## Vision, Action and Mathematics
## From Affordances to Euclid

# What can we learn about animal cognition including biological vision, by studying evolution of varieties of biological information processing?


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**Part of the Turing-inspired Meta-Morphogenesis project.**

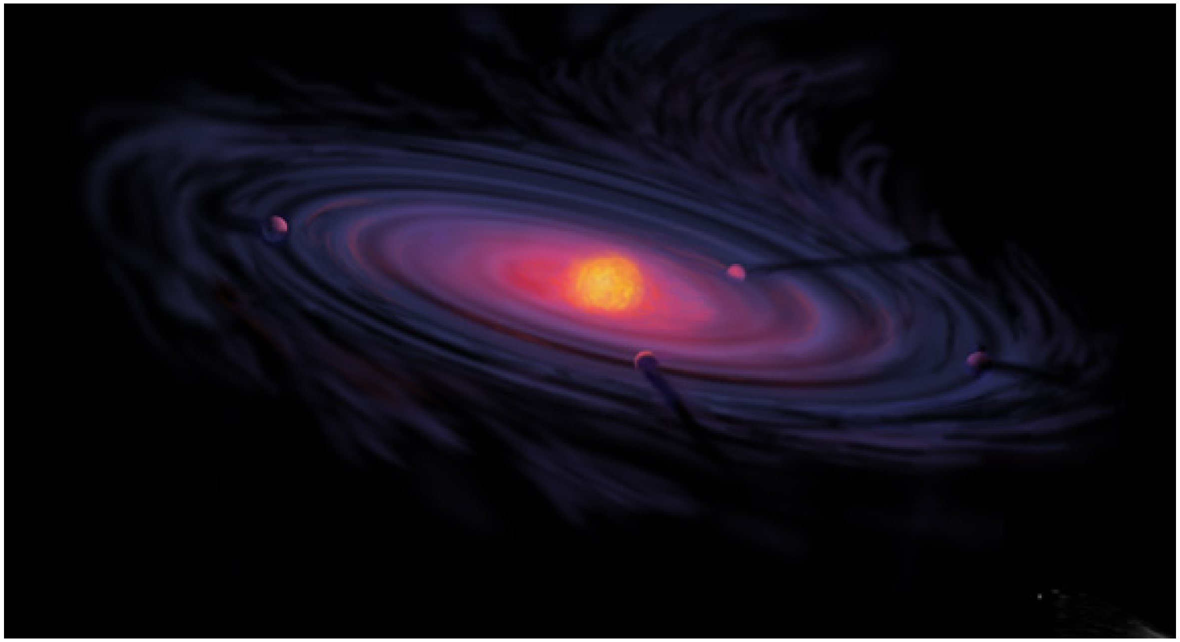
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-morphogenesis.html
http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#gibson

**SEARCH FOR:**

toddler theorems    meta-morphogenesis    sloman+j.j.gibson
sloman+vision+purposes    chappell+sloman+"meta-configured"

# The BIG Question

**From dust to all of us ... How ?? ....**



**Artist's concept of a protoplanetary disk (NASA – Wikimedia)**

**How can a planet formed from a dust cloud produce**

**Microbes, Minds, Mathematics, Music, Marmite**

(along with murder, ebola, religious bigotry, and other nastiness).

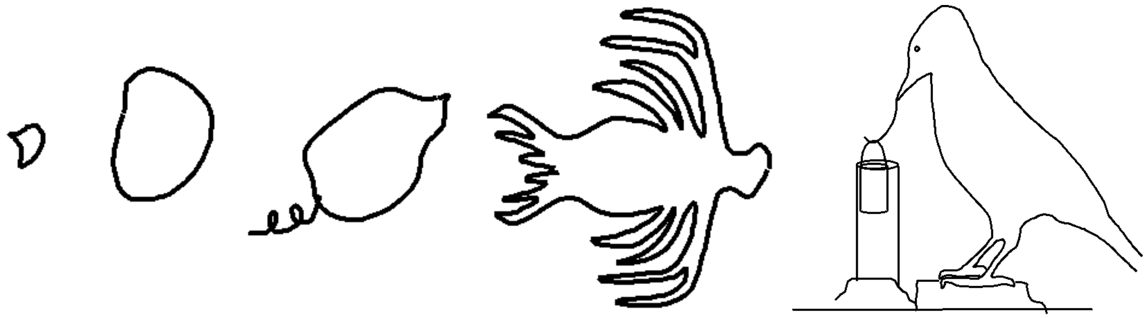
# What natural selection achieved on a planet

**Over billions of years, natural selection built on the extraordinary powers of increasingly complex chemical molecules to store and transfer energy, and provide physical structures, and information processors – before there were brains, and then added brains.** [REF Tibor Ganti on life.]

Products include increasingly complex and competent organisms, of many different sizes, shapes, structures, abilities, needs, ... interacting with very varied environments via diverse sensory and motor mechanisms, performing ever more complex actions, over increasingly varied spatial and temporal scales, with increasingly complex intermediate steps, using bodyparts and other objects as manipulators, tools, and information aids, and conspecifics or symbionts as helpers, teachers, collaborators, or competitors.

**Examples:** Membranes reacting to noxious molecules, protozoa following chemical gradients, foragers eating berries, orangutans and birds rearranging foliage to make nests, carnivores opening up their kill and feeding young, parents teaching toddlers how to put on a garment,engineers designing spaceships, philosophers and psychologists trying to understand how minds work, roboticists trying to design, build and test life-like robots, mathematicians discovering and proving theorems: all these, and more, are products of evolution, using increasingly abstract competences built from earlier competences.

# Information-processing requirements can also evolve



## Both organisms and their I-P requirements/possibilities evolve

- Microbes in a chemical soup with nutrients and other contents
- Soup with detectable gradients
- Soup plus some stable structures, and places with good or bad contents.
- From soup (sea, lakes, ...) to land, foliage, air,
  ... new information needed for new means of locomotion.
- Things that have to be manipulated to be eaten (e.g. disassembled).
- Controllable manipulators (e.g. mouths, claws – affordances, and control problems)
- Things that need to be built, maintained, and/or repaired (e.g. nests)
- 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 ... Try to extend this list!)

# Unobvious functions of vision

**David Marr wrote:**

"... the quintessential fact of human vision – that it tells about shape and space and spatial arrangement".

What else could there be, besides shape and space and spatial arrangement?

**Lots!**

Gibson noted some of it (Gibson, 1966).

There is a useful but brief discussion of Gibson's ideas and how they relate to AI in section 7.v of (Boden, 2006), pp. 465–472.

Some philosophers (and others) who are ignorant of that work by Gibson think the ideas came up much later, when philosophers and others started discussing embodied cognition, around 20 years after Gibson's first book.

Some of the ideas were also in (Simon, 1969).

To understand all this we need to trace the various requirements for perceptual systems at various stages in the evolutionary history of species that now use vision.

# The problem: what's vision for?

- Very many researchers assume that it is obvious what vision (e.g. in humans) is for, i.e. what functions it has, leaving only the problem of explaining how those functions are fulfilled.
- So they postulate mechanisms and try to show how those mechanisms can produce the required effects, and also, in some cases, try to show that those postulated mechanisms exist in humans and other animals and perform the postulated functions.
- The main point of this poster is that it is far from obvious what vision is for – and J.J. Gibson's main achievement is drawing attention to some of the functions that other researchers had ignored.
- I'll present examples showing that there is much more to the functions of vision and other forms of perception than even Gibson had noticed.
- Unlike Gibson, many researchers ignore vision's function in on-line control and perception of continuous processes; and nearly all, including Gibson, ignore meta-cognitive perception, perception of possibilities and constraints on possibilities and the associated role of vision in reasoning – which may have led to human mathematical abilities.

# What needs to be seen? Depends who you are.

**Evolution provides not only the abilities to chunk perceptual information and find useful sensory-motor correlations, but also to develop powerful ontologies, at different levels of abstraction, referring to possible structures and processes that exist independently of the perceiver, in the environment – i.e. not as patterns in sensory-motor statistics.**

**Examples include**

– static and moving objects, with materials, locations, orientations, shapes, relations to other objects, spatial and causal relations between parts, and

– processes in which locations, orientations, shapes, and relations change,

– invariant mathematical and empirical relationships between aspects of structures and processes. (Many examples in Gibson 1979, and earlier work.)

– "higher order" properties that produce or constrain changes in properties and relations, e.g. rigidity, flexibility, elasticity, solidity, liquidity, stickiness, etc.

– Information and information-bearers. Some objects have semantic properties: providing information about other things,

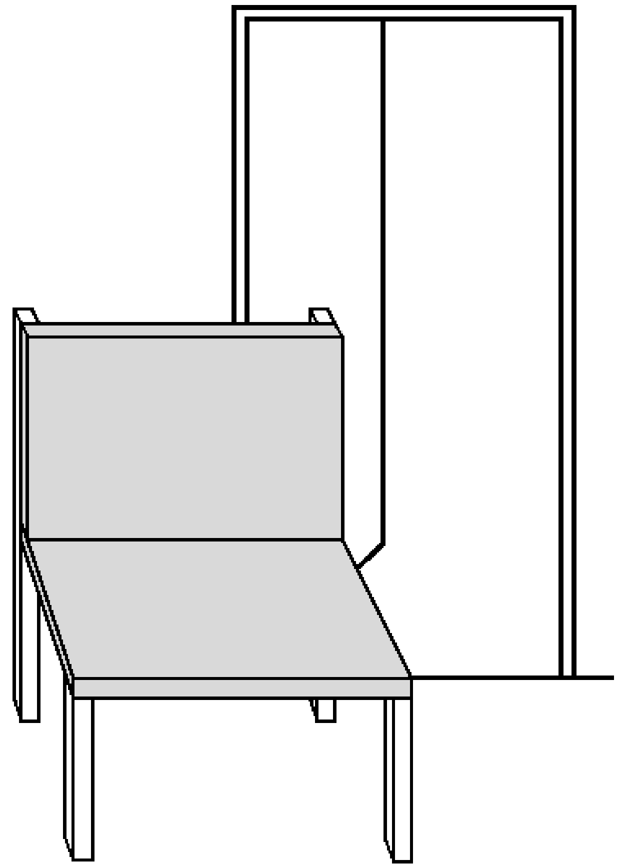
E.g. A's ability to obscure more or less of B as you move gives information about relative distances.

– Information users. Many objects have semantic content for information-using organisms that manipulate semantic contents and use them to control decisions, actions, learning, etc. Some organisms also use meta-semantic content, including information about their own and others' beliefs, intentions, etc.

# Carrying a chair through a door

**Possible process fragments can be combined, in sequence or in parallel, in action or in hypothetical reasoning, to form new complex processes (actual or possible).**

Affordances can interact in complex ways when combined, because of changing spatial relationships of the objects involved during the processes of performing the actions.



A large chair may afford lifting and carrying from one place to another, and a doorway may afford passage from one room to another, but attempts to combine the two affordances by lifting and carrying the chair to the next room may fail when the plan is tried.

A very young child may not be able to do anything about that, but an older child who has learnt to perceive the possibility of rotation of a 3-D object, may realise that a combination of small rotations about different axes combined with small translations some done in parallel, some in sequence. can form a compound process that results in the chair getting through the doorway.

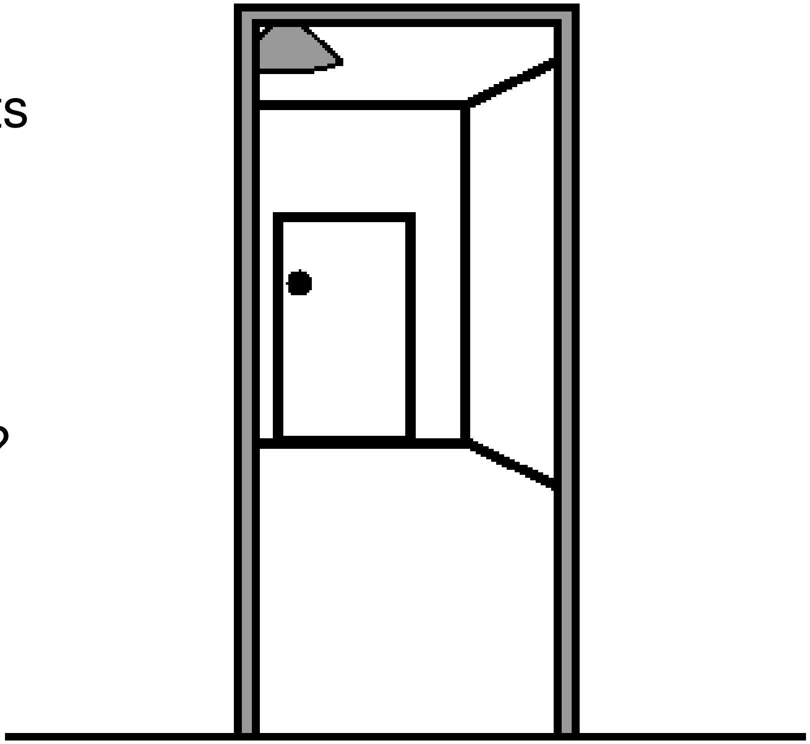
How? What changes as the child acquires such capabilities?

# Getting information about the world from the world

**An action affordance concerns what can and cannot be done by the perceiver, whereas an epistemic affordance concerns what information is and is not available in the environment.**

Actions can change both action affordances and epistemic affordances.

**Things you probably know:**

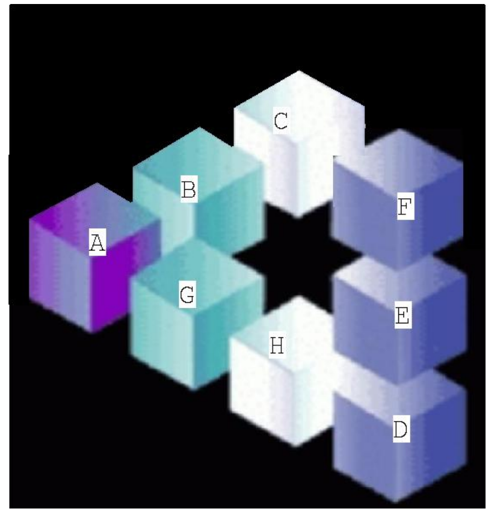


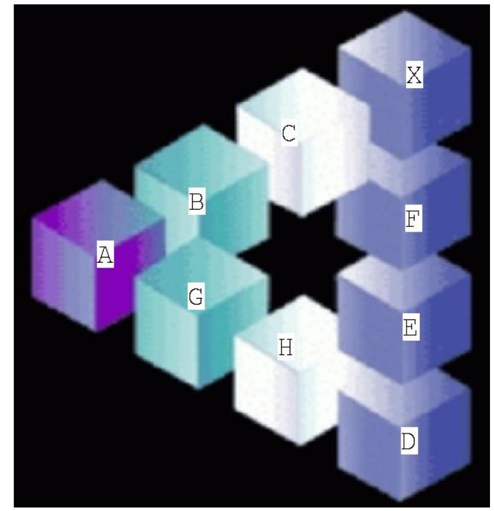
- You can get new information about the contents of a room from outside an open doorway
  (a) if you move closer to the doorway,
  (b) if you keep your distance but move sideways.
  Why do those procedures work? How do they differ?
- Why do perceived aspect-ratios of visible objects change as you change your viewpoint?
- Why do you see different parts of an object as you move round it?
- What else can you do to get information about parts of an object?
- It seems many other animals can use such competences: how do they acquire abilities to cope with such epistemic affordances?
  Could that come from the genome?

# Perceiving what is and is not possible

**James Gibson introduced the idea of perceived affordances, involving possibilities for action by the perceiver, relevant to the current or possible goals or needs of the perceiver.**

**But perception of what's possible or impossible is far more general.**



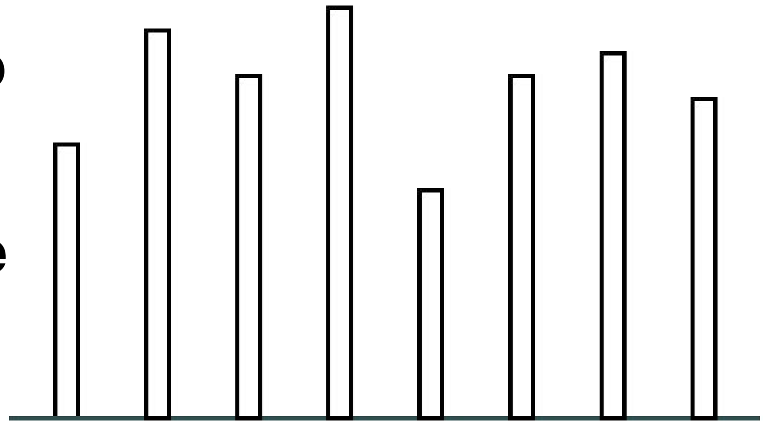

Oscar Reutersvärd, Swedish artist, produced the picture on the right in 1934 (minus the letters).

In both pictures you see a configuration of coloured cubes, making possible a collection of possible processes, including a hand moving in the spaces between the cubes, or a cube being swapped with another cube.

**But you also see that the second configuration is impossible. How?**

At what age can a child see the impossibility?
What is needed in a brain to support that ability?
Why/how did it evolve?
Conjecture: This is related to evolution of mathematical abilities.

# A mathematical hut builder



**Suppose you are building a hut and want to make a door frame, with two upright pillars and a horizontal bar on top.**

**You go to the local wood-merchant, and see a row of available pillars, as on the right. Which two should you choose?**

A non-mathematical mind could keep trying pairs of pillars with a bar on top until the bar is horizontal.

What form of information processing would allow that process to be replaced by something much more efficient – even before measuring devices had been invented?

Perhaps the solution of problems like this led to the discovery of the notion of measurement? And perhaps from there to the understanding of space as metrical – Euclidean?

(Compare Piaget's investigation of block-sorting competences in young children.)

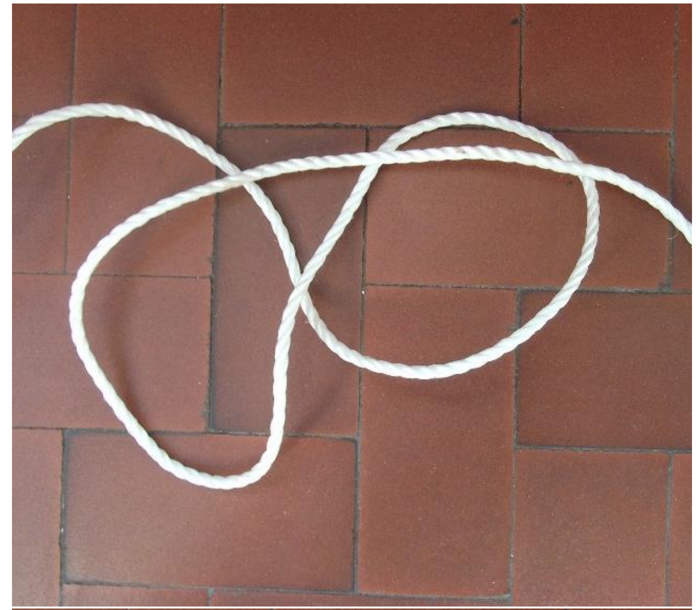
**When you grasp the structure of a space of possibilities you can devise procedures for using information that must work: there's no need to collect statistical evidence that it does work – though I don't think anyone understands the mechanisms that provide such insights in the case of geometry.**

## Understanding knots.

Here are two pictures each showing a length of rope with two ends:

Can you work out what will happen if you pull the ends apart?

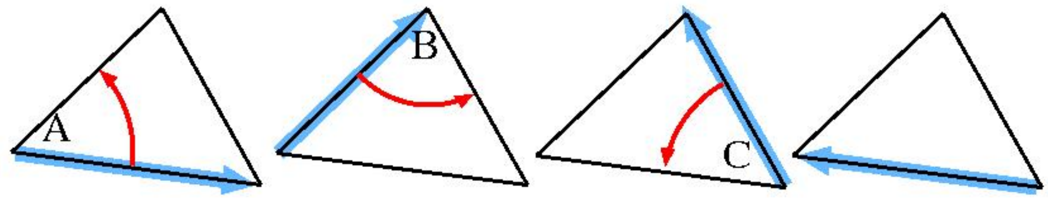
What kind of mathematical knowledge do you have about what happens to a string of fixed length as you pull its ends apart? How do you reason about this?



# Connections with evolution of mathematical competences

**Long before there were mathematics teachers, our ancestors must have begun to notice facts about geometrical shapes that were later codified in Euclidean geometry.**

**Here's a proof by Mary Pardoe that angles of ANY (planar) triangle sum to half a rotation (180 degrees).**
**Can you be sure that there are no exceptions to the proof?**




Long before forms of logical reasoning powerful enough to serve the purposes of mathematicians were discovered/created by Frege, Russell and others in the 19th century, mathematicians were making discoveries and proving them: but the representational and reasoning mechanisms are still unknown. Bayesian nets can't do this!

Extending Gibson's notion of "perception of affordance" we can see that some of the roots of mathematical cognition used in discovery and proof of theorems in Euclidean geometry and topology may have developed from ancient animal abilities to perceive and reason about affordances required for selecting complex goals and plans in novel situations.

Similar processes can be observed in the discovery of "toddler theorems" by young children, though they normally go unnoticed. (See the Toddler theorem web page.)

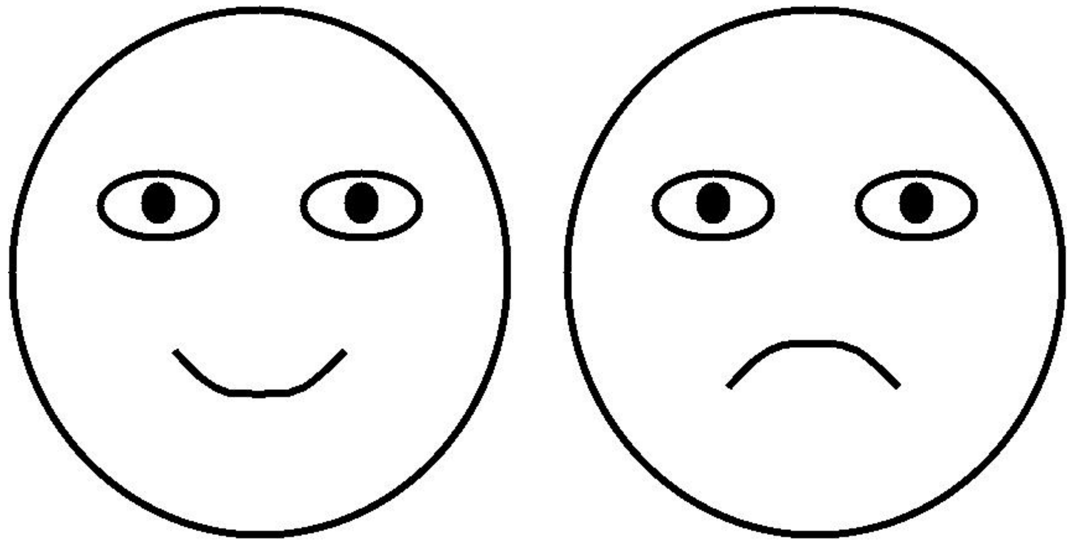
These proto-mathematical and mathematical discoveries are closely related to Annette Karmiloff-Smith's ideas about "Representational Redescription" in Beyond Modularity (1992)

**But nobody knows how to model these processes, or how brains do these things!**

# Evolution also produced abilities to see other minds

**Visual contents can be very abstract, even non-physical: As other-related meta-cognitive abilities developed in new architectural layers, evolution also modified perceptual mechanisms to support perception of other minds.**

**EXAMPLE**



Stare at each face for a while.
Do the eyes look different? How?

They are geometrically identical.

Compare Kanizsa's illusory contours?
http://en.wikipedia.org/wiki/Illusory_contours

Another example:

Perception of "biological motion" in Johansson's movies with moving point lights. When stationary they just look like isolated lights. When they move they appear to fuse into humans or animals moving in characteristic ways: walking, dancing, climbing, fighting, etc.

# The Meta-Morphogenesis project

**This project was inspired by Turing's work on the Chemical Basis of Morphogenesis.**

It provoked the question: how could morphogenesis have started in the first place.

It's clear that the processes of morphogenesis change hte processes of morphogenesis: hence Meta-Morphogenesis.

Perhaps if we can identify a lot more intermediate stages in the evolution of modern intelligent animals we'll get new insights in to the both what their visual an other mechanisms achieve so that we can search for deeper and more powerful mechanisms that explain what they achieve.

This could provide a basis for new theories about how to build intelligent robots.

When would you trust a robot to change your baby's nappy: the old fashioned type with safety pins?

When will a robot grasp what's happening when a piece of curled up string is pulled straight?

When will a robot know why you shouldn't start pulling on a shirt by pushing your hand through a cuff?

# THERE'S LOTS MORE

**There is lots more than I've put on this poster.**

**If you are interested in joining the meta-morphogenesis project, let me know.**

**Nobody will fund it, but perhaps people can contribute part time and informally.**

**http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-morphogenesis.html**



## References

Boden, M. A. (2006). *Mind As Machine: A history of Cognitive Science (Vols 1–2)*. Oxford: Oxford University Press.
Gibson, J. (1966). *The Senses Considered as Perceptual Systems*. Boston: Houghton Mifflin.
Simon, H. A. (1969). *The sciences of the artificial*. Cambridge, MA: MIT Press. ((Second edition 1981))