The Open University

In Two Minds: Dual-Process Theories of Reasoning and Rationality

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Abstracts

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INVITED PAPERS

An architecture for dual reasoning

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How are dual systems of reasoning realized in the human mind–brain? What are the component mechanisms underlying System 2, in particular, and how do they connect and interact with one another? The distinctive facts about System 2, for my purposes, are that its operations are characteristically conscious, slow, and serial in nature; that it is malleable and can be influenced by instruction; and that it often operates through the application of learned rules and normative beliefs.

Two claims are crucial to my account. One is that a privileged class of perceptual states and quasi-perceptual states (images) are globally broadcast to a wide range of consumer systems, thereby becoming conscious (Baars). The other is that activated action schemata can be used to generate perceptual images of the action and its immediate effects, using, inter alia, the efferent pathways normally involved in fine-grained control of action (Kosslyn, Wolpert).

My thesis is then that System 2 processes consist of cycles of activation and mental rehearsal of action schemata (often, but by no means always, in 'inner speech'). This yields imagistic representations of action that are globally broadcast to an array of System 1 mechanisms. These then draw further inferences etc., altering the cognitive landscape for the selection of the next action schema to be rehearsed.

Since the account is action based, System 2 will be malleable in all of the ways that actions and sequences of actions are malleable. One can learn behavioral skills by imitation; likewise one can learn System 2 reasoning skills by imitation. One can acquire a skill by internalizing and being guided by a verbal instruction; likewise System 2 sequences can result from instruction. And beliefs about what ought, or ought not, to be done can have the same sort of influence on System 2 reasoning processes as they do upon actions themselves.

Unconscious knowledge and inference

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I will take unconscious knowledge to be knowledge people are not aware of having even when actively using it. Testing whether people have unconscious knowledge

therefore means testing whether people are aware of having knowledge when they are using the specified knowledge. Two different knowledge contents can be distinguished in most learning tasks: Knowledge of the structure of the stimuli seen so far (structural knowledge) and knowledge of whether a particular test item has this structure (judgement knowledge). I will argue that when structural knowledge is unconscious, it can lead to inferences, namely judgement knowledge, that can be either conscious or unconscious.

The multiplicity of mind

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Dual process theories have developed in parallel in several psychological literatures, notably those concerned with the study of learning, reasoning, decision making and social cognition. These theories seem to be related as they all contrast implicit cognitive processes (fast, unconscious, automatic) with explicit processes (slow, conscious, controlled) leading to some theorists to propose generic cognitive Systems 1 and 2 which underlie these dual process accounts. However, closer inspection suggests that while System 2 may be a coherent concept, System 1 is not. There are in fact a number of quite different forms of implicit cognition (for example, implicit learning, modular cognition, attentional processes, pragmatic retrieval processes, automated cognitive skills) which do not operate as a single system and do not share the same cognitive architecture or evolutionary history. The common factor to dual process theories is the presence of a single system of analytic thought, requiring central working memory resources, which may optionally intervene to alter default behaviours prompted by a variety of implicit cognitive systems.

Dual-process theories and the personal-subpersonal hypothesis

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Data from reasoning tasks and other sources have led some psychologists to posit the existence of two distinct systems in human reasoning and decision-making – a view sometimes referred to as 'dual-process theory'. Dual-process theorists have been less than explicit about the way these two systems are implemented, but the standard view seems to be that they are realized in distinct neural subsystems, which operate in parallel, albeit with some interaction. In this paper I outline an alternative reading of dual-process theories. The key suggestion is that the distinction between the two systems should be thought of as one of levels, corresponding to that between subpersonal processes and personal-level actions – a view which, I argue, has some

very attractive features. Overall, the paper will take the form of a non-rhetorical question to dual-process theorists: Can this hypothesis accommodate some or all of the relevant data? If it can, then some rethinking of dual-process theories may be in order.

Multiple reasoning systems: the case from common sense and neuropsychology

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[See conference website]

Counterintuitive age trends, dual processing, and the development of irrationality—or, Obesity is contagious, but what does one catch?

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Results from a variety of studies indicate that children sometimes surprise us by outperforming adults on cognitive, judgment, and decision-making tasks. In this presentation, I present data from two new studies that add to these counterintuitive age trends. The first study is focused on age trends in the obesity stereotypes of Latino- and Caucasian-American children and adolescents. The second study involved use of eight identically flavored beverages and examination of how an "illness" prime and endorsements by obese and non-obese children affect the perceived taste of 7-11 year-olds. The findings raise a number of issues, such as: Is rationality really bound by information processing constraints? Why, under some conditions, does the size of the normative/descriptive gap *increase* with age? Why does the tendency to base judgments on implicit or intuitive processing increase with age? The ultimate hope of this presentation is to engage the interests of dual-process theorists such that the take more seriously the need to understand the developmental antecedents of the non-normative thoughts and behaviors often seen in adults.

Reflective and reflexive processes in social cognitive neuroscience

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In this talk I will review the neurocognitive bases for distinguishing between two types of social cognitive processes. The "C-system" is responsible for reflective processes that are symbolic, slow, and effortful. Activity in the C-system typically feels like self-generated thought and is linguistic. The C-system consists of several neural regions including lateral prefrontal cortex, lateral parietal cortex, medial prefrontal cortex, medial parietal cortex, rostral anterior cingulate, and the medial temporal lobes. Alternatively, the "X-system" is responsible for reflexive and intuitive processes that are non-symbolic, fast, and effortless. Activity in the X-system, typically feels like reality being directly experienced and is more often perceptual or affective (and sometimes nonconscious). The X-system consists of several neural regions including ventromedial prefrontal cortex, amygdala, basal ganglia, dorsal anterior cingulate, and lateral temporal cortex.

After describing the general framework of the X- and C-systems, I will focus on the special case of when C-system activity disrupts X-system activity in the absence of any intentional attempt to regulate the X-system. Specifically, I will present a number of studies that indicate that symbolic processing of affect activates right ventrolateral prefrontal cortex in the C-system which in turn appears to disrupt activity in a number of X-system limbic regions that support non-symbolic processing of affect.

Two systems of thinking across cultures

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Many theorists have postulated two distinct systems that govern human thinking—one is holistic, experience-based and reliant on similarity relations, the other analytic, language-based, and reflecting the application of rules. Until recently, little was known about these systems of thinking outside of North American and Western European cultures. In recent years, cross cultural researchers have examined these two systems of thinking across diverse cultural groups. I review this evidence, and conclude that 1) these systems of thinking exist in principle in the cognitive repertoire of all cultures, but 2) there are marked and systematic cultural differences in the default tendency to rely on one or the other system in solving cognitive problems. This latter finding contradicts a longstanding assumption in cognitive science that cultural differences affect the content of thought but not the cognitive processes themselves. Finally, I review evidence that speaks to possible social psychological and ecological explanations for these cognitive differences.

Dual processes or dual aspects?

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Dual process accounts of human reasoning usually contrast low level, associative, automatic processes with higher level, symbolic, controlled processes. The probabilistic approach (Oaksford & Chater, 2001, in press) is characterising all human reasoning as being at the lower level. This level is concerned with the inductive strength of an inference, i.e., the probability of the conclusion (C) given the premises (P), P(C|P). However, Rips (2001) has shown a dissociation between assessing an inference for P(C|P) vs. deductive correctness, i.e., whether the premises logically entail the conclusion, P → C. We argue that P(C|P) and P → C reflect the contributions of structure and content respectively and that in real human inference both aspects are required. Computing P(C|P) over complex chains of inference requires structural knowledge which in many AI systems is captured by the logical entailments between propositions, i.e., P → C. We suggest that such systems are required to generalise accounts of human reasoning to argumentation which is arguably the more general human activity. On this view, while structure and content may have dissociable effects on human reasoning, the norm is for them to work together in evaluating an inference or argument. Thus rather than dual processes, P(C|P) and P → C are really just dual aspects of a common underlying process.

The constructive/non-constructive duality and dual process theory

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We can observe that someone is cheating us by seeing him take more than his agreed proportion of a benefit to be shared out. Such an observation, from "below", gives us a constructive justification that some specific person is cheating us: we can name or point out this cheater. In contrast, we can infer in non-constructive reasoning, "from above", that someone or other we cannot name or point out is cheating us. Constructive thought depends primarily on System 1 and non-constructive thought more on System 2. Our ability to identify the cheater in the constructive case may even be found in a domain-specific module, though the arguments for innate massive modularity have been weak. Our capacity for non-constructive reasoning rests on general logical abilities that are not domain specific. This general capacity is useful in a number of ways. One of these is inferring a conditional from disjunction. For the ordinary natural language conditional, it cannot be logically valid to infer "if not-p then q" from "p or q". This inference is only valid for the material conditional, and there is very strong evidence that the ordinary conditional is not the material conditional. It would be obviously invalid to infer "if not-p then q" from "p or q" after

inferring "p or q" from p constructively. However, we are sometimes pragmatically justified in inferring "if not-p then q" from "p or q" when these are assertions. We can also sometimes be justified in making this inference in our beliefs. Such an inference can rely on non-constructive reasoning in System 2.

The magical number two, plus or minus: some comments on dual-processing theories of cognition

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[See conference website]

How well are two process models standing up to the Bayesian Challenge?

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A popular view in cognitive science challenges the dual process perspective both on normative and descriptive grounds. Normatively, if behavior can be assimilated to a single rational model, there's no need to posit different systems to explain fallacious versus normatively-appropriate reasoning. Descriptively, if all reasoning pursues the same computational goal of maximizing the likelihood of some hypothesis given the data, then reasoning should be explainable with a single computational system. I don't believe these arguments present a fatal challenge to the dual system view, but they do force dual-process theorists to clarify their theories. For instance, how dual system theories apply to causal reasoning is opaque.

Intuitive and reflective inferential processes

DAN SPERBER — *Institut Jean Nicod, Paris*

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Inference is an essential and ubiquitous aspect of animal cognition whereas reasoning proper, understood as involving a reflective attitude to assumptions, is a specifically human and rather puzzling development. We argue that reasoning is first and foremost an adaptation aimed at best exploiting communication (both for the communicator and the addressee). For the communicator, it is a means to persuade; for the addressee, it

is a means not to be too easily persuaded. We outline a dual-process approach based on this evolutionary point of view.

Is it time for a tri-process theory? Distinguishing the reflective and the algorithmic mind

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In this talk I explore whether System 2 in dual-process theory needs to be partitioned into two mechanisms, here labelled the reflective mind and the algorithmic mind. I conjecture, based on extant theory and on empirical studies of individual differences in reasoning, about the cognitive operations in the algorithmic mind (and also in the reflective mind) that support human rationality. I will use the algorithmic/reflective distinction to develop a taxonomy of cognitive errors that are made on tasks in the heuristics and biases literature.

SUBMITTED PAPERS

A mixed Rasch model of dual-process conditional reasoning

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A fine-grained dual-process approach to conditional reasoning is advocated: Responses to conditional syllogisms are reached through the operation of either one of two systems, each of which can rely on two different mechanisms. System1 relies either on pragmatic implicatures or on the retrieval of information from semantic memory; System2 operates first through inhibition of System1, then (but not always) through activation of analytical processes. It follows that reasoners will fall in one of four groups of increasing reasoning ability, each group being uniquely characterized by (a) the modal pattern of individual answers to blocks of affirming the consequent, denying the antecedent, and modus tollens syllogisms featuring the same conditional; and (b) the average rate of determinate answers to AC, DA, and MT. This account receives indirect support from the extant literature, and direct support from a mixed Rasch model of responses given to 18 syllogisms by 486 adult reasoners.

What is *dual* in dual process theories of reasoning? A critical assessment of Goel's data.

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Goel and al. have provided neural bases for dual processes of reasoning by putting in evidence different neural contrasts when congruent and incongruent belief based syllogisms are assessed as to their validity by subjects. We would like to make explicit the reading grid underlying the assumption that the observed neural contrasts provide evidence for a dual process theory of reasoning or, at least, take advantage of these data to make clearer what kind of cognitive duality is involved by such data.

Do two-systems models constitute a theoretical advance?

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The present paper examines critically dual-system theories. We start by raising three potential concerns for dual-systems modelers: (i) whether or not the systems are isolable; (ii) whether or not the dichotomous characteristics used to define the dual-system models are uniquely and perfectly correlated; and (iii) whether or not these characteristics are truly dichotomous. Next, we discuss the type of empirical evidence that would be needed to support a dual-system framework, and briefly examine the extent to which such evidence is indeed available. Our analysis questions the scientific utility of dual-system theories for the understanding of aspects of human behavior. Yet, we acknowledge their popularity, and examine why they are so prevalent as explanatory tools. We end by speculating about alternative theoretical frameworks to the dual-system models.

Reasoning with complementary pathways, not competing processes

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The core of our argument is that the human mental architecture is composed of nine subsystems of *equal* status that interact as parts of a coherent overall system, and therefore one mind. Two of these subsystems represent qualitatively different types of meaning, one propositional in nature and the other a more abstract holistic representation, called implicational meaning (Barnard & Teasdale, 1991). Implicational meaning integrates over sensory, conceptual and bodily inputs and so captures affective states. Two aspects of this model relate to the claims of dual process theory. First, the two semantic subsystems stand in rather different relationships to the seven others. Implicational meanings receive direct and therefore fast inputs from visual, acoustic and body state subsystems while the construction and use of propositional meanings relies on inputs derived from longer, and therefore slower, processing routes. Interactions between these two meaning systems are argued to form the central engine of human ideation (Teasdale & Barnard, 1993). The second aspect of the model is that in these interactions processing activity can reflect properties of the two representations to differing degrees as a function of *the mode* in which meaning is processed. The mode of processing also directly relates to conscious experience. When implicational meanings dominate processing activity over time the same kinds of properties as are proposed for System 1 would be emphasised but when propositional meanings dominate the characteristic properties of System 2 would be more in evidence.

Examining the mapping problem in multi-mode models

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Multi-mode models have proposed several criteria to divide the realm of mental processes into two (e.g., Sloman, 1996; Strack & Deutsch, 2004), three (Leventhal & Scherer, 1987), or four categories or modes (Conrey, Sherman, Gavronski, Hugenberg, & Groom, 2005). Examples of criteria (and categories obtained with these criteria) are operating conditions (automatic/nonautomatic), formal process or mechanism (sensori-motor/associative/rule-based), format of the representations or codes on which the process operates (sensory/analog/conceptual/propositional), content of the representations on which the process operates (heuristic/systematic), and neurophysiological routes (neocortical/subcortical).

Construing categories on the basis of one or another criterion is legitimate. Most multi-mode models, however, choose two or more criteria and make a priori assumptions of overlap among the categories obtained with these criteria. For example, the category of associative is often mapped onto the category of automatic and the category of rule-based onto the category of nonautomatic (e.g., E. R. Smith & DeCoster, 2000). The question one may ask is whether these mappings are justified. I propose to investigate the mapping problem in a step-wise manner. A first step is to engage in the conceptual analysis of a pair of criteria and see whether they can be defined in non-overlapping terms. If it turns out that theoretical overlap is not mandatory, a second step is to investigate empirically whether there is actual overlap among both categories in the real world.

Dual processes in reasoning and decision making: fuzzy rationality

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In this talk, I discuss the commonalities and distinctions between fuzzy-trace theory and other dual-process approaches to reasoning, judgment, and decision making. The commonalities include the acknowledgment that adult reasoning encompasses alternative modes of processing: one that is analytical, quantitative, and operates on precise memory representations toward the verbatim end of a continuum and another that is intuitive, qualitative, and operates on gist representations toward the fuzzy end of the continuum (e.g., Reyna, Lloyd, & Brainerd, 2003). The detailed experimental and modeling data gathered under the rubric of fuzzy-trace theory (e.g., Brainerd, Reyna, & Mojardin, 1999; Reyna & Brainerd, 1995) provide additional, independent evidence favoring a general dual-process perspective (e.g., Evans, 2003, in press;

Klaczynski, 2005). These dual-process data include paradoxical memory effects and troubling, but theoretically predictable, variability in human reasoning performance in a wide range of tasks, such as logical reasoning (e.g., difficulties with modus tollens reasoning in the Wason card problem; Falmagne, 1975; Reyna, 1991) and judgment and decision making (e.g., heuristics and biases in probability judgment; Gilovich, Griffin, & Kahneman, 2002; Reyna & Brainerd, 1991, 1994).

In the domain of memory, fuzzy-trace theory subsumes contradictory findings from both the constructivist (i.e. schema memory) and learning theory traditions. For example, it was shown in numerous experiments with different age groups that verbatim and gist memory representations are encoded, stored, and retrieved roughly in parallel, contradicting semantic integration predictions of traditional psycholinguistic theory. These dual representations account for schematic memory effects, such as false recognition in sentence verification tasks (Brainerd & Reyna, 2005; Bransford & Franks, 1971; Loftus, 1979) as well as seemingly conflicting findings that verbatim and gist memories can be accessed independently (Alba & Hasher, 1983; Reyna & Kiernan, 1994, 1995).

In the domain of reasoning, three assumptions accommodate the findings: (a) people encode both verbatim and gist representations for any meaningful stimulus (e.g., pictures, words, numbers, sentences, narratives, and events, all of which have been studied); but (b) they have a fuzzy-processing preference, which means that they rely on the least precise gist representations that can be used to accomplish a task (regardless of whether the task is called memory or reasoning); and (c) this tendency to operate on fuzzy memory representations increases with experience (e.g., with age from childhood to adulthood and, in adulthood, with increases in expertise; Reyna & Adam, 2003). Hence, fuzzy-trace theory is the only developmental theory that predicts that intuition develops into adulthood and represents an advanced form of mature reasoning (Jacobs & Klaczynski, 2002; Reyna, 2004; Reyna et al., 2003; Reyna, Adam, Poirier, LeCroy, & Brainerd, 2005).

Fuzzy-trace theory has been applied to diverse tasks, including classic Piagetian (e.g., class-inclusion, conservation, probability judgment), verbal reasoning (e.g., syllogistic reasoning, transitive inference, spatial reasoning, metaphorical interpretation), and judgment and decision making tasks (e.g., framing effects, hindsight bias, base-rate neglect, conjunction, and disjunction fallacies), as well as older findings from Gestalt theory involving transfer and learning theory involving transposition effects (see Reyna, 2005; Reyna et al., 2003; Reyna & Brainerd, 1995, 1998 for overviews; Wolfe, Reyna, & Brainerd, 2005). Fuzzy-trace theory has also been the source of new, counterintuitive findings, such as mere memory testing (non-suggestive recognition tests foster false memories of gist), false memory persistence (false memories are more consistent across memory interviews than true memories), non-numerical framing effects (removing numbers in decision scenarios increases framing biases), reflection (gain-loss) effects in early childhood, reductions in risk-taking preference from childhood to adulthood, developmental shifts from trading off risks and rewards in childhood to gist-based categorical thinking in adulthood, and selective processing effects that disconfirm expectancy based theories (e.g., prospect theory).

Results of process-level analyses of these tasks support both coherence and correspondence criteria for rationality, and support the further idea that these criteria are distinct (e.g., Reyna & Farley, press). That is, reasoners can excel in achieving good outcomes in the world, accurately discriminating reality (correspondence), but

nevertheless evince failures of coherence (violations of internal coherence according to semantics, logic, or probability), and vice versa (e.g., Adam & Reyna, 2005; Reyna & Brainerd, 1994). These detailed, process-level analyses of tasks also support the claim that there are degrees of rationality (that map onto different underlying processes), and that goal achievement is not sufficient for rationality (i.e., that goals themselves are fair game in evaluating rationality; see also Doherty, 2003; Stanovich, 2005).

In addition to discussing the theoretical and empirical developments that underlie fuzzy-trace theory, I will also address findings from traditional dual-process tasks, such as matching in the Wason card problem (Evans, 2003), and differences among dual –process theories' assumptions relating to memory representations versus processing, intuition versus association (Sloman, 2002), and the role of emotions in reasoning and decision making (Stanovich, 2004).

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'In two (or more) minds' about rationality? Dual process theory's contribution to the rationality debate

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This paper shows how the advent of dual process theories provides us with a framework which can be used to resolve the 'rationality debate' – whereby research into human reasoning has moved us to ask not only 'how rational are we?', but also 'what *counts* as rational?'.

To illustrate how dual process theory equips us to answer this problem, I first outline how Evans & Over's (1996) account both preserves a distinction between descriptive

and normative theories of human reasoning, and provides a principled basis upon which to ground their account of what counts as normative. However, their 'starting point for… human rationality… [is] to ask how decisions taken and actions performed serve the goals of the individual' (Evans & Over 1996:1); yet it can be notoriously difficult to determine 'the goals of the individual' – rendering their account vulnerable to the accusation of 'redefining rationality at will', and thus imperilling its normative force.

I suggest that this challenge can be met by recognising that the fundamental locus of rationality is the human agent (rather than discrete reasoning mechanisms, for example); and that the requirement to understand someone as an intentional agent introduces conceptual constraints on 'what counts as rational', and thereby guards against the charge of interpretationism. Crucially, this requires us to invert Evans & Over's account – the foundational notion of rationality is that 'sanctioned by a normative theory' (their 'rationality$_2$'). This is a prerequisite for agency; only then does 'rationality$_1$' (which 'serves the goals of the individual') come into play.

Reason and intuition in the moral life: a cognitivist defense of moral intuitions

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It is common in moral philosophy to appeal to so-called "moral intuitions" about cases as a means of building and defending moral theories. Intuitions are often taken as the starting point for theories, and intuitions are tested against moral theories until reflective equilibrium is achieved. The process of reflective equilibrium is supposed to provide rational justification for moral theories and moral intuitions, but any explanation of how moral intuitions could be rationally grounded faces two distinct challenges. The first is that of moral dumbfounding, which seems to show that moral intuitions are arational emotional responses to situations that we then try to rationalize by appeal to socially accepted rules. The second challenge comes from the two-systems theory of reasoning, which generally holds that intuitions are not corrigible to explicitly reasoned theories, and therefore not subject to rational revision. This paper addresses both of these challenges, and draws upon a recent model of the mental architecture subserving norms to show "how possibly" the two-systems theory of rationality can actually support the view that moral intuitions can be subject to rational criticism and modified by explicit reasoning. This model, suitably filled out, demonstrates how reflective equilibrium can be psychologically realized, and thus, how moral intuitions can be rationally grounded.

What are System 1 processes like? Defeasible but logical perhaps?

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1) Background

Evans' dual process account of human reasoning grew out of the subfield known as the 'psychology of deduction' which is strongly influenced by a particular conception of the relation between logic and human reasoning. The resulting conception of dual processes identifies System 2 processes as 'logical' thinking and System 1 processes as non-logical (associative, pragmatic, . . .). Psychologically System 1 processes are fast, cheap, automatic, inaccessible, not-isolable from general knowledge, and primitive; whereas System 2 processes are slow, expensive of cognitive effort, requiring deliberate control, are isolated from knowledge, available to conscious reflection, and evolutionarily advanced, possibly uniquely human.

On many grounds, the conception of the relation between psychology and logic embodied in the 'psychology of deduction' is anachronistic. When a more adequate modern conception of the multiplicity of logics and their association with different reasoning tasks is adopted, the distinction of the two systems by the criterion of what is 'logical' is called into question. This paper builds on a program of research which assumes that the task of interpreting the experimental materials of 'the psychology of deduction' into suitable logics, is a substantial part of the problem facing subjects in these experiments, and that the logical interpretations which result are the chief determinants of subjects reasoning. This approach throws new empirical and theoretical light on the main experimental paradigms of the field (the selection task [Stenning and van Lambalgen(2004)], the suppression task [Stenning and van Lambalgen(2005)], syllogistic reasoning [Stenning and Cox(2006)]), in particular explaining what have been claimed to be 'content' effects as logical interpretation e_ects, and opening the way to explanations of the generality of human reasoning [Stenning and van Lambalgen(in press)]. An important range of logics required are defeasible nonmonotonic logics, and evidence accumulates that for most subjects these are likely to be a first interpretational resort. [van Lambalgen and Hamm(2004)] have shown how these same logics can be applied to a range of problems in temporal discourse semantics.

Here we will argue that once it is acknowledged that nonmonotonic logics are at the centre of human discourse interpretation, explorations of their tractability become highly relevant to the basis of the distinction between dual processes.

2) Dual logical systems.

For modelling the credulous process of interpretation, [Stenning and van Lambalgen(2005)] adopt a family of fast and efficient default logic based on logic programming, which formalise closed world reasoning. These logics are highly tractable, allowing the computation of unique 'intended models' of sets of assumptions and databases of 'general knowledge' conditionals in linear time. They show that this logic, given a suitable three-valued semantics, is susceptible to neural network implementations in spreading activation networks. The classical logic assumed to constitute logic by most of the psychological subfield (but see

[Evans(2003)] for an at least partial exception) is well known to be resistant to any such efficient treatment.

Unusually for a neural network treatment, there is a plausible outline available of the processes which create the working memory/long term memory networks which represent discourse interpretations. This outline draws on neuroscience studies of the different timescales of plasticity required [von der Malsburg(1981)]. Interestingly, it is the three-valued semantics necessary for the treatment of negation which points to the need for the process of retinotopic mapping which network construction involves [Stenning and van Lambalgen(2005)].

So our proposal is that it is possible to take seriously observations of dual processes with their gross psychological characteristics, but to see logics (of different kinds) underlying both Systems 1 and 2. The remainder of the paper is about the advantages of making this adjustment.

While the external characteristics of System 1 processes listed above have received much attention, their substance has remained remarkably little specified. Thinking of these processes as 'associative' raises fundamental problems. Much of natural language processing as studied in psycholinguistics has all the external properties of System 1 (fast, automatic, etc.), yet demolition of associative approaches to natural language processing was the first requirement and achievement of the cognitive revolution. Credulous language processing *is* System 1 but *is not* associative.

Basing human discourse interpretation on defeasible logics might be seen as a move from the frying pan into the fire: nonmonotonic logics have a bad reputation for intractability. However, logic programming is an exception, being both rather expressive and yet highly tractable, as befits its technological origins. Once a three valued semantics allows a more general treatment of negation, this family of logics provides a natural framework for natural language discourse processing.

So System 1 processes must be logical (rather than associative) and could be logical (in some defeasible logic). We will argue that these observations can greatly enrich our conceptions of dual process theories, and point us at insightful questions.

The paper concludes with a discussion of implications for the relation between System 1 and Systems 2 in the development of communication and learning, and in evolutionary accounts of how the modern human cognitive architecture arose. Defeasible logics related to that proposed for System 1, are known as 'planning logics' and underlie low-level motor planning in some approaches to robotics [Shanahan(1997)]. This accords with an idea proposed by several strands of research that the continuity of human language with ancestral cognition is to be sought in planning rather than communication capacities [Greenfield(1991)] [Arbib and Rizzolatti(1997)]. On this view recursion, far from being the critical innovation of human language evolution [Hauser et al.(2002)Hauser, Chomsky, and Fitch], is already a feature of our ancestors' cognition, but its employment in social interaction is the innovation that led to language.

Our ancestors' working memories were capable of holding their model of their current situation and goals, as supported by their long term representations of environmental regularities and their current perceptual input. However, they had quite severe limitations in the 'semantic distance' possible between this model and the current situation. System 1 processes continually defeasibly updated this model as information arrived or goals changed. In humans, the possible semantic distance

between working memory model and current situation is hugely extended, and this capacity has to be supported by sophisticated interpretational machinery which can accommodate the fact that the interpretation of working memory often has highly indirect implications for action. We propose that System 2 processes arose by the development and extension of interpretative supervisory systems driven by the need to repair breakdowns in interpretation arising in System 1. Such breakdowns inevitably occur both in individual cognition and an social communication. The balance of forces between these two modes is of course one of the major unsolved problems of human cognitive evolution.

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Dual-process theories: questions and outstanding issues

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The goal of this paper is to offer a critical analysis of the contribution of Dual Process Theories (DPT) to psychological theory. A key advantage of DPT is that they offer an integrated framework for generalising across specific tasks and situations; this

represents a clear advantage over the traditional approaches that have focussed on task- and process- specific explanations. At the same time, it can be argued that the level of description offered by DPT lacks the predictive power normally required of cognitive theories. That is, whilst recent proposals have made some progress towards developing testable assumptions, they nonetheless lack specification at several levels. Specifically, the distinctions between System 1 and System 2 address the properties of representations and processes, and downplay the principles by which the representations are formed and the processes executed. Thus, to date, theoretical proposals either focus on lists of potential processes or on high-level, general descriptions. Neither approach allows principled prediction: The former because it lacks integrating assumptions and the latter because it is not sufficiently precise. In this paper, I propose that an intermediate level of description might be useful, and illustrate how basic principles of attention and metacognition may be developed to advance theorising about issues such as "What information is extracted from the problem space" and "When and under what circumstances does System 2 intervene?"

POSTERS

The dynamics of reasoning: chronometric analysis and dual-process theories

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Dual-process accounts of reasoning often differ in subtle but important ways in their specification of the flow of control between heuristic, System 1 processes and analytic, System 2 processes. For example, some dual-process accounts of the indicative selection task emphasise a *staged* flow of control, whereby System 1 provides default responses that are simply rationalised by System 2 processes, only being overturned through more rigorous System 2 analysis in a minority of individuals. Other accounts of the indicative task describe parallel streams of System 1 and System 2 processing that *compete* for control of behaviour, with System 2 winning the competition for only a few people who possess the requisite analytic power to override responses primed by System 1. The former accounts invoke notions such as non-consequential reasoning and 'deciding before you think', whereas the latter accounts downplay the rationalising functions of System 2 and refer, instead, to System 2's potential to produce normative task construals. We suggest that differentiating between stage and competition accounts is a major research challenge that is not well served by standard response data. Instead, we propose that chronometric analysis using response latencies and inspection times can provide more useful evidence to tease out the dynamics of reasoning. As an illustration we outline how inspection-time studies have clarified the involvement of dual systems in reasoning with indicative and deontic selection tasks. We also consider how the combined deployment of chronometric and process-tracing techniques may further illuminate the interplay between System 1 and System 2 processes.

Misunderstanding ourselves: vagueness and two systems of classification

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A great many of our concepts are vague in the sense that they appear to draw no boundary separating those things that fall under them from those that do not. To take a famous example, by removing one grain at a time from a heap of grains of sand, there will not be a point – a particular number of grains – at which the heap becomes a non-heap. There will be borderline cases of heap before we reach the non-heaps:

collections that are neither clearly or determinately heaps or non-heaps. But this seems to suggest that there must be boundaries between the determinate and the borderline cases. Introducing higher order borderline cases to eliminate boundaries at one level merely seems to multiply them a level above.

Attempts to capture the boundaryless nature of vague concepts seem always to bring us back to boundaries. In this paper, I explore whether vagueness and our inability to make sense of it have their roots in a conflict between two systems of categorisation that we have: the pragmatic and the scientific. I explore whether we can say that the pragmatic system is part of System 1 with the scientific is part of System 2 (using the terminology of Stanovich and West). Pragmatic classification is rough and ready classification with the aim of generating a taxonomy good enough for management of the world relative to a creature's aims and restrictions. Scientific classification is classification with the aim of mapping reality at its joints.

Vague concepts are pragmatic classifiers that we attempt to understand from within the scientific system. In so doing, we distort them and generate problems that we can't solve. The distortion is entirely natural, however, for three reasons. First, analysis is naturally undertaken from a scientific perspective. Second, scientific classification is required for complex classification. Third, there is a desire for vague concepts to be stable that leads us to think of them as bounded. If so, there may be no analysis of vagueness that dissolves the tension between being bounded and being boundaryless. Vagueness will always feel problematic.

Rationality$_2$: no guide for the perplexed?

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My aim in this paper is to suggest that the dual notion of rationality cannot be sustained. More specifically, I argue against the notion of normative rationality, the Rationality$_2$ of the Evans and Over (1996) concept of dual rationality, based on having 'a reason for what one does sanctioned by a normative theory' (ibid, p. 8). To elucidate the difference between these two type of theories, I draw on an example from linguistics were the distinction is well established, and suggest that the same would benefit the rationality debate in reasoning and decision making. I propose that normative rationality is commonly conflated with a computational level analysis, and that this muddle gives rise to the 'is-ought' fallacy. This fallacy means that, while one can empirically arbitrate between competing computational accounts, there is not way to do so for competing normative ones. To demonstrate how acute is the need to decide between normative theories, I examine two extreme cases, first, where there are too many normative theories, and the secondly where there is not even one. I then proceed to examine two prominent rationality agendas, rational analysis of Oaksford and Chater (e.g., 1998) and the use of the understanding / acceptance principle in Stanovich's individual differences programme (e.g., 1999). Each of these programmes commits the is-ought fallacy in some part of its arguments. I conclude that normative

rationality cannot be an issue for empirical research, and that dual process theories of reasoning are better off without the dual normative framework.

Inductive reasoning and dual processes

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One assumption that has been made about inductive reasoning is that it relies more on associative, belief-based, Type 1 processes than it does on symbol manipulating, structure-sensitive, Type 2 processes. The results of two sets of studies suggest that this assumption is incorrect. In the first set I showed that both sensitivity to evidential diversity and the monotonicity effect, two key phenomena in the study of category-based inductive reasoning, are associated with cognitive ability. Such associations are normally interpreted under a dual process framework as evidence for the involvement of Type 2 processes. In the second set of studies we show that when logical validity and causal consistency are independently manipulated on a simple reasoning task, sensitivity to structure is associated with ability whereas sensitivity to causal consistency is not. This pattern holds whether participants are instructed to judge conclusions on the basis of necessity or plausibility. These results support two conclusions: first, inductive reasoning appears to be supported by both types of process; and second, the distinction between these processes may be more important psychologically than is the distinction between induction and deduction.

Application of dual-process theories in mathematics education (and vice versa)

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The gap between intuitive and analytical thinking is of fundamental concern for mathematics education research and practice. There are interesting similarities and differences between the intuitive/analytical framework in mathematics education (ME) on the one hand, and the System 1/System 2 distinction in dual-process theories (DPT) on the other, but these links so far have hardly been noticed by either of the two communities. In this presentation I discuss the application of DPT in ME, and, conversely, a possible contribution of ME research to DPT. To this end, I compare a typical use of DPT in cognitive psychology (the *bat-and-ball task*, Kahneman, 2002) with a recent DPT analysis of a *group-theory task* from a college-level abstract algebra class (Leron & Hazzan, in print).

In ME research, students' performance on the group theory task would traditionally be explained by analyzing their faulty knowledge of the relevant logic or mathematics. The DPT interpretation, which invokes general cognitive mechanisms, clearly adds a new perspective for ME researchers. Cognitive psychologists largely study *everyday* cognition: Tasks such as the bat-and-ball, 'Linda', or the card selection task, do not require prior tutoring or deep reflection. These situations *invite* System 1 responses. In contrast, the group theory phenomenon occurred in the context of a university abstract algebra course, where the name of the game is abstraction and formal proofs, and where the students were explicitly prompted to explain their answers. This context would clearly seem to invite System 2 responses. This is a further testimony to the power of intuitive thinking, that might still 'run the show' even in college-level mathematical classrooms.

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Impact of dual process models in scientific progress and communication: The case of the role of affect

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Dual process models fulfil a communicative role in two areas. First they fulfil a communicative role between scientists that work in different domains in psychology and neuroscience to establish a common understanding of state of the art research questions. Secondly, dual process models fulfil a communicative role to a broader public e.g. on the role of affect in information processing. A deeper understanding of the role of an affective response in information processing has been gained from insights in neuroscience and have been expanded from research on stereotyping to risk perception. Notwithstanding the gains of these endeavours the dual process approach remains disputed by some. Very often the data on which these disputes are based are ill defined with respect to the conditions under which the conclusions hold. If these disputes could be aimed at a sharpening of the formulation of these duals models e.g. in terms of the conditions under which either mode of processing may occur, these disputes could become more fruitful.

Undoing one's learning

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Post-task questionnaires presented at the end of complex problem solving tasks have revealed dissociations between participants' performance and their declarative knowledge of the task and their behavior during the tasks (e.g., Berry, 1991; Berry & Broadbent, 1984). This kind of dissociation has been taken as evidence for functionally separable inductive reasoning processes (i.e. implicit reasoning vs. explicit reasoning). Contrasting this position, studies of goal specificity effect (i.e. Non-goal orientated instead goal-orientated learning leads to global processing of task information and successful transfer of knowledge) show that individuals have access to, and can accurately report on their hypothesis testing behavior during complex problem solving tasks (e.g., Burns & Vollmeyer, 2002). To reconcile these competing positions Buchner, Funke and Berry (1995) proposed that, rather than evidence of dissociations between implicit and explicit inductive reasoning, this kind of evidence suggests differences in the diversity of learning experiences that are generated during the tasks. The aim of the present study was to investigate Buchner et al's (1995) claims. In order to achieve this, a novel procedure was employed in which participants solved two control tasks under Non-goal orientated learning conditions. For half, the learning phase from the first task was recorded and replayed in the second task (i.e. restricted learning experiences). For the remaining half a different learning phase from their first was presented in the second task (i.e. diverse learning experiences). The findings showed decrements in control performance under conditions in which the diversity of the learning experiences was restricted; these findings are discussed in light of dual system frameworks.

Dual-process and cognitive checking

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My paper has three main sections. In the first I argue that a greater understanding of the mechanisms underlying human reasoning is required to advance the debate about human rationality. In the second I argue that in order for dual-process theories to make a significant contribution to the rationality debate they must provide a more detailed and empirically testable account of the interaction between system 1 and system 2 processing. The third section outlines my own 'Complex Cognitive Checking Model' of that interaction.

Heuristics and biases research has revealed a surprising difference between possible reasoning competence and reasoning performance. This evidence has sparked the 'rationality debate' which focuses on defining rationality and assessing how rational we are. Much of this debate now turns on an interpretational issue of whether poor

reasoning performance reflects special interference (due to particular task demands) with the operation of otherwise rational reasoning systems or genuinely systematic errors in human reasoning. I argue that a more detailed understanding of the mechanisms underlying human reasoning is an essential pre-requisite for advancing this debate.

Dual-process theories of reasoning are well placed to give an account of the mechanisms underlying the competence/ performance gap. However, they currently lack detail concerning how systems 1 and system 2 interact. I argue that much of the explanatory power and theoretically important implications of dual-process theories depends on how the account of this interaction is fleshed out. The crucial methodological point is that we need to develop empirically testable models of the interaction between system 1 and system 2 processing.

My paper proposes the 'Complex Cognitive Checking Model', which is loosely based on Jonathan Haidt's (2001) Social Intuitionist Model' of moral judgements. My model places both system 1 and 2 processes within the same 'cognitive stream'. That is to say the outputs of system 1 can become inputs into system 2. According to my model system 1 generates intuitive provisional judgements or solutions which can be checked by the conscious rule-or model based processing of system 2. However, due to the limited capacity of system 2 processing and real time constraints this checking procedure is often not engaged. Whether the checking procedure is engaged or not is determined by the principles of Relevance Theory. As a result of system 1 processes being the input for system 2 processes we often engage in 'Lazy Checking'. This is where system 2 processing searches for any potential justification of the intuitive judgement generated by system 1. If even weak justification for the intuitive judgement is found before any disconfirming evidence the intuitive judgment becomes the final judgement.

The 'Complex Cognitive Checking Model' has a number of advantages. It can explain the considerable evidence of post hoc justification in moral reasoning and why conscious reasoning tends to focus on justification. The model can account for the substantial evidence demonstrating that people search exclusively for evidence which supports their view, and often stop searching after finding even a single piece of supporting evidence. The checking stage provides a natural point for the application of the principles of Relevance Theory, which are otherwise in danger of floating freely throughout cognition. Finally, the model provides an explanation of how performance is improved, when it can be improved.

The acquired language of thought hypothesis (ALOT)

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Dual process theories of human reasoning and rationality are theories about cognitive architecture. One step in understanding this architecture is determining how the distinct serial and parallel processing systems interact. My thesis about the nature of this interaction falls under the cognitivist conception of the connection between

language and thought (Carruthers and Boucher 1998). In particular, I contend that the common vehicles of thought, the basic representations over which these systems operate, are the words of our natural languages. In short, our lexicon is the bridge that makes the dual processes, processes of the same mind.

The structure for which I am arguing is that of an interconnected network of natural language words. This, of course, is hardly a new claim; something along these lines is a cornerstone of associationism and is even endorsed by the archenemy of associationism: Jerry Fodor. "Suppose the mental lexicon is a sort of connected graph, with lexical items at the nodes and with paths from each item to several others" (Fodor 1983, 80). What is importantly new about my proposal is how the lexicon is situated in the overall architecture.

I claim that the lexicon is not part of a language faculty in the way that linguists have understood it to be. While the data from aphasics do not yet admit of uncontroversial interpretations, there is some evidence that general cognitive abilities dissociate more from grammatical than verbal abilities (Varley 1998) and there is also evidence of dissociations between grammatical and lexical competencies, supporting my position. The alternative to a modularized lexicon that I am proposing is that as we learn words of our natural language they are encoded into our brain at interface sites between modules. Activity in a number of modules can token a word. Words are also connected to each other, thereby *creating* a centralized cognitive domain in which activation of any word has the potential to cause the activation of any other word. Furthermore, since they are words of a natural language, having the requisite syntactic features, words can be operated on by the modular grammatical processors that linguists have identified. Thus parallel processing provides novel content to a serial processing system that is compositional. An example will help make the proposed structure more concrete.

David Milner and Melvin Goodale (1995, 1998, 2004) propose a dual route model of vision. The older dorsal stream is involved in action. It helps us respond to the real time dynamics of our environment, allowing us to duck, grasp, reach, etc. This stream can be thought of as a modular sensory-motor system that does not involve higher cognitive processing. The more recently evolved ventral stream is involved in object recognition. When we do recognize an object we are in a position to recall past encounters with the object, or objects of the same type, we are prepared to make certain inferences about it, and to behave in a number of relevant ways in response to it. In order to call up relevant memories, make appropriate inferences, and behave appropriately, the visual system has to interface with other systems. We are committed to the existence of these interface sites independently of any claims about dual processes of human reasoning. I am claiming that our neural encoding for natural language words exploits these interface sites. The ventral stream's role in our recognizing a dog *qua* dog is to produces signals that will activate appropriate cognitive and motor responses. My view is that the word "dog" is encoded in our brain so that when it is tokened the same cognitive and motor responses are activated as would be by visual (or auditory or olfactory) recognition of a dog and in this way the word stands in for what it represents. Learning words gives us new access to the pre-existing interface between modularized systems.

Once words are encoded in the system they can be associated with each other to form a lexical network. While it is possible that we possess some kind of innate representational system that mediates the learning of words, such as Fodor (1975)

suggests, for several reasons it is not plausible that those representations are interconnected in the way that our natural language words must be. First, many associations are culturally mediated and so cannot be innate, such as 'salt' with 'pepper', 'cup' with 'saucer', or 'Jack' with 'Jill'. Second, it is more conservative to impose structure on newly encoded representations, leaving our innate system intact, which has the advantage of not compromising existing cognitive abilities. Finally, priming effects show that words can be connected in a variety of ways, some of which depend on the physical properties of the words themselves, such as pronunciation or spelling, which innate representations are not likely to share.

My position deviates from standard dual process theories in that the parallel processing operations of the interconnected lexicon are higher cognitive functions. However, I do not deny that other higher cognitive functions are serial because I do not deny the existence of a language faculty much as linguists have described it. It is possible that many different mechanisms can operate on the lexicon, each being sensitive to specific features of lexical entries. For example, phonological processing is sensitive only to phonological features and ignores many other syntactic features of a lexical entry. The lexicon does not have to be part of a language module in order for there to be a language faculty—so my view does not conflict with at least the spirit of linguistic theories[1]—and much of this processing is serial. My emphasis in this paper is how words of our natural languages provide the common ground over which these two systems operate, thereby facilitating their interaction. Since the lexicon of a natural language plays this crucial role in our ability to reason, I call this position the acquired language of thought hypothesis or ALOT.

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[1] It is interesting to note in Minimalism how much is built into the lexicon.

Personal preferences for rationality or intuition

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We address the question whether there is a relation between a learned general preference to respond to judgment or decision situations either rationally or intuitively, and personality characteristics. Intuitive responses are fast, based on affect and experience-based associations and given automatically, and rational responses are slow, based on rules and given after deliberation. We hypothesize that people with an open personality may be more intuition-minded, and that conscientious people would prefer to respond more rationally. We examined two self-report questionnaires that measure individual differences in decision making style preferences, and we administered a personality questionnaire. We found clear evidence for the independence of the two reasoning styles. A possible binary structure in intuitive processing (automatic versus affective) is suggested. We found a conscientious personality characteristic to be related to a preference for rational and not intuitive information processing, and openness to be related to both decision making preferences.