting, theory-dependent conceptualizations of latent cognitive concepts, and community-specific use of the same linguistic terms for differently defined cognitive concepts. It is based on UFO and involves various models of working memory. This operational ontology contains 7 concepts of the 15 concepts present in their reference model, all designed with memory as the key entity. It also include 1,712 instances from the Cognitive Atlas, as well as few concepts and their definitions, such as **Theory**, **Cognitive Concept**, **Task**, **Condition**, and **Indicator** which are validated by the cognitive neuroscience community.

Table 1
Overview of existing proposals on the representation of concepts related to memory.

	Domain	No. Concepts	No. Memory Concepts	Reference
Cognitive Atlas	Cognitive Sciences	915	24	[20][21]
CogMemo	Cognitive Psychology	1459	1459	[22]
MF	Health	418	4	[23]
BCIO	Behavioural Sciences	+ than 1000	6	[24]
CogPO	Cognitive Neuroimaging	199	0	[26]
NBO	Behavioural Sciences	4548	42	[25]
CoTOn	Cognition	7	7	[17]

3. Mem'Onto: A Memory Ontology

For this first modelisation, the ontology is structured in four levels: (1) the top-level ontology (i.e. the UFO), (2) the middle level ontology (i.e. an adaptation of the CoTOn), (3) the domain level ontology and (4) the level of instances. Figure 1 depicts the different levels of Mem'Onto. In the following, the purpose identification, ontology development processes and the ontology levels are detailed.

3.1. Purpose Identification

The ontology presented here is adapted from the Cognitive Theory Ontology (CoTOn) as an initial representation of memory concepts. As stated in Section 2, CoTOn aims to represent objectifiable knowledge about the observable entities of the experimental setting and subsequently use it to annotate neurocognitive datasets with domain-specific metadata. For the purpose, it focused on the representation of cognitive concepts, their commonly used linguistic terms and objectifiable measurements. With the working memory as its use-case, this representation does not cover important aspects of memory such as the notion of *process*, required for modeling Tulving's SPI model.

Five models of working memory are defined, including the Multicomponent model and its components (i.e. Central Executive, Episodic buffer, Phonological loop and Visuospatial sketchpad), all of which could be considered as instances of the ontology, both the models themselves and their components. On the one hand, this modelling does not accurately represent the hierarchical relations between mnemonic entities. On the other hand, we consider instances to be the real-world manifestation of a given concept. For example, the concept of episodic memory refers to the notion of episodic memory and its instances would be Endel Tulving's episodic memory (during his lifetime) or Cassia Trojahn's episodic memory.

In order to explicit the representation needs, a set of competency questions have been defined (**concepts** in bold, *instances* in italics and the `relations` in typewriter):

- **CQ1**: What are the **Cognitive Memory Systems** `defined` in the **SPI Model**?
- **CQ2**: Which **Author** `created` the **Theory SPI Model**?
- **CQ3**: What *Tulving* `consider` as a **Mnesic Process**?
- **CQ4**: What is the **Awareness Form of memory expression** of the **Retrieval Process** for the **Episodic Memory** as `part of` the **SPI Model** of *Tulving* (in 1995)?
- **CQ5**: What are the **Linguistic Term** of the **PRS Memory** for *Tulving*?

3.2. Ontology Development Process

With a view of re-using an existing ontology, we investigated existing methodologies, and set our sights on NeOn. The NeOn methodology suggests guidelines for different processes and activities described functionally, procedurally and empirically, in order to develop reproducible ontological models. They provide scenarios adapted to the different types of resources to be integrated into the ontology, depending on the ontology's design stages. Scenario 4 considers the reuse and reengineering of ontological resources at the ontology conceptualization stage, which corresponds to our application of CoTOn. In Scenario 3, we drew on Ontology Reuse Statement which aimed to reuse parts of a defined ontology when the latter has not been designed for the intended task.

The reuse process is divided into 4 activities: Ontology Statement Search, Ontology Statement Assessment, Ontology Statement Selection, Ontology Statement Integration and Check Local Inconsistencies. Following the process steps, we have determined in our source ontology (CoTOn) that the statements will either be deleted (because they no longer meet the objectives of our ontology) or reengineered (between the three possibilities: be reused as they are, reengineered or merged). For the statements we kept, we had three other technical options: import ontology statements, copy ontology statements and establish mappings with ontology statements. We chose to copy the ontology statements (e.g. the `Author` and the `Linguistic Term` concepts) in order to avoid potential side effects, notably that other elements could have an impact on the ontology created. Likewise, we have replicated the statements adapted from CoTOn (e.g. the `Theory` and the `Concept` concepts (derived from the `Cognitive Theory` and the `Cognitive Concept` concepts from CoTOn)). The following section details the concepts adopted and/or modified from CoTOn.

The ontology development process was conducted between the three authors of this paper including a specialist in memory terminology, but will be reviewed by memory experts at a later stage.

3.3. Adaptations from CoTOn

CoTOn's purpose is to provide a framework for the representation of objectivable and experimental cognitive entities. Adaptations have been performed to ensure that our ontology meets our objectives. To represent the theoretical vision of Tulving's SPI model, we propose a multi-level representation containing the different levels of granularity of our ontology. The statements adapted from CoTOn are at the middle level ontology. Here, we will detail the reuses and adaptations of the CoTOn model, and explain our specific additions made at this level in Section 3.4.2.

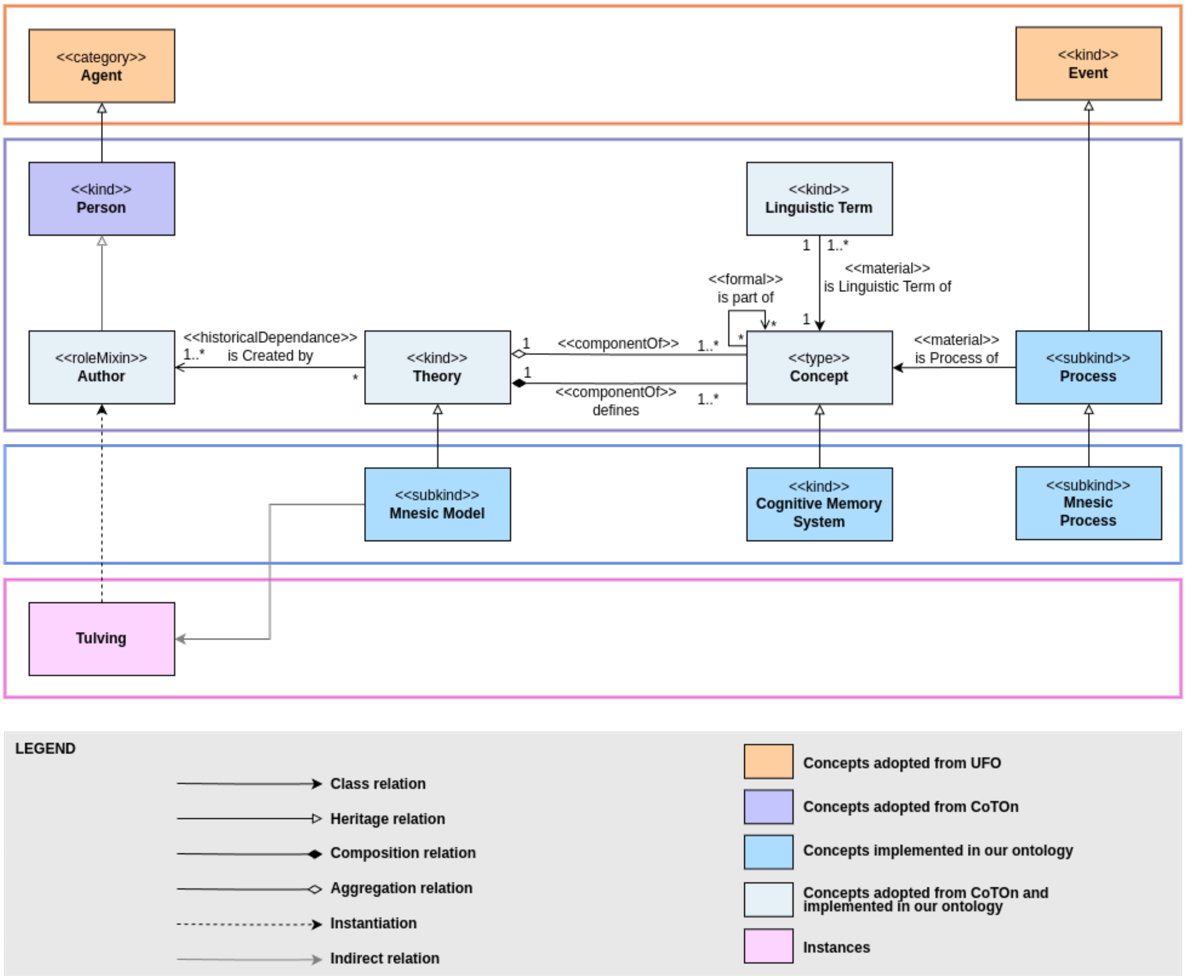

Figure 1: Mem'Onto model including: the Top Level (UFO) in orange, the Middle Level (CoTOn adapted) in purple, the Specific Domain Level in blue and the Instantiation Level in pink.

The models presented in CoTOn depended significantly on the experiments carried out prior to their development. Hence this ontology includes the concepts of **Cognitive Subject**, **Cognitive Task**, **Task Condition** and **Indicator** into their modelling. Given that we aimed to model the different theories of memory, there was no need for experimentally related notions, we decided not to include these four concepts in our ontology. Additionally, we have removed the word **Cognitive** from the other concepts (i.e. **Cognitive Concept** and **Cognitive Theory**) in order to emphasise the multi-domain aspect of our ontology. These concepts can be found in Figure2. To summarize, the concepts included are **Person**, **Scientist**, **Scientific Community**, **Terminological Usage**, **Creator**, **Author**, **Artifact**, **Linguistic Term** and **Agent**, the only concept kept from CoTOn in our Top Level of ontology.

3.4. Ontology Levels

3.4.1. Top-Level Ontology

As stated before, CoTOn is grounded in the Unified Foundation Ontology (UFO) [18]. We assume that the top-level ontological distinctions used in CoTOn are the same for us. We invite the reader to refer to their paper to obtain their (and by extension, our) distinctions. In particular, CoTOn integrates the notion of **Agent** from which the **Person** type inherits. The **Agent** class ('substantial that creates actions, perceives events and to which we can ascribe mental states') [27] comes from the UFO-C ontology and is a subclass of the **Substantial** class ('Independent Endurants' [18]) itself a subclass of the **Endurant** class ('individuals that exist in time with all their parts'). We have also included the

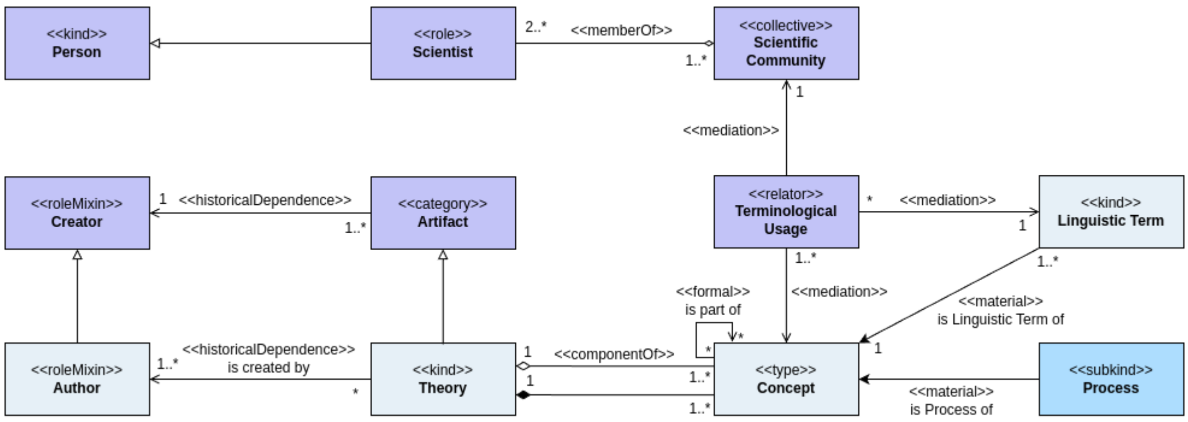

Figure 2: The Middle Level Ontology: CoTOn Adapted.

concept of memory processes into our modeling. After investigating existing UFO concepts, we settled on UFO-B's definition of events ('entities composed of temporal parts that occur over time') and decided to add this concept to our modeling, as its definition is consistent with Tulving's view of processes, as further detailed below.

3.4.2. Middle Level Ontology

The concepts removed, adapted and kept unchanged from CoTOn are detailed in Section 3.3. The concept **Process**, which has been added, is a sub-concept and inherits the properties of **Event** (Figure 2). We have also introduced the `isProcessOf` relation to highlight the **Process** working with a given **Concept** (in the context of the SPI model, a **Cognitive Memory System**).

This Middle-level ontology is intended to be more general and adaptable to different domains, conceptualizations and theories of memory.

3.4.3. Domain Specific Level

In CoTOn, the second level was the instantiation level, where the different models, the tasks and indicators were considered as instances. In our representation, we decide to model that differently, following a better distinction between A-Box and T-Box (Figure 3). For example, in CoTON, the instances of the **Theory** concept, which are working memory models, including the Early decomposition model, the Embedded-process model, the Modal model and the Multicomponent model would also be considered as sub-concepts of **Mnesic model**, the sub-concept of **Theory**. Those sub-concepts from the representation of the adaptation of CoTOn (i.e. the middle level of our ontology) are represented in the domain specific level. This level is the link between the conceptual level in the vision of CoTOn and the instantiation level. In contrast to our middle level ontology, our domain specific level is specialized in memory and has been developed using the organisation of memory model of Tulving from 1995 as a use case.

Hence, this level contains three main concepts that emerged from the conceptualisation of Tulving's SPI model: **Mnesic model** (detailed in the above example), **Cognitive memory system** and **Mnesic process**. From the **Cognitive memory system** concept derives the following 5 sub-concepts: **Episodic memory**, **Primary memory**, **Semantic memory**, **Procedural memory** and **PRS memory**.

All concepts and sub-concepts coming from **Cognitive Memory System** are linked to the sub-concept of the corresponding **Mnesic model** (here, the **SPI model**). Another main concept of the domain specific level is **Mnesic process**, coming from the **Process** concept of the middle level. Tulving considers mnesic processes to be the mechanisms of acquisition, storage, and retrieval of information, as opposed to memory systems. Therefore, we add the 3 process of remembering as sub-concepts of **Mnesic process**: **Encoding**, **Storage** and **Retrieval**.

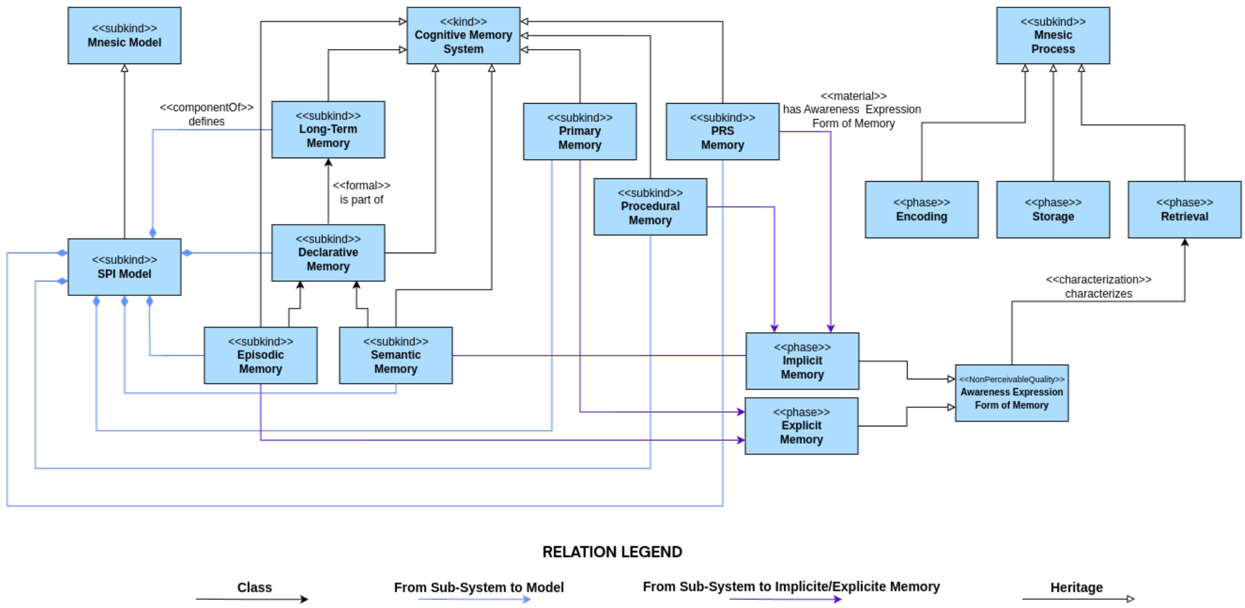

Figure 3: Domain Specific Level. Relation labels are written only once per arrow type for improved readability.

A further aspect of Tulving's model [19] we have represented here is the level of consciousness during the **Retrieval** process. This quality `characterising` the **Retrieval** process is called **Awareness Expression Form of Memory** in our representation, after Tulving who called it 'forms of expression of memory' in order to distinguish them from memory systems. We have added the term 'Awareness' in order to clarify the notion of awareness or lack of awareness of the event and to avoid confusing it with the notion of consciousness, which is much debated in the community. This quality is binary and can take on two distinct values: **Implicit Memory** ('expression of what the individual has learned without necessarily remembering how, when, or where the learning occurred') or **Explicit Memory**.

Additionally, each of the 5 memory subsystems defined by Tulving have either an **Implicit Memory** or an **Explicit Memory** value. The memory subsystems with an **Implicit Memory Awareness Expression Form of Memory** are **PRS Memory**, **Procedural Memory** and **Semantic Memory**. Conversely, the memory subsystems with an **Awareness Expression Form of Memory** of type **Explicit Memory** are **Primary Memory** and **Episodic Memory**. We cannot infer the type of **Awareness Expression Form of Memory** of the **Long-Term Memory** and **Declarative Memory** as they contain the **Semantic Memory** and the **Episodic Memory**, each having different **Awareness Expression Form of Memory**.

3.4.4. Instances Level

CoTOn considers instances as first-order types, individuals forming neurocognitive data sets. Given that, the instantiation level is composed of the instances of our ontology (i.e. the members of a class also called individuals or objects). Here, there is for example the member of the class **Author** which can be *Tulving*, *Baddeley*, *Hitch*, etc.

4. Implementation

Figure 4 presents a fragment of the ontology metadata and metrics. Mem'Onto has 34 classes, 1 object property, and 24 annotation properties. Each ontology entity was annotated with a definition (skos:definition) and a bibliographic citation (terms:bibliographicCitation).

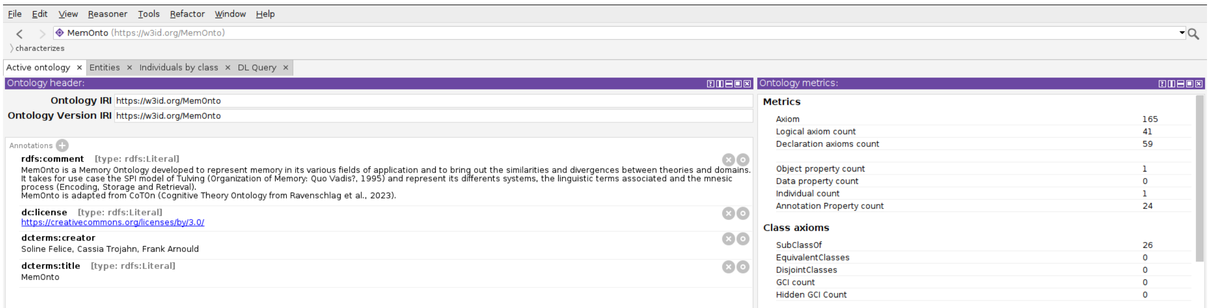

Figure 4: A fragment of the ontology metadata and metrics.

4.1. Class Elicitation

In addition to the conceptual model presented, we provide a first version of a digital ontology[1] expressed in OWL (the Web Ontology Language) [28] and provided in a turtle file (MemOnto.ttl).

As explained in Section 3, Mem'Onto was developed to match UFO. In the model presented in Figure 1, the orange section corresponds to the UFO concepts that have been included in Mem'Onto in order to highlight the links with concepts at other levels of our ontology. Furthermore, they have not been integrated into our functional ontology so that UFO and Mem'Onto can be loaded together in Protege without interfering with each other. It is therefore possible to import both; one simply needs to recreate the hierarchical relationships between the **Agent** and **Event** concepts from UFO and the **Person** and **Process** concepts respectively, as the Mem'Onto concepts are typed to be compliant with UFO.

From our model, a portion of the concepts have been implemented within the ontology, using Protégé. Among them, the concepts belonging to our Middle level ontology (CoTOn adapted) are: **Author**, **Theory**, **Concept**, **Linguistic Term** and **Process**.

We also introduce concepts from the domain specific level of Mem'Onto. Among them, the **Cognitive Memory Systems** are a subclass of **Concept**, with the systems cited in Tulving's paper: **Procedural Memory**, **PRS Memory**, **Semantic Memory**, **Primary Memory**, **Episodic Memory**, **Declarative Memory** and **Long-Term Memory**. The **Mnesic Process**, a subclass of **Process** are **Encoding**, **Storage** and **Retrieval**. We have considered as **Linguistic Terms** (a concept from CoTOn) what Tulving called 'Other terms' which are synonyms of the **Cognitive Memory System** (for example, **Procedural memory** can also be referred to as **Nondeclarative memory**). This class could have been expressed in labels as annotation property, but we followed CoTOn's modeling on this point which was motivated by the need to limit the list of selectable terms to a predefined range of options, given that they imported the linguistic terms commonly used for cognitive concepts from the Cognitive Atlas. The **Mnesic Model** class has been added as a subclass of **Theory** and a parent class of the **SPI Model**. Then, the **Awareness Expression Form of Memory** is the last class represented in our model. The **Implicit Memory** and **Explicit Memory** correspond to its subclasses.

4.2. Contextual Requirement

Most relations between classes, are implemented as annotation properties, as OWL's object properties are dedicated to linking instances. Among the relations we implement are `characterizes`, `creates`, `defines`, `isLinguisticTermOf` and `isProcessOf`. These properties do not fully allow to represent all the competency questions. **CQ3-5** can not be answered with mere binary relations. In order to represent the contextual links between a process (always **Retrieval** in the SPI Model), an **Awareness Expression Form of Memory** and a **Cognitive Memory System**, we required ways to express n-ary statements. In our ontology, **CQ3** and **CQ5** are tackled by using Standard Reification. This appears to be adequate as we aim to represent a context for a single triple, respectively about the subtyping in **CQ3** and `isLinguisticTermOf` in **CQ5**. **CQ4** however, is less intuitively represented using Standard

[1] An aplha release of Mem'Onto is available via https://gitlab.com/sfsoline.felice/memonto

Table 2
Definition and examples of classes in the Middle Level Ontology that are implemented in the operational ontology.

Entity	Definition	Example
Author	The creator of a Theory. [17]	E. Tulving
Theory	A principle or body of interrelated principles that purports to explain or predict a number of interrelated phenomena. [29]	SPI Model
Concept	Mental representations that encode sets of attributes that describe real or imaginary classes of items, processes or relationships. [15]	Cognitive Memory System, Declarative Memory, Procedural Memory
Linguistic Term	A colloquial name used by the cognitive neuroscience community (and by extension, the scientific community using it) to denote Concepts [17]	Primary Memory, Short-term Memory, Working Memory
Process	An occurrent entity that exists in time by occurring or happening, has temporal parts, and always depends on some (at least one) material entity. [30]	Mnesic Process, Encoding

Reification. As it involves a relation between three entities, the whole being held true only within the context of a certain theory, a n-ary relation seems more fitting. We introduce the **Model_Relation** class, which is the class of n-ary relation nodes between a **Cognitive_Memory_Systems**, one of the **Process** it involves, and the **Awareness Expression Form of Memory** this process has according to a certain theory, as is done in the SPI Model framework. Instances of this class are represented using blank nodes linking the three classes mentioned above. They are linked to these nodes by relationships (in the form of annotation properties) `asAwarenessExpressionForm`, `linkedToProcess` and `memoryComponent`. The mnesic model within which this relation is described using the `holdsTrue` (here, the SPI Model).

5. Evaluation

A first evaluation of the ontology consisted in verifying that the ontology is able to cover the defined competency questions. For that, the corresponding SPARQL queries have been written and tested (Table 3).

Since the class **Theory** has the type Kind ('Functional Complex, i.e., a whole that has parts contributing in different ways for its functionality', [31]), we considered the class **Mnesic Model** to be a subkind, given that it is part of the **Theory** class. The **SPI Model** was also considered to be a subkind as it `inherits` from **Mnesic Model** and therefore from **Theory**.

Cognitive Memory System has also been considered as a kind `inheriting` from the **Concept** class. Its sub-concepts are thus all subkind (e.g. **Declarative Memory**, **Primary Memory**).

UFO-B's Event class been considered as a kind, so the **Process** and **Mnesic Process** classes were considered subkinds. The three **Mnesic Process Encoding**, **Storage** and **Retrieval** were considered as phases, because they only have exactly one identity provider and in this conceptualisation they represent a disjoint and complete set.

Awareness Expression Form of Memory has been considered a quality due to its nature as an intrinsic property having a structured value, yet NonPerceivable because it cannot be directly measured by an instrument, such as money. Its sub-classes are **Implicit Memory** and **Explicit Memory**, which are themselves Phases, also considered as a disjoint and complete whole (according to Tulving, we cannot retrieve memories with both explicit and implicit awareness of their acquirement).

Alongside the typing of the additional concepts, we have added relations to ensure that our formal representation reflects Tulving's perspective. Among these, which are all found in Mem'Onto, we have the `defines` relationship, which was already used in CoTOn to bound a concept to the theoretical

Table 3
SPARQL queries and query results for the specific competency questions.

	SPARQL Query	Results

CQ1	`SELECT ?cms WHERE {`
	`    ?cms rdfs:subClassOf :Cognitive_Memory_System. :`
	`        SPI_Model :defines ?cms.`
	`}`
		Declarative Memory, Episodic Memory, Long-Term Memory, PRS Memory, Primary Memory, Procedural Memory, Semantic Memory

CQ2	`SELECT ?author WHERE {`
	`   :SPI_Model :isCreatedBy ?author .`
	`}`
		Tulving

CQ3	`SELECT ?mnesic WHERE {`
	`    :Tulving :considers ?statement.`
	`    ?statement rdf:subject ?mnesic.`
	`    ?statement rdf:predicate rdfs:subClassOf.`
	`    ?statement rdf:object :Mnesic_Process.`
	`}`
		Encoding, Storage, Retrieval

CQ4	`SELECT ?awareness WHERE {`
	`    :SPI_Model :holdsTrue ?relation.`
	`    ?relation :linkedToProcess :Retrieval.`
	`    ?relation :memoryComponent :Episodic_Memory.`
	`    ?relation :asAwarenessExpressionForm ?awareness.`
	`}`
		Explicit Memory

CQ5	`SELECT ?linguisticTerm WHERE {`
	`    :Tulving :considers ?statement.`
	`    ?statement rdf:subject ?linguisticTerm.`
	`    ?statement rdf:predicate :isLinguisticTermOf.`
	`    ?statement rdf:object :PRS_Memory.`
	`}`
		PRS Memory, Priming Memory

framework to which it belongs. By converting instances of **Theory** and **Concept** into sub-concepts, we have at the same time transposed this relationship to the latter. For example, **Episodic Memory** and **Semantic Memory** define the **SPI Model**, in a compositional relationship with this **Mnesic Model** because each sub-concept of the **Concept** class can only be interpreted within the framework of its theory and therefore depends on it.

Following this, we adopted the transitive `is part of` relationship between **Semantic Memory** and **Episodic Memory** with the **Declarative Memory**, as well as between **Declarative Memory** and **Long-Term Memory**. Indeed, it was clearly accepted in the literature at the time that semantic and episodic memory were categorised together as declarative, itself associated with long-term memory.[32, 33]

We then introduced that **Awarness Expression Form of Memory** `characterizes` the **Mnesic Process Retrieval**. This same concept **Awarness Expression Form of Memory** has as children the classes **Implicit Memory** and **Explicit Memory**, which are themselves linked by our relation **is Awareness Expression Form of Memory** to the respective **Cognitive Memory Systems**.

6. Discussion

In our modelling, we made various choices that are specific to memory studies. First of all, our priority was to reuse as much as possible CoTOn, and to do so, we decided to keep the top-level ontology UFO. This choice is debatable, particularly in regard that processes are more detailed in other ontologies such as BFO or DOLCE. The mapping of our ontology to UFO is not rigid and we plan to change our foundation ontologies if needed. In addition, we have chosen to integrate the Mnesic Processes under this term, because we relied on the work of Tulving to propose a first version of an ontology of episodic memory and, as a result, wanted to use his terms as much as possible. Nevertheless, the term Process refers to two distinct concepts in this research:

- the memory process (called mnesic process by Tulving and by extension, in our ontology) which refers to 'a process that realizes a memory disposition' [22].
- the ontological process which refers in UFO to a variable embodiment of ordinary events [34].

In Mem'Onto, we consider the concept **Mnesic Process** to be what we define as a memory process, which inherits the concept **Process** from our middle-level ontology, which we consider to be an ontological process.

According to UFO-B, the concepts from which **Mnesic Process** could `inherit` are **Event** and **Process** [34]. To decide which concepts to adopt, we have relied on Stout's distinction to which 'an event is something that happened/will happen, while a process is something that is/was/will be happening or occurring' [35]. Therefore, we have chosen not to type the 'Process' concept as an event into our ontology in order to avoid confusion with the event experienced and recalled by the participant. In UFO-B [36], events are considered to be individuals that may be composed of temporal parts, giving as examples the sinking of the Titanic or a football game. An event composed of at least two events is considered a complex event. As for processes, they are considered complex events, with examples such as chemical processes. Following UFO's terminology, we have considered our mnesic processes as processes that themselves inherit events. To give an example, 'I learned to ride a bike when I was about 6 years old', and this skill was integrated into my working memory through the encoding process. It has since been stored and is retrieved every time I ride a bike again. During these three processes, different brain activation's and cognitive sub-processes are involved, each of which can be characterized as a complex event (the event of my encoding when learning to ride a bike is considered here to be on the same level as the sinking of the Titanic).

7. Conclusion and Future work

Memory is a concept that is studied in different disciplines within different theories and yet is represented in a wide diversity of ways. Researchers between different memory sciences refer sometimes to the same concepts, while at other times they use the same linguistic term to designate different concepts. This happens between disciplines but also within disciplines, between theories themselves.

In order to bring out these consensuses and disensuses, we provide in this paper a first multi-level representation of mnesic concepts based on a model of memory organisation according to Tulving from 1995.

Four hierarchical ontological levels are modelled in this representation: (1) the concepts linked to our top-level ontology, UFO, (2) the cognitive meta-concepts adapted from the CoTOn ontology linking the philosophical concepts of our top-level ontology to the mnesic concepts, (3) the domain level ontology including cognitive memory systems, the mnesic model and mnesic processes, and (4) the instantiation level.

We have adapted the ontology described with CoTOn based on working memory. Tulving's SPI model served as a use-case and it allowed us to integrate the mnesic processes and the link he makes between them and the cognitive memory systems. In particular, we formalised the link between how the encoding of the event during retrieval, which can occur implicitly or explicitly depending on the memory system involved, and to which we refer with Awareness Expression of Memory. Based on this representation, we derived a model and implemented a first operational version of it in Protégé.

In future work, we intend to extend and adapt this ontology to other models, but also to integrate a versioning of theories in order to track their evolution, and then expand it to other memory disciplines.

A verification-action step by memory experts in psychology and neurocognition will be implemented later. Another perspective of this work is the addition of contextualization to distinguish mnesic models as cognitive representations from mnesic models as theories, themselves considered within the framework of an author, a year and a movement.

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Disclaimer

This paper focuses on the representation of episodic memory theories and concepts. However, by working on some of Tulving's work, we are only representing one facet of the studies on memory, focusing solely on studies on adult humans with no apparent pathologies.

Declaration on Generative AI

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

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