COGNITIVE SCIENCE 107A

Brain Development

Jaime A. Pineda, Ph.D.
Self Organizing System
(and the watchmaker argument)

• A collection of simple entities that interact based on some inherent operating principles (learning rules, attractors).

• This process leads to very ordered, stable, and complex behavior without being guided or managed by an outside source.

• The resultant system typically displays “emergent properties” – i.e., no longer solely exhibits the collective properties of the parts themselves (“The whole is more than the sum of its parts”).
Self-organization usually relies on some basic ingredients:

- Reentrant or interdependent systems
  - Positive feedforward
  - Negative feedback
  - Parallelism
- Balance between competition (neural Darwinism) and cooperation (coherence)
- Multiple interactions
Properties of Self-Organizing Systems

- Dynamic
- Absence of centralized control (competition)
- Multiple equilibria (possible rules/attractors)
- Global order (emergence from local interactions)
- Redundancy (insensitive to damage)
- Self maintenance (repair)
- Complexity (multiple parameters)
- Hierarchies (multiple self-organized levels)
Phases of Brain Development

1. Neural Induction    E18-E24    Genetically
2. Proliferation      E24-E125   determined
3. Migration          E40-E160
4. Differentiation    E125-postnatal
5. Synaptogenesis     
6. Cell Death/Stabilization  
7. Synaptic Rearrangement  

- Sensitive and
- Self organizing
- Environmentally
Phase 1: Neural Induction

• **Neural induction**
  - A process that induces a region of embryonic ectoderm to form the *neural plate* on the dorsal surface of the embryo.

• **Neurulation**
  - A process during which the neural plate forms the *neural groove*, which then forms the *neural tube*.

• **Neural Patterning**
  - A process in which the neural tube is divided into distinct regions that form the different areas of the nervous system.
    • Establishment of polarity
    • Segmentation (neuromeres)
Neural Induction

- Mangold and Spemann, 1930s
  - Gastrulation: Major regions or germ layers of the embryo
    - Ectoderm
    - Mesoderm
    - Endoderm
  - Spemann’s Organizer: initiates the formation of neural tissue
    - Signals to organize the head (Head organizer)
    - Signals to organize the tail (Tail organizer)
Neural Induction (cont.)

- Trying to identify the “organizer” molecules has been the holy grail of developmental neurobiology since the 1940s.
  - “permissive” vs “instructional”: ectoderm is predisposed to become neural tissue
    - BMP 2/4 – induce ectoderm to become nonneural
    - Follistatin, noggin, and chordin – inhibit BMPs (bone morphogenic proteins)
    - BMPs are members of polypeptide growth factor (PGFs) and transforming growth factor (TGF-B) families
  - MAPK – mitogen activated protein kinase

FGF – fibroblast growth factor
IGF - insulin growth factor
MAPK – mitogen activated protein kinase
Neural Induction (cont.)

Ectoderm produces BMPs, which causes it to become epidermal (nonneural), and Spemann’s Organizer produces neural inducers (follistatin, noggin, and chordin) to block the effects of BMPs, which induce ectoderm to become neural tissue.
Neurulation

Day
17
19
20
22
26

Surface ectoderm

Neural plate

Neural folds

Neural groove

Neural tube
Neural Plate

Neural Groove

Neural Tube

**GENESIS OF THE NERVOUS SYSTEM** from the ectoderm, or outer cell layer, of a human embryo during the third and fourth weeks after conception is represented in these four pairs of drawings, which show both an external view of the developing embryo (left) and a corresponding cross-sectional view at about the middle of the future spinal cord (right). The central nervous system is derived from the neural plate, a sheet of ectodermal cells on the dorsal surface of the embryo. This plate subsequently folds into a hollow structure called the neural tube. The peripheral nervous system is derived largely from the cells of the neural crest and from motor nerve fibers that leave the lower part of the brain at each segment of the future spinal cord.
Neural Patterning

1. The primary step for constructing the CNS.
2. Stage in which neural cells acquire positional identities.
3. CNS is patterned along its anteroposterior, dorsalventral, and left-right axes.
Neural patterning in the CNS

CNS SEGMENTATION

Metameres – repeated segments
A variety of teratogens have been implicated in NTDs, including radiation, folic acid deficiency, drugs, and infections.

*Spinal bifida and anencephaly*

NTD = neural tube dysfunction
Phases of Brain Development

1. Neural Induction  E18-E24  Genetically
2. Proliferation  E24-E125  determined
3. Migration  E40-E160
4. Differentiation  E125-postnatal
5. Synaptogenesis  
6. Cell Death/Stabilization  
7. Synaptic Rearrangement  

Sensitive and Self organizing

Environmentally
Phase 2: Proliferation

• Ventricular/Marginal Zone: In the early embryo, the wall of the emerging brain is one cell deep, with cells extending their processes across the ventricular zone.
  – Phases of cell proliferation: G1-S-G2-M
    • S = DNA synthesis; M = Mitosis
  – Neurogenesis (begins ~ E40)
    • Radioactive thymidine and cell’s birthday
Interkinetic nuclear migration
Development of Cerebral Cortex
**Figure 19.1 Embryonic development of the human brain.**

(a) The neural tube becomes subdivided into (b) the primary brain vesicles, which subsequently form (c) the secondary brain vesicles, which differentiate into (d) the adult brain structures. (e) The adult structures derived from the neural canal.