Computational models for understanding of the role of brainstem in disorders of consciousness

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Introduction

Consciousness is the highest-level control function enabling awareness of oneself and the environment. This function results from the integration of information in the whole brain, and therefore is one of the most complex processes within human organism. Consciousness is embodied in the whole human brain, and its neural correlates depend on particular context.
The brain stem plays very important role in regulation of the overall arousal of the brain and in control of the information flow from and to the body. Lesions of the brain stem lead to serious disorders of consciousness, including coma, minimally conscious state, vegetative state or locked-in syndrome. Understanding the details of the brainstem's role in consciousness control is still a challenge [1, 2] that we try to address using computational simulations [3, 4, 5].

Concepts of the consciousness control

The process of consciousness control may be viewed from several points of view. It requires synchronous co-operation of many parts of the central nervous system (CNS) including Ascending Reticular Arousal System (ARAS) and cerebral hemispheres. Conscious perception of external stimuli requires activation of frontoparietal cortices and low-level specialized cortices. Frontoparietal activation can also be found during subliminal stimulus processing. The approach of Parvizi and Damasio is focused on the brainstem reticular formation contribution to the basic somato-sensing processes critical for emerging core consciousness reflected in cerebral cortex activations. The process of non-specific brain activation underlies wakefulness and attention which enables consciousness. According to this concept consciousness involves at least two sets of mechanisms:

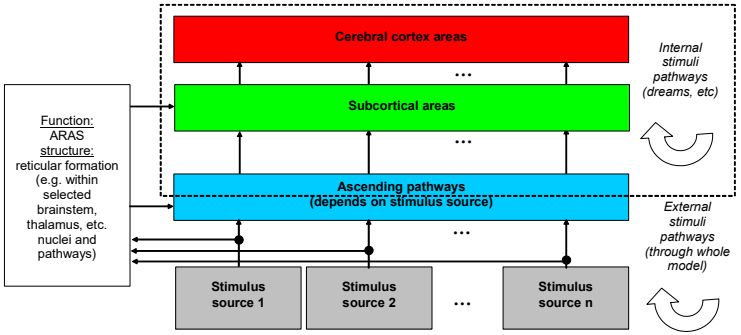
- core consciousness, the most basic form of consciousness that maps generally body state and interactions with subjects, environment and other people within spatial and temporal context, responsible for "the feeling of being conscious";
- extended consciousness build on the core consciousness, memory, language abilities, etc.

Activation of the widespread regions of cerebral cortex by the brainstem is mediated through at least several neurotransmitter channels originating from distinct sets of brainstem nuclei.
Consciousness functions using results of cortical computations, cognitive binding, synchronization of the neural correlates of consciousness and preserved functions of the most important CUN parts, including thalamus and brainstem. Consciousness based on integrated information processing is necessary for flexible control of behavior. The thalamocortical system can play unique role in this process providing both:

- specific connections involved in representing externally-directed attention,
- nonspecific connections involved in higher-order cognitive processing, self-awareness and introspective mentalizing [3, 4, 5].

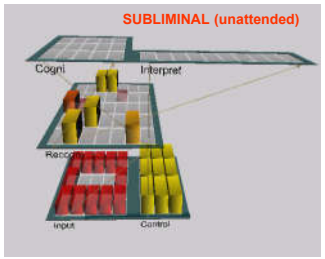
General brainstem role within consciousness control

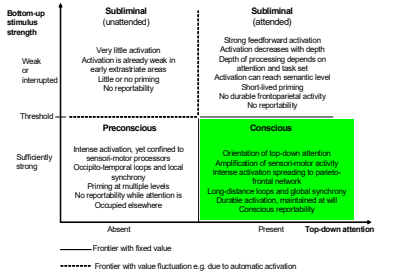
according to the concept by Duch [6]:

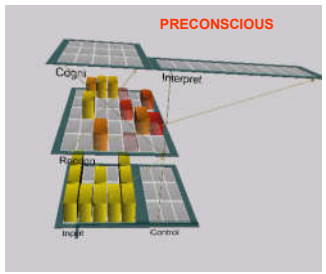


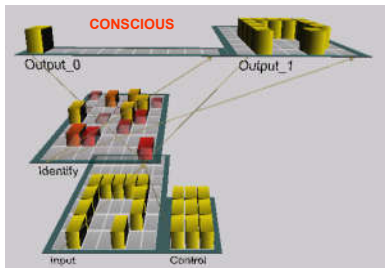
Models

Basic models: switchboard (activation selection device), physiological, hierarchical (ARAS).
Example: Taxonomy of conscious, preconscious and subliminal processing by Dehaene et al. [7]





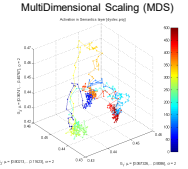




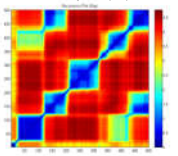
Further modelling work

- More detailed models based on three-stage neuro-computational modelling using Emergent or Genesis software [8].
- Modelling using PGenesis on the Tryton supercomputer (with Gdańsk Technical University).
- Physiological vs. pathological information processing in vegetative and minimally conscious states, locked-in syndrome, etc.(InterDoctor Project, Neurocognitive Lab).
- Influence of noise on functions relevant to consciousness.
- Conclusions from computational simulations on deep brain stimulation – how to maximize brain arousal?
- Traditional vs. new measures of information integration.
- Modelling of neural plasticity as s result of e.g. post-stroke neurorehabiltiation.
- Visualization for understanding of neurodynamical systems via Fuzzy Symbolic Dynamics and recurrency plots [9, 10].

MultiDimensional Scaling (MDS)



Recurrency Plot (RP)



Conclusions

Computational approach to consciousness as a flexible control seems to be a good solution for better understanding of the nature of these complex processes. The role of brainstem in conscious information processing is not sufficiently acknowledged and there is a great need for further interdisciplinary research in this area.

References

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