



Publications and references related to the Meta-Morphogenesis Project

(Still disorganised -- to be improved later).
(DRAFT: Liable to change)

Aaron Sloman
School of Computer Science, University of Birmingham.

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This document is

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/m-m-related.html>

A PDF version may be added later.

A partial index of discussion notes is in

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/AREADME.html>

Publications and projects related to the Meta-Morphogenesis project **(Project overview)**

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- [Possibly related Penrose presentation](#)

Papers and presentations on the Birmingham M-M web site **(List probably incomplete!)**

Online papers and presentations

- [The Meta-Morphogenesis \(M-M\) Project \(or Meta-Project?\)](#)
([Top level M-M web site.](#))
How can a cloud of dust transform itself into a planet full of living things as diverse as life on Earth?
- <http://www.cs.bham.ac.uk/research/projects/cogaff/11.html#1106>
Four Papers for: **Alan Turing - His Work and Impact** (Elsevier, 2013) including the first paper introducing the Meta-Morphogenesis project.
The four papers are:
 1. [Virtual Machinery and Evolution of Mind \(Part 1\) \(Pages 97-101\)](#)
 2. [Virtual Machinery and Evolution of Mind \(Part 2\) \(574-579\)](#)
 3. [The Mythical Turing Test pages \(606-610\)](#)
 4. [Virtual Machinery and Evolution of Mind \(Part 3\)](#)[Meta-Morphogenesis: Evolution of Information-Processing Machinery \(849-856\)](#)
- <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evolution-info-transitions.html>
A DRAFT, incomplete, list of types of transition in information processing produced by biological mechanisms.
- <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/bio-math-phil.html>
Mathematics is at root a biological, not an anthropological, phenomenon.
- <http://www.cs.bham.ac.uk/research/projects/cogaff/math-evol-sloman.pdf>
A draft speculative paper on the nature of mathematics and evolution of mathematicians (Sept 2013):
- <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/mathsem.html>
Extended abstract for a seminar talk: "From Molecules to Mathematicians" on 1st Nov 2013:
- <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? (Seminar summary. June 2013))
- <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/triangle-theorem.html>
Hidden Depths of Triangle Qualia
Theorems About Triangles, and Implications for Biological Evolution and AI
The Median Stretch, Side Stretch, and Triangle Area Theorems: Old and new proofs.
- <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/triangle-sum.html>
The Triangle Sum Theorem
Old and new proofs concerning the sum of interior angles of a triangle. (More on the hidden depths of triangle qualia.)
- <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/torus.html>
Reasoning About Continuous Deformation of Curves on a torus and other things.
- <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/beyond-modularity.html>
An incomplete, and personal, review of some of Annette Karmiloff-Smith's ideas about 'Representational Redescription', as presented in her (1992).
- 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/cogaff/07.html#717>

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,
- (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. See [the diagram](#) on the main M-M web page.

- <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/autism.html>
Aaron Sloman,
Autistic Information Processing
Steps toward a generative theory of information-processing abnormalities.
- <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/vision>
Aaron Sloman
How to study human vision. (How to look at what you see.)
A presentation of some hard, apparently unsolved, problems about natural vision and how to replicate the functions and the designs in AI/Robotic vision systems.
- <http://www.softbox.co.uk/cybertalk-issuethree>
An invited summary of the M-M project published Sept 2013 in Cybertalk Magazine
<http://www.cs.bham.ac.uk/research/projects/cogaff/13.html#1303> (HTML and PDF)
More readable version on this web site.
-
- <http://www.cs.bham.ac.uk/research/projects/cogaff/crp/>
Aaron Sloman [1978, revised]
The Computer Revolution in Philosophy: Philosophy, Science and Models of Mind
Harvester Press (and Humanities Press), 1978, Hassocks, Sussex,
- A. Sloman, R.L. Chrisley, (2003,) Virtual machines and consciousness, *Journal of Consciousness Studies*, 10, 4-5, pp. 113--172,
<http://www.cs.bham.ac.uk/research/projects/cogaff/03.html#200302>
- <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/fully-deliberative.html>
Aaron Sloman,
Requirements for a Fully Deliberative Architecture (Or component of an architecture),
Research Note, COSY-DP-0604,
School of Computer Science, University of Birmingham, UK, May, 2006,
This presents a variety of intermediate cases between simple reactive information-processing architectures and "fully deliberative" architectures with several concurrently active layers of processing, that evolved at different times, and develop at different stages in individuals.

- <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/vm-functionalism.html>
A. Sloman (2013, revised)
Virtual Machine Functionalism (VMF)
(The only form of functionalism worth taking seriously
in Philosophy of Mind and theories of Consciousness)
- <http://www.cs.bham.ac.uk/research/projects/cogaff/09.html#905>
Aaron Sloman, 2011,
What's information, for an organism or intelligent machine?
How can a machine or organism mean?,
In, *Information and Computation*, Eds. G. Dodig-Crnkovic and M. Burgin,
World Scientific, New Jersey, pp.393--438,
- <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)
- <http://www.cs.bham.ac.uk/research/projects/cosy/papers/#tr0804>
Aaron Sloman,
Some Requirements for Human-like Robots:
Why the recent over-emphasis on embodiment has held up progress, in
Creating Brain-like Intelligence,
Eds. B. Sendhoff, E. Koerner, O. Sporns, H. Ritter and K. Doya, Springer-Verlag, 2009, pp.
248--277,
- **Further information about the Meta-Morphogenesis project:**
[Long PDF slide presentation introducing the Meta-Morphogenesis project](#)
(Also flash version on slideshare.net.)
- [Abstract for Meta-Morphogenesis tutorial](#)
At: [AGI 2012 -- Dec 11th Oxford](#)
St Anne's College Oxford

Video presentations related to the M-M project

- Adam Ford's video recording of the tutorial at AGI 2012 (about 2 hrs 30 mins) available online:
<http://www.youtube.com/watch?v=BNuI52kFI74>
Medium resolution version also available on the CogAff web site:
<http://www.cs.bham.ac.uk/research/projects/cogaff/movies#m-m-tut>

Also available here:
<http://www.scifuture.org/metamorphogenesis-how-a-planet-can-produce-minds-mathematics-and-music-aaron-sloman/>
27 Nov 2015
No also available here
<http://www.scifuture.org/metamorphogenesis-how-a-planet-can-produce-minds-mathematics-and-music-aaron-sloman/>
- Adam Ford also interviewed me the day before the Oxford tutorial and produced a video of the interview (about 57 minutes):
<http://www.youtube.com/watch?v=iuH8dC7Snn0>
Also available on the CogAff web site:
<http://www.cs.bham.ac.uk/research/projects/cogaff/movies#m-m-int>

A draft transcript of the interview was very kindly provided by Dylan Holmes (at that time an MIT student), then revised and slightly extended by me here:

<http://www.cs.bham.ac.uk/research/projects/cogaff/movies/transcript-interview.html>

Also an expanded PDF version.

<http://www.cs.bham.ac.uk/research/projects/cogaff/14.html#1401>

- Additional videos (including videos of children processing information adequately and inadequately):

<http://www.cs.bham.ac.uk/research/projects/cogaff/movies>

Related projects (In no significant order -- may be rotated)

- Minimal Intelligence Lab (MINT Lab)
Studying Plant Intelligence (and other forms)
<http://www.um.es/web/minimal-intelligence-lab/>
<http://www.um.es/web/minimal-intelligence-lab/contenido/manifesto>
Expanded Manifesto (PDF):
http://www.um.es/documents/2103613/2107123/MANIFESTO_PLANT+NEUROBIOLOGY+AND+ITS+PHILOSOPHY.pdf
The Minimal Intelligence Team:
<http://www.um.es/web/minimal-intelligence-lab/contenido/the-team>
"Frontiers" page on Minimal intelligence across Eukaryota
<http://journal.frontiersin.org/article/10.3389/fpsyg.2015.01329/full>
- <http://www-thphys.physics.ox.ac.uk/people/ArdLouis/>
Ard Louis research group
Interdisciplinary research, on the border between theoretical physics and chemistry, applied mathematics and biology, applying theoretical and computational tools from statistical mechanics to study how complex behaviour emerges from the interaction of many individual objects. Particularly interested in biological physics and the dynamics of soft-matter.
- Gert Korthof's superb collection of reviews and discussions of publications and theories in or related to biology, including the Chemoton Theory of Tibor Ganti:
<http://wasdarwinwrong.com/>
- Bob Doyle's web site is rich in content directly or indirectly relevant to this project (though his main goals seem to be different):
<http://www.informationphilosopher.com/>
(I learnt about this for the first time on 4th Apr 2014. Google should have introduced us sooner!)
- Steve Burbeck's project on life and computation:
<http://www.evolutionofcomputing.org/>
- Sexual reproduction as an adaptation to resist parasites (A Review).
William D. Hamilton, Robert Axelrodtt, and Reiko Tanese.
Proc. Natl. Acad. Sci. USA Vol. 87, pp. 3566-3573, May 1990 *Evolution*
<http://www.pnas.org/content/87/9/3566.full.pdf>

- Thanks to Chris Scambler for drawing my attention to the work of Andreas Wagner whose book [Wagner \(2014\)](#) claims that the structure of the search space generated by the molecules making up the genome increases the chance of useful, approximate, solutions to important problems to be found with **relatively** little searching (compared with other search spaces), after which small random changes allow improvements to be found. (This search strategy works well only under certain conditions.) I have not yet read the book but it seems to illustrate the importance for evolution of the types of construction-kit available. This work seems to be an unwitting but important contribution to the Meta-Morphogenesis project.

His earlier book, which I have also not read yet, seems to be very relevant too:
 The Origins of Evolutionary Innovations: A Theory of Transformative Change in Living Systems
 OUP Oxford (2011) (Oxford Biology)

An interview with Wagner in 2012 is online at
<https://www.youtube.com/watch?v=wyQgCMZdv6E>
 For more on construction kits see this (draft) paper:
<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/construction-kits.html>

Please send me additional items for this list.
 Email: a.sloman[AT]cs.bham.ac.uk

Publications and presentations by others (A seriously incomplete selection.)

- **Margaret Boden's work**

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 (2006). Here is a small sample of her work:

- M. A. Boden, 1972, *Purposive Explanation In Psychology*, Harvard University Press, Cambridge, MA, (Based on her Harvard Psychology PhD thesis.)
- M. A. Boden, 1978, *Artificial Intelligence and Natural Man*, Harvester Press, Hassocks, Second edition 1986. MIT Press,
- M. A. Boden, 1990, *The Creative Mind: Myths and Mechanisms*, Weidenfeld & Nicolson, London,
- M. A. Boden, 2000, Autopoiesis and life, *Cognitive Science Quarterly*, 1, 1, pp. 115--143,
- Her "Magnum Opus":
 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>
 The discussion starting in section 15iii (Mathematical Biology Begins), continuing to the end of 15iv (15.iv. Turing's Biological Turn) is specially relevant to the M-M project, summarising work by D'Arcy Thompson, Alan Turing and others. Most of the rest of the book is also relevant, some portions more closely than others. In particular see her discussions of the role of the notions of "information" (as opposed to matter, energy, force,

etc.) both in explanations of natural phenomena and in design of new machinery.

4.v. Cybernetic Circularity: From Steam-Engines to Societies (p.198)

"...the focus of cybernetics was on the flow of information, as opposed to the matter or energy involved. Because information is an abstract notion, it could be applied to many different types of system--even including minds."

- Graham Bell

Selection: The Mechanism of Evolution

2nd Ed. OUP, 2008.

- 15 Aug 2014: Jack Birner drew my attention to his paper: Jack Birner (2009).

"From Group Selection to Ecological Niches: Popper's rethinking of evolutionary theory in the light of Hayek's theory of culture." In

Z. Parusnikova & R.S. Cohen (eds.), *Rethinking Popper*, Springer.

[PDF available here.](#)

From the Abstract:

Hayek's *The Sensory Order* contains a physicalistic identity theory of the mind. Popper criticized it, saying that it could not explain the higher functions of language. Hayek took up that challenge in a manuscript but failed to refute Popper's arguments. Drawing upon the same manuscript, Hayek developed a theory of behavioural rules and cultural evolution. Despite his criticism of the theory of mind on which this evolutionary theory was based, Popper adopted Hayek's idea of group selection. He transformed it into a theory of the selective power of ecological niches. This became a central element of Popper's theory of evolution. The chapter traces the influence Popper and Hayek had on each other in the fields of the philosophy of mind and evolutionary theory. ...

NOTE: an online PDF version of Hayek's *The Sensory Order* is available [Hayek \(1952\)](#).

NOTE: Jack Birner has recently written a draft paper that includes more on Hayek, Popper, and theory of mind, available on Academia:

[How Artificial is Intelligence in AI? Arguments for a Non-Discriminatory Turing test.](#) (2014)

- <http://people.csail.mit.edu/brooks/papers/ascona.pdf>

Rodney A. Brooks, From earwigs to humans, in

Robotics and Autonomous Systems, 20, 1997, pp. 291 - 304

(Reply to [Kirsh\(1991\)](#))

- Paco Calvo, What Is It Like to Be a Plant?, *Journal of Consciousness Studies*, 2017, vol 24, 9-10, pp. 205-227,

<http://www.ingentaconnect.com/content/imp/jcs/2017/00000024/F0020009/art00012>

- https://www.youtube.com/watch?v=RIYS_GiAnK8

Life as Evolving Software, Greg Chaitin at PPGC UFRGS Uploaded Sep 2011

"...The crucial idea: DNA is multi-billion year old software, but we could not recognize it as such before Turing's 1936 paper, which according to von Neumann creates the idea of computer hardware and software."

- 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)

Added 26 Aug 2014

The idea of a system with generative power was previously well understood in mathematics and computer science: e.g. a turing machine has generative power, and a recursive or iterative computer program can give a turing machine or conventional computer infinite competence in Chomsky's sense, though with performance limitations, in exactly the same way as he claimed human minds have infinite competence but finite performance -- mainly because of physical size limits. It was also known much earlier that a finite rule or set of axioms can have infinitely many consequences, a point discussed by Kant in his Critique of Pure Reason (1781).

One of the claims of the M-M project is that natural selection is also a mechanism with infinite competence and finite performance limitations. In part that is obvious insofar as natural selection can produce human brains. But long before that happened the mechanisms driving increases in physical complexity and increases in information processing powers had the same sort of "infinite competence", which could more modestly be described as "potentially unbounded competence".

- 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)
- 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. For a draft incomplete discussion of his contribution, see <http://www.cs.bham.ac.uk/research/projects/cogaff/misc/kenneth-craik.html>

[Crick, 1954]

F. H. C. Crick, 1954/2015 The structure of the hereditary material, in *Nobel Prizewinners who changed out world*

Scientific American, Topix Media Lab, New York USA 1954/2015 pp. 6--15

- 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.
- Dhar, P. K. and Giuliani, A., 2010, Laws of biology: why so few?, *Systems and Synthetic Biology*, 4, 1, pp. 7--13, <http://doi.org/10.1007/s11693-009-9049-0>

This project seems to be addressing problems related to ours. I suspect it could use our idea of layered construction kits, but does not seem to yet:

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/construction-kits.html>

- Terrence Deacon (https://en.wikipedia.org/wiki/Terrence_Deacon) in his book *Incomplete Nature: How Mind Emerged from Matter*, W.W. Norton & Company, 2011, attempts to cover ground that is similar to the Meta-Morphogenesis project. The book is summarised in https://en.wikipedia.org/wiki/Incomplete_Nature. I have not yet read it all, but my impression is that he does not know enough about computation (and especially developments in the use of increasingly complex types of **virtual machinery** in the last 70 years or so) and also seems to know nothing about Classical Artificial Intelligence (as opposed to the numerical/statistical forms of AI). Classical AI work on planning, reasoning, theorem proving, language understanding, problem solving, theory formation, etc. enriches our ideas about forms of information processing in much deeper ways, that are related to the theory of computation. (However, there remain deep gaps in AI, which I try to analyse in depth elsewhere.)

Like many who put forward theories about the evolution of mind from matter, Deacon completely ignores the need to explain how evolution could produce animals with the kinds of **mathematical** capabilities that led to the discoveries (and proofs) reported in Euclid's elements, discoveries that must have been made originally before there were mathematics teachers. The need to explain such capabilities has also been ignored by most researchers in AI, Robotics, and Neuroscience, as far as I know. See this incomplete survey:

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/bio-math-phil.html>

- D.C. 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.

- 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.
 - D.C. Dennett
Elbow Room: the varieties of free will worth wanting,
Oxford: The Clarendon Press, 1984,
(See also his later book *Freedom Evolves*)
 - 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 extended my notes and made them clearer.)

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, and which need not be rational in most of its processing. However, Dennett *sometimes* also seems to hold that view. (There is more on Virtual Machine Functionalism [above](#).)

- Ideas of David Deutsch. See his old and new web sites, and his two books:
<http://193.189.74.53/~qubitor/people/david/David.html>
<http://www.qubit.org/people/david/>

David Deutsch, 1997 *The Fabric of Reality*,
Allen Lane and Penguin Books

David Deutsch, 2011 *The Beginning of Infinity: Explanations That Transform the World*,
Allen Lane and Penguin Books, London,

- Merlin Donald's book
A Mind So Rare: The Evolution of Human Consciousness (2002)
Is very relevant. It is spoilt especially near the beginning, by excessive rants against reductionism, which originally put me off reading the rest of the book. So it lay in a pile of books to be read for several years before I returned to it. Despite the complaints about reductionism much of the book attempts to relate empirical claims about the capabilities of humans and other animals to requirements for explanatory information processing mechanisms. The author does not seem to be well informed about achievements of AI and the nature of symbolic computation, so his sketchy ideas about explanatory mechanisms can mostly be ignored. But the book gives a superb introduction to many of the evolutionary transitions that involve information-processing, e.g. Chapter 4.

In particular, much of what Merlin Donald has written about evolution of consciousness is relevant to this project, though it is not clear that he appreciates the importance of virtual machinery, as outlined in

<http://www.cs.bham.ac.uk/research/projects/cogaff/10.html#sab>

A. Sloman

How Virtual Machinery Can Bridge the "Explanatory Gap", In *Natural and Artificial Systems*,
Invited talk at SAB 2010, Paris, in
Proc. SAB 2010, LNAI 6226, Eds. S. Doncieux and et al., Springer, 2010, pp. 13--24,

- Peter Gardenfors
How Homo Became Sapiens: On the evolution of thinking
Oxford University Press, 2003
- 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".

- Brian Goodwin, http://en.wikipedia.org/wiki/Brian_Goodwin whom I met and talked to occasionally at Sussex University, 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", which as far as I know they did not discuss, 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.

- F.A. Hayek, 1952, *The Sensory Order*
The University of Chicago Press, Chicago
W. J. Gage & Co., Limited, Toronto 2B, Canada
Routledge & Kegan Paul Ltd., London, E.C.4, England
Online PDF versions are available here:
<https://archive.org/details/sensoryordering00haye>
(The 'BW/PDF' version (on left) is smaller and slightly more readable.)
- Andrew Hodges, (2004), What Would Alan Turing Have Done After 1954?, in *Alan Turing: Life and Legacy of a Great Thinker*, Ed Christof Teuscher,
http://dx.doi.org/10.1007/978-3-662-05642-4_3 Springer Berlin Heidelberg, 43-58,
- David Lambert, Chris Chetland and Craig Millar, Eds.,
The Intuitive Way of Knowing: A Tribute to Brian Goodwin,
Floris Books, Edinburgh, 2013,
Contributors: Stuart Kauffman, Lewis Wolpert, Fritjof Capra, Margaret Boden, Michael Ruse, Fred Cummings, Mae-wan Ho, Philip Franses, Stephan Harding, Nick Monk, Claudio Stern, Johannes Jaeger, Craig Millar and David Lambert. There are three interviews with Brian Goodwin. (Some of the contributions implicitly or explicitly refer to processes involving information.)
- 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>

- Annette Karmiloff-Smith
Beyond Modularity,
A Developmental Perspective on Cognitive Science,
MIT Press (1992) --Informally reviewed in
<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/beyond-modularity.html>
 - Stuart Kauffman's work, e.g. see this useful overview by Gert Korthof
<http://wasdarwinwrong.com/kortho32.htm>
- Kauffman's 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>
- <http://adrenaline.ucsd.edu/Kirsh/Articles/Earwig/earwig.pdf>
David Kirsh, Today the earwig, tomorrow man?, in
Artificial Intelligence, 47, 1, 1991, pp. 161--184,
(A criticism of what Rodney Brooks was writing in the late 1980s).
 - Gert Korthof's web site is full of relevant reviews and discussions: highly recommended, though I've not yet read more than a tiny subset. Don't be fooled by the name of the web site:
<http://wasdarwinwrong.com/>
 - Imre Lakatos, *Proofs and Refutations*,
Cambridge University Press, 1976,
 - Imre Lakatos, Falsification and the methodology of scientific research programmes, in
Philosophical papers, Vol I,
Eds. J. Worrall and G. Currie, Cambridge University Press, 1980, Cambridge, pp. 8--101,
 - 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.
 - <http://www-formal.stanford.edu/jmc/child.html>
John McCarthy (1996). "The Well Designed Child"
(Later published in the AI Journal, 172, 18, pp 2003--2014, 2008)
 - Ulric Neisser wrote in *Cognition and Reality*, W.H. Freeman, 1976.
"... 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."
 - Mark Pallen, 2009. *The Rough Guide to Evolution*, Rough Guides, London, UK,

- J. Maynard Smith and E. Szathmáry, 1995. *The Major Transitions in Evolution*. OUP, Oxford, England.
- J. Maynard Smith and E. Szathmáry, 1999. *The Origins of Life: From the Birth of Life to the Origin of Language*, OUP, Oxford,
- Tibor Ganti, 2003. *The Principles of Life*,
Eds. E. Szathmáry, & J. Griesemer, (Translation of the 1971 Hungarian edition), OUP, New York.
See the very useful summary/review of this book by Gert Korthof:
<http://wasdarwinwrong.com/korthof66.htm>
- Steve Burbeck's web site:
<http://www.evolutionofcomputing.org/>
- K.R. Popper, *The logic of scientific discovery*, Routledge, London, 1934,
- Karl R. Popper, 1976,
Unended Quest, Fontana/Collins, Glasgow,
- Popper's Darwin Lecture: (Linked here 5 Apr 2014)
http://www.informationphilosopher.com/solutions/philosophers/popper/natural_selection_and_the_emergence_of_mind.html
Natural Selection and the Emergence of Mind
Delivered at Darwin College, Cambridge, November 8, 1977
Kindly made available on Bob Doyle's remarkable web site listed [above](#).
- Jean Sauvy and Simonne Sauvy, with an introduction by Bill Brookes
The Child's Discovery of Space: From hopscotch to mazes -- an introduction to intuitive topology,
Penguin Education, Harmondsworth, 1974. Translated from the French by Pam Wells,
- Juergen Schmidhuber (2013)
PowerPlay: training an increasingly general problem solver by continually searching for the simplest still unsolvable problem
Frontiers in Psychology, Cognitive Science June 2013, Vol 4, Article 313
<http://arxiv.org/abs/1112.5309>
- Juergen Schmidhuber, (2014)
Deep Learning in Neural Networks: An Overview,
Technical Report IDSIA-03-14,
<http://arxiv.org/abs/1404.7828>
- Erwin Schroedinger (1944) *What is life?* CUP, Cambridge,
I have annotated version of part of this book here
<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/schrodinger-life.html>
- A. Sloman, The mind as a control system, (1993), in *Philosophy and the Cognitive Sciences*,
CUP, Cambridge, UK, Eds. C. Hookway and D. Peterson, pp. 69--110,
<http://www.cs.bham.ac.uk/research/projects/cogaff/81-95.html#18>

- A. Sloman (1995), Exploring design space and niche space, in *Proceedings 5th Scandinavian Conference on AI*, Trondheim, 1995, IOS Press, Amsterdam,
<http://www.cs.bham.ac.uk/research/projects/cogaff/81-95.html#41>
- A. Sloman, (2000) Interacting trajectories in design space and niche space: A philosopher speculates about evolution, in *Parallel Problem Solving from Nature -- PPSN VI*, Ed. M.Schoenauer, et al., Springer-Verlag, Berlin, Lecture Notes in Computer Science, No 1917, pp. 3--16,
<http://www.cs.bham.ac.uk/research/projects/cogaff/00-02.html#62>
- **Peter Strawson on Descriptive Metaphysics (Added 30 Jul 2014)**
The Meta-Descriptive Metaphysics project.
A note on Strawson's notion of "Descriptive Metaphysics", which claims:
"There is a massive central core of human thinking which has no history - or none recorded in histories of thought; there are categories and concepts which, in their most fundamental character, change not at all."
Perhaps that core actually has a history, in the evolution of human minds and some of their precursors, and perhaps slightly different cores have evolutionary histories along different lineages. This suggests a new project: investigation of Meta-Descriptive Metaphysics described in
<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-descriptive-metaphysics.html>
- http://www.amazon.com/On-Growth-Form-Complete-Revised/dp/0486671356/ref=cm_cr_pr_orig_subj
D'Arcy Wentworth Thompson
On Growth and Form (1992)
The Complete Revised Edition (Dover Books on Biology) Originally published 1917.
There are some abridged editions, the latest of which has been much criticised in Amazon reviews.
I have been aware of this book for some time, but, alas, never got around to reading it. It is more concerned with evolution of physical forms and their development in individual organisms than with evolution and development of information processing. But what Thompson tried to do for physical forms in organisms is close to what the M-M project aims to do for forms of biological information-processing, including the claim that the processes of change of information-processing capabilities during evolution and during individual development and learning, like the processes of physical growth and development studied by Thompson, have rich mathematical structures. See also the Wikipedia entry on Allometry:
<https://en.wikipedia.org/wiki/Allometry>
Compare the work of [Brian Goodwin](#) on "Laws of Form".
- A. M. Turing, 1952, The Chemical Basis Of Morphogenesis,
Phil. Trans. R. Soc. London B 237, 237, pp. 37--72,
- Andreas Wagner, 2014, *Arrival of the Fittest: Solving Evolution's Greatest Puzzle*
Published by: Oneworld Publications,
- Web site listing common misconceptions about evolution:
http://evolution.berkeley.edu/evolibrary/misconceptions_teacherfaq.php

Others -- to be added: request for suggestions

I know there are lots more related books and papers -- 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](#).

Possibly related Penrose presentation

Presentation by Roger Penrose, Manchester 2012

Roger Penrose seems to agree partially with one of the ideas here. At the Alan Turing centenary conference in Manchester (June 2012) <http://www.turing100.manchester.ac.uk/>, he 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 available online: http://videlectures.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://www.cs.bham.ac.uk/research/projects/cogaff/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](#).

Penrose seemed to agree with the 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://www.cs.bham.ac.uk/research/projects/cogaff/talks/#gibson>

Maintained by [Aaron Sloman](#)
[School of Computer Science](#)
[The University of Birmingham](#)
Email: a.sloman[AT]cs.bham.ac.uk