Neural Darwinism

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Plan

- Comments on AI, PDP and their relationship to real brains. (Just to heat things up...)
- Review of physiological data that Edelman is trying to account for.
- Overview of the theory of Neuronal Group Selection (NGS) theory.
- Specific results.

Neural Darwinism

- Nobel prize winner in Physiology for his work on the role of CAM/SAM in development.
- Director of Neurosciences Institute at Rockefeller University.
- "Neural Darwinism" ranges over key problems in developmental and evolutionary biology, anatomy, physiology, ethology and psychology.
- Some of it is hard to read for non-specialists. He is very clear about what he is claiming, what would disprove his theory, what parts are tentative, etc.

Criticism of AI

- Goal of AI: Make computers more useful and understand the principles that make intelligence possible.
- AI is Aristotelian Science. A *synthetic* enterprise largely isolated from the *analytical* study of the biology of natural intelligence through psychology and the neurosciences.
- Wrong epistemology. Finding the representation, not the algorithm is the problem of intelligence.
- The assumption that categories and signals encoding information about them are the basic stuff around which computations are organized constitutionally biases AI to equate perceptual and intellectual performance with algorithms.
- This assumption leads to the inability of AI systems to cope with the complexity and unpredictability of the real world.

Criticism of Connectionism

- "Looking sideways at biology." Really based on physics and statistics rather than biology.
- The systems are still brittle. The possibility of dealing with the continuous stream of exceptions we call common sense seems remote.
- Models based on regularity rather than the variability found in biological systems.
- Formal properties are more important than biological plausibility.

Non-biological connectionist ideas

- Memory as replica of of information supplied by the world. (Human memory is highly context and affect-sensitive.)
- Memory retrieval as a relaxation to a stable state. (Always exposed to changing input patterns.)
- The brain decides more quickly than simulated annealing algorithms do.
- Symmetric connections.
- Learning by clamping desired states. (The motor output cannot be clamped externally.)
- In fairness, competitive learning schemes do not have these flaws.

Neurophysiological Facts

- Nervous systems are organized as networks with distinct areas having different patterns of connectivity for different functions.
- The different areas are arranged in a heterarchy. (Recurrent)
- New areas are added gradually and provide functional redundancy.
- No global synchronization.
- Extensive overlap of dendritic and axonal arborizations suggest extensive functional degeneracy.
- There are no critical neurons, so responses of populations are important.
- Enormous diversity of neuronal populations. Found at all phylogenetic levels, but greater in higher life forms. Even found in genetically

identical individuals and in functionally identical neurons.

Figures 2.6, 5.4 and Table 3.3 and Table 2.1

Requirements of a selectionist theory

- A selectionist theory turns variability into an asset. Unlike instructionist theories like Hebbs cell assembly theory that require specific circuits.
- Requires a source of diversification leading to variants.
- A means for sampling an environment that is not initially categorized.
- A means of differential amplification for successful variants.

Constraints on NGS

- Must explain developmental processes that lead to local groups with reentrant structures.
- A population view of neurophysiology where synaptic selection rules are related to the specific anatomy of group structure and not just neuron-to-neuron firing.
- A strict interdependency between the dynamics of reentrant neural mapping and perceptual categorization during behavior.

Primary Repertoire

- During development selection among competing neuronal cells and their processes determines the anatomical form and the pattern of synaptic connectivity.
- Cell adhesion and movement through the action of CAM and SAM molecules that are controlled by morphoregulatory and historegulatory genes.
- Differential growth, cell division and death.
- Brain has 10^6 groups with each group having from 50 to 10,000 neurons.

Degeneracy

- In each functional area, there exist a multitude of groups that can respond more or less well to a particular input.
- Exactly the result of epigenetic processes. Neurons with axonal trees that spread over a wide area.
- Insures that the "space" of possible stimuli is covered and that it is fail-safe against the loss of groups.
- The possibility of using transmitter specific synapse changes to increase the degeneracy.
- The optimal degree of degeneracy is like the optimal size of a receptive field.

Figures 3.1 and 3.2

Group Selection

- Group confinement: Limits the size of groups to a stable range that allows a tradeoff between coverage and specificity.
- Group selection: Temporally correlated inputs to nearby cells causes them to form a group where cells are more strongly connected to cells in the group than to cells outside of the group.
- Group competition: Different groups compete for cortical representation space.

Figure 6.4

Competition

- Group expansion beyond a certain size or below are unstable.
- Groups that overlap somewhat with neighboring groups are favored.
- Cells that are at a greater distance from the other cells in the group are more likely to be captured by another group.
- Extant groups have an advantage over incipient groups.
- Receptor density constrains the receptive field of a group and thus its competitiveness.
- The most competitive groups are the ones that are stimulated most frequently.

Secondary Repertoire

- Formed by changing the strength of the synaptic connections found in the primary repertoire.
- Must generate specificity of response while maintaining variablity.
- Must be consistent with both short and long term memory.
- Physiological evidence suggests that firing of both cells is neither necessary or sufficient.

Figure 7.1 and Figure 7.9

Post-synaptic rule

Responsible for short term changes. The response of a synapse increases when multiple synapses are correlated in time.

ηij: Strength of the postsynaptic connection from neuron j to neuron i.
ξ_j: Presynaptic strength from neuron j.
$S_j(t)$: Activity of neuron j at time t.
$c1, c2$: Constants.

$$\Delta\eta_{ij} = c_1\eta_{ij}\xi_j \sum_k \eta_{ik}\xi_k < \overline{S}_j(t) \cdot S_k(t) > -c_2(\eta_{ij} - \eta_{ij}^{\circ})$$

Pre-synaptic rule

Causes long term modification of all presynaptic terminals by shifting the transmitter release baseline as a result of large fluctuations in average presynaptic transmitter release. (Rescaling)

F_i: Degree of facilitation in a presynaptic terminal.
λ: Decay time constant.
S_i: Firing rate of neuron i at time t.
ϵ: Increase in facilitation per spike.

$dF_i/dt = \epsilon \cdot S_i(t) - \lambda \cdot F_i(t)$
$D_i(t)$: Degree of depression in the presynaptic terminal.
β: Decay time constant.
$\xi_i(t)$: The presynaptic efficacy of neuron i.
κ: Constant of proportionality between release and depression.
$dD_i(t)/dt = \kappa \cdot \xi_i(t) \cdot S_i(t) - \beta \cdot D_i(t)$
$\xi_i(t) = \xi_i^\circ \cdot (1 + F_i(t))^3 \cdot (1 - D_i(t))$

Accounting for plasticity

- Model has 1024 excitatory and 512 inhibitory cells that receives two superposed topographically ordered projections from the glaborous and dorsal surfaces of a hand.
- Uses the postsynaptic rule to cause the formation of neuronal groups.
- Model successfully replicates results of stimulation and transection performed on real monkeys.

Figures 5.5 and 7.5

Reentry

- Ensures consistency across map responses with respect to the current state and the environment.
- Reentry between maps on the same level allows one to change its categorization and coordinate that change with the other map.
- Global reentry is necessary to put the interpretation of representations in the same place as the representation.

Categorization

- An organism must generate its own categories for objects based on its raw perceptions.
- Recognize objects by their unique characteristics.
- Recognize similarities among things in the same class, and differences between things in different classes.
- It is the complex of capacities to carry out a particular set of procedures leading to categorization that is recollected.
- Categories correspond to polymorphous (disjunctive) sets of parallely sampled features.
- Memory is intimately linked to categorization and generalization.

Darwin III

- Multijointed arm and a head with two eyes.
- External criteria for amplification is not allowed.
- No specific information about the objects being perceived are built in.
- Darwin recognizes individuals by "matching to exemplars". No sense of continuity of features.
- Wallace recognizes classes of individuals by their continuous features. Insensitive to rigid and nonrigid transformations.
- System makes appropriate saccades and fine tracking movements demonstrating categorization, generalization and memory.
- Capable of using arm to reach for and touch tracked objects.

Darwin III picture

Conclusion

- Accounts for many of the biological facts that give other theories problems.
- Simulations successfully categorize, generalize and learn.
- There are many specific predictions that can be tested on real biological systems.

Figure 11.1

Problems with the brain as a computer

- *Coding:* Programmer must find an appropriate representation.
- *Categorization:* Define all categories that will be found in the world.
- *Procedure:* Specify the behavior of the program for all combinations of inputs.
- *Homunculus:* Symbols have no meaning in the system. The intelligence is embodied in the observer.
- *Developmental:* Can a programmed system come to exist without a programmer?