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# A Unified Neural Theory of Conscious Seeing, Hearing, Feeling, and Knowing

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**ABSTRACT**

Adaptive Resonance Theory does more than satisfy 'hard criteria' for ToCs.

## Hard criteria or explanatory scientific theory?

Doerig, Schurger, and Herzog list 'hard criteria for empirical theories of consciousness'. Their abstract notes that 'many Theories of Consciousness (ToCs) have been proposed,' 'diverse in nature,' that exhibit a 'lack of stringent criteria specifying how empirical data constrains ToCs'. They 'review 13 of the most influential ToCs' and 'their strengths and weaknesses from a strictly empirical point of view'.

Listing 'stringent criteria' is not how scientific progress on developing theories of mind and brain usually occurs. Typical humans have conscious experiences of seeing, hearing, feeling, and knowing. Thousands of psychological and neurobiological experiments about vision and these other faculties have been carried out for over a century. The psychological experiments clarify how visual stimuli cause conscious experiences of visual qualia – including perceived form, color, brightness, depth, and motion – and when consciousness fails. Many neurobiological experiments have correlated conscious experiences with brain dynamics.

To understand these data, theorists discover organizational principles that are embodied in a small number of equations. In mind/brain studies, these equations help to define modules, or microcircuits, which are specialized in *modal* neural architectures, where 'modal' stands for different modalities of biological intelligence, including vision. An integrated self with a conscious mind is possible because it builds on a shared set of equations and modules within modal architectures that can interact seamlessly together to generate emergent properties that mimic detailed properties of conscious psychological experiences (Grossberg, 2017b).

The foundational equations describe short-term memory, or STM; medium-term memory, or MTM; and long-term memory, or LTM, that were introduced in Grossberg (1968, 1969); see Grossberg (2013b) for a review.

In Section 1, Doerig et al. write about 'whether we can close the explanatory gap or whether it is impossible for principled reasons'. This gap actually started to be closed 40 years ago (Grossberg, 1980). They mention only a few data, and write that 'maybe the plethora of ToCs simply reflects the fact that we have too few experimental constraints' (Section VI), despite the existence of huge databases about conscious experiences that have been getting explained and simulated on the computer for many years. Their underconstrained analysis cannot lead to mechanistic understanding.

## All conscious states are resonant states, but not conversely

Humans also have conscious experiences of hearing, feeling, and knowing, and huge interdisciplinary databases describe them. In all these areas, the interdisciplinary computational neural theory called Adaptive Resonance Theory, or ART, links brain mechanisms to their emergent, or interactive, properties that embody psychological

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Commentary on *Hard Criteria for Empirical Theories of Consciousness* by A. Doerig, A. Schurger, and M. H. Herzog to appear in *Cognitive Neuroscience*

functions and conscious experiences. ART shows how *adaptive resonances* enable us to be conscious of all these kinds of experiences, while binding them together into coherent moments of unified conscious awareness. ART provides detailed mechanistic explanations of all the issues and data mentioned by Doerig et al., as sketched below.

ART has been incrementally developed since it was proposed in Grossberg (1976) to explain and predict how humans learn to attend, recognize, and predict objects and events in a changing world. ART was not derived to explain consciousness. However, as its unifying explanations became increasingly mature, it became clear that 'all conscious states are resonant states, but not conversely'. For recent reviews, see Grossberg (2013a, 2017b, 2018, 2020, 2021). For a summary of resonances that support different conscious experiences, see Figure 1.

### A thought experiment shows that ART solves a universal problem of error correction

ART design principles and mechanisms can be derived from a thought experiment that asks the question: How can a coding error be corrected in a changing world if no individual cell knows that one has occurred (Grossberg, 1980)?

Using only familiar environmental facts as hypotheses, every step of the thought experiment is translated into processes operating autonomously in real time with only locally computed quantities. Thus, when familiar environmental constraints on incremental knowledge discovery are overcome in a self-organizing manner, then ART circuits naturally emerge as a universal solution to correcting errors in a changing world.

### Resonances that are not conscious

Resonant states that are not conscious include parietal-prefrontal resonances that trigger selective opening of basal ganglia gates to enable the read-out of contextually-appropriate thoughts and actions (Brown et al., 2004; Buschman & Miller, 2007; Grossberg, 2016b) and entorhinal-hippocampal resonances that dynamically stabilize the learning of entorhinal grid cells and hippocampal place cells during spatial navigation (Grossberg and Pilly, 2014; Kentros et al., 2004; Morris & Frey, 1997). These resonances do not include feature detectors that are activated by external senses, such as those that support vision or audition, or internal senses, such as those that support emotion.

## "ALL CONSCIOUS STATES ARE RESONANT STATES"
### Grossberg (1980)

**Surface-shroud resonances** support conscious seeing of visual qualia

**Feature-category resonances** support conscious recognition of visual objects and scenes

**Stream-shroud resonances** support conscious hearing of auditory qualia

**Spectral-pitch-and-timbre resonances** support conscious recognition of sources in auditory streams

**Item-list resonances** support conscious recognition of speech and language

**Cognitive-emotional resonances** support conscious feelings and recognition of them

**Figure 1.** Some known conscious resonances and their psychological functions.

### *Why* did evolution discover consciousness? Seeing is for reaching

Evolution may have discovered conscious states because multiple processing stages carry out three functionally distinct processes of 'hierarchical resolution of uncertainty' to construct brain representations that are sufficiently complete, context-sensitive, and stable to control effective actions (Grossberg, 2017b). The visual representation on the retina is noisy and incomplete. For example, the large blind spot and retinal veins prevent the processing of connected objects that are registered by the retina at their positions. Multiple stages of boundary completion and surface filling-in complete the retinal representation.

How do our brains select sufficiently complete visual representations to control actions? My answer is that *brain resonance, and with it conscious awareness, is triggered at complete representational stages* to escape the disastrous consequences that could occur were actions based on incomplete representations at earlier processing stages. For example, we consciously see in order to look and reach based upon a *surface-shroud resonance* (Figure 2) that occurs between cortical area V4 and the posterior parietal cortex (PPC). The selected V4 representations attend objects to act upon via PPC (Grossberg, 2017b, 2019). We consciously recognize what we see using a *feature-category resonance* V4 and the inferotemporal cortex (IT); see Figure 3. These two resonances synchronize when we see and know about a familiar object.
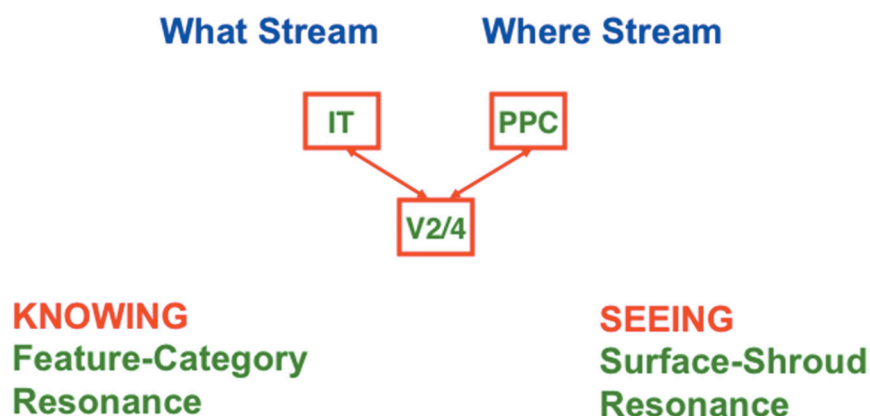
### Explaining mental disorders using ART

Resonances can fail or be degraded due to anatomical lesions or improperly functioning neuromodulators. ART provides neural explanations of psychological symptoms and neurobiological data about how consciousness is altered during mental disorders like Alzheimer's disease, autism, amnesia, Fragile X syndrome, and neglect, including a key role for acetylcholine neuromodulation in regulating the *vigilance* with which cognitive learning, attention, and consciousness occur (Franklin & Grossberg, 2017; Grossberg, 2017a, 2017b; Grossberg & Kishnan, 2018; Grossberg & Seidman, 2006).

### Rivalry, change blindness, crowding, masking, attentional blink, and Hermann grid

Doerig et al. mention several visual phenomena, notably those in this section's title, that have all been explained by interactions between model visual cortical processes that preprocess visual inputs and the surface-shroud resonances that support consciously seeing them; e.g., binocular rivalry and percepts of unimodal vision (Grossberg et al., 2008); change blindness, motion-induced blindness, masking, and attentional blink (Grossberg, 2017b); crowding (Foley et al., 2012); and

**WHAT KINDS OF RESONANCES SUPPORT KNOWING VS. SEEING?**

**What Stream**      **Where Stream**

IT      PPC

V2/4

**KNOWING**
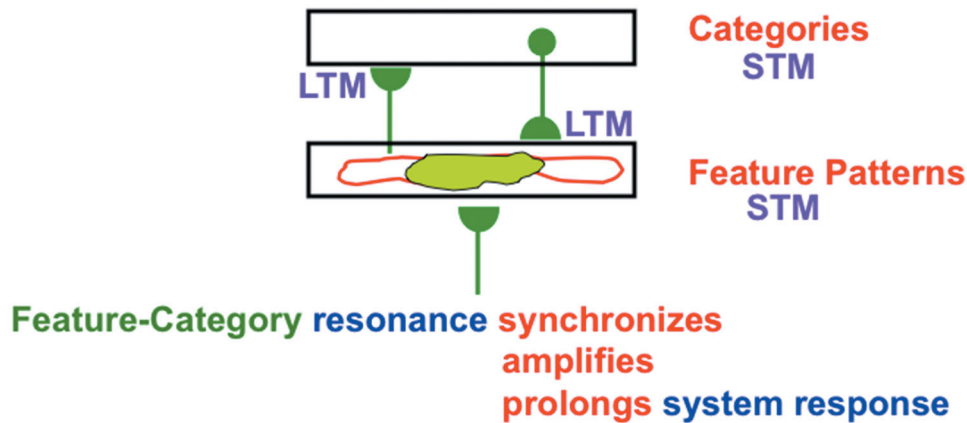Feature-Category
Resonance

**SEEING**
Surface-Shroud
Resonance

**Synchronous linkage between resonances enables us to KNOW what the object is as we SEE it**

**Figure 2.** Seeing and knowing. A surface-shroud resonance that supports conscious seeing and a feature-category resonance that supports conscious knowing, or recognition, can occur simultaneously and be supported by a synchronous resonance that bridges the What and Where cortical streams. [Adapted with permission from Grossberg (2017b).].

## ADAPTIVE RESONANCE

**Attended feature clusters reactivate bottom-up pathways**

**Activated categories reactivate their top-down pathways**



**Feature-Category resonance synchronizes amplifies prolongs system response**

**Resonance triggers learning in bottom-up and top-down adaptive weights: *adaptive* resonance!**

**Figure 3.** During a feature-category resonance, a bottom-up input pattern activates a distributed pattern of feature-selective cells which send bottom-up signals to a category coding level. These bottom-up signals are multiplied by adaptive weights, or long-term memory (LTM) traces, that are tuned by learning. An activated category reads out a top-down expectation. These top-down signals are also multiplied by LTM traces. These expectations help to focus *attention* upon expected combinations of cues, called *critical feature patterns*, that control learning and action. If a good enough match occurs between the top-down expectation and a currently active bottom-up feature pattern, then a feature-category resonance begins to form between them via the active bottom-up and top-down excitatory pathways. This resonance supports conscious recognition of the object that is represented by the attended critical feature pattern. [Reprinted with permission from Grossberg (2019).].

Hermann grid (Grossberg and Todorovic, 1988). Scores of additional visual percepts have also been explained in a unified way; see sites.bu.edu/steveg.

### Cortical synchronization, gamma and beta oscillations, and wakefulness and sleep

The authors mention gamma oscillations in Section IV.4.a. In spiking laminar thalamocortical ART models, faster gamma oscillations emerge during a good enough match between bottom-up and top-down signals, as during a feature-category resonance, whereas a big enough mismatch causes slower beta oscillations (Grossberg & Versace, 2008), a prediction with subsequent support from neurophysiological experiments on V1, V4, and hippocampus.

ART clarifies how brains switch between wakefulness and sleep, and explains UP and DOWN sleep states (Grossberg, 2017a).

### Gaze direction and social cognition

How gaze direction enables us to 'infer the mental state of others and to predict their behavior' (Section IV.4.b) is explained by how joint attention supports goal-oriented orienting, reaches, and tool use during social cognition (Grossberg & Vladusich, 2010).

### Unfolding and large and small networks

The authors note that 'any function can be implemented by different physical systems' (Section III.4). However, sufficiently rich multiplexed combinations of functions cannot be so implemented. Indeed, ART uniquely follows from a thought experiment about a universal problem about error correction in a changing world (Grossberg, 1980).

ART feedback circuits that functionally link Consciousness, Learning, Expectation, Attention,

Resonance, and Synchrony – the CLEARS processes – cannot be unfolded into a feedforward network (Grossberg, 2019).

Classifying biological neural models like ART as either small or large is unhelpful because, to explain why we are conscious, ART's multiple processing stages carry out a 'hierarchical resolution of uncertainty' in a particular order.

## Disclosure statement

No potential conflict of interest was reported by the author.

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