What does AI have to do With Biology?

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The final slides will be in my talks directory:
http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk87

The videos shown are available here:
http://www.cs.bham.ac.uk/research/projects/cogaff/movies/vid/

The Main Point: Life, Mind, AI

All living things use informed control
They acquire and use information
They select between available options
They use stored (chemical) energy to execute their choices

Biological evolution produced more and more complex information processing systems dealing with

- Information about more and more varied things
- Acquired in more and more complex and indirect ways
- Manipulated and stored in more and more sophisticated ways
- Using increasingly sophisticated and varied forms of representation
- Expressing more sophisticated and diverse ontologies
- Used in more and more sophisticated ways
- Employing increasingly complex information-processing architectures.

A task for AI:

to work with biologists, providing, concepts, formalisms, questions, suggestions for experiments, theories, and working models.

The Scope of Artificial Intelligence

Most people who learn about AI learn about it as a narrowly focused activity, motivated entirely by practical goals, funded for commercial or military purposes. Those goals include:

- Trying to get machines to perform very specific tasks, e.g.
  - recognition of faces or other things in pictures
  - automatic translation of written or spoken words from one language to another
  - controlling processes like landing aeroplanes, optimising a chemical plant or power station
  - machining parts and assembling objects in factories
  - improving usability of interfaces to hardware and software systems by making them more intelligent
  - automatic generation of computer programs or other designs from high level specification
  - fault detection
  - building robots that can take over menial tasks from humans e.g. the Roomba vacuum cleaner made by iRobot
  - helping mathematicians by finding and checking proofs
- Trying to build machines that learn so that they don't have to be explicitly programmed
- Trying to design intelligent companions for the elderly and infirm.
- .... and many more ...

But there is far more than that to AI.

AI/Robotics in Birmingham is far more than that. (`www.cs.bham.ac.uk/go/irlab`)

Alternative view: AI as Science and Philosophy

There is an alternative view, held and promoted by the original founders and leaders of AI, including Herbert Simon, John McCarthy, Marvin Minsky, among others:

AI is a science concerned with the general study of intelligence in all its manifestations, both in living organisms and in present and future machines.

How can such science be done?

Current approaches:

- Theoretical analyses of architectures, algorithms, forms of representation

  E.g. studying complexity in computer science and applying complexity theory to AI problems in search spaces.

- Implement and study biologically-inspired designs (e.g. neural nets, language understanding systems, evolutionary computation) – to extend our knowledge of what is possible.

- Help the scientists studying living organisms by trying to build models inspired by their theories, to help test and refine the theories.

But AI researchers can use what they have learnt in a more powerful way: Imagine designing the organisms!

AI-Inspired Biology: AIIB

We can do biological research in a new way:

AI-inspired biology (AIIB).

Instead of simply

waiting for biologists to tell us what they have discovered and then trying to find out what the implications are for AI

we can also

Help biologists to understand the problems that have come up in AI so that they can then direct their research informed by what AI researchers have learnt, e.g. about

- perceiving the environment

  NOT to be confused with recognizing: you can see things you don't recognize, and you can also use what you have seen to avoid things, kick them, pick them up, prod them, test their behaviour, open them up, or eat them (not recommended), all without recognising them.

  Perceiving is a form of understanding. Recognizing is attaching a label – a class name.

- many kinds of learning
- many kinds of reasoning, problem solving and planning
- many kinds of information processing architectures
- many forms of representation for storing, manipulating and using information of different kinds
- many kinds of control, including reflexes, learnt skills, attentive action, ...
- how designs for complex systems have to relate to their environments

How can we do this ?

We have to study the environments animals evolved in:

The environments define many of the requirements evolutionary designs had to meet.

E.g.

- what kinds of structures and processes can occur
- what kinds of causal interactions can occur
- what kinds of stuff things can be made of
- how many other sorts of intelligent animals are in the environment
  - to eat
  - to avoid being eaten by
  - to compete with (for food, mates, shelter, ...)
  - to collaborate with
  - to mate with, to raise infants with
  - to communicate with
  - to teach
  - to be taught by

Toy problems constructed to test learning algorithms or problem solving algorithms (e.g. problems formulated using a “tile world”) usually do not present the same challenges.

Some ways to make progress

Main strategies:

- Look very closely at detailed behaviours of animals (including humans – e.g. videos of natural behaviour of children and other animals) and asking design questions:

  What are the features of the environment that make this possible, and useful to do?

  What are the features of the environment that make this hard?

  What are the features of the environment that the animal needs to be able to:

  – perceive
  – reason about
  – manipulate
  – make use of

  What would I need to put into a robot to enable it to do that information-processing?

- Look closely at limitations of what AI systems can do compared with what animals do

  E.g. can they think about what they did not do and why not?

  Why is that important?

- Try to formulate questions about what might be lacking in the AI systems, to be investigated by biologists

  See the videos: `http://www.cs.bham.ac.uk/research/projects/cogaff/movies/vid/`

  Robot: Big dog

  Birds: Parrot with feather; Betty making hooks (New Caledonian Crow)

  Child helping adult; Child pushing broom.

A fatal trap – watch out for it

This is a common trap among researchers.

Assume:

All intelligence is a product of learning

So:

Design an environment in which a real or simulated robot or other information processing system can learn

– possibly with the help of positive and negative “rewards” from the environment (including a human teacher)

Then develop and test general learning algorithms.

Assume:

The structure of the environment does not matter as long as it provides opportunities to learn.

Why is that wrong?

Objection:

The environments in which animals evolve, develop, compete, and reproduce, vary widely in the information-processing requirements.

If we ignore that environmental richness and diversity, our theories will be shallow and of limited use.

In simple environments everything can be represented numerically, e.g. using numbers for location coordinates, orientations, velocity, size, distances, etc.

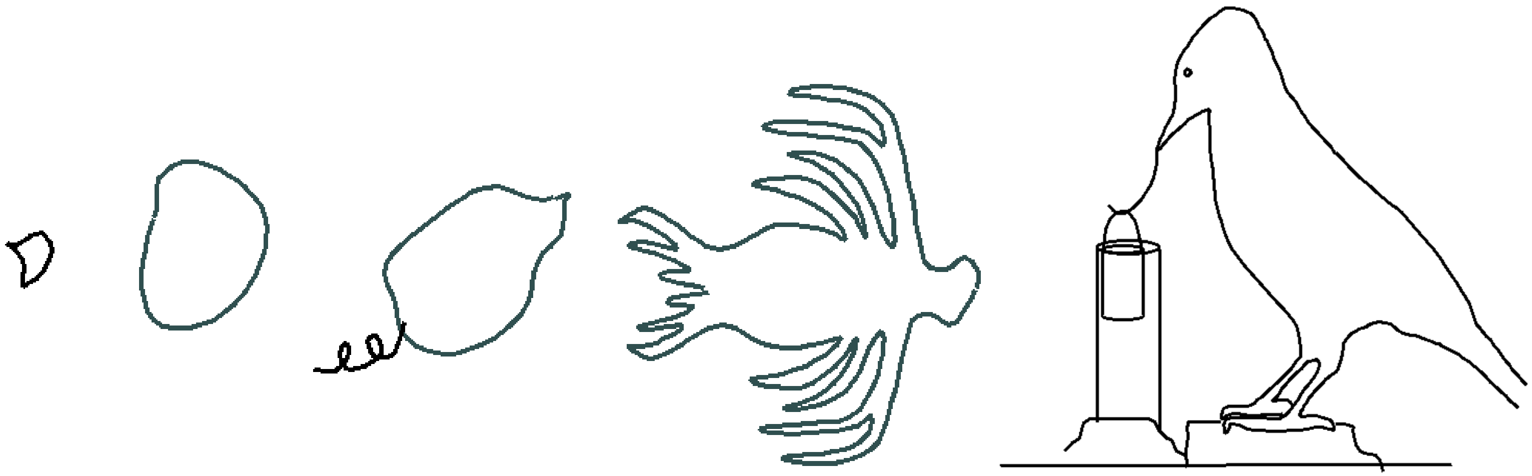
In more complex environment things to be represented include:

- Structures and structural relationships, e.g. what is inside, adjacent to, connected with, flush with, in line with, obstructing, supporting...
- Different sorts of processes, e.g. bending, twisting, flowing, pouring, scratching, rubbing, being compressed.
- Plans for future actions in which locations and arrangements and combinations of things are altered (e.g. while building a shelter).
- Intentions and actions of others.
- Past and future events and generalisations.

How can all those be represented?

But: simple environments are an unavoidable starting point for newcomers to the field, as long as they are treated as educational stepping stones to the real research.

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



From microbes to hook-making crows:
How many transitions in information-processing powers were required?

Contrast these transitions:

- transitions in physical shape, size and sensory motor subsystems
- transitions in information processing capabilities.

Fossil records don't necessarily provide clues.

Varied environments produce varied demands

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 – requiring enduring location maps.)
- Things that have to be manipulated to be eaten (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 .....

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

How can we study living things?

It is tempting to think we can understand how animals work if only we spend enough time

- Observing and measuring their behaviour in various conditions
- Cutting them open to find out what they are made of
- Putting them in brain scanners to find out what's going on when they see, think, learn, decide, enjoy etc.

But there are things you cannot learn that way? WHY?

- Because most of the details of sophisticated information processing are not made visible by such means.
- We need a less direct approach, including studying the environments in which the organisms have to survive.
- As designers we need to ask:
  – what sorts of information processing capabilities could explain **that**?
  – by what intermediate steps could such capabilities develop?
  – how does the environment provoke, help, hinder, such developments
  – what new opportunities for further development would such a change produce?
    (Design changes can form a partial ordering – not all sequences of changes are possible.)

Questions for hypothetical designers

- What ontology does that animal/robot need? e.g.
  - A "somatic" ontology – referring only to patterns in the sensory and motor signals of the organism or robot.
  - An "exosomatic" ontology – referring to things that exist in the environment independently of whether they are perceived or acted on – e.g. surfaces and their relationships, kinds of stuff, kinds of causal interaction.
- What sorts of forms of representation?

  Numbers, vectors, matrices ...

  Non-numerical labels : dog, tree, house, ...

  Structural descriptions: An X connected to a Y at one end, and ....

  Use of logic

  propositional logic

  predicate logic (including relations)

  model logics,

  reasoning with diagrams, models ...

  Neural representations (patterns of activation, strengths of synapses) in neural nets.
- What sorts of mechanism?
- What sorts of architecture combining multiple mechanisms?
- What sorts of developmental and learning processes?

What evolutionary and developmental transitions could produce all that?

What's an Architecture?

A complex object with different sorts of parts related to one another, and interacting with one another has **an architecture**.

- The architecture can be described at different levels of specificity/generality.
  - Different things can have the same general architecture while differing in specific details
  - E.g., two houses with the same configuration of levels, corridors, stairwell, doors and windows, but different paint on walls and doors and different pipework, and wall fittings and furniture in the rooms.
- At the most specific level, the architecture includes many details of how things work and exactly how they interact: only things sharing all the details have the same architecture.
- We can talk about a collection of different detailed architectures as being special cases (instances) of the same general "architecture schema".
- The schema may specify types of components and types of function for the components without specifying exactly which components there are, how they work and how they are connected.
- Common architectural schemas include:
  - pipelines – with components connected in a linear order, and information coming in at one end and flowing through the components, being transformed on the way, producing information and actions at the other end;
  - feedback-loops – where information from some parts of the pipeline go back to earlier stages.
- The CogAff schema, sketched below, is intended for describing a wide variety of information processing architectures that could occur in animals, robots and other machines that interact with some external environment.

Types of architecture: The CogAff Schema

Newer more complex mechanisms evolved after older simpler ones, and made use of them, forming a layered architecture.

This applies to perception and action subsystems as well as more central processing.

By dividing sub-mechanisms into “Perception”, “Central Processing” and “Actions”, and also according to whether they are “Purely reactive” or including some “Deliberative capabilities” (thinking about past, remote places, and possible futures) or including some “Meta-management” (self-monitoring, or self-modulating) mechanisms, we get a 3x3 grid of possible components (some boxes may be empty in some instances):

Perception	Central Processing	Action
	Meta-management (reflective processes) (newest)	
	Deliberative reasoning ("what if" mechanisms) (older)	
	Reactive mechanisms (oldest)	

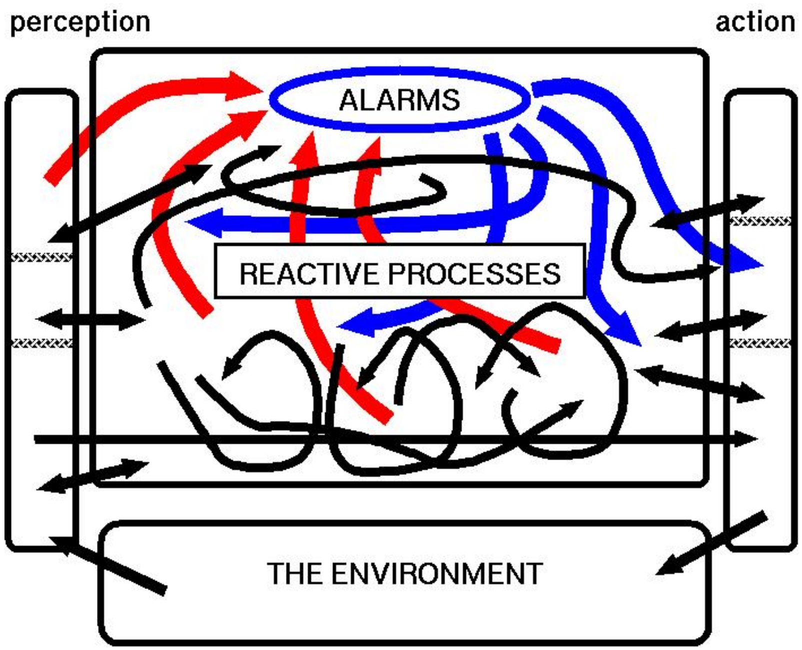
For more on this see the Cognition and Affect project papers:

`http://www.cs.bham.ac.uk/research/projects/cogaff/`

Special case of the CogAff Schema: Purely reactive

A purely reactive architecture lacks the deliberative and meta-management layers.

It seems likely that all microbes and insects (and most other invertebrates?) are like this:



Purely reactive mechanisms (no consideration of "what if" or "why not"), plus an "alarm" mechanism that detects dangers and opportunities that require immediate rapid re-direction of processing:

If you touch a woodlouse crawling along it will rapidly curl up: a defensive alarm mechanism grabs control?

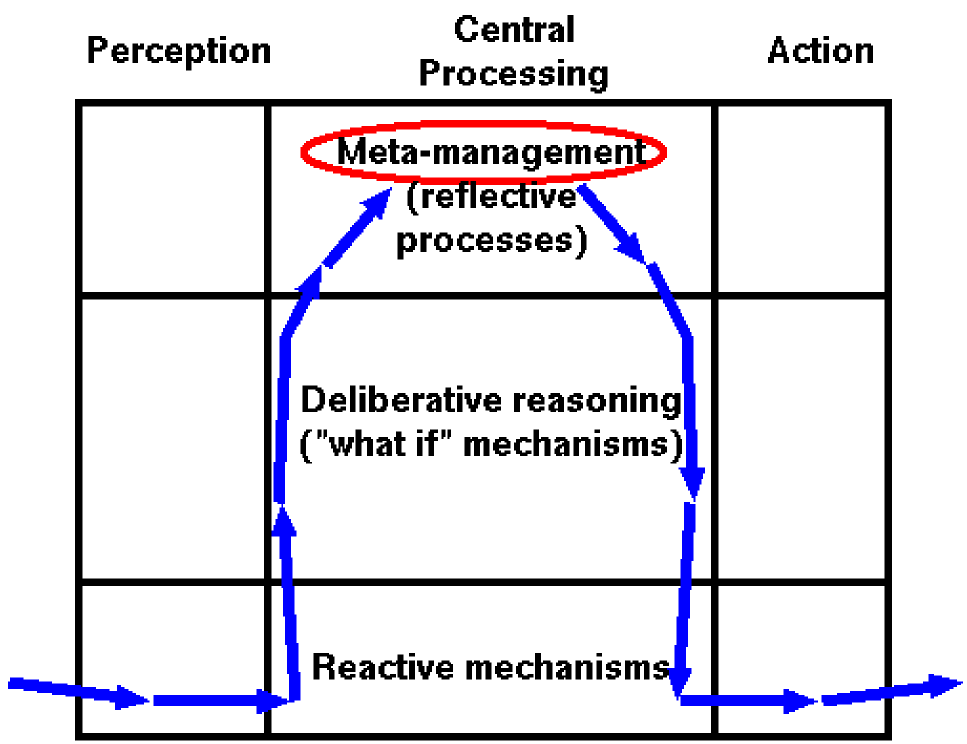
Likewise a fly that detects the approaching swatter will immediately abandon finishing its lunch and buzz off.

Some forms of adaptation or learning may modify the reactive processes, e.g. by strengthening or weakening connections, as a result of positive or negative reinforcement.

Another special case of the CogAff Schema

The Omega architecture

E.g. “contention scheduling” systems. (Norman, Shallice, Cooper).

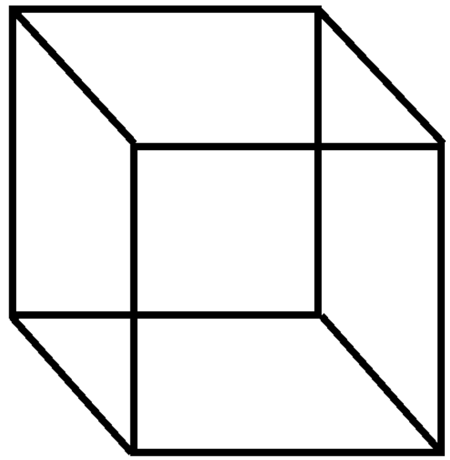


The “Omega” architecture, like many others, uses “peephole” perception and action, restricting the processes to very low level sensing and acting signals.

We can get clues as so what is missing by studying the changing perceptual experiences caused by ambiguous figures.

One sort of probe: ambiguity

What changes when this flips?

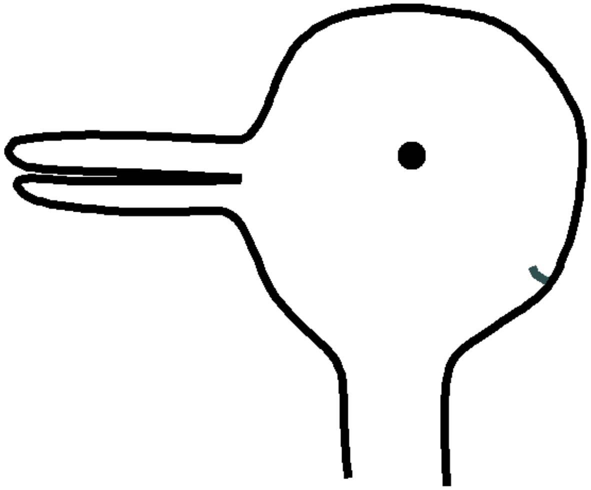


This shows that the content of a visual experience can include distance, and orientation in 3-D space, not just patterns of retinal stimulation.

This suggests that the human visual system includes modes of interpretation that require a much richer ontology than would suffice for characterising 2-D structure.

A different sort of ambiguity

What changes when this flips?



Here the ontology required to express the different contents of the experience of two different views involve even more abstract concepts:

- type of animal,
- functional parts of an animal,
- the direction the animal (duck, or rabbit) is facing: left or right.

This is an example where numerical forms of representation would not capture the important information.

Instead the visual system needs descriptions of shape, structure, functional role, relationships to the environment (what the animal can see), etc.

Perceiving the animal as perceiving uses semantic competences from the meta-management layer, which might originally have evolved only for self-description (what I currently think, perceive, want, intend, etc.).

Or could it be the other way round, starting from hypothesised information processing in other things?

Evolution often re-uses and modifies old structures and functions, sometimes extending and generalising, and sometimes duplicating then modifying.

Summary: perception can use forms of representation, and ontologies also required for deliberative and meta-management mechanisms.

A similar argument can be made for multi-layer actions: speaking and gesturing are different from grasping and pushing, and all are different from blinking and breathing.

Another sort of probe into your visual system

There is evidence that human vision systems analyse and interpret novel input at several layers of abstraction in parallel very quickly, in a mixture of different sorts of processing: top-down (knowledge based), bottom-up (data-driven) and middle-out (using constraint propagation).

For example you can test yourself on the pictures presented in this online experiment:

`http://www.cs.bham.ac.uk/research/projects/cogaff/misc/multipic-challenge.pdf`

Look at the pictures at the rate of about one per second (e.g. hit ‘PageDown’, or click on ‘Next’ once per second, depending on your PDF viewer), then see if you can answer any of the questions that follow.

After the demo there are some suggestions about the kind of information processing architecture a visual system needs.

Types of architecture: The CogAff Schema

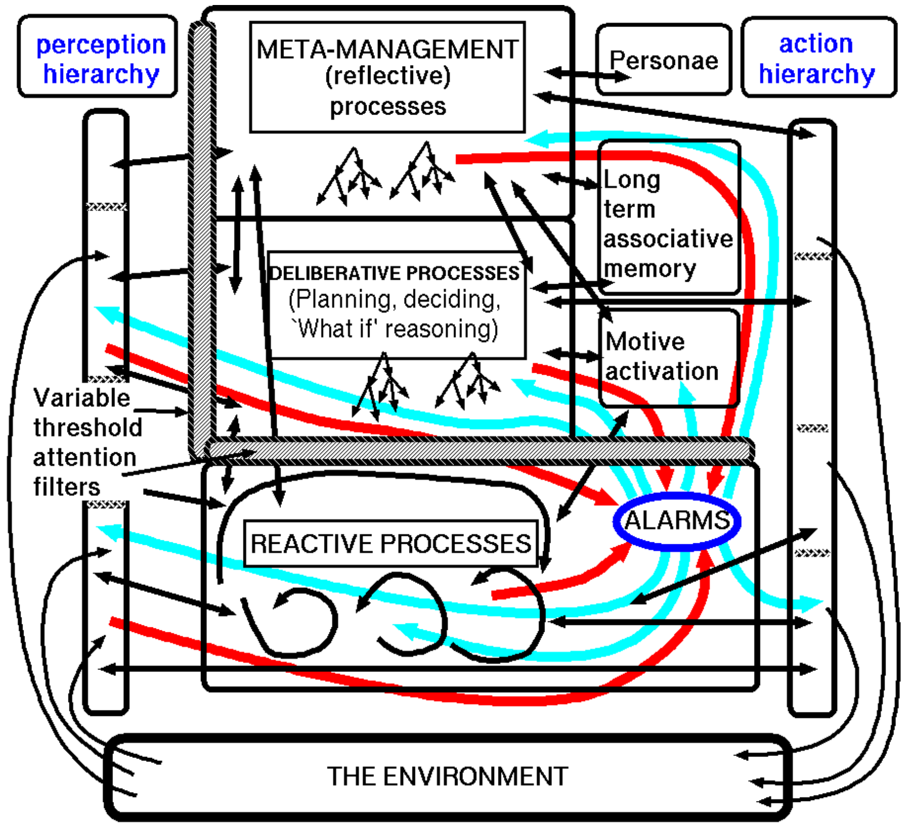
H-CogAff – Your mind?

Evidence can be presented for at least the three layers in humans (and perhaps some other species, e.g. some apes).

In humans we can distinguish different sorts of emotional (and more generally affective) states and processes depending on which layers of the architecture are involved.

Primary emotions, like being startled by a noise involve only the bottom layer: reactive mechanisms. Secondary emotions, like anxiety, relief, can involve the middle layer, deliberative mechanisms. Tertiary emotions, including shame, guilt, jealousy, anger, involve thinking of oneself or others as having mental states and processes, so they need the top layer, meta-management mechanism.

(This is a first crude subdivision, to be extended.)



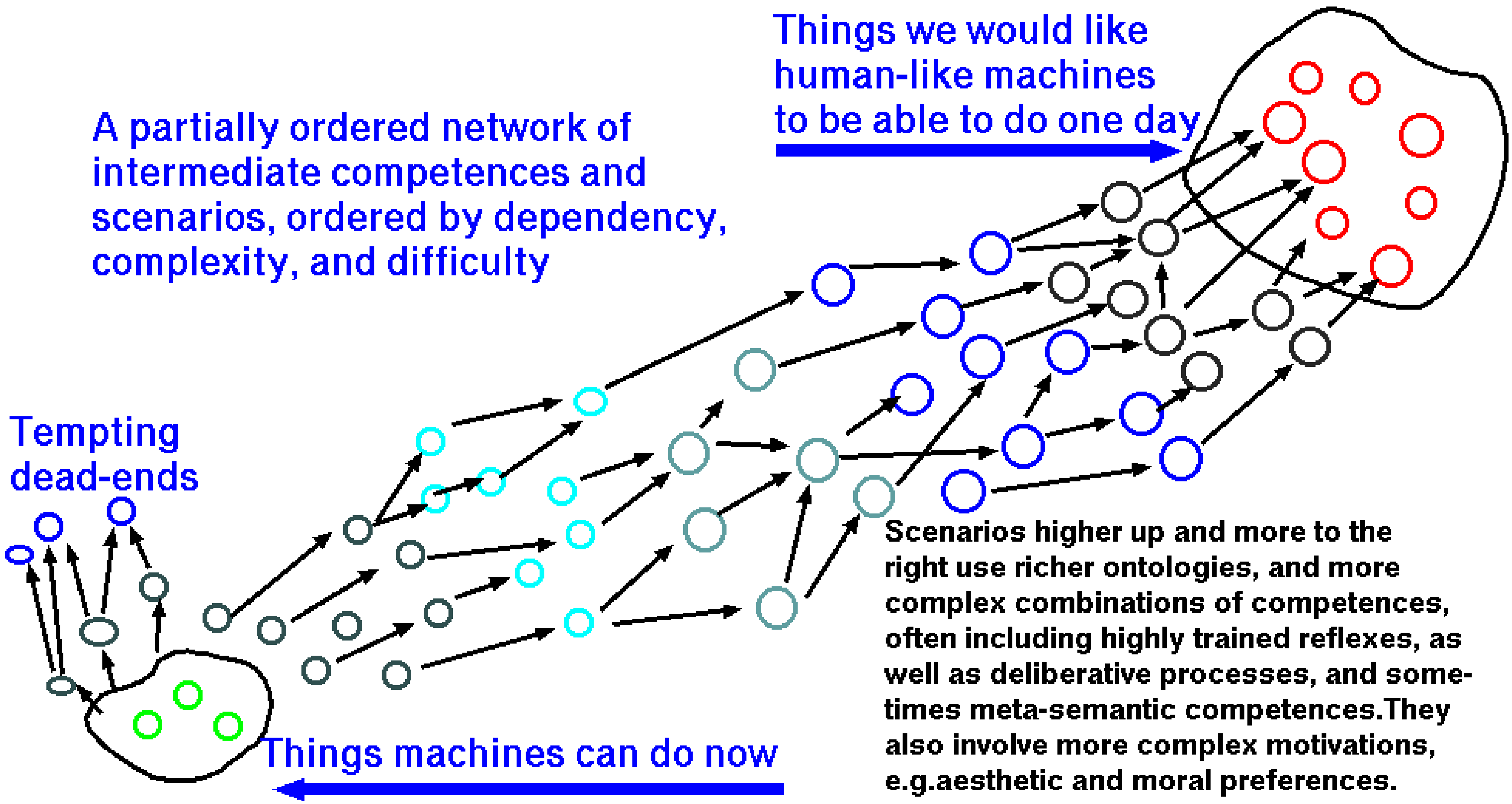
`http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#cafe04`

There's a lot of overlap with Marvin Minsky *The Emotion Machine*, though he sub-divides the layers to produce more of them.

For more on this see the Cognition and Affect project papers:

`http://www.cs.bham.ac.uk/research/projects/cogaff/`

How to build a research road map?



There's lots more in my "talks" directory.

http://www.cs.bham.ac.uk/research/projects/cogaff/talks/

Getting varied AI programming experience

If you wish to teach yourself a variety of types of AI programming then you could download poplog and run it on a linux machine, or use it on the school's linux machines.

There are some examples of what it provides here:

http://www.cs.bham.ac.uk/research/projects/poplog/examples

http://www.cs.bham.ac.uk/research/projects/poplog/packages/simagent.html

http://www.cs.bham.ac.uk/research/projects/poplog/primer

If you need help working out how to get started ask me.

Pop-11, Prolog and Lisp have been used for a lot of teaching and research in this school.