Steps Towards a 21st Century University:

Planting Seeds ... for a unified science of information

(Not in Shannon's sense.)

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These slides are in my 'talks' directory:
http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk82

The key unifying idea: information processing

What is the universe made of?

- matter
- energy,
- information.

Example:

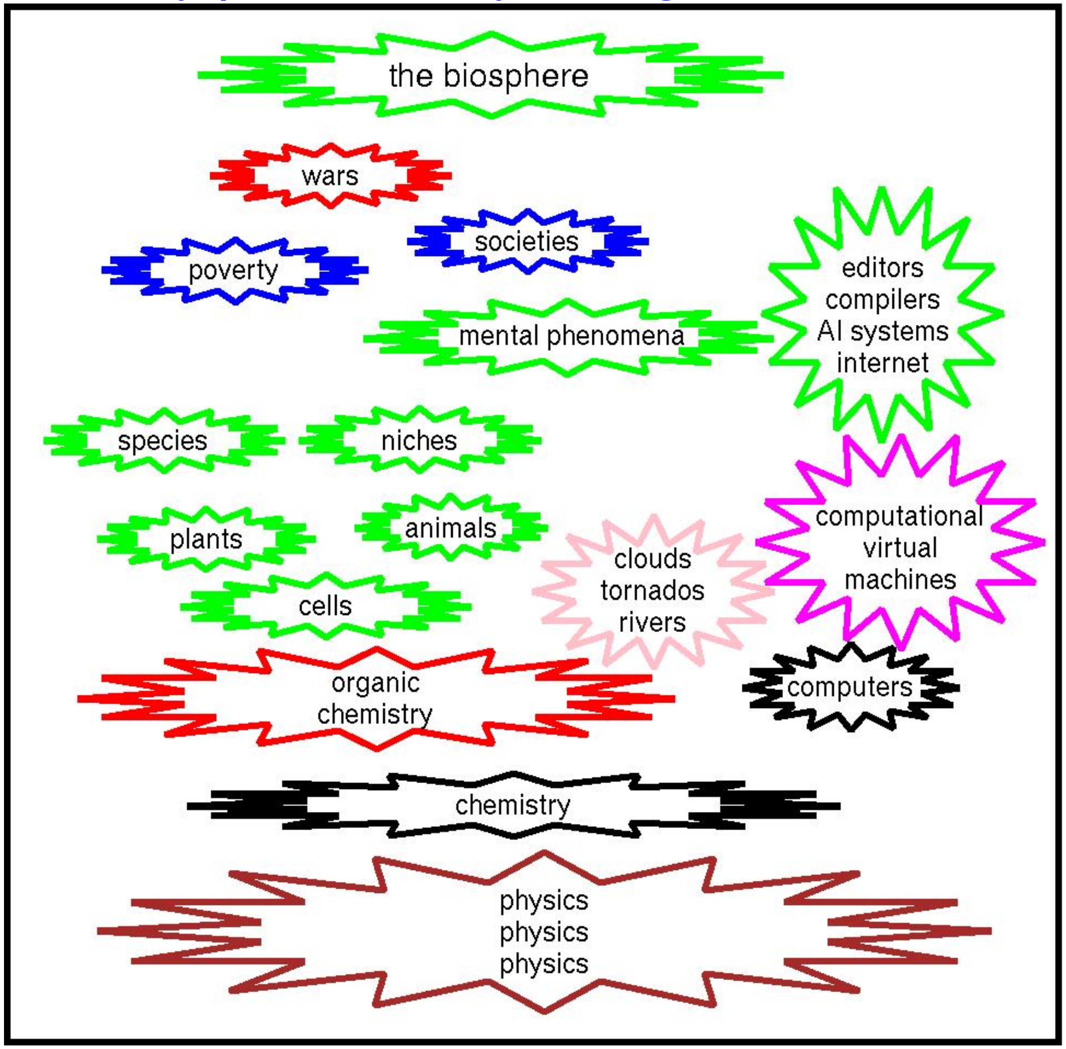
- a table (matter),
- the energy involved in assembling it, or moving it,
- the information it provides about
  - how you can and cannot move
  - where you can grasp it
  - what it can support
  - how it was made....

Unlike Shannon's information (a purely syntactic, quantitative, notion) we are talking about information with content

- that is structured,
- can be true or false,
- can be related to other information by implication, contradiction, consistency, etc.

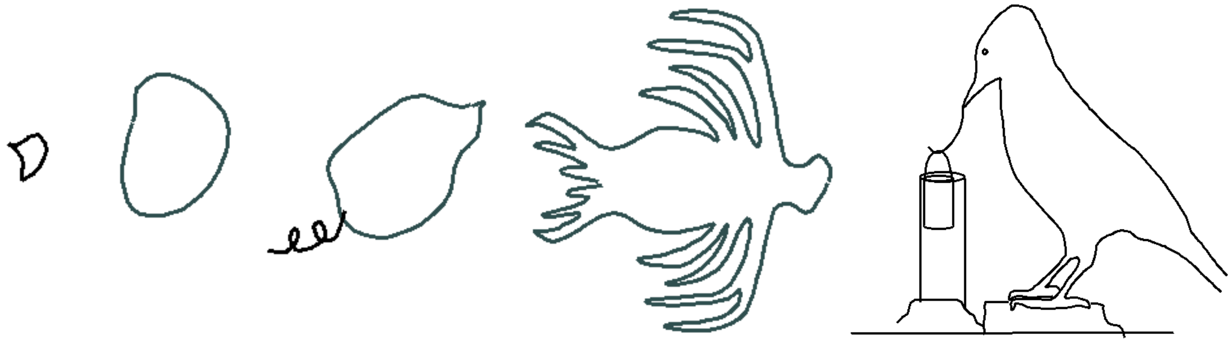
Machines manipulating matter energy and information exist at different levels of abstraction

Many produced by biological evolution



How many levels of (relatively) virtual machinery does physics itself require?

All organisms are information-processors but the information to be processed has changed and so have the means



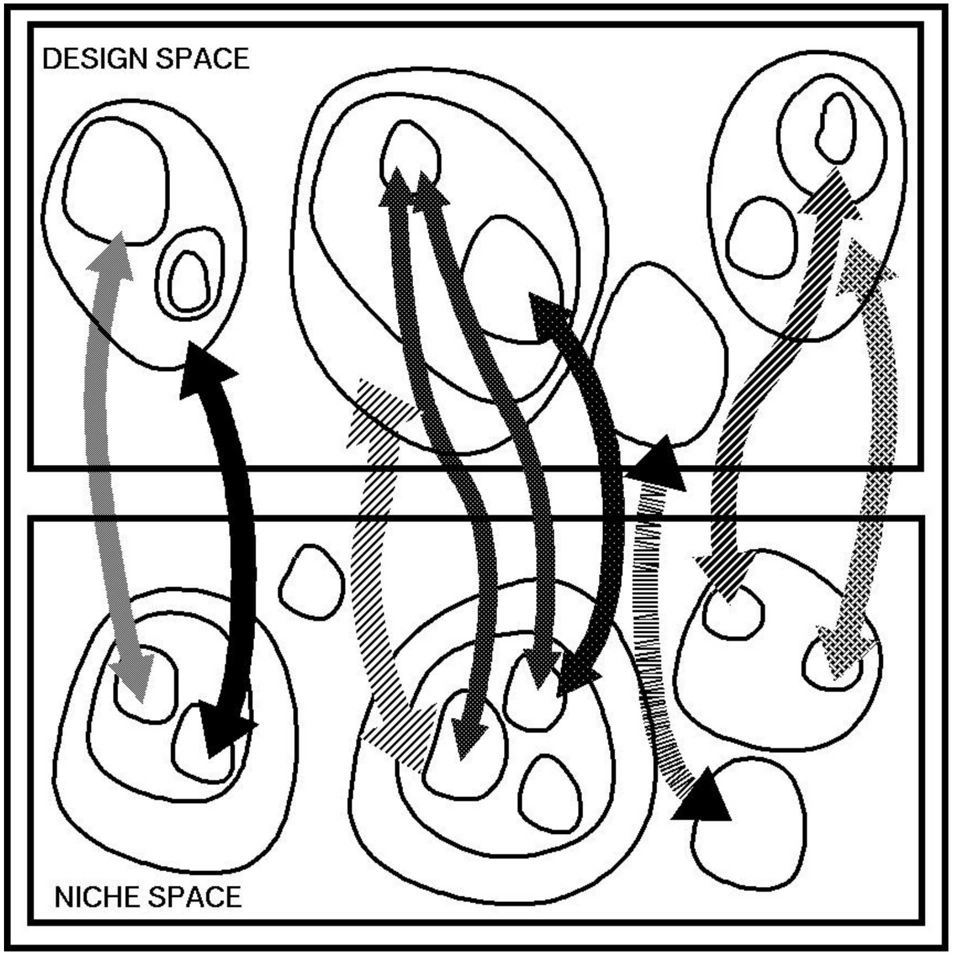
Types of environment with different information-processing requirements

- Chemical soup
- Soup with detectable gradients
- Soup plus some stable structures (places with good stuff, bad stuff, obstacles, supports, shelters)
- Things that have to be manipulated to be eaten (e.g. disassembled)
- Controllable manipulators
- Things that try to eat you
- Food that tries to escape
- Mates with preferences
- Competitors for food and mates
- Collaborators that need, or can supply, information.
- and so on .....

Discussion topic: How do the information-processing requirements change across these cases?

Many machines have competences explained by designs (without any designer)

We need to understand relations between sets of requirements (niches) and possible designs.



Fitness is a structured relation, not a numerical quantity.

Information-processing architectures evolved in layers

Microbes have sensors triggering processes that fairly directly produce behaviours:
– reactive architectures

Some animals can consider alternative possibilities, including branching possibilities, before acting
– deliberative architectural layers

Some can monitor and modulate their own information processes, using meta-semantic competences
– a meta-management architectural layer

These are very crude sub-divisions, needing much further refinement with many intermediate cases.

Different sorts of competence evolved at different stages, but did not always replace what was there before.

Often the old architecture was subsumed by the new.

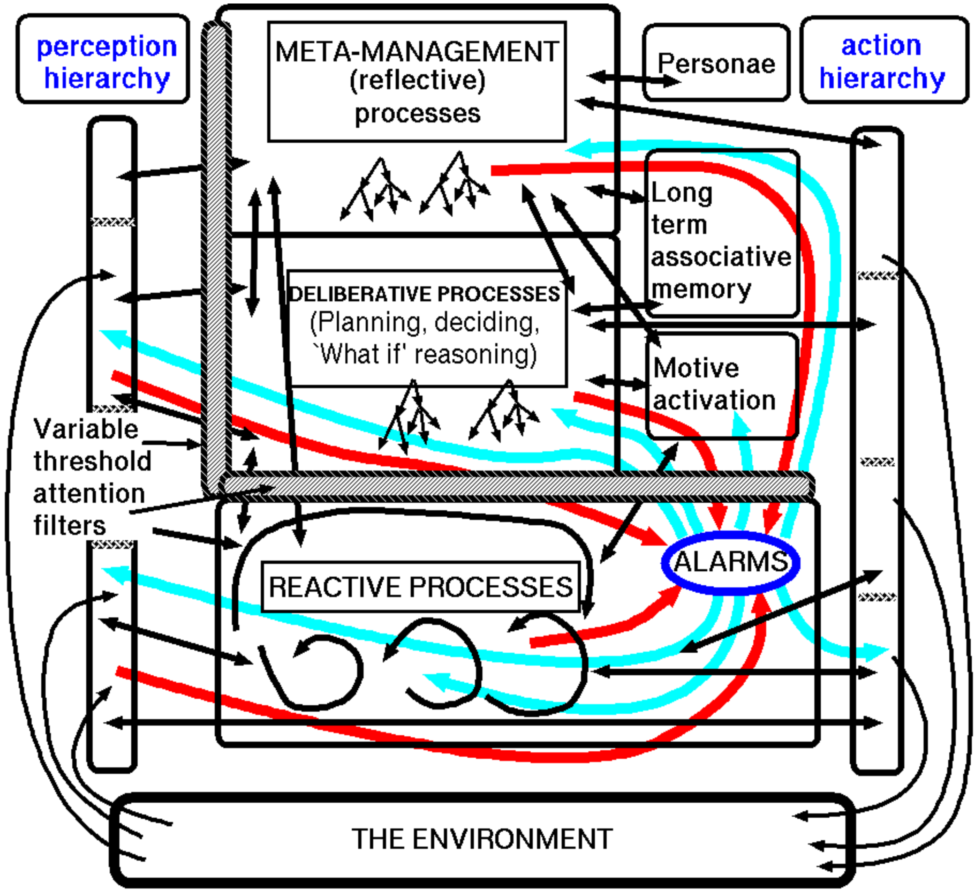
Conjecture: abstract commonalities across different spatial environments caused convergent evolution of similar cognitive mechanisms (virtual machinery) in animals with different morphologies and sensorimotor systems. (E.g. apes, birds, elephants, ...)

H-Cogaff: multi-layered architecture (much more work on this needed)

Such an architecture

- has to somehow be specified in the genome, at least schematically
- has to grow itself, possibly over many years in some species
- is mostly made up of components that are not physical mechanisms, but instead use virtual machinery, and therefore cannot be detected by physical observations, or physical measuring devices (e.g. brain scanners)

New multi-disciplinary approaches are needed for understanding the requirements, constructing explanatory designs, testing theories, working out practical implications, e.g. for psychology, for psychotherapy, for education, for social policy.

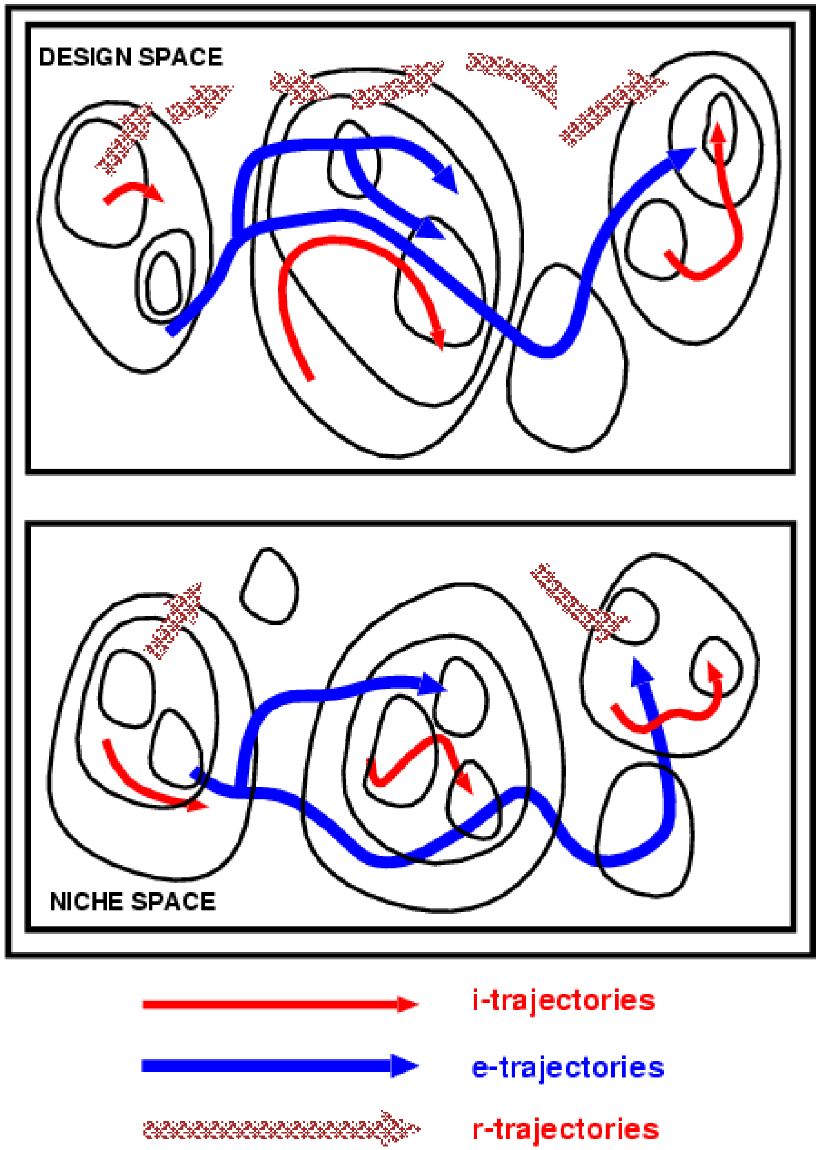


The conjectured H-Cogaff (Human-Cogaff) architecture

See the web site: `http://www.cs.bham.ac.uk/research/cogaff/`

Niches and designs change: There are related trajectories in both spaces

- i-trajectories: individuals develop and learn
- e-trajectories: species evolve across generations
- r-trajectories: a ‘repairer’ takes things apart and alters them
- s-trajectories: societies and cultures develop (Not shown)
- c-trajectories:
  e-trajectories where cognitive mechanisms and processes in individuals influence trajectories, as in mate selection, or adults choosing which offspring to foster in times of shortage, or selective breeding by farmers.



We shall almost certainly need new kinds of (largely non-numerical) mathematics to model these processes.

Information-processing can be invisible

We are used to kinds of science where the objects of study can be perceived, handled, measured using physical devices.

But the complexity and rapidity of state changes required for processing of information rules out the use of physical machinery that cannot reorganise itself fast enough.

In computers this has led to the construction of running virtual machines (RVMs) whose nature and function is very different from the nature and function of the underlying physical machinery

(which can be used for very different virtual machinery at different times).

Biological evolution has had the same problem, and has produced the same general sort of solution but

- the problems are more complex and diverse than those solved by human engineers
- and the solutions are more complex and diverse and still barely understood
- and the processes by which the biological designs were produced and tested are themselves among the most complex, and least understood.

Information and life

All biological organisms use and deploy energy in what they do.

The processes involve selection from options and control of details.

Informed control: both selections among alternatives and online modifications of behaviours are all based on **information**, about: needs, opportunities, constraints, achievements, discrepancies, resources available, structures, processes, opponents, helpers ....

The information can come from various sources, e.g. from external and internal sensors, from things learnt previously in the individual's life, by reasoning, and from the genome.

We need to educate far more people so that they can think about the workings of information-processing systems, on the basis of first-hand practical experience of designing, building, testing, debugging and explaining (initially simple) examples:

This should be a pre-requisite for studying and teaching biology, psychology, neuroscience, philosophy ... and several other subjects.

It can also help mathematicians explore mathematical spaces.

Information is used for initiating and controlling processes as well as for recording what already exists

By developing an integrated theory

- of types of information,
- types of information processing mechanism, and what they can and cannot do, and
- ways in which they can evolve, develop, interact, and communicate,
- and the different ways in which they can be implemented in (supported by) physical and chemical processes,

we can produce a new synthesis of many different academic disciplines – identifying and filling explanatory gaps in all of them.

We have submitted a proposal to the EU (FET-Open) for a multidisciplinary project exploring some of these ideas. (Led by Jackie Chappell, Biosciences.)

But there are many more possible projects,

e.g. investigating the evolution and development of mathematical competences, trying to understand various information-processing disorders and their possible causes and treatments, investigating how genomes produce such architectures, and many more.

By the end of this century

It may turn out that universities will be much more integrated in their teaching and research, with studies of varieties of information and information processing mechanisms and architectures unifying many different disciplines that currently don't interact.

There is a long way to go: it will require some academics to risk moving away from their traditional, separate, single-discipline approaches.

NB: I am not proposing a university dominated by Computer Science.

Computer Science at present is mostly focused on what can be done with current information processing technology and and its likely successors, generally assuming that all information processing must map onto what such machinery can do, and must be specifiable using formalisms based on ideas like Turing machine, lambda calculus, logic, algebra.

I see no reason to assume that all biological information processing is like that.

We need to extend our ideas with help from physics, chemistry, biology, neuroscience, and possibly new kinds of mathematics.

An example multidisciplinary long term research problem:

How can a genome specify an information-processing architecture that grows itself?

Some preliminary ideas are in:
Natural and artificial meta-configured altricial information-processing systems,
`http://www.cs.bham.ac.uk/research/projects/cosy/papers/#tr0609`
Jackie Chappell and Aaron Sloman,
International Journal of Unconventional Computing, 3, 3, pp. 211–239, 2007,

If anyone would like to follow this up, we could meet and talk about possible projects.
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