Scalable, (Non-)Evolvable, Emergent, Developmental ...

Nanotechnology

Susan Stepney
Non-Standard Computation Group
Department of Computer Science
University of York

SEEDS meeting, August 2003
Real nanotechnology

- K. Eric Drexler

- assemblers and disassemblers
  - “nanites”, “nanobots”
  - making macroscopic artefacts
    - assembling, from steaks to spaceships
  - making macroscopic changes to the world
    - from disassembling cholesterol in arteries …
    - to disassembling pollution in the environment

- CS challenges:
  - software, tools, techniques, models, …
    - hardware/wetware up to physicists, engineers, biologists
Assembling artefacts

• growth and development on two levels
  - bootstrap a small initial nanite population ...
    - pool of raw material (mainly carbon)
    - assemble many nanites, exponential growth
  - ... to large nanite population
    - assemble, or “grows”, the artefact

http://www.imm.org/

http://www.omahasteaks.com/
Disassemblers

• as part of assembly
  • disassembly of raw materials for assembly

• medical applications
  • scouring cholesterol from arteries
  • filtering blood toxins
  • removing damaged cells
  • repairing damaged nerves

• environmental applications
  • disassembling toxic chemicals into safe constituents
  • concentrating heavy metals
  • disassembling unwanted artefacts
  - assemblers make factories unnecessary
Caveat: when nanites go bad

• “grey goo” scenario
  - rogue nanites disassemble the planet

• safety critical application
  - current approaches totally inadequate
  - vast numbers of nanites, some will go wrong
    • evolution is an inevitable consequence of “reproduction, variation, selection”
  - new safety techniques and tools required
    • requires design of non-viable “adjacent possible”
Utility Fog

- J. Storrs Hall ("Josh")

- "foglets": programmable micromachines
  - become (inedible!) artefact of choice
    - reconfigure to become new artefact

http://discuss.foresight.org/~josh/Ufog.html
The design challenge

• assembled artefact is emergent property
  - of actions of vast number of nanites
• design requires “reverse emergence”
  - from desired emergent artefact
  - to behaviour of nanite assemblers
Beware the Gödel fallacy

• “emergent properties are in general unpredictable, so whole endeavour is flawed”
  - but, not interested in arbitrary artefacts
    • cf. Halting Problem v. proofs of program termination
    • cf. No Free Lunch theorem

• find classes of emergent properties
  - need only a sufficient theory
    • patterns of emergence, inspired by real world
      - We can never hope to predict the exact branchings of the tree of life, but we can uncover powerful laws that predict and explain their general shape. -- Stuart Kaufmann, 1995
Self-Organising Critical System

• large number of component parts
• even more interconnections
• no centralised control (internal or external)
  - large unbounded distributed systems
  - non-linear, positive feedback
  - dynamic, far-from-equilibrium
    • change, growth, adaptation, repair
  - emergent properties
    • higher level properties of interconnected parts
• embodied in and affecting environment
(1) Complex networks theory

• heterogeneous, unstructured – not regular
  - not “fully connected”, or “grid”, or even “random”
    • small worlds? ...

• open – not fixed topology or components
  - new kinds of nodes and connections arise, disappear

• dynamic – not steady state
  - non-linear, far-from-equilibrium
  - phase space, trajectories, attractors, bifurcations
  - co-evolving phase spaces
  - “gateway events” that change the phase space
(2) Emergent engineering

- design methods for SOCSs
  - including NFRs: safety, robustness, ...
  - growth and development approaches

- new tools for
  - SOCS modelling languages
  - expressing general laws/patterns of emergence

- emergent laws for classes of systems
  - design and predict emergent properties
  - an Emergent Pattern Language
  - scalable hierarchies of emergence
(3) Growth and development

• can’t just “switch on” mature far-from-equilibrium systems
  - SOCSs are “poised” systems
    • current behaviour dependent on entire history
    • e.g., can’t build ecosystems by throwing together lots of species

• so, “grow” them instead
  - environment changes during / because of growth
  - growth, adaptation, repair occur throughout the system’s lifetime

• growth of nanite populations / final artefacts
(4) Nanotech / Fog exemplars

• an assembler design for steak
  - raw, rare, or well-done!

• a disassembler design for destroying a toxin
  - via safe intermediate by-products
  - safe in face of evolutionary pressures

• a Utility Fog design for a chair
  - looks like wood, feels like silk
  - adjustable look-and-feel
  - self-cleaning
Summary

1. Complex networks theory
   - open, dynamic networks
2. Emergent engineering
   - patterns of emergence
3. Growth and development
   - of nanites, of artefacts
4. Nanotech/Fog exemplars
   - with safety critical opportunities