Amorphous Computing

http://www.swiss.ai.mit.edu/projects/amorphous
Characteristics

• Large number of computing units.
• Limited computational power.
• Fail with non-negligible probability.
• No predetermined arrangement in space.
• No global synchronization.
• Limited distance communication.
• **Goal:** Coherent robust global behavior.
Topics Covered

• Wave Propagation / Gradients
• Pattern Formation
  – Growing Point / Rules and Markers
  – Cell Shape Change
• Information Conservation
• Cellular Computing
• Nanoscale Computing
Wave Propagation / Gradients

- Common in biological systems (e.g., Hydra)
- Gives sense of position / distance.
Pattern Formation

• Use generative programs / not blueprints.
• Same in nature (e.g., cells).
• This is not programming of global behavior!
Growing Point Language

• High-level actions:
  – Pheromone secretion
  – Propagation according to tropism
  – Termination

• Tropism to pheromone concentration
  – towards / away / keep constant

• Translated to a low-level particle language.
Growing Point Language

• Thesis: any planar graph can be constructed.
  – Is that important?
  – What is the quality of the end result?
  – What is the size of the program?
  – How is the graph described?
  – What share of the drawing is actually done by the computing particles and what by the GPL programmer?
Rules and Markers

• Event-driven computation with local state.

• Events:
  – “message” received & “#” more hops to go
  – “marker” is set & expires in “#” time units

• Conditions:
  – “marker” is set / cleared

• Actions:
  – Set / clear “marker”
  – Send “message” for “#” hops
Cell Shape Change

- Cells interact by pulling and pushing.

Figure 5: Simulation images from folding a cup
Figure 4. Control of shape changes in a ring of cells, based on the mechanical cell models of [10]. Each cell has a simple programmed behavior and react to stresses in its neighbors.
Biologically-Inspired Primitives

• We’ve seen gradients, but what else is there?
• For local behavior…
  – Chemotaxis (following a gradient)
  – Local inhibition/competition
  – Counting/Quorum sensing
  – Random exploration/stabilization
Chemotaxis

- Move in response to a gradient, rather than only using local concentration as an indicator
- Query neighbors if differential across cell is below detection threshold
Local inhibition/competition

• Fast-growing cells cause slow-growing cells to die (programmed cell death)
• Leader election
• Base morphogen level on fitness
Counting/Quorum Sensing

- Send signal, use signals from others as feedback based on threshold
- Can be used to implement checkpoints
Random Exploration/Stabilization

• Explore randomly and in parallel, stabilize “good” path
• Think ants!
How to Combine Local Primitives?

• Role assignment
• Asynchronous timing
• Spatial modularity (subroutines)
• Scale-independence
• Regeneration
Conservative Systems

• Physics also provides metaphors for amorphous computing
  – Heat diffusion/chemical diffusion
  – Wave equations
  – Springs
Why is Mimicking Conservative Systems a Challenge?

- Sensitive to bugs and/or failure
- Could implement using explicit tokens, but how to keep track of tokens?
Cellular Computing

• Cool idea! But:
  • Proteins are produced very slowly.
    – Computation takes a long time.
  • Unwanted interactions with other genes.
    – Need different proteins for each gate.
    – Limits the size of circuits.
  • Cells have limited capacity for proteins.
    – Only small circuits can fit into a cell.
slides from

**Toward *in vivo* Digital Circuits**

*Ron Weiss, George Homsy, Tom Knight*

MIT Artificial Intelligence Laboratory
Approach

high-level program → logic circuit → genome

microbial circuit compiler

in vivo chemical activity of genome implements computation specified by logic circuit
Key: Biological Inverters

- Propose to build inverters in individual cells
  - each cell has a (complex) digital circuit built from inverters
- In digital circuit:
  - signal = protein synthesis rate
  - computation = protein production + decay
Digital Circuits

- With these inverters, any (finite) digital circuit can be built!

- Proteins are the wires, genes are the gates
- NAND gate = "wire-OR" of two genes
Inverter’s Dynamic Behavior

- Dynamic behavior shows switching times
Memory: RS Latch

Not a modular construction
Applications to the nano scale

• Spray walls with smart particles that detect and fill in the cracks.

• Inject nanorobots in body to fix:
  – Clogged valve problems
  – Failing neurons.

• Have personal nanorobots barbers / dentists.