thought is underlyingly propositional, or mentalase (Fodor 1975). The second is that there is both mentalase and LF, but only LF does the work of cross-modular thinking. That would seem to be Carruthers's position. The third is that mentalase of sufficient complexity to handle propositional attitudes would have to be virtually identical to LF (de Villiers & Pyers 1997; Segal 1998). If so, why duplicate the functions and structures? Why not assume that natural language is the medium for such thinking, especially as LF rather than inner speech? We raised that among a list of other logical possibilities for the relationship between natural language and the language of thought in this domain (de Villiers & de Villiers 2000).

Does Varley's aphasic contradict this possibility? Not necessarily, because LF could (logically) be preserved but inaccessible to the phonological input and output systems for language. Carruthers uses Varley's case study to deny that language is needed synchronically for false-belief reasoning, but that is because of his commitment to two other connected notions: (1) ToM is a module and (2) LF is only needed for cross-modular thinking. He is also tempted to say that animals have mental state representations, arguing that their "long chains" of social reasoning imply propositional mentalase. This is where our behaviorist beginnings show. We haven't seen evidence from primates or younger children that would convince us to posit both propositional mentalase and LF, once you allow LF to be the medium for false belief reasoning. But Carruthers needs both if he only allows LF to be the medium of cross-modular thought. It's curious, because the arguments in favor of the subtlety of syntax and semantics needed to capture propositional attitudes seem to us so much more convincing than those needed to capture "left of the blue wall!"

Carruthers has to avoid the conclusion that false belief reasoning is dependent on language if he is to keep to the claim that it is a module. So he argues that the full theory of mind system, a module independent of language, comes on line at age four. But it is accelerated by interpreting linguistic input, which leaves us wondering what might happen in the absence of complex linguistic input. This language-independent module would then come on line at what? 5 years? 8 years? 25 years? In addition, Carruthers states that the language-independent ToM module "has to access the resources of other systems (including the language faculty) to go about its work." Why? In particular, "mind-reading ability routinely co-opts the resources of the language faculty." Is this because it is routinely cross-modal? Maddeningly, Carruthers does not specify sufficiently which false belief tasks count as which type: The only example provided is one in which the subject believes a proposition that is itself cross-modal, "that the object is to the left of the blue wall." So, it's all very well to "cry out for experimental investigation," but only if it's clear enough to test.

Perhaps what Carruthers has in mind is that a person without sufficient language, say, a three-year-old, can imagine the false belief of another, and can token it in some system of thought but not explicitly deduce consequences or predict behaviors from it. So, logically, the theory of mind system could be language-independ-ent. That is the kind of picture that Clements and Reiner (1994) posit for their toddlers who look expectantly at the place a character will emerge premised on his false belief but then fail when asked the simple question, "Where will he look?" However, they argue that the children's expectancy might not be propositional at this point but behavioral (Dienes & Reiner 1999). To answer explicitly, a propositional format must be developed. Carruthers believes that the standard false belief tasks require only intra-modular thinking, hence not natural language, though maybe propositional mentalase. But in the development of such reasoning, he also admits that language plays a crucial role in input and output systems.

So the difference comes down to this. Our own data are just what one would expect if the acquisition of complementation under verbs of communication and belief in language made possible the representation of the relationships between people's minds and false states of affairs, representations that were inaccessible to explicit reasoning or incomplete before. It sounds like a good idea to us to propose that something like the LF of natural language is the format for such thinking, because LF has the necessary representational richness. But we would still need to explain why LF of sufficient complexity takes time to develop. For all we know, severe aphasics might have access still to LF, but primates would not. That is not to say there are many other subtle things that can be done (even in mind reading) without LF, and it is an exciting question to ask if such things really need propositional reasoning. Much experimental and philosophical ingenuity will be required (Dennett 1983)!

### Cross-domain thinking: Common representation format or generalized mapping process?

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**Abstract:** In Carruthers's formulation, cross-domain thinking requires translation of domain specific data into a common format, and linguistic LF thus plays the role of the common medium of exchange. Alternatively, I propose a process-oriented characterization, in which there is no common representation and cross-domain thinking is rather the process of establishing mappings across domains, as in the process of analogical reasoning.

Carruthers proposes that cross-modal thinking consists of the integration of central-process modules' outputs by the language faculty to build logical form (LF) representations, which thus combine information across domains, and that "all cross-modal thinking consists in the formation and manipulation of these LF representations (sect. 5.1, para. 7)." I will argue that cross-domain thinking can occur without intervention of the language faculty. Rather, such thinking relies on a generalized cross-domain mapping capability. Interestingly, this type of mapping capability can operate across diverse domains, including the mapping required for performing the transformation from sentences to meanings in language processing.

In Carruthers's formulation, cross-domain thinking requires translation of domain specific data into a common format, and linguistic LF thus plays the role of the common cross-domain medium of exchange. Alternatively, we can consider a process-oriented characterization, in which there is no common representation, and cross-domain thinking is rather the process of establishing mappings or transformations across domains, as in the process of analogical reasoning.

We can gain insight into this issue of cross-domain processing from its long tradition in the sensorimotor neurosciences. Consider the problem of cross-domain coordination required for visually guided reaching to an object. The retinal image is combined with information about position of the eye in the orbit, and the orientation of the head with respect to the body to determine the position of the object in space with respect to the body. This sensory domain representation is then used to command the arm reach that should be specified in the native motor system coordinates of the individual muscles. Interestingly, Kuperstein (1988) demonstrated that this cross-domain problem could be solved without invoking common representation format but rather by constructing a direct mapping from sensory to motor system coordinates.

Can an analogous mapping strategy be used for cross-domain thinking? In response to this question, I will illustrate a form of transformation processing for the mapping of grammatical structure in language to conceptual structure and then will demonstrate how this mapping capability extends to generalized cross-domain mapping, making this point with the analogical reasoning.
A central function of language is communicating “who did what to whom,” or thematic role assignment. In this context, consider the two sentences in which the open class words are labeled.

a. John(1) hit(2) the ball(3).

b. It was the ball(3) that John(1) hit(2).

Both of these sentences correspond to the meaning encoded by the predicate hit (agent, object), instantiated as labeled hit(2) (John(1), ball(3)). For each sentence, the structural mapping from open class words onto event and thematic role structure in the meaning is straightforward (123–213, and 312–213 for sentences (a) and (b), respectively). The difficulty is that the particular mapping is different for different sentence types. This difficulty is resolved by the property that different sentence types have different patterns of grammatical function words (or morphemes) that can thus identify and indicate the appropriate (sentence, meaning) mapping for each sentence type. Based on this mapping/ transformation characterization, we suggested that nonlinguistic cognitive sequencing tasks that require application of systematic transformations guided by “function” markers would engage language-related mapping processes. Indeed, in these tasks we observed (1) language-related ERP profiles in response to the function markers (Hoen & Dominey 2000), (2) correlations between linguistic and nonlinguistic transformation processing in aphasics (Dominey et al. 2003), and (3) transfer of training across these domains (Hoen et al. 2002). These data argue for the existence of a generalized transformation processing capability that can extend across domains and is thus a candidate for a cross-domain thinking mechanism.

Within this structural mapping context, Holyoak and colleagues (Gick & Holyoak 1983) have studied the process of analogical mapping in reasoning. A classic example involves the “convergence” schema. Consider: A general must attack a for (Gick & Holyoak 1983) have studied the pr...