

Consciousness and Cognition

Expanding the discussion: revision of the fundamental assumptions framing the study of the neural correlates of consciousness --Manuscript Draft--

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Abstract:	The way one asks a question is shaped by a-priori assumptions and constrains the range of possible answers. We identify and reexamine the assumptions underlying contemporary debates, models, and methodology in the study of the neural correlates of consciousness, as framed by Crick and Koch's seminal paper (1990). These premises create a sequential and passive conception of conscious perception, considered the product of resolved information processing by unconscious mechanisms. Major debates in the field such as the moment of entry reveal a consensus on these assumptions. We show how removing the assumptions can resolve some of the challenges and prompt additional questions. The potential non-sequential nature of perception suggests new ways of thinking about consciousness as a dynamic process, and in turn about the relationship between conscious and unconscious perception. Moreover, it allows us to present a parsimonious account for conscious perception while addressing more aspects of the phenomenon.
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Opposed Reviewers:	
Response to Reviewers:	

15/03/2021

Dear Prof. Bachmann,

We wish to submit an article titled “Expanding the discussion: revision of the fundamental assumptions framing the study of the neural correlates of consciousness” for consideration by Consciousness and Cognition.

The way one asks a question is shaped by a-priori assumptions and constrains the range of possible answers. Research in consciousness is relatively young, yet is full of disagreements and debates. In the suggested paper we examine these discussions from a whole different angle, rather than weigh in on either side. We show that a wide consensus on the assumptions about conscious perception is shared by the competing theories and approaches. These assumptions, mostly shaped by Crick and Koch’s 1990 seminal paper, are taken for granted and serve as ‘axioms’ in the study of consciousness.

These ‘axioms’ create a linear and passive conception of conscious perception: it is conceived as the product of resolved information processing by unconscious mechanisms that constitutes a singular event in time and place, automatically retained and utilized by post-conscious mechanisms. Major debates in the field, such as the moment of entry, the all-or-none vs graded nature, and report vs no-report paradigms, are driven by the consensus on these assumptions. We show how removing these assumptions can resolve some of the debates and challenges and prompt additional questions. The potential non-linearity of perception suggests new ways of thinking about consciousness as a dynamic and dispersed process, and in turn about the relationship between conscious and unconscious perception. Moreover, it allows us to present a parsimonious account for conscious perception while addressing more aspects of the phenomenon.

We suggest a fresh perspective on the study of consciousness, which has the potential not only to stimulate a discussion in this domain, but to be applicable to other topics and disciplines.

We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere. We have no conflicts of interest to disclose.

Please address all correspondence concerning this manuscript to me at danielre@post.bgu.ac.il.

Thank you for your consideration of this manuscript.

Sincerely,

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Moti Salti, PhD.

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Dear Prof. Bachmann

We want to thank you for a thorough and unbiased process. We feel that this has profoundly improved our paper. See below a point-by-point elaborated report of our revision.

Thanks again,

Daniel and Moti

(1) Revise the relevant sections as per the request of Reviewer 1 with maximum possible clarity.

Reviewer 1: In the most recent revision and response to reviewer comments, it seems like there was a bit of "talking past each other", perhaps due to a lack of clarity on both ends. I will try to spell out my biggest remaining concern in as straightforward terms as possible.

If I were to sit a subject down, connect them to whatever brain recording device I had available, and flash them an image on the screen, do the authors think that the visual information will be processed unconsciously for a period of time, followed by a time-period of conscious processing? In other words, on a single trial, in a controlled situation, will there be a time-point at which entry into conscious visual experience occurs? Yes or no?

If yes, please revise the relevant sections of the manuscript where this notion of a time-point of entry into consciousness is criticized.

If no, please revise the manuscript to include an explanation of why such a time-point of entry into consciousness does not exist.

Overall, while I do not agree with much of what the authors propose in this paper, I do not see too much danger in publishing this manuscript and letting the readers decide whether their points are worth considering or not.

We appreciate the reviewer's insistence on making this paper clearer. To make our answer as concise as possible:

Yes, there will be a time-point in which entry into conscious visual experience occurs. As discussed in the previous reviews, initial processing of information is unconscious (e.g. sensory periphery, thalamus); we have now made this explicit where it could have been interpreted otherwise:

(Pg 19, paragraph 1) "Activity associated with unconscious perception based on the subject's inability to report might in fact correlate with conscious experience that faded before the response. This could implicate that unconscious perception was preceded by conscious perception, even if initial processing of the

stimulus in primary sensory areas and the sensory periphery is unconscious."

(Pg 21, paragraph 1) "This in turn would require a reconsideration of the attribution of complex computation and integration to unconscious processing: consciousness might also be involved early on albeit not reported. Conscious perception is therefore not the final resolution of unconscious processes involved in perception, but can even precede some of them (other than initial sensory stages)."

(Pg 22, paragraph 1) "By considering the possibility of the evolving complexity of conscious perception, we are making no commitment to a fundamental distinction between early and late processes. From this point of view, the three-stage sequential order characterized by pre-conscious, conscious, and post-conscious processes becomes irrelevant. That is not to say that the brain activity in response to a stimulus does not start as unconscious, but that from that point on we do not expect to find a clear-cut transition between these three stages signaled by specific waves."

However, it is the details of what this means that we spend much of the paper dissecting:

1. Unconscious processing can become conscious, which could then fail to be sustained and become unconscious again, resulting in unconscious perception (see Wolfe, 1999; Chen & Wybel, 2016, Tononi, 2015). This is discussed under IA1.
2. There is not necessarily a single time-point of "entry" into consciousness (see Overgaard et al., 2006; He, 2018). This is discussed under IA2.
3. Importantly, we explain that this contrast between unconscious processing and entry into consciousness is problematic and should be supplemented by other contrasts and methods (see sections 4.1.1, 4.1.6, & 4.2).
4. Other sections (e.g. regarding IA4, IA5) explore further aspects of this, but we won't go on, for the sake of brevity.

The way the reviewer has framed the question, expecting a simple yes or no answer, is precisely what we are examining and questioning throughout the article. This reflects on our main claim that the NCC effort is framed by Crick & Koch 1990 and this framing should be reexamined.

(2) As for the issue of 'consciousness module' which unnecessarily would and very likely will cause misunderstanding among most of the potential readers it is advisable to avoid using this controversial concept. In most cases the

authors who associate 'modules' and 'consciousness' do this either in terms of modularity of mind or in terms of modules as MECHANISMS for consciousness (i.e., consciousness itself is not a module, but an outcome of some mechanism(s) regarded as (a) module(s)). Please revise text accordingly. (This is not necessary when instead of 'module' 'faculty' is used.)

We agree that the use of this concept might do more damage than good; fortunately, it is not essential to the paper and therefore we have avoided its use altogether:

(Pg 6, paragraph 2) "This is referred to as the entry of information into consciousness, an event with a precise temporal component. Hence, the NCC should be sought out at the moment in which a particular object in view becomes conscious (Andersen et. al, 2016; Koch et al., 2016)."

(Pg 8, paragraph 2) "Quintessential to the NCC project laid out is the implicit consideration of consciousness as a faculty very much like attention, memory, or even primary sensory regions."

(Pg 12, paragraph 1) "Indeed, consciousness is often treated as a faculty (Chalmers, 1996; Smythies, 2009; Champagne, 2018; Nani et al., 2019; see also criticism by Atkinson et al., 2000; Blackmore 2016)."

3. Thank you for these additional references. We have now incorporated them in our suggestions for additional approaches:

(Pg 27, paragraph 3) "On the subcellular level, the properties of integrated presynaptic signals have long been upheld as a possible explanation of phenomenological properties of vision (Bachmann 2015; see also Bachmann, 1997; Llinas et al., 1998; Larkum et al., 2013). While level 3 and 4 pyramidal neurons (PN) level-5 pyramidal neurons (PN) are responsible for binding together different features of objects. The temporal and spatial relations of presynaptic inputs to this layer impact whether and how stimuli will be perceived, capable of explaining, according to Bachmann (2015) some illusions and phenomena such as backward masking."

(4) The DIT (Dendritic Integration Theory) by Aru et al. is misspelled as Dendritic Information Theory (likely due to the mishap in print in the Abstract of the respective TICS paper).

This has been fixed now.

(5) Several references added in revision and present in text are not drawn in the Refs list.

We have now made sure all sources are referenced in the Refs section.

Highlights

- The contemporary study of consciousness is framed by explicit and implicit assumptions that are not debated.
- Conscious perception is often viewed as sequential, passive, and modular; the singular resolution of unconscious processes.
- Primary effort is in locating the when and where of the neural correlates based on conscious-unconscious contrast.
- Assumptions are challenged by taking into account diverse findings and theories.
- A consideration for alternative views of consciousness as active, evolving, transient, or spatiotemporally dynamic.
- New approaches, questions and methodology confronting the complexity of consciousness; a parsimonious unification of mechanism and phenomenology.

Expanding the discussion: revision of the fundamental assumptions framing the study of the neural correlates of consciousness

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Abstract

The way one asks a question is shaped by a-priori assumptions and constrains the range of possible answers. We identify and test the assumptions underlying contemporary debates, models, and methodology in the study of the neural correlates of consciousness, which was framed by Crick and Koch's seminal paper (1990). These premises create a sequential and passive conception of conscious perception: it is considered the product of resolved information processing by unconscious mechanisms, produced by a singular event in time and place representing the moment of entry. The conscious percept produced is then automatically retained to be utilized by post-conscious mechanisms. Major debates in the field, such as concern the moment of entry, the all-or-none vs graded nature, and report vs no-report paradigms, are driven by the consensus on these assumptions. We show how removing these assumptions can resolve some of the debates and challenges and prompt additional questions. The potential non-sequential nature of perception suggests new ways of thinking about consciousness as a dynamic and dispersed process, and in turn about the relationship between conscious and unconscious perception. Moreover, it allows us to present a parsimonious account for conscious perception while addressing more aspects of the phenomenon.

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Abstract

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1. Introduction

The modern scientific inquiry of consciousness and its counterpart, the unconscious, has consolidated over the past few decades. From a Kuhnian perspective, the resulting paradigm posits which entities are found in the world and what their relationships are (Kuhn, 1962, page 41). It selects which problems are more important to solve, which aspects of the subject matter are essential, which questions should be asked and which experiments are appropriate to answer them. The ensuing methods will not only reflect the dominant paradigm, but also determine how data will be interpreted and how the field will evolve.

In the study of consciousness, the contemporary paradigm can be traced back to thirty years ago: in 1990, Francis Crick and Christof Koch made the bold declaration that an understanding of consciousness could be achieved within a neurobiological context (Crick & Koch, 1990). Over time, the outlined program and its guiding questions were widely embraced (Seth, 2018). With them, the assumptions on which they stood were left unquestioned (Lau, 2008). Importantly, when we talk about assumptions, we do not necessarily refer to the intentions of Crick and Koch. As a constitutive text, it contains notions about the nature of consciousness that, whether or not intended by the original

authors, were nevertheless retained in the discourse, methodology and theory, and as such have influenced today's research and are consequently central to it. In a recent paper, LeDoux et al. (2020) treat Crick and Koch's approach as the inevitable result of the development of neuroscience. This gives the NCC program a deterministic quality, as if things could not be otherwise given the evolution of findings and methods. Here, however, we would like to counter this deterministic view: the NCC program is shaped by the assumptions and questions that were selected along the way, and could have developed otherwise.

Paradigms are essential to scientific progress (Kuhn, 1962, pages 52-54). They end the discussion between schools of thought that require constantly reverting back to fundamental assumptions. Furthermore, the confidence granted the researchers in their framework allows them to pursue increasingly precise and esoteric work. It allows synchronization between different labs and a coherent and efficient jargon. The framework proposed by Crick and Koch facilitates the study of consciousness but also restricts it. Moreover, it provides a prism through which we contemplate conscious perception and which, as any prism, risks distorting our conception of consciousness. The challenge in resolving ongoing debates and linking mechanism to phenomenology requires constantly revising the fundamental assumptions underlying our paradigm. We begin in section 2 by highlighting the explicit and implicit assumptions underlying Crick and Koch's approach. This will be followed in section 3 by identifying the same assumptions and their impact in current methodology, theory and discourse. We then proceed in section 4 to inspect these premises and consider additional questions and ways of approaching the study of consciousness.

2. Crick and Koch 1990: framing the discussion on consciousness

2.1. Explicit assumptions

Crick and Koch's paper is treated as a milestone as it has provided a methodological framework for the extraction of the neural correlates of consciousness (NCC) (Seth, 2018; Storm et al., 2017). In doing so, it has enabled the progress in the field over the past thirty years. The article has the twofold advantage of providing a synthesized and concise reflection of the research preceding it and of framing the research following it. For this reason, it serves as an ideal starting point. While it was meant to be as an open-ended, pragmatic approach for the study of consciousness, no phenomenon can be interpreted without the existence, even if implicit or unintended, of a body of beliefs and preconceptions (Kuhn, 1962, page 51). Although consequent papers by Crick and Koch (see 1995, 1998, 2001, 2003, 2004) have modified much of the theory, the core 'gestalt' of which entities exist, their relationships, and the right approach to understanding them, remained and consolidated to establish the current paradigm.

The proposed approach consists of three derivative explicit assumptions. The first concerns the discipline: Crick and Koch open with an explanation of the advantages of studying the neural basis of consciousness over cognitive models (Explicit Assumption 1, henceforth EA1): "(...) we believe that the problem of consciousness can, in the long run, be solved only by explanations at the neural level." According to Crick and Koch, attending visual awareness indirectly by observing its correlated brain activity, enables us to render tangible a phenomenon that is often viewed as 'metaphysical'. In doing so, they hoped to simplify this multifaceted phenomenon and provide more clarity: A description directly linking the physical properties of stimuli to the physical properties of the brain was aimed at demystifying consciousness. The authors emphasize the value of focusing on the biological properties of visual awareness by describing how the physical world affects the brain via stimuli. A map of consciousness could then be superimposed onto this physical description by use of objective measurements of behavior. Despite diverging from behaviorism and in line with cognitivist design (Gardner, 1985), this strategy still aims for an understanding of consciousness through the measurement of observable events in the brain.

The second explicit assumption concerns the methodology. In order to study the neural correlates of a cognitive function, one should define a critical contrast that would reveal

the minimal neuronal mechanisms jointly sufficient for any specific conscious experience (Koch et al., 2016). In other words, the identification of NCC requires that the ‘conscious’ condition be compared to another condition that would be similar in all other parameters but subjective experience. The obvious candidate was ‘unconscious’ perception, reflecting the premise that unconscious perception exists and is crucial to the understanding of consciousness (EA2). As stated in their article, “at any one moment some neuronal processes correlate with consciousness, while others do not. What are the differences between them?”

However, Crick and Koch were fully aware of the inherent problem in the suggested framework. Our conceptualization of consciousness is vague. In particular, the boundaries between ‘conscious’ and ‘unconscious’ are unclear. Moreover, the relations between ‘conscious’ and ‘unconscious’ are quod erat demonstrandum. Therefore, their third explicit assumption is that this paradox could be resolved by avoiding a precise definition of consciousness and its function: “We feel that it is better to avoid a precise definition of consciousness because of the dangers of premature definition. (...) Arguments about what consciousness is for are probably premature.” Instead, what is necessary is what we here call a Reflective Approach (EA3). This would comprise of constantly discussing our conception of consciousness, the posited entities, and in this manner revise the paradigm and move its boundaries. Accordingly, an open-ended exploratory method would require maintaining reciprocal relations between the empirical findings and the theory. This dialogue should elicit new conceptions of consciousness and new questions. These in turn should create new predictions to be tested and updated again, and so on and so forth. With these assumptions, the authors define the NCC endeavor: where and when are the neural correlates of consciousness?

2.2. Implicit assumptions

Guided by these explicit assumptions, Crick and Koch put forward a tentative theory. While this theory has evolved and changed over time, what we are interested in is the underlying approach. Their framework reflects implicit assumptions that conform to a

well-defined conception of consciousness and the entities related to it. A detailed discussion of these assumptions will take place in section 3, where they are demonstrated within the context of current research. On the one side, there are mechanisms that are necessary for consciousness but do not entail conscious experience; on the other are those mechanisms that are directly responsible for consciousness. The division considers unconscious processes to support conscious perception, necessary for its emergence but insufficient. This reflects the first assumption, Conscious Resolution (henceforth implicit assumption 1, IA1): unconscious perception of a particular object precedes conscious perception of that object, and only some of the contents perceived unconsciously are resolved as conscious experience (for a discussion of IA1 in current research, see section 3.1). In this manner perception is visualized as sequential; consciousness represents the result, or resolution, of a perceptual process. It is unconscious mechanisms that are responsible for processing incoming information; once they are successful, a conscious percept ensues. Should they fail, the observer would be left with no more than unconscious perception, which is limited in form and function. Francis Crick put it similarly (and explicitly) later on in a 1999 interview for the UCSD Guestbook: “A lot of what goes on in your brain is unconscious. A lot of the processing. Some of the results of that processing you become conscious of. What's the difference between the two when you look inside the brain?”

Crick and Koch suggest that this event, where unconscious processing is resolved into a conscious percept, is manifested at a specific moment somewhere between 50-250ms post stimuli. Accordingly, this event is dependent on the existence of specialized mechanisms for consciousness, so that the NCC might be found in the neocortex, and possibly in the paleocortex. This view reflects two connected assumptions: the assumption of Temporal Modularity (IA2) holds that there is a singular event with a fixed temporal component, i.e. the moment of resolution, in which a stimulus goes from being unconsciously perceived to being consciously perceived (see section 3.2). **This is referred to as the entry of information into consciousness, an event with a precise temporal component.** Hence, the NCC should be sought out at the moment in which a particular object in view becomes conscious (Andersen et. al, 2016; Koch et al., 2016). Meanwhile, the assumption of Spatial

Modularity (IA3) considers that this transition between unconscious and conscious perception is achieved by a specialized region or mechanism (see section 3.3). Consciousness is thus spatially and temporally modular in that we expect a specific mechanism distinct from other mechanisms in the brain to activate in a specific place and time in order to enable the conscious percept.

In their 1990 article and those following it, Crick and Koch seek a mechanism that would bind together the scattered processing of the various aspects of a stimulus to produce a coherent representation of the target object. Once the binding is resolved, the product is stored in short term memory, which acts as the container of conscious information for a given amount of time thanks to a stable configuration of neural activity. This account reflects the assumption of Conscious Retention (IA4): once a conscious representation is produced, it is retained for a given amount of time (see section 3.4). The percept will not simply fade after being generated, but will rather last in a way that characterizes short-term or working memory. The automatic retention of the conscious percept serves a purpose. Crick and Koch combine the ideas proposed by Johnson-Laird (1988) and Jackendoff (1987) to suggest that “one of the functions of consciousness is to present the result of various underlying computations”. The first stage of information processing is those underlying computations, while the second stage is the conscious result. Finally, the third stage in the sequential order of information processing reflects the assumption of Post-Conscious Mechanisms (IA5), according to which higher mechanisms interact with this consciousness faculty or mechanism in order to utilize the conscious information (see section 3.5). This could include motor response, executive functions, or language faculties, to name a few, which rely on the retention of the conscious percept in order to engage with it. As Crick and Koch say, “consciousness should have easy access to the higher, planning levels of the motor system.” These mechanisms, by necessity of their relation to consciousness, should themselves be unconscious.

The proposed NCC framework emphasizes the role of bottom-up attention when suggesting that objects are selected from the visual field based on saliency. This bottom-up process endeavors to reproduce a “veridical representation of the object being attended

to” (Crick & Koch, 1990, p. 9), which, if successful, results in a conscious percept accessible to other neural networks. Despite the long-established notion that perception involves top-down engagement (Kinchla & Wolfe, 1979; Meyer & Petry, 1987), this notion of veridical representation reflects the assumption of the Passive Observer (IA6): the conscious percept conforms to and is dependent on an objective standard (see section 3.6). This objective standard rests on the source of the stimulus, whose ‘captured’ features will determine how successful and complete (or incomplete) the conscious percept is. The Passive Observer assumption grants only secondary importance to top-down mechanisms, for example attentional mechanisms selecting the object, or higher mechanisms engaging with the resolved percept. Consequently, the NCC are expected to be consistent for different goals and subjects, so long as the stimulus is the same.

2.3. The ‘when’ and ‘where’

Without drawing attention to the premises themselves, what was a working definition becomes further consolidated. Quintessential to the NCC project laid out is the implicit consideration of consciousness as a faculty very much like attention, memory, or even primary sensory regions. As such, it should interact with its counterparts, such as primary sensory processing and post-conscious mechanisms, in specific places and at specific stages. Regarding the mechanism of consciousness as yet another faculty of the brain has shaped the experimental boundaries in which the attempts to reveal the NCC should be carried out.

Crick and Koch’s approach allows framing the discussion on consciousness by asking, when is the precise moment of transition between unconscious and conscious and where is the specialized network responsible for it. While insisting that a broad and flexible conception of consciousness and its mechanisms is crucial for a successful development of the field, the goals and methods have since shaped a paradigm that on the one hand, as any paradigm, has allowed the necessary focus for scientific progress, but on the other hand suffers from few degrees of freedom. In fact, we can view this approach on a two-

dimensional space. This two-dimensional, sequential modeling of consciousness expects an event singular in place and more importantly - in time.

3. Premises in current methodology and theory

A paradigm is essential in that it enables normal science (Kuhn, 1962, page 38), which maps out the space already defined by the paradigm. Normal science is based on the assumption that the community knows what the world is like, and the success of its enterprise on the willingness of the scientific community to defend this assumption. The ‘normal science’ of the neuroscience of consciousness characterized by long-standing disagreements. However, a firm consensus underlies these debates, as they are restricted to a narrow path paved by Crick and Koch’s framework. The ensuing paradigm guides the questions asked and consequently defines the space of available answers. The assumptions underlying the current NCC approach are fundamental to current methodology, theory, and discourse; given their axiomatic nature, they themselves are not questioned.

3.1. IA1 Conscious Resolution

The explicit assumptions of the NCC project pursue a description of the relationship between conscious and unconscious processes. The project’s account of this relationship relies on the implicit assumption of Conscious Resolution (IA1), according to which conscious perception is the resolution of preceding unconscious processing. This attributes consciousness a passive role, which might explain the NCC program’s focus on the when and where of this entry into consciousness. Accordingly, conscious processing is not actively involved in constructing the representation over time; instead, it is no more than the container of an object that has successfully completed the journey up the information processing ladder. This conception is embedded in the jargon we employ: we speak of ‘entry’ into consciousness (see comments by Blackmore, 2016). Similarly, we speak of ‘access’ to consciousness. Based on this assumption, neural activity associated with consciousness would be revealed by contrasting it to related unconscious activity. Since

consciousness is simply the result of unconscious processing, the contrast between conscious and unconscious perception is expected to be a minimal difference in neural activity.

The need to distinguish these two forms of perception raises many questions regarding the way conscious and unconscious perception interact and coexist. One of the most prominent questions relates to whether stimuli are perceived in an all-or-none or in a graded fashion (Windey & Cleeremans, 2015; Windey et al., 2014). In support of the all-or-none view, the attentional blink paradigm was employed to show that although subjects were given a continuous scale to rate the target's visibility, they only used the scale's extremes of 'all' or 'none' (Sergent et al., 2005). This conclusion was questioned by proponents of graded perception, who hold that an object can be perceived in graded or partial manner. Nieuwenhuis and de Kleijn (2011) produced contrary results using similar paradigms, showing that subjects made use of the whole scale to report degraded perceptions as well. Ramsøy & Overgaard (2004) established a four-level perceptual awareness scale (PAS) that corresponds to the visibility a stimulus: no experience, brief glimpse, almost clear experience. Alternatively, Kouider et al. (2010) propose partial awareness to be possible when lower representational levels are accessed instead of higher levels. Despite being directly opposing views, the entire debate stands on the assumption of Conscious Resolution (IA1). From a methodological perspective, Aru et al. (2012, see also De Graaf et al., 2012) depict this relation between a conscious experience and the unconscious processes leading up to it by labeling the latter 'NCC prerequisites' (NCC-pr). Sergent & Naccache (2012) refer to upstream neural events occurring before consciousness. From the all-or-none point of view, the resolution into visual awareness by these unconscious processes requires an integration of the entire object attended to (Farah, 2000; Super et al., 2001). From the gradedness point of view, resolution by unconscious processes can be achieved even with a partial or graded representation of the object's aspects (Moutoussis & Zeki, 2002; Bar et al., 2001). Even when considering multiple entry thresholds (Eastwood et al., 2001) in support of the graded view, these entries stand in complementary distribution with each other, each representing the event of resolution (Overgaard et al.,

2006). Both sides seek the conditions, or prerequisites, for this transition from unconscious to conscious.

3.2. IA2 Temporal Modularity

In seeking the signature of conscious resolution, the two questions raised by the NCC project, namely where and when the NCC occur, become the crux of current research. In the temporal domain, the inquiry into when consciousness arises generates a major source of debate today (Förster et al. 2020). Proponents of early entry insist on the visual awareness negativity (VAN, or N2) at ~200ms post stimuli as the most promising candidate (Railo et al., 2011; Koivisto & Revonsuo, 2010). They claim later activity to reflect higher level response to the perceived information. Proponents of late entry instead suggest the late positivity (LP/P3b) at ~300ms post stimuli (Del Cul et al., 2007; Dehaene, 2014). Despite these directly opposing views, the entire debate stands on the assumption of Temporal Modularity (IA2): the generation of conscious experience, or the Conscious Resolution, occurs as a singular event in time. This approach is made clear in papers summarizing the NCC endeavor as finding that point in time (Melloni et al., 2021). All that is left to do is discover whether this event takes place at 200ms, or at 300ms post stimulus. This does not mean that the percept and associated brain activity is not assumed to last longer, but that the only NCC sought after are those related to the moment when the percept is produced, while any activity following it is treated as non-NCC. As Zeki (2003) puts it, the NCC program seeks a single neural correlate of consciousness.

3.3. IA3 Spatial Modularity

As for the spatial domain, models like the recurrent processing (Lamme, 2000) single out a unique mechanism activated at a particular time and place which produces conscious experience. Alternatively, GNWT (Dehaene et al., 1998) identifies the fronto-parietal network as the region which produces and retains the conscious percept. Regardless of the diversity of neurobiological theories, this inquiry into what or where this unique

mechanism is, reflects the assumption of Spatial Modularity (IA3) responsible for the binary transition from no conscious experience to a fully-fledged conscious percept, or “entry” into consciousness. Indeed, consciousness is often treated as a faculty (Chalmers, 1996; Smythies, 2009; Champagne, 2018; Nani et al., 2019; see also criticism by Atkinson et al., 2000; Blackmore 2016).

3.4. IA4 Conscious Retention

The designs used today to identify the neural correlates of when and where conscious resolution occurs rely on the assumption of Conscious Retention (IA4). Consciously perceived information should accordingly be available for manipulation, goal-oriented action, and report (Railo et al., 2011; Pitts et al., 2014). This is implied by the association of consciousness with a stable state (Schurger et al., 2015; Dehaene et al., 2017; Baars et al., 2013). As a result, many paradigms today classify a stimulus as consciously perceived if and only if it was available for report (Liu et al., 2012; Schurger et al., 2015). More importantly, a stimulus is considered not to have attained consciousness if at the time of report it was unavailable. In addition, there was a need to separate conscious activity not only from the unconscious activity preceding it, but from the subsequent activity as well. The suspicion that report paradigms are confounded by neural patterns related to report led to the implementation of no-report paradigms (Tsuchiya et al., 2015). Despite differences, no-report paradigms assume Conscious Retention (IA4) just the same. While the methodology separates the stage of report from the stage of perception, it relies on report to associate neural activity with consciousness in the first place. For example, Pitts et al. (2011) decoupled neural activity underlying report from that correlated with perception by postponing subject report to after the completion of an entire block. This solution embraces the notion that stimuli which have entered consciousness will be available later on for report.

3.5. IA5 Post-Conscious Mechanisms

No-report paradigms reflect the idea that subsequent activity is not associated with consciousness itself, and therefore “contaminates” the NCC in report paradigms (Aru & Bachmann, 2015; Block, 2019). This restricted role attributed to conscious processes has been taken to its logical extreme in current methodology. Block (2019) observed that no-report paradigms do not eliminate post-perceptual processes linked to thoughts about the stimulus. In their stead, a no-post-perceptual cognition paradigm used by Brascamp et al. (2018) is endorsed. This drives current methodology to treat any activity following the moment of entry as non-NCC. One example is the early entry view that treats the P3b as response-related activity, despite appearing only ~100ms (at 300ms) after the N2 (at 200ms). Explaining what happens after this entry into consciousness, and specifically the relationship between conscious information and later processes has produced many competing theories, predominantly the “global workspace” and “higher order” perspectives (Block, 2009). While disagreeing on the mechanisms, all sides of the debate adhere to the assumption of Post-Conscious Mechanisms (IA5), according to which the information-processing resulting in conscious experience is rendered available for higher processes, such as report (Byrne, 2001; Rosenthal, 2005; Baars, 1988; Dehaene et al., 2006). We can identify this sequential or linear relation involving post-conscious processing with downstream activity (Sergent & Naccache, 2012) and NCC consequences (NCC-co., which “do not directly correspond to the conscious experience of the stimulus” (Aru et al., 2012, see also Graaf et al., 2012). The sequential view of consciousness has culminated in the unwarranted restriction of the NCC being searched and distilled, mainly those associated with conscious entry, to a fraction of a second. This NCC represents a specific moment between the completion of unconscious lower sensory operations and the further processing or use of their results by higher networks. In fact, it sets the mechanism behind the conscious representation apart from information processing. Early on, Baars (1996) advocated the division of conscious experience and the unconscious mechanisms that utilize this experience: “conscious contents become globally available to many unconscious systems.” In line with this, Gazzaniga (2000) conjured the interpreter-self, which involves higher mechanisms analyzing the conscious representation. Based on the idea that consciousness is no more than the resolution of unconscious processes, the proposed models require subsequent mechanisms to interact with the conscious product

(Dehaene and Naccache, 2001; Lau and Rosenthal, 2011). This renders the concept of consciousness extremely limited and void of explanatory value in and of itself. As mentioned in section 3.1, this passive role attributed to consciousness explains the NCC program's focus on the moment of conscious resolution: conscious processing is not actively involved in constructing the representation of a stimulus over time; instead, it is no more than the culmination of the unconscious processing of this stimulus.

3.6. IA6 The Passive Observer

Besides a sequential view of the unconscious-conscious dynamics, another characteristic that seems to underlie some of the methods and debates mentioned above is the assumption of a Passive Observer (IA6). Importantly, many researchers do consider the observer to be active. For example, the GNWT model proposed by Dehaene and colleagues gives a role to top-down activity involved in attentional mechanisms (Dehaene et al., 2006). Higher-order theories similarly posit a key function for higher processes that shape or fill in the representation based on the observer's expectations (Lau & Rosenthal, 2011). However, this top-down processing is not fully implemented in the methods and questions that drive research. First, top-down contributions are examined in accordance with the conscious-unconscious contrast; the role they are tested for is their influence on whether the stimulus is consciously perceived or not, rather than *how* it is perceived, leaving out to a large extent phenomenological considerations. In addition, when we test the NCC, there are various methods of creating a minimal contrast between conscious and unconscious perception (Dehaene & Changeux, 2011). Accordingly, different tasks on different stimuli are expected to lead us to the same minimal NCC, regardless of the subject's goals or their relation to the stimulus and task at hand. For example, differences in report and no-report experiments are meant to separate the NCC from non-NCC (Tsuchiya et al., 2015; Pitts et al., 2014; but see discussion of Melloni et al., 2012 in section 4.1); what is not taken into account is that each method might influence conscious perception itself: asking a subject to report the object she saw could actually impact her perception, and with it produce different NCC. By assuming that the conscious representation and its NCC are consistent

despite variations in task and subject conditions, we are in fact using the stimulus as the point of reference rather than the observer. We thus adopt the object's point of view and trace its journey up the information-processing ladder to the moment when it becomes a conscious experience.

This object's-point-of-view approach has us referring to the physical source of the stimulus for an objective standard of what is consciously perceived. This can be seen in studies that distinguished a subjective measure based on report from an objective measure based on performance (Lamy et al., 2009; Carmel & Lamy, 2014; Seth et al., 2008; Szczepanowski & Pessoa, 2007). Subsequently, it was held that stimulus evaluation might be dissociated from awareness of the stimulus (Salti et al., 2012). While the Passive Observer assumption is most prominent in methodological discussions meant to refine and choose the best tools, these discussions impact the theory as well. We can return to the all-or-none vs graded debate and consider how both views reflect, to varying degrees, the idea that conscious experience results only with the achievement of a 'veridical' account of the object perceived. The all-or-none view sees any partial representation of a stimulus as incomplete relative to the objective standard and therefore as a failure to be resolved as a conscious percept (Lamme et al., 2000; Sergent & Dehaene, 2004). While the graded view does consider that degraded representations of the stimulus can be resolved into conscious representations, these are considered lower or partial forms of awareness (Merikle & Reingold, 1998; Mangan, 2001), since they constitute a partial representation relative to the objective standard. Both theories ignore what the observer herself might consider as complete, based on her goals, predilections, and circumstances.

Table 1

Abbreviation	Assumption	Explanation	Explicit/ Implicit
EA1	Neurobiological approach	Consciousness should be studied via its neural basis.	Explicit
EA2	Conscious-unconscious contrast	The study of the NCC requires a minimal contrast between conscious and unconscious perception.	Explicit
EA3	Reflective approach	An open-ended exploratory method would require maintaining reciprocal relations between the empirical findings and the theory	Explicit
IA1	Conscious Resolution	Unconscious perception of an object precedes conscious perception of that object, and only some of the contents perceived unconsciously are resolved as conscious experience.	Implicit
IA2	Temporal Modularity	There is a singular event with a fixed temporal component in which a stimulus goes from being unconsciously perceived to being consciously perceived.	Implicit
IA3	Spatial Modularity	There is a specialized region or mechanism activated at the singular moment which allows a stimulus to go from being unconsciously perceived to being consciously perceived.	Implicit
IA4	Conscious Retention	Once a conscious representation is produced, it is retained for a given amount of time.	Implicit

IA5	Post-Conscious Mechanisms	Once a conscious representation is produced, it is followed by higher mechanisms that utilize the conscious information	Implicit
IA6	Passive Observer	The mind does not produce the representation based on top-down goals; conscious resolution conforms to and is dependent on an objective standard.	Implicit

4. Expanding the discussion

The inevitable challenge in mapping a conscious mechanism that is not well defined requires a reflective engagement that would allow constantly revising the assumptions behind our conception of consciousness in light of empirical results, or in other words, systematic thinking outside the box. Yet there is little if any attempt to reconcile conflicting findings (see recent reviews of NCC theories, Förster et al., 2020; Mashour et al., 2020) by reframing the question. A flexible attitude towards the theoretical background could help resolve seemingly contradictory empirical findings and resulting debates, if only by making them irrelevant in their current formulation. In this section we demonstrate how applying the Reflective Approach, originally suggested by Crick and Koch, can challenge some of the assumptions, or at least undermine their axiomatic nature. This in turn can resolve current questions relying on these assumptions and reveal new ones that would lead to additional lines of research. In order to properly inspect the framework, the assumptions are not treated in the same order as previous sections. Importantly, we are not interested in disposing of these assumptions and their derivative approaches, but aim to show that our assumptions can and should be constantly discussed and reverted back to in order to understand their implications and the opportunities they offer.

4.1. Revisiting the implicit assumptions

4.1.1. The unconscious & reportability

Much of our conception of consciousness and the assumptions framing its study is influenced by our idea of the unconscious and its relationship to its conscious counterpart.

As shown in the previous section, contemporary theory of perception gives the unconscious a central role. Its contrast with conscious experience has played a key part in defining consciousness. Its implementation in cognitive frameworks precedes Crick and Koch's collaboration. Marcel (1983) identified unconscious perception with the gap between subjective report and objective performance. At the beginning of the 21st century, the computational and integration capacity of the unconscious was considered very limited (Dehaene & Naccache, 2001). However, since then, the role attributed to unconscious perception has become more and more dominant. Studies have shown that complex computations and manipulations could be performed on stimuli considered as unseen (Qiao & Liu, 2009; Opstal et al., 2010; Yeh et al., 2012). Even tasks demanding long retention of perceived information like solving an arithmetic equation (Sklar et al., 2012, but see Moors & Hesselmann, 2018 for criticism) or maintaining information in working memory (Trübtschek et al., 2017) could be performed on unconsciously perceived information (Dehaene et al., 2014). Scott and colleagues (2018) challenged the mainstream view that integration could be achieved only consciously. In a set of experiments, they demonstrated cross-modal associations between subliminal stimuli. Biderman & Mudrik (2017), on the other hand, showed that consciously perceived stimuli benefit integration. As they state however, this is a quantitative advantage: "integration can be defined over different window sizes (in temporal, spatial, or semantic spaces), and consciousness might be required only for integrating over bigger windows" (Biderman et al. 2020). If both unconscious and conscious processes can perform the same tasks and describe a quantitative rather than qualitative difference between conscious and unconscious, this blurs the lines between them. This makes the conscious-unconscious contrast ineffective in revealing what sets consciousness, and its NCC, apart from every other neurocognitive process.

Alternatively, it is possible that the methods used to map the contrast do not properly separate conscious processes from unconscious processes. Research makes a clear distinction between unconscious and conscious perception: the ability to report the experience (Merikle, 1982). Consciousness is identified with reportability; based on this trait, a contrast is established which allows to define the boundaries of conscious and

unconscious perception. The circularity of this approach is hard to overlook: the characteristics of conscious perception are already assumed within the method producing the contrast. A stimulus is considered to have been consciously perceived if it is available for conscious response at a later time. In turn, the NCC are identified based on their correspondence with this a-priori contrast. The trust in the relation between consciousness and reportability relies on Conscious Retention (IA4). Once unconscious processing is resolved into conscious experience, the information should remain and therefore be available for report later on. Interestingly, Wolfe (1999) contemplates the possibility that stimuli reported as unseen might have in fact been consciously perceived but unavailable at the time of report (see also Moore, 2001; Driver et al., 2001). He suggests calling this phenomenon inattentional amnesia as a more accurate depiction of what is currently viewed as inattentional blindness. Thibault et al. (2016) complement this perspective with results showing that the difference between reported and non-reported stimuli was not in their conditions, but in the conditions of subsequent stages, suggesting that the stimuli could have been perceived but not retained. This view has remained marginal, though there is still ongoing debate (see rebuttal by Ward & Scholl, 2015 vs support by Chen & Wyble, 2015, 2016; Born et al., 2019; Fu et al., 2021). Either way, we should not be in a hurry to assume inattentional amnesia and inattentional blindness are mutually exclusive, so that only one phenomenon can exist. Inattentional amnesia takes the phenomenological overflow argument (Block, 2011) a step further: phenomenology can occur even when later denied by the subject at the moment of report (Block 2007; Lamme, 2006). While we do not call for a rejection of report-based experiments, it would be overly restrictive to identify consciousness solely based on reportability (Vandenbroucke, 2014). Activity associated with unconscious perception based on the subject's inability to report might in fact correlate with conscious experience that faded before the response. This could implicate that unconscious perception was preceded by conscious perception, even if initial processing of the stimulus in primary sensory areas and the sensory periphery is unconscious.

We are mainly concerned here with bringing to awareness the possible limitations of the assumption of Conscious Retention and the resulting report-centered methodology, yet

some alternative methods that could complement current ones are worth consideration. These would not dispose entirely of report, but make it supplementary. For example, studies propose back-projections to V1 as an objective marker of consciousness (Super & Lamme, 2007; Pascual-Leone & Walsh, 2001). Using electrode-implants in animals, we can map out the NCC as indicated by back-projections. By comparing the properties of conscious perception identified by this method with those identified by report and no-report paradigms in the same conditions, we can get a sense of the efficacy of back-projections as an indicator of consciousness. This approach would draw different boundaries between conscious and unconscious perception than those currently held by report paradigms, potentially providing new insights on the dynamics of consciousness. Another method can draw on IIT's measure of global information transfer (Toker & Sommer, 2019; see Merker, Willford & Rudrauf, 2021): research might investigate spatial and temporal changes in neural complexity correlated with perception and performance. Both of these methods can make use of procedures such as Thibault et al. (2016) and Sergent et al. (2013): by creating a contrast between late-cued (and seen) vs not cued (and unseen) stimuli, we can investigate what is common (and what is different) to the neural activity in both seen and unseen trials before the attentional cue.

4.1.2. IA1 Conscious Resolution

If unconscious perception can follow conscious perception, it would defy the sequential conception of perception. Conscious experience could not be reduced to an event that reflects the successful resolution of primary unconscious processing. Under such terms, the Conscious Resolution assumption (IA1) should at least not be taken for granted. Snodgrass (2002) suggested that differences in performance and report might be explained without the need to postulate unconscious mechanisms (but see Snodgrass, 2004). Instead, the gap may be due to differences in the dynamics of conscious processing across time, suggesting a transient view of the nature of consciousness (Baria et al., 2017). Transience refers to activity states that are constantly evolving, in which no stable equilibrium is reached (Rabinovitch et al., 2008). According to Tononi (2015), the brain might not be conscious only as a result of a large-scale synchronized activity that prevents a return to the unconscious, whether it be the broadcasting of information (Baars, 2003; Dehaene et al.,

2014) or back projections to V1 (Lamme & Roelfsema, 2000); subjective experience could also be manifest when the brain is nearly silent, should it still perform some integration of information. This in turn would require a reconsideration of the attribution of complex computation and integration to unconscious processing: consciousness might also be involved early on albeit not reported. **Conscious perception is therefore not the final resolution of unconscious processes involved in perception, but can even precede some of them (other than initial sensory stages).** Consequently, the categories of NCC-pr or antecedent upstream activity would not be as self-evident and indeed lose much of their significance, since such processes would themselves contain NCC. In other words, distilling the minimal NCC from preceding activity risks creating an arbitrary distinction and an oversimplified account conforming to the singular event that represents conscious resolution. As Dennett (2001) says, “(consciousness) is not a privileged medium of representation, or an added property some states have; (...) consciousness is not a momentary condition, or a purely dispositional state, but rather a matter of actual influence over time.” Revisiting IA1 allows bringing into discussion an alternative conception of consciousness which considers it not the resolved product of unconscious processing, but the very *process* of resolving incoming information (see section 4.2 on Process Philosophy).

4.1.3. IA5 Post-Conscious Mechanisms

Once our confidence in the sequential conception of conscious resolution is deterred, we must examine the Post-Conscious Mechanisms assumption (IA5), insinuated in the categories of NCC-co or subsequent downstream activity. Studies showing that later processing of information correlates with modified subjective experience (Salti et al., 2012) indicates that activity in higher regions might also represent NCC. Tononi (2012) proposes that changes in the state of the neural system reflect changes in subjective experience; in such case, not only do first-order elements change, but also higher-order concepts superimposed over the same elements. These findings undermine the axiomatic nature of

IA5. The correlation of post-conscious activity with consciousness itself could potentially remove the need for higher mechanisms to observe, utilize, or interpret the information entering awareness: a more complex representation simply requires the recruitment of higher areas. By considering the possibility of the evolving complexity of conscious perception, we are making no commitment to a fundamental distinction between early and late processes. From this point of view, the three-stage sequential order characterized by pre-conscious, conscious, and post-conscious processes becomes irrelevant. That is not to say that the brain activity in response to a stimulus does not start as unconscious, but that from that point on we do not expect to find a clear-cut transition between these three stages signaled by specific waves.

4.1.4. IA2 Temporal Modularity and IA3 Spatial Modularity

After the above considerations, the questions of when and where the decisive event of conscious generation takes place are not as tempting as before. To substantiate our concern with the Temporal Modularity assumption (IA2), Melloni (2011) identifies expectation as a factor determining the latency of neural signatures. According to this view, both early and late ERPs are indicative. The dependence of NCC on expectation encourages us to remember that perception is an active process involving top-down activity. This notion is corroborated by research showing how the subject's goal impacted early and late ERP components (Pitts, 2011). Another line of research demonstrates the role of action selection influencing interpretation of sensory and motor information (Desantis & Haggard, 2016; Desantis et al., 2018). Such perspective would render the early vs late debate void of meaning in its current formulation. Nevertheless, it should be noted that even findings such as those produced by Melloni and Pitts conform to a sequential view of information processing, where unconscious processes are resolved as conscious experience in a singular event. Similarly, the assumption of Spatial Modularity (IA3) would need to be opened up for discussion. The suspicion that additional stages of information processing constitute NCC compels us to consider the possibility of the decentralized nature of consciousness.

Bisenius et al. (2015) have shown by a meta-analysis a diffused and inconsistent pattern of activation correlated with conscious experience. Zeki (2003) demonstrates that the diverse cortical sites for processing information are also perceptual sites, undermining the distinction between consciousness and information processing. We ought to take these insights back to the theoretical discussion and ask ourselves whether a conscious representation obtained via the collaboration of dispersed and varying regions might not make the question of where conscious perception occurs too restrictive. Instead, it might be more fruitful to ask what collaboration of regions correlates with what subjective experience (Tononi & Edelman, 1998). It would rid us of the burden of postulating additional entities responsible for the task of producing consciousness. In addition to the dominant line of inquiry, we might benefit from asking how the varying timing and temporal dynamics of neural activity correlates with varying subjective experience and performance (He, 2018). This allows the possibility that for a single stimulus and task there can be several ERPs associated with conscious perception. For example, evidence indicating that the N2 is an NCC would not exclude subsequent waves such as P3b. Furthermore, a certain ERP could represent both an NCC and a non-NCC in different circumstances, depending on the dynamics in which it is involved; the properties of any wave (and whether it is an NCC) is only meaningful in the context of its relationship with other neural activity. Instead of seeking a particular ERP, we would be tracking the relationship between ERPs and identify the NCC with patterns of activity. Would these patterns differ for different stimuli, tasks, or subjects?

4.1.6. Non-sequential relations and the active nature

Dismantling the questions of when and where unconscious processing becomes conscious experience raises significant implications for the relationship between these two modes of perception. Whether stimuli are perceived in an all-or-none or a graded fashion relies on a passive and sequential conception of consciousness as the product of resolved unconscious processing (IA1 & IA6). A fresh consideration for the active, ubiquitous, and evolving

nature of subjective experience could potentially render the debate altogether irrelevant. Assuming the subject's point of view, the completeness or gradedness of a percept relative to an objective criterion is meaningless. When a representation is classified as lower or partial, one feels the urge to ask "partial relative to what?" Since the mind making sense of the stimulus does not aspire to a particular objective standard independent of circumstance and goals, each qualia is a complete experience in and of itself, regardless of what the experimenter regards as the complete set of features a representation should have. Otherwise for example, we would be compelled to treat as partial or degraded any representation lacking details which would be captured under closer observation, through a microscope for example.

Kouider et al. (2010) propose a "refined account of access that relies on a hierarchy of representational levels and on the notion of partial awareness, whereby lower and higher levels are accessed independently". Even Kouider's formulation seems to classify the subjective experience based on the objective criterion: a degraded percept would be one that would include only a subset of the object features. In that sense a degraded percept would not include color, for example. In comparison, assuming the observer is active would solicit a subjective criterion: compared to a 'complete' percept, a degraded percept correlate with more complex neural activity and a higher likelihood to be reported if the it is more important or relevant for the observer.

Nevertheless, Kouider rightfully insists that reframing the issue of dissociable forms of consciousness into dissociable levels of access provides a more parsimonious account of the existing evidence, instead of the dissociation between rich phenomenal consciousness and limited access consciousness (Block, 1995). From this angle, we might consider access consciousness as a more complex, richer experience, rather than a consciously-limited interaction with the phenomenal component (Naccache, 2018). Examining the underlying foundation of our current conception of consciousness widens the boundaries of the scientific investigation of conscious perception. We have shown that the implicit assumptions should not be axiomatic and have valid alternatives. One consequence for our conception of consciousness is the possibility that consciousness is complex in a manner that undermines the importance of unconscious processes, such as characterize

preconscious and post-conscious stages. While we are far from removing unconscious perception from the equation, we would do well not to take it for granted (Phillips, 2020). Revisiting the assumptions in this section offers questions about conscious perception that give less weight to the conscious-unconscious contrast, as will be further discussed in section 4.2. This would solicit the use of different contrasts in addition to the unconscious-conscious distinction. The inclusive attitude expressed here is a direct result of the reflective approach highlighted by Crick and Koch. As with a folding hand fan, realizing that the base itself is also flexible can help open up the gamut of questions and consequent answers in the young field of consciousness (see Figure 1).

Figure 1

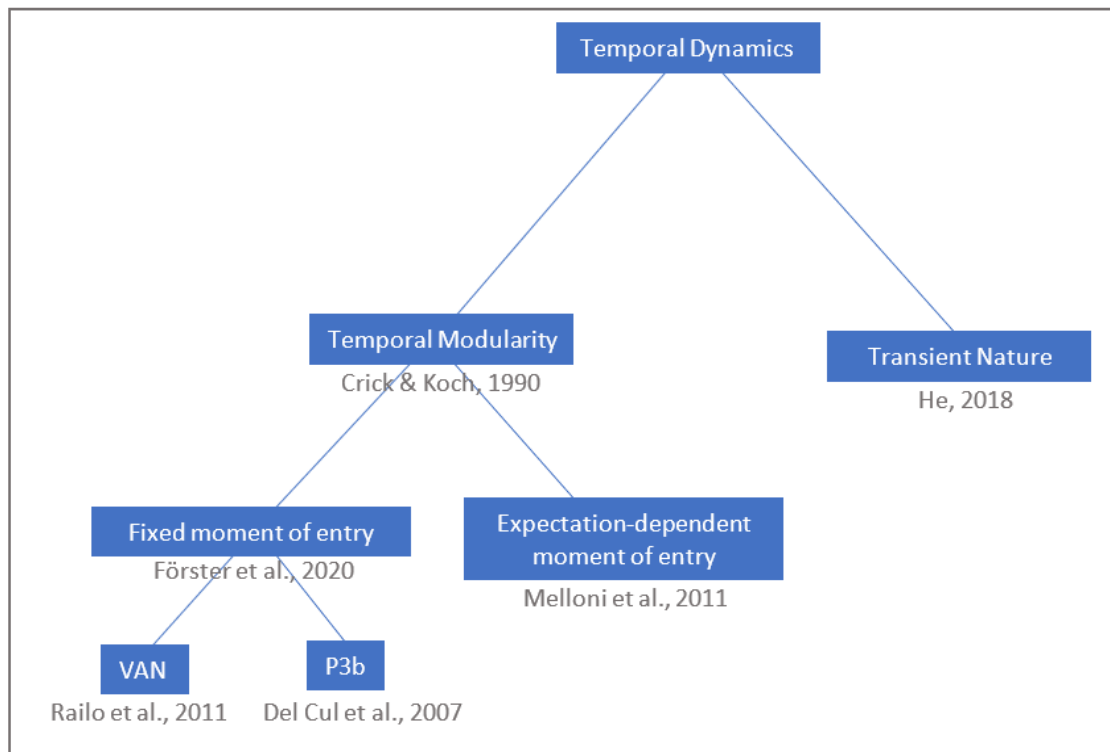


Figure 1. A visualization of the discussion on the temporal dynamics of conscious perception with examples of articles supporting the various views. When too many anomalies arise, we should retrace our steps and reconsider our models. Realizing that the base itself is flexible can help open up the gamut of questions and consequent answers.

4.2. Additional approaches

It is necessary at this point to reiterate that the purpose of the paper is not to dispose of the current framework for the study of consciousness. In fact, that wouldn't be an option, since from the moment a paradigm is consolidated, it cannot be invalidated without a worthy alternative (Kuhn, 1962, page 99). Nevertheless, what we have done is point to the boundaries of the current paradigm and show that they can be pushed. In this section, we suggest a few options to additional ways of approaching consciousness. There are certainly more, and we hope to encourage other researchers to raise them. This would reflect on the entities populating our conception of subjective experience and encourage more questions and lines of research. In the section 4.1, we examined each assumption and the possibilities opened up by questioning it. In this section 4.2, we take a broader look, focusing on existing and possible approaches rather than the existing one.

Largely speaking, there are two things we are interested in when discussing consciousness: the mechanism and the phenomenology (Dennett, 2001; Oizumi et al., 2014). Unfortunately, the last decades of research could be largely characterized by a dissociation between the phenomenology and the mechanism (Lau, 2008). The contemporary approach seeks at a particular place and time the neural indication that the consciousness faculty has been activated, as would characterize neurocognitive research (Brown, 2014). However, it is essential that a mechanism be sought out that would explain the phenomenology, while a study of the phenomenology would help explain the mechanism (Pokropski, 2019). This would require taking into account what is now treated as the "metaphysical aspects" of subjective experience, such as subjectivity, body boundaries, and sense of agency and volition. The phenomenological side of consciousness should thus guide our methodological choices and our models. Instead of shying away from phenomenology, this approach could comprise of integrating it into the neurobiological framework (EA1) in a systematic way (Seth and Hohwy, 2020). This should provide explanatory and predictive power for certain patterns of brain activity and the structure and form of their correlated phenomenology. One requirement would be the formation of an adequate language to efficiently account for phenomenological, or "metaphysical", properties of consciousness.

In this manner we may learn more about the composition of the neural system and the varieties of phenomenology as we learn to better link the two.

Focusing on when and where stimuli enter consciousness, especially under the expectation of a singular answer, comes at the expense of and might even challenge attempts to describe the complex and continuous mosaic of subjective experience. Additional lines of investigation could benefit from avoiding averaging neuroimaging results in order to determine the contrast between conscious and unconscious activity. One possibility is single-trial studies using EEG (for example, see Navajas et al., 2013). This would prevent an oversimplified or misleading model of perceptual processes, and allow picking up weak or inconsistent neural activity which could otherwise be overlooked. Instead of the universal, pursuing the particular might also help with the question of how the same stimulus might evoke contrasting subjective experiences (and NCC) depending on varying circumstantial factors as well as personal differences. Salti et al. (2015) track the temporal dynamics of neural activity characterizing conscious vs unconscious perception. This paradigm could be used while focusing on seen trials, and examining the differences in temporal dynamics of conscious perception. This could be done with both between-subject and within-subject designs, as well as manipulating the task and goal while controlling for stimulus. Such an approach would give less weight to the conscious-unconscious contrast, rely on other contrasts, and take into account phenomenology.

Some models have indeed attended to the phenomenological side of conscious perception, offering compelling ideas for a way forward. Northoff and colleagues (Northoff, 2013, chapters 21-24; Northoff & Huang, 2017) propose a temporo-spatial theory of consciousness (TTC), according to which consciousness comprises of different dimensions, such as level or state, content or form, phenomenal aspects, and cognitive features. Different mechanisms account for different dimensions, and are distinguished by their spatial and temporal properties. On the subcellular level, the properties of integrated presynaptic signals have long been upheld as a possible explanation of phenomenological properties of vision (Bachmann 2015; see also Bachmann, 1997; Llinas et al., 1998; Larkum et al., 2013). While level 3 and 4 pyramidal neurons (PN) level-5 pyramidal neurons (PN) are responsible for binding together different features of objects. The

temporal and spatial relations of presynaptic inputs to this layer impact whether and how stimuli will be perceived, capable of explaining, according to Bachmann (2015) illusions and phenomena such as backward masking. From a broader perspective, GNWT also links between mechanism and phenomenology, albeit to a limited degree. The regions involved in the meta-stable state contribute to the qualia (Dehaene & Changeux, 2005; Naccache, 2018). In contrast, IIT goes further than any theory to tie in the two aspects of consciousness based on the claim that subjective experience is a fundamental property in the physical world; it is a result of the causal effect of information when integrated by a system (Tononi, 2004). This theory, however, provides few predictions that are testable given our current capacities, and is therefore applicable to models all across the spectrum. Instead of allowing IIT to reframe the discussion, the lack of empirical anchorage has led to Crick and Koch's approach being imposed on IIT, bringing the focus back to the questions of when and where, as well as the contrast with the unconscious (Tononi & Koch, 2008).

One possible approach emphasizes the spatiotemporal dynamics of perception (He, 2018). It favors an evolving and distributed account of consciousness. Inspired by the IIT, the Temporally-Integrated Causality Landscape (TICL) model (Winters, 2020) offers an additional approach that takes into account the spatial and temporal dynamics of information integration. The model takes into account phenomenological characteristics, among them the sense that consciousness is temporally continuous rather than discrete. According to Winters, consciousness is composed of contents arising from neuronal subsystems that gain meaning by the larger, integrated system in which they are nested. These meaningful contents emerge from the subsystems because they exhibit a level of temporally-integrated causality (TIC) that is distinguishable from that of the larger system. Similarly, the Moment-to-Moment (MtM) model (Salti, Harel & Marti, 2019) proposes a mechanism consisting of a dynamic updating process dependent on the subject's goals, the stimuli's saliency and context. This model holds that a stimulus is consciously perceived for as long as it is recoded to fit an ongoing stream composed of all other perceived stimuli. By rejecting the sequential view, MtM avoids some of the assumptions (such as IA1) framing the pursuit of the particular 'when' and 'where'; conscious and unconscious

processes are in constant dialogue, integrating or disposing of incoming information. As such, could conscious and unconscious processes work together, operating alternately or in parallel? A percept is not resolved at any single moment, but is constantly shaped (or abandoned) depending on the areas recruited, be it a 'degraded' form composed by primary areas or a richer representation involving language faculties (perhaps reportable as a consequence). In this manner it takes into account phenomenology and tries to explain how one's subjective experience changes over time. These theories are not necessarily superior to the current paradigm, but once the assumptions framing it are shown to be contingent, they become viable alternatives that can expand our efforts.

This line of research resonates with the principles of Process Philosophy (Rescher, 2007), which prioritizes the description of the dynamical and interactive properties of natural phenomena. Rather than looking at objects, such as the stimulus, the consciousness faculty and the conscious percepts which are its product, this approach would suggest seeing consciousness as a process, such as the reduction of uncertainty (Tononi, 2008), or the attempt to construct a representation, rather than the result of this reduction or the representation itself. Applying Process Philosophy to the neurocognitive study of consciousness could comprise of exploring the interactions and relations between stimuli and between neurocognitive processes, with time and change as central factors.

Another possible guiding principle that complements this approach is the active nature of the observer. This would mean defining the conscious percept and its NCC based on the subject's goals and previous experiences rather than the number and type of features of an object, or the subject's point of view rather than the object's. Besides the MtM model's emphasis on the observer's goals, other attempts have been recently made to centralize the active observer by focusing on top-down processes (Seth & Friston, 2016; Solms & Friston, 2018). Among them, predictive processing sees the brain as constantly generating and updating a model of the world (Seth & Friston, 2016; Hohwy & Seth 2020). This shifts the focus on how downward streams construct the representation, or shape the conscious contents, rather than their general success or failure to consciously perceive the stimulus. Another model proposed by Aru et al., (2020; see also Bachmann et al., 2021) called

Dendritic Integration Theory (DIT) focuses on the role of top-down streams in selecting specific features and shaping the conscious experience as they integrate with bottom-up streams; in some cases, such as hallucinations and mental imagery, the top-down stream dominates perception.

In comparison, the advantage of asking when and where the singular event of conscious generation occurs was meant to reduce the complexity in order to simplify the problem. It is safe to say that no one truly believes consciousness depends on a single event independent of context (Förster et al., 2020), though as we have shown, methodological choices rely precisely on this assumption. What was hoped is that an understanding of this focal point would have a domino effect leading to a general understanding of conscious perception (Crick & Koch, 1998; cf. Lau, 2008). Now, after thirty years of research, we might benefit from additional strategies. Confronting the complexity of consciousness in all of its aspects and phenomena might actually simplify the subject matter in the long run (Seth and Hohwy, 2020). This would also help clarify and demystify the notion of consciousness by linking it to other domains such as physics and biology (Seth & Friston, 2016; Solms & Friston, 2018). It would conform to Occam's Razor by assuming a minimal number of entities. For example, viewing consciousness as transient, evolving and distributed might remove the need for the tripartite information processing involving primary unconscious processes, consciousness, and post-conscious processes: the neural mechanisms giving rise to and maintaining a conscious experience over time would operate on all levels, including those currently outside of but interacting with the 'consciousness faculty'. The difference between conscious and unconscious processing would be reduced to the variations in the dynamics of neural activity. In this manner it would clear away entities such as specialized and post-conscious mechanisms, or a distinction between phenomenal and access consciousness (Block, 1995; cf. Kouider, 2010; Overgaard, 2018). Whatever the approach or line of research, striving for a parsimonious account is not just inherently valuable; it forces us to revise and strengthen our grasp of conscious perception such that the theoretical scaffolding around it (e.g. the multitude of entities complementing consciousness) would no longer be necessary. The potential benefits offered by additional approaches are all the motivation we need for new discussions, ideas, and techniques.

5. Conclusion

In comparison to any other scientific field and preceding eras of philosophy of mind, the current study of consciousness is determined to bind together the objective with the subjective. The complexity of this challenge is increased by the opacity of the subject matter. As such, our conception of consciousness guiding our inquiry must be constantly revised. Examining the assumptions underlying the current paradigm can bring to light broad ways of thinking and new questions. Not only can superfluous entities be removed for the sake of efficient accounts, but new territories that were believed to be currently out of reach can be ventured into.

Data availability

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The authors declare that there is conflict of interest.

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