thought is underlyingly propositional, or mentalese (Fodor 1975). The second is that there is both mentalese and LF, but only LF does the work of cross-modular thinking. That would seem to be Carruthers's position. The third is that mentalese 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 mentalese. 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 mentalese *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-modular, "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-independent. That is the kind of picture that Clements and Perner (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 & Perner 1999). To answer explicitly, a propositional format must be developed. Carruthers believes that the standard false belief tasks require only intramodular thinking, hence not natural language, though maybe propositional mentalese. 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-modular 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-modular 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 fortress at the center of a town. His army is too large to approach the fort by any one of the many paths that converge on the fort. He divides his army into small groups, each converging simultaneously on the fort. Now consider: A doctor must eliminate a tumor in a patient's thorax. The doctor has a radiation beam that can destroy the tumor, but at full strength, it will destroy the intervening tissue as well. Gick and Holyoak (1983) demonstrated that subjects could use the analogical mapping to solve the radiation problem. This analogical reasoning process does not appear to rely on translation into language or a propositional representation. Rather, we can consider that it is based on mapping of the target problem onto a nonpropositional spatial image schema of the analog problem. Thus, we can consider that not all cross-modular thinking is propositional. Similarly, when physics students discover that resistor-capacitor circuits behave like the physical mass-spring systems they have studied, an analogical mapping process is triggered that yields a number of new insights. These can potentially be expressed in language, but they do not originate in any language-related format. On the contrary, the structural properties required for analogical mapping would likely be lost in the LF conversion. A related form of nonpropositional cross-domain reasoning has been well explored in the mental models paradigm by Johnson-Laird (1996).

In summary, I have the impression that Carruthers has overextended the original function of LF as an interface between language and conceptual systems. It appears implicit in Carruthers's theory that all cross-domain thinking must be propositional (or must be of the type that can be realized by the language faculty). "All" is a strong word. The cross-domain analogical mapping examples above define cases where cross-domain interaction cannot occur via a propositional LF-like data structure. Rather, these cases require mapping processes that establish the cross-domain correspondences, independent of a neutral common representation.

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The role of language in the dual process theory of thinking

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Abstract: Carruthers' proposals would seem to implicate language in what is known as System 2 thinking (explicit) rather than System 1 thinking (implicit) in contemporary dual process theories of thinking and reasoning. We provide outline description of these theories and show that while Carruthers' characterization of non-verbal processes as domain-specific identifies one critical feature of System 1 thinking, he appears to overlook the fact that much cognition of this type results from domain-general learning processes. We also review cognitive psychological evidence that shows that language and the explicit representations it supports are heavily involved in supporting System 1 thinking, but falls short of supporting his claim that it is the medium in which domain-general thinking occurs.

Carruthers proposes that language is the medium for general thought, serving to integrate the outputs of various domain-specific conceptual systems. He briefly mentions links with dual process theories of thinking. The most relevant in this context are those of Reber (1993), Evans and Over (1996), and Stanovich (1999). All of these theorists argue that humans have two separate cognitive systems with distinct evolutionary histories. System 1 evolved early, is shared with other animals, allows rapid and parallel processing of information and is independent of general intelligence. System 2 evolved late, is uniquely human, is slow and sequential, requires central working memory, and is highly correlated with general intelligence. Both Reber and Evans and Over label System 1 as implicit and System 2 as explicit.

The first question is how well do these two systems map onto Carruthers's distinctions? System 1 functions are generally regarded as domain-specific, whereas System 2 allows general-purpose abstract and hypothetical reasoning. However, Carruthers apparently presupposes that domain-specific cognition is grounded in specific innate modules, which is unwarranted. Much domain-specific cognition is the result of *domain-general* learning processes. Implicitly acquired knowledge is limited to the domain in which it is learned (Berry & Dienes 1993), but this in itself is not evidence for innate specificity. There is a high degree of biological preparedness for some learning, for example, in the human visual and language systems, but general associative learning processes can account for much of our domain-specific knowledge (Almor, in press).

We translate Carruthers's hypothesis as the claim that language provides the medium of System 2 thought. This does link with some tentative suggestions made by Evans and Over (1996). We too are struck by the fact that both language and System 2 thinking are uniquely human and agree with Carruthers that language is strongly related to domain-general thought, but we will refer to further psychological support for this view.

System 1 is responsible for much linguistic understanding and production: It is automatic in function and broadly universal in efficacy across human beings. Like other System 1 processes, language delivers its products into consciousness. We comprehend the meaning of a sentence even though we have not the slightest idea of the process by which we derived it. However, the key aspect of language for the present purpose is that it supports explicit representations. Language is the medium of explication. To refer to System 1 as implicit and System 2 as explicit is to associate language with the distinction. With language, we can formulate rules and principles that apply generally. For example, if we learn statistical principles by experience, we will apply them in a domain-specific manner (Jepson et al. 1983). If we learn them through verbal instruction, we can apply them generally (Fong et al. 1986). We can also use System 2 to reason nonconstructively, inferring, for example, a disjunction "from above" with the help of general rules without knowing which disjunction is true. In the purest case