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Short Communication

Efficient Cognition needs Sleep

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Abstract

Sleep appears to be a mandatory prerequisite of cognition for all animals including humans. There are many studies on the interrelation between cognition and sleep emphasizing the positive effect of sleep on memory consolidation, especially during SWS phases. Here, it is argued that, in some sense, complimentary, REM sleep is required for beneficial forgetting. A novel cognitive architecture, the Ouroboros Model, can shed some light on the multifaceted interdependence of efficient cognition and getting enough sleep.

ABBREVIATIONS

SWS: Slow Wave Sleep; REM: Rapid Eye Movement Sleep

INTRODUCTION

All animals without exception appear to require some sleep for their survival, and no account of cognition could be claimed as anywhere near complete without taking note of the fact that the wakeful cognitive capabilities of the most successful actors (and also not so highly sophisticated ones) depend on sufficient sleep.

The Ouroboros Model proposes a novel algorithmic architecture for efficient data processing in living brains and for artificial agents [1]. At its core lies a general repetitive processing loop where one iteration cycle sets the stage for the next. During perception, sensory input activates data structures (schemata), which bind together similar constituents, which have been encountered as linked before. Expectations are kindled, and slots are filled with the currently available input. This effective biasing facilitates the actual excitation of representations for corresponding attributes. In particular, it also affects slots, which stay empty at the time. At regular intervals in an overall cyclic process, predictions are compared with the actually available input. Depending on the outcome of this "consumption analysis" different next steps like searching for further data or a reset, i.e., a new attempt employing another schema, are triggered.

Given stringent time constraints in the real world concerned with survival, consumption analysis inevitably produces "leftovers", i.e., not-allocated features as well as not-confirmed concepts, which inescapably accumulate with time. Proposed already some years ago, substantial evidence supporting key tenets of the Ouroboros Model has been accrued in widely dispersed fields [2].

The Ouroboros Model explains sleep as a specific and multifaceted housekeeping function for maintaining appropriate signal / noise conditions in brains with one main function of actively erasing data garbage during REM ("paradoxical") sleep. Many at first sight rather diverse observed characteristics and proposed functions of sleeping and dreaming can thus be seen as consequences of efficient data processing and appropriate clean-up.

It is claimed that this comes in addition, and the view dovetails with better established memory consolidation accounts, which primarily focus on SWS stages [3].

In the following some key points and hypotheses are enlisted with the intention to very coarsely sketch the outline of some promising research directions.

Facets of the interlinked relation of cognition and sleep as highlighted by the Ouroboros Model:

- All partly activated but not "consumed" content stays "tagged" and constitutes "left-overs"
- Quite generally, exciting and especially novel activities necessitate an increased need for sleep as the involved schemata are overflowing more, in particular, when they are still developing
- Amongst others, for this reason, babies and children need more sleep than adults
- More remainders occur during novel and challenging activities compared to routine operations; independent of the age, and the same for humans and animals, e.g., after travelling in unknown countries or settings, sleep demand and quality is enhanced
- Disturbing, threatening and unresolved issues will predominantly surface as dream content as their processing could not be concluded yet; getting somehow rid of (parts of) them might indeed help in coping or preparing for threatening situations in the future [4]
- Emotions mark situations as significant / relevant for an actor; episodes, which stir emotions, because expectations – e.g., norms – are violated, will preferably provide material for dreams
- Explicitly suppressed content will preferentially resurface in dreams [5]

- The deletion or at least damping of erroneous associations and traces of expectations or of perceptions, which have not been accounted for, frees capacities for more useful stuff, and
- It preserves and even enhances correct and well-established connections; the ensuing increase in signal / noise makes memory entries, checked for consistency by successfully completed consumption analysis, stand out and thus easier to retrieve and reactivate
- The variations in neuromodulator levels during REM sleep phases reported in the literature appear to be well in line with their proposed role in this general "cleaning up", i.e., some general wide-spread activation without an enhancing modulation for storage (monoamine neurotransmitters at very low levels) [6]
- Inhibition of return suppresses synapses locally, and consequently also temporarily linked assemblies in cortex, which, in the absence of a suitable modulator, will not be linked permanently, and neither will an index entry be recorded
- Much of the "replay" of activations during vivid dreams as observed given the available technical means is hypothesized to be similar but not identical to the original activations (i.e., possibly sharing "index" entries in hippocampus but not all fine details) [7]
- The idea is that with the activation under special conditions of REM sleep "tags", which mark unresolved issues are erased, while no new permanent memory and no fresh entry in the hippocampal "index" are laid down (similar as for accompanying atonia, i.e., no actual movements are performed)
- The paradoxical activity of brain cells and -areas during sleep thus seem to fit well under this account with the functions, which they are assumed to perform during awake behavior while the lack of sleep causes severe degradation of cognitive capabilities; in particular, staying focused, concentrating and keeping options apart for decisions are compromised to the point of hallucinations occurring [8]
- Consumption analysis is partly suspended during dreaming
- The combination of activations, which could not be properly processed before, certainly might be experienced as bizarre according to the standards during waking
- The focus here is on removing data garbage; some overall weakening of earlier established connections results but this does happen in a meaningful way, i.e., not at all indiscriminately; previously successfully consumed connections are spared and in fact "carved out" more distinctly, as predominantly scattered remainders (probably in many cases near fits) are removed and the signal/noise ratio for valid memories is thus enhanced
- "Unlearning" had been proposed before [9]; here it is hypothesized how harnessing the basic lay-out of the Ouroboros Model with consumption analysis at its core removes "disturbing" material from memory and thus optimizes a complete cognitive system
- In case that some "randomly" excited activations (unexpectedly) fit very well and make new sense, the overall activity can be high enough that a fresh link is created, maybe even a memory entry is directly generated; they surface as later remembered Aha experience during dreaming or enhanced creativity and improved understanding after waking [10,11].

One mechanism of increasing available capacities and enhancing the accessibility of useful memories via improvements in signal / noise does of course not exclude that there are other, even more direct, processes also happening during sleep (in particular, during non-REM phases), which can also boost wake performance.

Taken together, the Ouroboros Model claims to shed some light on manyfold and hitherto independent observations. It does this on a most restricted conceptual basis, i.e., schemata organized and stored in non-strict hierarchies and just one general purpose data processing procedure for all types of content.

Dreaming is mainly to forget disturbing or unimportant left-overs, which arise and accumulate inevitably during cognitive processing under tight time-constraints according to the Ouroboros Model.

In this short note, the above hypotheses are given with only very limited references. Attempts to work out in detail the proposed relations are ongoing. Collaborations to this end are highly welcome.

An immediate hypothesis to be tested would be that individual persons with different interests and expertise dream and remember dreams differently when subjected to identical priming procedures, but always involving content somewhere close to and (slightly) beyond the borders of their ready-made schemata.

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