VIII. Review of Key Concepts
Complex Systems

• Many interacting elements
• Local vs. global order: entropy
• Scale (space, time)
• Phase space
• Difficult to understand
• Open systems
Many Interacting Elements

• Massively parallel
• Distributed information storage & processing
• Diversity
  – avoids premature convergence
  – avoids inflexibility
Complementary Interactions

- Positive feedback / negative feedback
- Amplification / stabilization
- Activation / inhibition
- Cooperation / competition
- Positive / negative correlation
Emergence & Self-Organization

• Microdecisions lead to macrobehavior
• Circular causality (macro / micro feedback)
• Coevolution
  – predator/prey, Red Queen effect
  – gene/culture, niche construction, Baldwin effect
Pattern Formation

- Excitable media
- Amplification of random fluctuations
- Symmetry breaking
- Specific difference vs. generic identity
- Automatically adaptive
Stigmergy

- Continuous (quantitative)
- Discrete (qualitative)
- Coordinated algorithm
  - non-conflicting
  - sequentially linked
Emergent Control

• Stigmergy
• Entrainment (distributed synchronization)
• Coordinated movement
  – through attraction, repulsion, local alignment
  – in concrete or abstract space
• Cooperative strategies
  – nice & forgiving, but reciprocal
  – evolutionarily stable strategy
Attractors

• Classes
  – point attractor
  – cyclic attractor
  – chaotic attractor

• Basin of attraction

• Imprinted patterns as attractors
  – pattern restoration, completion, generalization, association
Wolfram’s Classes

• Class I: point
• Class II: cyclic
• Class III: chaotic
• Class IV: complex (edge of chaos)
  – persistent state maintenance
  – bounded cyclic activity
  – global coordination of control & information
  – order for free
Energy / Fitness Surface

- Descent on energy surface / ascent on fitness surface
- Lyapunov theorem to prove asymptotic stability / convergence
- Soft constraint satisfaction / relaxation
- Gradient (steepest) ascent / descent
- Adaptation & credit assignment
Biased Randomness

• Exploration vs. exploitation
• Blind variation & selective retention
• Innovation vs. incremental improvement
• Pseudo-temperature
• Diffusion
• Mixed strategies
Natural Computation

- Tolerance to noise, error, faults, damage
- Generality of response
- Flexible response to novelty
- Adaptability
- Real-time response
- Optimality is secondary
Student Course Evaluation!