Good ideas in System Biology

1. Structure of biological networks (W)
2. Sequence evolution (J)
3. Game theory (W)
4. Population genetics (J)
5. Populations dynamics (J)
6. Signal processing in the nervous system (W)
7. Self-organizing maps and associative memory (W)
8. Evolutionary algorithms (J)
9. Allometry and bionics (W)
10. Pattern formation (J)

1. Structure of biological networks

- basics question:
  - What are the structural features in biochemical networks?
  - What determines their shape?
- Scale-free and small-world networks
  - Definitions
  - Structures of real-world biological networks
  - Possible evolutionary advantages
- Network motifs
  - Defining and detecting network motifs
  - The feed-forward loop

2. Sequence evolution

- basics question:
  - How do macromolecules (RNA, DNA, proteins) evolve?
  - How can information content of genes be maintained/increased?
- Modelling self-replicating molecules
  - Mutation and selection dynamics
  - Quasi-species
- The hypercycle
  - Principle of natural self-organization
  - “the analog to Darwinian systems at the next higher level of organization”

3. Game theory

- basics question:
  - What determines whether individuals cooperate or compete with each other?
  - How can 'useless' things like the peacock's tail evolve?
  - Does optimal behaviour of individuals lead to Modelling self-replicating molecules?
- Evolutionary game theory
  - Prisoner's dilemma and hawk-dove game
  - 5 ways to make cooperation a successful strategy
- Applications
  - Cheating viruses and bacteria
  - How could multicellular organisms arise?
  - The peacock's tail

4. Population genetics

- basics question:
  - How does the frequency of a mutant gene in a population change over time?
  - How is genetic variability maintained?
  - What are the main factors that drive establishment of new mutations in the population?
- Selection
  - Modelling selection
  - Selection types
- Random genetic drift
  - Effective population size
  - Fixation probability and time
- Neutral and nearly neutral theory of evolution

5. Population dynamics

- basics question:
  - How can we understand dynamics of single and interacting populations?
- Single species populations
  - Growth dynamics
  - K, r –strategies
  - Threshold phenomena and catastropes
  - Hysteresis in fish populations
- Interacting populations
  - Predator-Prey systems
  - Mutualism and symbiosis

6. Signal processing in the nervous system

- basics question:
  - How do nerve cells generate spikes?
  - How can nerve signals code and filter complex signals?

- Nerve cells
  - Hodgkin-Huxley model and its dynamics
  - Synapse strengths and Hebbian learning

- Information processing
  - Processing of auditory signals in grasshoppers
  - Processing of visual signals in flies

7. Self-organizing maps and associative memory

- basics question:
  - How does our memory complete noisy and incomplete information?
  - How is high-dimensional information represented on the 2-dimensional brain cortex?

- Associative memories
  - Spin glasses and the Hopfield model
- Self-organising maps
  - Representation in the visual cortex
  - Self-organising maps
  - Application for statistical learning

8. Evolutionary algorithms

- basics question:
  - How can we find the highest mountain in a hilly landscape?
  - Problems and solutions
- Local versus global optimization
- Gobal optimization
  - Simulated Annealing
  - Genetic algorithms
  - Evolutionary strategies

9. Allometry and bionics

- Basic questions:
  - How do the shape and physiology of organisms depend on their body size?
  - How do the shape of trees reflect their mechanical function?

- Scaling laws
  - Scaling laws and dimensionality analysis
  - Fractal shapes
  - Allometric relationships

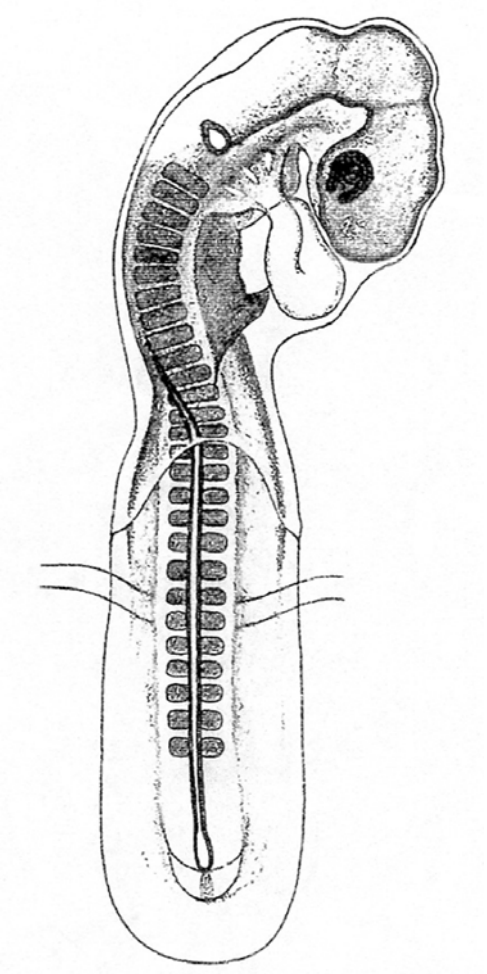
- Bionics
  - Shapes of healthy and injured trees
  - Trees can teach us how to shapes mechanical components

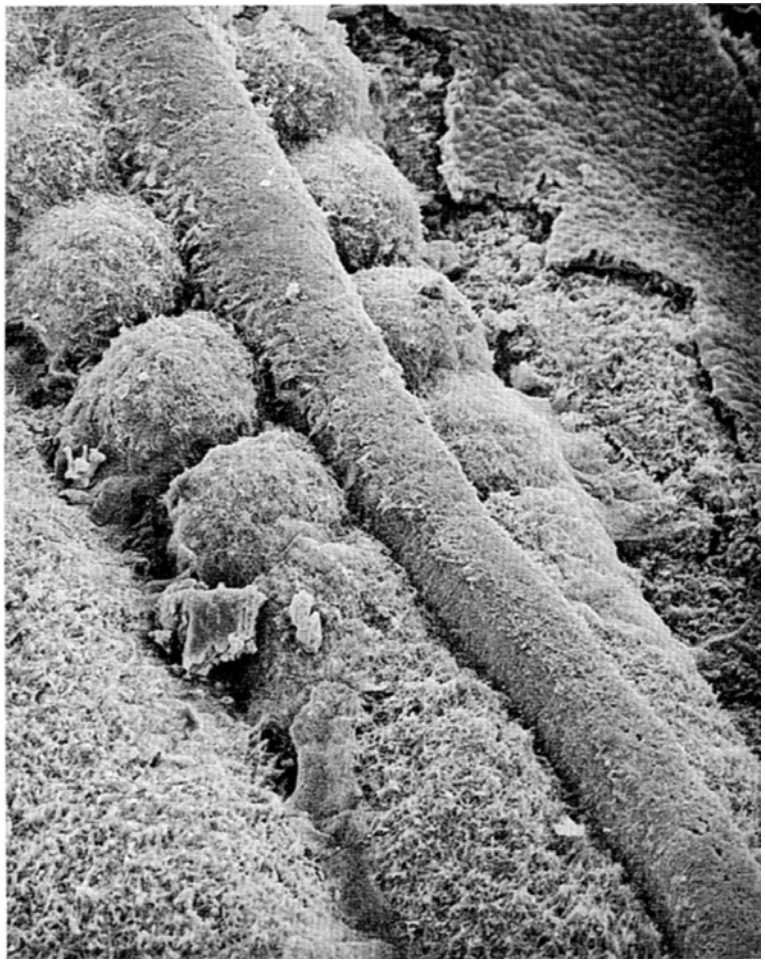
10. Pattern formation

- Basic questions:
  - How do regular patterns in biology arrise?

- Reaction-Diffusion Systems
  - One dimension: Belousov-Zhabotinskii reaction
  - Multiple dimension: Turing patterns

Chicken embryo





S.F.Gilbert, Developmental Biology 8th ed.
Movie by Lars Wittler, MPI mol. Gen.