Recently hatched ideas about hatching and intelligence

Using very low energy physics and chemistry at "normal" temperatures in egg-laying vertebrates, with surprising implications for several research fields, possibly including fundamental physics.

Alternative title: Implications of Meta-Morphogenesis in hatching vertebrate eggs

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I'll try to show how hatching processes in eggs of vertebrates have important but unobvious links with a collection of apparently unrelated problems in several disciplines, including philosophy of mathematics, philosophy of mind, metaphysics, artificial intelligence, theoretical physics, biological evolution, developmental biology and psychology, and the Symbiogenesis theory of Lynn Margulis. Later I'll suggest (tentatively!) that those hatching processes may also challenge current theories in fundamental physics.

My investigations linking these disciplines and problems began in 2020 (extending related research in Philosophy/Al/Cognitive Science since 1959), triggered by reflection on the well known fact that there are many species of vertebrate hatchlings that emerge from eggs, possessing not only bodies containing a wide variety of extremely intricately interconnected internal physiological substructures and mechanisms, but also unlearnt species-specific spatial competences combining complex perception and action mechanisms used in performing various tasks, such as following a parent, or going to food and eating it, all done without first having to train neural networks after hatching, for which there isn't time before feeding is required.

This is illustrated by the post-hatching behaviours of avocet chicks in a 35 second videoclip from a BBC Springwatch programme in June 2021, https://www.cs.bham.ac.uk/research/projects/cogaff/movies/avocets/avocet-hatchlings.mp4, showing new hatchlings engaged in rich interactions with a complex environment.
including walking to a river and "fishing" for food.

The abilities of such hatchlings must somehow be produced by hitherto unnoticed biochemical hatching processes in eggs. How?

There are many different egg-laying vertebrate species, including chickens, avocets, alligators, turtles, pythons, etc., whose young emerge from eggs with very different physical forms, all possessing intricately interrelated general and species-specific physiological structures, and a collection of species-specific behavioural competences available after hatching, without having to be learnt.

So, hatching processes in the eggs of such species both:
-- transform the original chemicals in new-laid eggs into a much larger variety of chemicals used in multiple, intricately interrelated, body-parts with many different functions, in the new hatching.
and also
-- construct mechanisms that provide a variety of post-hatching spatial competences, used without requiring any training, e.g. new hatchlings of many species can perceive objects in the environment, select goals, plan and execute suitable actions, including moving toward, or avoiding, objects, in the environment, following a parent, and feeding themselves.

Note:

Related phenomena occur in insects that start life as grubs that grow by feeding themselves then produce cocoons in which processes of metamorphosis occur that transform the grubs into adults that have both completely new physiological structures (e.g. including wings) and new behavioural competences, e.g. flying, feeding in a new way and mating. The insect examples may provide evidence that can suggest or test answers to my questions about processes in vertebrate eggs, but will not be discussed further in this document.

How can so much extremely complex internal rearrangement of physical matter happen inside the eggshell of a developing vertebrate animal, starting with a single fertilised cell surrounded by a relatively small number of chemical substances separated by membranes in the egg?

How can chemical processes in eggs also produce competent new animals with a combination of enormously complex and varied species-specific internal physiological structures and processes as well as unlearnt behavioural competences? (Like the competences of the avocets, above.)

There are also difficult questions about how evolutionary processes were able to get the required information into the chemical structures in a newly formed egg.

[After I asked myself that question, an internet search led me to this surprising answer: https://www.ucdavis.edu/food/news/study-challenges-evolutionary-theory-dna-mutations-are-random (by by Emily C. Dooley).

I suggest that answers to these questions, i.e. explanations of the evolutionary and developmental phenomena, depend on sequences of extremely complex biochemical developmental control mechanisms in eggs of many different species, bootstrapping
construction of both physiological structures in the eggs, and also construction of increasingly complex forms of virtual (non-space-occupying) machinery, that control intricate multi-strand, highly parallel, chemical assembly processes inside the egg, and also produce and control species-specific post-hatching behavioural competences, illustrated by the post-hatching behaviours of young avocets above.

How is all that possible?

An incomplete answer is sketched in my talks and online notes on this topic, involving (among other features) use of a previously unnoticed [*], parallel, branching, growing collection of increasingly species-specific “Maxwell demons”, implemented using conjectured increasingly complex multi-layered forms of virtual machinery operating within the egg, but without occupying physical space in the egg, since no spare space is available!

[*]. If anyone knows of useful related work on hatching mechanisms, I'll be grateful for information. [Contact: a.sloman AT bham.ac.uk]

Could all that be achievable using large collections of simultaneously active electromagnetic signals, some of which trigger production of both new physiological structures and also new control machinery during hatching?

What mechanisms could enable so many concurrently active construction/assembly mechanisms to operate in parallel in the same small space (i.e. inside the hatching egg) without seriously interfering with one another during normal development, though sometimes things go wrong, producing deformities, conjoined twins etc., as reported in https://www.thepoultrysite.com/articles/chicken-embryo-malpositions-and-deformities

Successive collections of virtual machinery in the egg control constructions in different developmental stages during hatching, both controlling chemical processes that produce new, increasingly complex, species-specific physiological structures, and also controlling processes that produce the next level, species-specific, more recently evolved, successor control machinery, i.e. more recently evolved (virtual) assembly demons! (Compare Levin’s work.)

These ideas are crudely depicted in a complex online diagram (liable to change), available at http://www.cs.bham.ac.uk/~axs/fig/evo-devo/evo-devo-final.jpg, used during the presentation.

The conjectured mechanisms, including a great deal of simultaneous more or less coordinated "action at a distance", performing much more complex sorting and construction tasks than Maxwell’s demon, may point to gaps in current fundamental physical theories, in addition to the need for important revisions of theories in philosophy, psychology, neuroscience, theoretical biology, and AI.

Increasingly sophisticated forms of virtual machinery have been developed by human designers during the last half century, especially since the advent of the internet and applications such as online banking, online distributed databases of information, online reservation systems, and applications such as email, discussion support mechanisms (e.g. Zoom), online games, etc.
Perhaps ancient processes of biological evolution anticipated such achievements for use in far more complex and intricate biological control processes, using biochemical mechanisms rather than the kinds of digital computing technology used by human engineers.

That seems to be a possible interpretation of claims made by Lynn Margulis, referenced below, regarding the role of symbiogenesis in the history of this planet. Compare Shubin et. al. (1997)

[End of extended abstract]

More details can be found below. This document presents still evolving work-in-progress, and is liable to change. Offers of help are welcome. I'll also be grateful for information about relevant mechanisms not mentioned here.

There is more or less closely related work by other researchers, notably research by Mike Levin and collaborators that will be presented at the same conference in January 2023.

However, as far as I know neither he nor anyone else has attempted to explain either how so many very different chemical decomposition and assembly processes in eggs can be coordinated in parallel, or how they produce organisms that hatch with important cognitive competences ready for use, as illustrated by the avocets, shown in the video above.

Many more details and more questions related to this project are linked, above and below on this web page
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo.html

Note: We don’t yet know what we don’t know!

Although this document mentions important gaps in our knowledge (search for occurrences of the word "gaps"!), there are likely to be additional unnoticed serious gaps or errors in my reports and conjectures above and below, in part because this work relates to a very wide range of research fields -- including much under-developed or mistakenly constrained research. (I think much research on neural network mechanisms is mistakenly constrained because the researchers have not yet understood what needs to be explained or modelled, e.g. in mathematical discovery processes.)

Many of the questions raised here will surely have possible answers that I have failed to consider. It is even more likely that there are important questions that nobody (on this planet?) has noticed! I’ll be grateful for information or tips about such flaws, and suggestions for correcting them or improving clarity, etc.

Selections from this document will be used for conference presentations. Next one in January 2023, announced above.

Earlier, simpler, online documents, partly overlapping with this one, were used for talks during 2020, 2021 and 2022, while the ideas were growing increasingly complex.
(End of note)

Location of This Document
Since 8th Nov 2022, this document is available at:
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo.html

All other versions that are still accessible are now out of date, as this one is, because several of the web sites referenced (like this one) are still subject to minor or major modifications/extensions.
I can provide a PDF version if requested. It too will soon be out of date!

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**NB: THIS IS STILL UNDER CONSTRUCTION AND LIKELY TO CHANGE**

Some of the major changes are listed above and below!

Last updated: 9 Dec 2022

9 Sep 2022: Added [link to avocet video](http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo-stepney.html).

10 & 17 Sep 2022: Added information about meta-configured genomes.

15 Sep 2022: New versions of main diagrams:

A precursor of the diagrams below, based on a pencil sketch by Susan Stepney after she had heard me talk about these problems early in 2022, can be found, along with Susan's sketch, in [http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo-stepney.html](http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo-stepney.html), presenting development going from top to bottom and evolution from left to right, unlike the newer diagrams used below.

17 Oct 2022: added links to (a subset of) Related work

08 Nov 2022: shortened web address of this document.

Oct-Nov 2022: Much reorganisation. Added references. Still in progress

Revised version of main (complete) Evo-Devo diagram

26 Nov 2022: added 'stub' section on unanswered questions.

[**] BACKGROUND: About the title ("Recently Hatched ...")

This web page (used as a basis for online presentations) is an attempt to explain how a collection of apparently unrelated topics have deep, important connections that are not widely recognized. The topics include problems in philosophy of mind, Immanuel Kant’s philosophy of mathematics, biological evolution, developmental biology, developmental psychology, fundamental physics, and also aspects of biochemistry that are crucial to biological evolution, reproduction, development, and implicit forms of spatial intelligence required by reproductive processes in many species. The partial answers proposed below, illustrated by some complex diagrams, remain incomplete. Some deep unanswered questions are raised below, including questions about the adequacy of current theories in fundamental physics. As mentioned in the abstract above, the work of Lynn Margulis on chemistry-based symbiogenesis referenced below is very relevant.

Although I have learnt a great deal from developments in computer science and technology (since I first started learning to program, around 1969) I do not assume that the biological products based on biochemistry can be implemented in digital technology. One advantage of chemistry over digital circuitry is that it intrinsically combines continuous and discrete processes: e.g. processes in which particles smoothly change their spatial relationships and also non-continuous processes in which bonds are formed or released. (Alan Turing’s [1952 paper](http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo-stepney.html) on chemistry-based morphogenesis seems to make similar assumptions, and also Schrödinger in What is life? (1944).)

I’ll try to show why extremely complex, but largely unnoticed, developmental control mechanisms in eggs, using a sequence of increasingly complex forms of virtual (non-space-occupying) machinery, may be related to forms of spatial intelligence used by many animals shortly after hatching, i.e. without having to be learnt. The mechanisms are also related to the ideas about "Meta-Configured" genomes, developed in collaboration with Jackie Chappell, since about 2005.

I suspect these ideas are also relevant to explaining forms of intelligence used by ancient humans, including ancient engineers, architects, designers and builders of complex machines and buildings (e.g. temples, pyramids, and the temporary structures used to aid construction) some of whom
made discoveries in geometry and topology and used them for practical activities, long before well
known ancient mathematicians such as Pythagoras, Archimedes and Euclid were born, and even
longer before logic-based reasoning mechanisms were invented and used by humans. I doubt that
they are used by any other intelligent species (at least on this planet!).

I have focused on the special case of reproduction in *vertebrate* species using eggs, although
much of the discussion is potentially relevant to evolution and development of other species,
including mammals and insects, though there are important differences.

Egg-laying vertebrate reproduction processes have sufficient complexity to illustrate the main
points, and, because the processes occur in eggs, not in wombs (as in mammals), their reliance on
self-bootstrapping is more obvious.

But the processes remain extremely complex. I am confident that no human-designed construction
process (so far!) matches, or even comes close to matching, the complexity of the transformations
that occur in eggs of vertebrates during hatching, as conjectured here.

It is also very likely that I have *under*estimated the complexity of the hatching problems and
mechanisms!

Later work will attempt to bring out more clearly the relationships between control of assembly of
multi-layered structures in systems designed by humans and the multi-layered forms of control
discussed in hatching vertebrate eggs.

I'll also try to show later how philosophy of mathematics (defending Immanuel Kant’s claims about
mathematical knowledge) takes on a new life as part of, or at least a close relative of, philosophy of
biology, including biochemistry, because of the topological and geometrical structures and
processes involved in hatching, and the connections between mathematical understanding and
effective control of complex assembly processes.

This could be thought of as work in biology, or theoretical biochemistry or theoretical physics or
philosophy of mind or philosophy of mathematics or philosophy of ...: one of many examples of the
fact there can be deep overlaps between scientific and philosophical theories.
(A note on the history of some of the ideas presented here is available below.)

Important details remain to be worked out. (Offers of help are welcome!) My focus for now is on
hatching processes in eggs of vertebrates, partly because of the combination of detailed
differences and high level similarities in the hatching processes of different vertebrate species, and
also because hatching processes are relatively isolated processes, unlike development of an
animal in its mother’s uterus, influenced by continually changing interactions between mother and
foetus. (The key ideas are also relevant to mammals and insects, but that is not obvious.)

As mentioned above, there is comparable complexity in other biological processes, e.g.
spectacular physiological and behavioural changes produced by metamorphosis of insect-grubs
inside cocoons, which seems to imply either that evolution made relevant discoveries before
divergence of the evolutionary histories of insects and vertebrates, if they have common ancestors,
or made related discoveries at least twice.
I have not encountered philosophers of physics, philosophers of mind or philosophers of mathematics who have shown any interest in the detailed chemical/biological phenomena in hatching eggs discussed here, though there are physicists who have been interested in some aspects of the problems, notably Erwin Schrödinger in *What is life?* (1944), Roger Penrose in his presentations on the foundations of geometry, and some colleagues in private conversations. I suspect unpublished work by Alan Turing addressed these problems.

**What’s so interesting about hatching?**

For about 60 years, I failed (and many researchers still fail) to notice the deep relevance of hatching processes to problems about the nature and evolution of minds, consciousness, and mathematical competences, discussed below.

The line of thought presented here began when, in October 2020, triggered by a discussion in an online conference, I suddenly realised, for the first time, that well-known competences of newly hatched young vertebrates of many kinds, e.g. chickens, ducks, alligators and many other species, refute some of the comments being made at the conference, e.g. about intelligence resulting from processes of training of neural networks. Such post-hatching competences also present serious challenges for current theories in biology, neuroscience, psychology, philosophy and related disciplines, including Artificial Intelligence.

Less obviously, I’ll try to show that facts about hatching also (indirectly) challenge popular views about the nature of mathematical knowledge, including knowledge of geometry and topology, and also seem to me to pose challenges for current theoretical physics -- unless there’s already something relevant in theoretical physics of which I am ignorant.

The mathematical facts discussed below are concerned with aspects of geometry and topology that are relevant to reliable control of assembly of very complex, intricately interrelated, physiological structures composed of many different kinds of physical material (bones, muscles, cartilage, nerve fibres, blood vessels of different sorts, glands, digestive mechanisms, injury repair mechanisms, outer coverings such as skin, scales, shells, feathers, or fur), which assemble themselves in increasingly complex parallel, processes, and do so in much smaller, much more crowded, spaces, than the working environments of any machines designed by human engineers.

The assembly mechanisms in vertebrate eggs apparently make intelligent use of increasingly complex spatial structures, relationships and functional requirements, though I am not claiming that intelligent agents are involved.

Those structures and processes involve complex, changing, geometrical and topological relationships between components of eggs and the animals that emerge. Unfortunately, many highly intelligent researchers have had an education in mathematics that does not include the relevant aspects of geometry and topology, mostly discovered by ancient mathematicians and engineers.

In the middle of the 20th century, teaching in geometry was dropped from the school mathematics syllabus in many countries for bad reasons. To help victims of that education change, some relevant geometry tutorials are referenced below.
I began to think about and talk about processes and mechanisms inside hatching eggs in September 2020. During 2021, until early 2022, my talks kept extending ideas previously presented. Early in 2022 the ideas linking evolution and development grew more complex. After hearing me talk about the new ideas Susan Stepney sent me a pencil sketch linked below in which she attempted to summarise what I had been saying.

Inspired, at first, by Susan’s sketch, I started using more complex diagrams presented below emphasising different aspects of a large, complex, and still incomplete, collection of ideas linking mechanisms and processes of evolution and development, and their consequences.

The consequences are relevant to problems in philosophy of mathematics, philosophy of mind, neuroscience, psychology, theoretical physics, and possibly also gaps in current ideas about the foundations of physics.

The remainder of this document omits much of the background detail that was included in earlier versions that eventually grew too long and too disorganised, e.g.:
(Alas some of the problems still affect this version!)

So this new document/presentation includes only a key subset of the ideas. I hope that restriction makes the paper easier to understand. References to some related work are included below.

Note: I am not claiming that research in biology and related disciplines has already provided detailed answers to the questions raised below. Instead I claim that they are deep, difficult, and important questions that have not yet been answered, though I’ll try to describe some recent steps toward answers taken in the multi-faceted meta-morphogenesis project.

Why focus on hatching processes in eggs rather than mammalian reproduction in wombs?
The contrast between development of a foetus inside an eggshell and development in a uterus (e.g. in mammals) is mentioned in a recent publication referenced below.

For the purposes of our research on mechanisms of reproduction, the eggshell case is more useful because it shows how much intricately structured complexity can be achieved by an embryo developing with little or no scope for phenomena outside the egg (e.g. the mother’s physiology) to control details of processes of development inside the egg, e.g. initiating and guiding growth of blood vessels or nerve fibres, or controlling relationships between different sorts of structures, e.g. relations between bones in a spinal chord and nerves, blood-vessels, and muscles.

In eggs, very many physical organisation decisions are taken during hatching processes. More surprising is the fact that the chemical hatching processes in eggs can somehow provide information about how the new individual should act in its environment after hatching -- information that many researchers explicitly or implicitly claim has to be acquired by learning mechanisms after hatching (or birth) has occurred. That claim is refuted by many species, including the behaviour of the recently hatched avocets shown in the videoclip below.

(Suggestions for improvement of any of my online documents/presentations are welcome!)
Original Stepney-inspired diagram, followed by later versions

Below I’ll present several diagrams, developed since March 2022, combined with text, in an attempt to summarise a complicated collection of ideas about evolution and development in egg-laying vertebrate species.

The "Evo-Devo" diagram referenced below is based on an idea for such diagrams originally suggested in a pencil sketch sent to me by Susan Stepney, after she heard me present an early version of the most recent ideas below.

I later switched to a more complex sequence of diagrams shown below, in the hope of bringing out some of the ideas more clearly.

I now provide both the simpler version giving a simplified overview, followed by more complex diagrams, giving more details. But I suspect all this can be done better! (Suggestions welcome.)

The key idea developed during 2022 was that newly evolved complexity in the organism required new layers of structure in the in-egg hatching processes, which in turn required new layers of increasingly species-specific control mechanisms used during hatching.

In more recently evolved species of vertebrate egg-laying animals, there are more distinct layers of development, with later layers using species-specific meta-mechanisms also specified in the genome, i.e. mechanisms for using the later genetic information, in combination with information about what has so far been achieved in the egg, to control later stages of embryo assembly.

I am claiming that later stages of hatching in vertebrate eggs are controlled by more recently evolved meta-mechanisms for interpreting and using more recently evolved assembly instructions.

So gene expression (in the egg) includes parallel paths of specification of different parts of the new hatchling contents, and increasingly complex specifications of mechanisms for using increasingly complex, more recently evolved genetic details. The genetic specification controls not only the formation of the animals physiology within the egg, but also the behavioural abilities shown by the new animal shortly after hatching.

The increasing complexity of more recently evolved biochemical/biological mechanisms for gene-expression and control of gene-expression corresponds loosely with the increasing complexity of bootstrapping mechanisms in computer science and computer systems engineering since the 1950s, documented (incompletely!) by Wikipedia: https://en.wikipedia.org/wiki/Bootstrapping

(Many computer scientists and computer systems engineers think only about subsets of these mechanisms.)

My original diagram inspired by Susan Stepney’s sketch showed evolution as going from left to right and in-egg development going from top to bottom. The later diagrams swap these: development goes from left to right and evolution from top to bottom. I think this made the diagram easier to understand (partly because English text flows from left to right!).
Use of virtual machinery

The presentation makes use of a notion of "virtual machine" that has emerged from a collection of increasingly complex developments since about 1960 that allow computational processes of many sorts, to be implemented in increasingly complex networks of physical machinery that can change over time while the virtual machines persist and change in different ways, often running on changing, possibly cross-continental, physical computing machinery.

Examples of such virtual machines include online banking systems, international email systems, flight reservation systems, trans-national air-traffic control systems, and, more recently, systems like Zoom, that make possible international, including trans-continental, meetings that bring together, at short notice, collections of users with different background knowledge, different hardware, in different locations, for lectures, discussions, family get-togethers, and many other purposes that don’t require physical contact but make use of visual, auditory and textual communication across a very complex international network of information processing mechanisms and (constantly changing) information stores. For more information on Zoom see: https://en.wikipedia.org/wiki/Zoom_(software).

Beware of oversimplified/out-of-date notions of Virtual Machinery

Much (most?) of the online information about virtual machinery is out of date and over-simplified. A useful exception is this tutorial (which I have so far only sampled in part): https://www.vmware.com/topics/glossary/content/virtual-machine.html

It describes several different kinds of virtualisation, but does not cover all the types that have become available during the 21st century, and does not mention the much older uses of virtualisation discovered millions of years ago by biological evolution, and, if I am right help to explain control of hatching processes in vertebrate eggs and probably many other ancient biological phenomena. In other words the biosphere was using very complex varieties of virtual machinery long before humans did, and long before any humans existed.

The presentation below claims that long before human scientists and engineers discovered the powers of virtual machinery, biological evolution "discovered" and made use of virtual machinery in processes that transform the relatively homogeneous collections of matter inside an egg into the richly differentiated and enormously complex collection of interacting physiological structures in a developing organism, hatching in the egg.

I am not claiming that such mechanisms are used only in eggs -- there are many even more complex examples in other forms of reproduction, e.g. in mammals, but the key ideas are easier to present in relation to hatching processes in eggs of vertebrates because they achieve so much inside the eggshell, with so little interaction with the environment, unlike an embryo developing in a womb, for example, or gene expression in a plant seed during increasingly complex interaction with the environment as the plant grows.

This implies that, during individual development inside an egg, members of recently evolved vertebrate species, with multi-stage evolutionary histories, will go through several changes in control mechanisms for assembling various parts of a new organism during the hatching process.
As explained below this is not a variant of the “Recapitulation Theory” according to which ontogeny recapitulates phylogeny.

The importance of virtual machinery
Why virtual machines?

Both
-- the control mechanisms used within the hatching egg for assembling physical particles to form the new hatchlings,
and
-- the control mechanisms for creating those new control mechanisms

must be virtual machines (in the sense evolved by 20th and 21st century computer systems engineering), because there is no room in an egg for machines composed of physical matter to manipulate millions of molecules to form the new physiological structures required by the developing embryo.

The virtual machines that achieve those results must somehow be implemented in physical/chemical machinery in the egg, without taking up extra physical space that physical manipulating mechanisms would require. Such virtual machinery could be implemented using extremely intricate networks of electromagnetic fields or signals, for example.

I suggest that there will be stages in construction of the new individual, corresponding to major transitions in their evolutionary history, and part of what happens at each stage is construction of new, more recently evolved, controlling virtual machines as well as construction of new chemical structures created by disassembling complex molecules and reassembling components to form new, increasingly complex, chemical structures, in processes controlled by increasingly complex new virtual machines as the physiology in the foetus becomes more complex.

As hatching proceeds both the physical/chemical subsystems produced, and the types of virtual machinery controlling those production processes become increasingly varied, increasingly complex, and increasingly species specific.

Note: claiming that the changes in virtual assembly-control mechanisms during hatching partly reflect changes in assembly-control mechanisms during the evolutionary history of the species does not imply that physical changes in the foetus repeat physical adult stages that occurred in the evolutionary history of the species. There may be some partial replication, but I am not endorsing the old idea that ontogeny recapitulates phylogeny in that sense. (See https://en.wikipedia.org/wiki/Recapitulation_theory)

Rather mechanisms of ontogeny recapitulate some of the evolutionary history of mechanisms of ontogeny.

This also raises the question: Which such chemistry-based virtual machines continue to play important roles in cognitive processes after hatching -- roles that apparently have never been noticed by neuroscientists? Please let me know if I am wrong. Roles of hormones in later stages of human development are special cases.
NOTE: Neither evolution nor development can be continuous

Evolution and development must both be at least partly discrete insofar as the mechanisms of change are chemical, and chemical changes include formation and removal of bonds between physical particles: discrete changes.

The claim that reproductive processes that produce biological evolution must be at least partly discrete was clearly stated by Erwin Schrödinger in his 1944 book *What is life?* and the updated 1967 version: [https://archive.org/download/WhatIsLife_201708/What%20is%20Life_text.pdf](https://archive.org/download/WhatIsLife_201708/What%20is%20Life_text.pdf)

It is possible that the point was made earlier by one or more other scientists.

I think this clashes with much that is written by philosophers of physics, using notations suggesting that all general physical facts/laws can be expressed in the form of equations using variables that range over numerical values, using functions that take such values as inputs and produce them as outputs. Such formats are not suited to express facts about what is physically possible and cannot capture facts about mixtures of continuous and discrete physical processes producing changes in complexity, used most dramatically by mechanisms of biological evolution and development, as emphasized by Lynn Margulis.

Whatever collection of numerical values captures the state of a new laid egg, something richer than changes in those values is required to describe the processes that occur during hatching, including chemical transformations that produce an increasing variety of new types of physical structures interconnected in increasingly complex ways, performing increasingly varied physiological functions.

Can those functions be specified in terms of changes in numerical values of quantities that existed in the new laid egg? No, a sequence of increasingly complex ontologies seems to be required to capture both developments during hatching in an egg and, on a grander scale, the developments that occur during biological evolution. Later ontologies need not be definable in terms of their evolutionary predecessors.

This is related to the well known inadequacy of systems of numerical equations linking a fixed collection of numerical variables to capture changes in linguistic competence that involve changes in number and variety of grammatical structures used and understood, along with acquisition of an increasingly complex and varied vocabulary.

The diagrams below are not intended to capture all these details: they merely refer in a very general way to changes of variety and complexity of structures and processes that occur in an egg during the hatching process.

_Evo-Devo diagrams_

The first diagram below, inspired by Susan Stepney’s pencil sketch (which had less detail), was my first attempt to represent, at a high level of abstraction, the combinations of evolutionary and developmental processes and mechanisms, using collections of virtual machines indicated as (VM)
below, including new VMs created by older VMs as new stages of hatching emerge.

Attempts to add more detail to the diagrams led to the revised format presented below. But the new diagrams remain very abstract compared with all the details of chemical changes that occur in eggs. For example -- no species-specific details, such as the details specific to hatching chickens, or turtles or alligators, are represented here.

A NEW COLLECTION OF EVO-DEVO DIAGRAMS

The figures below, produced in September 2022, are more recent, presenting a different view of the combinations of evolution and development. However they still leave questions unanswered as mentioned below.

The third diagram below labelled Figure Evo-Devo (latest stage of evolution), summarises the changes in development across evolutionary transitions in a different way from the diagram above: Figure Evo-Devo-Multi-VM.

At first I used only one new diagram, namely the third diagram but after deciding that it was too complex to be absorbed I added the first two diagrams showing how the third diagram is built up. Readers who find the third diagram below intelligible can skip the previous two!

The first diagram below summarises ideas about an early stage of evolution of an ancestor of current vertebrate egg-laying species, and adds some hints about effects of later evolutionary changes produced by genetic mutations.

The second diagram shows a later stage of evolution, in which there is a major new transition during development of the foetus inside an egg, requiring a transition to a new, more complex, form of control of development because of the need to coordinate development of more, and more diverse, components.

The third diagram below subsumes the two preceding diagrams, and adds a much later stage of evolution, where processes controlling developments in the egg have several new layers of complexity, because the physiological structures being assembled are more complex and diverse -- as a result of more evolutionary transitions.

If a better form of presentation occurs to me, or the ideas evolve, I may change these diagrams later. (Suggestions welcome!)
Figure Evo-Devo-a (early evolution)

WHY DO IN-EGG ASSEMBLY PROCESSES IN RECENTLY EVOLVED EGG-LAYING VERTEBRATES REQUIRE A SUCCESSION OF DISTINCT (“VIRTUAL”) MECHANISMS CONTROLLING ASSEMBLY?

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Part 1: EARLY EVOLUTION OF EGG-LAYING VERTEBRATES

INDIVIDUAL DEVELOPMENT IS A MIXTURE OF DISCRETE AND CONTINUOUS PROCESSES,
(Changes in chemical bonds are discrete. Motion in space is/seems to be continuous)

[ = genome ]

SINGLE CELL EGG
Available chemicals
New growing embryo

DEVELOPMENT
unused matter

New organism
(Ancient species)
(includes virtual machinery)

MULTI-CELL ADULT

EFFECTS OF MUTATIONS
Include: adding new joints, new coverings, new control mechanisms and new behaviours

NEW CLAIM:
There’s no space in an egg for physical space-occupying mechanisms able to assemble intricately structured vertebrate bodies.
Evolution “discovered” the powers of non-space-occupying (virtual) machines long before human computer scientists did (or even existed)!

KEY: Virtual machines are implemented in, and control behaviours of, physical bodies. Both grow increasingly complex during species evolution. VMs are needed to control assembly of new organisms in eggs: there’s no space in eggs for physical assembly machinery as in factories.
Figure Evo-Devo-b (later evolution)

More than one stage of development.

Note: this figure and the next one slightly modified 16 Sep 2022

**WHY DO IN-EGG ASSEMBLY PROCESSES IN RECENTLY EVOLVED EGG-LAYING VERTEBRATES REQUIRE A SUCCESSION OF DISTINCT ("VIRTUAL") MECHANISMS CONTROLLING ASSEMBLY?**

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(Sept 2022)

**DEVELOPMENT IN EGG-LAYING VERTEBRATES**

INDIVIDUAL DEVELOPMENT IS A MIXTURE OF DISCRETE AND CONTINUOUS PROCESSES. EVOLUTION OF SPECIES THAT REPRODUCE BY MATING MUST BE DISCRETE AND MUST BRANCH BACKWARD AND FORWARD

[Figure showing evolutionary processes with labels:]

- **SINGLE CELL EGG**
  - Small creature
  - Available chemicals

- **EVOLUTION**
  - Ancient Genome
  - Effects of mutations include: adding new joints, new coverings, new control mechanisms and new behaviours
  - Egg of later species
  - New core embryo
  - Available chemicals

- **EVOLUTION**
  - Later Genome
  - More mutations
  - Mutations produce more joints, new outer layers, new behaviours etc.

- **DEVELOPMENT**
  - New growing embryo
  - Unused matter

- **NEW CLAIM:** There’s no space in an egg for physical space-occupying mechanisms to assemble intricately structured vertebrate bodies. Evolution “discovered” the powers of non-space-occupying (virtual) machines long before human computer scientists did (or even existed)!

- **MULTI-CELL ADULT**
  - New organism (includes virtual machinery)

- **Individual of new species**
  - New core embryo
  - New growing embryo
  - Construction controlled using new virtual control machinery specified in new genome

**KEY:** Virtual machines are implemented in and control behaviours of physical bodies. Both grow increasingly complex during species evolution. VMs are needed to control assembly of new organisms in eggs: there’s no space in eggs for physical assembly machinery as in factories. As evolution adds new layers of structure to physical designs, it also needs new VM components to control physical assembly during hatching. In 2021 presentations, I claimed that the VMs controlling assembly of new organisms in eggs would need to grow new VM layers to control later stages of assembly. The above crudely depicts an early evolutionary development.
Changing Control Ontologies
A feature of the theory that is not captured in the above diagrams is that the mechanisms involved in controlling developmental processes in the eggs must use different kinds of information, including:

- information about the current state of development in various parts of the embryo,
- information about states that do not yet exist but need to be brought into existence, and
- information about possible changes that should be made to occur, or should be prevented from occurring, i.e. information about goals and preferences: control information.
As the reproductive process continues, new kinds of information become available for use in controlling embryo-construction actions. Such useful information includes information about what has so far been achieved, derived from internal sensing, i.e. factual information and information about what needs to be achieved in the current situation, derived from species-specific control information in the genome, which only becomes accessible to action-selection processes at later stages of reproduction.

Such factual and control information can be used to evaluate current states of affairs, e.g. as desirable, incomplete, undesirable, or better or worse than some other possible states. Such evaluations can then be combined with factual information about possible actions in the current situation, or target information, about future states to be achieved. This can drive control processes that select changes to be made, or changes to be prevented (e.g. which states should be preserved, once achieved).

In abnormal cases, where something unusual has happened during development, unusual compensatory developmental processes may be triggered. (How? Different cases need to be distinguished and investigated.)

Such varieties of information about what has been achieved so far and about what needs to be achieved, or prevented, will depend on the current state of development of the embryo, and will keep changing over time.

As the embryo grows, new controlling sub-processes will be generated, combining information about what has been developed so far with genetic information about what to add, which will be different at different stages of development in an individual and will also differ across species.

A new control layer will need to use information about what materials and structures have already been assembled in different locations and which new ones need to be assembled in different locations, and how the components of the new ones need to be related to old components (e.g. extending, or branching, or attaching a muscle, or providing new blood vessels or nerve fibres for the new anatomical structures).

As the parts of the new embryo become increasingly differentiated the variety of types of information about what exists and what needs to exist will also become increasingly differentiated, as will processes controlling changes in different parts of the developing embryo.

That may (occasionally?) include information about something that exists that should not exist and therefore needs to be undone or compensated for in some way.

For example, if a developing embryo for some reason starts to develop two heads, this will require changes in control of other developments, so that the two heads become connected with appropriate resources, including blood supply, nerve fibres, bone structures, muscles, etc. In some cases the compensatory changes do not succeed and the foetus dies, whereas in others a complex collection of coordinated adjustments to standard developmental processes occurs and a highly abnormal individual emerges, which may or may not survive for some time after hatching.

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**UNSOLVED PROBLEMS**

Many questions are not yet answered by the above conjectures

(Added 26 Nov 2022)
The above presentation on multiple, species specific, relationships between evolution and development is not presented as an answer to all the questions that started this research. Questions remain about various details of the mechanisms, their consequences, how they evolved, how so many species-specific variants evolved, and what we can learn about ancient forms of geometric and topological reasoning abilities in humans.

One of the most important still unanswered questions is this: Does any current version or form of fundamental physical theory have the potential to explain everything about how all the species-specific versions of the reproductive processes in eggs sketched above can achieve what I claim they do achieve?

I’ll try to add more here, but I need help from theoretical physicists, or possibly some unusual philosophers of physics who have thought about these problems.

Conjecture: Relevance to Fundamental Physics
Studying the physical processes involved in hatching processes may yield results that are at least as important for future fundamental physical theories as the information obtained by running experiments on expensive, large, particle smashing machines.

In particular, are there important analogies between
-- the mechanisms controlling decomposition of chemical structures in eggs and re-using the components in building far more richly differentiated new physiological structures in the new hatchling, and
-- Maxwell’s mythical demon controlling separation of gas molecules into two volumes containing molecules travelling at different speeds as discussed below?

Is it possible that investigating the physical mechanisms involved in hatching processes will yield entirely new surprises for theoretical physics? In particular, could new developments in physical theory be required to explain the processes described above that occur during hatching? Or is everything relevant already part of current theoretical physics?

Is all this a version of recapitulation theory?
(Added 17 Sep 2022)

The ideas presented above may appear to constitute a variant of the discredited "Recapitulation Theory", which claims (roughly) that the development of individual organisms recapitulates the evolution of their species, summarised as "ontogeny recapitulates phylogeny". Wikipedia explains the idea: [https://en.wikipedia.org/wiki/Recapitulation_theory](https://en.wikipedia.org/wiki/Recapitulation_theory).

I am not claiming that ontogeny recapitulates phylogeny. The relationship between developmental processes and evolution is far more complex and more subtle than mere "replication".

What I have been claiming is that for many vertebrate species that lay eggs, development of the mechanisms controlling development of an individual organism partly replicate the mechanisms and processes used during the evolution of the species. This could perhaps be called "Process recapitulation theory", in contrast with "Result recapitulation theory".
One of the implications is that the earliest stages of gene expression in these organisms use mechanisms that have a lot more in common across species than the mechanisms used in later stages. This is most obvious for species that emerge from their shells with very different outer coverings e.g. feathers, shells, scales, etc. and very different behaviours (e.g. walking, crawling, swimming).

The very earliest stages of replication, i.e. splitting and duplication of the initial DNA in one cell of the new-laid egg have been studied in great detail and have much in common across different species that use sexual reproduction. But as reproduction within an individual egg continues, the process-patterns that unfold in different species, and the mechanisms used to achieve those developments, diverge more and more.

The aim of this document is to draw attention to that divergence, its origins, and its implications, while admitting that although the processes diverge widely across species, there are some higher order common patterns in that divergence, shown clearly (I suspect) in the reproductive processes of egg-laying vertebrate species that hatch with fully functional bodies and a collection of useful cognitive competences that don’t come from learning in the environment.

Perhaps my claims could be given a label something like "Meta-process recapitulation theory".

Associated with those general goals is an attempt to draw attention to the depth and the powers of species-specific mechanisms of reproduction that produce not only enormously complex, species-specific, physiological structures in newly hatched individuals, and species-specific patterns of physiological development after hatching, but also produce species-specific cognitive competences available shortly after hatching without requiring learning or training, including perceptual competences, goal formation competences and goal achievement competences.

**Example: video of newly hatched avocets**

It is not clear to me whether current physical theory can explain how those in-egg developments are controlled, especially insofar as the in-egg processes somehow produce not only complex physiological structures but also complex post-hatching competences that do not need to be learnt, e.g. the abilities of newly hatched avocets shown in this 35 second videoclip from the BBC Springwatch programme in June 2021: [https://www.cs.bham.ac.uk/research/projects/cogaff/movies/avocets/avocet-hatchlings.mp4](https://www.cs.bham.ac.uk/research/projects/cogaff/movies/avocets/avocet-hatchlings.mp4)

How can chemical assembly processes in an egg produce an avocet that has not only enormously complex and intricately interconnected internal physiological structures and mechanisms, but also motion and feeding competences available for use without having to be learnt?

I am constantly amazed by the number and variety of researchers who mistakenly believe that such competences in animals (including humans!) have to be acquired by training neural networks to derive consequences from sensory and motor data.

I’ll also suggest that those theories are refuted by Immanuel Kant’s observations in his *Critique of Pure Reason* (1781) about human abilities to discover truths that are necessary, non-empirical, and not analytic, i.e. not based simply on definitions and logical derivation.
Such theories, proposed or believed by many distinguished researchers, are clearly refuted by the competences of many newly hatched individuals of many species. They don’t have to learn how to move around, detect food, eat it, etc.

There are clearly mechanisms that are much more powerful than trainable neural networks and are used to produce a huge variety of post-hatching competences in the young of many different species, with different physiologies, shapes, sizes, external coverings, different environments, different forms of behaviour and different requirements for food.

There are also many differences in post-hatching competences of different egg-laying species, just as there is a huge variety of physical forms, including many types of bird, alligators, turtles, snakes, ... and many more.

At present I know of no attempts to describe developmental mechanisms that could explain how all those competences are produced by mechanisms in eggs. Or how related competences could be produced in wombs of mammals, e.g. new-born foals able to run with the herd within a few hours of birth!

These explanatory problems appear not to have been noticed by most philosophers and scientists (e.g. psychologists and neuroscientists) working on cognition. Please inform me if you have encountered or produced work that states the problem (explaining spatial cognitive competences of newly hatched or newborn animals) and provides, or attempts to provide an explanation.

Note:
There are also egg-laying species whose newly hatched young are NOT ready to move around and find food, e.g. birds that hatch in nests in trees or on cliff faces. For them, moving around successfully involves flying, and that requires development of powerful muscles that are not needed for newly-hatched walkers or crawlers. So their post-hatching behaviours are restricted to acquiring and consuming food brought to the nest by parents, until they have strong enough muscles to support flying.

IMPLICATIONS FOR FUNDAMENTAL PHYSICAL THEORY???

Are the assembly mechanisms used during different stages of hatching, comparable to increasingly sophisticated Maxwell Demons?

Thinking about the processes mentioned above led me to wonder whether features of hatching processes may have previously unnoticed implications for fundamental physical theory, although I am still groping for a good way to characterise those implications.

Is there a connection between these mechanisms and Maxwell’s "Demon"

The mechanisms proposed here as controlling the (enormously complex) biochemical changes involved in development of the new organism inside the egg are partly similar to the much simpler mechanism described as "Maxwell’s Demon" in a thought experiment attributed to James Clerk Maxwell, summarised here: https://en.wikipedia.org/wiki/Maxwell's_demon.

However, the in-egg demons, especially the later versions, need to be far more complex than Maxwell’s version in two respects: (a) the in-egg controllers produce far more intricate structural differentiation than Maxwell’s demon, which merely separates a collection of molecules in a gas into two categories faster-moving and slower-moving, whereas the in-egg version introduces many
kinds of structural and functional differentiation, and (b) the demon or demons that are active at any stage somehow also produce the more sophisticated demons required to control later, more recently evolved, stages of assembly in the egg. The diagrams above crudely represent such layered processes of gene expression.

Types of development that need to be controlled at later stages include growth of bones, of muscles, of tendons, of nerves, of blood vessels, of skin or other covering material, etc. Moreover, these developments are all parts of larger developments, each of which forms a subsystem that requires coordination of its own components, as well as coordination between systems. Examples of such sub-systems could include:
- outer covering materials (skin, hair, fur, feathers, scales, shells, etc.),
- blood transport and delivery systems, including arteries, veins, capillary networks where veins and arteries merge, and the blood pumping system, and after hatching transportation systems for the oxygen brought in via lungs and carbon-dioxide exhaled via lungs,
- networks of nerve-fibres carrying information signals in various directions, to control and coordinate internal and external behaviours.
- others ...

Many philosophers who write about physics assume that the mathematical structures required for representing the physical structures and processes in organisms will need to represent relationships between numerical values and rates of change of numerical values. But such forms of mathematics are not enough: there is also a need to represent assembly and disassembly of structures of various sizes and also relations between structures, including contiguity, containment, attachment, and local transfer of forces.

Clearly a level-N demon cannot already have the knowledge required for the level-N+1 assembly task. The information is presumably available in portions of the DNA that have not yet been used to control assembly. But a new more sophisticated, more recently evolved control process for the level-N+1 task has to be triggered by the level-N demon: it "knows" how to create the level-N demon that will have the competences required to control the level-N+1 assembly processes.

Is the comparison with Maxwell’s demon mistaken because the mechanisms controlling increasingly complex forms of differentiation in the egg can use chemical energy liberated when complex molecules provided in the new-laid egg are decomposed to provide the fragments used to construct new components of the physiological structures in the developing embryo?

A question about post-hatching results
Is it possible that the mechanisms outlined above help to answer the question: What makes it possible for many newly hatched animals to have both fully formed bodies and also cognitive functions that enable them to behave appropriately in the environment, without having to train neural networks or undergo any other form of learning, like the newly hatched avocets mentioned above.

I suspect the answer to that question will turn out to be that there is an additional developmental process that evolved as a side-effect of the mechanisms outlined above. Perhaps the evolutionary processes that enabled in-egg assembly processes to be controlled in order to produce a duck, chicken, alligator, turtle, etc. were copied and modified in a manner that allowed them to support post-hatching manipulations of external physical objects instead of only internal manipulations of
components of physical structures assembled during production of a new animal in an egg.

Turning that very crude idea into a precise theory that can be tested is a major challenge for this project.

DRAFT ADDITIONS
The remainder of this document is still an early draft. I hope to be able to include references to more related work in future. Suggestions welcome.

Background 1: The Kant/Hume Disagreement

One of the key disputes about the nature of mind or cognition was Immanuel Kant’s disagreement with David Hume’s claims about the contrasts between

-- kinds of knowledge that are either (a) about "matters of fact" or (b) about definitional "relations between ideas",

and

-- supposed advances that are neither of type (a) nor type (b), which Hume claimed to be "mere sophistry and illusion", including theological arguments.

The contrast between (a) and (b) is sometimes referred to as "Hume’s fork".

David Hume and Immanuel Kant (from Wikimedia)

Kant criticised Hume by claiming that there are significant discoveries, including ancient mathematical discoveries, that are in neither branch of Hume’s "fork". Those discoveries are not based solely on empirical observation and they are not discovered merely by deriving logical consequences of (explicit or implicit) definitions of the concepts used combined with purely logical assumptions. Such knowledge is therefore neither empirical nor analytic.
Moreover those discoveries are not about contingent truths or falsehoods but about necessary truth or falsehood.

Examples include Pythagoras’ theorem and other discoveries in geometry and topology made centuries before well known ancient mathematicians such as Pythagoras were born. Another example is the discovery that one-to-one correspondence is a transitive relation between sets: not understood by humans until they are five or six years old (as Jean Piaget discovered).

Such discoveries are

-- synthetic, not analytic, i.e. not simply based on logic and definitions,
-- non-empirical (i.e. a priori), and
-- necessarily true (i.e. they are non-contingent: counter-examples cannot exist).

Kant seemed to think it was impossible for humans to understand the mechanisms making such discoveries possible. He suggested that the mechanisms would lie “forever concealed in the depths of the human soul”.

I suspect that if he had lived two centuries longer he might have proposed reasoning mechanisms supported by brain chemistry -- not the currently fashionable “neural network” mechanisms that merely collect statistical evidence and then derive probabilities from the data. Such neural networks are constitutionally incapable of producing proofs of necessity or impossibility. They are restricted to discovering low or high probabilities.

The current majority view among philosophers (especially those lacking a good education in geometry and topology) seems to be that Kant was mistaken in claiming that we can discover necessary truths that are neither empirical nor simply logical consequences of definitions.

I think Kant was not mistaken, but a full defence of his views will require progress in the Meta-Morphogenesis project, investigating chemistry-based reasoning mechanisms, on which I suspect Alan Turing had been working shortly before he died. I am not referring to Turing’s work on chemistry-based 2D pattern formation published in 1952 which I think was simply a sideline in a deeper investigation. Some of those ideas are discussed in this long, messy document, which will later be revised: http://www.cs.bham.ac.uk/research/projects/cogaff/misc/hatching-talks-2022.html

That work provides some of the long term motivation for the ideas presented here, concerning processes of development in eggs of vertebrate species whose young have complex competences available soon after hatching, which they could not have learnt after hatching. The competences must be products of hatching processes in eggs.

Background 2: The Meta-Morphogenesis project

The ideas presented here are closely related to, and emerged from, the Meta-Morphogenesis project, inspired by some of Turing’s ideas. The project was triggered around 2011 when I was asked by Barry Cooper, the main editor of a commemorative volume on Alan Turing, to comment on Turing’s 1952 paper on 2-D chemistry-based morphogenesis (i.e. 2D pattern formation on the surfaces of organisms).
My commentary conjectured that Turing’s study of processes producing changing 2-D surface patterns turned up merely as a "side issue" for Turing, during much deeper, more complex, still unpublished, research he was doing at the time, on chemical mechanisms involved in controlling reproduction and development of biological organisms, closely related to conjectured chemical mechanisms underpinning ancient human mathematical reasoning about spatial structures and processes.

These ideas are also relevant to spatial intelligence in many other species and are closely related to earlier work with Jackie Chappell on "Meta-Configured" genomes, referenced below.

One of the aims of all this work is to show that current theories of intelligence based on neural networks (NNs) are seriously misguided, partly because many newly hatched animals (like the avocets shown in the BBC videoclip below) display important competences that they have not had time to acquire by training neural networks, and partly because some of those competences involve detecting impossibility or necessity, which cannot be determined on the basis of statistical evidence or derived probabilities: impossibility and necessity are not extremes on a probability scale. They cannot be detected by neural net based mechanisms that collect statistical evidence and compute probabilities.

This seems not to be understood by most researchers who investigate learning and reasoning mechanisms based on trainable NNs. Many of them have never studied geometry and topology using diagrammatic proofs because of the disastrous changes in mathematical education around the middle of the 20th century mentioned below.

The most popular alternative to both diagrammatic reasoning and empirical learning in mathematics is use of logic-based symbolic reasoning. This has led to many deep mathematical results and development of computer-based mathematical reasoning systems.

But that still leaves unexplained the mechanisms used in ancient forms of mathematical discovery using spatial reasoning centuries before Pythagoras was born, and related features of spatial intelligence in non-human animals, e.g. squirrels and some nest-building birds.

A new, chemistry-based, approach
I think we can learn about a potential role for chemistry-based mechanisms in providing explanations, if we study hatching mechanisms in eggs of vertebrates, as sketched below. I did not recognize the significance of hatching processes in eggs until around September 2020.

In fact much of the relevant evidence is already widely known, but its significance goes unrecognized. As the work progressed, I kept noticing previously unrecognized complications in hatching processes. No doubt there are even more, not yet recognized.

Moreover the mechanisms that make such mathematical spatial reasoning possible are not yet known. Statistical evidence may persuade a neural network that something is false, e.g. it is false that a planar polygon can have more vertices than edges. However statistical evidence cannot establish impossibility.

No statistics-based mechanism could enable a neural network to establish a mathematical necessity, e.g. that some proposition is necessarily false, i.e. its truth is impossible, or necessary truth, with falsity impossible. Statistical evidence is irrelevant to proof of necessity or impossibility, though it can be useful for other purposes. So we need to make use of alternative, non-statistical
forms of evidence. I suggest that previously unrecognized chemical mechanisms may be able to do that, and that precursors of such mechanisms have an important role to play in hatching processes.

This Document
This document is available at:
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo.html

Since September 2020, I have been investigating, and giving talks about, processes and mechanisms that I conjecture are involved in reproduction using eggs in many vertebrate species, after I first realised that hatching mechanisms were relevant to some deep unsolved problems about spatial intelligence. As far as I can tell, nobody else has noticed the connection with hatching.

[If I there are others, please send me details (a.sloman AT bham.ac.uk).]

The restriction to vertebrate species does not imply that the ideas are not relevant to eggs of non-vertebrates, e.g. insect eggs, or plant seeds. I focus on egg-laying vertebrates because that includes so many different species, with widely varying physiological forms and complex, but different, post-hatching behavioural competences, e.g. species-specific abilities to control spatial movements and feeding processes shortly after hatching. That indicates both the wide applicability and the many detailed variations in the mechanisms used.

Increasingly complex extensions to those ideas about hatching processes, were presented in "evo-devo” talks during 2021.

In January 2022 a new strand emerged, investigating changing relationships between evolution of egg-laying species, and chemical developments during hatching of each egg.

It was not clear to me whether current physical theory could explain how those in-egg developments were controlled, especially insofar as the in-egg processes somehow produce very complex and intricately interrelated physiological structures and also produce complex post-hatching abilities that do not need to be learnt, including the motor abilities of newly hatched animals of many kinds, such as chickens, ducks, avocets (illustrated in the videoclip below), turtles and many other species of egg-laying vertebrates.

How can chemical assembly processes in an egg produce an animal that has such competences — competences that many researchers nowadays (mistakenly) believe have to be acquired by training neural networks to derive consequences from sensory and motor data? Those beliefs, held by many distinguished researchers, are clearly refuted by the competences of many newly hatched species.

A useful, but shallow, introduction to hatching processes in eggs is provided by this 2013 video showing chicken embryo development: https://www.youtube.com/watch?v=PedajVADLGw

Here’s a video from China showing a chick hatched without an eggshell, in a transparent bag, in 2018: https://www.youtube.com/watch?v=j0XmhPZwMuA

This collection of images shows stages in the development of a chick in an egg: https://i.pinimg.com/736x/62/28/a6/6228a61f6607dcd92fcc775ccf8cd867--chicken-life-a-chicken.jpg
It is impossible for a few such videos and images to convey the huge variety of patterns of development that occur in eggs of different vertebrate species, including variations in body form, in outer coverings, and in post-hatching behaviours, e.g. in turtles, alligators, various kinds of snakes, chickens, and the avocets shown in a video-clip below.

I have not encountered anyone else (apart from Alan Turing if my guess above is correct) who takes seriously the suggestion that such post-hatching competences are produced by chemical assembly processes in eggs, though I suspect Immanuel Kant would support this suggestion if he were still alive. The relevant biochemical knowledge and recording technologies did not exist when he was writing.

My thanks to Professor Susan Stepney (York University)
https://www.cs.york.ac.uk/people/susan
As mentioned above Professor Susan Stepney (York University), with whom I have discussed related ideas over several years, after hearing one of my talks early in 2022, sent me a pencil drawing attempting to summarise my latest ideas in a 2-D array of evolutionary and developmental changes, with evolutionary changes shown horizontally from left to right and developmental changes shown vertically from top to bottom. She claimed her diagram had helped her to understand the claims I was making!

That inspired me to incorporate a more complex version of her diagram, later replaced by the evo-devo diagrams above, in which the directions of evolution and development have been switched.

More Complex Diagrams
My diagrams above were originally inspired by Susan Stepney’s depiction ideas, now moved into a separate document

Later I switched to the figures presented above, with development going left to right and evolution top to bottom. All the diagrams are hard to take in without a verbal explanation.

There is a lot of research on related but simpler problems
There are now many researchers investigating organisms that are capable of re-organising their physical structures (e.g. slime moulds), but I have not encountered researchers who attempt to explain not only how self-organising hatching processes in eggs can produce extremely complex physiological structures but also how they provide newly hatched individuals with important behavioural and cognitive competences, like the newly hatched avocets mentioned above, and many other species that display complex forms of (species-specific) spatial intelligence shortly after hatching, used in activities such as walking, crawling, feeding, following the mother, etc.

E.g. the otherwise excellent work of Mike Levin below that I have found so far does not address, or even mention, this problem of explaining how development in an embryo can produce complex post-hatching spatial competences.
There are many other researchers studying self-organising life-forms, e.g. processes in slime-moulds, or development of human embryos, and other organisms or proto-organisms. Unless I have missed something, none of the processes studied involve production of the extremely complex, intricate, concurrent, structural differentiation and re-organisation during parallel development of very many physiological structures performing different biological functions of the sorts discussed below, which occur in many kinds of vertebrate eggs during hatching.

In contrast, eggs of mammals, develop in more complex and supportive environments, using rich interactions with the mother, whereas eggs of insects have a somewhat more complex process of development: first hatching a grub that feeds on vegetation for a while then undergoes metamorphosis, forming a new egg-like structure that produces an organism with entirely new physiology (e.g. including wings) and new behavioural competences (e.g. flying, feeding, mating, and, in the case of females, laying eggs.)

The above are all very interesting, but I have focused on vertebrate egg-layers that produce competent hatchlings, because their hatching processes most clearly illustrate the core ideas of the theory being developed and also illustrate the need for new deeper explanatory theories, i.e. theories capable of explaining the particularly complex and intricate mechanisms involved in the assembly of the ready-to-go physiological structures inside a newly hatched birds, reptiles, the physiology of a young animal.

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Previous presentations (when the ideas were simpler)
The two most recent talks (both invited) on this project, both using the title Recently hatched ideas about hatching and intelligence: Using very low energy physics and chemistry at 'normal' temperatures in egg-laying vertebrates were given to a group of biomedical engineering researchers in Singapore, with philosophical interests (on 21st June 2022) with recording of the talk and discussion now available here: https://www.a-star.edu.sg/bii/highlights>. In case of problems try this instead: https://drive.google.com/file/d/1hyjam-wBEx7zliR_8TNRbYF14vddsNZa/edit

The talk given on 20th August 2022 to the International Society for Philosophy of Chemistry (ISPC) was much shorter (possibly too compressed) and the recording is available here https://www.youtube.com/watch?v=m2FnBnlqns

Another relevant thread: Meta-Configured Genomes
A collaboration with Jackie Chappell

(Perhaps this section should be replaced by a link to a separate document?)

My work on hatching mechanisms began in 2020 but relates closely to a much older investigation of "Meta-Configured Genomes" developed in collaboration with Jackie Chappell (https://www.birmingham.ac.uk/staff/profiles/biosciences/chappell-jackie.aspx) after she came from the Ecology laboratory in Oxford to the School of Biosciences at the University of Birmingham in 2004. Some of the ideas we developed were presented at a conference (IJCAI) in 2005 and published in Chappell and Sloman(2007).
Our collaboration produced the idea of forms of gene-expression that provide incomplete patterns or templates expressed at various stages increasingly late in life, whose "gaps" are filled using data acquired (from the environment, including conspecifics) during earlier development and learning. For example, a child who first encounters the linguistic pattern "for example, XXXX" can use it with "XXXX" replaced by some generalisation learnt previously from the then available environment. In that way, early forms of gene expression allow information to be acquired that is put to new uses during later, more recently evolved, forms of gene expression.

We used the label "Meta-configured genome" (MCG) to draw attention to the "parametrised" genetic bases of these capabilities.

This contrasts with Waddington's idea of development as "downhill" motion along a fixed "Epigenetic" landscape specified by the genome (1957). That idea fails to capture the fact that the same genome can have very different products in different environments, as illustrated by the diversity of languages used by humans who presumably share a mostly common human genome, producing very varied spoken languages, sign languages, written languages and languages created for special purposes, e.g. mathematics, computer programming, scientific theories, etc.

MCGs are not complete genetic specifications, because they don’t contain all the information required for gene-expression. Instead some of the genetic material expressed at relatively late stages of development contain "gaps" that are filled using information acquired at earlier stages during individual development while the individual was interacting with the then current environment, including physical and social aspects of that environment, i.e. not the environment that existed when the genes first evolved.

So expression of a 6 year old’s meta-configured genes will produce "gaps" that are filled using information picked up earlier by that individual --- information that can vary across geographical locations and across species history in a fixed location. For example, genetic mechanisms controlling learning during play activities of a 6 year old can use information acquired earlier (e.g. during play, or social interaction) by that individual in that location, and the results can differ widely across geographical locations and across human history in a fixed location, despite the common genome.

Some of the differences between languages, including sign-languages used in deaf communities and ‘click’ based languages in Southern Africa, illustrate effects of shared meta-configured genomes. (For example, see https://en.wikipedia.org/wiki/Khoisan_languages.)

Some of the differences between cognitive development of six-year-old humans born during the 21st Century and cognitive development of their parents at the same age (who could not have encountered mobile phones, email, or the internet) illustrate this kind of interaction between gene-expression mechanisms and the environment in which development occurs.

Of course that raises questions about what those generic templates specified at different stages of gene expression are, and how templates that evolved very many centuries ago can now help to produce sophisticated scientists, engineers, teachers, etc. dealing with concepts, theories and techniques that none of their ancestors encountered. (Some readers may notice a partial analogy...
with Karl Popper’s notion of a “Third world”.

This is very different from theories that postulate “bottom up” learning mechanisms such as trainable neural networks producing different results in different contexts, which I claim (though will not argue here) could not produce changes in products of development across generations of humans that depend on meta-configured genomes.

The use of a (highly parametrised) meta-configured genome allows later processes of gene expression to be partly genetically determined by evolutionary changes many centuries earlier, and partly tailored to details of the current environment, including details recorded by the learner during earlier stages of individual development. Those details may depend on the recent history of changes in the learner’s environment. Such an environment can fill gaps in (provide parameters for) portions of the genome that are expressed later and provide generic capabilities that are partly instantiated using information picked up by the individual, e.g. from the physical and/or social-linguistic environment.

That can include linguistic information as well as information about objects and processes in the environment. For example, a young language learner may pick up information from the environment about plurality of sounds, tenses of verbs, ways of modifying verbs, etc. etc. in the current environment then at a later stage of development a new stage of gene expression may make use of all the previously acquired linguistic information, in providing a new form of linguistic communication or a new form of thought generation.

Perhaps the most obvious and spectacular example of this is the way in which genetically specified features of human language development that occur relatively late in life can vary enormously across individuals that are born at different times or in different locations. (Or both!)

In particular, later stages of language development at any time can depend on how features of language development in the current culture have changed in the past. This explains how young humans with the same language-related genetic mechanisms can develop enormously varied detailed linguistic competences in different locations on this planet, and also how, across generations in the same culture, a language can change because each new generation picks up, makes use of and possibly extends, modes of linguistic communication and reasoning that were not available to their distant ancestors.

This also helps to explain how use of language by humans includes signed languages developed in deaf communities (or sub-communities) and written languages, as well as accounting for the huge diversity of spoken languages that have developed among spatially separated groups of humans.

(I have argued elsewhere that, in human evolution, sign languages used in cooperative activities must have developed before spoken languages. Other phenomena to be explained include human abilities to create entirely new spoken or written or printed languages for particular applications, e.g. in mathematics, science or computer programs.)

We (Jackie Chappell and I) claim that these ideas apply not only to human linguistic competences, but also other competences that are built up in stages in ways that allow previously evolved patterns to be instantiated in ways that are profoundly influenced by developments in earlier generations that altered the developmental environment for later generations --- as in the history of technology, science and mathematics.
Extreme examples of this include recently developed mathematical and scientific notations, along with thousands of new programming languages, that current humans acquire, use, extend, etc., which none of their (adult) ancestors would have been able to understand if introduced to them.

Bonobos and other non-human primates that have learnt to use fragments of human sign languages illustrate extreme examples of flexibility in some non-human genomes. For a variety of examples, try giving a web search engine "chimps learning sign language".

This process can have several developmental layers, so that individual development includes several stages at which meta-configured genomes are activated, whose interaction with the environment provides information used later, during later expressions of (more abstract) meta-configured genome features.

This is totally different from theories that assume that there is some uniform learning mechanism (such as a trainable neural network) starts from scratch with each newborn individual, collecting data, and deriving statistical patterns, as in most currently fashionable models of learning.

Some of the later threads connecting the Meta-Configured genome theory with biochemical details were suggested by Prof Peter Tino (https://www.cs.bham.ac.uk/~pxt/) around 2019. The ideas are now summarised here (still work in progress):

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

A video tutorial presenting some aspects of these ideas is available here:

https://www.cs.bham.ac.uk/research/projects/cogaff/movies/meta-config/metaconfig.webm

There are also deep connections with the ideas of Lynn Margulis in her "Symbiogenesis" theory.

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Neural nets cannot learn to recognize impossibility or necessity

Many researchers appear not to have noticed that currently popular "neural" mechanisms can discover only statistical regularities with associated probabilities. They cannot explain ancient and not so ancient mathematical discoveries concerning mathematical impossibilities and mathematical necessities, for example, discoveries in geometry and topology, such as proofs of Pythagoras’ theorem, or discovering that spatial containment is necessarily transitive.

Many such mathematical discoveries were made centuries before Pythagoras was born!

Those ideas were almost certainly related to discoveries about necessity and impossibility that were first made in contexts of performance of more or less complex physical tasks, for example the tasks of building large constructions using materials that had to be transported long distances cut into appropriately sized and shaped components and then moved into final locations on partly constructed buildings, including large pyramids, temples, bridges(?), aqueducts(?), etc. Much time can be wasted by individuals incapable of learning that an upright table cannot pass through a doorway narrower than the width of the table, though the impossibility can be removed (in many cases) by tilting the table through 90 degrees, so that one edge of the tabletop is on the floor.

Related forms of relatively recently developed human activities using new languages or formalisms tailored to specific mathematical, scientific or engineering tasks, using linguistic structures that do not occur in any previously developed human languages include modern programming formalisms of many different kinds mainly used not for communication between humans but for creation of new kinds of computer-based technology.
As far as I know, there are no theories in linguistics, philosophy, psychology or neuroscience, that explain how humans are able to create and use such languages and to create new forms of machinery that use them in processes with speed and complexity that cannot be matched by human thought processes. I.e. biological evolution has provided humans with abilities to create new forms of non-biological language users that can perform information-processing tasks that no humans can perform, individually or collectively.

**What has all the above to do with eggs?**

Short answer: I don’t yet know, but I suspect that when we understand a lot more about how hatching mechanisms work, we shall get new ideas about processes of development of competences in other vertebrates, especially primates, but also other intelligent mammalian species with meta-configured genomes, such as elephants, dolphins, etc.

**Work to be done**

Work for the future includes: combining the ideas about mathematical cognition with more detailed versions of the above proposals for mechanisms of gene-expression in eggs, and then using these ideas to give a new account of the mechanisms underlying ancient forms of mathematical competence and mathematical consciousness, which are not explainable

- either on the basis of statistics-based neural networks (which are constitutionally incapable of discovering cases of necessity or impossibility)
- or on the basis of modern formal reasoning mechanisms that are 20th century extensions of 19th century formal logic.

Those modes of reasoning are recent inventions and I know of no evidence that they were used consciously or subconsciously by the ancient mathematicians who first discovered theorems in geometry or the ancient engineers who used informal versions in their practical activities (e.g. transporting very heavy objects and constructing pyramids, temples, etc.).

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**Some online geometry/topology tutorials**

-- Presentation on Euclidean geometry by Zsuzsanna Dancso at MSRI.  
"Trisecting angles and calculating cube roots was a big problem for Euclid and his cohorts." [https://www.youtube.com/watch?v=6Lm9EHhbJAY](https://www.youtube.com/watch?v=6Lm9EHhbJAY)

Now at University of Sydney  
[https://www.msri.org/people/12337](https://www.msri.org/people/12337)

[https://www.youtube.com/watch?v=SXHHvoaSctc](https://www.youtube.com/watch?v=SXHHvoaSctc)

-- Topology & Geometry - LECTURE 01 Part 01/02 - by Dr Tadashi Tokieda  
Including cutting a mobius strip down the middle: count the number of twists.  
(He has many more online tutorials and demonstrations.)

-- Online lectures by Prof Cem Tezer (recently deceased)  
Middle East Technical University  
[https://www.youtube.com/watch?v=AJvjtK2mmpU](https://www.youtube.com/watch?v=AJvjtK2mmpU)

MATH 373 - Geometry I - Lecture 1  
[https://www.youtube.com/watch?v=1hNR-iCuw7g](https://www.youtube.com/watch?v=1hNR-iCuw7g)

MATH 373 - Geometry I - Lecture 2
RELATED WORK

Earlier work leading up to this
The above significantly extends the ideas presented in my 2020 paper

That paper extended work on the Meta-Morphogenesis project, which was triggered around 2011 by an invitation to contribute a comment on Alan Turing’s 1952 morphogenesis paper for the Elsevier volume celebrating the 2012 Turing Centenary. That book was published in 2013 http://www.cs.bham.ac.uk/~axs/amtbook.

My contribution, in pages 849-856, speculated that Turing’s paper on 2D pattern formation merely reported a side-issue that had turned up in a deeper, unpublished, investigation of relationships between chemistry and brain functions. I later tried to specify that deeper investigation, labelled a study of "Meta-Morphogenesis" here: https://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-morphogenesis.html (Also PDF)

Note on history of this presentation:
This work follows on from a collection of changing ideas developed starting around October 2020 and continuing through 2021, reported in a series of invited talks at seminars and conferences. These recent ideas extend lines of thought begun in my DPhil thesis (1962) defending Immanuel Kant’s philosophy of mathematics, and continued since then, branching out in many directions.

During 2021, as the ideas developed, I gave several invited talks presenting facts and speculations about hatching processes in (vertebrate) eggs, and their relevance to developmental biology, neuroscience, psychology of mathematics, and various philosophical research areas, including philosophy of mathematics, philosophy of mind, epistemology and philosophy of biology.

During 2022 the ideas about hatching processes grew increasingly complex as I noticed more details. The new "evo-devo" ideas were presented in Zoom talks to a variety of audiences starting in March 2022. The ideas continued to develop between talks. This web page was set up in October 2022 in an attempt to present the new collection of ideas as compactly as possible, combining portions of previous web pages used for presentations. New developments will be accommodated here as they occur, though new branches may be spawned later.

A slightly shorter title "Recently hatched ideas about hatching and intelligence" was used for talks given between March and August 2022, though the contents of the talks changed as my understanding of the problems and possible (partial) solutions changed -- an ongoing process. The phrase "and depicted" was added to the title above on 25 Oct 2022.

There is also an older, longer, fairly indigestible web page: http://www.cs.bham.ac.uk/research/projects/cogaff/misc/hatching-talks-2022.html developed since early 2022, which in turn is part of a very large, messy and frequently expanded web site with many presentations linking aspects of philosophy, mathematics, language, biology, chemistry, physics, computer science, AI, psychology, and education.
The "hatching-talks-2022" web page includes links
-- to earlier work on this project,
-- to related online or published information, and
-- to a variety of scientific and philosophical disputes about the nature of mathematical discovery,
and the cognitive/biological mechanisms that made possible ancient mathematical discoveries,
especially discoveries in geometry and topology.

This much shorter version was created in October 2022 and, with luck, will survive for some time.
(It is no longer as short as it once was, partly because there are some recent additions!)

Background information that took up a lot of space near the top of earlier versions of this
presentation has either been moved down the page or replaced by links to separate documents
presenting or referencing related work.

MORE RELATED WORK
(This is a tiny subset! Email a.sloman[AT]bham.ac.uk with suggestions for inclusion in a more
comprehensive survey.)

There is a huge amount of relevant literature, along with a growing number of online video
presentations and tutorials, of which I have so far encountered only a small sample. So far I have
not encountered any attempting to address the specific questions raised in this document about
what chemical process in eggs of vertebrates can achieve, and how they do it. Levin's work is very
relevant, but so far addresses only much simpler developmental processes.

A lot of relevant research has been done and is being done on self-organising biochemical
systems. A small subset is referenced below. However, I have so far not found any such work that
explains, or even tries to explain, how hatching processes in vertebrate eggs can produce new
hatchlings that have extremely complex interconnected fully functional physiological components
and have competences that don’t need to be learnt in the environment, e.g. by training neural
networks.

For example they can move around, avoiding obstacles, following the mother (in some cases), and
feeding themselves, like the newly hatched chicks and ducklings detecting and eating food while
walking around and avocet hatchlings shown in the above video clip feeding in water.

Many of the detailed post hatching competences are species-specific so there must be a lot of
cross-species variation in the transformations of egg contents during hatching that are relevant to
post-hatching cognitive competences and modes of locomotion evident shortly after hatching, e.g.
in chickens, swans, alligators, crocodiles, turtles, various kinds of snakes, etc., in addition to
hatching mechanisms that control species-specific features such as size, physical forms, outer
coverings (shells, skin, feathers, etc.).

Proposed "self-organisation" mechanisms (e.g. training of neural networks) that I have encountered
so far do not explain how the biochemical processes in eggs of vertebrates can assemble animals
containing a large variety of different types of highly intricate, richly differentiated, functionally and
spatially related, partly species-specific, physiological structures that exist in newly hatched
vertebrates, in addition to sophisticated behavioural competences. (Compare the excellent
explanations and diagrams showing some late stages, shortly before hatching, in chicken embryos:
Hermann Rahn, et.al. (1979).)
I have also not encountered any recent attempt to explain the phenomena mentioned by Immanuel Kant, such as the human ability to use spatial reasoning about what is impossible or necessarily the case, as in ancient mathematical discoveries in geometry and topology.

**Mike Levin’s work**

There is a lot of impressive work being done on chemical mechanisms controlling growth of organisms, including self-modifying or self-extending organisms of many sorts, including artificially created organisms. An important example is work done by Michael Levin's group at Tufts University, on xenobots, including: [https://ase.tufts.edu/biology/labs/levin/publications/index.htm](https://ase.tufts.edu/biology/labs/levin/publications/index.htm), E.g. 'Top-down models in biology: explanation and control of complex living systems above the molecular level' by Giovanni Pezzulo and Michael Levin: [https://royalsocietypublishing.org/doi/epdf/10.1098/rsif.2016.0555](https://royalsocietypublishing.org/doi/epdf/10.1098/rsif.2016.0555).

He has a large (and growing) number of publications and online video presentations of his ideas. The work is extremely impressive, but so far I have not seen any reference to the complexity, intricacy, and multiplicity of parallel developmental changes that occur during hatching of eggs of vertebrates. Moreover, as far as I can tell, he offers no explanation of how such chemical processes in eggs can produce complex cognitive skills, using knowledge that does not have to be (and could not be) derived from statistical evidence.

I don’t know whether he would regard his work as helping to explain the information processing mechanisms involved in ancient human discoveries in geometry and topology, or the spatial intelligence of squirrels, many nest-building birds, and primates such as bonobos, orangutans, and many other species, a long term goal that motivates the work reported here.

**Note added: 20 Nov 2022**

A colleague has drawn my attention to this very interesting online discussion dated Nov 9, 2022, between Michael Levin and Joscha Bach, chaired by Curt Jaimungal, that is clearly relevant to the problems discussed here, though it is not yet clear to me whether they have answers to my specific questions -- including questions about the chemical basis of ancient mathematical (geometric and topological) intelligence -- or the detailed control of multiple, parallel, highly intricate, spatial developments in eggs of a wide variety of vertebrate species with different physiological details, outer coverings, modes of locomotion, food requirements, and post-hatching forms of intelligence: [https://www.youtube.com/watch?v=kgMFnfB5E_A](https://www.youtube.com/watch?v=kgMFnfB5E_A)

**NOTE: Related topics**

This web site focuses on vertebrate egg-laying species, but there are also important things to be said about processes in other sorts of eggs, e.g. insect eggs, cocoons, germinating seeds, etc. In principle it would be desirable to produce a survey of attempts to explain how hatching mechanisms work across a wide range of species. As far as I can tell most or all of the explanations produced so far regarding post-hatching physical forms and behaviours refer only to the early stages of gene-expression that are common to a wide variety of species, before highly species-specific structures are produced in the eggs.

**Contrast with development in a uterus**

Animals that develop within the mother’s uterus, rather than inside an eggshell out of contact with internal parts of the mother, may be very different from animals that develop in the uterus, because the latter species allow much richer interactions between mother and foetus during the
development of the foetus. In particular different chemical resources can be provided by the mother
at different stages of development in the uterus, whereas the egg-laying mother has to provide all
the chemical resources in the egg.

Information about the mammalian case is provided in a recent publication by Anna Ciaunica and
colleagues:
The first prior: From co-embodiment to co-homeostasis in early life
Anna Ciaunica, Axel Constant, Hubert Preissl and Katerina Fotopoulou, in

Note added 22 Sep 2022: Book by Jonathan Bard
I have recently been informed about this book Evolution: The Origins and Mechanisms of Diversity
https://www.amazon.co.uk/Evolution-Mechanisms-Diversity-Jonathan-Bard-ebook/dp/B09NQS91MX/
(published in 2021). From a partial reading, it appears to be very relevant to the above ideas,
though I have not yet had time to decide whether there are any conflicts, or whether the book
answers questions raised here. My impression so far is that it focuses on different questions. But a
close reading may reveal important connections, in which case details will be added here.

Some older work relevant to the Meta-Morphogenesis project
Immanuel Kant, Critique of Pure Reason (1781) (several editions?), Translated (1929) by Norman
Kemp Smith, London, Macmillan
https://www.gutenberg.org/files/4280/4280-h/4280-h.htm

Jackie Chappell and Aaron Sloman, (2007), Natural and artificial meta-configured altricial
211--239, http://www.cs.bham.ac.uk/research/projects/cogaff/07.html#717

Zsuzsanna Dancso University of Sydney Mathematics tutorials

A. M. Turing, (1952), The Chemical Basis Of Morphogenesis, Phil. Trans. R. Soc. London B 237
237, pp. 37--72, http://dx.doi.org/10.1098/rstb.1952.0012

The 2012 commemorative book mentioned above is:
Alan Turing: His Work and Impact, published in 2013,
Eds. S. Barry Cooper and J. van Leeuwen,
Publisher: Elsevier, Amsterdam,
It includes three invited papers presenting precursors of some of the ideas presented above.

The new ideas presented here are closely related to themes I have been exploring since I switched
from research in mathematics and mathematical logic to research in philosophy of mathematics,
around 1959.

Old publications that provide some of the ideas that are relevant to or motivate the most recent
work include the following:


- Erwin Schrödinger, What is life? 1944, CUP, Cambridge,
  (Later reprinted in a different format, with additions.)


  (Based on my DPhil Thesis, 1962)

- Virtual-Machine Functionalism
  (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/misc/vm-functionalism.html

- What About Their Internal Languages?


NOTE
Comments, criticisms and suggestions are welcome, including comments pointing out that I am seriously mistaken! (Email a dot sloman at bham.ac.uk)

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