# The integration of motivation

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## Abstract

We propose that a control system framework will address the causal dynamics of the neural network that Depue and Collins regard as underlying extraversion. We briefly describe a control system approach and articulate the notion of integration. In this framework, the integration of goals and regards is achieved by subcortical assessment of reward in the nucleus accumbens and VTA, transmission of this information largely by dopaminergic systems and representation of reward in the MOC. Thus reward information is collected, integrated, and evaluated in the MOC. Such control decisions rely on constraining processes, a functional property of the MOC mediated largely by serotonergic neurons.

## Commentary

If we regard the brain as a hierarchy of control systems, key issues arise regarding how these systems work together to optimize the internal (e.g., endocrine) and external (e.g., motor) manifestations of extraversion.

**Control systems.** In the simplest case, each control system contains perception, action, and motivational mechanism. Perception mechanisms represent relevant situations (e.g., low blood glucose concentrations) to the control system. Action mechanisms include internal (e.g., mobilization of glycogen) and external (e.g., foraging) activities undertaken by the control system. While a very simple open-loop control system may merely connect specific perceptions with specific actions (in a reflex type of control), most subsystems also include a set point that represents a desired situation or goal. The system computes an error signal from the difference between the desired and the perceived situations and selects actions that reduce the error signal. Thus a control system determines goals and incentive levels, prescribes actions, assesses error and correction, measures progress, and ascertains whether goals have been attained.

**Integration.** We concur with Depue and Collins that multiple neuroanatomical regions and transmitter systems are involved in the control of extraversion. We also share their view that there are multiple incentives (e.g., food, attachment, sex, and safety) that depend on many control systems. These control systems vary according to the type of incentive and which components of the perception-action hierarchy are involved. Nonetheless, to ensure appropriate internal (e.g., endocrine) and behavioral outputs these multiple control systems must function together; they must be integrated. In this context, integration involves the resolution of conflicting action tendencies (e.g., approach vs. avoid). Integration also involves generating courses of action that uses available resources to satisfy the systems goals as completely as possible and takes into account all the separate constraints the different control subsystems impose of action. Thus integration mechanisms include the comparison and prioritization of control systems, combination of control systems, and the constraint of one system by others. We agree with Depue and Collins suggestion that specific, specialized control systems (e.g., those involved in thirst or hunger) function relatively autonomously. Typically they are non-interactive with other systems, although the threat of predation or other danger may suppress their function. Such systems are likely to involve primarily phylogenetically ancient neuroanatomical structures and neurotransmitters. At a less specific, higher level, control systems are more likely to interact - facilitating and constraining each other. Such systems are likely to include multiple cortical and subcortical components and to rely on diverse, interacting neuromodulators.

Subsystems must be able to generate information such as reward potential, the resources needed to meet the specified goal, and to assess current progress toward that end. Subsystems must be able to use information about the status of other subsystems, and need to be able to constrain their output accordingly. The system would not need to function linearly and sequentially - causes of behavior could arise from alterations anywhere with the system. Control systems supporting extraversion would be continuously operating, unceasingly evaluating and maintaining goals. As Depue and Collins indicate, the available human and animal data implicate the MOC as playing a primary role in such a control system.

Our figure presents an idealized control system framework for extraversion. We can conceive of a *goal signal* to be information describing perceivable properties of a desired state, and a *reward signal* as information describing the satisfaction of, or progress toward, a goal. A *constraint signal* is information sent from one area to another which reduces that area's options and/or activation level, and a *constraining process* as a process within an area which evaluates and selects one possible activation pattern and reduces others. Goal and reward processes would be mediated by dopamine, and selection and constraining processes by serotonin. We can tentatively identify VTA and NAS with the setting of goals and assessment of reward in the subcortical subsystem. The extended amygdala may be involved as an intermediate integration process for goal and reward signals.

**FIGURE ABOUT HERE**

**Extraversion.** Depue and Collins suggest that individual differences in dopaminergic function underlie individual differences in extraversion. A control system model would suggest that individual differences in dopaminergic function may achieve this end by altering the *rate* at which the system processes information. This might be tested by examining the effects of dopaminergic agonists on the latency to engage in the behavioral manifestations of extraversion (e.g., approach). The prediction would be that differences between highly extraverted and less extraverted individuals would disappear with this treatment. Less extraverted subjects would be more responsive to this pharmacological intervention. The control system approach would also lead to the expectation that individuals with diminished serotonergic function in the MOC would be less able to develop integrated and constrained actions and so less likely to engage in extraverted patterns of behavior. This could also be tested by localized application of serotonergic agonists to the MOC. Again the expectation would be that more extraverted individuals would be less sensitive to such treatments.

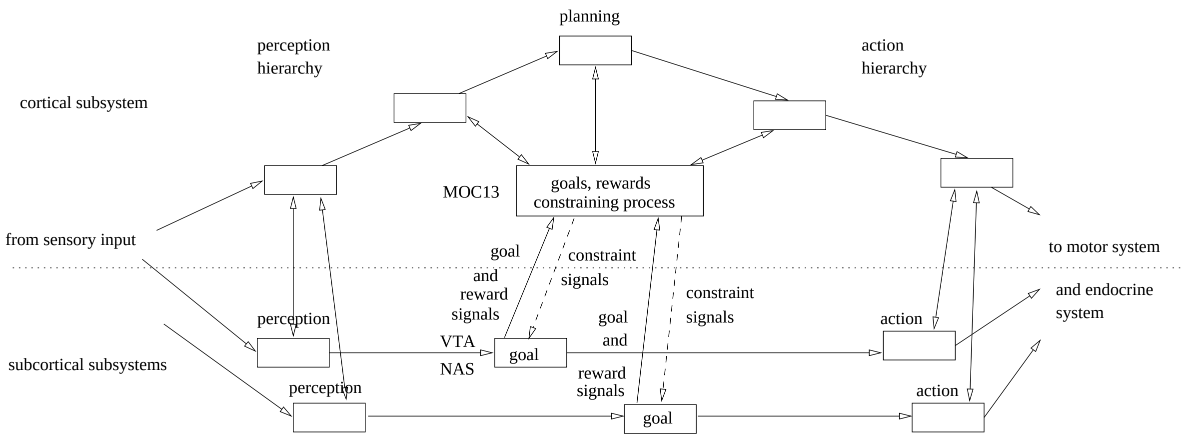


Figure 1: Two-level system framework consisting of cortical and subcortical substems

Figure caption

**Two-level system framework consisting of cortical and subcortical subsystems**