Title: "Hot" cognition and dual systems: Introduction, criticisms, and ways forward

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Models distinguishing two types of different processes or "systems" are prominent and widespread in many fields of psychological science. However, they recently have been substantially criticized and challenged. In this chapter, we focus on so-called dual-process or dual-system models that differentiate between more automatic (often "hot" emotional-affective) versus more controlled (often "cold" cognitive-deliberative) processes. We start out with an attempt to describe and clarify different terminologies, including a clarification of the temperature metaphor of "hotness versus coldness." We then propose to ground and decompose the notion of "hotness" in emotion-relevant basic biological processes of the autonomic nervous system and incentive salience. Extending the scope, we then focus on two types of dual-process or dual-system models, discussing both their strengths as well as shortcomings. Finally, we suggest a diagnosis of the current state of affairs and propose possibly more fruitful directions for future research and theory-forming. As part of this, we briefly describe our *R3* model, a novel model of reflectivity that here serves as a proof-of-principle thought-experiment to address several shortcomings of existing dual-process and dual-system models.

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The future: asking better questions

The models discussed above describe interesting and important phenomena, but suffer from concerning flaws. The general underlying problem appears to be premature abstraction: “Hotness” is an intuitively appealing abstraction from physiological states and mesolimbic functions, but studies appear to use the term only as a vague abstraction, without resolving the metaphor to concrete, precise relationships. Similarly, positing the existence of “systems” suggests that we have some knowledge of what these systems are, what they consist of, what set of equations describes them, etc. In contrast, again, they appear to be used more as suggestive placeholders, appealing to common sense and intuition. Due to premature abstraction, studies will be aimed at answering badly defined questions, will be unable to specify precise measures and operationalizations, and hence will be unlikely to converge on a clear theory. This may play a role in the general methodological problems of psychological research that have recently come under scrutiny. If we don't really know what we're looking for, we are far more likely to commit some form of data-snooping or method-snooping—and have far more freedom to do so—to at least find *something*.

Of course, many researchers have recognized these problems and attempted to deal with them. One question that has been raised concerning dual-process models is whether there are, perhaps, a *different* number of systems—one, or three, or more. While this skepticism concerning the duality of models is commendable, perhaps we should be questioning the use of "systems" itself. Is defining a system for this and a system for that, a system with these features and a system with those, the best way to understand decision making, response selection, emotion, etc? We briefly note some general approaches that may lead to important alternative ways forward. First, frameworks of dual-process theories could be built more rigorously on conditioning processes (de Wit & Dickinson, 2009; Dickinson & Balleine, 2011), which may provide insight into conflict between well-defined processes related to types of conditioning, for instance by re-interpreting affective versus deliberative processes as Pavlovian-instrumental interactions (Dayan et al., 2006). Second, computational modeling of controlled and automatic processes forces researchers to at least making explicit what we do and do not know and what theories say in exact terms; such models have for instance made clear how working memory may be related to reinforcement (Hazy et al., 2006). Third, we may need the creative generation of novel fundamental types of processes such as iterative reprocessing (Cunningham, Zelazo, Packer, & Van Bavel, 2007), as explored in the next section.

R3: The Reprocessing and Reinforcement model of Reflectivity

We have previously suggested a broad class of model, termed the *Reprocessing and Reinforcement model of Reflectivity* or *R3* model (Figure 1), in an attempt to address criticisms of dual-process models (Gladwin et al., 2011; Wiers, Gladwin, Hofmann, Salemink, & Ridderinkhof, 2013). The core of the model is a cyclical process of response selection based on prior reinforcement, in particular of act-outcome associations (de Wit & Dickinson, 2009; Dickinson & Balleine, 2011). In the basic "step" of the model, current-state representations activate a set of associated responses, which activate associated outcomes given the state, which in turn are used to select responses. "Responses" in the model are highly abstract, in the tradition of Schneider & Shiffrin's (1977) nodes, and include all kinds of behavioral and cognitive responses. A response node could include functions traditionally termed executive or controlled, such as an attentional shift, search for information, or update of information in working memory. We emphasize the time-dependence of activation in the selection process due to iterative reprocessing (Cunningham et al., 2007). The available set of responses may change over time passed since stimulus presentation; and the incentive value of the predicted outcome of an act may also change over time, and is assumed to also be dependent on the state. As an example showing the potential relevance of iterative reprocessing and time dependence, recall that the attentional bias towards and away from alcohol cues in alcohol-dependent patients was highly time-dependent, moving from an initial approach to a—possibly more reflective—avoidance bias (Noël et al., 2006). Control, or reflectivity, is defined within the model as *the effective time the response selection process is given to converge by the parameters of the system*. That is, reflective processing means that sufficient time is given to allow time-dependent processes affecting response options and incentive values to converge on a stable optimum, which would not be replaced if more processing cycles were completed. Impulsive behavior occurs when responses are executed after a "too short" reprocessing time, although in certain situations external constraints would make reflective processing disadvantageous.

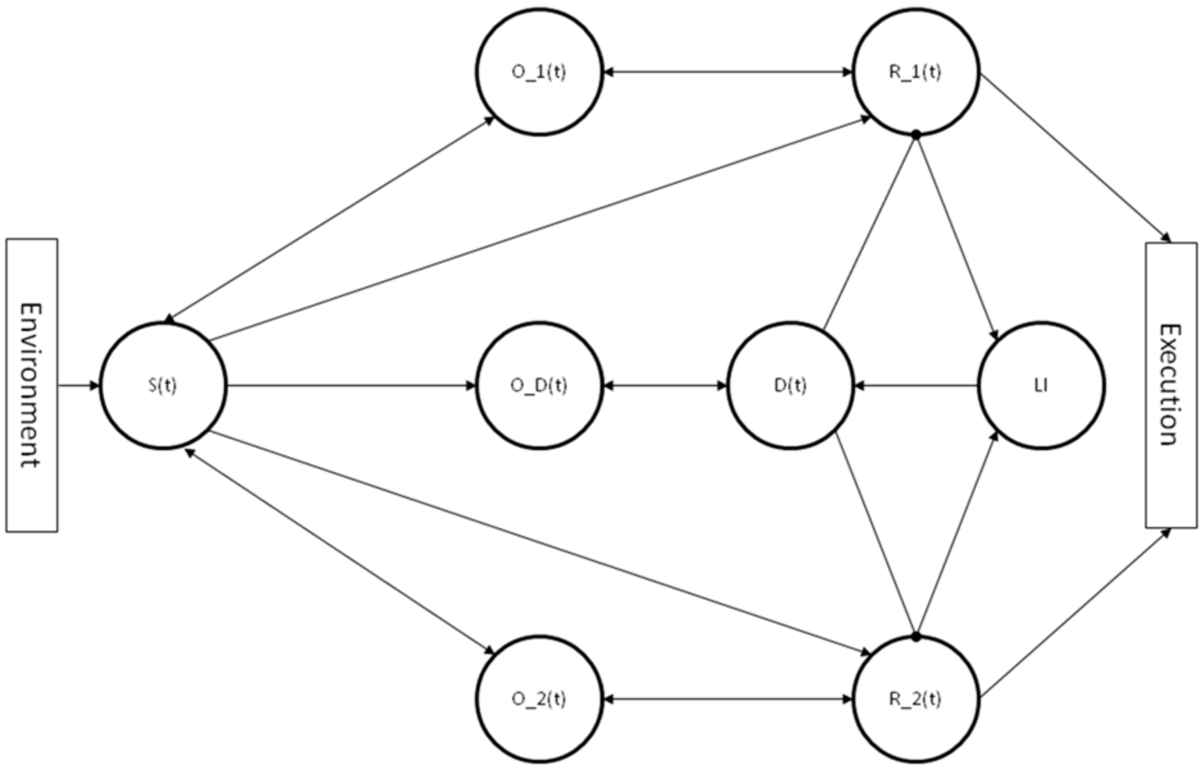

Figure 1. Illustration of the R3 model

The basic function of the unified system of the R3 model is the selection of the response (R_*i*) associated with the optimal outcome (O_*i*), given the current state (S). We show a simple case with only two activated responses. The essential feature of the model is that the activation of responses and the value of the associated outcomes varies over time. This implies that different responses could be selected at different time points following an event. A delay parameter (D) allows the selection process time to settle on non-impulsive responses that require longer to win the competition, represented here via simple lateral inhibition (LI). In the figure, arrows show (often bidirectional) effects on interaction between nodes; arrowheads represent, roughly, activating effects while blunt line-endings represent inhibtory effects. In this abstraction, the output of outcome nodes is assumed to be signed: positive for reinforcing outcomes and negative for punishing outcomes. Delay here is shown to be dependent on the State and the amount of conflict, encoded in the activation of the Lateral Inhibition node. Thus, simply changing the delay parameter can shift processing from a more impulsive to a more reflective state, without needing to assume separate systems. Each node may involve various brain networks. Reflectivity, however, is defined as an emergent property of the system as a whole, and is not assigned to any element within the system. Note further that delay is itself a response with an expected outcome (O_D), that must be associated to appropriate situations via reinforcement.

The R3 model, beyond attempting to capture the nature of reflective or controlled processing, serves as a thought-experiment intended to make four main points. First, the model addresses the motivational homunculus problem: Assuming a purely cold, unemotional control system, the question arises why such a system would serve our interests, why it would be aimed at achieving positive outcomes, even if at longer delays. Our reflective behavior has to be motivated by emotion and incentive as much as our impulsive behavior. The R3 model shows a system in which emotion and motivation, in the form of the incentive value of outcomes, are part of every response selection or decision. “Hot” stimuli could well disrupt the reprocessing cycles within the model, but note that these disruptions take place in the same system that would serve response selection in a “cold” situation with little immediate arousal (but nevertheless always some value to giving the correct response). Second, we used the model to illustrate category mistakes that can be made by ignoring what we term levels of emergence. Features that are relevant to behavioral patterns or subjective thought should not be attributed to elements of a model containing underlying processes. That is, no *process* is either reflective or reflexive, or controlled or automatic: The system as a whole functions in a more or less reflective state, depending on certain parameters—in particular the time allowed for reprocessing (note that this essential delaying is a *response* itself, subject to selection and learning processes; it is therefore not a "delaying homunculus," and could well be tuned incorrectly). One could say that every sub-process is "automatic," as reflectivity or control is only defined, or only exists, at the level of the system as a whole. Third, the time allotment serves as an illustration of a single parameter that determines how reflective response selection will be. That is, the model shows that we can have reflective and impulsive states of processing without any kind of conflict between a reflective and impulsive system, and without having to distinguish subsets of types of processes that can be classified as either automatic or controlled. Possibly interesting from this perspective is that no single brain area, such as dorsolateral prefrontal cortex, which is strongly related to working memory, should contain "control." Recent brain stimulation work provides a possibly interesting illustration of this point. Transcranial Direct Current Stimulation (tDCS) of dorsolateral prefrontal cortex has been found to enhance performance in working memory tasks (Fregni et al., 2005; Ohn et al., 2008); we recently replicated and extended this basic finding using a Sternberg task involving distraction (Gladwin, Uyl, Fregni, & Wiers, 2012). However, the same stimulation protocol failed to reduce the congruence bias on an insects-and-flowers Implicit Association Test (Gladwin, den Uyl, & Wiers, 2012). Even more surprisingly, DLPFC stimulation actually selectively enhanced performance on congruent trials, on which there was no conflict involving evaluation but there was the need to apply a stimulus-response rule. Although this line of research is only starting, such studies start to show that the function of the stimulated region is not "control," but a specific subprocess that could either aid or hinder the efficiency of reflective processing. Finally, the model changes the focus from an unspecific “strength” metaphor to a learning perspective that emphasizes how successful reflective processing at least partly results from an individual’s reinforcement history. Has an individual been rewarded for responding to certain situations with, e.g., delaying responses, or with a slow memory search strategy to look for downsides to immediate response options? Does an addict, beyond being burdened with fast and easily available drug-seeking responses associated with high incentive value, have any reinforced alternatives to which response selection could converge given sufficient time? The model appears to fit very well with the “Tools of the Mind” approach (Diamond, Barnett, Thomas, & Munro, 2007) for reinforcing the use of executive function in young children, and is perfectly illustrated by the "Think About The Answer Don't Tell Me" song (which can be found by searching for "Diamond - Day Night Presentation.mpg" on the internet). We briefly mention that the model also extends the "binding" concept—the need to temporarily associate elements in memory—from stimulus features and stimulus-responses connections to act-outcome associations. This is beyond the scope of this chapter, but may connect dual-process models to psychophysiological methods and results involving phase coding and synchrony (Gladwin, ’t Hart, & de Jong, 2008; Gladwin, Lindsen, & de Jong, 2006; Jensen & Lisman, 1998).