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Extending Turing's Pattern
From Morphogenesis to Meta-morphogenesis

Aaron Sloman
School of Computer Science, University of Birmingham, UK
http://www.cs.bham.ac.uk/~axs

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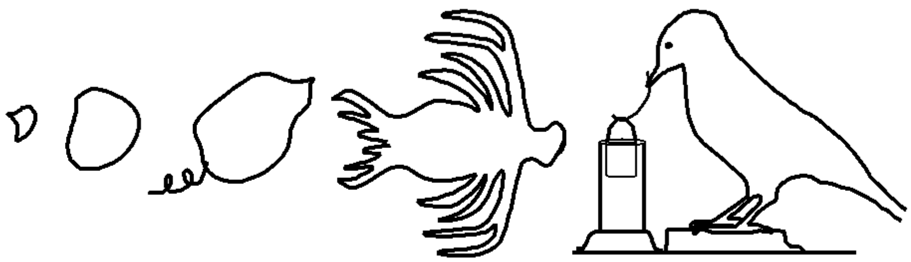

Turing's 1952 paper on chemical morphogenesis can be compared with his earlier work on Turing machines (TMs). Both demonstrate that some very simple local interactions can produce strikingly varied and complex large scale results. In a TM, many small, discrete changes in contents of a linear tape, with an engine controlled by very simple rules, can transform initial linear patterns, representing many different problems, into patterns representing solutions. This requires two important features: *representational power*: the ability of the patterns used to support a wide variety of rich and complex problems and solutions, for a fixed interpreter of the patterns, and *inference power*: the ability of the engine to transform those patterns from representations of *problems* to representations of *solutions*.

The 20th century saw major advances in digital electronic machines with those capabilities. An electronic computer can be understood as a TM with a finite, very fast, tape, nowadays often linked in networks and connected with various physical interfaces between the memory (tape) and things in the environment, allowing them not only to solve problems but also to produce useful behaviours by monitoring and controlling external devices.

Turing's 1952 paper showed, among other things, that in chemical morphogenesis local processes, in which chemicals diffuse through a growing structure and interact when they meet, can produce complex and varied global patterns, like dots, stripes, blotches, spirals, and others. Patterns on organisms can have rich biological functions, including camouflage, mate selection, attraction of pollinators, deception of predators, and probably many others. (His paper discussed far more than this.)

His 1936 computing machine was originally intended to replicate analogues of processes that occur in familiar human mathematical reasoning, whereas his chemical theory was intended to account for some familiar biological phenomena. In the first case all the structures and operations are discrete, whereas in the second case, continuous diffusion and changes of concentration play a role. However, molecular changes are discrete: there are not infinitely many intermediate cases between any two molecules (e.g. between O_2 and H_2O) as there are between two rational numbers, such as three fifths and seven eighths.

In 2011, reading the morphogenesis paper made me wonder whether, if Turing had lived, he might have attempted an even bigger challenge, namely showing how local interactions between molecules in a lifeless world might eventually produce the huge variety of living organisms now found on our planet: a far greater challenge than explaining the development of structure in a developing embryo, or the production of a proof in a symbol-manipulating engine.

The Darwin-Wallace theory of natural selection shows that, in principle, diverse and complex organisms, and ecosystems containing them, could emerge from much simpler systems by many small steps, provided that the mechanisms operated on by selection had the power to accommodate that diversity and complexity. But that left open the question: what sorts of underlying machinery could do that?

Computational experiments on artificial evolution suggested that in principle modern computers could replicate evolution of all living phenomena. However, combining and extending Turing's ideas about computation and morphogenesis may reveal previously unnoticed potential in the mixture of continuity and discreteness found in chemical information processing but unavailable in discrete symbol manipulators.

A possible clue: transformations from one molecular structure to another often require rotation, and a complex 3D molecule can be rotated without losing any information, whereas rotation of digitised images or models will lose information except for special cases (e.g. 90 degree array rotation). Non-rigid discrete transformations e.g. forming a spiral, are also problematic.

A mixture of discrete and continuous mechanisms may turn out to be crucial for providing new, deep and general explanations of processes in which a dust cloud condenses to form a planet that several billion years later includes microbes, monkeys, music, mathematics, manslaughter, metropolitan cultures and other marvels.

Would Turing have contributed to developing that idea? Thousands of researchers have investigated trajectories in the evolutionary history of the planet, but they have tended, with a few exceptions, to leave out one of the most important types of change, partly because they are invisible and hard to study, namely changes in *information processing*, including perception, learning, decision-making, problem-solving and control of many internal functions and external actions.

There is masses of evidence about the diversity of *physical forms* and *physiological structures* that evolution has produced. Our knowledge of that diversity increases with developments in technology for inspecting and experimenting on life at very small scales, and technology for accessing more varied environments, such as deep sea vents.

It is possible to acquire vast amounts of information about the diversity of *behaviours* of organisms, by direct observation of living systems, using inferences from fossil records, analysing requirements posed by environmental changes, and using laboratory experiments.

There has also been rapid expansion in our knowledge of the *chemical mechanisms and structures* underpinning biological evolution and individual development, including chemically implemented genetic mechanisms that, together with the environment of growing organisms, control the diverse developmental trajectories of organisms as different as bacteria, earthworms, giant fungi, daisies, giant redwood trees, squirrels, bats, crows, elephants and whales.

To that rich and growing store of knowledge about long past and very recent changes in structure, in behaviours, and in chemical mechanisms, Turing might have contributed new theories about the changes in *information processing*, combining and extending the kinds of thinking displayed in his work on morphogenesis and on Turing machines and computability.

There is a deep, rich, and largely unknown, repertoire of forms of information-processing required for the types of reproduction, development, control of behaviour, learning, perception, reasoning, communicating, forms of social interaction, and, in the case of humans, construction of powerful new explanatory theories and technologies and works of art. Research in psychology, linguistics, psychiatry, education, and other fields has enriched the set of facts to be explained by theories about biological information processing, but only in very complex systems most of whose details are inaccessible, and mostly cannot be inferred from their effects. What we've learnt from neuroscience leaves many explanatory gaps between physical mechanisms and information-processing, e.g. musical composition or mathematical reasoning.

Forms of information processing required in microbes, plants and animals of various kinds differ enormously. Sources of diversity include: sensory-motor morphologies restricting what information is available and what actions can be controlled, environments constraining what the information needs to refer to and diverse requirements for cooperation and competition using different forms of communication.

Those variations in information contents and types of information processing (e.g. acquiring, analysing, interpreting, deriving, storing, matching, communicating, and using information) suggest the need for variations in information processing mechanisms over evolutionary times, and in some cases during individual development – e.g. changes in information processing capabilities between a caterpillar and the moth it turns into, and changes between a new-born baby and the physics professor some years later. Besides mechanisms for producing new forms of information-processing there were also new mechanisms for producing those mechanisms, e.g. mate-selection and cultural evolution.

Researchers interested in what Turing might have done are invited to join the Meta-morphogenesis project: a multi-pronged attack on the problem of identifying unobvious forms of biological information-processing, such as explaining how the same genome can enable learning of thousands of possible languages, but not all possible languages, and explaining how our ancestors acquired the ability to make mathematical discoveries before there were mathematics teachers.

We can try to fill gaps in our knowledge about current systems by creating plausible, and, wherever possible, observationally tested, hypotheses about intermediate states between the earliest, simplest forms of life and the ones we are now trying to understand.

For example, microbes can detect the presence of chemicals in contact with their membrane and let some enter, others not. More complex mechanisms may use internal state sensors and admit different substances at different times, according to sensed needs. Still more complex organisms may not only sense external stimulation and react immediately, but sense changes over time, and, use the direction of change to influence motion: e.g. if the intensity of something harmful is increasing make a move. Later the moves might be controlled so as to follow trajectories of increasing or decreasing density. Even more complex changes in the mechanisms are required to allow organisms to acquire, store and use information about the spatial layout of important parts of the environment, near and far, or information about things that process information, e.g. other animals and themselves, or information about states of the environment that can be observed only from close up. Further complexity comes from abilities to take account of multiple needs. All of those changes require changes in information processing, often supported by new physical/chemical mechanisms.

Researchers wishing to join this very ambitious Turing-inspired project, can start by analysing what is already known about evolutionary changes and individual development, in order to come up with good theories about changes in the mechanisms responsible.

These web pages (still under development) present many more examples of changes in information processing during evolution, and in development of young humans:

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http://tinyurl.com/CogMisc/evolution-info-transitions.html
http://tinyurl.com/CogMisc/toddler-theorems.html
http://tinyurl.com/CogMisc/meta-morphogenesis.html
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