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Discrete states of consciousness

An inquiry into the dynamics of conscious cognition based on neurophysiological evidence.

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Introduction

Life can be described as a higher order process and its seemingly infinite complexity is continually revealed as each process can be discovered as a higher order expression of lower-level phenomena. For example, a macroscopic phenomenon like locomotion as a function of muscle contraction can be considered a higher order expression of microscopic phenomena where sarcomere contraction is a function of sliding filaments (Silverthorn, Johnson 2010). Going further into the molecular dynamics of sliding filaments, there is the interaction of actin and myosin in the formation of dynamic crosslinks. Going even deeper down the rabbit hole, eventually the level of quantumdynamics seems the limiting edge of small particle research, not even speaking of its relevance to macroscopic muscle contraction. Similarly the brain can be considered as a higher order structure that implements a higher order process as it integrates streams of information, coming from both the external sensors, as well as from specialized brain areas that participate in the realization of conscious cognition.

The brain is a network of communicating units that encode, receive and distribute information. The basic unit is known as a neuron, which can functionally participate in the neural network with the capacity to communicate the universal language of the network i.e. the action potential signal transduction. A neuron can represent information in great diversity and has the ability to develop functional specialization. For example, light is captured by the retina of the eye, which is a collection of specialized neurons that are able to transduce sensory information that is coming through the eye. These photoreceptor cells correspond with neurons in the brain, through one or more neurons, dependent on the level of amplification of the transduced signal (Purves 2012). The first-order visual representation consists just of contrasting dots, as a function of ON and OFF ganglion cells, which reflect the relative contrast between center and surround intensity of their respective receptive field. The corresponding neural maps for first-order visual processing are located in the primary visual cortex (V1), denoting its engagement in low-level stimulus processing.

Research in visual neuroscience has revealed that low-level receptive fields are gradually integrated into more complex receptive fields, as neuronal activity spreads from the primary visual cortex to secondary and higher visual cortical areas i.e. there is a distinctive visuotopic hierarchy, in which higher order cortices process increasingly expanding retinotopic fields. For example the receptive fields of multiple neurons in V1 are integrated through a neuron in V2, giving rise to a higher order visual representation, such as spatial frequencies. As neural activation progresses into higher order cortical processing visual perception is increasingly enriched with visual detail, including edge orientation, gestalt properties, hue, motion, object and face recognition, scene analysis, movements, causality, event organization and higher order visual phenomena such as object permanence, size constancy, color constancy and shape inference. Visual perception is shown to be organized and structured to support effective cognitive functioning (e.g. providing constancy and stability in the eye of rapidly changing visual parameters). This facilitates object awareness by isolation and tracking through figure-ground segregation (Wolfe, Keith R. Kluender & Levi).

The brain is a complex neurodynamic network with the innate capacity to evolve and adapt towards optimal use of cognitive resources. Repeatedly it has been demonstrated how flexibly the brain can adapt to extreme environmental conditions and even when suffering severe brain damage. Recent

developments in neuroscience have revealed that the brain is highly plastic. For example, the brain is capable of cross-interpreting sensory signals in sensory substitution (Doidge).

In addition the brain is capable of establishing an almost infinite diversity of conscious experiences that are unique and phenomenally rich. Consciousness can be considered as one of the highest expressions that can possibly be conceived of. The higher order properties of consciousness appear almost as transcendent, like operating on a completely different level with different laws. This shows even more from the multitude of theories that are developed over time, as consciousness often appears to emerge on a higher level through a 'metaphysical leap'. Until now there has always been a metaphysical gap in understanding consciousness, which some theories (e.g. dualist views) adhere as an indefeasible truth. The presence of a metaphysical gap that is unsurmountable by any existing theory is known as the hard problem.

Even though the metaphysical gap cannot be currently resolved, evidence in brain research shows that consciousness is functionally constraint and related to the dynamics of the neural network. The neural network is a system of massive neuronal connections, easily obscuring any observation of functional organization that is involved in the realization of consciousness of what turns out to be an 'ordered mess'. Although it is not known how the brain can exactly implement conscious cognition, neurophysiological research slowly reveals a functional neural network that is organized in relation to certain constraints. These exist on the level of neuronal communication that is fundamentally built on the mechanism of the action potential. Every higher order network property emerges through neuronal interaction via the action potential. Even though the action potential is a higher order expression of the underlying molecular dynamics, this is not directly relevant in the establishment of consciousness.

Given that neural network communication fundamentally involves discrete signaling, the neural network has been compared to a digital circuit. From this perspective the brain can be compared to a computer, which can be considered as a causal medium that can realize computational processes. A computer that could replicate the complex causal organization of the brain could then simulate neural network states and its associated causal patterns that presumably give rise to conscious cognition. The validity of this comparison depends on whether consciousness can be reduced to a computational process or a neural correlate of consciousness. This question is relevant to the field of artificial intelligence that concentrates among other on modelling and simulating conscious processes. Even though the exact mechanism of conscious cognition has not been discovered yet, current scientific evidence already indicates globally how conscious processes are implemented on the neural network. This has inspired models to replicate these causal neural dynamics through an artificial substitute in order to facilitate reciprocal insight in conscious processes. That is to say, there is a partial assumption to the extent that neural patterns can fully account for conscious phenomena, based on what can be explained by existing data.

Conventional criticism of reductionist theories state that the whole is not the sum of its parts. This is not quite correct. One better says: properties of the whole are not the *sum* of the properties of the parts, but a different *function* of these. It is actually the challenge of science to discover this 'function', to discover what properties emerge when several parts work together in the right way. Sodium Na and chlorine Cl are poisonous; but their combination NaCl, table salt, is (in small quantities) an essential nutrient. Another example is a desktop computer system that is functionally operating as

such, because it contains many essential parts. None of the parts can provide the functionality of the whole. Moreover, each part, like the memory unit, again forms a whole consisting of parts. And so on. Therefore there often exists a hierarchy in complex systems. Going down a step in this hierarchy, the essential parts of a level cannot function as the whole, but are necessary for this whole to operate well; moreover one needs a coupling mechanism. When examining a particular layer in a complex system one is essentially exploring two questions. First, how this particular layer is organized using its interacting parts. Second, how the properties of this particular layer are expressed by those of its parts. These questions are based on the thesis that the properties of the whole can be understood or expressed as a 'function' of the properties of its parts. The success of science is partly due to the fact that in many cases this 'function' can be understood pretty well.

This review focuses in particular on the functional mechanisms of consciousness and its relation to the brain on the level of the neural network. Conscious experience will be described in terms of the behavior of neural networks, with an emphasis on the intention to understand dynamic properties of consciousness, rather than identifying precise causalities in the emergence of consciousness. It is taken as a premise that consciousness is not rooted in a specific locus, but is realized by a dynamic neural network interaction. In this way properties of the neural networks will determine boundaries to the possibilities that consciousness can come to expression.

Perhaps the interdependence between dynamic network activity and conscious expression is most evident in the temporal dimension, because the way in which this activity evolves is constraint by the temporal interval of neuronal communication. Therefore the temporal properties of the network will be explored first and how different phases relate to specific neurophysiological signatures that differentiate conscious from unconscious processes. Higher network properties, including synchronization, reverberation and recurrence will be discussed and their implicated role in conscious cognition, the maintenance of conscious content and conscious discreteness. Synchronization can be considered as the coupling mechanism for interacting local processing networks (Fries 2005).

There is ample supporting evidence that consciousness acts in a discrete way, which will be discussed in the beginning. Conscious discreteness, particularly inspired by Dehaene, is a recurrent theme in this review that is considered as the fundamental property on which mental state is build. The theoretical advantage of discreteness is to be able to compare conscious processing with a digital processing algorithm. This smoothes the process of understanding consciousness through dynamic network interaction and is also the basis of modelling consciousness, in particular the global workspace and neural Turing machine. As emphasized by Barendregt and Raffone, the human advantage of conscious discreteness is the ability for meta-awareness, which enables deautomatization (i.e. deconditioning) through reflection.

The following properties of conscious cognition will also be examined: that is biologically innate driven adaptation (i.e. biological determinism), mutually exclusive discrete content (i.e. internal consistency), an implicit self-system representing unconscious processes that shape the experience of conscious content, and limited capacity (i.e. conscious access is constraint). A higher order mechanism of access-based consciousness will be described that is meta-representational and can adapt to different types of content, but also different types of awareness will be discussed in relation to these properties, spanning the sensory modalities, but also cognitive sources that include inner life.

First, consciousness is described in relation to visual awareness, because there exists a great deal of data about conscious processing of visual stimuli. Studying the visual domain has the benefit of accurate methods that are available to measure attention, which is a determining factor, in not only visual consciousness, but consciousness in general. Therefore the role of attention and the associated neural processes that regulate attention will be discussed in relation to unconscious and conscious processes, in which unconscious processes primarily shape a first-order phenomenal awareness, which contrasts with a second-order access-based consciousness that is shaped by conscious processes. A comparison between visual awareness and auditory awareness reveals similar neural mechanics in the realization of these types of sensory awareness, indicating a higher order conscious mechanism.

Perception and action are related via sensorimotor mechanisms, which are also involved in a wider context of complex cognitive abilities, such as cognitive monitoring. Therefore action awareness, which includes motor awareness and the establishment of executive intention, will be discussed in relation to perception. Integration of sensory information about the body, which is acquired via interoception, proprioception and kinesthesia, is essential in the establishment of motor awareness, which can be more accurately described as a form of intentional awareness. A monitoring process is a continuous process that consists of discrete cognition action cycles. In this process error-awareness plays an important role in directing cognitive resources to adjust current conditions towards envisaged conditions. The discussion of error-awareness in the broader field of perception, action and differential network activation that regulate attentional bias is a lead-up towards an integrated concept of conscious processing in the form of discrete cognition cycles.

Neurophysiological data on conscious processing is integrated in a framework of conscious cognition that is particularly inspired by the global workspace model. Variations of the global workspace and similar architectures like the neural Turing machine are considered to provide an extensive and elaborate understanding of the mechanics of awareness. In the last section, different forms of meta-awareness will be described, including stimulus-oriented subject-object awareness and reflexive awareness based on recollection of an explicit self (i.e. inner life).

Finally first-order and second-order awareness in relation to attentional processes in meditation will be explored, because meditation is a pure cognitive practice or training in attention. This includes open-monitoring, because it involves a non-selective open field of endogenous attention that is naturally distributed, but also focused attention, because it involves sustained bias in a singular dimension. These pure meditative states have provided valuable neuroscientific insights on awareness and attention, minimizing possible confounders. States of awareness in meditation are patterned in differential network activation that can functionally be explained by the global workspace model.

A concluding summary lists the most important findings and its implications for conscious cognition. Subsequently, limitations of the data and areas that are in need of specification are discussed in the wider context of neuroscientific research together with suggestions for future research.

Section 1: Sensory awareness (input)

The first section aims at understanding how sensory input gains access to consciousness. Specifically it is aimed at the question: what is the abstract mechanism of operation in the process of establishing conscious content and what are the neural components that are repeatedly expressed in the formation of conscious frames that drive a content-independent adaptive neurodynamic process. In other words, referring to the question stated in the introduction, how is sensory awareness realized by its interacting parts in a dynamic neural network interaction. Therefore this section starts with an analysis of the type of neural signalling that is involved in conscious processing, which is also a determining factor to the second question that was stated in the introduction: how are the properties of consciousness dynamics expressed by those of its parts i.e. how does the neural network behave and evolve with a concurrent emergence of conscious cognition in specific expressive boundaries.

EEG recording is a valuable tool for measuring brain activation with high temporal resolution. This allows visual brain activation to be tracked through time with temporal precision, making it possible to record the neural correlates, and especially the temporal mechanics of stimuli detection in unconscious versus conscious processing. On the other hand fMRI can measure brain activity with high spatial resolution, which allows the visualization of the spatial distribution of network activation in relation to conscious processing.

A description of different forms of conscious processing and their associated network behaviour reveal that oscillatory gamma synchronization and recurrent patterns are neural signatures of conscious access. These dynamic properties will often be mentioned in relation to conscious processing throughout this review, as will be the discrete nature and limited capacity of conscious access.

Temporal correlates of consciousness

The action potential is a short voltage spike with a temporal resolution of about 5 ms (Purves 2012). This imposes a constraint on continuous sampling of the environment by discretizing the stream of sampled input. Initially sensory inflow is closer to the resolution of the voltage spike of 5ms, followed by an accumulation of temporal delay as each processing step is asynchronously recruited during the incremental construction of a higher order sensory representation, peaking with the establishment of a conscious frame.

A study by Lamme and Roelfsema, (2000) demonstrated that the temporal resolution for conscious cognition is at least 120 ms. This implies that conscious cognition is a temporally discrete process with perceptual sampling frames spaced out by at most 120 ms. In contrast, other studies have demonstrated early visual activation in the absence of conscious perception (Sergent, Dehaene 2004). For instance, Schiller and Chorover, (1966) observed early visual activation of masked stimuli through EEG recording. This implies that cortical activation in the absence of conscious cognition ssuggests that ongoing unconscious processes could accommodate higher sampling rates than conscious processes.

Experiments with EEG measurements have demonstrated that stimuli that could be consciously reported, correlated with a strong positive current that was broadly spread across the scalp, called the P3b event related potential (ERP) (Dehaene, Changeux 2011). It was described as a late positive current with a temporal onset of about 300 to 500 ms. P3b ERP correlated fMRI recordings revealed that broad

current spreading in P3b correlated with broad fMRI activation in multiple brain areas, including the hippocampus, the temporal cortex and higher association parietal and frontal cortices. Widespread cortical activity was also found exclusively on conscious trials compared with unconscious trials in visual processing. For example, unmasking of a visual stimulus increased widespread cortical activity that correlated with verbal reports of stimulus visibility (Tse et al. 2005). This implies that conscious processing has a unique neurophysiological signature that is both temporally and spatially exclusive.

Phase synchronisation

There are several studies demonstrating that conscious processing is correlated with phase synchronisation. A study by Melloni et al. (2007) showed an increase in local gamma oscillations in both unconscious and conscious processing; however conscious processing was differentiated by a transient long-distance synchronization of gamma oscillations, including higher cortical areas. After this initial transient shift, unconscious and conscious processes continue to diverge in different neurophysiological patterns. Also the measured P300 component during conscious processing correlated with the transient global increase in gamma oscillatory phase synchronization and enhanced theta oscillations were found as a reflection of internally buffering a conscious working memory representation Melloni et al. (2007). This suggests that large-scale integration of gamma synchronous neural assemblies arise and dissolve at a frequency in the theta band.

This is supported by a study on binocular rivalry by Doesburg et al. (2009), in which it was demonstrated that perceptual switching correlated with gamma synchronizations that reappear at a theta rate. This implies that the occurrence of a stable conscious percept during binocular rivalry is represented by the emergence of a new gamma synchronous neural assembly. From this experiment it was concluded that discrete conscious perception is realized by oscillatory gamma synchronization in the relevant cortical areas, which is in sync with an ongoing theta rhythm.

Awareness in the visual modality

In a review based on brain imaging data about conscious visual perception Dehaene et al. (2006) delineate different forms of visual processing that extends beyond dissociation between unconscious and conscious processing. They state that conscious access is a function of vigilance, bottom-up activation, long distance reverberation and top-down amplification.

Vigilance is a function of brain stem nuclei that project to a global thalamo-cortical network, constituting a modulatory effect by bringing the thalamo-cortical network closer to threshold, and therefore more receptive to external stimuli.

Early visual activation in the form of bottom-up activation builds incrementally into a more visual complex representation of the visual scene. As explained above the integration of receptive field information is essential to this mechanism. For example, visual area V4 is responsible for processing a higher order visual attribute, in this case color.

Long-distance reverberation and top-down amplification are concurrently active in maintaining a recurrent brain state by connecting early brain activation with the cortical association areas (parietal and frontal cortices). This mechanism is conducive for reverberating information, thereby stabilizing a coherent perceptual frame independent of initial stimulus duration. It is also effective in rapidly

propagating information throughout the brain. Dahaene et al. (2006) argue that these are the prerequisites for conscious cognition as "a distinct internal space, buffered from fast fluctuations in sensory inputs, where information can be shared across a broad variety of processes including evaluation, verbal report, planning and long-term memory."

Discrete conscious cognition

The notion of an internal space that can hold a perceptual frame online indicates that at least conscious perception is not continuous, as a conscious frame is buffered away from the fast fluctuations of sensory input. This is consistent with the late onset of P3b as correlate of conscious awareness and the early transient global increase in phase synchrony of gamma oscillatory activity, evidencing that a conscious frame is stabilized with a sample of visual information. Also the bottleneck principle, thought to underlie the psychological refractory period, is consistent with an online internal space. A dual task paradigm demonstrates a clear constraint on cognitive load: when information is buffered for executive manipulation, no simultaneous sensory information can reach the one and only available buffer. Together this data aims to a discrete process of conscious sampling that is supplemented by parallel unconscious processes that move towards a threshold for conscious reverberation.

Visual attention

From the visual perspective attention and consciousness seem to be totally different phenomena. Talking about consciousness only is not something substantial, as the hard problem still remains open. And talking about attention in its place does only dismiss consciousness as an epiphenomenological rehash. The question to what extent attention is a prerequisite for conscious perception is complicated, as it involves a bidirectional relation. First, attention can be divided in two components: On the one hand bottom-up automatic activation, on the other hand top-down amplification or directed attention (Dehaene et al. 2006). Studies show that bottom-up processing can extent as far as the frontal eye fields and amygdala, capable of inducing emotional and semantic priming effects in the absence of conscious access. This is especially the case when the stimulus is charged with emotional value. Furthermore attention can be voluntarily directed, stimulating bottom-up processing, without conscious detection. Thus conscious access does not equal attention, however attention can direct conscious access, and vice versa (explored in modelling consciousness).

Conscious, preconscious and subliminal processing

Based on the dualistic nature of attention Dehaene et al. (2006) dissociates two different forms of unconscious processing: subliminal processing and preconscious processing (see *figure 1)*. Subliminal processing refers to bottom-up activation that is insufficient to induce a recurrent activation pattern. Top-down amplification through attention may be involved, reinforcing bottom-up activation in a linear fashion, but it remains below threshold. Preconscious is defined as having high potential for consciousness. The only requirement that is needed to trigger global reverberant activity is top-down amplification by attention. This could be potential stimuli in a high mental load setting, in which local reverberating activity can be triggered by free mental resources. This means winning a competition for central access in the midst of concurrent stimuli.

According to this theory, conscious perception is not a linear process; instead the boundary between preconscious and conscious processing is a sharp transition, a trigger that ignites global reverberant activity. This is consistent with the P3b, which shows a sharp temporal peak upon conscious processing. The distinction between two different forms of unconscious processing is more accurate, because it takes into account the dualistic nature of attention i.e. neither bottom-up attention (as in preconscious) or top-down attention (as in subliminal) on its own is a valid criterion for conscious access. Neurological data demonstrates that a great deal of visual information is processed without any awareness of visual features, including masked stimuli (Enns, Lollo 2000), non-dominant information during perceptual rivalry (Leopold, Logothetis 1999), physical wavelengths (Zeki, Marini 1998) and high temporal and spatial frequencies (He, MacLeod 2001).

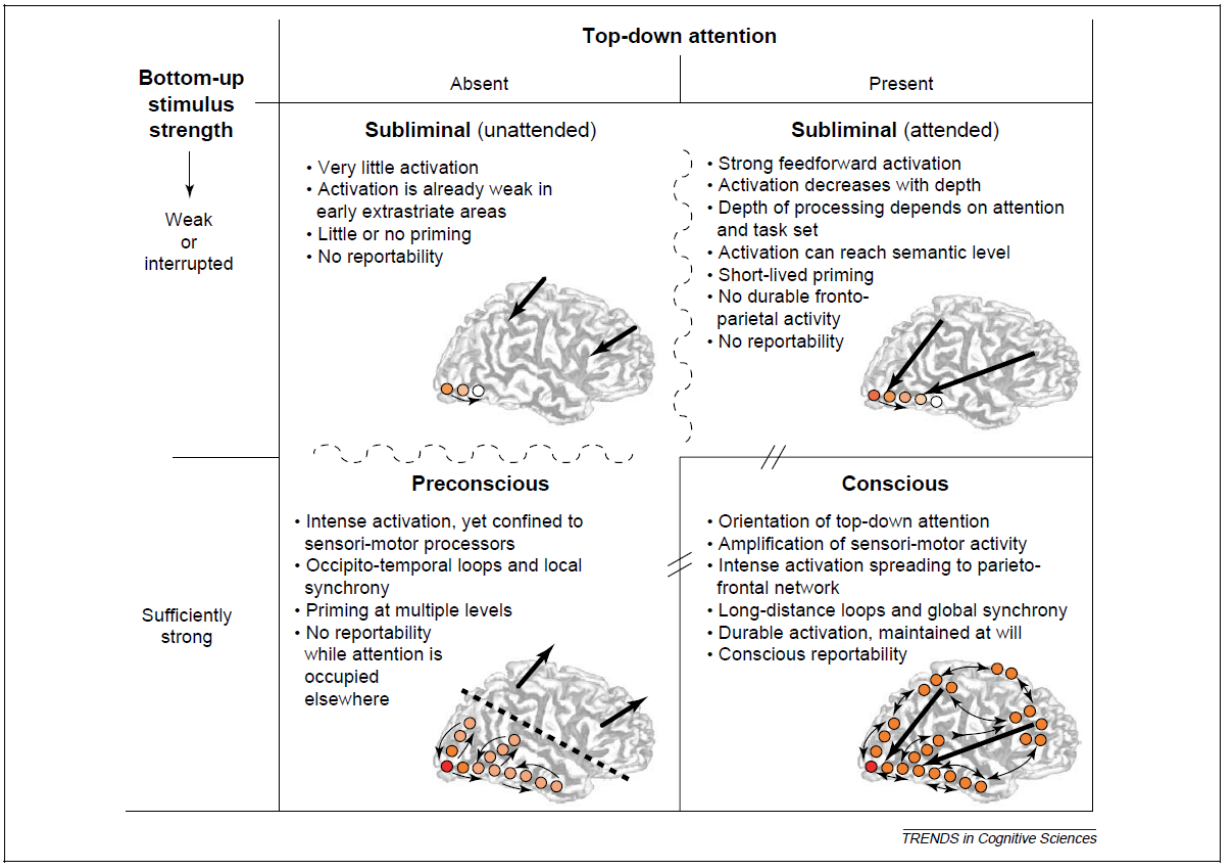

Figure 1: Dahaene et al. *Conscious, preconscious, and subliminal processing: a testable taxonomy* Different forms of processing based on top-down and bottom-up attentional processes. Thick arrows: orientation of attention. Small arrows: neural interaction. Subliminal processing is characterized by weak bottom-up activity, though it can be slightly enhanced by top-down amplification. Preconscious processing is characterized by strong bottom-up activation in the absence of top-down amplification (attention is diverted away). Conscious processing is marked by reverberant activity extending to the higher association cortices, allowing the maintenance of information online through recurrence and available for cognitive manipulation (e.g. planning, verbal report).

Phenomenal awareness

Even though humans don't have conscious access to every object in the visual scene, perception is still experienced as a subjectively rich phenomenon. To what extent this is the manifestation of subjective belief, illusion or reality remains often disputed. Awareness that comprises a rich subjective experience is often referred to by phenomenal awareness, comprising a seemingly holistic awareness involving one or multiple sensory modalities. It is though that each sensory modality is associated with its own enriching quality over and above the physiological mechanisms involved in perception, often referred to by qualia (Tye 2013). On its own the concept of qualia is not substantiated by tangible evidence to explain metaphysical notions of phenomenal awareness, because qualia are deemed to be irreducible, and thus inevitably leading to the mind-body problem. The introduction of qualia only supposes that phenomenal awareness can be spliced in individual sensory constituents.

The following subsections constitute an in-depth elaboration on the nature of phenomenology from a neurophysiological perspective. Zeki's theory about the disunity of consciousness is used to illustrate the difference between conscious access and phenomenal consciousness and to describe how a contextual phenomenal consciousness is constructed. In contrast to access-based consciousness, phenomenal consciousness has a high capacity to represent sensory input and reflects an ongoing process of bottom-up evidence accumulation. Phenomenal consciousness provides the context, in which an access-based consciousness is embedded with the capacity to represent or match fast fluctuations of high environmental input. The capacity to represent incoming environmental stimuli is constraint by neurophysiological properties of the neural network, so that the construction of a phenomenal representation is an incremental assembly of temporal asynchronous stimulus dimensions. In other words, phenomenal consciousness is an expression of a complex system, of which its properties are determined by those of its parts in a dynamic neural network interaction.

Peripheral awareness is explained to illustrate how access-based consciousness functions in a contextual phenomenology that is highly integrated, however is still governed by biologically innate driven adaptation. This form of biological determinism is discussed in relation to partial self-determination that is associated with meta-awareness, providing a short preview of reflective awareness and self that is described in the section about meta-awareness.

Microconsciousness

There are different hypotheses formulated that point to the existence of a neural correlation with qualia. For example Zeki (2003) argues that a microconsciousness is involved whenever an area responsible for a visual attribute gets substantially activated. For example V4 is conducive for the microconsciousness of color in the visual scene and V5 for motion. This is based on experimental findings with a blind patient GY, who could perceive visual motion, despite damage to V1. It was demonstrated that V5 receives direct visual input, independent of V1 input (Buchner et al. 1997). This is consistent with an MEG recording that correlated stimulus awareness with induced synchronous gamma oscillations in patient GY (Schurger, Cowey & Tallon-Baudry 2006).

The phenomenon of conscious motion perception as a neural correlate of V5 activation, despite the absence of V1 as a major source of visual input is supposed to reinforce the idea that a

microconsciousness is involved in specialized prestriate areas. Thus Zeki (2003) postulated that these cortical processing sites are also perceptual site.

Temporal asynchronicity in visual processing

Experimental research shows that visual perception is asynchronous and temporally organized. This means that higher order visual attributes that integrate information from lower order brain areas are perceived with a temporal delay. There is psychophysical evidence revealing that color is perceived slightly faster than motion by about 80ms (Arnold, Clifford & Wenderoth 2001). Also perception of location precedes color (Pisella, Arzi & Rossetti 1998). And spatial orientation is perceived even faster than location (Moutoussis, Zeki 1997). These findings demonstrate that higher order visual attributes are temporally asynchronous with first order visual attributes due to longer processing times. It may come as a surprise that the very intricate mechanism of visual perception, with its ability to present a coherent image of the world with seemingly perfect spatial and temporal registration, is actually asynchronously sampling the environment. This is consistent with other neurophysiological data, summarized above that suggests discrete perceptual sampling.

However Zeki (2003) proposes asynchronous sampling is also associated with the expression of microconsciousnesses. Asynchronous perception of visual attributes would imply that 'microconsciousnesses' are spatially disparate due to different cortical representations and temporally disparate due to differences in processing time, so that there is a spatial and temporal hierarchy of microconsciousnesses.

Macroconsciousness

Still there is the apparent registration of a coherent image that is not a muster of isolated diffuse microconsciousnesses. Zeki states that these microconsciousnesses are eventually bound together in a coherent picture, a macroconscious event. It is not clear yet how the mechanism of binding works exactly: if binding takes place only if the involved microconsciousnesses are established altogether or during the processing stage. Based on the fact that microconsciousnesses are temporally and spatially dependent on cortical processing and that a coherent conscious frame is extending even further temporally, a post-conscious binding mechanism sounds reasonable. The formation of a new conscious percept that involves two or more microconsciousnesses cannot be established simultaneously with lower order processing of the involved visual attributes, just as color cannot be perceived until visual processing in V4 has occurred.

Referring again to Dehaene et al. (2006) theory of conscious processing, the neural mechanism of conscious access was described as global recurrent activation, keeping information online through reverberation and higher cortical propagation. This neural formation was not a linear increase in activity, but instead a sudden surge of global ignition. Consequently there is no antecedent involved before this global ignition, which carries information of a phenomenal quality that can be linearly compared with conscious access. Therefore, information build before the initiation of a global cascade cannot be simultaneously active with a neural correlate of access consciousness. Thus, according to Dehaene et al. (2006) the conscious binding mechanism is at least 'post-global-ignition'. It is hard to say if it is absolutely a post-conscious binding mechanism, because the interval between the onset of global

ignition and the establishment of a full global recurrent pattern is so small that it is almost impossible to dissociate a subtle evolution of conscious access. Nevertheless the threshold for global ignition provides already valuable information on the constraints of conscious processing. Note, however the conscious binding mechanism refers to binding in conscious processing.

It seems that there is an important difference between access consciousness and macroconsciousness. It appears that the concept of macroconsciousness resembles the concept of phenomenal consciousness. Therefore macroconsciousness seems to refer to the implicit 'richness' of experience, which may appear as if one is aware of particular phenomena within the environment, as these phenomena are part of the experience as whole. Nevertheless it would not be surprising that many phenomena or stimuli would be considered as preconscious according to the model from Dehaene et al. (2006). It is a whole other discussion to suspect the concept of microconsciousness to fall under the same phenomenal reference, but apart from the difference in terminology the use of microconsciousness is still relevant to understand the interdependence between the construction of a visual coherent percept and its underlying neurological architecture. Actually it is not microconsciousness referring to the perception of visual attributes, but instead the availability of neural representations of these visual attributes.

Difference between phenomenal awareness and access consciousness

Reframing the findings about microconsciousness within the perspective of Dehaene et al. (2006) on conscious processing, a conscious visual percept through V5 activity is actually conscious access for motion perception. Upon the finding that V5 activity correlated with conscious access of motion Zeki (2003) suggested that a microconsciousness is involved for each visual attribute, because one could become conscious of motion in the absence of other major processing areas like V1. Actually this is hasty generalization, because the 'focused constituent' of access consciousness is confounded with access conscious itself as process. V5 is a neural correlate of visual motion, but that doesn't make V5 the absolute cause of the whole mental context it is set in, in this case access consciousness with visual motion in the center of focus. Single-neuron phase adaptation to ongoing rhythms is evidence that conscious content can be very localized (see modelling consciousness).

This implicates that temporal asynchronicity constraints the availability or update of visual attributes and that there is a conscious lack of 80ms for motion relative to color perception, however this doesn't involve a miraculous microconsciousness, just potential access consciousness. There is one hard problem, and better to keep it simple as one major problem instead of introducing microconsciousness as a fancy substitute of consciousness. The fact that V5 motion can only be perceived when it is processed together with its temporal delay, at least counts as a premise for discrete access consciousness, because what was really tested, was conscious access to motion, verified by verbal report (Stoerig, Barth 2001). Only during conscious access can the perceptual information be shared with other cognitive functions, in this case verbal report.

Peripheral awareness

Interesting to mention is that the visual system supports high peripheral awareness. For example, something is moving in the far corner of one's eye, whereupon the person reacts to shift its head to direct its attention to the moving stimulus**.** Both cognitive and physiological research on visual perception indicates that peripheral awareness actually relates to peripheral motion sensitivity, rather than specific stimuli details. Although motion sensitivity prevails in peripheral processing, unconscious processing has its part too in facilitating behavioral responses.

According to Dehaene et al. (2006) first automatic attentional processes would be involved that depend on the interplay between memory, emotional charge and vigilance. Each of these cognitive variables facilitates automatic bottom-up attention. Bottom-up attentional activity can get as far as is biologically relevant. From weak bottom-up activation, which is denoted by subliminal processing, to strong bottom-up activation, which is denoted by preconscious processing? The incentive to be vigilant to peripheral motion is biologically consistent with the way in which the visual system registers information from the periphery.

In the transduction of visual information, two different main layers can be discriminated. These are known as the magnocellular and the parvocellular layers. The parvocellular layers are found to process visual information with high acuity, at the expense of having low temporal resolution, while the magnocellular layers are found to process visual information with low visual acuity, but with high temporal resolution. Moreover peripheral information is mainly transduced by magnocellular layers, while the center of the visual field is mainly transduced by parvocellular layers (Wolfe, Keith R. Kluender & Levi).

This implicates that the perceptual system is adapted according to values and criteria that serve the biological program. Also that absolute perception is biologically shaped, since information is processed selectively from both a physiological perspective (e.g. distribution of photoreceptors), as well as from a psychological perspective (e.g. emotional salience). According to biological survival values, it is advantageous to have high temporal resolution for peripheral stimuli in order to register approaching danger signals. Peripheral perception is abstract, involving contours in concert with the interplay between memory, emotional charge and vigilance. Each of these cognitive variables facilitates automatic bottom-up attention.

Something moving in the periphery could be classified as preconscious, especially when it is something novel and salient. Not every stimulus has high potential for conscious processing, as many stimuli would have weak bottom-up activation and therefore less likely to be amplified by top-down attention. In contrary, top-down attention can be directed to preconscious stimuli in the periphery to center a stimulus within the high acuity visual field (by headshifting), revealing certain stimuli characteristics in order to apprehend concrete meaning to the stimulus. This event can be considered as involving two-stage conscious processing, whereby the visual process transitions from preconscious processing (parallel unconscious processing) succeeded by conscious access by top-down global ignition.

Contextual phenomenology and stimulus dimensions

The example of peripheral vision illustrates that one event can be differentiated in moment to moment perceptual frames, which may comprise different stimulus dimensions. Even though attention may be directed upon a particular object, that doesn't mean that every stimulus dimension is within the focus of conscious processing. One may be watching a bottle of water, but isn't specifically aware of the symbol printed on the etiquette, though the etiquette has its part in the contextual phenomenology. The same counts for microconsiousness as a confounder of access consciousness. The stimulus dimension of motion can be in focus in particular. Concurrently other stimulus dimensions resolve in contextual phenomenology. The stable conscious pattern (i.e. focused access to a particular stimulus dimension) is the consequence of shared conscious content in global reverberant activity. That cortical areas representing certain stimuli characteristics are conducive to phenomenology also follows from the fact that particular phenomenal content (e.g. visual attributes) are lost with selective lesioning of the representing areas (Dehaene et al. 2006).

Temporal onset of conscious frames

Zeki (2003) asserts that a macroconscious frame is established by about 500 ms. Probably this refers to a fully bound phenomenological frame across one or more perceptual modalities. Within that phenomenological frame, something in particular may be accessed, i.e. does have conscious access. This doesn't have to be a visual object, but can be any object or mental concept, as will be discussed later in the section about metacognition. According to the models of conscious access and the psychological refractory period, information that is processed on a higher level is internally buffered and prevents other information from entering.

This suggests that waking life is characterized by trains of conscious frames, where each momentary experience is associated with contextual phenomenology and conscious access of one particular sensory or mental object, on the condition that there is sufficient thalamo-cortical modulation for sustained vigilance. If this is the case, then every momentary episode is comprised of a neural cycle ending in recurrent activity. Massive parallel projections account for contextual phenomenology, however this is gradually built, accumulating visual information or having sustained information from previous events. There is no clear cut line to be discerned that indicates the end of a phenomenal episode. Phenomenology, in contrast to conscious access, is not differentiated with sharp transitions like widespread global ignition. It is more like a stream of experience as a function of massive neuronal projection, involving sustained activation and new perceptual input. The role of massive parallel projection in contextual phenomenology will be explained in models of consciousness, including the global workspace model and the neural Turing machine.

Zeki (2003) stated that it takes about 500 ms for a macroconscious frame to evolve. Given the nature of phenomenal awareness and its relation to massive parallel projection it is not unlikely phenomenal awareness is gradually build. However it is likely that macroconsciousness refers to a full conscious episode that includes both contextual phenomenology and conscious access to something particular, because the phenomenal context would be complete if something is assigned conscious access to. This is also consistent with the temporal onset of the P3b, which is between 300 and 500 ms.

A study by Lamme and Roelfsema (2000) demonstrated that V1 activity is initiated after 40 ms stimulus onset, followed by increasing response latencies for higher order areas. At 80 ms stimulus onset it was demonstrated that all visual areas are activated and at 120 ms visual information has reached widespread activation in cortical areas. This is consistent with the findings on temporal asynchronicity mentioned earlier.

The difference between 500 ms and 120 ms is rather big, which cannot be attributed to assigning different phases of conscious processing, because conscious processing is supposed to be ignition like. According to Lamme and Roelfsema (2000) early visual processing, a.k.a. the feedforward sweep doesn't differentiate between unconscious and conscious processing. This is consistent with the finding of Melloni et al. (2007) that both unconscious and conscious early visual processing is marked by an increase in local gamma oscillations. On the contrary a transient long-distance synchronization of gamma oscillations, as a neural signature of conscious access, was found at 300 ms stimulus onset. This timing difference of diverging conscious and unconscious processes may be attributed to early visual recurrent patterns. Even though some advocate early visual recurrent patterns sufficient for conscious awareness (Lamme, Roelfsema 2000, Zeki 2003), most of the data tells something different i.e. only late (~300 ms) and global recurrent activity corresponds with conscious processing.

For example a neurophysiological investigation by Gaillard et al. (2009) using intracerebral electrophysiological recording tools to study conscious processing of masked and unmasked words in epileptic patients demonstrated that early visual processing is characterized by similar temporal dynamics in both intracranial event-related potentials (iERPs) and event-related spectral perturbations (ERSPs), comprising beta and alpha suppression, and gamma enhancement. However, the iERPs and ERSPs show clear divergence after 200 ms, because masked-stimulus evoked activity decayed around 200 ms occipitally and frontal activity at 300 ms, while unmasked-stimulus activity was still sustained in the late temporal interval.

Conscious access was contrasted with unconscious processing by massive involvement of the prefrontal cortex and long-distance cortical exchange of information. Processing of unmasked stimuli was correlated with phase synchrony between distant pairs of electrodes in the beta range during the 300-500 ms interval, reflecting long-distance reverberation. This form of long-distance coherence was found to co-occur with long-lasting iERP and ERSP effects within the same temporal interval. It was concluded that long-distance synchrony simultaneously takes place with the preservation of locally encoded representations.

As a last tool Gaillard et al. (2009) did causality based electrophysiological measures between distance cortical sites. Conscious processing of unmasked stimuli was associated with a late increase and sustained causal gain in the 200-500 ms time interval. This increase in causal gain was bidirectional, but slightly stronger in the bottom-up direction. It was supposed that late conscious processing is reflected by posterior inflow of visual information towards anterior higher association cortices.

Altogether Gaillard et al. (2009) assessed conscious processing by using four neurophysiological markers: iERPs, ERSPs, interelectrode phase synchrony and Granger causality, thereby providing electrophysiological measures that stretch across temporal, frequency and causality domains. This data is consistent with a theory of feed-forward processing, in the manner that unconscious and conscious processes exhibit similar patterns in early neural activity. Only the timing at which conscious access

differentiates does not correspond with 120 ms, but instead with ~300 ms that is consistently observed the majority of studies on the neural correlates of conscious access.

However based on the finding that the neural correlates of consciousness converge in a late time window, Gaillard et al. (2009) proposes that conscious processing is instead reflected by only late sustained long-distance synchrony and late amplification at the >300 interval. It is supposed that this definition was introduced for pragmatic purposes and doesn't need to preclude a theory of ignition-like conscious access. The reason being that ignition of global recurrent activation during conscious processing starts at 300 ms stimulus onset, however this cannot always be differentiated experimentally. For example, Gaillard et al. (2009) found concurrently present signals across all physiological parameters for both unconscious and conscious processing. Therefore it is thought that no single neurophysiological index is exclusive to access conscious alone. Instead conscious access is differentiated by the convergence of these neurophysiological parameters in a late time window.

A late time window for conscious access is consistent with other studies, such as dual task paradigms that demonstrate a psychological refractory period of 500 ms (Pashler 1994). This is based on the concept of a psychological bottleneck that is involved with cognitive processing, thereby limiting simultaneous executive ability. Though this is not a measure of conscious directly, it still indicates that executive flexibility is probably restricted by processes in conscious access. Another example is the attentional blink, which interferes with conscious access of a second target stimulus if it is in close temporal succession to the first target stimulus. It has been estimated that a stimulus onset within 500 ms of the first stimulus causes the attentional blink (Kihara et al. 2011).

Altogether there is substantial evidence for discrete conscious processing and the existence of temporal asynchrony makes for an unapparent discrete phenomenology.

Phenomenal integration versus reflection

Zeki (2003) explains that beyond macroconsciousness there is an even higher level of consciousness, unified consciousness. Zeki argues for a temporal hierarchy between micro-, macro- and unified consciousness, based on the findings of temporal asynchronicity in different forms of microconsciousness. Actually this is better rephrased as asynchronous phenomenology i.e. different visual attributes can become part of phenomenology in a temporally disparate manner. In the combinatory integration of visual attributes in macroconsciousness the visual attributes represent a variable influence on binding time i.e. depending on what type of visual attributes are integrated in macroconsciousness determines the binding time. However, macroconsciousness is actually a reference to phenomenology and therefore this definition is redundant to sensory phenomenology, except for a possible covert criterion for involving multimodal integration in macroconsciousness, and therefore with extended temporal processing time.

According to Zeki (2003), unified consciousness, in turn has even longer processing time, because the phenomenal richness is expanded to include an "I as the perceiving person". Later Zeki (2003) explains he is referring to "consciousness of oneself as the perceiving person amounts to being aware of aware". However this implies a second order metacognitive awareness (i.e. subject-object relation of self in reflection) instead of first order subjective awareness (see section on metacognition). Zeki's assertion that communication and language are important for this unified state a fortiori

reinforces the concept of reflection. On the other hand reflexive conscious access involves recollection of self as object and its distribution to cognitive resources for manipulation and metamemory, including language.

The dissociation between implicit self ("I as the perceiving person"), and explicit self (the awareness of being aware) will be described in the section about metacognition in the framework of differential network activation that involves specialized attention networks (e.g. default mode network).

Biological determinism

Zeki (2003) concludes that unified consciousness is totally determined by the constituents of microconsciousness i.e. the cortical programs that are responsible for processing visual information. Therefore the apparent illusion of a higher unified consciousness is ontogentically rooted in "microconscious programs." In other words, the programs are defined a priori and read in every experience as it occurs, therefore determining the contours of unified consciousness. This supposes a form of biological determinism, which constraints the action space of body and mind, thereby confining the options that are available to the agent interacting with the world, as perception is partial selective sampling (i.e. based on a biological system evolved to conserve itself).

Actually it supposes a stronger form of absolute determinism that exists on a foundation of potential microconsciousnesses that constitute a closed causal loop for combinatorial binding in phenomenal consciousness. It would be more consistent with the ability for skill development and functional plasticity that fundamental constraints are not absolute, but rather abstractions with variability, like abstract types in functional programming. The "I" that is evolving over time is constraint by abstract types, in which there is space for flexible development to a certain extent. A different "I" that could evolve over time, instead of a preconceived one that evolves as a function of the environment.

The mental space is part of the environment, only in the sense that a sequence of stimulus-independent thought can influence successive mental states in the same way as sensory stimuli can activate reafferent schemas. However the agent could follow a carefully established mental program in order to transcend all conditioning, also called the development of meta-awareness, thereby cultivating cognitive flexibility. The relation between meta-awareness and self-determined focused will be extensively discussed in the section about meta-awareness.

Conscious processing and memory

Before going into the details of action awareness it should be mentioned that perception and action are sometimes intricately related to each other, as widespread global synchronization in the establishment of a conscious frame can reflect synchronized reintegration of a large-scale cortical network that includes motor and memory related brain areas. In this way perception in conscious access can set the context for response initiation or even directly affect motor output through neurophysiological memory traces that are wired in the neural network as efferent and reafferent connections that dictate conditioned stimulus-response mappings.

Essentially the neural network represents memory both implicit in the state of the network and as explicit memory systems that participate in conscious processing. Therefore consciousness is related

to memory in two ways: by an attentional biasing mechanism that influences sensory salience, and by the recruitment of memory systems during large-scale global synchronization. The former is also determined by internal milieu variables that determine the attentional context by top-down attentional modulation, including goals, expectations and biologically innate propensities. The latter, concerning the involvement of memory-related systems in conscious processing will be explained in more detail in the section about modelling consciousness. Memory is also involved in unconscious forms of processing, including subliminal processing, priming effects and even exists in single-neuron firing patterns.

Last, auditory awareness is discussed with the intention to reveal a higher order mechanism of binding sensory information in a conscious frame, which involves transient global synchronization that is reflected as a late and widely distributed neural marker. Conscious processing of auditory stimulus information relates to general properties of memory that are expressed independent of sensory content.

Earlier it was explained that bottom-up attention is guided by memory, emotional, charge and vigilance. This is closely related to memory function as a state constituent and its directional influence on conscious content. According to Lamme (2003) salience or attentional selection is a manifestation of adapted sensory processing as the interaction between long-term memory, innate wiring, experience and recent events. Attention stimulates synchronous activity in the areas that process the selected stimulus dimensions, thereby stabilizing recurrent interactions between groups of neurons (neuronal coalition), referred to as a phenomenal coherent percept, however not yet conscious. Lamme (2003) makes a clear distinction between phenomenal awareness, with tentatively bound features and totally unconscious perception with separate stimuli that may not even be perceivable. The transition between phenomenal awareness and access consciousness is thought to depend on the degree of recurrent interactions that integrate motor and memory related areas. This is supported by the fact that transient long-distance gamma synchronization, representing conscious processing, was localized as recurrent interactions from parietal and prefrontal cortices (Doesburg et al. 2009).

Even though unconscious stimuli involve a very transient memory (i.e. an iconic retinotopic memory), they can potentiate subliminal priming, ranging from receptive field to semantic, to even motor priming (Dehaene, Changeux 2011). This shows an ongoing phenomenal background in the form of neural activation and inhibition patterns that contrasts with a foreground of conscious access, which can be both simultaneously present.

It has been found that these subliminal priming effects decrease with depth of processing, only showing subtle influences as information is processed at a higher level (Dehaene 2010). Also subliminal priming decreases with elapsed time, as priming is not detectable after 500ms (Dupoux et al., 2008). Besides it has been demonstrated that classical conditioning can only extend beyond this temporal boundary if the person was conscious of the relation between the coupled stimuli. Furthermore, subliminal stimuli fail to induce durable changes in executive control. Humans are capable of applying flexible cognitive strategies in the face of challenging tasks, a sign of excellent creativity or insight that thus requires conscious awareness (Posner, Snyder 1975). Altogether, this implicates that memory shares neural mechanisms with conscious processing, and phenomenal awareness shares neural mechanisms with iconic memory.

Internal milieu variables

Memory is thought to comprise a neural mechanism that changes the state of the neural network (Lamme 2003). According to (Dehaene, Changeux 2011) attentional selection refers to: "the separation of relevant versus irrelevant information, isolation of an object or spatial location, based on its saliency or relevance to current goals, and amplification of its sensory attributes." Indicating that attentional bias is partly influenced by internal milieu variables, like current needs, goals and contextual cues that selectively lead and facilitate corresponding sensory pathways via feedback loops.

A study by Melloni et al (2007) showed that conscious access is influenced by sensory evidence and stimulus expectations. It was found that expectation lowers the threshold for conscious access. This was evident from neural signatures that differentiate seen from unseen stimuli. Normally conscious latency was found to be about 300 ms, but with expectation this latency was lowered to ~200 ms after stimulus onset. The amplitude of this component decreased as visibility increased. It was concluded that conscious access can determined by stimulus saliency or by a combination of sensory evidence and expectancy.

Another study by Melloni et al. (2007) has demonstrated besides a P300 correlation with conscious processing, an increased phase synchrony in gamma oscillations during stimulus expectation. And a study by Doesburg et al. (2009) demonstrated that transient theta-modulated long distance gamma synchronization not only reintegrated a large scale cortical network that includes prefrontal and parietal cortices, but also other cortical areas that are relevant for particular conscious access. They found that large scale cortical reintegration expanded to include temporal and motor areas for conscious processing of imagery and response initiation. Moreover this expanded cortical reintegration occurred within the interval of conscious processing, indicating that behaviour is directly affected by conscious processing.

Another experiment that reveals the existence of internal milieu variables was done by Wyart and Tallon-Baudry (2008). Using MEG recording Wyart and Tallon-Baudry, (2008) tested how conscious awareness was influenced by spatial attention (i.e. top-down modulation of ongoing neuronal activity in visual areas). They found that pre-stimulus activity in the form of gamma oscillations in the lateral occipital areas could predict conscious awareness independent of top-down modulatory effects. On the other hand top-down modulation inhibited alpha activity in the same regions could also predict conscious awareness. Thus it was concluded that conscious awareness was influenced by two different mechanisms: top-down modulation in the alpha range and pre-stimulus activity in the gamma range.

Human single neuron recordings

There is one study by Quiroga et al. (2008) that measured single neuronal responses in the medial temporal lobe (MTL) in a conscious recognition task. They measured the relation between stimulus duration and conscious recognition by using backward masking and neuronal firing rate recordings in the MTL. It was shown that single-cell neuronal responses lasted longer than the initial stimulus duration. Even with stimulus durations of 33 ms sustained neuronal activity was found in the MTL that lasted around ~300 ms after stimulus onset. Quiroga et al. (2008) argue that this could not be attributed to sustained activation in lower visual areas, as this information was filtered out by backward masking. Therefore it is thought that a single neuron response encodes some sort of memory that represents a

single complex object. This was supported by the observation of a priming effect i.e. conscious recognition increased as trials passed.

It is argued that a single-neuron coding mechanism could sustain information of a target object, thereby providing some pre-stimulus visual cue. Conscious recognition was associated with stronger single-neuron activity in the MTL and single-neuron activity could predict conscious recognition. This was verified to be independent of stimulus duration, as an effect of stimulus duration was not found until the transition between 132 and 264 ms.

Altogether these findings confirm that higher order visual representation is even realized on the single-neuronal level. It was shown that single-neuron firing patterns can represent complex objects like faces and can even sustain this information long after the initial stimulus is gone. Also the single-neuron activation pattern was found to resemble an all-or-none coding mechanism. This is consistent with other neurophysiological markers of consciousness like the P3b and gamma synchronization, as is the time interval with within the information is sustained. Sustained single-neuron representation at ~300 ms stimulus onset was a significant predictor of conscious recognition. Revealing that consciousness as a higher order neuronal mechanism is even reflected in single-neuron representation.

Awareness in the auditory domain

One study by Bekinschtein et al. (2009) demonstrated a dissociation between unconscious and conscious processing of auditory stimuli and the existence of a neural marker for conscious access in the auditory modality. Bekinschtein et al. (2009) did experimental research on perceptual processing of rare irregular auditory stimuli within a serial presentation of regular auditory stimuli. They tested two different categories of irregular stimuli: local interval (within trial) and global interval (across trials). An early temporal mismatch negativity (~130 ms) was found that correlated with the processing of local deviant stimuli, which is supposed to represent early auditory processing.

In addition to normal test subjects minimally conscious patients and patients that were in a vegetative state were also tested. These patients are characterized by the absence of conscious awareness in vegetative patients and intermittent discrete signs of consciousness in minimally conscious patients. Interesting was that the early mismatch negativity was also found in these patients, reflecting non-conscious, fast-decaying auditory processing. Also this early mismatch negativity was found in different states of diverted attention: during mind-wandering, during competitive attentional processing in a simultaneous visual task, and when subjects had counted the number of global deviations as reflection of conscious recognition.

Furthermore conscious recognition of a global deviant stimulus correlated exclusively with a late P3b ERP after ~300 ms stimulus onset. Parallel fMRI recordings showed that the P3b effect involved a large-scale brain networking, including prefrontal, cingulate, parietal and temporal regions. The P3b effect and conscious recognition of global irregularities was absent in all task conditions that diverted attention. Altogether this implies that conscious access of an auditory stimulus also involves the same ERP correlate that is associated with conscious access of a visual stimulus and both temporal and spatial consistency with respect to wide-spread cortical activation during conscious processing of different sensory stimuli.

It has been revealed that the P3b effect can be fully observed by inter-stimulus intervals that exceed even 10 minutes (Wetter, Polich & Murphy 2004), while the MMN effect is already lost after a few seconds (Mantysalo, Naatanen 1987). This suggests the P3b effect as a neural marker for auditory conscious access reflects active maintenance of stimulus information in a conscious working memory, while non-conscious auditory processing reflects a fleeting iconic memory. An iconic fleeting memory has also been postulated in the analogous case of early visual processing.

The mechanism of a conscious working memory is consistent with a global increase in gamma oscillatory phase synchronization and enhanced theta oscillations that correlated with the P300 and reflected internally buffering a conscious working memory representation of the presented stimulus (The P300 is an ERP complex that consists of the P3a and P3b. While the P3a is associated with unconscious processing, the P3b is specific for conscious processing. Generally p3b is referred to as an exclusive conscious marker, because it does not include early forms of processing that are shared by both unconscious and conscious forms of processing).

It appears that more evidence indicates that conscious access involves a transient global activation and sustained reverberation between sensory areas and higher order cortices that is reflected as a late and widely distributed neural marker that can be differentiated from early sensory processing of any sensory modality involved.

Section 2: Action awareness (output)

Even though action awareness is associated with output, they are not one and the same, because this type of awareness doesn't directly relate to executive output or physical action. Earlier it was stated that neurophysiological traces are wired in the neural network as efferent and reafferent connections that dictate conditioned stimulus-response mappings. These stimulus-response maps can be activated during synchronized reintegration of a large-scale cortical network in the establishment of a conscious frame, or can be triggered completely outside the focus of conscious access. Just as conscious access of sensory information is limited, so is sensory motor feedback too, implying that motor patterns are most of the time unconscious and automatic, concealed in a phenomenal background.

However in every discrete conscious event, access-based conscious content is limited and also mutually exclusive and internally consistent. This means that different pieces of content cannot be maintained consciously (Franklin et al. 2012). However there exists a flexible and adaptive higher order mechanism of binding sensory content in a conscious frame. Content, as represented by specialized neuronal maps, can be bound across mind-body-world divisions. Exteroception that involves the visual and auditory senses have already been discussed as binding sources. Sensory information about the body would be acquired, for example, via interoception, proprioception and kinaesthesia. Cognitive binding sources concerning stimulus-independent thought will be discussed in the section about meta-awareness.

Action awareness is actually closely related to intention, that is dependent on the integration of peripheral sensory information (e.g. prorioceptic and kinaesthetic) with an intended motor representation. Thus motor awareness is manifested through large-scale global ignition of a sensory motor feedback representation. The mechanism of error-awareness will be discussed, because it is not only related to the action domain, but training and skill acquisition in general. This includes monitory skill development in attention training that will be discussed extensively in the section about meta-awareness.

Error- awareness is closely related to interoceptive visceral awareness and autonomic regulation that is associated with activity in the anterior insular cortex. The anterior insular cortex seems to be involved in a wider context of attention regulation through differential network activation of functionally dissociated neural systems. Thus error-awareness is described in regard to mental orientation and engagement that implicate the involvement of an attentional biasing mechanism in error-awareness.

This section elucidates the complexity of conscious expression in a hierarchical system and emphasizes the necessity of its interacting parts for this whole to operate well. Different neuronal representations, as explained above, that can participate during synchronized integration of a large-scale cortical network, determine the gist of the conscious frame that is to be expressed. Just as motor patters are a form of sensory motor feedback representation, there exist specialized neuronal maps that can bind specific content across mind-body-world divisions in a conscious frame. In essence, the properties of conscious cognition can be understood or expressed as a 'function' of the properties of its neuronal components.

Motor awareness

Desmurget et al. (2009) demonstrated a strong double dissociation between motor awareness and conscious intention by using electrical stimulation in patients that underwent awake brain surgery. It was found that stimulation of the posterior parietal cortex induced an intention to move (i.e. an internally generated desire to move). When the stimulation intensity was increased, it induced strong movement sensation. Meaning that the patients convincingly believed they had performed an actual movement, even though not any movement was registered through electromyographic recording.

Desmurget et al. (2009) hypothesize that this illusion of movement sensation may be the consequence of a combination of conscious priming of a particular motor representation and feed-forward modelling towards executive cortices by motor computations in the posterior parietal cortex. Thus the conscious sensation of an illusory movement could arise from a computation of the anticipated movement before execution.

The supplementary motor area (SMA) has been found to encode a representation of intention too (Fried et al. 1991). However the SMA seems to generate movement intentions independent of the will i.e. an exogenous sensation in the form of an urge to move that is close to movement initiation (Desmurget, Sirigu 2012). It is timed at the moment when inhibitory control on low-level motor areas is released, reflecting that it signals the timing when the planned movement is about to start. This contrasts with an endogenous intention to move that is generated by posterior parietal stimulation with specification of a particular motor goal. This is supported by the fact that higher intensity stimulation of the SMA induced movement in contrast to posterior parietal stimulation that didn't induce movement. This suggests intentional representation can be divided in different stages of motor planning and executive functioning. While the SMA may be specifically differentiated to direct motor commands, the posterior parietal cortex may be specialized to integrate peripheral sensory information with the aim to update predicted motor programs.

Furthermore, stimulation of the pre-motor cortex induced motor movement in the absence of any motor awareness. The absence of motor awareness is thought to reflect lack of integration of proprioceptic and kinaesthetic feedback with an intended motor representation that is needed to construct a veridical motor awareness. This suggests that pre-motor afferent connections are not conducive to motor awareness, but instead the intention that is associated with an internally constructed motor program. The limited capacity of conscious access would imply that the sensory feedback about the ongoing motor system is largely constraint, reflecting that sensory motor feedback is most of the time unconscious and automatic. This is definitely more obvious in experts who express a particular skill, appearing unconscious competent. However before such automaticity and finely tuned motor patterns are acquired, a long procedure of training with lots of explicit motor reflection is needed. The learning stage is marked by the intention to refine and calibrate motor programs according to a certain mental representation. Meaning that peripheral sensory information is repeatedly integrated in order to compare actual movement with expected movement in veridical motor awareness.

Altogether motor awareness and intentional representation seem highly interrelated and expressed in the posterior parietal cortex. Thus subjective executive awareness does not manifest as the consequence of movement itself, but rather from a priori conscious intention and its expected motor representation. This is confirmed by Zschorlich and Köhling (2013) that investigated the influence of

conscious intention on directed motor movement while stimulating the motor cortex with transcranial magnetic stimulation (TMS). Motor output was observed by analysing the amplitudes of evoked motor potentials in different muscles. When subjects mentally intended a particular movement without actual movement a strong relation was found with an increase in the amplitude of motor-evoked potentials of the muscles that were specifically involved in that movement. In the reference condition without intention, the motor output was characterized by an undirected random distribution across all the muscles with weak and simultaneous activity. The data demonstrates that conscious intention directs movement and the existence of a neural intention network prior to executive movement that functionally relate to target-specific motor circuits.

Farrer et al. (2008) postulate that action awareness arises from the discrepancy of actual movement with the intended movement and that this distinct awareness of one's own actions is associated with a representation of this discrepancy in the angular gyrus. Farrer et al. (2008) showed that interference with veridical motor awareness by delaying sensory feedback induced a strong experienced discrepancy between actual movement and intended movement, though a sense of agency was still maintained.

This discrepancy correlated with activity in the angular gyrus. Most interesting is that the angular gyrus is not only postulated as a neural locus of action awareness, but is also believed to encode a sense of agency. It was shown that by strongly increasing a delay in sensory feedback, the subject lost a sense of agency over the movement, experiencing movement in control of someone else. This was coupled with strong activation in the angular gyrus. Also schizophrenic patients that experience a sense of foreign agency i.e. not feeling their own words and actions intentionally, demonstrate strong activity in the angular gyrus during episodes of these recurring symptoms (Spence et al. 1997).

The angular gyrus is located in the posterior inferior parietal lobule, which may reflect a fine specification within the posterior parietal cortex (that is associated with internally representing motor intentions) that encodes motor awareness.

Error-awareness

One of the neural correlates that is consistently correlated with performance monitoring is the error-related negativity (ERN), an ERP signal reflecting an erroneous response in speeded choice reaction time tasks. The ERN has a temporal onset of 50-100 ms with a centrally distributed peak within the posterior medial frontal cortex (pMFC), specifically in the rostral cingulate zone (RCZ) (Debener et al., 2005). The pMFC is involved in performance monitoring, rather conflict monitoring, because it is engaged when the outcome of an event is worse than expected or the expectation of an event involves a risk, whereupon it signals for adjustment.

Klein et al. (2007) investigated how conscious error awareness is related to post-error adjustment and how it modulates error-related brain activity by experimenting with an antisaccade task. It was shown that error awareness had no influence on activity in the rostral cingulate zone (RCZ). The RCZ is reported to be involved with task performance monitoring, as fMRI activity correlated with the error-related negativity (ERN). The ERN is also found to be present in both aware and unaware conditions of error responses (Endrass, Franke & Kathmann 2005). Thus it seems the ERN is not a

reflection of error awareness, instead it is suggested to be a preconscious correlate of performance monitoring (Overbeek, Nieuwenhuis & Ridderinkhof 2005).

Another ERP that is associated with performance monitoring is the error positivity (Pe), that is characterized by a late centroparietal distribution with a temporal onset of 300-500 ms (Ullsperger et al. 2010). It has been shown that the Pe can be modulated by error-related awareness and that it compares with the P3b both temporally and functionally. This suggests the Pe may share neural networks with the P3b that possibly expresses a form of access conscious, however the exact functional generators are still unknown.

Klein et al. (2007) found a strong relation between error awareness and activity in the anterior insular cortex (AIC). AIC activity is significantly stronger with perceived errors compared with unperceived errors. The AIC is associated with interoceptive visceral awareness and the regulation of autonomic responses (Ullsperger et al. 2010). Autonomous responses function to both physically and mentally prepare an individual for both changed internal and external requirements in response to environmental changes. A double dissociation was found between the RCZ and the AIC: RCZ activity was associated with correct trials that required strong monitoring and behaviour adjustments, while AIC activity was associated with error trials (Magno et al. 2006). This indicates that the RCZ may be involved in performance monitoring only, without being directly related to increased autonomic responses. It may be the case that the RCZ is involved in cost-benefit calculation, by estimating available effort-risk properties.

Several neurophysiological markers are associated with ANS variability in performance monitoring, among others heart rate deceleration, pupil dilation and skin conductance response (SCR). The SCR has been shown to significantly increase in error trials, but only if the subject was aware. Heart rate deceleration has also been associated with error-related awareness. In case of pupil dilation the effect was twofold: first an early dilation in response to a luminant imperative stimulus (the pupillary light reflex), second a slow latency modulation by error-related awareness if the stimulus led to an error (Critchley 2005). These ANS associated changes in pupil diameter were correlated with both AIC and pMFC activity.

In addition it is suggested that pupil diameter variability is closely related to norepinephrine activity in the locus coeruleus (LC) (Gilzenrat et al. 2010). Given this relation and shared neural connections between the LC and the AIC, they possibly co-vary in their activation patterns. The LC is a nucleus located in the brainstem with many cortical norepinephrine projections that function in regulating sympathetic activation and parasympathetic modulation. The LC is thought to play a central role in higher cognitive functioning by modulating engagement. Phasic increases in LC activity are found to correlate with unexpected events. This suggests activity in the AIC, the LC and autonomic activity are functionally related.

It has been found by indexing pupil diameter variability to LC activity that decreases in tonic LC activity are associated with decreases in task utility and disengagement, as does reduced stimulus evoked phasic LC activity. The relation between tonic LC activity and task engagement can be explained by a modulatory effect by ascending brain stem nuclei, including the LC. It modulates the baseline firing rate of the thalamocortical network, lowering its depolarization threshold, and thereby increasing receptivity for external input (Dehaene et al. 2006). In addition the P3b has been related to phasic LC

activity, reflecting that LC activity is crucial for signalling vigilance (Nieuwenhuis, Aston-Jones & Cohen 2005).

Strong correlation between various ANS indices, error related cognition and the AIC suggests that error awareness is mediated via the AIC. By registering error-related visceral reactions, it has been observed that autonomic reactions are associated with error-related events, however it remains unclear whether AIC activity is specifically related to enhanced awareness to an error-related autonomic response (i.e. registering error-related visceral reactions) or the increase in autonomic response (i.e. AIC generates autonomic activity). It is unlikely that the AIC is the neural generator of the Pe ERP, although they are modulated by error-related awareness in the same way. Klein et al. (2007) postulated that the AIC may indirectly affect the Pe through connections with frontal and parietal cortices.

Ullsperger et al. (2010) closely associated error-related ANS activity with the orienting response. The orienting response is described as an organism's automatic reaction towards stimuli that are biologically relevant, including rare, novel, deviant and error-related stimuli. This reaction is driven by automatic increases in ANS activity, including increases in different ANS indices described above. It is thought the error-related response is a manifestation of a more generally described orienting response. The orienting response is described as having realized the motivational significance of the stimulus before the emergence of full engagement. This denotes that an orienting response towards an erroneous stimulus encompasses error-related awareness, which is corroborated by AIC correlated ANS increases and the associated phasic LC activity with awareness.

Erp analysis shows that the Pe and P3b not only compare neurophysiologically, but also reflect variations of a similar neurocognitive mechanism i.e. the conscious processing of emotionally salient stimuli. In this regard the P3b is functionally related to the more general orienting response, while the Pe is more specifically related to error-related awareness (Ridderinkhof, Ramautar & Wijnen 2009). Interestingly the association between P3b, phasic LC activity and the orienting response suggests they are components in a higher order neurocognitive network.

One network that is closely associated with LC activity and performance monitoring is the salience network, that comprises the pMFC, the AIC and the orbitofrontal cortex (Seeley et al. 2007). The salience network is involved in the allocation of attentional resources towards unexpected and emotionally salient stimuli by monitoring biologically significant events that require autonomic regulation. Phasic LC activity is thought to represent an interrupt signal that breaks into current attentional settings and captures attentional control whenever there is an event outside the focus of attention that has sufficient potential biological relevance. Thus the salience network allows for flexible re-orientation towards motivationally significant stimuli, including unexpected events.

It has been postulated that the AIC is central in the regulation of competitive dynamics in large-scale neural networks, including the salience network. Large-scale networks can be dissociated as functionally coherent neural systems that underlie different cognitive states, including rest, cognitive performance and rumination. Other networks are known as the default mode network (DMN) and the control network. The DMN is deactivated during cognitive effort, while the salience network and the control network show increased activity (Weissman et al. 2006). Furthermore DMN activity during task-related cognitive performance can predict executive failure, while salience network and control network activity can predict performance enhancement. It is postulated that the AIC is important in directing

differential network activation and resolves large-scale network competition by allocating attentional resources. In cognitive performance it does so by engaging salience and control networks, thereby enhancing the processing of relevant stimuli and facilitating engagement, while simultaneously deactivating the DMM (Sridharan, Levitin & Menon 2008).

Likewise the AIC is regulative in engaging salience and control networks to facilitate reactive allocation of resources towards the OR, or more specifically, to an erroneous event. This is supported by a functional connectivity between the AIC and the somatosensory cortex (a salience network structure) and oculomotor areas error-related awareness. This implies the AIC may synchronize with these structures in order to amplify error-related stimulus content and prepare an oculomotor response. Also pupil diameter variability before stimulus onset co-varied with AIC connectivity in error-related awareness. Pupil diameter indexed an increase in functional connectivity between the AIC and the salience network, while simultaneously decreasing functional connectivity with DMN. This reflects that pre-stimulus autonomous activity in subsequent error awareness increases AIC connectivity that facilitates a neural state, advantageous and calibrated towards cognitive monitoring and performance.

In the subsection about meta-awareness differential network activation as related to the regulation of endogenous attention will recur as a central mechanism in dynamic models of consciousness. It will be explained that large-scale network dynamics reflect an ongoing competition to represent content across mind-body-world divisions. But first, a dynamic model of consciousness will be described that is particularly inspired by the global workspace model.

Section 3: Modelling consciousness (discrete network states)

In conscious modelling, parallels are repeatedly drawn between insights from neuroscientific research and its representations in models of conscious cognition. Especially the way in which recurrent properties of conscious cognition are implemented in these models is particularly inspired by the global workspace theory. In the global workspace model binding and distribution of conscious content, which is based on neurophysiological processes that include bottom-up competition, top-down amplification, long-distance synchronization and adaptive resonance, inhere conscious properties that describe consciousness in the brain, with particular reference to conscious discreteness. Meaning, the properties of conscious cognition can be understood or expressed as a 'function' of the properties of its neuronal components.

There exists a high variety of potential binding resources that can give rise to an almost infinite number of different conscious events, as explicated in previous sections. Binding sources that were discussed in the previous section, corresponding to neuronal maps that are specialized to process information of a particular domain, are given perspective in the context of adaptive signaling. Adaptive perception in the visual domain will be illustrated on the basis of flexible binding across visuotopically organized cortical layers that include neuronal maps that encode higher spatial frames in addition to neuronal maps that are involved in first-order visual processing, so that flexible binding allows for balanced integration of visual properties or amplification and emphasis of visual features in a particular order class.

A cycle of successive discrete conscious frames can be dissociated, in which each conscious core influences the way in which the next conscious core appears. In addition to the workspace or core of the global workspace there exists a massively distributed parallel system with many specialized circuits, that either process incoming sensory information, compete for attentional selection or give shape to conscious content as unconscious secondary processes that constitute an implicit contextual self-system.

In contrast to previous sections that aimed at describing a higher order conscious process as a function of its neuronal components, this section aims at describing a complex system that constitutes an integrated whole. System dynamics have been addressed a little in previous sections in order to describe structural and behavioral relationships, however, in this section, there is explicit emphasis on the integrated whole that contains structure and behavior. The structure consists of the neuronal components that are directly or indirectly related to each other, including the global workspace and specialized modules. In addition, the system has a behavior that can be expressed by processes that fulfill a particular function. These processes can be divided in specialized modules, that each can be decomposed via subsystems and sub-processes to elementary parts and process steps that are restricted to the level of the neural network. Each structure and process has a functional role that can be described by certain properties, just as conscious cognition, as the integrated whole, has a functional role in recruiting the necessary circuits that are most relevant for solving the current state of affairs. In short, a system is described of interacting components forming an integrated whole that has structure, behavior and interconnectivity.

The theoretical advantage of discreteness is to be able to compare conscious processing with a digital processing algorithm. A distinction between two fundamental mechanisms that contrast implicit and explicit processes in conscious cognition parallels discrete states in a Turing process on the one hand, and a continuous process of massive parallel evidence accumulation on the other hand. A fusion model that is closely related to the global workspace model, that integrates both mechanisms, will be described as the neural Turing machine. It compares conscious cognition with a serial multi-step computational process by combining massive parallel processing with a serial production system. The neural Turing machine illustrates how a neural network state can be realized, including the representation of internal milieu and memory parameters.

The global workspace model

The global workspace is the most accurate model of consciousness that is currently available. It can be described as a local-global theory, contrasting local theories of consciousness, including the theory of microconsciousness by Zeki (2003), discussed earlier. Current neurophysiological evidence from a wide variety of experimental data is more consistent with local-global theories about consciousness than local ones. In the following section an outline of the global workspace model will be given based on supporting neurophysiological evidence.

The global workspace revolves around a central mechanism of binding and distribution for the manifestation of conscious awareness. Content is flexibly bound in binding coalitions that allows for rapid propagation of content across different specialized cortical modalities updating local receiving coalitions. Each of these specialized modalities receives and interprets the distributed content locally according to their own cognitive functionality, after which it is signalled back to the source network. This form of re-entrant signalling reflects an ongoing flexible, selective and adaptive communication between local interpreters and workspace units stabilizing adaptive resonance between source networks and receiving networks (Baars, Franklin & Ramsoy 2013).

It is postulated that every conscious episode is reflected by directional broadcasting of a dominant binding coalition. Different networks and signalling routes can reflect various modes of conscious awareness, so that different conscious content is reflected by different source networks and distribution patterns.

Neurophysiological architecture

It is proposed that the neurophysiological substrate of the global workspace is implemented in the thalamocortical (TC) complex. Conscious content can be bound flexibly in the TC-complex, which is potentially capable of expressing a wide variety of conscious experiences. The thalamus and cortex consist of two-dimensional arrays of neurons that are stacked in a multi-layered fashion. These arrays and their arborisations show highly interconnected network properties. Besides strong local connectivity long cortical projections run along white matter tracts, directed in functionally precise sophistication. Rich and bidirectional connectivity within the TC-complex allows for flexible signalling between TC-units.

Conscious content is dependent on what type of binding source forms the winning coalition within the TC-complex, so that visual content is bound by visual cortical areas and auditory content by the auditory cortex. Other forms of rich conscious experiences such as feelings of knowing, which may

not be sensory driven, involve binding sources in frontal cortical regions. Long precise and coordinated projections from the TC-complex with wide-ranging specialized brain modules can potentially sustain adaptive resonance equilibria between source networks and specialized brain modules in order to coordinate a wide range of biological functions, including memory, executive functions, motor planning. Each of these specialized cortical regions is mirrored in thalamic nuclei in a multi-layered array structure, functioning as a gateway for relaying cortical signals from different areas. Thalamic nuclei are not directly connected to each other, but do communicate via cortical synapses. The mirrored TC connections feature topographically consistent labelled line coding i.e. the relative neuronal location is preserved in higher order cortical maps.

For example, retinal ganglion cells, which transduce visual sensory information, are mirrored in the later geniculate nucleus of the thalamus, which in turn projects on a 1 on 1 consistent basis to V1. Visuotopic mapping is organized and maintained in higher order retinotopic maps, even though receptive field integration increases and spatial resolution decreases. Sensory integration of other sensory modalities is also regular and topographically consistent, including tonotopic correspondence in the auditory cortex and somatotopic correspondence in the somatosensory cortex. Extending even further TC arrays project to higher level frames, including self-centered and object-centered spaces, which work in congress to coordinate a coherent action space and regulate executive functioning. Frame binding just like feature binding plays an important role in giving shape to events and objects which arise in conscious awareness. Frame binding, including allocentric and egocentric framing in parietal arrays, do not lead directly to conscious awareness, but provide a context in which spatial knowledge is specified.

Frame binding vs feature binding

Systematic visual organization in arrays with seemingly more complex receptive fields, allows for structured coherent perception that serves the organism's needs. Perception can be described as a relative process that facilitates biologically relevant selection and amplification in a stable percept in the face of a rapidly changing and seemingly disorganized environment. Each visuotopically organized cortical layer has its own specialized contribution, in which arrays can signal across multiple arrays, cooperating or competing, respectively reflecting balanced integration of visual properties or amplification and emphasis of visual features in a particular order class. The flexibility with which dominant binding coalitions can be formed reveals an intricate mechanism that allows for adaptive perception. In fact there exists an evolutionary pressure that seems to force adaptive perception with the intention of being able to handle a fast changing environment with many unexpected stimuli, including momentary dangers and opportunities that may be hidden, camouflaged or in any other way ambiguous. Contextual integration in visual perception allows for ambiguity resolution, easing navigation and comprehension. The concept of adaptive resonance has more emphasis on a functional selection mechanism than feedback driven coordination i.e. dynamic spatial activity is directed by trajectories that evolve by adaptive resonance, indicating selective and adaptive properties beyond just re-entrant signalling (Baars, Franklin & Ramsoy 2013).

To illustrate the concept of flexible binding and adaptive resonance, it can be considered how the brain is capable of distinguishing between a single star on a dark night and a dot spot in a dotted

painting. A single star on a dark night may reflect strong bidirectional activity between the lateral geniculate nucleus of the thalamus and V1. Neurons in these areas reflect high resolution contrasts, as emphasized in a single star space. Flexible binding activity in V1 and the visual thalamus magnifies relative activity in these regions in the formation of a dominant binding coalition, which can then be ignited in a flexible broadcast for widespread adaptation in previously established networks, enabling conscious awareness of a star in black space. Conscious awareness of a dotted painting may comprise a different sort of binding coalition with relatively higher synchrony in higher order arrays. Thus flexible binding integrates relative array contributions for the same physical stimulus in different contexts.

Amplification of relative neural activity is a function of both implicit and explicit attentional modulation, enabling conscious content to arise anywhere within the TC-complex when multiple input streams compete for a winner take all equilibrium. Vice versa spatial activity maps can also reflect attentional modulation or focus shifting.

Neurophysiological dynamics

The TC-complex is a parallel-interactive structure, as shown with different spatial and temporal neuronal recording methods. The TC core expresses oscillatory activity across a wide frequency spectrum, including delta, theta, alpha, beta and gamma rhythms, exhibiting long-distance synchronisation and cross-frequency phase coupling, both reflecting dynamic integrative inter-array signalling. For this reason it is postulated that conscious awareness is not localized in a single anatomical hub, rather a functional hub or adaptive resonance unit, which at least constitutes two layers of interconnected arrays that can sustain a functional network unit with a bidirectional dynamic signalling capacity (Baars, Franklin & Ramsoy 2013). However this does not exclude the importance of single-neuron activity. Neuronal spike timing and other mechanisms of synaptic plasticity are also used as neural coding forms in the TC-core. Essentially brain rhythms are dependent on both excitatory and inhibitory activity on the neuronal level and these rhythms may even interact with single-neuron activity, including single-neurons that phase adapt to frequency peaks.

Thus the TC-core uses multiple ways of neural coding in parallel-interactive signalling that constitutes both global and local processing with a high integrative capacity for concurrent spatial and temporal encoding. The complexity and massive connectivity in the parallel-interactive TC-core is corroborated by human abilities to see a single near-threshold star in dark space, voluntary control over single motor units, and even voluntary control over single cortical neurons (Cerf et al. 2010).

Large-distance synchronisation and cross-frequency coupling are implicated in conscious cognition for synced activation of a large-scale cortical network. Bursts of coherent gamma firing, reflecting the emergence of an array-to-array gamma synchronous neural assembly, arise and dissolve at a frequency in the theta-band, which may subsequently be in sync with other ongoing oscillatory rhythms. Slow wave oscillations assist by lowering and syncing global neuronal firing thresholds, thereby coordinating and regulating long-distance coherence between neural assemblies. A slow to fast wave hierarchy can be observed that is involved in the coordinated integration of oscillatory activity, ranging from linking and unlinking local neuronal assemblies and single-neuron activity with ongoing rhythms to regional grouping and long-distance coherence, culminating in a parallel-interactive signalling complex that underlies conscious cognition.

Brain rhythm dynamics reflect the organization of a conscious cycle. In a cycle of conscious cognition, as reflected by the P3 ERP, conscious processing seems only a minor component, covering only 100-200 ms of the cycle. Concurrently many unconscious processes give rise to an ongoing rich background. Conscious content is also mutually exclusive and internally consistent, meaning that different pieces of content cannot be maintained consciously, certainly not when they contradict each other. Unconscious processes on the other hand don't have to be consistent and can overlap in different consecutive binding episodes (Franklin et al. 2012). Conscious processing induces widespread adaptation in the TC-system and the subcortical satellites it projects to.

Baars, Franklin & Ramsoy, (2013) postulated adaptation to novelty in conscious processing by establishing permanent memory traces. This is evident from fMRI studies that show strong decreases in cortical activity in repeated processing and learning. For example the beginning stage in procedural learning is seemingly overwhelmed by incoming novel stimuli that trigger widespread activation and adaptation. By learning, over time a sharp decrease in conscious processing and cortical activity can be observed as complex patterns in skill acquisition become automatic and unconscious. Widespread activation in the TC-core triggers output to basal ganglia, which with repeated learning becomes a self-sustaining re-entry loop together with the TC-core, reflecting an unconscious processing cycle. Novelty triggers widespread distribution of focal information in order to recruit brain areas for problem solving and non-trivial acquisition of knowledge and skills.

The cognition action cycle

Global workspace dynamics can also explain a recurrent cognition and action cycle where conscious action can be described by a similar mechanism as conscious perception, just as motor awareness is based on the activation of an intentional motor representation with integrated proprioceptic and kinaesthetic information. Sensory binding in conscious access is primarily located in the posterior cortex, from where it is widely distributed. Conscious action, rather voluntary action (because not every motor expression is within the scope of conscious access due to habitual and automatic components in controlling motor expression and inner speech) emerge primarily in the frontal and parietal cortices but can be triggered by broadcasting of a sensory event.

Given the high variety of potential binding resources, ranging from single cell single star representation and single cell voluntary control to complex object representation in the inferior temporal cortex and abstract non-sensory content representation in the frontal regions, there exists an almost endless potential for possible conscious-action streams (see *figure* 2). A conscious experience originating in the posterior cortex can thus initiate a broadcast, which subsequently triggers binding in frontal executive cortices, which is spread by a subsequent broadcast. Intracranial recordings in epileptic patients revealed brain rhythm dynamics that correspond with a recurrent cognition-action cycle. Bursts of oscillatory gamma synchronization corresponded with the conscious perception of an auditory word stimulus and subsequent verbal report. According to the global workspace model this reflects binding in the auditory cortex and subsequent broadcasting, including Broca's area and other relevant speech production area that are primed by adaptive resonance for consecutive verbal speech execution (Baars, Franklin & Ramsoy 2013).

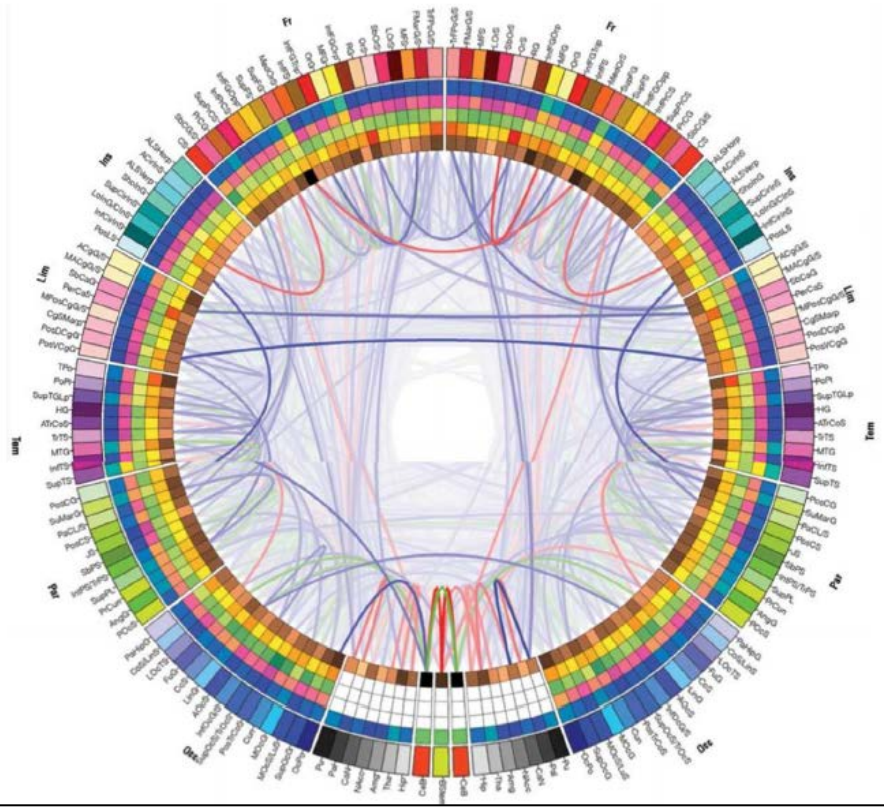

Figure 2. Schematic illustration of potential inter-array signaling routes. It shows a dynamic integrative inter-array signaling capacity with high combinatorial variety for long-distance synchronization (long cortical projections along white matter tracts). The left and right halves of the circle represent the left and right hemisphere respectively. The color code is an estimate of neural scaling. S*ource:* (Baars, Franklin & Ramsoy 2013)

Altogether GWT is a very accurate model for describing conscious and unconscious processes, as is both demonstrated by neurophysiological evidence and simulations in neural architectures (Franklin et al. 2012). GWT is developing in complexity, increasingly encompassing a functional description of the extensity of cognitive processes in the brain. It is useful that GWT is primarily based on experimental research with the aim of elucidating how the mind is implemented on the brain, so that this functionally descriptive model of consciousness can serve as a blueprint for constructing an architecture that might possibly implement a mind, intelligence, or at least higher order cognitive properties. Important to note is that it is not necessary to mimic local neural structures precisely in order to give rise to an expression of higher order mental dynamics that approximates the way it is expressed by the brain. Even though relatively little is elucidated about the brain's functional cognitive mechanism, in absolute sense there exists considerable knowledge that can already explain various properties of cognition and even consciousness.

For example, the GWT exhibits four essential properties that govern the behaviour of the model. The first property is *informativeness*: Novelty triggers widespread distribution of focal information in order to recruit brain areas for problem solving and non-trivial acquisition of knowledge and skills, leading to general habituation by establishing a memory trace, thereby constraining information that is contained in the global broadcast. The second property is *internal consistency* of conscious contents: conscious content is mutually exclusive, so that different pieces of content cannot be maintained consciously, certainly not when they conflict each other. This is among other things apparent in visual illusions with different visual appearances depending on the focus of awareness, which tend to provoke one coherent percept at the time, excluding concurrent existence in conscious awareness. The third property is an *implicit self-system*: during a global broadcast a range of specialized sub-systems are recruited, including higher level frames like self-centered and object-centered spaces. They are postulated as unconscious contextual processes that give shape to events and objects which arise in conscious awareness (Baars 1988). In this way allocentric and egocentric framing recruited by parietal arrays, do not lead directly to conscious awareness, but provide a context in which spatial knowledge is specified. In the same way a multitude of specialized unconscious processes work in congress to coordinate a coherent action space and regulate executive functioning through an implicit self-system. The fourth property is *limited capacity*: the global workspace has a limited capacity, necessitating competition between coalitions to participate in the global workspace.

In summary GWT reflects a massively distributed parallel system with many specialized circuits that either process incoming sensory information, competing for attentional selection in the global workspace or give shape to conscious content as unconscious secondary processes. Conscious cognition has a functional role in recruiting the necessary circuits that are most relevant for solving the current state of affairs, by updating unconscious processes with each cognitive cycle, including memory circuits. Therefore conscious cognition has an essential and functional role in learning by updating unconscious habituated processes and memory systems in order to improve and develop non-trivial skills for better interaction with the environment.

GWT architecture

The essence of a cognitive cycle can be illustrated by an hourglass (see *figure 3*), whereby the top of the hourglass represents broad sensory inflow that is narrowed down to the winning coalition by competition for the global workspace, which is reflected by the center. The center (bottleneck) symbolizes a limited capacity and a functional role for conscious cognition by serving both as a filter (attentional modulation) and recruiter (broadcasting). The subsequent conscious broadcast is reflected by the bottom portion of the hourglass, symbolizing recruitment of unconscious processes for optimal problem solving.

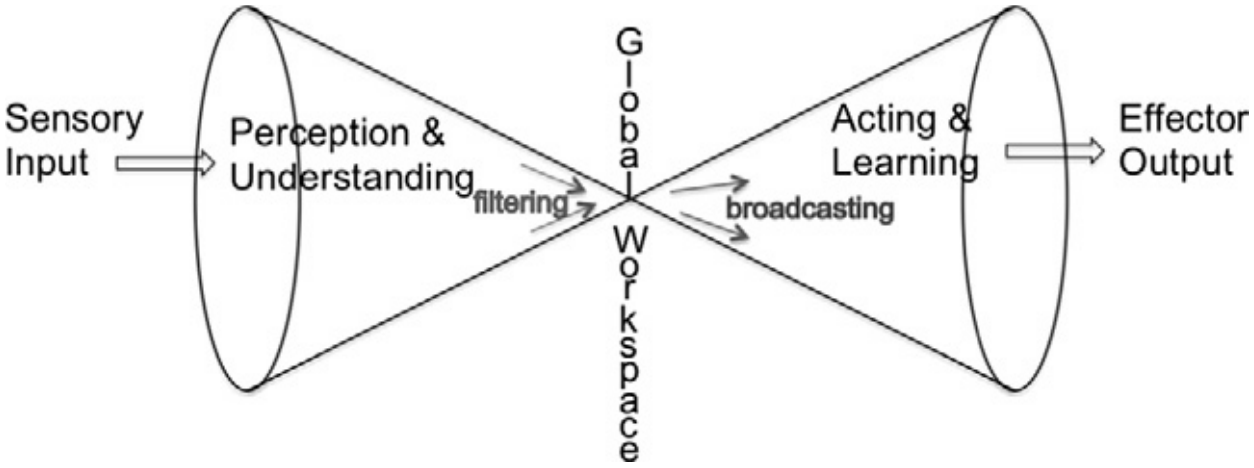

Figure 3: Abstract cycle in GWT. *Source*: (Franklin et al. 2012)

Shadahasan (2010) postulates a hierarchically modular small-world-network model of the brain's infrastructure that supports the expression of a cognitive cycle in GWT. In his model neurons represent nodes and synapses links. A small-world-network property is described by locally dense internal connections with less external projections connecting to other dense local networks. The network is hierarchically organized and modular in structure, ranging from single cell assemblies to local sub-modules and higher order specialized modules. In addition there exist connector-hubs that function as gateways for interconnecting modules. Combined, the connector-hubs and interconnections constitute the connective core, which together with the modular network allows the system to broadcast local content, thereby implementing a local-to-global architecture, enabling global dissemination of a mutually exclusive winning coalition.

A neurophysiological infrastructure of the brain has been mapped by revealing a dense fiber network connecting distant cortical brain regions that resembles a connective core. Connecting-hubs have been found linking cortical and subcortical distant areas with dense internal connections and sparse external projections (van den Heuvel, Sporns 2011). The neurophysiological connective core also behaves according to a bottleneck principle, enabling effective distribution of a dominant binding coalition established by criteria for biological relevance and emphasizing the serial nature of conscious cognition. Updating of distributed unconscious processes that regulate an effective action space is almost exclusively dependent on conscious content in the global workspace, thus reinforcing action selection that is determined by discrete conscious content. Important to note is that unconscious processes do influence the dynamics of competing coalitions for conscious access, however this is represented by massive parallel projections that constitute an implicit self-system. Before elucidating how a single neural step algorithm can be reconciled with massive parallel projection in a neural architecture that approximates a cognitive implementation of the brain, the universal Turing machine is discussed as a suitable metaphor to illustrate discrete cycles of input-state-action.

The universal Turing machine

Barendregt and Raffone, (2013) described conscious cognition as a discrete, deterministic, and universal Turing machine. In short, the Turing machine was described by Turing as a machine that could initiate an action based on delivered input. However the action was not only determined by the input, the machine state was also a variable influence. Thus different state pairings with the same input could initiate different actions. Mathematically this is represented by the following function:

Input * State -> Action * State

As can be seen in this function, state can be modified or remain unchanged during a single transition step. The list of possible transitions is constrained by a predetermined set of transition rules that specify for a set of input-state configurations what action follows and how the state is modified subsequently. When the Turing machine is given an input, it can initiate a chain reaction of subsequent transition steps, provided there is a predetermined transition rule for each step, else it simply stops or it reflects a termination signal. However the machine could transition in a closed loop, as some transition rules lead back to previously passed input-state configurations. This concatenation of sequential operations could be described as a discrete dynamic process.

A code that is read this way by a Turing Machine is in this sense totally determined by the program, because there is only one way how the code is run with little space for flexible operation. Conversely, a universal Turing machine is a higher order machine with the capability to simulate first order Turing machines. It is like a Turing machine with a higher order skeleton, the higher order abstract structure with the flexibility to determine a range of first order definites (i.e. programs). The operating mechanism of conscious cognition works analogously by directional broadcasting of conscious content (i.e. running the program) without directly influencing the content itself.

The neural Turing machine

In the comparison of the brain's implementation of conscious cognition with a serial multi-step computational process it should be considered that the vast majority of brain processes constitute massive parallel processing. Even though brain processes are constraint by elemental seriality, as reflected by the neuronal refractory period and the neuronal threshold, individual neurons still exhibit greater complexity as nodes in a neuronal network compared to a nodes in a digital circuit. Neurons express complex integration of signals by gradual behaviour in the form of graded potentials. In this way single cell assemblies can operate with variable probability distributions, even with potential for adaptive signalling. This transforms the elemental seriality of the neuronal network with higher order randomness, which constitutes an 'ordered mess' on an even higher level. This introduced stochasticity promotes learning and exploration by injecting variability and adaptive signalling.

The 'ordered mess' represents the structure and organization of a higher order neuronal network through which the serial nature of conscious cognition emerges, the totality of neurophysiological evidence that constitutes the basis of the global workspace as a model of discrete conscious cognition. Even though the brain features massive parallel processing, the emergent discreteness of conscious cognition may behave according to a Turing machine (Barendregt, Raffone

2013, Zylberberg et al. 2011). Zylberberg et al. (2011) propose a hybrid neuronal architecture that reconciles massive parallel processing with a serial production system that is based on the Turing machine. Productions parallel discrete action steps or transition rules in the Turing machine by acting as an analog-to-digital convertor. Production rules are activated when certain conditions in the network are met (the tape in the Turing machine), after which the activated production can change the state of the network. Production selection is based on evidence accumulation by massively parallel brain circuits in large-scale network competition for central access in working memory, running parallel with the emergence of a winning coalition that can access the global workspace. This means evidence accumulation by neural circuits evolves towards a memory state that determines the selection of a discrete action step (i.e. production rule).

Neurophysiologically this corresponds with neuronal competition by mutual inhibition until a threshold is crossed that ignites in widespread global synchronization in brain rhythms, marking a discrete reverberating conscious state. The integration of multi-step processing with massive parallel processing enables non-conscious or sub-threshold activation to exert influence through sensory and memory systems, explaining subliminal priming effects. Transformation of massive parallel processing in discrete actions steps could have the advantage of correcting biological noise as a side effect of analogue signalling (Zylberberg et al. 2011).

Neurophysiological signatures of evidence accumulation and production signalling have been found to exist in widely distributed brain areas or even as different phases in single cell activity. For example ramping neurons in both frontal and parietal areas have been found to represent competing productions. Widespread distribution of neuronal production signatures is logically associated with the multitude of possible effects that can be driven by ignited productions. Furthermore close association of production signatures with the complete assortment of specialized brain areas allows productions to influence these areas according to current circumstances and its associated requirements for effective processing. For example productions can trigger customized motor actions and certain motor actions require discretization steps that can be carried out by phasic neurons. The recruitment of specialized peripheral processors in attentional modulation is another example.

The phenomenon of task-dependent cortical priming and adaptive signalling implies that specialized memory systems can be modulated by both non-conscious parallel processing and selected productions that subsequently influence production selection. Also certain spontaneous activity influences the production selection process in the form of supplementary stochasticity to current deterministic input, which augments exploration and learning. The system of production selection can represent complex multi-step algorithms by triggering motor actions through intermediate preparatory steps, representing modulations of working memory with each production selection or the consolidation of latent neural traces.

It is postulated that the primary mechanism for encoding memory traces is established by sustained neural activity. It has been shown that single cell activity can represent different kinds of memory attributes, including stimuli characteristics, semantic categories and abstract patterns and can flexibly switch between different representations (Zylberberg et al. 2011). Memory is inherent in the state of the network, biasing competition in the production selection process by encoding goals and sensory modulation with respect to both innate biological concerns as well as conditioning. This

reinforces production selection via contextual amplification systems according to sensory and memory constraints with respect to positive outcome by stimulating synaptic consolidation.

The hybrid model shares some key components with the global neuronal workspace model: first, there is a system of massive parallel projection that ignites into a discrete network state. Second discrete changes in the network are accomplished through competitive selection. And third, the ignition of a production/broadcast can influence the state of the network. Moreover iteration of the conscious cycle in the global workspace model parallels with a cycle in the neural Turing machine that characterizes parallel processing at sensory levels followed by a functional serial bottleneck at the transition step, as reflected by the top of the hourglass (see *figure 3)*, and subsequent influence on sensory and memory systems, as reflected by the bottom of the hourglass.

Section 4: Meta-awareness

This section will provide an integrated perspective on conscious processing with an emphasis on metacognitive consciousness. It builds on the global workspace model that was discussed in the previous section and expands on meta-cognitive processes in particular. The advantage of conscious discreteness is the possibility of reflection without an infinite regress. This allows the comparison of conscious processing with a digital processing algorithm, as demonstrated by the neural Turing machine. The human advantage of conscious discreteness is the ability for meta-awareness, which enables deautomatization (i.e. deconditioning) through reflection.

The capacity for meta-awareness is widely expressed in complex human-environment interactions, and especially in contexts that stimulate learning and development. Cognitive states that are associated with attention and emotion regulation practises, collectively known as meditation practises, are specifically aimed at developing monitoring skills and the cultivation of meta-awareness. These cognitive meditation states will be assessed with respect to the adaptive workspace model that represents a system of interdependent components and processes that can describe the establishment and dissolution of cognitive states.

Meditation states are minimally constraint by a goal-related context, allowing the examination of subtle changes in conscious awareness and their associated neural patterns. Attention regulation practices in meditation can influence activation patterns in the brain and can even transform the neural network in a dynamic equilibrium state, as will be explained in this section. This facilitates the development of attentional stability and vividness that allows awareness of first-order subjective "I" states by recollection in a second-order state of meta-awareness, in which the 'me' can be isolated from the object of awareness.

Before the meditation process and its associated cognitive states are tackled, attention and awareness will be analysed in relation to the adaptive workspace model. The properties of meta-awareness in conscious cognition as expressed as a 'function' of the properties of specific neuronal components will be discussed. A possible role of Brodmann area 10 is implicated in the regulation of attention, which operates at a meta-representational level that is cross-dimensional and indifferent to precise stimuli characteristics. It presumably operates as a routing system that directs the flow of information streams from stimulus-independent and stimulus-oriented networks in a competition for central access. This structure is involved in the regulation of meta-awareness, and determines the properties of meta-awareness.

Adaptive resonance can be considered as the coupling mechanism for interacting local processing networks, the essential signalling mechanism in the realization of conscious awareness. Adaptive resonance as the coupling mechanism for interacting parts and processes enables coherent patterns of neural network activation that represent cognitive states.

The adaptive workspace

Raffone and Srinivasan (2009) describe the adaptive workspace model in relation to the neural correlates of consciousness. This model adds complexity in comparison to the global workspace model and neural Turing machine discussed above, because it can functionally explain a wider range of

conscious phenomena, particularly the development of specific cognitive processes in meditation practices. This model implements a system of massive parallel projection that ignites into a discrete network state, just as a Turing machine inspired network accentuates a serial computational multi-step process with definite discretion steps without compromising the complexity of the system and its adaptive capability. Differentiation of distinct phases in conscious cognition constraints its underlying neural mechanism in favour of dissociating distinct sub-object relations. This is important to be able to dissociate between apparent different forms of consciousness and related phenomena that are often mentioned, like endogenous attention, access consciousness, phenomenal awareness and metacognitive consciousness.

Central in the adaptive workspace is the adaptive coding net (ACN), a network of neurons that reside within the TC-core, especially in the prefrontal cortex. Earlier it was described that this core network is rooted in the thalamus and cortex and consisted of two-dimensional arrays of neurons with dense arborisations realizing highly interconnected network properties. Access-based conscious content is represented by directional broadcasting of a dominant binding coalition and different networks and signalling routes can reflect various modes of conscious awareness, so that differences in conscious content are reflected by different source networks and their distribution patterns. Sources can potentially be bound across a wide range of sensory modalities, but also as non-sensory driven content like 'feelings of knowing' that is bound in prefrontal regions, as denoted by Raffone and Srinivasan (2009) as content-independent metacognitive consciousness. The mechanism of metacognitive consciousness is given elaborate consideration in the adaptive workspace hypothesis to dissociate reflection within the object-subject duality of second-order consciousness, which will also be related with the context of meditation practices.

ACN neurons can form dynamic links that can potentially sustain adaptive resonance equilibria between source networks and receiving networks, facilitating flexible and rapid propagation of content across different specialized cortical modalities (see section 3). This ACN-mediated re-entrant signalling is the central mechanism underlying the emergence of access-based consciousness. According to the adaptive workspace hypothesis the limited capacity of conscious access can be explained by a constraint on the number of possible dynamic links that can be formed by ACN neurons. However the functional dynamics of the ACN is not specified yet. Instead different possible implementations of an abstract ACN are suggested with emphasized reference to an oscillatory synchrony-based entrainment that is based on the communication-through-coherence hypothesis.

According to the model this means that in addition to direct communication via anatomical projection there is a form of flexible communication that is implemented via dynamical neuronal coherence between groups of neurons. This means that neural coherence facilitates effective neuronal communication. This is based on the observation that groups of neurons have an intrinsic ability to oscillate and the oscillatory effect of inducing rhythmic modulations in the membrane potential that affects both sensitivity in synaptic input and spike output. Excitatory peaks in rhythmic oscillations encode rhythmically reoccurring temporal communication windows for input and output. Only neurons that are rhythmically tuned to each other can communicate.

Neuronal coherence can be established across a wide spectrum of neuronal frequencies. For example oscillatory phase locking between groups of neurons within the same cortex is constituted by

frequencies within the gamma range. Actually the communication-through-coherence hypothesis is an elaboration of the functional mechanism behind neuronal communication via oscillatory synchrony. It describes a mechanism of communication for the coordination and integration of distant specialized brain modules to enable flexible and timed responses to cognitive demands. Even more ubiquitous in adaptation to novelty in conscious cognition where novelty triggers widespread distribution of focal information, particularly through long distance synchronisation, in order to recruit brain areas for problem solving and non-trivial acquisition of knowledge and skills.

In particular the TC-complex is described as a parallel-interactive structure, exhibiting bidirectional signalling through oscillatory synchrony and cross-frequency phase coupling. Based on the properties of oscillatory synchrony, Baars, Franklin & Ramsoy (2013) postulated a functional unit within the TC-complex as an adaptive resonance unit, which at least constitutes two layers of interconnected arrays that can sustain a functional network unit with bidirectional signalling activity through intrinsic oscillatory activity.

In the adaptive workspace hypothesis conscious emergence revolves around the adaptive and resonant involvement of the ACN. It has been found that dynamic coherence is determinant and selective in the effective gain of neuronal connections, over and above stimulation through anatomical projection. To give an example, when two neighbouring visual stimuli are converging on the receiving neuronal group for higher order visual processing, neuronal coherence of the receiving group tends to be higher with the attended stimulus compared to the unattended stimulus. This is manifested as a tendency to sync with gamma-band synchronized spikes that are driven by the attended stimulus, even to the exclusion of the unattended stimulus, despite receiving anatomical input from both stimuli. Furthermore this selectivity is corroborated by an exclusive feedback relation with the attention driven neuron. Thus dynamic coherence enables flexible modulation of effective neuronal communication over and above ongoing stimulation via anatomical projection (Fries 2005).

Neuronal coherence in directional signalling enables selective entrainment of neuronal groups or areas by oscillatory rhythms, thereby phase locking sub-threshold excitatory peaks to specific frequency channels. Distribution of a rhythm enables selective recruitment of distant cortical areas by tuning their temporal communication window through oscillatory entrainment, while simultaneously rendering communication ineffective in areas that are out of sync. This is especially relevant in the context of long-distance reverberation by broadcasting-centres in the TC-complex. Widespread reciprocal connections in the TC-complex facilitate the distribution of specific rhythms to selectively influence distant cortical areas, despite the apparent randomness of anatomical projections. In this manner top-down endogenous attention can be implemented through neuronal coherence, whereby cortical areas relevant to the current cognitive demands are modulated. This resolves the coordination of a spatial distribution by transforming spatial activity in the form of a temporal code with synchronous oscillatory entrainment.

Metacognitive consciousness

Metacognitive consciousness is a special kind of access consciousness that involves explicit subject-object awareness. It should be distinguished from an implicit memory awareness that is apparent in habitual stimulus-response mappings that aim to resolve a discrepancy between the actual state and a

referenced state. Previously in an extensive discussion about error-awareness, it became clear that error-resolution could occur without awareness. This was reflected in the error-related-negativity that was present in both aware and unaware conditions of error responses (Endrass, Franke & Kathmann 2005). Therefore it seemed that the ERN and its spatial correlate, the RCZ, are not a reflection of error awareness, but instead a preconscious correlate of performance monitoring.

The adaptive workspace model suggests that metacognitive consciousness, as in the conscious observation of experience, is realized by intrinsic ACN links (i.e. neuronal coherence between adaptive resonance units located in the PFC), while performance monitoring (not necessarily conscious) depends on the interaction between the ACN and consumer systems (Raffone, Srinivasan 2009). The same dynamic linking mechanism is involved in the formation of a conscious working memory representation that is related to metamemory and implemented memory strategies. This suggests that the degree of active monitoring is determined by the number of intrinsic ACN links, shifting more towards the formation of dynamic links with consumer systems as monitoring becomes more automatic and requires less explicit cognitive resources. Consumer systems can represent complex cognitive patterns by integrating efferent and reafferent processes in functional networks that regulate effective cognition without conscious effort.

As cognitive monitoring becomes less centred in conscious access, a reduction in the number of required ACN links makes free endogenous attentional resources available for a novelty-based adaptive conscious access. With enough cognitive resources free to observe and analyse momentary circumstances, the senses become grounded in an open field of distributed endogenous attention, increasing the likelihood for discovering new opportunities for action. The normal state of endogenous attention is an open-field distribution that becomes more selective as attention is drawn to whatever is most relevant according to individual goals in the moment.

Cognition consists of a stream of separate frames, each manifesting flexible discretization steps by selective entrainment through oscillatory synchronization, thereby dynamically encoding conscious content and unconscious patterns. The apparent discreteness and flexibility of cognition can be explained by the formation of transient global states that reflect phasic shifts in endogenous attention and goal representation. Directional regulation of endogenous attention is reflected by higher cortical areas, including the ACN and parietal and posterior cortices. Preservation of a global network state for the apparent continuity of conscious content through the maintenance of an endogenous attention bias is mediated by neuronal coherence between the ACN and perceptual networks. The ACN, Specifically the anterior cingulate cortex is involved in monitoring selective attentional focus against ongoing distractions in order to sustain neuronal coherence with perceptual networks that explicitly represent a conscious percept (Raffone, Srinivasan 2009).

The rostral or anterior PFC, cytoarchitectonically known as Brodmann Area (BA) 10 is hypothesized to be specifically involved with various aspects of metacognition, while surrounding areas in the ACN are primarily involved in the working memory representations and executive functioning. BA 10 covers a great proportion of the PFC and its implication in a wide range of cognitive functions renders this area as highly coordinating and regulating a multitude of independent processing resources (Burgess, Dumontheil & Gilbert 2007)**.** In addition, the PFC has emerged relatively recent in the evolution of the cortex and its accelerated development in human species coincides with the conscious

capacity that is distinctive in human species. Activity in BA 10 has been associated with conditioning, problem solving, language, motor learning, rule learning and different kinds of memory, including semantic memory, spatial memory and working memory (Burgess, Dumontheil & Gilbert 2007). Furthermore BA 10 covers a large proportion of the adaptive network (ACN, TC-network) which comprises the adaptive resonance units in the global workspace model. The central involvement of the adaptive network in the distribution of conscious content and its functional role in learning, problem solving and novelty adaptation relates to the widespread involvement of BA 10 in complex cognition.

Indeed functional overlap between processes in BA 10 and conscious cognition are directly revealed in shared distribution of cognitive resources. The extent of complex functions that is governed by BA 10 points towards a principal position in the directional organization of metacognition and metamemory. Actually BA 10 is implicated in a variety of metacognitive phenomena, including goal directed behaviour, evaluation, monitoring and manipulation, but also reflection on endogenously generated information, ranging from one's own thoughts, states of awareness or assessing the mental states of others, known as theory of mind (Johnson et al. 2002).

In particular a monitoring function has been attributed to BA 10 hypothesized to coordinate the activity between the ventrolateral PFC (engaged in updating and maintenance) and the dorsolateral PFC (engaged in selection, manipulation and monitoring) for optimizing cognitive performance. Shared memory networks enable the allocation of memory resources towards primary goals for online maintenance while exploring and processing secondary goals or attending directly presented stimuli (Fletcher, Henson 2001). The relation between BA 10 activity and episodic memory is thought to reflect the processing of conscious recollection. The fact that BA 10 reaches myelination only in a late stage of neural development also indicates its engagement in higher features of experience processing, as tardily myelinated areas are associated with experience processing (Fuster 1997)**.**

Finally BA 10 is a key component in the default mode network (DMN) that was mentioned earlier in relation to the AIC. Large-scale networks can be dissociated as functionally coherent neural systems that underlie different cognitive states, including rest, cognitive performance and rumination. One is the DMN, that shows an activation profile during states of rest or in the absence of cognitive performance that requires focused attention. DMN activity reflects a direction of internal resources towards any information that is multifariously presented from both the internal and external milieu for evaluation. Essentially this is an expression of metacognition, although with a very diffuse distribution of attentional resources. Mihaly expressed that "Entropy is the normal state of consciousness", i.e. in the absence of ordered activity, internally generated or externally triggered, attention will be attracted to whatever is most problematic at the moment, it will be drawn to some real or imaginary content that is deemed important according to deeply ingrained values (Csikszentmihalyi 1990). Therefore a resting state with high DMN activity can be characterized as a state of psychic entropy, a sign of distress that is closely associated with ruminating.

The DMN is deactivated during cognitive effort and DMN activity can even predict executive failure, indicating that the DMN is inversely related to focused attention. Novelty based processing, problem solving or endogenously directed focused attention all correlate with a reduction in DMN activity, reflecting a redirection of attentional resources while shifting from general information gathering and evaluation towards a specific target of focus. Earlier the AIC was implicated in the

regulation of competitive dynamics in large-scale neural networks, including the DMN. It is thought the AIC directs differential network activation to enhance the processing of relevant stimuli and facilitating engagement. It does so by engaging salience and control networks, while simultaneously deactivating the DMN to direct attention to stimuli that signal errors for example (Sridharan, Levitin & Menon 2008).

It is suggested BA 10 has a regulatory function in the coordination of independent processing resources, being axially organized along posterior and anterior regions as cognitive performance becomes more endogenously guided (Koechlin et al. 1999). Burgess et al. (2007) postulated a dissociation between stimulus-independent and stimulus-oriented thought in attentional regulation mechanisms mediated by BA 10. Situations that involve novelty or creative decision making require stimulus-independent processing e.g. considering possibilities that are not directly signalled by presented stimuli. Stimulus-independent processing can be described as non-routine self-determinant direction of action that does not involve the signalling of automatic schemas and has not been provoked by or is oriented towards sensory stimuli (e.g. mind-wandering, introspection, rumination). On the other hand stimulus-oriented means direct attendance of external stimuli in the present moment i.e. oriented towards stimuli that are experienced through the senses (Burgess, Dumontheil & Gilbert 2007). Rather than being an absolute dissociation, it is more a dimensional classification to dissociate different aspects of a complex cognitive event. Yet both ways of processing tend to exist in linear separation (note discrete frames in conscious cognition), often mixed in rapid succession, however not concurrently operating.

At any moment there's an ongoing competition between stimulus-independent thoughts and stimulus-oriented thought for central access in a cognitive representation. The competitive dynamics have a large implicit component where attentional bias can even be freely determined by context. One example is peripheral stimulus detection, discussed earlier in "peripheral awareness", where attention is captured through automatic bottom-up processes that depend on the interplay between memory, valence and vigilance. Bottom-up processes and comparably massive parallel projection represent a biological network system effecting attentional distribution where network activation increases dynamically towards strongly embedded stimulus-response relations that involve basic input/output systems, such as sensory, motor and speech systems, but also specialized systems that encode S-R relations in mental domains.

An example of a mental S-R relation would be expected stimuli that are congruent with momentary goals (e.g. rehearsed mental sequences, songs or simple calculations with inevitable outcomes). Often multiple S-R relations concatenate in schemas that carry out complex chains of mental actions. Therefore, in the absence of external stimuli, there is a propensity for stimulus-independent cascades. This resonates fairly with the notion of entropy as the default state of consciousness (e.g. in psychic entropy the mind tends to wander, as it is in rumination.) In addition stimulus-independent thought also dominates in situations that lack an obvious choice of right behaviour. Last, when the cognitive capacity is overloaded during stimulus oriented focus, stimulus-independent thought mixes in. This is the case in difficult skill learning that is not matched with competence, where cognition becomes overloaded with the surge of perceived errors, culminating in a state of excessive and inefficient reflection i.e. self-generated thoughts, whether or not ruminative, that hijack attentional resources, thereby perpetuating a negative cycle of ever decreasing effective allocation of attentional resources.

Given this distinction between stimulus-independent and stimulus-oriented thought Burgess et al. (2007) proposed the gateway hypothesis as a model for explaining a routing system for differential activation of stimulus-independent networks and stimulus-oriented networks. In this model BA 10 functions as a routing network that is able to direct the flow of information towards external stimuli or internally generated stimuli i.e. towards sensory input/output systems or reciprocal activation from currently active central representations.

Specifically BA 10 is recruited when consistent biasing is demanded (e.g. focused attention) or rapid switching is needed (re-engagement during distraction). Also novelty engages BA 10, as such situations require creative resources outside available S-R distributions that are present during automatic biasing processes. Bottom-up processes can account for weak subliminal processing to strong preconscious processing but top-down amplification is necessary for central access (Dehaene et al. 2006). BA 10 could be considered as the cortical representation of this top-down component that facilitates global ignition in conscious access.

BA 10 operates at a meta-representational level that is cross-dimensional and indifferent to precise stimuli characteristics or the precise nature of intended action. It operates as a routing system that directs the flow of information streams from stimulus-independent and stimulus-oriented networks in a competition for central access, not directly influencing the content of the stream itself (i.e. the encoded information is not affected in the directional flow that is governed by BA 10) (Burgess, Dumontheil & Gilbert 2007). In summary the gateway hypothesis acquiesces to a description of competitive dynamics for central access in conscious cognition, plus an explicit dimension that accounts for variations in conscious content or modes of awareness (e.g. metaconsciousness, or reflection).

Actually BA 10 shows functional differentiation in medial and lateral parts that correspond to stimulus-oriented and stimulus-independent processing respectively (Burgess, Dumontheil & Gilbert 2007). The medial part would be involved in focused attention by facilitating a sustained bias towards external stimuli. Actually performance lapses in cognitive tasks that require focused attention can be predicted by scanty activation in medial BA 10. The DMN activation is also inversely related to focused attention, though it is hypothesized to encompass BA 10 in its entirety (Weissman et al. 2006). However functional differentiation of BA 10 reveals opposing networks in the regulation of attentional bias Burgess et al. (2007).

Specifically medial BA 10 is activated when attending current sensory input, however it may also be involved in deliberate biasing of attention towards internally-represented information. This is in the form of post-retrieval monitoring, rather than internally generated information that is characteristic for lateral BA 10. Thus, medial BA 10 may also account a little for stimulus-independent processing, although in a functionally distinct phase than lateral BA 10 operates that has probably a sustaining quality. This may also be evident in resting states that is often associated with the DMN and could therefore explain why this apparently subtle differentiation was eclipsed by inadequate temporal resolution. Both medial and lateral networks regulate attentional bias by modulating the activation of currently selected schemata, enabling the potential for rapid transitions between different modes of attention, and even as distinct phases of the same mental operation in a small temporal window.

Despite seemingly mixed influences of medial and lateral BA 10 on the regulation of endogenous attention, a functional dissociation can be observed where medial BA 10 is predominantly associated

with stimulus processing and lateral BA 10 is associated with internally generated thought, including recollection, short-term retrieval and expectancy with respect to an online reference (e.g. goal setting) (Burgess, Gilbert & Dumontheil 2007).

Intrinsic ACN links

In the adaptive workspace model metacognition is realized by intrinsic ACN links. Actually there exists a functional dissociation between externally and internally distributed conscious content that is based on dynamic links with medial and lateral BA 10 respectively. The former is represented by an outward subject-object awareness (the awareness of the subject "I" of specific sensory content that is the object of attention in conscious access), while the latter is represented by an inward subject-object awareness (the awareness of the subject "I" of internally generated content (e.g. recollection) that is the object of attention in conscious access). It is the explicit subject-object relation that is attributed with a meta-representational frame, whether stimulus-oriented or stimulus-independent. This parallels the meta-representational level at which BA 10 operates.

Difference between phenomenal consciousness and metacognition

In the adaptive workspace hypothesis a limited conscious capacity imposes a large-scale network competition for central access that is subsequently broadcast to specialized networks in widespread global synchronization. Thus a conscious state is characterized by an explicit conscious representation (i.e. neuronal coherence between the ACN and sensory coalitions) together with an implicit system that is massively distributed and modular that establishes the contextual frame, in which the conscious content is embedded. The implicit system is updated with each conscious broadcast as local receiving coalitions are updated, but also with ongoing evidence accumulation. This implicit system constitutes the phenomenal background, in which an explicit foreground consciousness is embedded.

When such an explicit foreground, as represented by a discrete reverberating state, disintegrates by phase scattering, the ensuing network potential for resynchronization resolves the discrepancy between foreground and background attentional bias, culminating in an distributed open-field of endogenous attention that reintegrates the phenomenal background. Note that the open-field is still selective, but less, because there's an increased potential for creative neuronal coherence. The updated implicit context is determinant in the formation of the next conscious core by directional large-scale network competition for central access. The current implicit context can carry information on explicit object content together with its subjective phenomenal implicit context of the previous conscious state, which can potentially be disseminated in the establishment of a discrete reverberating conscious state. Actually this new state is metacognitive, as it surrounds in subject-object awareness.

Specifically a subject-object awareness that contains an explicit self-reference, or "Me" that is related to the contents of a previously established conscious core can be denoted as reflexive awareness. Even just an implicit contextual reference, that contains an implicit "Me", without any explicit foreground can become centered in a distributed open-field of endogenous attention, where there is the potential availability of a rich contextual field that can participate in a competition for central access, or in other words, this state is characterized by a high amount of free resources. Note also, as cognitive monitoring becomes less centred in conscious access, a reduction in the number of

required ACN links makes free endogenous attentional resources available for a novelty-based adaptive consciousness as the implicit context comes to surface. This allows for closer examination of subjective "I" states that resided in the "background" of a previously established conscious core associated with sensory object features, as subjective implicit content of the previous state together with its objective perceptual content become bound as one and emerges as a "new" conscious core that contains the "Me" or explicit self. Introspection of subjective "I" states can even be more refined as emergent conscious cores represent predominantly explicit "Me," not necessarily bound to any sensory maps.

Raffone and Srinivasan (2009) hypothesized that dynamic ACN links with neural markers of transient body states are implicated in the establishment of second-order awareness of experiential content. Particularly the right lateralized exteroceptive somatic cortex and the insular cortex are implicated in the emergence of momentary self-awareness. The insular cortex is associated with interoceptive visceral awareness and the AIC is implicated in error-related awareness, as discussed earlier. However it was unclear whether AIC activity is specifically related to enhanced awareness to an error-related autonomic response (i.e. registering error-related visceral reactions) or the increase in autonomic response (i.e. AIC generates autonomic activity).

A conscious event is determined by the pattern of adaptive resonance equilibria between source networks and receiving networks. In other words, conscious emergence revolves around the adaptive and resonant involvement of the ACN that facilitates large-scale, transient dynamical patterns of brain activity. The receiving networks are specialized sub-systems that are widely distributed, including anterior, posterior and associative cortices and subcortical regions. Consumer systems shape conscious events by relating conscious content to cognitive contexts, including explicit memory, evaluation, reasoning, planning, motor preparation, executive functioning and perceptual frames. The cognitive context provides implicit parameters that direct endogenous attention according to momentary goals that biases conscious access towards a working space. Conscious events can be renewed by re-initialization of broadcasting-related re-entry loops that are selectively led and facilitated by internal milieu variables that constitute the interplay between memory, emotion and vigilance.

Most of these contextual processes are unconscious, however become available for creative neuronal coherence after dissolution of a discrete reverberating state. These consumer systems range across the mind-body-world divisions encompassing self-systems that encode sensory-independent information and networks for interoception and exteroception, expanding the number of patterns in which transient large-scale assemblies can be organized in the interplay between ACN neurons and the implicit self-system that give rise to first-order and second-order modes of awareness bound to either a thought, a feeling state or external stimulus.

Open monitoring meditation

In open monitoring meditation there is no explicit object of attention. Instead there is an open-field of awareness that is present-centered and non-judgemental. The monitoring process involves an ongoing meta-awareness in which objects can be observed without explicitly focusing on any of them.

The metacognitive capacities that are described above are particularly evident in open-monitoring meditation, as it involves "pure" states of distributed endogenous awareness that is

minimally constraint by a goal-related context. Pure non-selective states cannot exist due to the ongoing presence of internal milieu variables that selectively lead and facilitate attentional bias via corresponding feedback loops and re-afferent schemas, however a minimally selective state is increasingly developed with expertise. In such an open-field of awareness there's the potential availability of a rich contextual field that can form dynamic links with adaptive resonance units. The ongoing availability of free endogenous resources increases the potential for creative neuronal coherence in establishing patterns of large-scale, transient dynamical brain activity. Distributed neuronal maps can participate in the formation of adaptive resonance equilibria, integrating information across external sensory fields as well as internal thoughts and feelings.

In experienced meditators the monitoring process is more efficient, exhibiting minimal reactive attentional bias that allows unallocated resources to freely center in an open-field of distributed endogenous attention. Raffone and Srinivasan (2009) hypothesize that the experience of open monitoring meditation reflects the rapid formation and decay of dynamic cores which are assembled via adaptive neuronal resonance, emphasizing transient meta-stability.

In contrast, consciousness is often related to working memory representations. Referring back to Dahaene et al. (2006) theory of conscious processing, the neural mechanism of conscious access was described as global recurrent activation, keeping information online trough reverberation and higher cortical propagation and making it available for cognitive manipulation. Conscious access was also associated with a distinct internal space that can hold a perceptual frame online and is buffered away from the fast fluctuations of sensory input. Also the measured p300 component during conscious processing correlated with a transient global increase in gamma oscillatory phase synchronization and enhanced theta oscillations were found as a reflection of internally buffering a conscious working memory representation. Furthermore the global workspace describes large-scale network competition for central access in working memory and ACN mediated adaptive resonance is postulated to be involved in the formation of a conscious working memory representation that is related to meta-memory and implemented memory strategies.

Conscious working memory representations have more emphasis on integration in foreground access consciousness that can be described as strong selective bias or focused attention with high intensity on a strongly segregated foreground, while experienced open monitoring meditation emphasizes differentiation, thereby facilitating integration of both foreground and a rich contextual background in an open-field of endogenous attention. In this way metacognitive awareness is maintained or expanded by ongoing signal exchanges that involve free adaptive resonance units. The maintenance of an ongoing open-field of endogenous attention increases the capacity to represent or match fast fluctuations across the mind-body-world divisions through adaptive resonance with the respective outer and inner content-related neuronal maps, thereby enhancing both phenomenal representation of experience and immediate access awareness of sensory contents. Mindfulness that can be defined as an open monitoring practise that is often associated with living in the moment without interference from cognitive projections. Often there is a discovery of new "aliveness" or "richness" of experience that can be considered as a realization of a better approximated reality through attentional acuity.

Focused attention meditation

In focused attention meditation the attention is sustained on an intended object, which can be the rise and fall of the breath. It involves the monitoring process of noticing distraction and non-judgemental redirection of the attention on the intended object. It is a concentrative practise with the aim of developing an internal witnessing observer that is non-reactive.

The intentional object-related attentional bias is sustained by an adaptive resonance equilibrium between ACN neurons and neuronal maps that encode the sensory object codes of the intended object. Attentional stability of the intended object-related conscious access is a function of pattern variability between each subsequent transient large-scale, neuronal broadcast. As each conscious core becomes increasingly associated with neuronal maps that are related to the intended object a dynamic equilibrium of endogenous attention stabilizes on the intended object. Attentional vividness or acuity is realized by the number of adaptive resonance units that are engaged in the maintenance of a dynamic resonant equilibrium that integrates the neuronal maps for the intended object. As attentional acuity increases the capacity to represent and match the intended object enhances.

Dynamic links between adaptive resonance units and the anterior cingulate cortex facilitate attentional monitoring of a selective attentional focus against distractions in order to sustain neuronal coherence with neuronal maps for the intended object. As attentional monitoring becomes more efficient and less effortful with experience, an automatic ACN perturbation-based process becomes more prevalent. ACN coherence perturbations are associated with distractions and neuronal representations of distractions exhibit reduced involvement of ACN coherence.

Neuroplasticity-based transformation of the baseline equilibrium state can integrate top-down attentional influences as part of the dynamical equilibrium itself, thereby shifting the influence on each successive large-scale brain activity from top-down modulation towards intrinsic modulation from a dynamic equilibrium. This transient meta-stability is enhanced by the rapid formation and decay of dynamic cores which are assembled through an adaptive neuronal resonant equilibrium, facilitating recurrent integration between each conscious core and reducing the possibility of distraction.

However thoughts and feelings can still present itself in the background concomitantly to an endogenous attention that is sustained on the intended object. Raffone and Srinivasan (2009) explain that these are represented by proto-cores, which are transient resonant assemblies that may co-occur with a dynamic core assembly in the neural network. According to Dehaene et al. (2006) these proto-cores are phenomenal pre-conscious neural assemblies that are characterized by strong bottom-up activation in the absence of top-down amplification, because attention is diverted away or of a possible attentional resource overload. The proto-cores would emerge with small transient perturbations of ongoing ACN coherence.

The transient and non-distracting quality can be attributed to relatively disengaged consumer network and a sustained selective conscious access that is oriented towards the intended object. The involvement of a relatively large portion of adaptive resonance units in a dynamic equilibrium that maintains focused attention form a buffer against incoming distraction, thereby constraining perturbations in ACN coherence to subtle deflections that coexist with the emergence of proto-cores. Thus a pattern of neural activity is maintained that facilitates meta-awareness that increasingly develops

as fewer resources are required to sustain attention on the intended object and long distance synchronization with inner and outer content-related maps decreases.

Phenomenal proto-cores can be triggered into conscious access cores by top down amplification of endogenous attention. A global reverberant state will be triggered in relation to an introspective intention that is possibly associated with cognitive control processes like visualization in order to renew and sustain conscious access through re-initialization of broadcasting-related re-entry loops.

Conclusion

A summary of the most important findings in research on consciousness reveals a complex neurodynamic network with the innate capacity to evolve and adapt towards optimal use of cognitive resources. Here, consciousness plays a functional adaptive role. This consist of a central mechanism that reflects a meta-representational process of flexible binding and distribution of conscious content across mind-body-world divisions via respective neuronal maps that are specialized to process information of a particular domain. These neuronal maps are distributed in a massive parallel network that compete for central access and shape access-based consciousness by implicit unconscious processes. This implicit network reflects an ongoing process of bottom-up evidence accumulation that can represent different dimensions of stimulus information, so that there exists a high variety of potential binding sources that can give rise to a very large number of different conscious events.

Conscious cognition consists of a stream of separate discrete events that reflect the dynamic formation of transient global states that underlie phasic shifts in endogenous attention and goal representation. Examination of discrete mental states in meditation practises revealed that sustained awareness can be described by transient meta-stability that is enhanced by the rapid formation and decay of dynamic cores which are assembled through an adaptive neuronal resonant equilibrium. Meditation expertise increases intrinsic modulation from a dynamic equilibrium that is maintained by ongoing signal exchanges that involve free adaptive resonance units. This contributes to the expansion or enhancement of an ongoing open-field of endogenous attention along with an increased capacity for phenomenal awareness. Immediate access awareness of content is also enhanced, because the capacity for this second-order meta-awareness is enhanced by the availability and participation of adaptive resonance units.

All of the evidence points towards a higher order mechanism in conscious processing that is based on a capacity for higher-order synchronization, which results in synchronized equilibrium states that are patterned in differential network activation. It clearly illustrates how conscious cognition is organized by its neuronal components and how some properties of consciousness are shaped by the properties of these neuronal components. Unfortunately most of the evidence is based on correlation that only answers ‘what’ is involved in conscious processing. For example, there is widespread synchronization of localized content through an adaptive resonant equilibrium. This is clearly represented in the models of consciousness, that were discussed, that describe a mechanism of binding and distribution. However the ‘intelligence’ of adaptive resonance seems to emerge as an irreducible higher order property of the network. This ‘intelligence’ constitutes the orchestration of a dynamic and adaptive system that is characterized by neuroplasticity and development. Non-trivial skill development and perception enhancement may take such forms that are beyond comprehension. Enhanced perception in meditation, which is described by attentional stability and vividness, is realized through high and stable meta-awareness. Increasingly more adaptive resonance units are involved to increase and sustain a necessary neural resonance in the brain.

Nevertheless the evidence and the models on consciousness that are available can provide insight in conscious cognition in the sense of dissociating cognitive processes and neural loci and the associated cognitive phenomena with the purpose of developing more detailed and complete theories

of cognition. Note the partial assumption presented in the introduction, which stated whether neural patterns can fully account for conscious phenomena. On the one hand, there is a lot of valuable insights from brain research on cognitive processes (e.g. cognitive monitoring, attentional modulation). On the other hand extraordinary manifestations of consciousness such in enhanced meta-awareness are accompanied by greater meta-physical clutter.

However, the lack of causal explanations in complex fields of consciousness doesn't need to offset the scientific value of this research. For example, if neural signatures of mental states can roughly be defined, then neurophysiological measurements can function as valuable insights on the presence of certain mental states. Even in the absence of clear causal factors, neurophysiological feedback can function as a visualization of what is to be desired or not. Especially in the field of meditation, which consists of complex introspective practises that includes attention and emotion regulation, neuroscientific research can provide abstract grounds on the way mental states are directed.

Literature

Arnold, D.H., Clifford, C.W.G. & Wenderoth, P. 2001, "Asynchronous processing in vision: Color leads motion", *Current Biology,* vol. 11, no. 8, pp. 596-600.

Barendregt, H.P. & Raffone, A. 2013, "Conscious cognition as a discrete, deterministic, and universal Turing Machine process" in [S.l.] : Elsevier, , pp. 92-92-96.

Bekinschtein, T.A., Dehaene, S., Rohaut, B., Tadel, F., Cohen, L. & Naccache, L. 2009, "Neural signature of the conscious processing of auditory regularities", *Proceedings of the National Academy of Sciences of the United States of America,* vol. 106, no. 5, pp. 1672-1677.

Buchner, H., Gobbelé, R., Wagner, M., Fuchs, M., Waberski, T.D. & Beckmann, R. 1997, "Fast visual evoked potential input into human area V5", *Neuroreport,* vol. 8, no. 11, pp. 2419-2422.

Burgess, P.W., Dumontheil, I. & Gilbert, S.J. 2007, "The gateway hypothesis of rostral prefrontal cortex (area 10) function", *Trends in cognitive sciences,* vol. 11, no. 7, pp. 290-298.

Burgess, P.W., Gilbert, S.J. & Dumontheil, I. 2007, "Function and localization within rostral prefrontal cortex (area 10)", *Philosophical Transactions of the Royal Society B: Biological Sciences,* vol. 362, no. 1481, pp. 887-899.

Cerf, M., Thiruvengadam, N., Mormann, F., Kraskov, A., Quiroga, R.Q., Koch, C. & Fried, I. 2010, "On-line, voluntary control of human temporal lobe neurons", *Nature,* vol. 467, no. 7319, pp. 1104-1108.

Chiesa, A., Serretti, A. & Jakobsen, J.C. 2013, "Mindfulness: Top–down or bottom–up emotion regulation strategy?", *Clinical psychology review,* vol. 33, no. 1, pp. 82-96.

Christoff, K., Gordon, A.M., Smallwood, J., Smith, R. & Schooler, J.W. 2009, "Experience sampling during fMRI reveals default network and executive system contributions to mind wandering ", *Proceedings of the National Academy of Sciences of the United States of America,* vol. 106, no. 21, pp. 8719-8724.

Critchley, H.D. 2005, "Neural mechanisms of autonomic, affective, and cognitive integration", *Journal of Comparative Neurology,* vol. 493, no. 1, pp. 154-166.

Debener, S., Ullsperger, M., Siegel, M., Fiehler, K., Von Cramon, D.Y. & Engel, A.K. 2005, "Trial-by-trial coupling of concurrent electroencephalogram and functional magnetic resonance imaging identifies the dynamics of performance monitoring", *Journal of Neuroscience,* vol. 25, no. 50, pp. 11730-11737.

Dehaene, S. 2010, "Conscious and nonconscious processes: Distinct forms of evidence accumulation?", *Progress in Mathematical Physics*, pp. 141.

Dehaene, S. & Changeux, J.-. 2011, "Experimental and Theoretical Approaches to Conscious Processing", *Neuron,* vol. 70, no. 2, pp. 200-227.

Dehaene, S., Changeux, J.-., Naccache, L., Sackur, J. & Sergent, C. 2006, "Conscious, preconscious, and subliminal processing: a testable taxonomy", *Trends in cognitive sciences,* vol. 10, no. 5, pp. 204-211.

Desmurget, M., Reilly, K.T., Richard, N., Szathmari, A., Mottolese, C. & Sirigu, A. 2009, "Movement intention after parietal cortex stimulation in humans", *Science,* vol. 324, no. 5928, pp. 811-813.

Desmurget, M. & Sirigu, A. 2012, "Conscious motor intention emerges in the inferior parietal lobule.", *Current opinion in neurobiology,* vol. 22, no. 6, pp. 1004-1011.

Doesburg, S.M., Green, J.J., McDonald, J.J. & Ward, L.M. 2009, "Rhythms of consciousness: Binocular rivalry reveals large-scale oscillatory network dynamics mediating visual perception", *PLoS ONE,* vol. 4, no. 7.

Doidge, N. *, The Brain That Changes Itself: Stories of Personal Triumph from the Frontiers of Brain Science by Norman Doidge*

Dupoux, E., Gardelle, V.d. & Kouider, S. 2008, "Subliminal speech perception and auditory streaming", *Cognition,* vol. 109, no. 2, pp. 267-273.

Endrass, T., Franke, C. & Kathmann, N. 2005, "Error awareness in a saccade countermanding task", *Journal of Psychophysiology,* vol. 19, no. 4, pp. 275-280.

Enns, J.T. & Lollo, V.D. 2000, "What's new in visual masking?", *Trends in cognitive sciences,* vol. 4, no. 9, pp. 345-352.

Farrer, C., Frey, S.H., Van Horn, J.D., Tunik, E., Turk, D., Inati, S. & Grafton, S.T. 2008, "The angular gyrus computes action awareness representations", *Cerebral Cortex,* vol. 18, no. 2, pp. 254-261.

Fletcher, P.C. & Henson, R.N. 2001, "Frontal lobes and human memory: insights from functional neuroimaging", *Brain : a journal of neurology,* vol. 124, no. Pt 5, pp. 849-881.

Fried, I., Katz, A., McCarthy, G., Sass, K.J., Williamson, P., Spencer, S.S. & Spencer, D.D. 1991, "Functional organization of human supplementary motor cortex studied by electrical stimulation", *The Journal of neuroscience : the official journal of the Society for Neuroscience,* vol. 11, no. 11, pp. 3656-3666.

Fries, P. 2005, "A mechanism for cognitive dynamics: neuronal communication through neuronal coherence", *Trends in cognitive sciences,* vol. 9, no. 10, pp. 474-480.

Fuster, J.M. 1997, *The prefrontal cortex: anatomy, physiology, and neuropsychology of the frontal lobe,* Lippincott-Raven.

Gaillard, R., Dehaene, S., Adam, C., Clémenceau, S., Hasboun, D., Baulac, M., Cohen, L. & Naccache, L. 2009, "Converging intracranial markers of conscious access.", *PLoS biology,* vol. 7, no. 3.

Gilzenrat, M.S., Nieuwenhuis, S., Jepma, M. & Cohen, J.D. 2010, "Pupil diameter tracks changes in control state predicted by the adaptive gain theory of locus coeruleus function", *Cognitive, Affective and Behavioral Neuroscience,* vol. 10, no. 2, pp. 252-269.

Hagmann, P., Cammoun, L., Gigandet, X., Meuli, R., Honey, C.J., Wedeen, V.J. & Sporns, O. 2008, "Mapping the structural core of human cerebral cortex", *PLoS biology,* vol. 6, no. 7, pp. e159.

He, S. & MacLeod, D.I.A. 2001, "Orientation-selective adaptation and tilt after-effect from invisible patterns", *Nature,* vol. 411, no. 6836, pp. 473-476.

Johnson, S.C., Baxter, L.C., Wilder, L.S., Pipe, J.G., Heiserman, J.E. & Prigatano, G.P. 2002, "Neural correlates of self-reflection", *Brain : a journal of neurology,* vol. 125, no. Pt 8, pp. 1808-1814.

Kerr, C.E., Sacchet, M.D., Lazar, S.W., Moore, C.I. & Jones, S.R. 2013, "Mindfulness starts with the body: somatosensory attention and top-down modulation of cortical alpha rhythms in mindfulness meditation ", *Frontiers in Human Neuroscience,* vol. 7.

Kihara, K., Ikeda, T., Matsuyoshi, D., Hirose, N., Mima, T., Fukuyama, H. & Osaka, N. 2011, "Differential contributions of the intraparietal sulcus and the inferior parietal lobe to attentional blink: Evidence from transcranial magnetic stimulation", *Journal of cognitive neuroscience,* vol. 23, no. 1, pp. 247-256.

Klein, T.A., Endrass, T., Kathmann, N., Neumann, J., von Cramon, D.Y. & Ullsperger, M. 2007, "Neural correlates of error awareness", *NeuroImage,* vol. 34, no. 4, pp. 1774-1781.

Koechlin, E., Basso, G., Pietrini, P., Panzer, S. & Grafman, J. 1999, "The role of the anterior prefrontal cortex in human cognition", *Nature,* vol. 399, no. 6732, pp. 148-151.

Lamme, V.A.F. 2003, "Why visual attention and awareness are different", *Trends in cognitive sciences,* vol. 7, no. 1, pp. 12-18.

Lamme, V.A.F. & Roelfsema, P.R. 2000, "The distinct modes of vision offered by feedforward and recurrent processing", *Trends in neurosciences,* vol. 23, no. 11, pp. 571-579.

Leopold, D.A. & Logothetis, N.K. 1999, "Multistable phenomena: Changing views in perception", *Trends in cognitive sciences,* vol. 3, no. 7, pp. 254-264.

Magno, E., Foxe, J.J., Molholm, S., Robertson, I.H. & Garavan, H. 2006, "The anterior cingulate and error avoidance", *Journal of Neuroscience,* vol. 26, no. 18, pp. 4769-4773.

Manna, A., Raffone, A., Perrucci, M.G., Nardo, D., Ferretti, A., Tartaro, A., Londei, A., Del Gratta, C., Belardinelli, M.O. & Romani, G.L. 2010, "Neural correlates of focused attention and cognitive monitoring in meditation", *Brain research bulletin,* vol. 82, no. 1–2, pp. 46-56.

Mantini, D., Perrucci, M.G., Del Gratta, C., Romani, G.L. & Corbetta, M. 2007, "Electrophysiological signatures of resting state networks in the human brain", *Proceedings of the National Academy of Sciences of the United States of America,* vol. 104, no. 32, pp. 13170-13175.

Mantysalo, S. & Naatanen, R. 1987, "The duration of a neuronal trace of an auditory stimulus as indicated by event-related potentials", *Biological psychology,* vol. 24, no. 3, pp. 183-195.

Melloni, L., Molina, C., Pena, M., Torres, D., Singer, W. & Rodriguez, E. 2007, "Synchronization of neural activity across cortical areas correlates with conscious perception", *Journal of Neuroscience,* vol. 27, no. 11, pp. 2858-2865.

Melloni, L., Schwiedrzik, C.M., Müller, N., Rodriguez, E. & Singer, W. 2011, "Expectations change the signatures and timing of electrophysiological correlates of perceptual awareness", *Journal of Neuroscience,* vol. 31, no. 4, pp. 1386-1396.

Moutoussis, K. & Zeki, S. 1997, "Functional segregation and temporal hierarchy of the visual perceptive systems", *Proceedings of the Royal Society B: Biological Sciences,* vol. 264, no. 1387, pp. 1407-1414.

Muller-Gass, A., Macdonald, M., Schröger, E., Sculthorpe, L. & Campbell, K. 2007, "Evidence for the auditory P3a reflecting an automatic process: Elicitation during highly-focused continuous visual attention", *Brain research,* vol. 1170, no. SUPPL.: COMPLETE, pp. 71-78.

Nieuwenhuis, S., Aston-Jones, G. & Cohen, J.D. 2005, "Decision making, the P3, and the locus coeruleus-norepinephrine system", *Psychological bulletin,* vol. 131, no. 4, pp. 510-532.

Overbeek, T.J.M., Nieuwenhuis, S. & Ridderinkhof, K.R. 2005, "Dissociable components of error processing: On the functional significance of the Pe vis-à-vis the ERN/Ne", *Journal of Psychophysiology,* vol. 19, no. 4, pp. 319-329.

Pashler, H. 1994, "Dual-task interference in simple tasks: data and theory", *Psychological bulletin,* vol. 116, no. 2, pp. 220-244.

Pisella, L., Arzi, M. & Rossetti, Y. 1998, "The timing of color and location processing in the motor context", *Experimental Brain Research,* vol. 121, no. 3, pp. 270-276.

Posner, M.I. & Snyder, C.R.R. 1975, "Attention and Cognitive Control" in *Information Processing and Cognition: The Loyola Symposium*, ed. Robert L. Solso, Lawrence Erlbaum, .

Purves, D. 2012, *Neuroscience,* Sinauer Associates, Incorporated.

Quian Quiroga, R., Mukamel, R., Isham, E.A., Malach, R. & Fried, I. 2008, "Human single-neuron responses at the threshold of conscious recognition", *Proceedings of the National Academy of Sciences of the United States of America,* vol. 105, no. 9, pp. 3599-3604.

Raffone, A. & Srinivasan, N. 2009, *An adaptive workspace hypothesis about the neural correlates of consciousness: insights from neuroscience and meditation studies*.

Ridderinkhof, K.R., Ramautar, J.R. & Wijnen, J.G. 2009, "To PE or not to PE: A P3-like ERP component reflecting the processing of response errors", *Psychophysiology,* vol. 46, no. 3, pp. 531-538.

Schiller, P.H. & Chorover, S.L. 1966, "Metacontrast: Its relation to evoked potentials", *Science,* vol. 153, no. 3742, pp. 1398-1400.

Schmalzl, L., Crane-Godreau, M.A. & Payne, P. 2014, "Movement-based embodied contemplative practices: definitions and paradigms ", *Frontiers in Human Neuroscience,* vol. 8.

Schurger, A., Cowey, A. & Tallon-Baudry, C. 2006, "Induced gamma-band oscillations correlate with awareness in hemianopic patient GY", *Neuropsychologia,* vol. 44, no. 10, pp. 1796-1803.

Seeley, W.W., Menon, V., Schatzberg, A.F., Keller, J., Glover, G.H., Kenna, H., Reiss, A.L. & Greicius, M.D. 2007, "Dissociable intrinsic connectivity networks for salience processing and executive control", *Journal of Neuroscience,* vol. 27, no. 9, pp. 2349-2356.

Sergent, C. & Dehaene, S. 2004, "Is consciousness a gradual phenomenon? Evidence for an all-or-none bifurcation during the attentional blink", *Psychological Science,* vol. 15, no. 11, pp. 720-728.

Shanahan, M. 2010, *Embodiment and the Inner Life: Cognition and Consciousness in the Space of Possible Minds,* Oxford University Press.

Silverthorn, D.U. & Johnson, B.N. 2010, *Human physiology: an integrated approach* Pearson/Benjamin Cummings, San Francisco.

Spence, S.A., Brooks, D.J., Hirsch, S.R., Liddle, P.F., Meehan, J. & Grasby, P.M. 1997, "A PET study of voluntary movement in schizophrenic patients experiencing passivity phenomena (delusions of alien control)", *Brain,* vol. 120, no. 11, pp. 1997-2011.

Sridharan, D., Levitin, D.J. & Menon, V. 2008, "A critical role for the right fronto-insular cortex in switching between central-executive and default-mode networks", *Proceedings of the National Academy of Sciences of the United States of America,* vol. 105, no. 34, pp. 12569-12574.

Stoerig, P. & Barth, E. 2001, "Low-level phenomenal vision despite unilateral destruction of primary visual cortex", *Consciousness and cognition,* vol. 10, no. 4, pp. 574-587.

Tang, Y.Y. & Posner, M.I. 2014, "Training brain networks and states ", *Trends in cognitive sciences,* vol. 18, no. 7, pp. 345-350.

Tops, M., Boksem, M.A.S., Quirin, M., IJzerman, H. & Koole, S.L. 2014, "Internally directed cognition and mindfulness: an integrative perspective derived from predictive and reactive control systems theory ", *Frontiers in Psychology,* vol. 5.

Tse, P.U., Martinez-Conde, S., Schlegel, A.A. & Macknik, S.L. 2005, "Visibility, visual awareness, and visual masking of simple unattended targets are confined to areas in the occipital cortex beyond human V1/V2", *Proceedings of the National Academy of Sciences of the United States of America,* vol. 102, no. 47, pp. 17178-17183.

Tye, M. 2013, "Qualia" in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, Fall 2013 edn,.

Ullsperger, M., Harsay, H.A., Wessel, J.R. & Ridderinkhof, K.R. 2010, "Conscious perception of errors and its relation to the anterior insula.", *Brain structure & function,* vol. 214, no. 5-6, pp. 629-643.

Vago, D.R. & Silbersweig, D.A. 2012, "Self-awareness, self-regulation, and self-transcendence (S-ART): a framework for understanding the neurobiological mechanisms of mindfulness ", *Frontiers in Human Neuroscience,* vol. 6.

van den Heuvel, M.P. & Sporns, O. 2011, "Rich-club organization of the human connectome", *Journal of Neuroscience,* vol. 31, no. 44, pp. 15775-15786.

Weissman, D.H., Roberts, K.C., Visscher, K.M. & Woldorff, M.G. 2006, "The neural bases of momentary lapses in attention", *Nature neuroscience,* vol. 9, no. 7, pp. 971-978.

Wetter, S., Polich, J. & Murphy, C. 2004, "Olfactory, auditory, and visual ERPs from single trials: No evidence for habituation", *International Journal of Psychophysiology,* vol. 54, no. 3, pp. 263-272.

Wolfe, J.M., Keith R. Kluender & Levi, D.M. *Sensation & Perception, Third Edition* Sinauer Associates Inc.

Wyart, V. & Tallon-Baudry, C. 2008, "Neural dissociation between visual awareness and spatial attention", *Journal of Neuroscience,* vol. 28, no. 10, pp. 2667-2679.

Xu, J., Vik, A., Groote, I.R., Lagopoulos, J., Holen, A., Ellingsen, Ø., Håberg, A.K. & Davanger, S. 2014, "Nondirective meditation activates default mode network and areas associated with memory retrieval and emotional processing ", *Frontiers in Human Neuroscience,* vol. 8.

Zeki, S. 2003, "The disunity of consciousness", *Trends in cognitive sciences,* vol. 7, no. 5, pp. 214-218.

Zeki, S. & Marini, L. 1998, "Three cortical stages of colour processing in the human brain", *Brain,* vol. 121, no. 9, pp. 1669-1685.

Zschorlich, V.R. & Köhling, R. 2013, "How thoughts give rise to action - Conscious motor intention increases the excitability of target-specific motor circuits", *PLoS ONE,* vol. 8, no. 12.

Zylberberg, A., Dehaene, S., Roelfsema, P.R. & Sigman, M. 2011, "The human Turing machine: a neural framework for mental programs", *Trends in cognitive sciences,* vol. 15, no. 7, pp. 293-300.