



Tutorial at Diagrams 2018 -- Monday June 18th: 14:00-15:30

<http://www.diagrams-conference.org/2018/>

Were "Super-Turing" diagrammatic reasoning competences ancient products of biological evolution?

Alternative, shorter title:

Evolved "diagrammatic" spatial intelligence.

PRESENTER Aaron Sloman

<http://www.cs.bham.ac.uk/~axs/>

[School of Computer Science, University of Birmingham](#)

(DRAFT: Liable to change)

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ABOUT THE SPEAKER:

A summary overview can be found here: <http://www.cs.bham.ac.uk/~axs/about.html>

Keywords/phrases for tutorial and its implications:

- Evolution of ancient spatial mathematical competences using "diagrams in minds";
 - Evolved biological construction kits: concrete and abstract, fundamental and derived;
 - Biological foundations for mathematics -- Evolution: the blind mathematician
 - Forms of representation for intelligent machines
 - Requirements for ancient mathematical consciousness (Archimedes, Zeno, etc.)
 - Examples of toddler and non-human mathematical competences.
 - Serious gaps in current computational, neural, psychological and philosophical theories of spatial reasoning and mathematical knowledge.
(But Immanuel Kant had major insights over 200 years ago.)
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TUTORIAL OVERVIEW

Depending on who comes, and their backgrounds, I'll present a subset of these topics (definitely including the roles of spatial cognition in mathematical reasoning):

Background: The Turing-inspired Meta-Morphogenesis project

Varied examples of natural intelligence will be used to introduce aspects of the Turing-inspired Meta-Morphogenesis project, investigating changes in information processing functions and mechanisms since the earliest proto-life forms. This may help us to identify and perhaps later fill major gaps in current understanding of how minds work and how different kinds of minds vary, and how minds with those capabilities are implementable in biological brains.

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

Evidence is sparse, so the project requires intelligent guess-work: expanding available evidence by interpolating possible functions and mechanisms between observed cases.

A driving assumption is that the main aim of science is not to discover and explain **regularities** but to discover and explain **possibilities**, and their limits (impossibilities and necessary connections), as explained in [Chapter 2](#) of [Sloman \(1978\)](#). (The focus on regularities leads to shallow science -- and philosophy.)

Evolving requirements for biological information processing

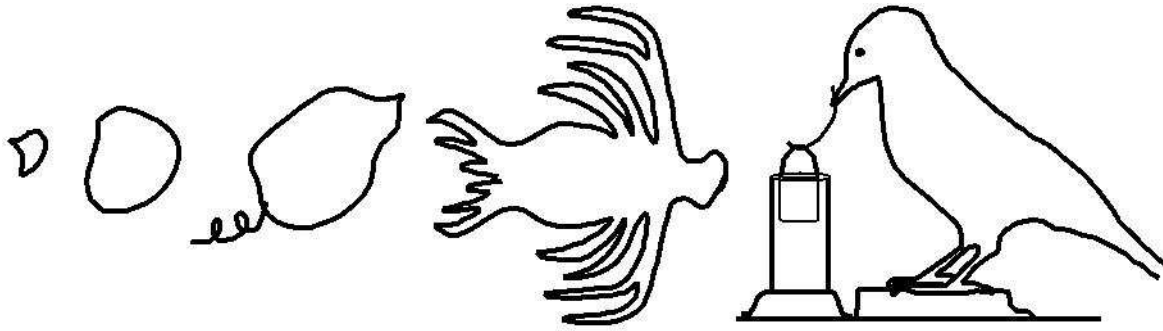
What's information? I use the word in the same sense as Jane Austen the novelist, rather than Claude Shannon, as explained here:

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

The most important fact about information is that it can be **used** (e.g. for control) not that it can be stored, transmitted and manipulated.

Changing life-forms include: changing needs, physical forms, control processes, kinds of terrain, opportunities, dangers, types of resource and *types of information* relevant to survival and reproduction.

Figure: Evolutionary Steps in Information processing



As a result, requirements for information-processing also change: organisms need increasingly complex and varied forms of information, and increasingly complex and varied mechanisms for acquiring, manipulating, storing, and using information, including, for example, [spatial information](#) for controlling actions and for reasoning about structures and processes, on various spatial and temporal scales. Current diagrammatic reasoning abilities build on this, but mechanisms are mostly unknown, and not yet in AI. The importance of statistics-based probabilistic learning is currently *vastly* over-rated.

Evolved cognition is increasingly [disembodied](#)

Because of the complexity and variety of kinds of information, uses of information, the diversity of needs and preferences, and the increasing spatial and temporal regions to be considered in making decisions and forming plans, [the cognitive processes become increasingly disembodied](#), i.e. disconnected from current environmental states, and current actions, and therefore disconnected from sensory input signals and motor output signals.

Modern engineering and architectural practices illustrate this: typically engineers and architects don't have physical contact with the things they design until long after all the main design decisions have been taken. Minor changes can sometimes be made at a late stage when physical interaction reveals something unexpected.

Likewise explanatory theories in modern science (e.g. subatomic physics, astrophysics, and theories about chemical processes in biological reproduction and gene expression) are also disconnected from the physical interactions of scientists with their environments, and from their sensory and motor signals. Humanly perceivable and manipulable laboratory objects (e.g. readings on measuring devices) are usually only very indirectly related to the concepts used in the theories being tested or applied. For instance, consider the unobvious relationships between scatter diagrams and chemical crystal structures in XRay crystallography.

All this is ignored in fashionable theories of embodied cognition [Note: It's hard to give references without giving offence! Compare the ["Chewing Test"](#) for intelligence.]

Likewise, most (all?) modern philosophers of consciousness (unlike [Immanuel Kant](#)), ignore mathematical qualia: the contents of mathematical experiences of possibility, impossibility and necessity.

Moreover, insofar as attempts are made to demonstrate the powers of embodied robots without complex computational control mechanisms, the abilities of the robots are usually pathetically limited, like the passive walker robots: the demonstrators fail to point out what will happen if you place a brick in front of the passive walker, or try to get it to walk up or down a staircase. A nice example:

<https://www.youtube.com/watch?v=rhu2xNlpgDE>.

Theories of embodied intelligence that I have encountered also ignore the commonalities between normal humans and those born blind or deaf, or lacking arms and legs, or inseparably conjoined with a twin, etc.

This tutorial is about some of the requirements for more intelligent systems.

Evolved construction-kits

Construction of those mechanisms in individuals requires increasingly complex **construction kits**, all ultimately based on the **fundamental** construction kit provided by physics/chemistry (about which there are still major gaps in our knowledge): As individuals develop new physical features and mechanisms they also build increasingly complex construction kits for building those new components.

Likewise, construction of new **information processing** mechanisms, requires construction of new construction kits for building those mechanisms, including meta-cognitive construction kits that build new mechanisms for meta-cognition.

This contradicts theories of learning and reasoning that assume uniform learning mechanisms throughout an individual's life.

Evolved mathematical (especially spatial) cognition

I'll give examples of requirements for construction kits and reasoning mechanisms that seem to have been used in ancient mathematical discoveries -- e.g. the amazing geometrical and topological discoveries reported in Euclid's *Elements*, extending earlier forms of spatial intelligence to use forms of spatial reasoning (e.g. "Diagrams in minds") that are still not replicated in current AI systems, using mechanisms as yet unknown to neuroscience, e.g. because current neural models explain only discoveries involving classification, correlation, and probabilities, but not discoveries of **impossibility** and **necessity** noticed by Immanuel Kant as essential features of mathematical knowledge.

I suspect, but cannot demonstrate, that when Turing wrote (Turing 1939, Sec. 11)

"Mathematical reasoning may be regarded rather schematically as the exercise of a combination of two faculties, which we may call intuition and ingenuity. The activity of the intuition consists in making spontaneous judgments which are not the result of conscious trains of reasoning. These judgments are often but by no means invariably correct. . . . The exercise of ingenuity in mathematics consists in aiding the intuition through suitable arrangements of propositions, and perhaps geometrical figures or drawings."

he was beginning to move toward ideas something like those presented here. I suspect, but cannot demonstrate, that this was connected with his thinking in the paper on morphogenesis.

What sorts of mechanisms can explain mathematical/spatial cognition?

The tutorial will analyse some requirements for such mechanisms and ask whether all are implementable as virtual machines on digital computers.

There are aspects of familiar spatial/diagrammatic/geometric reasoning that seem to be very hard to implement on digital computers/Turing machines, unlike types of logical/algebraic reasoning where everything is discrete and finite, and computers mostly outperform humans. Spatial reasoning, and perception and use of spatial affordances essentially involves continuous structures and processes. Can **digital** mechanisms go beyond approximate **simulation** of spatial structures and processes to include discovery of **impossibilities and necessary truths** about them?

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

Could new kinds of chemical computers help in some way? Could that be why Alan Turing's last great publication, in 1952 was about "The Chemical Basis of Morphogenesis"? If so, shouldn't sufficiently large and complex digital computers be able to approximate their functionality? Or could there be some deep difference between finding limitations of continuously varying structures and finding limitations of discrete representations of those structures?

What sort of Super-Turing multi-membrane machine might suffice?

I'll introduce the idea of a Super-Turing membrane computer that might be able to explain aspects of human spatial/diagrammatic/geometric/topological reasoning. This will introduce some of the ideas developed in this draft, incomplete, paper, posing some hard problems that I think nobody currently knows how to answer, though I suspect Turing was thinking about this in the last few years before his death in 1954.

An incomplete document (work-in-progress) attempting to make the ideas more precise is here:

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/super-turing-geom.html>

This requires solutions to problems in physics, chemistry, neuroscience, psychology, philosophy, AI, robot-engineering, and perhaps new kinds of mathematics. How much of this was Turing thinking about while writing his paper on chemistry-based morphogenesis? In [his 1939 paper](#) he showed that he was interested in intuitive thinking in mathematics as something distinct from "mechanistic" logic-based thinking. "Mathematical reasoning may be regarded rather schematically as the exercise of a combination of two facilities, which we may call intuition and ingenuity."

This tutorial will add much detail to my short paper accepted for the main Diagrams conference, available here:

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/diag-18-sloman.pdf>

Participants will be invited to comment on several types of example, selected from the documents linked below, and possibly others.

ONLINE EXAMPLES

An illustrative but incomplete list

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

A newly-discovered way of proving the triangle sum theorem.

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

Reasoning about what happens if you deform a triangle by moving just one vertex indefinitely along a line, continuously moving away from the opposite side. (There's an interesting discussion of what happens in the limit, in [Beccuti\(2018\)](#)).

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/ijcai-2017-cog.html>

Invited talk (video lecture) for a workshop on cognition at IJCAI 2017.

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

Many examples of reasoning about spatial impossibilities and necessity.
(Needs better organisation.)

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

"Toddler theorems" -- mathematical discoveries used (unwittingly) by pre-verbal human toddlers.

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

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

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/cardinal-ordinal-numbers.html>

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

The theory of evolution by natural selection presupposes but does not describe increasingly complex and powerful [construction kits](#) produced and used by evolution, and by products of evolution, to enable new designs to be used. including increasingly complex construction-kits for increasingly complex information-processing systems (many still unknown).

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-configured-genome.html>

Overview of the Turing-inspired Meta-Morphogenesis project

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

A biologist's use of the concept of "information".

For some time I have been collaborating with Jackie Chappell, a biologist who works on animal cognition, using the concept of (semantic -- non-Shannon) information I have been using, and attributing to Jane Austen ([above](#)). For a sample of Jackie's work see:

Jackie Chappell, 2014, Acting on the world: understanding how agents use information to guide their action, in

From Animals to Robots and Back: Reflections on Hard Problems in the Study of Cognition
Eds., Wyatt, J.L. and Petters, D.D. and Hogg, D.C., Springer, pp 51--64, 978-3-319-06614-1,

<http://www.cs.bham.ac.uk/research/projects/cogaff/chappell-action-on-the-world.pdf>

Abstract

Most animals navigate a dynamic and shifting sea of information provided by their environment, their food or prey and other animals. How do they work out, which pieces of information are the most important or of most interest to them, and gather information on those parts to guide their action later? In this essay, I briefly outline what we already know about how animals use information flexibly and efficiently. I then discuss a few of the unsolved problems

relating to how animals collect information by directing their attention or exploration selectively, before suggesting some approaches which might be useful in unravelling these problems.

REFERENCES AND LINKS

Francesco Beccuti, Stretching a triangle to infinity, May 20, 2018

<http://www.fbeccuti.it/pdfs/Triangolo.pdf>

Euclid, *Elements*

<http://aleph0.clarku.edu/~djoyce/java/elements/toc.html>

<http://www.gutenberg.org/ebooks/21076>

Brian V. Funt (1980), Problem-Solving with Diagrammatic Representations, in *Artificial Intelligence* 13 (1980), pp201-230 North-Holland

http://www.cs.sfu.ca/~funt/ProblemSolvingWithDiagrammaticRepresentations_AIJournal1980.pdf

Mateja Jamnik, 2002

Mathematical Reasoning with Diagrams: From Intuition to Automation

(Center for the Study of Language and Information Publication Lecture Notes)

<http://www.cl.cam.ac.uk/~mj201/book.html>

Immanuel Kant, 1781, *Critique of Pure Reason*, Translated (1929) by Norman Kemp Smith, London, Macmillan,

K. S. Lashley, The Problem of Serial Order in Behavior, in *Cerebral mechanisms in behavior*, Ed. L.A. Jeffress, Wiley, New York, 1951, pp. 112--131,

http://s-f-walker.org.uk/pubsebooks/pdfs/The_Problem_of_Serial_Order_in_Behavior.pdf

Tom McClelland, 2017, The Mental Affordance Hypothesis, in *Minds Online Conference 2017*,

<http://mindsonline.philosophyofbrains.com/2017/session-1/the-mental-affordance-hypothesis/>

Video of presentation: <https://www.youtube.com/watch?v=zBqGC4THzqg>

A. M. Turing, 1939, Systems of Logic Based on Ordinals, *Proc. London Mathematical Society*, pp. 161-228, <https://doi.org/10.1112/plms/s2-45.1.161>

Also reprinted in *Alan Turing: His work and impact* Elsevier 2013.

Eds. S. Barry Cooper and J. van Leeuwen, *Alan Turing: His Work and Impact*, 2013, Elsevier, Amsterdam,

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

Aaron Sloman [1978, revised 2001, ff.]

The Computer Revolution in Philosophy: Philosophy, Science and Models of Mind

Harvester Press (and Humanities Press), 1978, Hassocks, Sussex,

References to be expanded later.

See also the references in the conference paper:

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/diag-18-sloman.pdf>

This document is available as html and pdf

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

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/sloman-diagrams-tutorial.pdf>

A partial index of discussion notes in this directory is in

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

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