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RESEARCH ARTICLE

Human Reasoning Module

Enkhbold Nyamsuren , Niels A. Taatgen

Department of Artificial Intelligence, University of Groningen, Nijenborgh 9, 9747 AG Groningen, Netherlands

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Abstract
This paper introduces a framework of human reasoning and its ACT-R based implementation called the Human Reasoning Module (HRM). Inspired by the human mind, the framework seeks to explain how a single system can exhibit different forms of reasoning ranging from deduction to induction, from deterministic to probabilistic inference, from rules to mental-models. The HRM attempts to unify previously mentioned forms of reasoning into a single coherent system rather than treating them as loosely connected separate subsystems. The validity of the HRM is tested with cognitive models of three tasks involving simple casual deduction, reasoning on spatial relations and Bayesian-like inference of cause/effect. The first model explains why people use an inductive, probabilistic reasoning process even when using ostensibly deductive arguments such as Modus Ponens and Modus Tollens. The second model argues that visual bottom-up processes can do fast and efficient semantic processing. Based on this argument, the model explains why people perform worse in a spatial relation problem with ambiguous solutions than in a problem with a single solution. The third model demonstrates that statistics of Bayesian-like reasoning can be reproduced using a combination of a rule-based reasoning and probabilistic declarative retrievals. All three models were validated successfully against human data. The HRM demonstrates that a single system can express different facets of reasoning exhibited by the human mind. As a part of a cognitive architecture, the HRM is promising to be a useful and accessible tool for exploring deeps of human mind and modeling biologically inspired agents.

Abbreviations: HRM, Human Reasoning Module;
DM, decalarative memory;
VSTM, visual short-term memory;
MP, Modus Ponens;
MT, Modus Tollens;
DA, Denying the Antecedent;
AC, Affirming the Consequent

Corresponding author. Tel.: +31 50 363 7450.
E-mail addresses: e.nyamsuren@rug.nl (E. Nyamsuren), n.a.taatgen@rug.nl (N.A. Taatgen).

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Introduction

In this paper, we introduce a framework that attempts to unify various approaches to human reasoning. The Human Reasoning Module, or HRM, is an implementation of this framework developed as a part of the ACT-R cognitive architecture (Anderson, 2007). As opposed to ACT-R's core modules that represent specific types of cognitive resources such as vision or memory, the HRM does not add a new type of cognitive resource. The HRM extends the theoretical frameworks and corresponding computational functionalities of the existing modules of ACT-R. Therefore, the HRM is both a theory and a tool for modeling. As a theory, it advocates for a specific structure of knowledge organization in our declarative memory. The structure is still based on knowledge chunks, but adds specific requirements on chunk types and its slots. Furthermore, the HRM advocates the existence of task-general procedural knowledge that gives us the ability to reason and solve problems based on real-time information and previous experience. The proposed structures of declarative and procedural knowledge define grammar, axiom schemata and inference rules of human logic. As a tool, the HRM both extends and constrains the functionality of ACT-R's declarative module and also adds a set of task-general production rules to ACT-R's procedural module. Ideally, if the HRM is a valid model of human reasoning it should be able to tackle any form of reasoning process. However, the HRM's current unification attempt is limited to two dimensions depicted in Fig. 1. The next subsection discusses in details these dimensions.

Inductive and deductive reasoning

At the core of the HRM, there is an assumption that the human general reasoning skill is inherently probabilistic or inductive. Any true form of classical deductive reasoning requires a *closed world assumption* stating that what is not currently known to be true is false. This is an extremely unpractical assumption in the real world full of uncertainties (Rajasekar, Lobo, & Minker, 1989), and we subconsciously or consciously recognize this fact. Cummins (1995) demonstrated that even when someone is reasoning with ostensibly deductive arguments one still uses an inductive, probabilistic reasoning process. Further uncertainty arises due to limitations of our cognitive resources: our perception of the world can be noisy or limited and our memory may be forgetful. With such uncertainties, any deductive system will fail the tests of *validity* and *soundness*, necessary requirements for any formal deductive inference (Jeffrey, 1981). Furthermore, we do not often try to satisfy both of these requirements in our reasoning process (Thompson, 1996). Therefore, the HRM operates under the *open world assumption*, what is not proven is not necessarily false, and tries to prove truthfulness rather than falsity of knowledge.

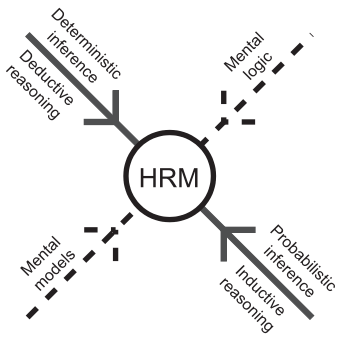

Fig. 1 Two dimensions of human reasoning that the HRM attempts to unify.

However, the HRM does not exclude a possibility that deductive reasoning occurs within the context of specific tasks. Let us assume a specific problem that eliminates environmental uncertainties by clearly and unambiguously specifying contextual boundaries, constraints and rules. We can further assume that the problem is tractable within capacities and limitations of our cognitive resources, and there is no interference to the solution from our past knowledge outside of the problem's context. Such context will follow the closed world assumption, and, hence, deductive reasoning may be used. Therefore, in the HRM, there are no two separate processes for deductive or inductive reasoning. Instead, the HRM assumes that deductive reasoning is an instance of inductive reasoning over a specific domain of discourse with a near-zero uncertainty. A degree of uncertainty is the common dimension that implicitly unifies inductive and deductive reasoning in the HRM.

Mental logic, mental models and bottom-up reasoning

Next, the HRM further argues that general human reasoning does not necessarily rely on formal propositional forms and is not strictly top-down (conscious). There is a long history of debate over the theories of mental models and mental logic. The mental logic theory argues that a set of inference rules is applied to logical forms abstracted from stimuli (Rips, 1983). A commonly agreed interpretation of mental models theory dictates that stimuli are abstracted into a form of mental diagram where configuration information reflects the relationship between entities (Banks & Millward, 2009; Johnson-Laird, 1983). In the HRM, the two theories are part of the same reasoning process. It is based on the assumption that these two are not mutually exclusive strategies. Roberts (1993) rightfully pointed to the fact that there are no obvious reasons why the two types of theories should be incompatible. Coney (1988) argued for individual differences based on a study showing that some people are better at spatial reasoning while others prefer reasoning based on formal propositions. Johnson-Laird (2004), a chief proponent of the mental models theory, admitted that the model theory does not imply that reasoners never rely on rules of inference.

The HRM consolidates the two theories by assuming that a mental model is a form of working memory that allows convenient representation and storage of knowledge required for reasoning. New premises, including ones not explicitly stated by the problem context, are assumed to be extracted on demand from the mental model during a rule-based inference similar to the mental logic. The mental model as a working memory simplifies a manipulation and retrieval of knowledge that otherwise has to be stored in a less efficient long-term memory. For example, items in