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

Nanotechnology

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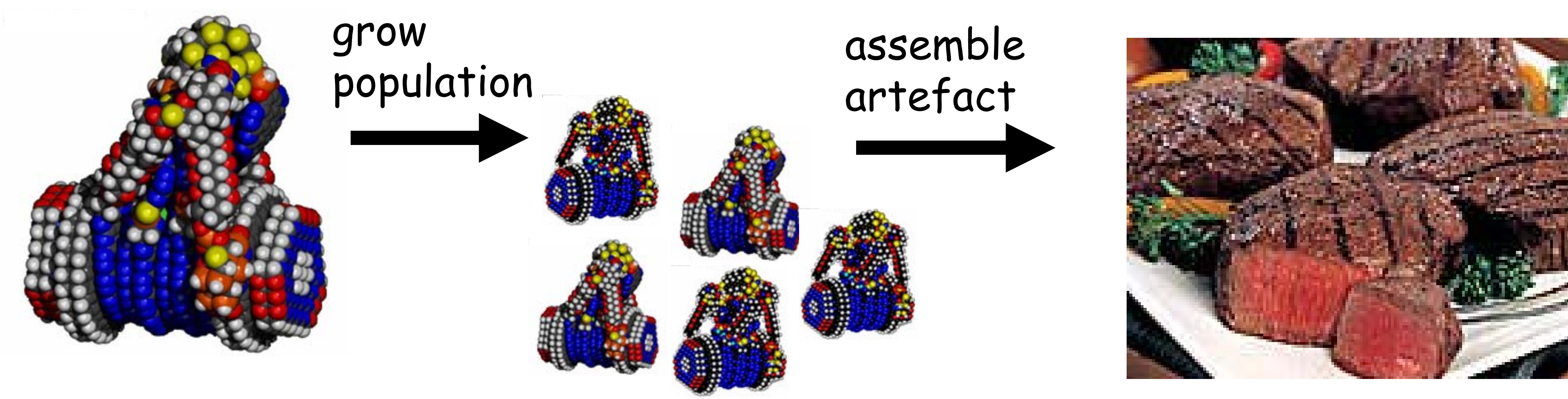
Real nanotechnology

– 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



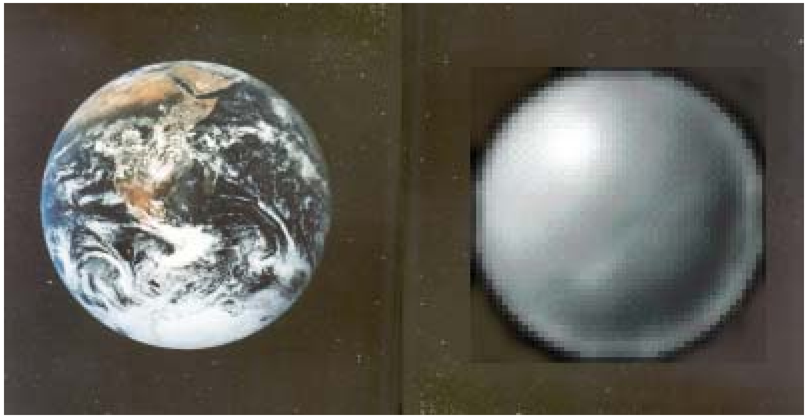
http://www.imm.org/ http:// www.omahasteaks.com/

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

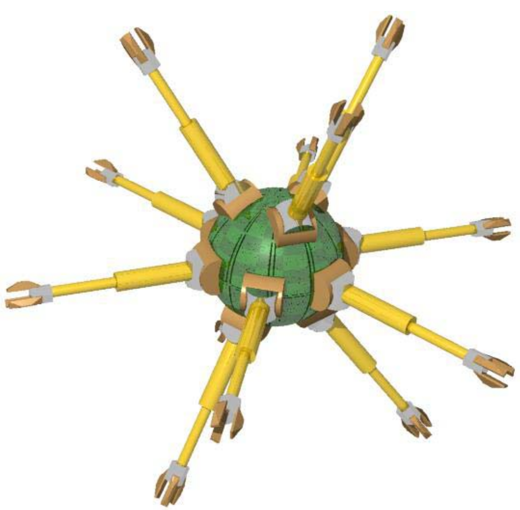


- safety critical application
  - current approaches totally inadequate
  - vast numbers of nanites, some will go wrong
    - evolution is an inevitable consequence of "reproduction, variation, selection"
  - new safety techniques and tools required
    - requires design of non-viable "adjacent possible"

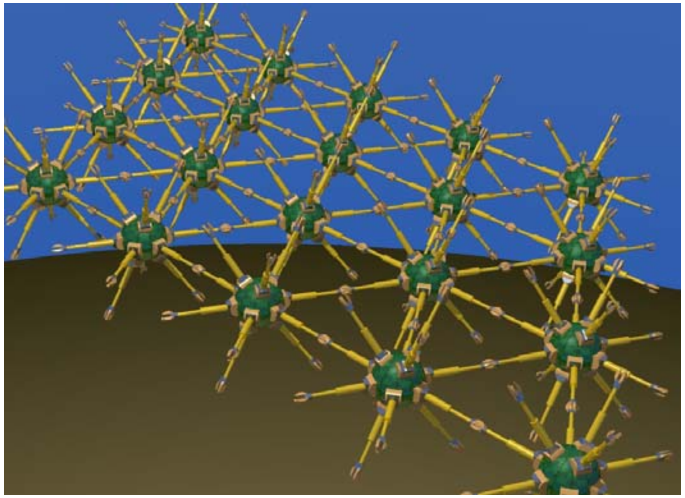
Utility Fog

– J. Storrs Hall ("Josh")

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



link up

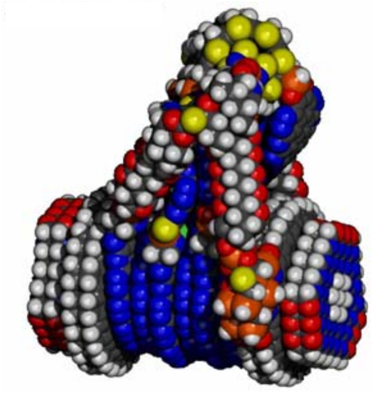


http://discuss.foresight.org/~josh/Ufog.html

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

design
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