A quick overview of LOCEN-ISTC-CNR theoretical analyses and system-level computational models of brain: from motivations to actions

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1. Introduction: the purposes of this brief document

The goal of this brief document is to give a focussed overview of the theoretical neuroscience and computational modelling work carried out by the Research Group Laboratory of Computational Embodied Neuroscience (LOCEN) of the ISTC-CNR (http://www.istc.cnr.it/group/locen). The overview focusses on the work of LOCEN directed to understand the system-level overall organisation of brain that allows organisms, in particular primates, to express multiple motor behaviours sub-serving multiple needs, and how such behaviors are acquired through learning processes. This overall goal of LOCEN involves some important topics of current cognitive science, in particular: (a) the goal-directed/habitual hierarchical organisation of behaviour; (b)
the organisation of motivational systems at the basis of the learning and selection of motor behaviours.

2. Computational models of goal-directed and habitual behaviour

Instrumental behaviour is a fundamental means through which animals, and in particular primates, flexibly and adaptively accomplish their multiple needs with variable internal and external conditions. Instrumental behaviour can be subdivided in habitual and goal-directed behavior. Habitual behaviour brain mechanisms link specific stimuli to instrumental behaviours (S-R), i.e. behaviours that are not innate but have been acquired by trial-and-error processes (Mannella and Baldassarre 2007; Ciancio et al. 2013; Caligiore et al. 2014). Goal-directed behaviour mechanisms, instead, link desired outcomes to instrumental actions (A-O) (Baldassarre et al. 2013), for which the triggering of behaviours is dependent on the animal's relative desirability of those outcomes given its current needs and stimuli in the world (Mannella et al. 2010).

The acquisition and expression of multiple behaviours relies on two highly integrated brain systems (Baldassarre and Mirolli 2013; Baldassarre et al. 2013; Thill et al. 2013). The first is related to the two main cortico-cortical pathways of brain (Caligiore et al. 2010): (a) the dorsal pathway that, from visual areas and passing through parietal and premotor cortex, reaches motor areas: this system subserves the encoding of affordances and the on-line guidance of action (Caligiore et al. 2010); (b) the ventral pathway, that from visual areas, reaches the temporal cortex, encoding the identity of objects/resources, and then the prefrontal cortex: this system encodes the animal's goals (Thill et al. 2013) and implements more sophisticated processes such as planning (Baldassarre 2003; Pezzulo et al. 2007) and imaging (Seepanomwan et al. 2013).

The second brain system is formed by the basal ganglia-cortical loops, anatomically 'intercepting' the late stages of the two cortical pathways, and formed by (Baldassarre et al. 2013; Chersi et al. 2013): (a) the ventral basal ganglia-prefrontal cortex loop, supporting outcome/goal selection; (b)
the medial basal ganglia-associative cortex loop, subserving
the selection of the contents of associative cortex – e.g.,
attentional targets, affordances, and objects identity–, and
goal-action contingencies; (c) the dorsal basal ganglia-motor
cortex loop, supporting the trial-and-error learning and
selection of actions (Baldassarre 2002; Caligiore et al. 2014)
possibly in concert with the cerebellum (Caligiore et al.
2013).

3. Motivational systems behind motivation and learning

Ventral striatum is a key nexus between the generation of
motivational value of action outcomes (e.g., ingested foods),
and the selection of goals (e.g., seen foods) implemented by
the ventral basal ganglia-prefrontal cortex loops (Mannella et
al., 2013). The values of outcomes can be generated by
extrinsic motivations, related to the attainment of resources
increasing the animal's biological fitness and involving areas
such as amygdala (Mannella et al. 2010; Mirolli et al. 2013).
This generation of value is based on Pavlovian processes
(underlying the triggering of innate reactions towards the
brain, body, and world, Mirolli et al. 2013) and their close
interplay with instrumental behaviour (Cartoni et al. 2013).

Alternatively, values can be generated by intrinsic
motivations (Baldassarre and Mirolli, 2013; Baldassarre et al.
2014), related to knowledge and skills acquisition
(Baldassarre 2011) and linked to the hippocampus, detecting
the novelty or surprise of stimuli (Barto et al. 2013), and
basal ganglia-prefrontal cortex processes, related to
competence acquisition and agency (Schembri et al. 2007;

The assignment of value to possible action outcomes and
goals strongly relies on the production of neuromodulators,
such as dopamine and noradrenaline, regulating the overall
brain functioning (Fiore et al., 2013), the basal ganglia
selection processes (Fiore et al. 2013a), and intrinsic and
extrinsic learning processes (Mirolli et al. 2013).
4. Conclusions

The overall organisation of brain architecture and processes subserving primates' flexible behaviour is very complex. However, the work of LOCEN-ISTC-CNR reviewed here shows that its interdisciplinary investigation, pivoting on system-level computational models and computationally informed theoretical analyses of empirical evidence, can lead to identify relatively few main architectural and functioning principles underlying them.

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