Artificial Immune Systems and the Grand Challenge for Non-Classical Computation

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ICARIS 2003

The UK Grand Challenges in Computing

- UK Computing Research Committee (UKCRC) initiative
  - to discuss opportunities for advancement of computing science
  - original call resulted in 109 submissions
  - merged and refined into seven "Grand Challenges"

1. IVIS: The Worm, the Weed, and the Bug
   Breathing life into the biological data mountain
2. Science of Global Ubiquitous Computing
3. Memories for Life
4. Scalable Ubiquitous Computing Systems
5. Architecture of Brain and Mind
6. Dependable Systems Evolution
7. Journeys in Non-Classical Computation
   Robust, adaptable, powerful computation, as inspired by Nature

But why "Journeys"?

- choosing the right metaphor
- "goal"
  - halting at the end-point
  - know where you are going
- "journey"
  - importance of entire process
  - exploration, open-ended, non-halting, …

- Contributors to the Challenge statement, so far:
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Classical computation assumptions

- Turing paradigm
  - finite discrete classical state machine, Halting, Universal
  - closed system, predefined state space
- Von Neumann paradigm
  - sequential fetch-execute-store
- algorithmic paradigm
  - initial input … deterministic function … final output
  - black-box isolated from the world
- refinement paradigm
  - a known specification is refined to provably correct code
- pure logic paradigm
  - substrate (hardware/physics) is irrelevant

Non-classical views

- Real World as inspiration
  - natural computation : physics inspired, bio-inspired
  - massive parallelism
    - emergence, "more is different"
- Real World as a computer
  - analogue computation
    - the great missed opportunity of the 20th Century?
  - all computation and all data is embodied
    - physical effects – particularly quantum
- Open systems
  - no Halting, rather ongoing developing interactive processes
    - computation itself as a journey, not a goal

The Grand Challenge

to produce a fully mature science
of all forms of computation,
that embraces the classical and
the non-classical paradigms

- like all science, the Challenge is an ongoing journey

Journeys described so far

- Quantum Software Engineering
  - computing with weird physics
- Reaction-diffusion and excitable processors
  - computing with spatio-temporal chemistry
- Approximate Computation
  - Non-boolean: statistics and probabilities
- Open Dynamical Networks
  - far-from-eqb, heterogeneous, unstructured, metadynamic
- Evolvable hardware
  - hardware that can adapt, evolve, grow, repair, replicate, learn, …
- Artificial Immune Systems

AIS : selection models

- non-classical bio-inspired algorithms
  - how to exploit essential non-deterministic / stochastic nature
  - how to design, build and use a continually learning system
    - the real immune system has no final output, does not Halt
- non-classical refinement
  - how do global classifiers and recognisers *emerge* from low level non-specific agents
    - how to design rigorously (if non-incrementally) desired emergence
    - how to reason rigorously, about use in critical applications

Challenge: a unified theory of learning systems

with evolutionary, neural, immune as special cases

AIS : network models

- many biological and other network models
  - autocatalytic networks
  - cytokine immune network
  - genomic control networks
  - dynamic neural networks
  - ecological webs
  - social and technological networks
- computation as a dynamic process
  - phase space attractors, computational trajectories
- computation at the "edge of chaos"
  - computational capabilities, self organisation

Challenge: a unified theory of
open dynamical systems

AIS : wet computation

- the real immune system is vastly more complicated than our current computational metaphors
    - remember Robin Callard's talk at ICARIS 2002
  - can we extract more realistic, but still useful, computational concepts and metaphors from the real immune system?

- how can we compute using components from the real immune system?
  - DNA computing uses real physical wet DNA

Challenge: computation with agents from real biological, chemical, physical systems

AIS : embodiment

- what is the effect of the physical substrate on the workings of the real immune system?
  - can all immune responses be implemented on *any* substrate?
  - if not, what do "alternative immune systems" look like on alternative substrates?
  - how can we theoretically unify these alternative systems?

- do diseases exploit the immune substrate?
  - do diseases exploit the system's computational limitations?

Challenge: a theory of the effect of the given substrate on any biological system

Biological necessities

- we see many features in biology
  - but have only one exemplar
- what are necessary for any complex adaptive system?
  - necessary for adaptability, robustness, …
- what are necessary on the given substrate that implements the system?
  - carbon *versus* silicon necessities
- what parts are merely contingent evolutionary aspects?
  - different if "the tape were played again"

Challenge: unified theory of biological computation

"better than reality", "different from reality" systems

If you want to contribute…

- join the Grand Challenge discussion group
  - critique the Challenge statements
  - suggest new "Journeys"
  - use the questions to help guide research
    - maybe even answer the questions!
  - suggest further questions
  - even tell us we've missed the point…
- come to the Breakout session tomorrow!