(DRAFT: BEING RECONSTRUCTED)

The Meta-Morphogenesis (MM) Project (or Meta-Project?) (Generalising Turing's ideas about morphogenesis.)

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Offers of collaboration welcome.

Introductory/Overview Materials

The main concept of information used for this project
The concept of "information used by organisms or machines or biological processes for various purposes" is central to this project. But it is not the concept unfortunately labelled "information" by the great Claude Shannon and his many admirers. He understood the differences but too many researchers ignore them. In fact many researchers think that is the **only** concept of "information" we have. But there is a much older one.
The concept of information whose role in evolution, in animal perception, learning, motivation, acting, interacting, thinking, asking, wondering, being puzzled, finding answers (etc.) I am referring to, was already known to Jane Austen over a century before Shannon's work, and to many others long before her. Several examples from her novel 'Pride and Prejudice' published in 1813, are presented here:

> http://www.cs.bham.ac.uk/research/projects/cogaff/misc/austen-info.html
> Jane Austen's concept of information (As opposed to Claude Shannon's)

Readers may find it useful to try making a list of the kinds of information they use in a typical day, and what they use those kinds for.

Further information about the Meta-Morphogenesis project:
Long PDF slide presentation introducing the Meta-Morphogenesis project
(Also flash version on slideshare.net.)

See also: Abstract for Meta-Morphogenesis tutorial
At: AGI 2012 -- Dec 11th Oxford
St Anne's College Oxford

Related Videos:

- Video interview by Adam Ford the day before the Oxford tutorial (about 57 minutes):
  http://www.youtube.com/watch?v=iuH8dC7Snno
  Also available on the CogAff web site:
  http://www.cs.bham.ac.uk/research/projects/cogaff/movies#m-m-int

- Video recording of the tutorial (about 2 hrs 30 mins -- audio problem fixed on 14 June 2013):
  http://www.youtube.com/watch?v=BNul52kFI74
  Medium resolution version also available on the CogAff web site:
  http://www.cs.bham.ac.uk/research/projects/cogaff/movies#m-m-tut

A growing collection of related papers and discussion notes:

- http://www.cs.bham.ac.uk/research/projects/cogaff/misc/vm-functionalism.html
  Introduction to Virtual Machine Functionalism
- http://www.cs.bham.ac.uk/research/projects/cogaff/misc/euclidean-ancestors.html
  Why is it so hard to get machines to reason like our ancestors
  who produced Euclidean Geometry?
- http://www.cs.bham.ac.uk/research/projects/cogaff/misc/bio-math-phil.html
  Mathematics is at root a biological, not an anthropological, phenomenon.
- http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evolution-info-transitions.html
  A DRAFT list of types of transitions in biological information-processing
  Note 2 Aug 2013: I have been reading Merlin Donald's 2002 book
  A Mind So Rare: The Evolution of Human Consciousness
  The book is spoilt by excessive rants against reductionism, and a seriously
  ill-informed account of symbolic computation, but is a superb introduction to many of
  the evolutionary transitions that involve information-processing, e.g. Chapter 4.
- http://www.cs.bham.ac.uk/research/projects/cogaff/misc/toddler-theorems.html
  Meta-Morphogenesis and Toddler Theorems: Case Studies
- http://www.cs.bham.ac.uk/research/projects/cogaff/misc/beyond-modularity.html
  Annette Karmiloff-Smith's ideas about 'Representational Redescription'
- http://www.cs.bham.ac.uk/research/projects/cogaff/misc/autism.html
  Autistic Information Processing
  Steps toward a generative theory of information-processing abnormalities.
- http://www.cs.bham.ac.uk/research/projects/cogaff/11.html#1106
  Four Papers for: **Alan Turing - His Work and Impact**
- To be extended....

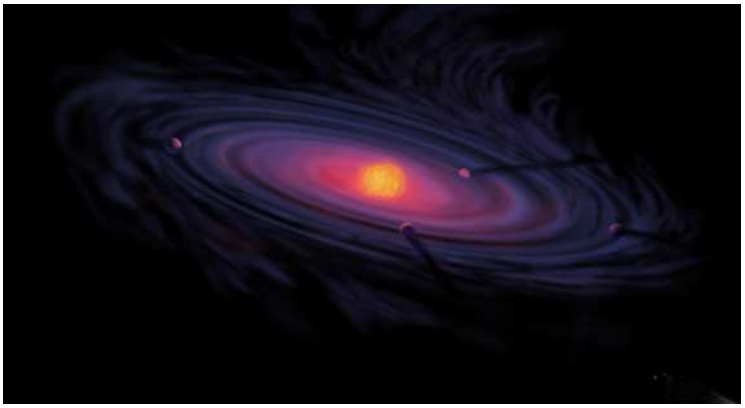
Introductory material

Meta-Morphogenesis: Evolution and Development of Information-Processing Machinery
(Including (recursively) mechanisms for changing the mechanisms)

The universe is made up of matter, energy and information, interacting with
each other and producing new kinds of matter, energy, information and interaction.

How? How did all this come out of a cloud of dust?

A Protoplanetary Dust Cloud?



[NASA artist's impression of a protoplanetary disk, from WikiMedia]

In order to find explanations we first need much better descriptions of what needs to be explained.

This is a multi-disciplinary project attempting to describe and explain the variety of biological information-processing mechanisms involved in the production of *new* biological information-processing mechanisms, on many time scales, between the earliest days of the planet with no life, only physical and chemical structures, including volcanic eruptions, asteroid impacts, solar and stellar radiation, and many other physical/chemical processes (or perhaps starting even earlier, when there was only a dust cloud in this part of the solar system?).

Evolution can be thought of as a (blind) Theorem Prover (or theorem discoverer).

- **Proving (discovering) theorems about what is possible**
  (possible types of information, possible types of information-processing, possible uses of information-processing)
- **Proving (discovering) many theorems in parallel**
  (including especially theorems about new types of information and new useful types of information-processing)
- **Sharing partial results among proofs of different things**
  (Very different biological phenomena may share origins, mechanisms, information, ...)
- **Combining separately derived old theorems in constructions of new proofs**
  (One way of thinking about symbiogenesis.)
- **Delegating some theorem-discovery to neonates and toddlers (epigenesis/ontogenesis).**
  (Including individuals too under-developed to know what they are discovering.)
- **Delegating some theorem-discovery to social/cultural developments.**
  (Including memes and other discoveries shared unwittingly within and between communities.)

- **Using older products to speed up discovery of new ones**
  (Using old and new kinds of architectures, sensori-motor morphologies, types of information, types of
  processing mechanism, types of control & decision making, types of testing.)

The "proofs" of discovered possibilities are implicit in evolutionary and/or
developmental trajectories.

They demonstrate the possibility of

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    development of new forms of development
    evolution of new types of evolution
    learning new ways to learn
    evolution of new types of learning
        (including mathematical learning: by working things out
        without requiring empirical evidence)
    evolution of new forms of development
    development of new forms of learning
        (why can't a toddler learn quantum mechanics?)
    how new forms of learning support new forms of evolution
    how new forms of development support new forms of evolution
        (e.g. postponing sexual maturity until mate-selection mating
        and nurturing can be influenced by much learning)
    ....
    .... and ways in which social cultural evolution add to the mix

These processes produce new forms of representation, new ontologies and
information contents, new information-processing mechanisms, new sensory-motor
morphologies, new forms of control, new forms of social interaction, new forms
of creativity, ... and more. Some may even accelerate evolution.

A draft growing list of transitions in types of biological information-processing:
    http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evolution-info-transitions.html

Biology, Mathematics, Philosophy, and Evolution of Information Processing
    Mathematics is at root a biological, not an anthropological phenomenon
    (as suggested by Wittgenstein).
    http://www.cs.bham.ac.uk/research/projects/cogaff/misc/bio-math-phil.html

An attempt to identify a major type of mathematical reasoning with precursors in
perception and reasoning about affordances, not yet replicated in AI systems:
    http://www.cs.bham.ac.uk/research/projects/cogaff/misc/triangle-theorem.html
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Even in microbes

I suspect there's much still to be learnt about the varying challenges and opportunities faced by microbes at various stages in their evolution, including new challenges produced by environmental changes and new opportunities (e.g. for control) produced by previous evolved features and competences -- and the mechanisms that evolved in response to those challenges and opportunities.

Example: which organisms were first able to learn about an enduring spatial configuration of resources, obstacles and dangers, only a tiny fragment of which can be sensed at any one time?
What changes occurred to meet that need?

- Use of "external memories" (e.g. stigmergy)
- Use of "internal memories" (various kinds of "cognitive maps")

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More examples to be collected here:
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evolution-info-transitions.html
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NOTE:
Stuart Wray produced this sketch of some of these ideas on 5th Jun 2012, after reading a draft workshop paper on Meta-morphogenesis and the Creativity of Evolution:
http://tinyurl.com/BhamCog/12.html#1203

For a (very) compressed history of information processing on our planet see
Evolution, Life and Mind: Some Startling Facts
http://tinyurl.com/BhamCog/misc/evolution-life-mind.html

For a messy, still growing, collection of examples relating to learning and development see this web page on "Toddler theorems":
http://tinyurl.com/BhamCog/misc/toddler-theorems.html
(including an introduction to the idea of a "Domain").

Document history
This (shortened) version installed: 21 Oct 2012
Previous (longer) version installed: 19 Oct 2011 now here.
Updated:
20 Oct 2011; 22 Nov 2011; 21 Feb 2012 (Appendix);5 Mar 2012; 19 Mar 2012; 23 Apr 2012; 10 May 2012; 22 May 2012; 19 Jun 2012; 29 Jun 2012; 7 Jul 2012; 24 Aug 2012; 13 Oct 2012; 14 Nov 2012;
6 Dec 2012 19 Dec 2012; 21 Oct 2012 **(Split in two: other part here.)**;
2 Feb 2013; 24 Apr 2013; 4 May 2013; 20 May 2013; 17 Jun 2013; **(Video fixed)** 24 June 2013; 2 Aug 2013; 16 Aug 2013

CONTENTS

This web site is
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-morphogenesis.html
Also accessible as: http://tinyurl.com/M-M-Gen
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/m-m.html
A slightly messy PDF version is also available: http://tinyurl.com/BhamCog/misc/meta-morphogenesis.pdf
This is one of a set of documents on the meta-morphogenesis project listed below.

A partial index of a wider collection of discussion notes is in
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/AREADME.html

Related Talks
Related talks (PDF) can be found here: http://tinyurl.com/BhamCog/talks/

What is Meta-Morphogenesis?
Draft answer (last revised: June 2012):

The study of meta-morphogenesis (MM) is the study of

- Forms of natural information processing, including perception, learning, inference, control, explanation, prediction, communication, ...
- The structures that can be used for these purposes
  (including physical structures and abstract, or virtual-machine structures, discrete and continuous structures, static structures, dynamic structures, ..., structures within organisms and structures in the environment),

  http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk102 (PDF)
  Meta-Morphogenesis: of virtual machinery with "physically indefinable" functions
  (Slides for presentation given at the Workshop "The Incomputable" -- likely to be updated.
  Royal Society Kavli Centre: 11-15 June 2012)
  http://www.mathcomp.leeds.ac.uk/turing2012/inc/

- Mechanisms involved in such forms of information processing
- Mechanisms for producing or modifying such mechanisms, including these mechanisms (recursively).
- Examples of meta-morphogenesis include the evolution of evolvability, the evolution (across generation) of new mechanisms for development and learning and the development of new mechanisms of development and learning.
- Often the changes occur in parallel streams of mutual influence of different forms of change or development (e.g. "arms races").
  "Mutual orchestration" can happen both in co-evolution, in co-development in different individuals and in co-development of different subsystems within an individual.
- Many of the developments make essential use of virtual machinery (why?)
- The more recent products of meta-morphogenesis include
  - forms of representation, mechanisms and architectures providing abilities to represent not only what is the case, but also **possibilities**, and **constraints on possibilities** (including many varieties of affordance)
  - forms of reasoning about what is **possible** and what is **necessarily** the case, which explains why mathematical interests and capabilities are biological phenomena.
  - forms of representation, mechanisms and architectures providing meta-semantic competences (including meta-management)
  - the phenomena referred to by Karmiloff-Smith as "Representational Redescription", discussed in http://www.cs.bham.ac.uk/research/projects/cogaff/misc/beyond-modularity.html
- Types of transition in which two or more different sub-systems begin to cooperate to provide previously impossible functions include introduction of abilities to scale-out (as opposed to scaling up) as discussed in http://tinyurl.com/BhamCog/misc/scaling-up-scaling-out.html
- See also:
  Abstract for talk about meta-morphogenesis in Cambridge, 8th May 2012:
  http://www.cs.bham.ac.uk/research/projects/cogaff/misc/cucats-abstract.html

Presentation By Penrose, Manchester 2012
Added 12 Aug 2012
Roger Penrose seems to partially agree with one of the ideas here

At the recent Alan Turing centenary conference in Manchester (June 2012) http://www.turing100.manchester.ac.uk/, Roger Penrose gave the final keynote lecture, which was open to the public. His lecture (The Problem of Modelling the Mathematical Mind) was recorded on video and is now available online:
http://videolectures.net/turing100_penrose_mathematical_mind/

Questions from the audience were also recorded. Near the end of the video (at approximately 1 hour 26 minutes from the start) I had a chance to suggest that what he was trying to say about human consciousness and its role in mathematical discovery might be expressed (perhaps more clearly) in terms of the kinds of meta-cognitive functions required in animals, children, and future robots, as well as mathematicians. The common process is first gaining expertise in some domain (or micro-domain!) of experience and then using meta-cognitive mechanisms that inspect the knowledge acquired so far and discover the possibility of reorganising the information gained into a deeper, more powerful, generative form. The best known example of this sort of transition is the transition in human language development to use of a generative syntax. (At one point I mistakenly referred to a "generative theorem" when I meant "generative theory".)

I suggested that something similar must have happened when early humans made the discoveries, without the aid of mathematics teachers, that provided the basis of Euclidean geometry (later systematised through social processes). I have proposed that there are many examples, that have mostly gone unnoticed, of young children discovering what I call "Toddler theorems", some of them probably also discovered by other animals, as discussed in http://tinyurl.com/BhamCog/misc/toddler-theorems.html.

This is also related to the ideas about "Representational Re-description" in the work of Annette Karmiloff-Smith, presented in her 1992 book **Beyond Modularity** discussed in http://tinyurl.com/BhamCog/misc/beyond-modularity.html

Penrose seemed to agree with my suggestion, and to accept that it might also explain why the basis of some mathematical competences are biologically valuable, which he had previously said he was doubtful about. I don't know whether he realised he was agreeing to a proposal that instead of thinking of consciousness as part of the explanation of human mathematics, we can switch to thinking of the biological requirement for mathematical thinking as part of the explanation of important kinds of human (and animal) consciousness.
This is also connected with the need to extend J.J.Gibson's theory of perception of affordances discussed in http://tinyurl.com/BhamCog/talks/#gibson

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PAPERS WITH FURTHER DETAILS

- **BASICS OF THE THEORY (In another paper)**
- **HOW TO COLLECT DATA (In another paper)**
- **HOW TO THINK ABOUT WHAT YOU OBSERVE (In another paper)**
- **BEYOND MODULARITY: The work of Annette Karmiloff-Smith** (In another paper).
- **Variations in Requirements and Architectures** (In another paper).

  A subset of the variations concerned with different concepts of deliberative competence is explored in:
  `http://www.cs.bham.ac.uk/research/projects/cosy/papers/#dp0604`
  Requirements for a Fully Deliberative Architecture (Or component of an architecture).
  (Separate paper.)

- **EXAMPLES: Domains for toddler theorems (and older theorems)**
  (In a separate file.)

  A collection of examples extracted from the papers and presentations, along with some new examples based on things I have read and conversations with friends and colleagues.
  Some of the examples illustrate portions of the process of information re-organisation
  (perhaps instances of what Karmiloff-Smith means by "Representational Redescription"?).

The list of examples is a tiny sample. I shall go on extending it.
(Contributions welcome.)

EXISTING PAPERS AND PRESENTATIONS

Example papers and presentations I have written on this topic over the last five decades (DPhil Thesis was in 1962), especially since the early 1990s, are listed.
(Currently this list duplicates the list in the Toddler theorems paper.)

PAPERS ON META-MORPHOGENESIS

- The first paper in which I used the label Meta-Morphogenesis
  http://www.cs.bham.ac.uk/research/projects/cogaff/11.html#1106d
  Virtual Machinery and Evolution of Mind (Part 3): Meta-Morphogenesis: Evolution of Information-Processing Machinery
  Invited contribution to a collection of papers on Turing. This web page is an expanded version of that paper.

- http://www.cs.bham.ac.uk/research/projects/cosy/papers#tr0802
  Kantian Philosophy of Mathematics and Young Robots (2008)
- http://www.cs.bham.ac.uk/research/projects/cosy/papers/#tr0807
  The Well-Designed Young Mathematician
- http://www.cs.bham.ac.uk/research/projects/cogaff/10.html#1001
  If Learning Maths Requires a Teacher, Where did the First Teachers Come From?

RELEVANT PRESENTATIONS (PDF)

- http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#toddler
  A New Approach to Philosophy of Mathematics: Design a young explorer, able to discover "toddler theorems"
- http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk102 (PDF)
  Meta-Morphogenesis: of virtual machinery with "physically indefinable" functions
- http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk7
  7: When is seeing (possibly in your mind's eye) better than deducing, for reasoning?
- http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk27
  Talk 27: Requirements for visual/spatial reasoning
- http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk56
  Talk 56: Could a Child Robot Grow Up To be A Mathematician And Philosopher?
- http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk63
  Talk 63: Kantian Philosophy of Mathematics and Young Robots
  Could a baby robot grow up to be a Mathematician and Philosopher?
- http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk67
  Talk 67: Why (and how) did biological evolution produce mathematicians?
  OR If learning mathematics requires a teacher, where did the first teachers come from?
  OR A New Approach to Philosophy of Mathematics:
  Design a young explorer, able to discover "toddler theorems"
- http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk79
  Talk 79: If learning maths requires a teacher, where did the first teachers come from?
- http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk90
  Talk 90: Piaget (and collaborators) on Possibility and Necessity
  And the relevance of/to AI/Robotics/mathematics (in biological evolution and development)

CLOSELY RELATED (To be expanded and re-ordered)

1. Richard Dawkins, 'The Evolution of Evolvability',
   in **Artificial Life: Proceedings of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems,**
   Ed. Chris G. Langton, Addison-Wesley, 1988, pp. 201--220.

Dawkins' paper is entirely about evolution of physical form, and of procedures for producing physical forms. The idea of meta-morphogenesis includes evolution of behaviours, evolution of information processing (including mechanisms for producing and controlling behaviour), evolution of forms of learning, learning, evolution of mechanisms of development of new information-processing capabilities, evolution of abilities to alter the evolvability of all of those. Dawkins paper is a useful introduction to the basic idea, with informative toy examples.

2. The Only Way is Up
   On A Tower of Abstractions for Biology
   Jasmin Fisher, Nir Piterman, and Moshe Y. Vardi
   17th International Symposium on Formal Methods, LNCS 6664, pp. 3-11, 2011
   http://www.cs.rice.edu/~vardi/papers/fm11a.pdf

   Abstract:
   We draw an analogy between biology and computer hardware systems and argue for the need of a tower of abstractions to tame complexity of living systems. Just like in hardware design, where engineers use a tower of abstractions to produce the most complex man-made systems, we stress that in reverse engineering of biological systems; only by using a tower of abstractions we would be able to understand the "program of life".

3. Beyond Modularity, by Annette Karmiloff-Smith MIT Press (1992)

4. Kenneth Craik's 1943 book (*The Nature of Explanation*), written nearly
   70 years ago makes some major contributions to the meta-morphogenesis project by drawing attention to previously unnoticed problems about biological information
   processing in intelligent animals.
   See http://tinyurl.com/CogMisc/kenneth-craik.html for an incomplete discussion of his contribution. (To be expanded)

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

   Abstract:
   The full variety of powerful information-processing mechanisms 'discovered' by evolution has not yet been re-discovered by scientists and engineers. By attending closely to the diversity of biological phenomena, we may gain new insights into
   (a) how evolution happens,
   (b) what sorts of mechanisms, forms of representation, types of learning and development and types of architectures have evolved,
   (c) how to explain ill-understood aspects of human and animal intelligence, and
   (d) new useful mechanisms for artificial systems.
   We analyse trade-offs common to both biological evolution and engineering design, and propose a kind of architecture that grows itself, using, among other things, genetically determined meta-competences that deploy powerful symbolic mechanisms to achieve various kinds of discontinuous learning, often through play and exploration, including development of an 'exosomatic' ontology, referring to things in the environment - in contrast with learning systems that discover only sensorimotor contingencies or adaptive mechanisms that make only minor modifications within a fixed architecture.

6. There is much relevant content in Margaret Boden's work, e.g. on purposive explanation in psychology, on achievements and limitations of AI, on creativity, her theoretical work on biology (especially the relations between life and mind) and her outstanding historical analyses of various aspects of the development of Cognitive Science:
   Mind As Machine: A history of Cognitive Science (Vols 1--2) (2006)
   http://www.cs.bham.ac.uk/research/projects/cogaff/misc/boden-mindasmachine.html

7. Brian Goodwin, whom I met and talked to occasionally at Sussex University
   http://en.wikipedia.org/wiki/Brian_Goodwin
   expressed ideas in conversation (and in his publications which I did not read, mainly because I could not keep up with the mathematical details), had ideas about natural selection being only part of the story of how evolution works: he used to talk about "Laws of Form" constraining the possibilities for growth in ways that did not require genetic control. In retrospect I think some of the ideas behind the M-M project may have come from him, and before him from D'Arcy

Thompson, Goethe and others. See Boden (2006) Sections 15x(b-d), Vol 2

However, some of the "laws of form" are concerned with forms of information processing and how possibilities are enabled and constrained by (a) the physical mechanisms in which the information processing machinery (even virtual machinery) has to be implemented and (b) the environments with which organisms need to interact in order to develop, learn, live their lives and reproduce -- some of which include other information processors: friends, foes, food, playmates, and things to observe or be observed by.

8. Stuart Kauffman's work, e.g. see this useful overview by Gert Korthof
   http://home.wxs.nl/~gkorthof/kortho32.htm

   His 1995 book is very approachable:
   At home in the universe: The search for laws of complexity
   http://www.amazon.com/At-Home-Universe-Self-Organization-Complexity/dp/0195111303

9. Ideas of David Deutsch. See his old and new web sites:
   http://193.189.74.53/~qubitor/people/david/David.html
   http://www.qubit.org/people/david/
   (Not working when I last looked)

10. TWo books by Jack Cohen (biologist) and Ian Stewart (mathematician)
    The Collapse of Chaos (1994)
    Figments of Reality: The Evolution of the Curious Mind (1997)

11. Immanuel Kant's *Critique of Pure Reason* (1781) has relevant ideas and questions, but he lacked our present understanding of information processing (which is still too limited)
    http://archive.org/details/immanuelkantscri032379mbp

12. Much of Jean Piaget's work is also relevant, especially his last two (closely related) books written with his collaborators:
    Possibility and Necessity
    Vol 1. The role of possibility in cognitive development (1981)
    Vol 2. The role of necessity in cognitive development (1983)
    Tr. by Helga Feider from French in 1987
    Like Kant, he had deep observations but lacked an understanding of information processing mechanisms, required for explanatory theories.

13. John McCarthy's 1996 paper "The Well Designed Child" is very relevant:
    http://www-formal.stanford.edu/jmc/child.html
    (Later published in the AI Journal, 172, 18, pp 2003--2014, 2008)

14. Ulric Neisser wrote

    "... we may have been lavishing too much effort on hypothetical models of the mind and not enough on analyzing the environment that the mind has been shaped to meet."

    In *Cognition and Reality,* W.H. Freeman., 1976.

15. Steve Burbeck's web site:
    http://www.evolutionofcomputing.org/

16. Daniel Dennett's very readable little book is very relevant:
    Kinds of minds: towards an understanding of consciousness,
    Weidenfeld and Nicholson, London, 1996,
    http://www.amazon.com/Kinds-Minds-Understanding-Consciousness-Science/dp/0465073514

    This book, like much of what Dennett has written is mostly consistent with my own emphasis on the need to understand "the space of possible minds" if we wish to understand human minds. Simply trying to study human minds while ignoring all others is as misguided as trying to do chemistry by studying one complex molecule (e.g. haemoglobin) and ignoring all others.

17. Dennett and I have also written similar things about how to think about discussions of "free will" in the light of changes produced by Biological evolution.
    Dennett
    D.C. Dennett,
    Elbow Room: the varieties of free will worth wanting,
    Oxford: The Clarendon Press, 1984,
    (See also his later book *Freedom Evolves*)

Sloman
A. Sloman, 'How to Dispose of the Free-Will Issue,'
In *AISB Quarterly,* No 82, 1992, pp. 31--32,
http://www.cs.bham.ac.uk/research/projects/cogaff/81-95.html#8,
(Originally posted to Usenet some time earlier.)

Also used (with my permission) as the basis for Chapter 2 of
Stan Franklin,
Artificial Minds, MIT Press, 1995,
(Franklin expanded my notes.)

Our main difference is that I don't regard what Dennett calls "the intentional stance" as a requirement for a science of mind, since reference to mental states and processes is not merely a sort of useful explanatory fiction: those states and processes, and qualia exist and their existence can be explained in terms of the operation of virtual machinery that is a product of biological evolution rather than human engineering. However, Dennett *sometimes* also seems to hold that view.

18. Noam Chomsky's early work deeply influenced my thinking, especially the idea of **generative** forms of representation able to cope with arbitrary (essentially infinite) variation in structure (not just values of a fixed size vector, so popular in much current AI). See his three notions of 'adequacy', observational, descriptive and explanatory adequacy, in *Aspects of the theory of syntax* (1965)

I know there are lots more -- most of them not yet read by me. I would welcome a volunteer collaborator (or a group of collaborators) to help setting up an annotated online bibliography of notes, books, papers, discussions, videos, etc. relevant to meta-morphogenesis, whether the label is used or not, especially freely available open access documents, for reasons given here.

Appendix: Schematic Summary

Transitions can occur in parts of organisms, in whole organisms, within a species, in interacting groups of species, in societies, and in environments (though organisms are part of the environment for conspecifics and for others).

Types of transition include:

1. Change of physical shape (in individual, in species)
2. Change in physical behaviour (in individual, in species)
3. Change in information processing (in individual, in species)
   (including control of growth, metabolism, immune system, processing of perception, motive formation, motive selection, action selection, action control, learning, reasoning, ...)
4. Change in developmental trajectory (physical, non-physical)
5. Change in what can be learnt (in individual, in species)
6. Change in type of interaction between individuals
   (in same species, across species, within 'family unit', prey, predators, others...)
7. Change in type of social organisation
   (including forms of collaboration, forms of nurturing, forms of education, forms of competition)
8. Changes in mechanisms of evolution (evolution of evolvability (Dawkins, 1988))
9. Changes in mechanisms of development
10. Changes in mechanisms of learning
11. Changes in mechanisms of interaction
12. Changes in mechanisms of self-monitoring, self-control
13. Introduction of new virtual machines, new forms of representation, new ontologies, new architectures

Note added 23 Oct 2012 An expanded version of this list is being created in
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evolution-info-transitions.html

These changes can interact and influence one another...

Types of Meta-Morphogenesis:
For any of the above biological changes B1, B2, B3,.. etc. and for any environmental states or changes E1, E2, E3,... there can be influences of the following forms ...

- E changes B
- B changes E
- Bi changes Bj
- Combinations of Ei, Bi, Bj, ... cause changes in Bk, BL, ... etc., etc.
- See also
  A DRAFT list of types of transitions in biological information processing

Meta-Morphogenesis (MM):
Things that cause changes can produce new things that cause changes.
Old phenomena may be produced in new ways
e.g. information acquired and ways of acquiring and using information can change.
Often new mechanisms can produce new biological phenomena

e.g. organisms that can discover what they have learnt.
organisms that make and use mathematical discoveries.

In particular, most forms of biological information processing that exist now are products of parallel trajectories of biological information processing over many stages of evolution and development, including cultural evolution in the case of humans.

This is quite unlike use of evolutionary computation (GA, GP, etc.) with a fixed evaluation function, often used to solve engineering problems.
For example, evaluation in natural evolution keeps changing, as environments change.

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