----------------------------- Unpublished Manuscript / 4.12.2022 -----------------------------

Modal and Amodal Cognition:
An Overarching Principle in Various Domains of Psychology

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We would like to thank Arthur Glenberg and Diane Pecher for their very helpful and inspiring input on the topics covered in this manuscript. We also thank all the doctoral and post-doctoral students in the research unit for recurring discussions on representational issues in cognitive science that greatly helped us develop the perspective presented here.

This research was supported by Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – KA 1422488154; 381713393, within Research Unit ``FOR 2718: Modal and Amodal Cognition''.

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Abstract

Accounting for how the human mind represents the internal and external world is a crucial feature of many theories of human cognition. Central to this question is the distinction between modal as opposed to amodal representational formats. It has often been assumed that one but not both of these two types of representations underlies processing in specific domains of cognition (e.g., perception, mental imagery, and language). However, in this paper we suggest that both formats play a major role in most cognitive domains. We believe that a comprehensive theory of cognition requires a solid understanding of these representational formats and their functional roles within and across different domains of cognition, the developmental trajectory of these representational formats, and their role in dysfunctional behavior. Here we sketch such an overarching perspective that brings together research from diverse subdisciplines of psychology on modal and amodal representational formats so as to unravel their functional principles and their interactions.

Key words: modal and amodal cognition, mental representations, perception, action, cognitive control, language, emotion, development, dysfunction

It often does more harm than good to force definitions on things we don't understand. Besides, only in logic and mathematics do definitions ever capture concepts perfectly. The things we deal with in practical life are usually too complicated to be represented by neat, compact expressions. Especially when it comes to understand minds, we still know so little that we can't be sure our ideas about psychology are even aimed in the right directions. In any case, one must not mistake defining things for knowing what they are.

(Minsky, 1988, p. 39)

Modal and Amodal Cognition: An Overarching Principle in Various Domains of Psychology

How humans mentally represent information is a fundamental issue within psychology and beyond. Not surprisingly, most theories about human cognition involve representational assumptions, at least implicitly. Depending on the domain of investigation, different types of mental representations are typically in the foreground. In research on thinking, memory, or language processing, the traditional assumption is that properties, objects, situations, and events are captured through symbolic representations (e.g., Evans et al., 1993; Fodor, 1975; Kintsch, 1998; Pylyshyn, 1984; Reed, 2016; Smith & Medin, 1981; Tulving, 1972). These symbolic representations do not resemble a specific state of affairs as it stands, but rather abstract from it, leaving out irrelevant details. These abstract representations allow for the categorization of the things they represent (dog vs. cats). For instance, the meaning representation of a word such as "dog" must somehow encompass features of very different types of dogs and can thus be considered an abstract representation. In addition, symbolic representations are usually considered to be independent of the characteristics of any particular sensory modality. In other words, although many of these representations emerge from sensory experiences, these experiences are no longer part of the resulting representations. For example, although the meaning of the word "melody" mainly will refer to auditory features, the representation of this meaning within the mental lexicon will no longer encompass a specific auditory experience because it is more abstract than any particular experience. Likewise, although the word "stain" mainly refers to visual features, its symbolic meaning representation will itself be abstracted from visual experience. It is thus reasonable to assume that these two symbolic representations -- for "melody" and "stain" – share a common format, despite them both referring to entities that are typically perceived via different senses. Accordingly, these symbolic meaning representations can be considered to be modality-unspecific.

By contrast, in research on perception, it is often assumed that representations are modality-specific and resemble the entity being represented. For instance, when perceiving a dog, humans appear to create a rather specific representation that preserves many of the properties of the particular dog being perceived. In this sense, the representation is concrete rather than abstract. From this perspective, perceptual representations can be seen as being inherently different, depending on whether the represented entity is mainly characterized by auditory, visual, olfactory, or other sensory features. Accordingly, these representations can be considered to be modality-specific. This is also a core assumption in various theories on imagery, which suggest that mental representations are concrete and modality-specific (e.g., Kosslyn, 1980; but see Pylyshyn, 1981, and also Pitt, 2013) and thus are quasi-perceptual (Ward et al., 2019).

However, researchers in most domains of cognitive psychology nowadays do not assume that all mental representations are of one exclusive type. For instance, in research on conceptual knowledge (for an overview, see Murphy, 2002, and Pecher, 2013), hybrid forms of mental representations are explicitly discussed. For example, a hybrid representation of the concept 'dog' could consist of a symbolic component listing typical attributes of dogs and also a component with experiential traces that stem from sensory experiences encountered in the past. Finally, it is worth noting that the two representational formats described above are unlikely to constitute a dichotomy in a strict sense. Instead, they may represent the endpoints of a continuum that ranges from modality-specific to abstract symbolic representations (see Figure 1; Meteyard et al., 2012; see also Gentner & Asmuth, 2019).

In summary, questions concerning the nature of mental representations are central to virtually all domains within cognitive psychology, and different types of mental representations are explicitly discussed in many of these domains. Nonetheless, an overarching analysis of representational issues, particularly concerning various types of representations, is to the best of our knowledge, not yet available. Consequently, it seems that cognitive psychology currently lacks a comprehensive theoretical account of the functions and interactions of different representational formats, which thus remain poorly understood. Needless to say, it follows that the same can be said of the domains of application, developmental trajectories, and possible malfunctions of these representational formats. Moreover, computationaly it is something of a given that the nature of a cognitive process will depend on the format of the representation it operates on (Bröker & Ramscar, 2020); as is the reverse, namely that particular processes might call for particular representational formats (e.g., putative combinatoric processes in language might require more abstract proposition-like representations, whereas processes utilized for immediate action might require very detailed representations in absolute metrics (e.g., Ganel & Goodale, 2003). Thus, a comprehensive understanding of cognitive processes also would also appear to require a better understanding of representational format.

We suggest that one goal of current research in cognitive psychology research should be to better understand representational issues in cognition. We consider it theoretically fruitful to assess whether it is possible to integrate the various representational formats from different subfields of cognitive psychology (e.g., propositional representations vs. mental models in research on spatial reasoning; prototypes vs. exemplars in research on conceptual knowledge; cf. Murphy, 2016). We would also suggest that it is worthwhile to investigate whether all representational formats can be located on one continuum from concrete to abstract. Such a research endeavor would not only allow parsimonious explanations of the respective phenomena but also allow for theoretical relationships between the different subfields of psychology to be uncovered, paving the way for a more general theory of human cognition.

One factor that complicates this endeavor is that a wealth of different terms are used to refer to the respective representational distinctions: *concrete* vs. *abstract* (Reed, 2016; Snodgrass, 2006), *symbolic* vs. *analog* (Dehaene et al., 1998; Furman & Rubinsten, 2012), *propositional* vs. *analog* (Johnson-Laird, 1983; Zimmer, 2006), *digital* vs. *analog* (Dretske, 1981; Katz, 2008), *perception-based* vs. *meaning-based (*Anderson, 1995*)*, *descriptive* vs. *perceptual* (Newen & Marchi, 2016), *modality-specific* vs. *modality-unspecific* (Vaina, 1984), *modality-specific* vs. *supramodal* (Binder & Desai, 2011; Kiefer & Pulvermüller, 2012), *perspective-specific* vs. *perspective-flexible* (Brunyé et al., 2008), to name just a few. One pair of terms that recently gained much attention in research on cognitive psychology is the opposition between *modal* and *amodal* representations (Anderson, 2009). In the following, we will base our considerations on these terms in the following way (see Figure 2).

Modal representations are fundamentally experiential in nature and are therefore rather concrete. The structure of these representations preserves structural aspects of how we experience the world: that is, mappings between the world on the one hand, and representations of it on the other, are isomorphic. Sensory representations in perception that rely on prothetic continua[1] (e.g., intensity) or involve mental images are classical examples of modal representations. As these examples suggest, modal representations can be relatively simple (e.g., representing one particular value of an attribute dimension) or highly complex (e.g., representing a rich image of a multi-faceted situation). Moreover, modal representations need not necessarily concern only one sensory modality, but may draw on several different modalities (for instance, by means of cue integration, e.g., Ernst & Banks, 2002). Information from various modalities may be associated in a modal representation (e.g., the smell and the sound of a dog), but, importantly, in a modal representation, there is no representational component that combines information in an abstract, modality-unspecific way. Instead, modal representations either concern only one modality or encompass several modality-specific representations (for one idea of how the individual modality-specific representations can be bound together, see the convergence zone framework proposed by Damasio, 1989). Modal representations are often also considered to be holistic rather than compositional (but see Barsalou et al., 2003).

Amodal representations, by contrast, encompass an abstract description of the state of affairs they represent. Their structure is different from the structure of the things they represent. Amodal representations may capture information from one or more modalities, but these representations themselves are modality-unspecific. Feature-based word meaning representations, semantic networks, schemata, and frames are examples of amodal representations. Propositional representations constitute another typical example. These representations are held to be symbolic codes emerging from combining elementary building blocks of meaning. These representations can be combined or "composed" into more complex propositional representations in much the same way words are combined into sentences (Frege, 1892). Thus, like language, propositional representations are held to be compositional. In this sense, propositional representations are often considered to be linguistic representations and are usually supposed to be the language of thought (Fodor, 2008; Pinker, 1999). Like modal representations, amodal representations can be simple (e.g., capturing only a single attribute or entity) or highly complex (e.g., capturing a series of events and situations interconnected by causal relations and involving many different objects and attributes). Although propositional representations are certainly a prime example of amodal representations, amodal representations need not necessarily be language-like. For instance, a representation of an object in terms of elementary geons (cf. the recognition-by-components theory of Biederman, 1987), as opposed to several viewpoint-specific holistic object representations (cf. Tarr & Bülthoff, 1995), is non-linguistic but shares

[1]Physical dimensions (e.g., sound pressure) that produce experiences (e.g., loudness), which allow quantitative judgments (e.g., “louder than”) are regarded to belong to the *prothetic* domain. By contrast, dimensions (e.g., the wavelength of visible light) that produce experiences (e.g., color) that allow qualitative judgments (e.g., “this apple is green but not red”) are considered phenomena belonging to the *metathetic* domain (Stevens, 1957).

several aspects of amodal representations (e.g., a finite set of basic components, compositional structure, view-point invariance). Thus, geon theory is closer to the amodal end of the modal-amodal continuum than, for instance, a visual image of an object (see Figure 3). In addition, although proposals for amodal representations with a compositional structure seem particularly suited to accounting for meaning representations in language and other higher-level cognitive processes (such as reasoning or problem-solving), they have also been postulated in other domains of cognition, such as in action planning (e.g., Glover, 2004).

The distinction between modal and amodal representation applies not only to information input but also to action. For example, a motor plan can be specific to a particular muscle group or a limb, which would be a modal representation of a concrete action (e.g., pointing with the right index finger to a target object). This notion resembles the motor plans suggested by Keele (1968). However, others like Schmidt (1975; see also Rosenbaum, 1980) assume that each amodal motor program is represented as a schema. For example, such a schema would allow one to produce one's signature even with different effectors (e.g., the fingers when signing a check or the whole arm when writing the same signature much larger on a blackboard; see Liu et al., 2020, for recent neuropsychological evidence for effector-independent action representations).

Our distinction between modal and amodal representations is largely consistent with the instance level of Reed's taxonomy of abstraction (Reed, 2016), according to which the terms modal vs. amodal refer to representations of instances, such as the representation of a particular dog. A modal representation is a concrete representation that resembles an earlier sensory experience that can be activated without external stimulation. By contrast, amodal representations are abstract, and under some accounts extend to including propositional representations of meaning, in which a proposition is anything that can be asserted or denied using words (e.g., my dog smells bad) and can be determined to be true or false (Reed, 2016). Therefore, according to Reed, amodal representations can be evaluated for their truth value and modal representations for their similarity.

Above, we specified several attribute dimensions on which modal and amodal representations may differ. The question arises whether these dimensions are correlated and whether a particular dimension is more prominent than others. We assume that two dimensions are particularly crucial and thus define our framework. One dimension runs from structure-preserving to structure-agnostic, or in other words, from analog to symbolic. The other dimension runs from modality-specific to modality-general, whereby modality here refers to perceptual modality or response modality (see Figure 4). We believe that virtually all representational formats are located in this two-dimensional plane. We come back to this point below.

The considerations above reveal how the psychological reality of different types of representational formats has been largely accepted in cognitive psychology (albeit this acceptance is typically implicit). It is further notable that this view has recently even found its way into related disciplines such as philosophy of mind (e.g., Camp, 2009; Butterfill & Corrado, 2014; Wajnerman Paz, 2018) and cognitive neuroscience (e.g., Leshinskaya & Caramazza, 2016, see also Kuhnke et al., 2022). Yet it remains the case that the relationship between these formats and their functions for cognition is intensively debated, especially in the literature on the human conceptual system (e.g., Barsalou, 2016). In fact, the theoretical accounts range from a strong view of grounded cognition, which assumes that concepts are modal representations (e.g., Glenberg

& Gallese, 2012) to a view that assumes that concepts are represented in an amodal format (e.g., Machery, 2016; Mahon, 2015). However, most accounts consider a hybrid view according to which the cognitive system involves both representational formats (e.g., Binder & Desai, 2011; Dove, 2009; Kiefer & Pulvermüller, 2012; Zwaan, 2014).

The fragmented debate about the role and functions of modal and amodal representations, along with the many implicit assumptions many theories make about them, calls for an explicit, overarching approach that addresses this issue from different angles within psychology (i.e., perception, action, learning, emotion, language, and thought) and brings together the various theoretical ideas about the interaction and function of amodal and modal representations. In order to arrive at a comprehensive understanding of cognition, these different perspectives on the distinction between modal and amodal representations need to be integrated. A synthesis is required beyond studies within isolated, individual subfields of cognition. Crucially, such an overarching approach would also allow us to distinguish between domain-specific and domain-general aspects of the cognitive processes that operate on modal and amodal representation. Accordingly, we consider it of central relevance for research in cognitive psychology to investigate the functions of modal and amodal representations for human cognition and to analyze their interplay within the subfields of psychology.

In what follows, we will briefly sketch the questions arising in the different subfields of psychology concerning the functions and interactions of modal and amodal representations. We start with the subfield of perception, and in subsequent sections discuss the topics of action, cognitive control, learning, emotion, language, thought, development and dysfunction.

Perception

In research on perception, a recurrent topic is whether human perception of the outside world is, or is not, holistic. We will start with an overview of this debate that is closely related to our distinction between modal and amodal cognition. We will then go on to address the representational questions arising for sensorimotor and crossmodal processes and speculate about some factors that might determine which representational formats are used in perception, and under which condition.

Philosophers and psychologists have long speculated about how people form their experiences. A core question is how our perception of the outside world comes about. Extreme positions can be distinguished and classified within the framework mentioned above. It is often assumed that perception comprises elementary units which are assembled or synthesized, a general assumption consistent with the amodal view. One appealing aspect of this view is that it is compatible with a more widespread research strategy, that of decomposing complex systems into their elements, thereby decreasing their complexity, and making research appear more tractable. The underlying assumption here is that the elements identified are functionally independent, and thus can be studied in isolation (Bechtel & Richardson 2010). This research strategy of decomposing complex systems is evident in cognitive research in general but particularly prominent in the study of perception.[2]

For example, the philosopher John Locke (1632-1704) assumed that complex ideas (e.g., the idea of an apple) are composed of impressions (i.e., sensations, e.g., the features "red" and "round" and "juicy") that emerge from the senses (see Hergenhan, 2009). Furthermore, he assumed that these atoms could be combined in an almost infinite number of ways. A similar idea was held by Wilhelm Wundt (1832-1920), who believed that perception is a passive process fed by many simultaneously active elementary primitives. Wundt's elementism, however, was later challenged by Gestalt psychologists, who coined the well-known phrase "The whole is more than the sum of the parts" and thus tried to understand perception within a holistic framework, a position that is consistent with the modal view. Gestalt psychologists therefore focused on wholes (Gestalten) rather than on parts (elements, atoms).

This basic distinction between holistic and compositional representation is also found in more recent theories of perception. For example, Neisser (1967) in his seminal book *Cognitive Psychology*, elaborated on the distinction between "template-matching" and "feature-analyses" to understand human pattern recognition, which at the time was inspired by the burgeoning field of artificial intelligence. Unlike Gestalt psychologists, who never moved away from the concept of "template-matching" to understand how humans recognize a letter such as A, pioneers of machine perception such as Selfridge (1959) assumed that features are first identified from a pattern resulting in a feature list, which is then synthesized in a subsequent hierarchical process. The basic idea of feature analysis and subsequent synthesis is also found in McClelland and Rumelhart's (1981) interactive activation model or in the Geon theory mentioned earlier (Biederman, 1987). Moreover, psychophysicists have assumed that even low-level processes assemble many spatial frequency codes (i.e., spatial "atoms", Campbell & Robson, 1968) to account for fundamental phenomena like the perception of Mach band patterns. Likewise, Miller and Ulrich (2004) assumed that basic perceptual processes involve many grains (i.e., temporal "atoms") to account for various basic findings on reaction time. By contrast, viewpoint-specific theories (e.g., Ullman, 1989) reinforce the notion of "template-matching." They proceed from the core assumption that each object is represented in memory by a single two-dimensional canonical view to which objects in the three-dimensional view are aligned to for recognition.

Although these two global approaches to object perception (template-matching vs. feature-analysis) are incompatible, each approach can explain certain phenomena that the other cannot (Palmer, 1999). Of course, on the flipside, each approach has its own problems. Similar to the case in physics (e.g., concerning the fundamentally different particle vs. wave-theory of light), traditionally no theory has united both approaches in the psychology of perception.[3] Rather, the field has traditionally been characterized by the existence of a contrasting framework of fundamentally different theories. However, some recent suggestions may help resolve the debate between template-matching versus feature-analysis. For example, the theory of predictive coding (Clark, 2013; Friston, 2010; Rao & Ballard, 1999) envisions perception as a processing hierarchy in

[2]The philosopher Immanuel Kant (1724-1804), however, claimed that the mind is not decomposable and therefore, among other things, psychology can never become a science. Early psychologists like Wilhelm Wundt, however, challenged his view.

[3]From the point of view of optimal encoding, Barlow (1972, p. 371) suggested that “the sensory system is organized to achieve as complete a representation of the sensory stimulus as possible with the minimum number of active neurons” which led the way to combining the advantages of feature and template-based approaches into the theory of “sparse coding” (Olshausen & Field 1996).

which bottom-up (sensory processing) and top-down processing (expectations) interact, an assumption that was also central for McClelland and Rumelhart (1981) in explaining the so-called word superiority effect.[4] From a predictive coding perspective, perception is based on a dynamic prediction system that generates downward expectations about sensory input and updates these expectations to minimize the error associated with subsequent predictions. Within this hierarchy of top-down and bottom-up processing, the knowledge used for making predictions is stored at several processing levels. Knowledge stored at higher levels represents abstract information that does not contain specific features. However, moving downward to the other end of this hierarchy, these representations become increasingly specific in their details. Thus, applying the terminology we outlined earlier, the knowledge represented within this hierarchical structure, from its bottom to its top, can be regarded as a modal-to-amodal continuum (cf. Gilead et al., 2020; Hutchinson & Barrett, 2019; Michel, 2020).[5]

The essential function of perception is to allow organisms to interact with the environment. From this perspective it is, understandable why many researchers have focused on the interaction between perception and motor function. Although predictive coding also seeks to understand this interaction (see Hutchinson & Barrett, 2019), several researchers have focused solely on sensor-motor interactions. For example, Wolfgang Prinz has argued that perception and motor processes rely on the same representation (i.e., "*common coding";* Prinz, 1990, 1997). Other researchers argue that conscious perception and sensorimotor processes are based on different processes and representations. For example, within the perception-action model (Goodale & Milner, 2018; Milner & Goodale, 1995), it is assumed that object perception and sensorimotor processing involve different cortical streams (the ventral *vision-for-perception* and the dorsal *vision-for-action* stream). Further, it has been suggested that the representations associated with these two streams employ different formats (e.g., Ganel & Goodale, 2003). The ventral stream is thought to depend on holistic processing in which single dimensions within an object cannot be isolated. By contrast, the dorsal stream is thought to be able to separate relevant dimensions of a visual scene for guiding actions. In short, Ganel and Goodale have argued that "vision for action operates in an analytical rather than a holistic fashion" (p. 667). However, recent studies raise questions about the evidence that has been used to argue for two different representational formats in these two processing streams. We address this in more detail in the section “Action”.

Typically, various sensory modalities (i.e., audition, vision, smell, and touch) contribute to perceptual experience because each sense processes different physical properties of the external world. Despite this, people can also compare information across modalities. For instance, people can compare the duration of a tone to the duration of light and vice versa (e.g., Bratzke & Ulrich, 2019; Ellinghaus et al., 2021). They can even compare the brightness of a visual stimulus to the loudness of a tone and vice versa (Heller, 2021; Stevens & Marks, 1965). This aspect of crossmodal processing has been extensively studied in psychophysics, but the cognitive mechanisms underlying this ability are not well understood. A typical assumption is that crossmodal matching operates on an amodal representation, such as a common intensity scale in intensity matching (Heller, 2021). However, even the representational format of such a fundamental

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[4]This effect describes the phenomenon that a letter is easier to recognize within words than in isolation.
[5]As noted by Hutchinson and Barrett (2019), the idea of top-down representations is not new. However, there is increasing research that tests this core idea embodied in this predictive coding framework.

perceptual quantity is not yet well understood (i.e., how intensity is coded and compared intra- and crossmodally).

With regards to time perception, the number of pulses registered by an internal timing mechanism during a time interval represents the psychological duration of this interval (cf. Bratzke & Ulrich, 2019; Ulrich et al., 2022). Because this mechanism is not modality-specific, it is possible to compare a tone's duration with a light's duration (for neurophysiological evidence see Tsao et al. 2022). Nevertheless, intramodal timing (e.g., comparing the duration of two successive tones) is typically easier than crossmodal timing, a finding that suggests that modality-specific timing also plays a crucial role in time perception. Accordingly, investigating the cognitive mechanisms underlying cross- and intramodal perceptual processes might constitute an essential step toward a better understanding of the interplay between modal and amodal representations in perception.

Research on perception, especially visual perception, usually focuses on stationary stimulus configurations. However, the visual input that humans typically encounter is temporally structured on multiple scales. Humans must deal with dynamic and transient information representing subsequent events. One prominent theoretical account of this dynamic perceptual process is the event segmentation theory (Zacks, 2020; Zacks et al., 2007). The theory assumes that an interplay of bottom-up and top-down processes guides perception of dynamic events. The continuous incoming stream of sensory information is segmented into meaningful segments at points of change (Zacks et al., 2009), leading to a structured perceptual representation of each event in working memory, the so-called “working event model”. Although working event models are still close to the sensory input, they already constitute a form of abstraction as they are internally structured and interconnected. Constructing working event models is guided by abstract knowledge in long-term memory -- more specifically by amodal event models and abstract event schemata. Thus, from the perpective we have laid out above, event perception in this theory can be characterized as an interplay of modal and amodal cognitive processes at different levels of abstraction.

Interestingly, and in line with the view that event segmentation is a vital process in event perception, possibly resulting in abstraction, it has been shown that while memory performance is better for excerpts with than without an event boundary (Huff et al., 2014, 2017; Newtson & Engquist, 1976), dual-task performance is worse at event boundaries. Also, the processing of sensory information seems to be increased at event boundaries compared to during an event (e.g., Huff et al., 2012; Zacks et al., 2020). These findings suggest that elaborate updating processes take place at event boundaries (Huff et al., 2012), possibly focusing particularly on sensory information processing. After perceiving an event boundary, however, participants’ memory for details of the sensory information declines. For instance, they are less likely to correctly indicate whether a particular probe is horizontally flipped compared to the original (Gernsbacher, 1985). This finding is in line with the view that updating involves the abstraction of information. However, as of yet, it is not fully understood how to best describe the processing that takes place at event boundaries. However, it seems clear that event perception is a prime example of a cognitive task in which the interplay of modal and amodal representations plays a key role. Future research is needed to determine precisely how the respective abstraction processes function, and how modal and amodal representations work hand in hand during event perception.

The representational formats associated with various aspects of perception may also depend on the specific contextual setting for other tasks, such as object recognition. For example, objects close to an individual's personal space may be represented in a more modal format when they become more relevant for actions. By contrast, objects outside their personal space may be represented in an amodal format that only includes a few categorical features of an object. This idea is reminiscent of theories of motor control that distinguish between an early phase of action planning and a later phase of action control that works on more modal and amodal representations respectively (Elliott et al., 2001; Fuster, 2001; Hommel et al. 2001; Jeannerod, 1986; Milner & Goodale, 1995; Thomaschke et al., 2012; Woodworth, 1899). In the same fashion, the Construal-Level Theory (e.g., Trope & Liberman, 2010) postulates an association between the psychological distance to a specific target entity and the level of abstractness at which it is construed (see also Sections on Language and Thinking below).

In conclusion, at their core psychological theories of perceptual processes have always revolved around representational formats. For this reason, the theoretical relevance of representational formats for understanding cognitive processes becomes particularly prominent in the study of perception. However, contemporary theories of perception have abandoned the traditional dichotomy between modal and amodal representations in favor of a hierarchical view. Here, the assumption is that representations become more abstract (i.e., move from modal to amodal) at higher levels of the processing hierarchy. For example, this view suggests that at higher levels of processing, people can compare information (e.g., stimulus intensity and stimulation duration) across sensory modalities. Moreover, since a primary function of perception is providing guidance for an organism in its environment, the question arises of how perceptual and motor processes interact with each other, and which representational formats are employed in this interaction. Finally, the environment is not static but changes dynamically. It is thus important that the organism be able to meaningfully organize environmental events. Again, the type of representation used in achieving this are theoretically important for understanding of how the cognitive system segments perceptual input.

Action

As mentioned earlier, it is often assumed that actions proceed in two subsequent phases: First, relatively abstract aspects of the action need to be decided, such as which effector to use and which type of action to perform. Traditionally, this phase has been called the *planning* phase of the action. Second, concrete details of the selected action have to be specified as, for example, how much force the muscles have to exert to achieve a desired trajectory of the effector or to grip an object, often referred to as the *control* phase (see also Flanagan, & Wing, 1997).

The gradient from relatively abstract planning to fairly concrete control suggests that the internal representations guiding these phases might range from more abstract to more concrete, with the latter including a specific response modality (e.g., left hand). Such a view is in line with the most influential current theories on action control, and ample evidence has been provided to support such a distinction (e.g., Ballard et al., 1997; Bridgeman, 1997; Glover, 2004; Goodale, 2020; Hommel et al., 2001; Jeannerod, 1994; Milner & Goodale, 1995; Thomaschke et al., 2012; Woodworth, 1899). However, a closer look shows that the evidence supporting the idea of a transition from amodal planning to modal control is not as clear-cut as is often assumed. For example, the theory of event coding (Hommel et al., 2001; see also Janczyk et al., 2022a) and the perception-action model (Milner & Goodale, 1995) currently dominate research on action planning and control. These theories focus on different aspects of actions and usually implicitly presume that representations of different formats underlie them: The theory of event coding is mainly concerned with planning and assumes the underlying representation is amodal and abstracted from modality-specific information. The perception-action model assumes a dedicated sub-system (the dorsal *vision-for-action* stream) that is mainly concerned with controlling actions and operates on modal representations, at least when executing well-practiced skilled actions. Unskilled actions, by contrast, are assumed to be guided by the ventral vision-for-perception stream.

However, while a good amount of evidence supports these postulates, recent results appear to contradict any straightforward distinction between amodal planning and modal control. For example, some studies have indicated that representations of duration and color, which are presumably modal, are involved in action planning (e.g., Koch & Kunde, 2002; Kunde, 2003), thereby challenging the idea of (purely) amodal planning. Likelwise, the idea that action planning is based on abstract, amodal representations is not fully compatible with recent studies targeting generalization in response-effect learning and compatibility (see Eichfelder et al., 2022; Koch et al., 2021; but see Hommel et al., 2003). Other studies have indicated that the execution of unskilled actions is similar to the execution of skilled actions (in terms of Garner interference; see Eloka et al., 2015; Janczyk et al., 2010), in contrast to what is assumed by the perception-action model (e.g., Ganel & Goodale, 2003), further challenging the idea of a qualitative difference between modal (i.e., here: analytical) control of skilled actions and amodal (i.e., here: holistic) control of unskilled actions. In general, the evidence suggests that the idea that perceptual tasks are influenced by Garner interference whereas motor control tasks are not is much less well-supported than was initially thought (Bhatia et al., 2022a).

Other studies also undermine the assumption that two fundamentally different types of representations are involved in perception and action control (see the Section on Perception). For instance, it has been claimed that certain visual illusions that are present in perception are not present in grasping (e.g., the Ebbinghaus-Illusion; Aglioti et al., 1995). However, there is good evidence that the Ebbinghaus-Illusion does in fact affect grasping to a similar degree (Franz & Gegenfurtner, 2008; for a multi-lab replication study, see Kopiske et al., 2016). Finally, many studies have claimed to show evidence that while perception follows Weber's law, grasping does not (e.g., Ganel et al., 2008). However, a recent evaluation of the literature by Bhatia and colleagues (2022b) calls this claim into question, arguing that when analyses are corrected for methodological problems, grasping follows Weber's law just as perception does,. In conclusion, there are a number of empirical findings that call into question whether it really is the case that early phases of action planning are based on more amodal representations and later phases of action control on more modal representations. Accordingly, further research is needed to understand the different functions of modal and amodal representations, along with their possible interactions in action planning and execution, especially in relation to the time course of actions themselves. For instance, it is possible that secondary tasks involving more amodal representations influence particular aspects of early action phases, whereas secondary tasks involving more modal representations influence particular aspects of later action phases.

Cognitive Control

One of the most fundamental principles in cognitive psychology is the distinction between automatic or controlled processes (e.g., Cohen et al., 1990; Kahneman & Treisman, 1984; Schneider & Shiffrin, 1977; Posner & Snyder, 1975; for a review, see Cohen, 2017). Automatic processes, which are typically thought of as involving overlearned stimulus-response associations, require little effort and are fast. Conversely, controlled processes allow humans to flexibly adapt their behavior to the specifics of situations, maintain behavioral goals, and plan long-term goals. However, since these processes involve deliberation, they require effort and are slow. Thus, cognitive control (or executive control) is a vital component of the human cognitive system, and two qualitative control modes may be distinguished (Braver, 2012). Proactive control actively maintains goal-directed information to optimize the cognitive system for a forthcoming, demanding event. Reactive control often shields the processing of goal-relevant information from goal-irrelevant information, as in the Stroop task, where participants experience interference from a word's meaning when they are asked to report the competing color of the ink it is printed in. Whereas proactive control leads to long-term behavior adjustments through top-down biases, reactive control is a transient process triggered by bottom-up processes that interfere with goal-directed behavior.

Representational issues are crucial for research on cognitive control. In line with the predictive coding view of cognition (e.g., Gilead et al., 2020), it has been suggested that cognitive control is hierarchically structured, operating on concrete stimulus-response associations at the lower end to more and more abstract and domain-general mechanisms and representations at the higher end of the hierarchy (Badre & Nee, 2018). For example, the conflict monitoring hypothesis (Botvinick et al. 2001) assumes that an abstract signal (i.e., Hopfield energy) is used to covey information about conflicting responses developing at lower processing levels to higher processing levels that serve to monitor for potential conflicts. When conflicting response are detected, cognitive control mechanisms that serve to increase the influence of task-relevant information (e.g., the ink color of a word in the Stroop task) and inhibit the influence of task-irrelevant information (e.g., word's meaning) are engaged, helping to resolve the conflict and achieve an agent's goals. These control mechanisms have recently been implemented in the diffusion model of conflict tasks (Ulrich et al., 2015; Mackenzie & Dudschig, 2021) to account for various conflict adaptation effects (Koob et al., 2022). More recent versions of the conflict monitoring theory even assume that the monitoring process does not register conflict but detects the affective response (i.e., negative valence, increased arousal) caused by conflict (Dignath et al., 2020, for a review). Thus, on this latter account the relevant representations are assumed to be more modal. By contrast to the conflict monitoring hypothesis, episodic memory or binding accounts of cognitive control (e.g., Hommel et al., 2004) assume that reactive conflict adaptations result from the processes operating on specific stimulus-response associations (Dignath et al., 2019; Frings et al., 2020). Accordingly, these theories predict adaptations specific to individual stimulus-response associations.

There are two main experimental approaches to studying conflict adaptation processes (e.g., Bausenhart et al., 2021; Dudschig, 2022b), resulting in either local or global adaptations of control. The local approach investigates changes of control on a trial-by-trial basis. Specifically, if an incongruency (i.e., conflict) is detected in one trial, this results in the upregulation of control. Thus, in the following trial, the influence of task-irrelevant information is reduced (see also Botvinick et al., 2001), resulting in a reduced conflict effect. The opposite holds for trials following congruent trials (i.e., non-conflict trials). This sequential congruency effect (or Gratton effect; Gratton et al., 1992; Stürmer et al., 2002) is generally assumed to reflect conflict adaptation after an incongruent trial. The second approach focuses on global instead of local changes in conflict adaptation that may mainly result from proactive control. Specifically, this approach varies the relative frequency of congruent and incongruent trials within a block, and the congruency effects are generally relatively small when the proportion of incongruent trials is high (for a review, see Bugg, 2017).

Further, and most importantly for the distinction between modal and amodal cognition, several studies have examined whether these global and local conflict adaptation effects are domain-specific or domain-general. For example, will the Stroop effect be reduced if the proportion of incongruent trials of a different conflict task is increased within the same block of trials ? Some studies have shown that domain-general adaptation occurs across very different tasks within basic reaction time paradigms (e.g., Kan et al., 2013) and eye-tracking paradigms (e.g., Hsu et al., 2022). However, recent attempts to directly replicate these original findings in the reaction time domain have failed (Aczel et al., 2021; Dudschig, 2022a). Moreover, further studies with slightly modified approaches in the reaction time domain do not show evidence for domain-general conflict adjustments but rather support the view that reactive control operates on stimulus-specific modal representations (Bausenhart et al., 2021) or is task-specific (Simi et al. 2022). However, it could also be the case that reaction times as measured by button responses are insensitive to minimal effects of domain-general adaptation and that other behavioral methods like ERPs or mouse-tracking measures are better suited to uncover these effects (Potamianou & Bryce, 2022).

For studying proactive control, other paradigms that provide information about the likelihood of a congruent or incongruent trial have proven to be especially useful (Gratton et al., 1992). For instance, when providing advance information about the congruency of the forthcoming trial, shorter RTs are observed in trials with a valid cue compared to an invalid one. However, although this result pattern has been observed (Gratton et al., 1992), Wühr and Kunde (2008) argue that it remains unclear whether participants adjusted attentional settings or switched to different processing strategies depending on the cue. There is some evidence for domain-general adjustments with this method (Bugg et al., 2016; Jiménez et al., 2021, but overall, not enough research has directly addressed these issues for firm conclusions to be drawn. Thus, it seems unclear whether proactive control routinely leads to domain-general adaptations as predicted based on the idea that proactive control mechanisms are based on amodal processes and representations.

In conclusion, representational issues are of central importance for cognitive control theories. For local conflict adaptation, current evidence suggests that adaptation is based on more modal processes and representations. Proactive control, on the other hand, is probably based on more amodal processes and representations. However, future research is needed to corroborate these representational assumptions in research on cognitive control.

Learning

One of the most basic types of learning is that of learning to represent associations between objects and events (and their attributes) in the world. This process involves learning to discriminate informative from uninformative environmental relationships by means of error-driven processes (Rescorla, 1988; see also Ramscar et al., 2013; Dayan & Berridge, 2014). The notion of associations plays a central role in several domains of cognitive psychology, such as in research on concept learning and semantic memory (e.g., Kelter & Kaup, 2012; Love et al., 2004), word learning (e.g., Ramscar et al., 2013) and conditioning (e.g., De Houwer et al., 2001; Hütter, 2022). However, although the term "association" has a long history, going back as far as Aristotle and Locke (see Strube, 1984), and is used to explain many phenomena in psychology, it is unclear whether associative learning involves the same types of representations in all cases. In particular, it is unclear to what degree associative learning involves abstraction from individual experiences and, accordingly, the degree to which it involves the forming of relationships between amodal rather than modal representations is also unclear.In addition, questions about the degree to which abstraction processes are involved in associative learning across defferent domains, and whether they differ between them, remain largely unexplored .

One way to study these questions is to investigate the factors that trigger abstraction processes and the creation of amodal representations during associative learning. It has been suggested that abstraction is triggered by variability in the exemplars on both sides of the relationship (e.g., Ramscar et al., 2010; Raviv et al., 2022). For instance, if a person sees many different female faces and these are always combined with one of several pleasant images, then this might ultimately trigger the learning of an association between two amodal representations ('female' – 'positive valence; Hütter et al., 2014). By contrast, if the person experiences only one specific exemplar on both sides of the relationship, then this is more likely to give rise to the learning of an association between two concrete modal representations (e.g., a visual representation of the face and a concrete positive image). Differences concerning the variability of the exemplars on both sides of the target relationship might explain differences in the stability of the learned associations as they are typically observed in classical vs. evaluative conditioning (Hofmann et al., 2010). A recent study directly manipulating the variability of the exemplars presented as CSs in an evaluative conditioning paradigm showed the hypothesized relationship between variability and abstraction (Reichmann et al., 2022).

One parsimonious explanation of why variability in the CS leads to abstraction suggests itself when considering that associative learning can be characterized as an error-driven process that serves to reduce learner's uncertainty about the environment (Rescorla, 1968; Kiefer & Hohwy, 2019). A critical part of the learning process is cue competition, by which the values of reliable cues are reinforced, and unreliable cues devalued during learning (Rescorla, 1988; see also Siegel & Allan, 1996; Miller et al., 1995). As a result, cues that produce little or no prediction error for an outcome will become positively valued at the expense of cues that lead to prediction errors, which become negatively valued (Ramscar, 2021). The result of cue competition is thus discrimination between relevant and irrelevant features, which leads to representations becoming more abstract and amodal . Cue competition is possible in a situation in which a set of complex stimuli predict a set of discrete elements (i.e., when a large cue set is used to predict a smaller set of outcomes, as is the case when a person sees an object with all its features and then hears its label). By contrast, learning from stimuli that lack a rich cue structure hinders cue competition and thus inhibits discrimination learning. For instance, as is the case when a person hears a label and then sees the object it refers to with all its features. Consistent with this, it has been shown that learning to appropriately apply labels to objects is easier for participants when they are trained with a "Feature-Label" procedure compared to when they are trained with a "Label-Feature" procedure (Ramscar et al., 2010). One reason may be that the former leads learners to develop representations that depict the predictive relationships between features and labels, discarding information on non-diagnostic features (i.e., more abstract amodal representations; see also Apfelbaum & McMurray, 2017; Hoppe et al., 2020; Nixon, 2020; Vujovic et al., 2021). The latter may, by contrast, produce representations that provide a more detailed (modal) picture of the structure of the world (i.e., the actual cue probabilities). Thus, there seems to be a trade-off between complexity and discrimination in more abstract amodal representations which seems to be advantageous for labeling (Ramscar, 2013).

However, it is important to note that although Ramscar et al.'s (2010) results fit nicely with the view that participants' superior performance resulted from abstraction at the representational level, they do not show this directly. Future research is needed to determine whether learning is advantageous when conditions allow for cue-competition because these conditions lead learners to distort input representations towards abstract representations more than when conditions do not allow for cue competition, and whether these latter situations lead learners to retain more of the modal features of these input stimuli. If this prediction were to be born out in future research, the view that error-driven learning leads to a trade-off between complexity and discrimination could offer a unifying account of the results of studies of the effects of variability on learning and generalization seen across various domains (Raviv et al., 2022).

There may, of course, be other factors that trigger abstraction processes in associative learning. For instance, it has been shown that in concept learning, redundant linguistic labels facilitate the learning process (Lupyan et al., 2007). One reason may be that, as a results of their importance, linguistic labels serve to trigger abstraction processes merely by their presence. In addition, abstraction processes in associative learning might depend on the particular task at hand as well as on the mindset of the learner. It also seems conceivable that the involvement of abstraction processes differs throughout development. Although grounded cognition researchers often implicitly assume a modal-to-amodal trajectory, there is also evidence for amodal representations being available very early in development (e.g., Rugani et al., 2015; Walker et al., 2010; see also section Development). In our view, examining which types of representations are involved in associative learning under which conditions, and at which points during development, will play an important role in better understanding the functions and interplay of modal and amodal representations. Of course, the nature of the representations involved (modal vs. amodal) is also relevant for other forms of learning, such as procedural or motoric learning (e.g., Pashler & Baylis, 1991a, 1991b), and further investigation in these domains will constitute another fruitful direction of future research.

In conclusion, research into associative learning suggests that variability in the learning exemplars leads learners to build more abstract representations, focusing on the relevant and ignoring the irrelevant stimulus dimensions. Also, in concept learning, learners seem to gain from conditions that allow for cue competition and thus in principle provide the opportunity for the learning mechanisms to acquire more abstract amodal representations. However, until now it is not clear whether the gain in performance seen in studies examing this idea is actually due to abstraction processes taking place. Future research is necessary to confirm the presumed relationship between learning success and the format of the representations created. Further relevant questions for future research concern not only the domain specificity of abstraction processes, but also their developmental path.

Emotion

Emotions constitute a fundamental part of human experience, serving several essential functions: Emotions drive our actions, communicate relevant information about our internal states to our social surroundings, and guide our attention by informing us about relevant environmental changes. However, theoretical accounts of emotion differ significantly when it comes to the question of representational formats. Some scholars see emotions as an (amodal) memory unit in an associative network where these emotions enter into relationships with coincident events (Bower, 1981). On the other hand, grounded-cognition accounts of emotion postulate a purely modal representational format for emotions (Niedenthal et al., 2005). In contrast to these more extreme views, most accounts assume a hybrid view, acknowledging that emotions have both modal and amodal components. For instance, theories distinguish between ´hot´ and ´cold´ aspects of emotions (Metcalfe & Mischel, 1999), feelings and appraisals (Lazarus & Smith, 1988), motor and conceptual level (Leventhal & Scherer, 1987) or between affective and semantic valence (Itkes & Kron, 2019).

Interestingly, when an emotional stimulus is repeatedly encountered (i.e., emotional habituation, Bradley et al., 1993), modal components of emotions seem particularly attenuated. For instance, physiological responses related to valence and arousal are reduced (e.g., Codispoti et al., 2016), as well as behavioral responses (i.e., Jia et al., 2022) and self-reports (Itkes et al., 2017). Thus, emotional habituation might be a means to bias processing away from modal and towards more amodal representations in processing emotional stimuli. However, as far as we know, our understanding of such a representational shift during habituation is not well understood.

Another area in emotion research where representational issues seem relevant is the affective priming paradigm (Klauer & Musch, 2003). When participants judge the valence of a stimulus, they are faster and more accurate when the stimulus follows a prime of the same valence as compared to its opposite. Semantic-priming accounts assume that the priming effect comes about because the (amodal) valence of the prime pre-activates the (amodal) target valence and thus facilitates processing in congruent conditions. By contrast, explanations based on grounded cognition assume that affective priming effects reflect re-activations of experiences triggered by the respective stimuli used as primes and targets (e.g., Niedenthal et al. 2003). The latter type of account thus represents a more modal perspective of affective priming. However, little research has been conducted to determine the extent to which affective priming involves more modal or amodal emotional components (see Rohr & Wentura, 2022). For example, suppose the above considerations are correct and emotional habituation biases towards more amodal processing. In that case, studies examining the effect of habituation on affective priming might be highly informative concerning the psychological reality of the two different types of accounts of affective priming.

In conclusion, although emotions are often characterized by comprising two components one of which is more modal and the other more amodal, it is still unclear how these components interact or under which one or the other component takes the lead. Addressing these open issues will not only enhance our understanding of emotions and has also the potential to inform our theories of learning and cognitive control.

Language

According to traditional theories in cognitive psychology, the representations of meaning involved in language comprehension and production are amodal, and have a compositional structure (e.g., Kintsch, 1988; McKoon & Ratcliff, 1992; Reed, 2016). During comprehension, people presumably create a coherent network of propositions by identifying the propositions in a sentence or text and their interrelations in terms of argument overlap or rhetorical structure (Asher & Lascarides, 2003; Kintsch & Van Dijk, 1978). Moreover, comprehenders presumably infer particular propositions to fill potential coherence gaps in the linguistic input. Likewise, for language production, such a propositional representation is assumed to constitute the starting point of the production process (e.g., Levelt, 1989). However, grounded comprehension and production models have received more attention within the last two decades. These models assume that modal sensorimotor processes play an essential role in meaning representation during language processing (e.g., Barsalou, 1999; Glenberg & Gallese, 2012; Gleberg & Kaschak, 2002; Zwaan, 2004; for critical reviews, see Machery, 2007, 2010; Mahon & Caramazza, 2008).

Meaning representations in language processing are assumed to involve the re-activations of experiences with objects, events, and situations that the linguistic stimulus (sentence or text) refers to. However, so far, the evidence for this view is mixed. While there is evidence that modal representations are activated during language processing, their activation seems context-dependent (e.g., Lebois et al., 2015; and Yee & Thompson-Schill, 2016 for an overview). Also, it remains unclear whether they play a functional role in language processing (e.g., Ostarek & Huettig, 2019). Thus, it is conceivable that modal representations constitute a mere epiphenomenon, possibly a residual from language acquisition during which sensorimotor meaning representations might be functionally relevant. Alternatively, language comprehension and production might be better characterized by hybrid representations comprising modal and amodal components. This would explain why some studies reported strong evidence for the involvement of modal representations during language processing, whereas others do not (for an overview, see Kaup et al., 2016; Kaup & Ulrich, 2017; see also Schütt et al., 2022). Although the hybrid hypothesis has become popular in recent years (e.g., Binder & Desai, 2011; Dove, 2009, 2011; Wajnerman Paz, 2018; Zwaan 2014), a systematic investigation of the factors that influence which type of representation gains the upper hand during comprehension and production is still missing.

An important question for future research is to understand better the conditions under which modal and amodal meaning representations play a functional role in language processing. One important factor seems to be the level of processing required by the task; with the increasing likelihood of modal representations, the "deeper" the meaning of the linguistic stimulus has to be processed (e.g., Miller & Kaup, 2020). In addition, the amount of direct experiences that a comprehender has made with the described entities and situations determine the degree to which modal representations are involved in comprehension (e.g., Günther et al., 2020; Günther et al., 2022; Yee et al., 2013).

Also, as implied by the Construal-Level Theory, one relevant factor might be the psychological distance to the objects, situations, and events that the linguistic stimulus refers to (Trope & Liberman, 2010).

In line with this assumption, some recent studies have observed relationships between both temporal and spatial distance and abstractness leve (Bausenhart et al., 2022; Bausenhart et al., in prep a). More specifically, a series of experiments based on the implicit association test paradigm (IAT, Greenwald et al., 1998; see also Bar-Anan et al., 2006), revealed that response times in a task in which participants decided about the psychological distance a stimulus refers to (proximal vs. distal) or its abstractness (concrete vs. abstract) were influenced by the particular response key assignment in the task. Decisions were faster when distal entities were assigned the same key as abstract entities and proximal entities the same key as concrete entities, suggesting an association between abstractness and psychological distance. Interestingly, this association was observed both for temporal and spatial distance, but for temporal distance, the effects were much clearer when the distal time point to which the "now" (proximal) was compared was the future compared to when it was the past. One potential reason for this is that the future is not only distant but also uncertain, which according to construal-level theory should additionally increase the psychological distance besides temporal distance. Overall, these experiments show that abstraction level and temporal and spatial distance are cognitively related. However, in the domain of temporal distance, this association seems to be less straightforward and symmetrical than one might expect, which might reflect a potential moderating role of hypotheticality and uncertainty associated with future events.

Another series of experiments investigated how spatial distance modulates cognitive representations. Participants were presented with sentence-completion tasks based on a paradigm by Kaup, Scherer, and Ulrich (2021), to assess how distance primes the completion of an incomplete sentence. For example, participants saw an initial sentence fragment as *In Los Angeles [vs. Stuttgart], the woman buys…*, that implied near or far spatial distance from the location at which the experiment took place. They were then asked to select a sentence completion from one of two options, differing in the level of abstraction (e.g., clothes vs. trousers). In another condition, the abstraction level was manipulated in the initial sentence fragment, and participants were to complete the sentence with the best-fitting spatial location (e.g., *The woman buys clothes in…* to be completed with Los Angeles or Stuttgart). It was predicted that participants would most often choose a close location for a more concrete term in the initial sentence fragment and a more distal location for a more abstract term in the initial sentence fragment. Similarly, it was predicted that participants would most often choose a more concrete term for a close location in the initial sentence fragment and a more abstract term for a distal location in the initial sentence fragment. These predictions were clearly born out in the experiment when spatial distance was implemented in absolute terms (e.g., by means of explicit locations as in mentioning city names), and in a forced-matching task, in which participants were presented both initial fragments and both endings at once and were asked to match them into two sentences. The latter task probably works well because it provides a sort of reference for interpreting the categories. For example, Stuttgart may be close or far, depending on whether it is compared to Los Angeles or Tübingen (the current location of the participants), and trousers may be specific or abstract, depending on whether it is compared to jeans or clothes (Bausenhart et al., in preparation b).

Another possibility is that cognitive control processes (Botvinick et al., 2001) influence which type of representations constitute the basis for processing. Specifically, it seems conceivable that following an experienced conflict, the linguistic system operates on amodal rather than modal meaning representations.

There is little relevant evidence yet with which to evaluate this possibility. The studies mentioned above, looking at the question whether control processes are domain-general or domain-specific did not observe any evidence that perceiving a semantic conflict in one trial of a linguistic task would influence the processing of semantic conflict in a subsequent trial (Simi et al., 2022). One might take this to suggest that conflict adjustments do not target the representational format utilized during language comprehension. However, as these studies did not directly investigate the format of representation, this conclusion is premature. We are not aware of any studies directly investigating the hypothesis of a relationship between the experience of conflict and the representational format used in language comprehension. However, recent studies concerned with the processing of negation may give some hints. Negation has been shown to be difficult to process, and it has been suggested that one reason for this difficulty has to do with the fact that in negative constructions, the non-factual situation is explicitly mentioned (i.e., "The destination is not on the left side", explicitly mentions the left side although this is the exact opposite of the true destination's property). This might lead to processing difficulties in particular, when comprehenders engage in full-fledged mental simulations of the sensorimotor aspects of the linguistic content, as "not on the left side" would activate sensorimotor processing focusing on the left side (see Kaup & Dudschig, 2020 for an overview on negation research). Indeed, participants show response activation of the contralateral effector when processing phrases like "not left" or "not right" as indicated by the lateral readiness potential (Dudschig & Kaup, 2018). Importantly, however, this tendency to activate the wrong response side following the processing of negation was strongly reduced when the previous trial also contained a negated phrase and thus the experience of a conflict between the explicitly mentioned spatial word and the action required for a correct response. This might suggest that the experience of a conflict led participants to reduce simulating the linguistic material and instead turn to more amodal representations that are less prone to automatically activate sensorimotor processes related to the individual words in the linguistic phrases. However, before definite conclusions can be drawn with respect to the relationship between conflict detection and representational format in language comprehension, future research that directly tests the format of the created representations is needed.

In conclusion, there is much evidence that language comprehenders use modal meaning representations during comprehension. However, it is still unclear whether these modal meaning representations are functional for comprehension or not. Further, the exact conditions under which comprehenders use more modal or more amodal representations have yet to be determined. A number of factors are likely to play a role here, including the level of processing required by the task at hand and the amount of experience a comprehender has with the reference entities. Additionally, it seems likely that the psychological distance to the reference situation or the disruptions that occurred through modal processing in previous processing may also play a role. Future research is required to investigate the interplay between modal and amodal meaning representations during language comprehension, and to establish their functional role for comprehension.

Thought

According to many researchers in cognitive psychology, thinking is deeply rooted in how people perceive space. Space is thus assumed to be an essential component of cognition. Accordingly, space serves to structure thoughts and thus enables humans to understand the world around them. According to metaphoric mapping accounts (Boroditsky, 2000; Gentner et al., 2002; Lakoff & Johnson, 1980; Lakoff & Núñez, 2000, Winter et al., 2015), abstract thinking is achieved by mapping abstract domains that cannot be directly experienced onto modal domains that can be more directly experienced. In particular, it is often believed that spatial experiences structure thinking about non-spatial domains such as time or numerosity (Boroditsky & Ramscar, 2002, Casasanto et al., 2010), allowing reasoning about magnitude. For example, a study by Janczyk and colleagues (2022) indicated that although space and time are mentally associated, as are space and numbers, time and numbers are not mentally associated in the same way. This result is consistent with the notion that the non-spatial domains, numerosity and time, draw on spatial thinking.

However, not all authors agree that space is a predominant feature of quantitative reasoning. For instance, Walsh (2003) proposes that humans rely on a general magnitude system, which processes magnitude information regardless of whether it relates to space, numbers, or time (see also Bueti & Walsh, 2009). In contrast to the metaphoric mapping view, this view assumes an amodal representation as the basis of quantitative reasoning (but see Patro et al., 2016b). To summarize, it is controversial whether quantitative reasoning exclusively operates on amodal or modal representations, or a hybrid of both.

For example, the Spatial-Numerical Associations of Response Codes (SNARC) effect describes the associations between smaller numbers with the left side of space and larger numbers with the right side of space observed in Western cultures (Dehaene et al., 1993). Many influences have been demonstrated in SNARC research that are typically explained by referring to modal representations, in particular by assuming that numbers are positioned on a mental number line, which is shaped by experiences (e.g., Fischer & Shaki, 2015; Patro et al., 2016a). However, little is known about how different modal representations interact with space-number associations, because different modalities are usually associated. Some studies provide first evidence concerning different modal influences on the SNARC effect by employing a VR setup, in which the perceived placement of the hands is manipulated independently of their actual location. These studies suggest that when the numbers are presented close to the body within the reaching space of the hands, then the arrangement of the perceived hands in space does not matter that much. Instead, the decisive factor in this case seems to be which hand (left or right) is used for responding. By contrast, when the numbers are presented further away from the body and hands, the hands' arrangement matters, strengthening the horizontal or sagittal SNARC depending on their perceptual arrangement (Koch et al., 2022; Lohmann et al. 2018). In summary, the influence of different modalities for the SNARC seems to depend on the sensory and motor conditions of the setup.

Other accounts seek to explain the SNARC effect by exclusively invoking amodal representations. For instance, the serial order working memory account (e.g., van Dijck et al., 2014) postulates a domain-general mechanism that spatially orders all numerical and non-numerical sequences. In typical SNARC studies, there is a strong correspondence between the ordinal position of numbers and their magnitude, making it difficult to differentiate whether the ordinal position or the numerical magnitude is the crucial factor of the SNARC effect. In a recent study, however, the two accounts were compared directly using different stimulus sets in which the ordinal position of particular critical numbers differed considerably from their magnitude position on a continuous mental number line (e.g., 1,2,3,8; 2,3,4,9; 1,6,7,8; 2,7,8,9). Overall, the response-time pattern obtained with a parity-judgment task requiring left vs. right-hand responses supported the view that number magnitude is mentally mapped to space according to magnitude as well as ordinal sequence. This effect even held when the serial position of the numbers was made salient by having participants learn the serial order of the numbers beforehand and recall the number sets after the parity judgment task. One potential limitation of these result could be that the learned set was irrelevant for solving the parity-judgment task. Thus, follow-up studies are needed to rule out that different results would be obtained when the learned sets are relevant for the SNARC task (Koch et al., 2021).

As mentioned earlier, space is believed to modulate the representational format of human thinking in another research domain, langauge. In particular, the construal-level theory postulates that thinking about specific states of affairs involves representations at different levels of abstractness depending on the psychological distances to the state of affairs in question (Trope & Liberman, 2010). However, although previous research has indicated that representations differ for proximal vs. distal things, the cognitive format of these representations has not yet received much attention. First evidence for distance-dependent representational formats was obtained in a recent study on spatial landmark memories. More specifically, LeVinh, Meert, and Mallot (2020) investigated the so-called position-dependent recall effect in a virtual environment simulation of familiar places in Tübingen, a small university town in Southern Germany. Participants were immersed in a virtual environment showing a familiar location in downtown Tübingen. After ensuring that the location was recognized, subjects turned until they found a workspace laid out so that they had to take a particular body orientation to complete the task. The workspace comprised five objects identifiable as buildings surrounding a particular target area (in this case, the Timber Market). Participants were then asked to drag and drop the blocks into a configuration rebuilding the target area. The compass bearing of the produced viewing direction was recorded. These compass bearings clearly showed a position-dependent recall effect, meaning that participants built their configuration from the viewing direction consistent with their current location. More importantly for our present purposes, however, the strength of this position-dependent-recall effect decreased with the distance to the target area for two-thirds of the participants.

In conclusion, space seems to play a fundamental role in thinking related to the planning of actions and navigation and for more abstract thoughts such as reasoning about time and number. However, whether these phenomena can best be explained through modal or amodal representations is still a matter of debate. So far only a few research studies have been conducted to understand the interplay between modal and amodal representations in explaining the respective effects. We think that this is a pressing issue for future research.

Development

The issue of the representation format has only started to become the focus of developmental research. However, the idea that sensorimotor information initially drives ontogenetic cognitive development and thus forms the basis of higher cognitive processes has been around for a while. It was already an important aspect of Jean Piaget's work (Piaget, 1952). However, Piaget did not argue for strong interactions between modal and amodal cognitive processes. Instead, he suggested that children progress to concepts that are independent of their sensorimotor experiences during their primary school years. Contrary to this assumption, more recent work suggests that perceptual simulation is crucial for the development of higher cognitive processes, even in school-aged children (e.g., De Koning et al., 2017; Engelen et al., 2011; Vogt et al., 2019) and in adults (e.g., Borghi et al., 2004; Pecher et al., 2003; Stanfield & Zwaan, 2001).

However, one objection must be considered when interpreting these and other similar results. The involvement of modal representations in higher cognitive processes appears to be context- and task-dependent in adults (e.g., Areshenkoff et al., 2017; Bub & Masson, 2010; de la Vega et al., 2012; Lebois et al., 2015; Louwerse & Jeuniaux, 2010; Pecher, 2013; Ulrich & Maienborn, 2010; Van Dam et al., 2014; Yee & Thompson-Schill, 2016). Thus, as mentioned earlier, the claim that modal representations in adult higher cognitive processes constitute a mere epiphenomenon without functional relevance cannot be ruled out (Ostarek & Huettig, 2019). One possible explanation for why adult modal representations can nevertheless become activated during higher cognitive processes is that such activations are merely residual manifestations of earlier cognitive development. According to this view, modal representations are functionally relevant for higher cognitive processes early on during development, but they lose their functional relevance during the course of development such that their manifestations in adults are epiphenomenenal (see Figure 5, left side). This view in turn suggests that the cognitive-developmental trajectory proceeds from modal to amodal representations.

Such embodied conceptualizations contrast with recent theorizing based on evolutionary psychology and comparative research (e.g., Spelke & Kinzler, 2007). This line of argument maintains that early cognitive development is guided by abstract core knowledge (e.g., about objects, actions, numbers, and space), presumably preparing humans to process modal information in a particularly efficient way. A somewhat comparable perspective also emerged in associative learning beginning with Seligman's findings indicateing that abstract visual properties promote specific types of learning (e.g., rapid learning of snake- or spider-fear associations, Seligman, 1970). Interestingly, preparedness has been shown to be already evident in infants, who rapidly establish fear of snakes even when they had no experience of snakes (DeLoache & LoBue, 2009). In other words, in contrast to the the modal-to-amodal trajectory proposal mentioned above, other accounts favor the idea that amodal representations are available even early in development. According to this view, rudimentary abstract concepts scaffold the encoding of modal experiences and thereby enrich and re-structure amodal representations (see Figure 5, right side).

Further relevant evidence come from studies employing the looking-while-listening paradigm (Bergelson & Aslin, 2017; Bergelson & Swingley, 2012) to investigate the processes underlying vocabulary learning in infants (Kartushina & Mayor, 2019; Steil et al., 2021). In this paradigm, infants hear spoken words and see two pictures on a screen while their eye-movements are recorded. If an infant focuses on an apprpriate object when hearing a label, this is taken as evidence that the infant has learned the label. The results of such studies appear to provide further evidence that cognitive processing makes use of amodal information even in infancy. Specifically, it has been shown that the success of infants matching objects to labels correlates with differences in the frequency with which objects occur in their lives: infants correctly fixate on the labeled object more often when the the difference in frequency between the two objects shown is higher. This result can be interpreted as showing that infants learn to match objects that they frequently see to labels that they frequently hear, which in turn suggest that children’s associative learning mechanisms are capable of mapping between experiences in different modalities. In terms of our proposed framework, this suggests that the learning mechanisms that lead to the development of abstract, amodal representations are available even at the earliest stages of development.

In addition to these considerations concerning the two different developmental trajectories, research in developmental psychology can also be informative regarding the function of amodal representations for cognition. For example, it is well known that achievements in cognitive development are often correlated with achievements in linguistic abilities (e.g., Schneider et al., 2004). This relation has been particularly intensively discussed concerning the theory of mind abilities (e.g., De Villiers, 2007; Milligan et al., 2007, and the contributions in Astington & Baird, 2005). In principle, these relationships may reflect an underlying development in the ability to use amodal representations (cf. Dove, 2014). Amodal abilities might then boost linguistic abilities (e.g., using terms for mental states) and non-linguistic cognitive abilities (e.g., understanding the mental state of others). If so, studying the relationship between the developing linguistic and non-linguistic cognitive abilities will contribute to a better understanding of the functions of amodal representations for cognitive processes in general.

In conclusion, representational issues seem of great importance to developmental theories. In principle, two different perspectives can be outlined that postulate either a modal-to-amodal trajectory or an early-amodal-representations view. Further, developmental research can be very informative for more general representational theories, particularly concerning the functions that modal and amodal representations play. It thus appears a promising avenue for future research to investigate different issues by exploring the functions and interactions of modal and amodal representations during early childhood and later stages of development. In particular, it seems important that the psychological reality of the two different developmental trajectories be assessed in different cognitive domains.

Dysfunction

A further important question is whether the representational concepts outlined above can be profitably applied to clinical research to understand dysfunctional behavior and cognition better. Despite their often being neglected, resolving representational issues could be a key to describing dysfunctional behavior and improving treatments for abnormal behavior. In this vein, impulsivity is crucial for a better understanding of many kinds of dysfunctional behavior (Blume et al., 2019; Dawe & Loxton, 2004; Diamond, 2013; Fineberg et al., 2014; Schroeder et al., 2020). Although impulsive behavior often has a strong negative impact on an individual's life, and on and society more broadly, it is still unknown what mechanisms underlie or trigger impulsivity. One possibility is that overly impulsive individuals cannot inhibit behavior triggered by modal representations. Another possibility is that inhibitory issues are generally problematic in impulsive individuals, and that this applyies to both modal and amodal representations of objects, events, and situations.

Impairments in inhibitory control are considered a central mechanism in the maintenance of pathological eating behavior such as food-related craving, emotional eating, restrained eating and binge eating (Lavagnino et al., 2016; Wolz et al., 2020; 2021). It is possible that pathological eating behavior is only triggered by modal food representations (e.g., picture-like representations, which are often targeted in food advertisements or experienced with food, such as when passing by the tempting display of a bakery), but that it is not triggered, or triggered less, by amodal food-related representations (e.g., verbal description of a nice meal, the menu in a restaurant; cf. Rumiati & Foroni, 2016). A better understanding of the type of representations that are involved in overeating can lead to improved treatments by revealing their exact relationships with the mechanisms that complicate daily food choices. Such understanding is essential because overeating can be observed in most societies and has already led to pandemic health problems such as overweight and obesity (Ng et al., 2014). In a more general sense, understanding modal and amodal aspects of dysfunctions and disorders can help us understand what is necessary for healthy functioning. In the same vein, the exploration of the effectiveness of if-then plans (i.e., on implementation intentions) that specifically target abstraction processes is of great importance (for research on if-then plans, see Gollwitzer, 1999; see also Gawrilow & Gollwitzer, 2008; Gawrilow et al., 2011). If pathological eating behavior indeed reflects a predominance of modal food representations, then interventions that focus on abstraction processes should be especially effective. To our knowledge, this option has not been investigated in research on pathological eating behavior.

To date there has been little research on the format of representations in research on pathological eating behavior. This is surprising as the view that particular formats are more likely to trigger pathological eating behavior seems to suggest itself. However, further support for this proposal comes from two recent studies using the stop signal task (SST; Logan, 1994; Logan & Cowan, 1984) in which representational format was manipulated indirectly by varying the format of the presented stimuli (pictures vs. words). Satiated individuals were relatively good at inhibiting pictorial stimuli compared to word stimuli, whereas this was not the case for hungry individuals (however, this difference between the two groups was similar for food- and non-food items; van den Hoek Ostende et al., 2022a). Although future studies are needed to determine the relevant factors that lead to an increase or decrease of inhibitory control in stimuli of different formats in different groups of participants, this is clearly a promising line of research.

An additional complication arises from the possibility that experimentally induced homeostatic states (i.e., hunger and satiety) may be insufficiently sensitive to reveal differences between healthy populations and populations with trait overeating. To this end, restrained eaters may provide a better sample for study because they are characterized by investing *cognitive* effort to restrain food intake despite homeostatic signals of hunger, but also by occasionally losing control over food intake eventually leading to weight gain (Adams et al., 2019). Indeed, when comparing participants with very high and very low restraint scores (Restraint Scale; Herman & Mack, 1975), only individuals with high restraint scores showed differences in processing pictures and words specific for food pictures. More specifically, for food stimuli, high-restraint individuals were particularly good at inhibiting pictures but not words (Van den Hoek Ostende et al., 2022b). This is interesting because it opens the possibility that this group of people strategically upregulates control for a type of stimulus (i.e., pictures) that seems most threatening them, perhaps because these stimuli convey sensorimotor features that trigger pathological eating behavior. Future research is necessary to investigate whether these differences also transfer to actual food intake after processing these types of stimuli.

The above considerations concern the role of modal and amodal representations in the elusive boundary between normal and abnormal behavior as incorporated in the Research Domain Criteria (RDoC) matrix (Insel et al., 2010). However, the functional role of these different representational formats may even be a key to understanding severe clinical disorders. In fact, functional cognitive differences with direct relation to amodal representations have typically been associated with schizophrenia (e.g., Silberstein, 2014). Another example is a newly emerging cognitive approach in autism literature, the "Thinking in pictures" theory (e.g., Bòkkon et al., 2013; Kunda & Goel, 2011; Landgraf & Osterheider, 2013). It hypothesizes that some characteristics individuals with autism when solving specific tasks are due to the predominance of modal representations, compared to the more amodal – verbally mediated – approach that individuals without autism use.

In conclusion, although representational issues seem highly relevant to a number of areas of clinical psychology, to date only minimal research on the role of different representational formats in human dysfunctions has been conducted. However, some recent studies concerned with inhibitory capacities that indirectly manipulated representational formats by varying the stimulus type indicated that representational issues seem to offer a key to better understanding the mechanism behind pathological eating behavior. In general, we believe that understanding modal and amodal aspects of dysfunctions and disorders can help us understand what is necessary for healthy functioning and pave the way for effective interventions and prevention programs.

Conclusion

The distinction between modal and amodal representations has been prominent in cognitive psychology, particularly in perception and language. Yet, it is evident that this distinction also plays a crucial role in other fields of psychology, albeit less prominently. Our review shows that the distinction between modal and amoal representations is less sharp than might perhaps have been hoped. However, it is worth bearing in mind that the vagueness of concepts might sometime be beneficial for scientific progress, in that it can inspire new ideas and enable us to see relationships that might otherwise not be evident, allowing us to connect different research fields. We thus agree with William James (1890, p. 6) that the mental is undoubtedly vague and therefore “it is better not to be pedantic but let the science be as vague as its subject”. Accordingly, we suggest the distinction between modal and amodal representations can foster a fruitful exchange of theoretical ideas between domains. This endeavor is undoubtedly made more difficult if each area uses other terms for similar theoretical concepts. What we have sought to show is how overarching principles of different types of representations can be identified, and our hope is that they may contribute to the development of more integrative accounts of human cognition.

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Figure 1. Illustration of the continuum ranging from very concrete modality-specific representations on the one hand (left side) to more abstract symbolic representations on the other hand (right side).

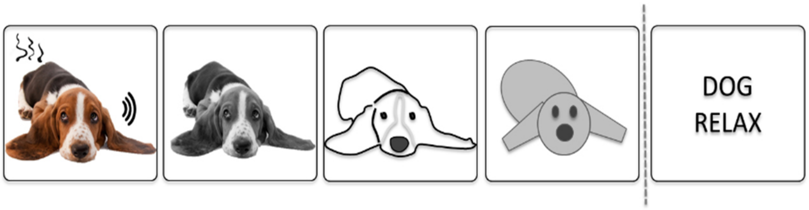

Figure 2. Properties and examples of modal and amodal representations (see text for further explanations).

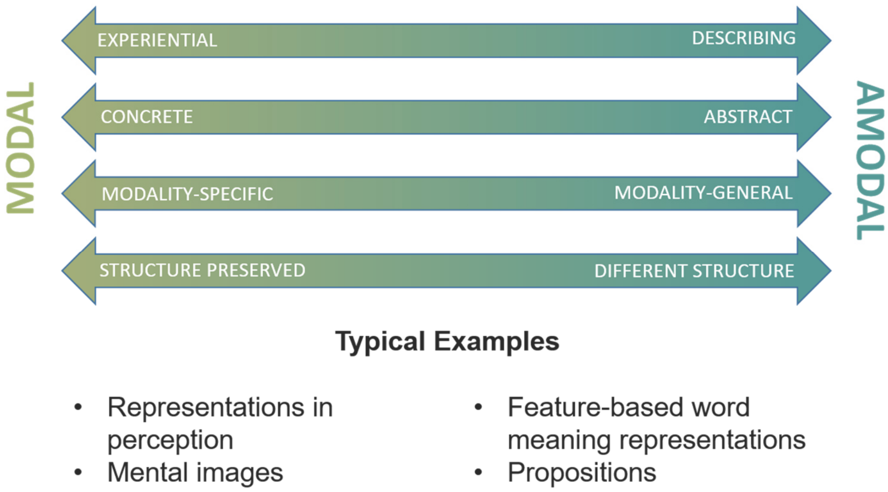

***Figure 3*.** The modal-amodal continuum comprising different forms of representations, ranging from image-like representations to frames and propositions.

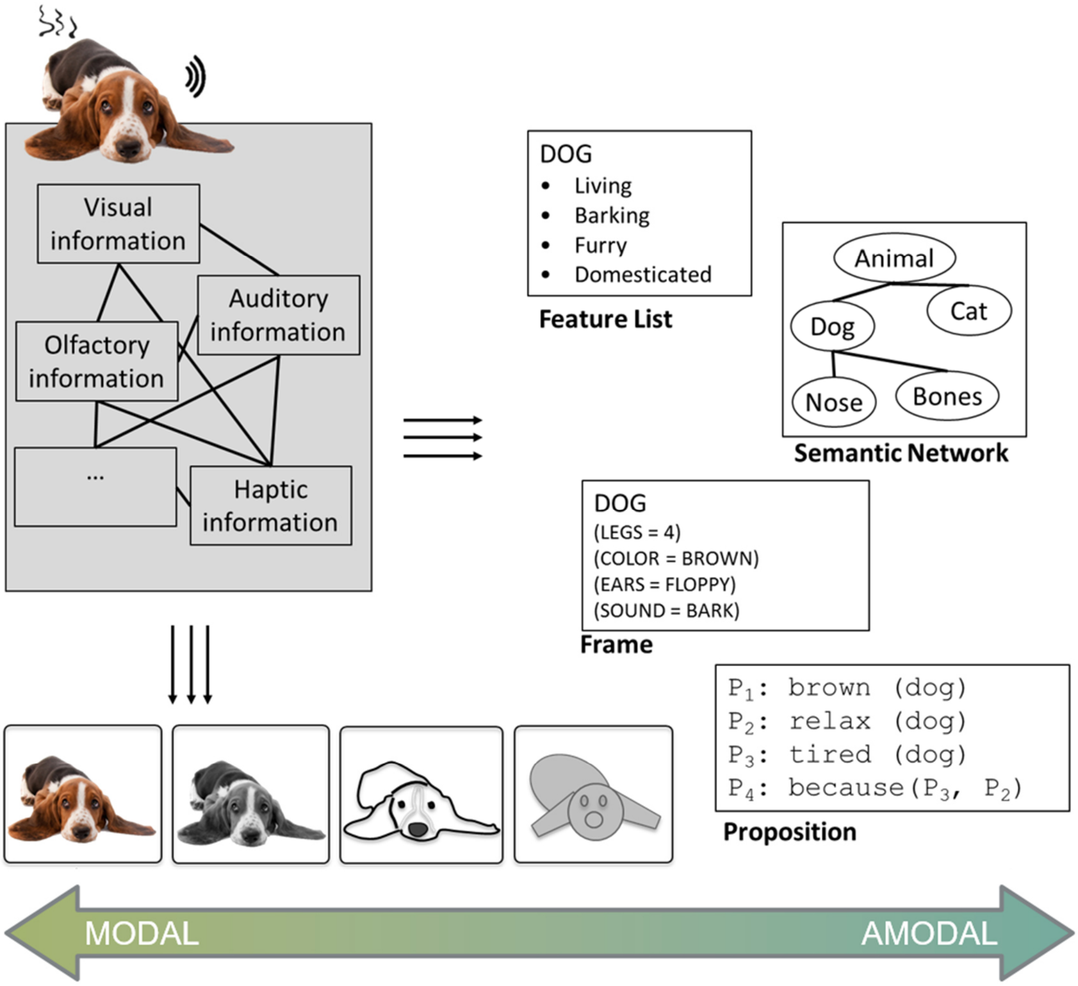

Figure 4. The modal-amodal continuum in a plane given by the two dimensions “analog-to-symbolic” and “modality-specific-to-modality-general”.

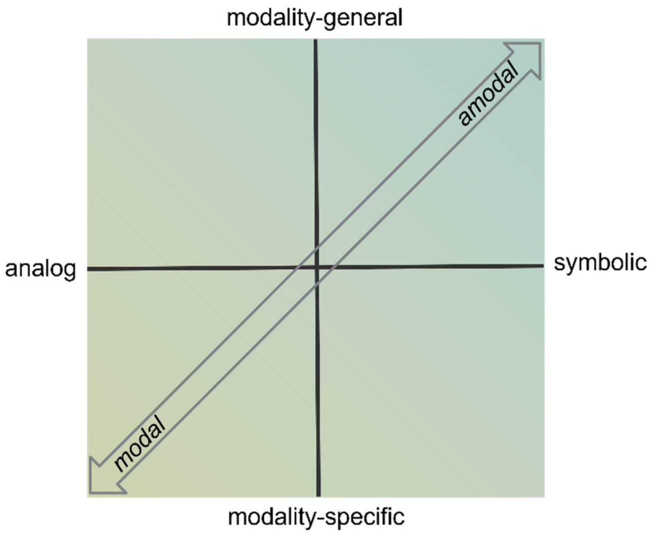

Figure 5. The modal-to-amodal trajectory view (left) versus the early-amodal-representations view (right)