

New Models for Old: Taking the Neural Network Seriously

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Transition

At Millenium's end we are in transition between models of the brain. The classical, static model of unidirectional information flow through a vertically organized network has repeatedly been recognized as simplistic and unphysiological. I propose that a foundation exists for it to be replaced in the new millenium by a dynamic model based on horizontally organized continuous reciprocal interaction, as befits a self-organizing and self-stabilizing autonomous agent, that predicts and prepares. I nominate the following design characteristics of the forebrain as pointing to new concepts.

Recursive Organization

The cortical mantel is a recursive network. Microcolumns of neurons aggregate as macrocolumns, that aggregate as processing units, that aggregate as trends, within the parallel reciprocally interactive global neuropil. Scattered polymodal areas complete the cortical network (Pandya, Seltzer, & Barbas, 1988).

The polymodal patches of cortex are not endpoints of information transfer, and no patch caters to all modalities. The network displays no focal point for assembling an omnimodal model of the world; it nowhere all comes together (Dennett & Kinsbourne, 1992). Correspondingly, no focal cortical lesion extinguishes awareness globally. The network does not cobble fragments or features into aggregates, but rather continually reshapes the activation topography. "Binding" does not arise; the pattern of neural activation yields the percept, idea, or intention.

An activation manifold offers explanatory potential beyond nodes and their interconnections. Levels of local activation determine neuropsychologi-

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cal state and system integrity. Experience with hemisphere priming manipulations and syndromes such as unilateral neglect, has shown that activation level is a potent neuropsychological variable (Kinsbourne, 1993). This concept is no longer revolutionary, but until 30 years ago, it was absent from the theoretical armamentarium (Kinsbourne, 1970). Even now, it has been only marginally exploited.

Self Organization

Network neurons are not silent until galvanized into action. They continuously discharge at individual base rates, from which they depart by firing more or less rapidly. This base rate firing is not neural noise, an unwanted but inescapable imperfection of design (Ferster, 1996). It is the very life of the brain, which the network is exquisitely self-organized to protect and preserve.

The recursive organization favors field theories of cortical function. Rather than an idle brain stimulated into transient activity, brain architecture implies the priority of an active internal state, in continuous causal circular interaction (Clark, 1997). The brain's circuitry pursues a ceaseless trajectory through activation state space. It not only accommodates to perturbations but anticipates and forestalls them, thus stabilizing them. The peaks in an activation/inhibition topography control responding, whereas the remaining topography serves as ground to that figure. Behavior is not driven by a lone specialized "module," or several yoked together, but by the peaks and valleys as a whole, a unity in diversity. Mental capacity is limited not by some hypothetical resource, but when the network is fully engaged: The network is the resource.

Reciprocal Connections

Waves of activation are propagated through the cortical mantle by local graded and action potentials. But specific areas of cortex are also interconnected by fast-conducting myelinated fiber tracts, that bypass intervening cortex. These cortico-cortical connections are typically bidirectional, contradicting their conventionally ascribed role as aft-to-fore communication channels. Lateral commissures are also symmetrically bidirectional, as are the vertical corticohippocampal projections. Projections from cortex to basal ganglia are unidirectional, but their connections loop back to their origin through thalamus. Such connections may equilibrate, or reciprocally inhibit, the areas that anchor them.

Split-brain symptomatology largely reflects the actively engaged hemisphere's failure to coactivate the passive hemisphere, leaving it unready to process (Kinsbourne, in press). Conduction aphasia's defining repetition deficit can be understood as a failure of coactivation of Broca's area by an activated Wernicke's area. The corpus callosum, though mostly excitatory,

may also mediate inhibition, for instance accounting for left speech lateralization. Lower level commissures, such as the intercollicular, mediate reciprocal inhibition between opponent processors that control lateral orientation.

Bidirectionally Connected Sequential Processors

Cerebral processors interconnect in bidirectional sequence “trends.” The sensory trends are anchored in the thalamocortical periphery at one end and in archaic limbic cortex on the other end. Patterned neural activity flows from each end, centripetally from thalamus, and centrifugally from limbic cortex (Pandya et al., 1988). This two-way access to modality-specific areas enables both perception and imaging. Correspondingly, inability to image appearances that can be recognized, and recognition failure leaving imaging intact, are doubly dissociated.

Colliding Waves Interpenetrate

Centripetal waves of activation sweeps inward, unit by unit, from cortical layer three to layers three and four to the next adjacent unit. Centrifugal activations sweep outward from layers five and six to layer one. Superimposed and interpenetrating in separate laminae of six-layered cortex, they instantiate the current brain state and experience. Generalized anticipation (centrifugal) is differentiated into specific percepts by the pattern of selectively attended input (centripetal). A percept or action that is incompletely realized indicates an arrested process; the error patterns uncover stages through which the cognition normally evolves (Brown, 1988).

The traditional reflex-like stimulus–response chains apply only when prediction fails or is not feasible: for unanticipated, yet biologically relevant, stimuli (novel, painful), or when brain immaturity or damage negate anticipation (stimulus-bound behavior of infants, echopraxia and utilization behavior of prefrontal damage). Inability to predict leaves many events unanticipated and therefore novel and compelling, and renders the individual a captive of his surroundings.

Interactivity versus Intraactivity

The network’s activity variably engages the exterior. In extreme interactivity, its resources are fully committed to action and resulting percept, or the reverse. Activity loops between effector and receptor through body and ambient exterior, coupling brain and world, implementing embodied and situated cognition (Clark, 1997). Extreme intraactivity turns inward and pursues a trajectory through state space uninfluenced by input and output, virtually uncoupled. Anticipation dominates.

Extreme interactivity obtains during mentally effortful interaction with the environment that leaves no scope for introspection or self-awareness. The

opposite is extreme intraactivity, in autistic and hallucinating states, in which dream-like endogenous images simulate reality. Intraactivity is extreme in perceptual deprivation. Precluded from patterned sight, sound, and touch, subjects report increasingly elaborate visual hallucinations, from lines and whirls to edifices and panoramas. Although intact, if the visual channel is uninformative, the anticipations gather strength and complexity and control experience. Cortically blind patients with Anton's syndrome, who are convinced that they can see, and make wild claims about appearances, are a pathological instance of disinhibited anticipations in the lesioned visual channel acquiring the vividness of reality.

Consciousness

Local lesions can deplete consciousness, generating unawareness syndromes, such that the patients not only cannot access information in the mode in question, but cannot image or conceive of it. If the activation topography of the network, rather than a privileged consciousness module, represents conscious experience, awareness becomes an attribute of heterogeneous neural circuitry, any part of which can contribute to consciousness (Kinsbourne, 1994). Neural networks can experience their own states.

Next Millennium

The inventory of design characteristics and illustrative syndrome interpretations is a personal choice. But it may illustrate the trajectory of neuropsychological theory into the next millenium.

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