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Dynamics in Spatial Interactions

KEYNOTE

We see the world the way we do because of how our brain activity moves

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Cognitive neuroscience has been observing brain activity with increasing spatio-temporal resolution. This has enabled a shift in focus from localization to self-organization. As a result, there is increasing demand for a unifying perspective on the question: how do self-organized patterns of brain activity relate to information processing and conscious experience?

To start with the latter, the philosopher Daniel Dennett referred to the standard model of conscious experience as the “Cartesian Theater”. This is the location consciousness occupies, a place in the brain where all the information comes together. He rejected such a model in favor of “Multiple Drafts”: there are multiple streams of information, partially conflicting and continuously changing. The simultaneity and unity of our experience thereby is no more than an illusion, albeit one that gives the notion of Cartesian Theater a seductive plausibility.

A Cartesian Theater is not needed to enable a single representational medium for subjective simultaneity. Dynamic patterns of synchrony in brain activity may constitute the basis for the unity of experience. These intervals have a certain duration; the phenomenal counterpart of which is the psychological present (Stroud 1967).

Similar intervals are manifested in visual perception. Let us consider the case of multi-stable figures. While watching Fig. 1 you will repeatedly experience spontaneous changes in the perceived groupings between its components. Certain groupings appear, and stay for a while, but none of them persists forever. A specific case is perceptual switching, the reversal of spatial orientation as observed with ambiguous figures, such as the Necker cube.

We experience perceptual switching as instantaneous. The processes in the visual system that produce it, however, typically require approximately 0.5 s to complete (Ito et al. 2003; Nakatani and van Leeuwen 2005, 2006). This is, by all means, a noticeable duration. Why, then, do we have the illusion that switching is instantaneous? During this time interval, the system is in-between two synchronized states, so there is no experienced duration.

The system that produces these experiences is the product of evolution. But this doesn’t mean that evolution has selected it for that sake. Much more likely is that they have been selected for the sake of their information processing function (van Leeuwen and Bakker 1995; van Leeuwen 2006). Information processing is taking place in a distributed fashion within neural groups, or clusters. At the level of the dynamics of their collective signal, this is manifested as irregular activity that is noise to the rest of the brain. As time proceeds, the smaller units connect into larger ones to form temporary cooperative clusters. This is manifested in the activity growing more regular; certain units enter a period of synchronized activity.

For communicating information computed in a certain region to the rest of the brain, it is essential that the information is not changed during this interval. This is why these synchronized activity patterns are functional for distributed computation. I called these periods coherence intervals.

The length of coherence intervals depends on how long it takes for other parts of the brain to receive the information. Information takes variable time to travel from one region to another and as a result, the coherence interval will vary in duration. This leads to the prediction that the duration of synchronized activity is correlated with information processing demands—the more complex the information, the longer the duration. The prediction follows simply from the distributed character of information processing. The more complex the information, the larger the number of different circuits, or clusters, involved. The larger this number, the longer the interval will have to be for information transmission to be effective. Information will arrive from different

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clusters in different rates. The total transmission time is determined by the slowest transmission rate. The maximum from a random sample of almost any distribution will increase with sample size. This principle, when applied to coherence intervals, is called hologenesis.

To understand why hologenesis is called that way, consider that, when a coherence interval is short, all communication beyond a certain level is cut off. Thus information of certain complexity can never be reached. Therefore, the shorter the interval, the more restricted is the range of interaction, the less complex the information communicated. The resulting direct relationship between complexity and time to complete a process are fundamental to mental chronometry since Donders (1969) and provide an obvious link with reaction time studies. The difference with Donders' approach is that response times do not measure processing latencies but "waiting times" needed for neural communication. The limited duration of the coherence interval prevents feature integration from reaching a level of full saturation—in the sense that information is prevented from becoming available everywhere in the system. This prevents the percept from becoming an undifferentiated global whole, but enables it to be more than a set of pair-wise connections. Note: I use "global" and "local" exclusively as functional notions, referring to the complexity of the information. So these notions are unrelated to spatial extent of a stimulus. However, because many parts of the brain have a topological organization, functionally and spatially local or global are sometimes correlated. According to our current concepts, processing starts from local features and proceeds in time towards an increasingly encompassing range of integration automatically (van Leeuwen and Bakker 1995). But this does not necessarily mean that small comes before big.

I propose that hologenesis belongs to the intrinsic dynamics, while the coherence interval could be controlled adaptively. Some tasks require more complex information than others. For instance, detecting symmetry in the plane can be done through detecting pair-wise correspondences between points; for detecting symmetry in three dimensions, four-tuples of points are needed (Wagemans 1993). To enable the same system to calculate information of different complexity in minimal time, we consider the length of coherence intervals to be controlled—through the outer loop. Longer coherence intervals automatically imply the availability of a wider range of contextual information. In experiments, this will enhance priming and interference effects. Context-dependence is itself contextdependent. This explains the way in which perceptual priming (Stins and van Leeuwen 1993), shape detection (Hogeboom and van Leeuwen 1997), interference (van Leeuwen and Lachmann 2004) depend on task.

The proposed framework also pertains to perceptual dysfunctions, such as encountered in developmental dyslexia. Feature integration is generally more global in non-letters than in letters (van Leeuwen and Lachmann 2004). For non-letters, e.g. simple geometrical shapes, global properties such as symmetry are useful because they represent an object as invariant under different orientations. For letters, this is confusing, for instance with "b" and "d". Readers, therefore, learn to suppress the symmetry although typically beginning readers make 'reversal errors'. Fundamental to developmental dyslexia is that symmetry suppression fails to occur. Lachmann and van Leeuwen presented two items in succession, with the task to decide whether they are same or different. A same response must be given to objects that are identical under rotation or reflection. Both non-letters (dot patterns) and letters were used in this task, which could be symmetric as well as asymmetric. For instance, the letter "A" has a central symmetry, which is lacking in the letter "R". For dot patterns, reaction times depended strongly on their symmetry. In normal readers, we found no advantage of symmetry for letters. Dyslexics showed a symmetry advantage for letters also. As a result, they performed the letter task better than normal readers. The effect is a powerful demonstration; dyslexics, almost by definition, generally perform worse with linguistic materials.

Because behavioral studies can only provide indirect evidence for the proposed framework, we investigated brain activity. Hologenesis and coherence intervals are a property of the spontaneous brain activity. Spontaneous EEG shows preferred states of synchrony that last for sufficient time to count as coherence intervals (Gong et al. 2003; Ito et al. submitted). Spontaneous brain activity shows dynamic preferences for certain states of synchrony, as we may expect if these states are meaningful.

When the brain is processing information, its dynamics is irregular but once a perceptual state has been reached, a period of synchronous activity can be observed (Nakatani and van Leeuwen 2005, 2006). Such periods also occur prior to the presentation of stimuli, when these are being anticipated (Nakatani et al. 2005). We measured the length of coherence intervals in single trials of event-related EEG and obtained preliminary evidence that the length depends on task (Nikolaev et al. 2005). Coherence intervals starting 200 ms after stimulus presentation were longer in a task condition than in a control condition, where participants made arbitrary responses to the visual stimulation. We are currently investigating whether coherence intervals are adjusted in accordance with the complexity of information processed.

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