Nanotechnology: opportunities and challenges

GC7: Journeys in Non-Classical Computation

Robin Milner
The Computer Laboratory, University of Cambridge

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

• assemblers, nanites, nanobots
  • molecular scale robots
    - making macroscopic artefacts
      • assembling anything, from steaks to spaceships
• assemblers make conventional factories unnecessary

• CS challenges:
  - software, tools, techniques, models, ...
    • hardware/wetware up to physicists, engineers, biologists
nanoscale fabrication

• “desktop” fabrication plant, comprising
  - many very small devices
    • trillions of molecular scale robot assemblers, conveyors, manipulators, ...
  - early concepts used centralised computer control
    - electrical, mechanical, chemical, ...
    • assembly instructions broadcast to all the robot assemblers
    • each assembler has some local state to customise the instructions

• universal assembler
  - given the right assembly instructions, and the right raw materials, the plant can assemble anything
assembling artefacts

- growth and development on two levels
  - bootstrap a small initial assembler population
    - pool of raw material (mainly carbon)
    - assemble trillions of nanites (exponential growth)
  - eg, to build a new nano-fabrication plant
    - which then assembles, or “grows”, the artefact

http://www.imm.org/

http://www.omahasteaks.com/
the MNT 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

design appropriate assemblers
disassemblers

• as part of assembly
  • disassembly of raw materials required for assembly
  • disassembly of “scaffolding” required during 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
when nanites go bad

• “grey goo” scenario
  - where replicating nanites escape, go rogue, and disassemble the planet

• “Some Limits to Global Ecophagy by Biovorous Nanoreplicators” -- Robert A. Freitas
  
  http://www.foresight.org/NanoRev/Ecophagy.html
Foresight Institute guidelines (excerpt)

- Artificial replicators must not be capable of replication in a natural, uncontrolled environment.
- Evolution within the context of a self-replicating manufacturing system is discouraged.
- Any replicated information should be error free.
- Any self-replicating device which has sufficient onboard information to describe its own manufacture should encrypt it such that any replication error will randomize its blueprint.
- Mutation (autonomous and otherwise) outside of sealed laboratory conditions, should be discouraged.
- MNT device designs should incorporate provisions for built-in safety mechanisms, such as: 1) absolute dependence on a single artificial fuel source or artificial "vitamins" that don't exist in any natural environment; ...

http://www.foresight.org/guidelines/current.html
evolution happens

- given vast numbers of nanites, some will go wrong
  - if they are self-replicating, they will evolve
    * evolution is an inevitable consequence of
      "reproduction, variation, selection"

- safety critical application
  - current approaches totally inadequate
    * "proof of correctness" doesn't help with a mutant
  - new safety techniques and tools required
    * design of non-viable "adjacent possible"
      - Foresight Institute guidelines are an excellent start
    * evolution will exploit anything
      - even (especially) things outside your abstract model
the proposed journey

• to solve the MNT design challenge, safely
  - designing the desired emergent properties
    • simple rules give complex behaviour
      • but which simple rules give the desired complex behaviour?
      • thorough understanding of Self-organising Complex Systems
  - designing the lack of undesired emergent properties
  - searching for suitable designs
    - large complex search space, bioinspired search algorithms
  - effect of embodied nanites
    • strange physics at very small sizes
      - friction, flow, etc all very different
    • inevitability of evolution
      - evolution exploiting embodied properties