The physical dynamics of neurological computation

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All real computers are dynamical systems.

for extended computations
- noise, imperfections necessitate restoration (convergent dynamics)
- computer dynamics are driven and dissipative,

digital computers are a special case having
- analog restoration at the single 'bit' level
- dynamics provided by a system clock
- computation and dynamics kept conceptually separate

Lesson from silicon VLSI deployed in an analog 'neural' fashion

hardware is very effective when there is clever use of the device physics in implementing an algorithm—a handshake between algorithm and hardware.

a particular subset of details of the underlying devices matter in this synergy

neurobiology
- has a choice of algorithms for any particular computation
- algorithms need not always work (illusions)
- has huge number of details from which to select
- significant details can be enhanced in evolution

The great size divide in biology

Nematode
- 302 individually identifiable neurons, same in genetically identical individuals
- 95% of connections (synapses) are identical
- destroying a particular cell creates a well-defined behavioral deficit.
- system 'computes' on the basis of defined circuitry—a microprocessor

Humans
- roughly 10^{11} neurons, 10^{14} synapses
- 1:1 correspondence of neuron types, but not of individual neurons.
  - statistics of circuitry conserved, but not the details
- when behavior is repeated, the microdynamical pathway is not
- destroying 10^{7} neurons at random produces no behavioral consequence

The 'laws' of higher animal behavior and psychology are emergent or collective properties of a large network of neurons and synapses

Example of collective dynamical properties of a conventional physical system

Hydrodynamics and the Navier-Stokes equations are emergent dynamics of molecular motions

Follow from locality of collisions and microscopic conservation of energy and momentum.

Deriving them does not require any detailed molecular understanding

Finding higher emergent relations (e.g. lift/drag for a family of shapes) is not easy. Requires new concepts (e.g. boundary layer)

The circuitry and activity dynamics of neurobiology lack such overarching principles

the nature of the emergent properties of neural dynamics even at the lowest level are not trivially deduced or independent of details.

We are unlikely to understand animal behavior or the 'laws' of psychology without following the collective dynamical hierarchy upward from the bottom neurons and their properties, suitably abstracting at each level.

some particular details will matter, it is important to be able to observe details at an appropriate microscopic level, and this will most often necessitate understanding animal behaviors and studying details in animal brains, not humans

insofar as 'algorithms' can be said to be implemented by a brain, they will be chosen for hardware effectiveness, not mathematical beauty

natural tasks and behaviors

We need a library of theoretical understanding of large neural circuits with plausible properties of neurons and connections, their collective dynamical properties, and how their natural dynamics represent useful algorithmic processes

Problems

- What circuits are plausible?
- What algorithms are useful or desirable?
- At what level to do the modeling?
- The absence of a theory of equivalence for dynamical systems