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Editorial

Human reasoning is heterogeneous—as Jon Barwise informed us

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It is sad but true that most people in AI and related fields, upon hearing the word 'reasoning', imagine a sequence of purely linguistic expressions which follow standard rules of deductive inference for elementary two-valued logic. (Other similarly one-dimensional schemes may come to mind at the mention of this word. For example, so-called 'Bayesian reasoning' is probabilistic, but relative to the issue at hand, this is of no help because, compared with the human case, probabilistic formalisms are also thoroughly one-dimensional; they make no use, for example, of diagrams or other pictographic representations, or of semantic models.) Human reasoners greatly exceed such rigid inflexible modes of reasoning.

The present issue is devoted to taking seriously the brute fact that human reasoning is 'heterogeneous'; it involves not just declarative formulae of the classical sort, processed in the classical way, but also diagrams, images, models, underlying semantic relationships between propositions (e.g. intuitive similarity), etc., and non-deductive procedures (e.g. abduction) for processing such things. In addition, when (untrained) human reasoning involves linguistic information, it often departs radically from the canon of what is normatively correct reasoning over such standard information, and the departure is sometimes very effective for the particular task at hand.

Johnson-Laird has long held that human reasoning extends well beyond standard logic, and he stands as a seminal figure in the history of heterogeneous reasoning, as it is uncovered and studied via empirical techniques, and rendered at least to some degree in computational form. According to his mental models theory (which by now is supported by a large amount of empirical data), logically untrained people predominantly reason not over formulae or their relatives (e.g. declarative sentences in some natural language), but rather over 'mental models'. His paper explains the mental models theory in connection with spatial reasoning, and shows that this theory predicts something that some other contributors to the volume have presupposed—diagrams facilitate human reasoning.

Although mental models theory appeared on the scene long ago, another scheme (minus experiments in psychology that support mental models) predates Johnson-Laird's theory by many years: Peirce's alpha, beta, and gamma systems

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for reasoning in 'visual' form. Van Heuveln offers an interesting argument for the view that Peirce's approach, although devised long ago, captures a blending of two currently competing schools of thought in the psychology of reasoning: the aforementioned mental models theory, and so-called mental logic theory, which holds that untrained human reasoners abide by rules of inference over formulae—just not all the rules of inference that are in standard elementary extensional logical systems.

Our own contribution presents a method, originally devised by Yang and fine-tuned a bit by Bringsjord, for cracking the kind of reasoning problems seen on the Graduate Record Examination (GRE) in a manner which, like van Heuveln's account of Peircean reasoning, integrates mental models and mental logic. This method makes use of the semantics of modal logic, is decidedly heterogenous, and in general flows from a new theory of human reasoning known as 'mental meta-logic'. If such methods are in fact followed by humans taking the GRE (and there is some empirical evidence that that is the case), then even when tackling tightly defined reasoning problems on 'high-stakes' standardized tests, they far exceed the old-style form of reasoning seen in elementary logic.

Three of the papers in this issue (by Sun, by Wang and Hofstadter, and by Wang, Johnson, and Zhang) are linked by seeking to model heterogeneous human reasoning in working computer models.

Sun explores the difference between rule-based reasoning (which corresponds to standard deductive inference in elementary logic) and similarity-based reasoning, a phenomenon (in which the underlying semantic categories referenced by the relevant arguments affect judgments regarding whether these arguments are valid) which is well supported by empirical data. He explains how the impressive CLARION cognitive architecture can encompass these and other forms of (as he puts it) 'everyday' reasoning in humans.

Wang and Hofstadter describe a fascinating reasoning system known as NARS, designed to model categorization. NARS is heterogeneous across both inference type (syllogistic inference and an interesting form of parallel inference), and representation. Although NARS is said to be a 'reasoning system', it exceeds the reach of the narrow interpretation of that phrase, and lies closer to a full-blown cognitive architecture.

Wang, Johnson, and Zhang explore the order effect in belief revision. Belief revision is a process in which one revises one's current belief in the light of new data, and is commonly thought to be an essential component of human abductive reasoning. The order effect is seen when the final belief is significantly affected by the temporal order of information presentation. The authors explore the effect in traditional experimental fashion and via the UECHO cognitive architecture. This two-pronged approach appears to show that, at least under certain conditions, the order effect results from one's coherently and dynamically adaptive expectations of the statistical properties of the environment.

Stenning and Gresalfi show, through examination of data obtained in connection with students tackling certain classroom-level tasks involving mathematics and biology, that heterogenous representation and reasoning is irrepressible, even in contexts that at least seem to be based on only homogeneous linguistic processing. Stenning and Gresalfi not only mention the Hyperproof system, in good part a reflection of Jon Barwise's conception of heterogeneous reasoning, but also provide

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a fascinating argument for the view that there is no fundamental 'interlingua' into and out of which the diverse representation and reasoning systems used by humans come and go. This view is one that Barwise explicitly affirmed.

Note that this 'heterogeneous reasoning' issue is dedicated to none other than K. Jon Barwise, arguably (to this point, at any rate) *the* seminal figure in the study of formal heterogenous reasoning. While much of Barwise's contributions to logic, mathematics, and the rigorous study of information will probably never be forgotten among relevant experts, and while we stand in awe of much of this work, we point out that Jon brought heterogenous reasoning to life in the form of working computer programs that could be profitably used even by students in introductory logic courses. One of us (SB) began his study of infinitary logic (in connection with the foundations of AI) with his reading of Barwise, but it was that first proof built in Hyperproof that was truly unforgettable. Here was a system in which proofs incorporated visual reasoning in a real way, *and* a natural way. The present issue contains a fascinating vision, expressed by John Etchemendy and Dave Barker-Plummer, of how Hyperproof can be generalized. John and Dave were collaborators with Jon Barwise and others in the development of Hyperproof and the textual material associated with it, and their generalization will no doubt carry his work forward into the future.