**How to build a cognitive ontology: A practical task-oriented approach for cognitive neuroscience**

**Abstract**

Two major obstacles for cognitive ontology building informed by neuroscience are the many-to-many mapping between cognition and brain, and the problem of demarcating neural mechanisms. I propose a novel, practical task-oriented methodology that weighs different criteria to find the best systematization of behaviour, and I show how it solves both problems. This task ontologies approach yields more differentiated and context-dependent cognitive concepts, allowing cognitive neuroscience to provide explanations of cognitive capacities better tailored to our everyday life.

1. **Introduction**

One of cognitive neuroscience’s major ambitions is to map cognitive capacities to neural mechanisms in order to find out how the parts and processes of the brain explain the parts and processes of the mind. This raises the question of what the parts of the mind actually are, and how we can best carve up and categorize our cognitive capacities. These questions are central to the cognitive ontology debate which has given rise to a variety of approaches and answers from both philosophers and neuroscientists (Poldrack et al. 2011; Price and Friston 2005; Klein 2012; Khalidi 2023; McCaffrey and Wright 2022; Anderson 2010; Poldrack and Yarkoni 2016). In particular, positions differ regarding the extent to which neuroscientific evidence can play a role in informing or reforming our current cognitive ontology (see for recent overviews Dewhurst 2021; Anderson 2015; McCaffrey and Wright 2022).

Recent discussions have focused on two major problems in building cognitive ontologies informed by neuroscience. First, the many-to-many mapping between cognition and brain presents a challenge to cognitive ontology building because it becomes difficult to infer what cognitive capacity we explain with a particular set of neural data (Francken and Slors 2014; 2018; Khalidi 2023; Klein 2017; Khalidi 2017; Sullivan 2017; Westlin et al. 2023). Second, it has been argued that the idea of identifying and demarcating neural mechanisms and then using these as objective arbiters for categorizing cognitive concepts is problematic, and therefore cannot be drawn on to determine the ‘right’ taxonomy for cognition (Francken, Slors, and Craver 2022; Craver 2009).

In this paper, I will argue that these two problems call for an alternative approach to cognitive ontology construction. I will propose a novel, practical, task-oriented methodology and show how it solves both problems.

In section 2, I will describe the two problems for the bottom-up neuroscience approach to cognitive ontology building and show why a novel approach is required. In section 3, I will first discuss the requirements for a useful cognitive ontology and subsequently present my novel ‘task ontologies approach’. In section 4, I will discuss the main philosophical implications of the task ontologies approach and explain how it answers both the many-to-many mapping and mechanism demarcation problems.

1. **Two problems for cognitive ontology**

*2.1 How cognitive neuroscience is characterized by a many-to-many mapping*

While the early days of cognitive neuroscience were characterized by a strong optimism about brain mapping efforts, research findings over the past two decades now demand a more modest stance. That is, most of our cognitive capacities, such as memory or attention, cannot be linked in any simple way to neural structures or functions. Instead, cognitive neuroscience is characterized by a many-to-many mapping between cognitive concepts[[1]](#footnote-1) and neuroscientific data. I will use the cognitive concept of ‘memory’ to elucidate this.

There are many different daily-life contexts in which the cognitive concept of memory is used. For instance, we remember our childhood memories, or we are playing a memory game. Recently, awareness has been raised to the historical and cultural circumstances in which cognitive concepts have developed and are used (Danziger 1997; McGeer 2021), amplifying the context-dependence[[2]](#footnote-2) of both the concepts referring to cognitive capacities and cognitive ontologies (Francken and Slors 2018; McCaffrey and Wright 2022). Moreover, cognitive terms are employed differently across scientific contexts. For instance, cognitive psychologists might design an experiment to study ‘long-term memory’, or develop a psychological model that aims to explain data from ‘working memory’ experiments. Since the advent of neuroimaging methods, what we think memory is can also potentially change as a result of neuroscientific findings.

One scientific strategy to deal with context-dependence is to carve up the concept of memory into different sub-concepts, such as ‘working memory’ and ‘long-term memory’. However, since we cannot observe cognitive capacities directly, we need to ‘operationalise’ them to enable experimental manipulation and measurement. In cognitive neuroscience (and cognitive psychology), behavioural tasks are used for this aim providing stimulus conditions and behavioural outcome measures that allow interpreting brain activity in cognitive terms. For example, if we want to experimentally study working memory in the brain, we can use the so-called n-back task in which participants are asked to remember a series of presented digits (stimulus conditions) and produce a response (e.g., button press) upon a particular stimulus configuration, that is subsequently used to calculate a behavioural outcome measure (e.g., error rates).

This process of operationalising a cognitive capacity would not necessarily lead to a plurality of working memory concepts if a standard ‘working memory task’ would exist. However, in cognitive neuroscience there is no standard way to operationalise cognitive capacities. That means, there is a large variety of different experimental tasks that can be used to operationalise working memory, such as the n-back task, digit span task, and delayed match to sample task. These different tasks are supposed to measure the same cognitive capacity of working memory, but it is debatable whether they measure *exactly* the same process or rather slightly different, related processes (see for discussions in the context of neuroscience Francken, Slors, and Craver 2022; Sullivan 2015; 2010; Feest 2025; Sullivan 2016). Moreover, here we also find the reverse problem, since these experimental task operationalisations are often not uniquely associated with one cognitive (sub-)capacity. For instance, the Wisconsin card-sorting task is used to manipulate and measure both working memory and ‘task-switching’, with the latter capacity related to the more general capacity of ‘cognitive control’.

Finally, empirical studies show that the neural activation patterns associated with different task operationalisations of the (supposedly) same cognitive capacity vary and are in addition sometimes method dependent (see e.g. in the context of neuroscience of consciousness Yaron et al. 2022; Bisenius et al. 2015). Moreover, since many brain areas (and brain networks alike) flexibly perform different functions, it is generally not possible to infer from a particular activation pattern which cognitive capacity was engaged (Poldrack 2006).

Thus, rather than having a clean one-on-one mapping, we end up with a many-to-many mapping between common-sense cognitive concepts as used in daily life, cognitive concepts in scientific contexts, experimental task operationalisations, and neuroscientific data. This makes it difficult to infer *what* exactly we are explaining with brain data, and consequently, how to carve up the cognitive capacities in our cognitive ontology.

*2.2 Demarcation problems for a bottom-up neuroscience approach to cognitive ontology*

Many neuroscientists suppose that they will be able to find the ‘right’ cognitive ontology by studying the brain. For instance, suppose we find that the same neural mechanism underlies both the cognitive capacities of task-switching and ‘response inhibition’, the bottom-up neuroscience approach would suggest lumping the two ontological categories, and use one concept instead of the two that are in our current cognitive ontology. Put more strongly, neuroscience findings would thus ultimately determine the ‘correct’ use and categorization of our cognitive concepts (see e.g., Lenartowicz et al. 2010; Buzsáki 2021).

However, recently Francken, Slors and Craver (2022) have argued that that the bottom-up neuroscience approach to cognitive ontology is idealized and problematic (see also Krickel 2024). In brief, the authors argue that there are two problems when demarcating neural mechanisms, which they call the ‘Abstraction problem’ and the ‘Boundary problem’. To identify and demarcate neural mechanisms, one needs to abstract away from the complex network of causal connections in the brain. However, at one degree of abstraction two neural mechanisms might be not of the same kind, yet when abstracted further, both fall under the same kind of mechanism. Thus, the Abstraction Problem occurs because there is no uniquely correct degree of abstraction for describing neural mechanisms (Craver 2007; 2009; Levy and Bechtel 2013). The Boundary problem arises because one faces the non-trivial tasks of distinguishing constituent parts of mechanisms from the background conditions, and of deciding where one mechanism ends and another begins. Again, one can be led to lump or split neural mechanisms differently depending on where these boundaries are drawn (Craver 2007; 2009; Craver, Glennan, and Povich 2021)

To solve these problems, we need to have some idea of ​​the cognitive capacities that are realized by the mechanisms, which is in turn dependent on conceptual decisions. That means that neural mechanisms cannot be decisive for what counts as a cognitive capacity. Therefore, the authors conclude that we cannot ‘read-off’ neural mechanisms from the brain in a neutral way to inform our cognitive ontology.

In summary, cognitive neuroscience is characterized by a many-to-many mapping between cognition and brain, which hinders interpretation of neuroscientific data in terms of cognitive capacities that make up our cognitive ontology. The bottom-up neuroscience approach to cognitive ontology also suffers from two fundamental problems for demarcating neural mechanisms[[3]](#footnote-3). Since both of these obstacles preclude a direct influence of neuroscience on cognitive ontology, a novel approach to cognitive ontology building is needed.

1. **How we can devise a useful cognitive ontology with a task ontologies approach**

Given the many-to-many mapping between cognition and brain and the problems with demarcating neural mechanisms, can we find an alternative for the bottom-up neuroscience approach? In this section, I will first discuss the requirements of a useful cognitive ontology and describe what a task ontologies approach entails. Then, I will develop such a novel approach together with a clear practical application and argue that this task-oriented methodology can meet these requirements.

*3.1 Requirements of a useful cognitive ontology*

To elucidate what is at stake in building a useful cognitive ontology I will invoke the image of finding a balance between two extremes on a granularity axis (Figure 1). Moving to the extreme on the left means moving in the direction of conceptual differentiation, while the reverse movement means moving in the direction of conceptual integration. I will argue that the first requirement of a useful cognitive ontology is having concepts that are neither too fine-grained, nor too coarse-grained.

A diagram of a working memory

AI-generated content may be incorrect.

***Figure 1.*** *Finding a balance between conceptual differentiation and conceptual integration for context-sensitive cognitive concepts.*

In section 2, I argued that many of the current concepts in our (scientific) cognitive ontology, such as ‘memory’, ‘attention’ and even sub-concepts such as ‘working memory’ are very broad. Therefore, these supposedly unitary cognitive capacities consist of different aspects that often cannot all be operationalized in a single experimental design. As a result of the negligence of these different aspects and the use of different experimental tasks to manipulate and measure ‘the same’ cognitive capacity, lumping errors occur. Moreover, using general terms such as ‘memory’ obscures and does not sufficiently allow for the context-dependence that we would like to have. These considerations give us reason to move in the direction of conceptual differentiation.

However, in the extreme case, we end up with concepts that are too fine-grained, resulting in operationalism, which *defines* cognitive capacities in terms of their tasks (Chang 2021; Bridgman 1927). For example, a too-fine grained ‘memory’ concept would be its identification with a specific experimental task, e.g., the n-back task. If we then move back to the other extreme to allow for a certain extent of generalization or conceptual integration, we risk ending up again with a cognitive ontology of too coarse-grained concepts including umbrella terms such as ‘working memory’ and ultimately ‘memory’ that we wanted to avoid. In the specific research context of cognitive neuroscience, I contend that we are generally looking for finer-grained notions than the ones our cognitive ontology currently contains, that still allow for a certain degree of generalizability.

The second requirement of a useful cognitive ontology is having a certain degree of flexibility and allowing for tailoring concepts to explanatory needs. In this way, we can recognize that the ‘right’ level of conceptual granularity might flexibly differ depending on use-context or purpose, for instance, studying the neural mechanisms of memory in fundamental research or in a clinical context to predict the progression of Alzheimer’s disease. On our granularity axis (Figure 1), this means that we might end up more to the left in one case and more to the right in another context.

To conclude, having a useful cognitive ontology means that we should find a middle ground between conceptual differentiation and integration, with concepts that allow for more flexible and pluralist notions of the cognitive capacities to which they refer.

*3.2 What is a task ontologies approach?*

Task ontologies in the context of cognitive neuroscience and the cognitive ontology debate have been discussed by various authors (Bilder et al. 2009; Figdor 2011; Francken and Slors 2014; 2018; Sullivan 2017; Burnston 2022; Gomez-Lavin 2025). Generally, the idea is that a task ontology includes semantically stable and distinguishable items (Figdor 2011) which are task behaviours (examples will be discussed in section 3.3). These task behaviours can be described at a detailed level, including task parameters such as interstimulus intervals and stimulus presentation durations, or rather at a more abstract level, e.g., describing just their characteristic task conditions. The task behaviours are then categorized according to some criterion, resulting in a taxonomy in which similar tasks cluster together.

Importantly, building a task ontology does not presuppose a cognitive ontology, but starts with systematizing or grouping behaviour, as I will show in the next section. Note that in principle, any level of description of behaviours could be categorised, including behaviours in everyday life settings. Since the task ontologies approach is developed in the context of cognitive neuroscience research, I will focus here on the behaviours as they are studied in experimental cognitive tasks.

*3.3 A novel approach to task ontologies and its application*

Here I will present my novel approach to task ontologies by applying it to the cognitive concept of ‘working memory’ to demonstrate how the approach works in actual scientific practice (Figure 2). Various experimental tasks are used to manipulate and measure working memory (see e.g., Baddeley 2012). In my task ontologies example case–a hypothetical, simplified application–I will use five of such commonly used tasks. The point is that these tasks arguably do slightly or very different things. For instance, in a forward digit span task participants passively recall items, while an n-back task requires the continuous updating of information in working memory.

A diagram of a working memory

AI-generated content may be incorrect.***Figure 2.*** *The task ontologies approach applied to ‘working memory’. Note that this figure shows a hypothetical and simplified analysis.*

In Step 1 ‘Task collection’, a database is created with published papers on the concept and from these papers we derive a comprehensive list with tasks used to study working memory. Obviously, there are other ways to build such an inventory, but here the method is less important than the result, which is a complete collection of tasks associated with the cognitive concept.

In Step 2 ‘Criteria application’ the aim is to group these tasks according to different criteria. In Figure 2, three possible criteria are included: task history, neural data and expert survey. For instance, we could perform a task history analysis (Figdor 2013; Bilder et al. 2009) in which the criterion for grouping tasks depends on their historical relatedness in the literature. In our hypothetical working memory example, the analysis might result in a task ontology with three different categories, indicated by three boxes. Next, we could perform a neural data analysis (Lenartowicz et al. 2010; Kenett et al. 2020) in which tasks are grouped depending on the similarity of their elicited neural activation patterns. This analysis potentially results in a different grouping of the tasks. We could also perform an expert survey, in which we ask memory researchers to rate the similarity of the tasks (Kenett et al. 2020). In the example this analysis produces two boxes or categories.

Crucially, these three criteria present *possible* ways for task categorization, but these criteria are not necessary nor sufficient for the task ontologies approach. Criteria should be chosen depending on the context in which the concept ‘working memory’ is used and on the aim of the study. In another case, we might want to include different criteria, such as developmental criteria, or clinical information. As I will argue later, criteria choice is essential for ensuring context-sensitivity of the resulting task ontology.

In Step 3 ‘Criteria weighing’ the different task ontologies created in Step 2 are combined resulting in one final task ontology to achieve the best systematization of behaviour. This combination process involves a weight adjustment of the different criteria relative to each other. This weighing process is again tailored to the use-context of the cognitive concept. In Figure 2, for instance, the neural data and expert survey criteria are weighed more heavily reflecting the research context of the concept, resulting in a final task ontology with two different categories. Note that depending on the weight adjustment, slightly different versions of the task ontology may result. In Step 4 ‘Task ontology evaluation’ the resulting task ontology is evaluated or tested in the context of its intended use. Future research is required to flesh out both the specific (statistical) process of weight adjustment and the process of evaluation.

Step 5 ‘Conceptual labelling’ connects the final task ontology (Step 4) back to the level of cognitive concepts. This can be done by proposing novel sub-concepts that capture the differences between the task groupings, here for instance, ‘working memory manipulation’ and ‘working memory maintenance’ (cf. Gomez-Lavin 2025), or by connecting task groupings to existing sub-concepts, but in a novel or more systematic way. This conceptual labelling process demands from the scientist using the intentional stance (Francken and Slors 2014; Sullivan 2014; Dennett 1987). The main box at the top right of Figure 2 represents the end point of the task ontologies approach, and we can compare the resulting cognitive ontology with the starting point on the top left.

*3.4 How a task ontologies approach meets the requirements of a useful cognitive ontology*

After introducing my novel task ontologies methodology, I will now argue that this approach meets the requirements that I set for a useful cognitive ontology in section 3.1.

The first aim was to balance conceptual differentiation and integration. This aim is achieved because task groupings describe and categorize behaviour at a more general level than individual tasks, avoiding the operationalist worry of identifying every single task with a distinct cognitive concept. On the other hand, the focus on the level of behaviour avoids the use of umbrella concepts like or ‘memory’ or ‘attention’ that currently make up our cognitive ontology. As a result, the conceptual labels resulting from the task ontologies approach (Step 5) are most likely right in the middle between too fine-grained and too coarse-grained concepts.

Second, regarding the flexibility in finding the ‘right’ level of granularity and tailoring to our explanatory needs, we can see that this requirement is accommodated by weighing different criteria to produce the best systematization of context-dependent behaviour. This is crucially different from standard cognitive ontology approaches. First, it allows for the inclusion of different criteria (Step 2) and thus goes beyond just bottom-up neuroscience information, or top-down conceptual analysis, to build the ontology. Moreover, the weighing process is based on the context-relevant considerations of the task behaviour (Step 3), and thus guarantees the best systematization or grouping for this particular context.

In conclusion, I propose that the task ontologies approach that I advanced in this section offers a promising alternative to the bottom-up neuroscience approach to cognitive ontology.

1. **Philosophical and practical implications of the task ontologies approach**

In this section, I will discuss four main implications of the task ontologies approach developed in section 3. First, I will show how this approach solves the two problems for cognitive ontology building described in section 2. Next, I will discuss why the task ontologies approach endorses ‘taxonomic pluralism’, and how it calls for a different view on validity of a cognitive ontology.

*4.1 How the task ontologies approach solves the two problems for cognitive ontology*

According to the bottom-up neuroscience approach, cognitive concepts refer to the brain directly. For instance, ‘working memory’ is considered a specific brain process that one can engage by performing any of the available ‘working memory tasks’. This is a strong assumption on the relation between mind and brain that is not necessary in the task ontologies approach. This approach instead anchors cognitive concepts to behaviour and explicitly acknowledges that operationalizing cognitive capacities is a compulsory step to studying e.g., working memory in the brain (Dennett 1987; Francken and Slors 2014; Burnston 2022; Sullivan 2010). Consequently, the task ontologies approach will likely reduce the complexity of the many-to-many mapping that characterizes cognitive neuroscience. For one, the grouping of tasks is made in a more systematic way, potentially reducing the heterogeneity in linking brain processes to experimental tasks. Moreover, the final ‘Conceptual labelling’ step (Step 5) of the task ontologies approach involves explicit consideration and justification of the way we interpret behaviour in terms of cognitive capacities. As a result, we can expect more consistency in the use of both scientific and everyday concepts to describe cognitive capacities.

The second problem for cognitive ontology is solved by the task ontologies approach because it does not suppose that the brain is the ultimate arbiter of our cognitive ontology. Therefore, the criticisms on the bottom-up neuroscience approach by Francken, Slors and Craver do not apply. The bottom-up neuroscience approach presupposes that there exists a ‘true’ cognitive ontology, that we can find in the biology of the brain: Biological information ‘cuts nature at its joints’. In contrast, the task ontologies approach denies that cognition has a ‘nature’ that has definite joints. Consequently, this approach can incorporate other considerations as well, because it weighs neuroscientific information with other taxonomic criteria.

Researchers adhering to a more realist conception of cognitive capacities might see this feature of the task ontologies approach as a (relativist) flaw rather than an advantage. That is because they suppose the existence of criteria for ‘consilience’ or ‘convergence’ among tasks that can be derived from some underlying causal entities or structures (Khalidi 2023). Three responses can be made here. First, assuming the existence of ‘true’ criteria for categorizing tasks takes the strong stance on the relation between mind and brain that the task ontologies approach aims to avoid (see above), to maintain a more metaphysically neutral position. Second, locating these alleged criteria in the brain will run into the problems described by Francken, Slors and Craver (2022) for demarcating neural mechanisms and is therefore epistemically a difficult position to uphold. Third, assuming (a set of) single right criteria for categorizing tasks is incompatible with a more pluralist view of cognitive ontology, that will be discussed next.

*4.2 Further implications of the task ontologies approach*

The task ontologies approach explicitly endorses ‘taxonomic pluralism’ (McCaffrey and Wright 2022; Sullivan 2017; Hochstein 2016). While the bottom-up neuroscience approach (explicitly or implicitly) aims to find a single, stable, ‘true’ cognitive ontology, the task ontologies approach allows for the possibility that there is no cognitive ontology that is relevant to all contexts and times. In fact, we may need multiple cognitive ontologies because goals and aims of scientific studies and researchers differ–consider clinical studies versus fundamental neuroscience, or Western versus non-Western psychological concepts. It is unlikely that this diversity can be accommodated by the same, single taxonomic structure. The requirement of flexibility and context-sensitivity for useful cognitive ontologies was discussed in section 3 and is one of the key premises in the design of the task ontologies approach.

A final implication of the proposed methodology is that justification of a particular cognitive ontology–or its validity–requires something fundamentally different, following from an updated concept of ‘validity’. According to the bottom-up neuroscience approach, validity of cognitive ontology means correspondence with (causal) processes or mechanisms in the brain (Lenartowicz et al. 2010; Feest 2020). In contrast, the task ontologies approach entails a more instrumentalist and context-dependent view on validity (Han 2024). Here, validity means justifying why a range of task behaviours should be grouped together. Going back to the practical process of developing a task ontology, we can see where the justification for task groupings is located: in Step 2 and 3. That is because the goodness of fit of a task category results from the weighing of multiple different criteria that are chosen and adjusted based on the specific context in which the behaviour is used or displayed. In other words, the criteria that can be flexibly used to *build* a task ontology at the same time *establish* its validity.

1. **Conclusion**

Two major obstacles for cognitive ontology building informed by neuroscience are the many-to-many mapping between cognition and brain, and the problem of demarcating neural mechanisms. I have shown how the novel task ontologies methodology developed here solves both problems. By weighing different criteria–including, but not limited to, neuroscientific criteria–we can find the best systematization of behaviour. The task ontologies approach will yield more differentiated and context-dependent cognitive concepts, allowing cognitive neuroscience to provide explanations tailored to our behaviours in everyday life.

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1. Cognitive concepts (e.g., ‘memory’) refer to cognitive capacities (e.g., the ability to remember past events). Thus, we use cognitive concepts to categorize and label these capacities, resulting in a subdivision of cognitive capacities–or: a cognitive ontology. [↑](#footnote-ref-1)
2. I will use the notion of ‘context-dependence’ in a general sense here to refer to sensitivity of cognitive concepts, behaviour or cognitive ontologies to a specific research or everyday life context, which includes/as a synonym for ‘purpose-oriented’, ‘use-context’. [↑](#footnote-ref-2)
3. Note that the many-to-many mapping ‘problem’ and the mechanism demarcation problems are related. This needs to be further elaborated in future research. [↑](#footnote-ref-3)