

Last updated 17 Dec 2023

Temporary version, still changing

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This is likely to have errors and omissions, after many changes.

I also apologise for repetition in this document -- a result of too much editing over a long period. I shall later try to improve this and will then remove this comment.

Report flaws (apart from repetition!) to: a.sloman-At-bham-ac-uk

This document is:

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

This document has been much revised and extended since January 2023

New title

**Evolution and development of some biological information processing mechanisms
With implications for theories of intelligence in humans and other species**

New sub-title

And possible implications for fundamental physical theories.

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An invited workshop talk about some of these ideas was given on
21st January 2023 with title:

Recently hatched ideas about hatching and intelligence

Responder (via pre-written comments):

Anthony Leggett

<https://physics.illinois.edu/people/directory/profile/aleggett>

https://en.wikipedia.org/wiki/Anthony_James_Leggett

<https://royalsociety.org/people/anthony-leggett-11804/>

Talk and response were presented at

THE 14TH INTERNATIONAL WORKSHOP ON NATURAL COMPUTING, TOKYO, JAPAN

<https://www.natural-computing.com/iwnc-ws>

January 20-22, 2023.

Original (pre-workshop) summary:

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 previously unnoticed features of fundamental physics required for hatching mechanisms of highly evolved species.

An important new sub-theme since June 2023

Including implications of forms of self-reorganisation during post-hatching development of invertebrates, e.g. in cocoons

NOTE ADDED 1 Jul 2023

During June 2023 I realised that my complex and messy diagrams below, and my presentations, were flawed insofar as they did not allow for the complex forms of biochemical reorganisation that occur in an insect's cocoon or chrysalis, including *decomposing* some of the physiological structures in a previously developed grub or caterpillar, that has been steadily increasing in size and complexity since initially hatching and feeding on vegetable or other matter in its environment, then decomposing/disassembling parts of itself into chemical constituents that are then reorganised to produce a new very different organism, e.g. with new body-parts, new feeding mechanisms, new forms of motion (e.g. flying, in many cases) and a new ability to mate (in some cases while flying!), and then, in the case of females producing new individuals by laying eggs.

A discussion of some of the implications of metamorphosis and new questions arising can be found in a document begun during June 2023, and much expanded since then, referenced [below](#).

Note: Most of this document was written before the above portion in red. It now needs much re-organisation/re-writing! In addition I now realise that the complex evo-devo diagrams presented below are insufficiently complex insofar as they do not include the possibility of meta-morphosis during development, mentioned in the above note.

BACKGROUND NOTE by A.S.

Last updated: Mid June 2023

When I first began to think about hatching processes in vertebrate eggs in September 2020, I wrote to an old friend since our student days, Anthony Leggett (Tony below), now a distinguished theoretical physicist, asking for comments on my initial ideas about the problem of explaining how biochemical mechanisms in eggs could produce newly hatched animals with significant competences that they did not have to learn before first use -- not a standard topic of discussion among physicists!

This seemed to me to raise new questions about the physical mechanisms used in such hatching processes, including (at first) a thermodynamic challenge which seemed to be related to the task of James Clerk Maxwell's "Demon", which I now suspect was an unimportant connection.

In response, in a zoom conversation and later by email, Tony offered encouraging, but generally non-committal, comments and questions -- understandably suspending judgement! He also attended some of my invited zoom presentations about this topic in 2021 and 2022, as the ideas evolved and became much more complex, as explained below. Maxwell's demon's thermodynamic challenge then seemed less important than the challenge of controlling increasingly complex multi-strand, richly interacting developmental processes occurring inside eggs, including transitions

to new levels of complexity inside developing embryos related to evolutionary transitions to new forms of structural and behavioural complexity in the history of the species.

(N.B. This claim about changes in developmental mechanisms is different from "Recapitulation Theory", which postulates that development of each organism passes through ancestral stages. The difference is summarised [below](#).)

Later, when I was invited to talk about those ideas at the above workshop in January 2023, I suggested that Tony should be invited as commentator. He was invited, and agreed to respond to my talk, but was not able to connect to the workshop at the time of my presentation, so he produced some written comments in advance, linked [below](#).

His comments were reactions both to my notes made available shortly before the workshop in an earlier, shorter, and much simpler version of this document, and to some of our earlier interchanges. The comments were read out by the workshop chairperson after my presentation, and the text was displayed on the zoom screen.

Post-workshop ideas related to metamorphosis

(Updated: 17 Dec 2023)

Several months after the January 2023 workshop, while I was still trying to develop the ideas, I suddenly noticed (in June 2023) the importance of processes of metamorphosis in insects that can occur in a cocoon or chrysalis, summarised in this (now very large) document, with many unexpected implications and connections:

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

In such processes the insect disassembles a subset of its physical structure and uses the resulting chemicals to transform itself into a new insect with some new very different body parts, e.g. including wings in many cases, and entirely new capabilities, e.g. flying and feeding itself by obtaining nectar from flowers, instead of chewing leaves etc. The new document gives more details and discusses evolutionary and developmental mechanisms, with some surprising implications, including new suggestions about the relative importance of synapses and neurons (work in progress).

Additional Background information

(Last updated: 24 Sep 2023)

Since the workshop in January 2023, this document has been extended with a considerable amount of background information, including pointers to related items and more recent information. Among the new additions is a discussion of the extraordinarily complex and sophisticated information processing mechanisms involved in processes of reproduction including metamorphosis in many insects [below](#).

For date of most recent update see the top of this page.

I apologise for any errors and unnoticed repetitions produced by the updates. This has grown into a very messy document that needs to be completely re-written (if I ever have time...)!

Portions of an earlier version of this document, indicated below, were used for my workshop talk on 21st January 2023 using zoom, at 16:45 - 17:45 Tokyo time.

About the responder

Theoretical physicist Antony Leggett, referred to as Tony above and below, is an old friend whom I first met while we were both students at Balliol College, Oxford (in 1959 if I remember correctly), with whom I have interacted intermittently in various ways since then (including co-teaching an Arts-Science course at Sussex university at one stage, when I was a member of the Philosophy group and he was in Physics, and reading drafts of some of each others' publications, in which each of us thanked the other).

He was invited to reply to my talk at the 2023 workshop, but was not available at the scheduled time, so, after reading my notes in an earlier, much shorter, version of this document, he submitted some written comments shortly before the event.

His comments, read out during the workshop, are available here:

<http://www.cs.bham.ac.uk/research/projects/cogaff/misc/tony-leggett-talk-notes.txt>

As explained above, a lot has been added to this document since the workshop, and more will be added, partly because my ideas have continued evolving! I don't know whether the additional material would have led to any significant change in Tony's comments, if he had seen it before the workshop. More information about that may be added here later, after he and I have had further discussions.

About our discussion of hatching mechanisms

Tony and I began discussing specific aspects of hatching processes in eggs in September 2020, after I reported to him that discussions in a recent philosophy workshop had suddenly made me realise that everyone (at least everyone I knew about) had been ignoring important well known aspects of hatching phenomena in a wide variety of vertebrate species. I had also been ignoring them, until then! I soon began to think that hatching mechanisms might provide not only a challenge to current theories about mechanisms required for various forms of intelligence but also a challenge to current theories in fundamental physics.

When we talked, Tony listened patiently, but reserved judgement about my conjectures, especially my hunch that the phenomena provide a challenge to current fundamental physical theories. Since then we have continued interacting intermittently mainly by email.

He also attended some of my increasingly complex zoom presentations about hatching mechanisms, given as invited talks at conferences during 2021 and 2022, while my ideas about the topic continued to evolve, as I repeatedly noticed new, more complex, previously unnoticed or ignored, features of egg-hatching processes, including the fact that the biochemical assembly problems during hatching are not uniform, but repeatedly grow more complex as hatching proceeds, providing challenges both for theories about the "bootstrapping" chemical developmental mechanisms in eggs, and for theories about how those mechanisms could have evolved.

In my January 2023 workshop talk I attempted to summarise those (hard to digest!) multi-faceted ideas, loosely represented in a collection of diagrams in this document, in which I have tried to show dynamic relationships between the biochemical processes, changing over time, both during *evolution of the species* and during *processes of gene-expression controlling developments in individual eggs, while hatching occurs*.

The talk, and the notes, did not include relevant aspects of insect metamorphosis, referenced [above](#), whose importance I did not notice until several months later.

A summary of the workshop schedule is in a text file linked [here](#).

The full Conference Schedule, including book of abstracts is available at <https://www.natural-computing.com/iwnc-ws>

Post-workshop follow-up

Last updated: See [top of page](#)

Since the workshop in January 2023, many new points of detail have been added to this document, and also some history of ideas about intelligence related to the topics discussed in this document.

In June 2023 notes were added about the remarkable self-reorganisation processes that occur in some forms of invertebrate reproduction, e.g. use of cocoon or chrysalis to decompose the organism and reassemble the biochemical constituents to form an entirely new organism with new morphology, and new competences, e.g. flying, feeding while flying, and mating. This reorganisation of atomic and sub-atomic particles seems to require far greater intelligence than any human-designed machine has demonstrated, or is likely to demonstrate in the foreseeable future, especially operating in such a small space.

Some previous updates:

11 May 2023: more tidying up, more references more clarification.

16 April: More references added, e.g. Kauffman (2019), further details added by A.S., some repetition reduced, some re-ordering.

20 Jan 2023: More tidying up.

16 Jan 2023. Some changes of structure, providing shorter abstracts + various...

12 Jan 2023 (Added more references.)

I apologise for the messy structure, and in some parts lack of clarity, of this presentation.

This is largely a consequence of the complexity of the mechanisms and processes discussed and the inadequacy of my attempts to allow for the unfamiliarity of the ideas for most readers. I may not have found the clearest forms of exposition of the ideas, and there may also be confusions, errors of substance and/or 'typos'!

I'll be grateful for feedback concerning details that need fixing as well as substantive comments.

Recently hatched ideas about hatching and intelligence

<https://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo.html>

Background Information for invited talk at the
International Workshop on Natural Computing, Tokyo, 21st Jan 2023:

<https://www.natural-computing.com/iwnc-ws>

Further details.

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VERY SHORT ABSTRACT

The study of biological morphogenesis has a very rich variety of subfields, as indicated by the Wikipedia entry <https://en.wikipedia.org/wiki/Morphogenesis>.

This document, introducing my online presentation given on 21st January, is about aspects of biological morphogenesis that involve hard to observe processes that occur inside eggs of vertebrates after they have been laid: including processes that produce extremely complex physiological structures and also behavioural competences required by new hatchlings, e.g. as they move around, feed themselves, drink, follow a parent, etc.

These hatching processes, and the mechanisms that make them possible, seem to have gone unnoticed by most (possibly all) other researchers interested in natural or artificial cognition or forms of intelligence, though various fragments have been mentioned by thinkers in several disciplines, including several who influenced my work.

In particular the complexity, variety, and specific forms of self-extension, of hatching processes in eggs of egg-laying vertebrates have apparently not been noticed by many well-known researchers in philosophy, psychology, AI, or cognitive science.

Many of the detailed implications of well known facts were not noticed by me for several months after I started thinking about hatching! Several such details are presented below in this document, and in other referenced documents.

[A longer abstract is available below.](#)

Connections with Ideas of Immanuel Kant, and others.

I'll try to show how some of those hatching processes in eggs of vertebrates have important links with a collection of apparently unrelated problems in a variety of research and engineering domains, including philosophy of mathematics, especially some of Immanuel Kant's ideas, and also: philosophy of mind, philosophy of science, philosophy of language, metaphysics, artificial intelligence, theoretical physics, transitions in biological evolution connected with changes in biological development, chemistry, biochemistry, neuroscience, developmental psychology, and the Symbiogenesis theory proposed by [Lynn Margulis](#).

There are connections with the work of many other thinkers from whom I have learnt, and probably many more from whom I should have learnt!

EXTENDED ABSTRACT

Last modified: 11 May 2023

This extends the ideas in the Very Short Abstract, above, with additional facts, questions and theories concerned with sub-processes of development and evolution and the biochemical mechanisms they require. Most of these details appear to have gone unnoticed by most (possibly all?) other researchers.

I first began to think about hatching processes around September 2020, triggered by a (zoom-based) conference discussion during which I suddenly noticed that everyone was ignoring the fact that hatching processes in eggs must be able to produce competences which they were all assuming *had to be* acquired by interacting with the environment and employing a variety of learning and inference mechanisms. But many newly hatched animals clearly have useful behaviours, involving complex coordination of multiple muscles and sensory organs that they have had no time or opportunity to train before they were used.

Moreover an important, but unobvious, feature of processes of gene expression in eggs (but not only in eggs) is that the processes are not uniform.

As gene-expression inside an eggshell produces increasingly many and increasingly diverse new biochemical structures mechanisms and processes, the degrees and kinds of complexity of the gene-expression mechanisms used in the egg must change dramatically over time, becoming increasingly diverse, more complex, more difficult to observe and understand, and increasingly species-specific.

It is not surprising that making more complex parts, or producing more complex behavioural competences, requires more complex mechanisms,

Less obviously, if the mechanisms creating more complex parts at a particular stage of development also have to create different (e.g. more recently evolved) mechanisms for creating the parts produced at a later stage of complexity, different types and levels of bootstrapping will have to proceed partly in parallel. More varieties of parallelism are needed at later stages of development of the foetus, when more parts are being created, or extended, or related to other parts of the animal ... all going on concurrently.

Those changes make the details increasingly hard to understand: as the embryo grows more complex and the mechanisms operating in parallel at multiple levels grow more numerous, more complex and more varied -- both within different parts of a hatching egg, and the same parts at different times. There is also much additional variation across egg-laying species, even considering only vertebrate egg-layers, not insects, etc.

Subsets of the changes in complexity of biological assembly mechanisms have been studied in many research and engineering fields, including biochemical engineering for medical purposes.

But the variety of forms of complexity-increase that occur in parallel, and grow more complex in parallel, both during gene expression in an egg, and also during the evolution of the species, appear not to have been studied sufficiently closely, causing important features to be missed, as I'll try to explain, with the help of [the "final" diagram](#) presented below.

In the past, because I failed to think about hatching processes in eggs, I missed most of this while investigating aspects of biological information processing between 1959 and 2020. I am not the only one.

Note-2 on Kant

Some readers may notice specific connections between these ideas and the ideas of Immanuel Kant, including his thoughts on the nature of mathematical discovery mentioned [below](#), and his conclusion in his ([Critique of Pure Reason 1781](#)) that some human mechanisms of reasoning ignored by Hume "may lie forever concealed in the depths of the human soul". Unfortunately there has not been time to discuss this connection in any detail at conferences where these ideas were presented.

What about mammals?

Many of the key ideas presented below, about processes of development and evolution in egg-laying animals, are also relevant to other vertebrates, including mammalian reproductive processes in which a newly fertilised cell develops within the mother's womb.

The womb mechanisms enable more complex forms of development prior to birth than reproduction in eggs outside the mother, because of the rich biochemical interactions between a mammal mother and her foetus before birth, and continuing varieties of influence after birth.

But discussion of those mammalian mechanisms is not required for the purposes of this talk, although I think the issues discussed here are relevant (in unobvious ways) to understanding mammalian reproduction.

Some important aspects of those mechanisms are discussed as part of the [Meta-Configured Genome \(MCG\) theory](#), developed mainly in collaboration with Jackie Chappell (<https://www.birmingham.ac.uk/staff/profiles/biosciences/chappell-jackie.aspx>) starting around 2005. Human language development includes many fairly obvious examples, but Jackie drew my attention to less obvious examples in other species, e.g. in crows and orangutans.

Thanks to Peter Tino

Some important extensions to the MCG theory were triggered by suggestions from Peter Tino (<https://www.cs.bham.ac.uk/~pxt/>) who first drew my attention to the relevance of known biochemical aspects of gene expression to the Meta-Configured Genome theory, after hearing me talk about it.

Thanks to Iain Styles

who, among other things, drew my attention to the potential relevance of some of the ideas of theoretical physicist [P.W. Anderson](#).

Some important closely related sub-topics are not included in this Evo-Devo presentation for lack of time. It is likely that others are absent because of my ignorance or accidental omissions -- on which I'll be happy to receive education or reminders.

Key Ideas and questions

The talk offered tentative and incomplete answers to some "key-questions", including:

- questions about mechanisms that are able to initiate and help to control increasingly complex construction processes in eggs of vertebrates during hatching,
 - questions about what those construction processes achieve, how they achieve it, and how they evolved.
 - Implications for theories in neuroscience, psychology, philosophy and other fields -- severely restricted by the time available for the presentation.
-

Insects and other examples

Metamorphosis in insects, summarised usefully in

<https://nhm.org/marvelous-metamorphosis>, is very interesting and closely related to my topic, but for now it suits my purposes to focus mainly on hatching processes in **vertebrate** egg-laying species: they present important challenges and (largely unnoticed) clues, discussed below. As mentioned [above](#), metamorphosis in insects is discussed in a later document.

Some vertebrate egg-layers are also ignored here. In particular, some bird species that have to keep their helpless newly-hatched offspring in the nest to be fed and cared for by parents until they have the strength to fly, are not discussed below. Those cases are partly similar to mammalian reproduction: both require parental care in later stages of foetus development.

Note updated 17 Dec 2023

Some time after after the comments below were inserted in June 2023, I started a new document providing a more detailed discussion of metamorphosis and a host of related biological processes:

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

Insect development

I now suspect that I need (and various research communities need) to learn more about astonishingly varied types of insect metamorphosis, all of which involve (at least?) two very different processes of gene expression in the same individual to assemble a new animal: first the mechanisms producing the grub or caterpillar develop, then later, after much feeding and growth, the mechanisms used during metamorphosis to produce the adult

develop, in many cases producing adults with wings and abilities to fly, including abilities to find and consume new types of nourishment (e.g. consuming nectar during later stages of development instead of the solid plant matter consumed during earlier stages) and also producing abilities to mate, in some cases even mating while flying. Many of these transformations occur inside cocoons, though not all insects use cocoons.

There are several websites explaining differences between a chrysalis and a cocoon, but for this document the differences are not important.

Some readers may object that these self-transformation processes in insects and egg-laying vertebrates are no more relevant to the study of consciousness and intelligence than the self-organising processes controlling a tornado or typhoon, while it lasts. However, a major difference is that there is a far greater variety and complexity of types of change, and types of control of changes, required during the transformations inside cocoons or eggs (whether vertebrate or invertebrate). Tornadoes and typhoons do not develop comparable intricate physiological structures and control mechanisms. For more on this see the references to metamorphosis [above](#).

Use of cocoons:

Added 18 Jun 2023

In previous presentations on hatching mechanisms and in various online documents, I mentioned only developments in eggs of vertebrates. However, many invertebrate species hatch from eggs as grubs or caterpillars that forage for a while, then create a cocoon or chrysalis with an external shell, in which *metamorphosis* occurs, during which the animal transforms itself into a new organism with new species-specific physiology, including male or female mating mechanisms, in many cases with wings, e.g. wasps, butterflies, moths, etc., where the later physiology, forms of motion, and preferred foods are totally different from the earlier versions, when they existed as grubs or caterpillars after hatching from eggs laid by their mothers.

After metamorphosis, males and females emerge with different physiologies and complementary mating behaviours, followed, in the case of females by species-specific egg-laying behaviours (e.g. see <https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/insect-eggs>).

After metamorphosis they also have new feeding behaviours, e.g. in some cases flying to obtain nectar from flowers, which they suck in using a long proboscis, which did not exist before the cocoon phase.

The sequences of transformations using metamorphosis in insect species are in some respects more spectacular than the transformations that occur in eggs of vertebrates, where chemicals provided by the mother, while the egg is assembled, are transformed to form the new physiology, of chicken, duck, alligator, turtle, etc.

During the process of metamorphosis inside a cocoon or chrysalis of many invertebrate species, the chemicals used to produce the final form of the new organism (e.g. butterfly, moth, etc.) were not all provided by the mother, in the original egg, as happens in vertebrate egg-layers. Instead, the invertebrates have to acquire most of their chemical matter needed for later stages of development during a substantial earlier feeding process, after initial

hatching as a grub or caterpillar.

During metamorphosis, the new enlarged organism is created by disassembling complex physiological structures grown during the extended feeding process in the previously hatched grub or caterpillar, much enlarged during the feeding process.

Inside the cocoon or chrysalis, the disassembled complex physiological structures are replaced by recombining physical particles to form an entirely new animal with new physiological structures, e.g. a moth or butterfly or beetle, which eventually emerges with wings that did not previously exist.

The new animal also possesses entirely new, but unlearned, abilities to fly and to feed, using new forms of action control, e.g. landing on flowers and sucking nectar, instead of feeding by chewing parts of plants or other solid matter, as they did before the cocoon stage. There are also new abilities, and physiological structures required for mating with a conspecific of the opposite sex, a process in which males and females have very different roles, with very different consequences.

There are many online videos showing aspects of insect metamorphosis, e.g. this one showing transformation of a dragonfly: <https://www.youtube.com/watch?v=pMq5IY4XUkc> (Note: I am ignoring many detailed differences of physiological structures and processes across insect species For example, there are several thousand different species of dragonfly.)

In an insect, all the information required for producing the new adult physiology and the new adult competences must have existed in the original fertilised egg, but remained unused while the newly-hatched grub or caterpillar crawled over plant matter, feeding and growing, until ready to stop all activity, enclose, or partly enclose, itself in a new case (e.g. cocoon, or chrysalis) and transform itself into a new animal with new physiology, new needs, and new behaviours, while in the case.

Genetic information about the later stage (e.g. butterfly or moth stage) must be present throughout the earlier stages, but is not used until enough chemical matter has been assembled to start the transformation to the winged, flying, form.

This (still very superficial) comparison of vertebrate and invertebrate hatching processes was not mentioned in any of my presentations or papers before 2023, which referred only to hatching processes and mechanisms used by vertebrate egg-layers, such as birds, tortoises, lizards, etc.

Intelligent gene-expressing mechanisms

There is an implication of all this discussion about hatching and metamorphosis that I did not explicitly reflect on or notice earlier. Most, if not all, of the researchers that I have encountered (including my earlier self!) seem to have assumed, most of the time, that intelligence is essentially a property of a complete organism or machine, manifested in its interactions with the environment, including finding or catching food, escaping predators, interacting with conspecifics (including competing, collaborating, teaching, caring for, protecting, feeding, informing, deceiving, fighting, etc.).

In contrast, much of my recent work (presented in talks and in this document and other online documents since 2020) has been about competences of subsystems controlling very complex processes within an organism, in ways that would probably be described as highly intelligent if done consciously by a human, e.g. assembling a complex structure by disassembling parts of pre-existing structures and reassembling them in new ways to perform new functions.

Metamorphosis processes invertebrates contribute something new and significant to the top level project: namely, the project of describing and explaining varieties of information processing that are possible in this universe and what fundamental physical features of the universe make them possible. For more on this see the note on post-workshop-discussion [above](#).

As regards evolution of flight in vertebrates, I have found the work reported here interesting:

<https://www.audubon.org/magazine/january-february-2015/which-came-first-dinosaur-or-bird>

It discusses evolution and development of physiological structures and transitions in behaviours, but does not mention the information-processing requirements or evolution of control mechanisms satisfying those requirements.

A challenge for fundamental physical theories

Added 20 Jun 2023

I don't know whether currently known fundamental features of physics can explain all the biological phenomena described here, including the control processes in eggs, insect-cocoons, etc. If not, changes to fundamental physical theories will be required -- as has happened several times in the history of physical sciences!

THIS EVO-DEVO DIAGRAM IS AN ATTEMPT TO SUMMARISE MY CONJECTURES ABOUT INTERACTIONS BETWEEN PROCESSES OF EVOLUTION AND IN-EGG DEVELOPMENT

Figure Evo-Devo (latest stage of evolution)

Including multiple layers of evolution, and corresponding new layers of in-egg development, combining evolutionary stages depicted separately in simpler diagrams below.

XX

Note: 1 Jul 2023

I now realise that that complex evo-devo diagram is insufficiently complex insofar as it does not include the possibility of metamorphosis during development, e.g. within cocoons, mentioned [above](#).

Key sub-questions: Implications for theoretical physics.

As mentioned earlier, I suspect (but cannot yet demonstrate) that some of the hatching mechanisms and processes in eggs of vertebrates discussed above, and depicted (crudely) in the diagram, challenge current theories in fundamental physics.

One possible challenge concerns an analogy between the task of Maxwell's demon, namely to sort a collection of gas molecules moving between two boxes into two categories fast-moving and slow-moving, where the difference is based on some arbitrary "normal" speed. For more detail see the Wikipedia presentation:

https://en.wikipedia.org/wiki/Maxwell%27s_demon

Clearly the "sorting" process that goes on during hatching in an egg is far more complex than the sorting into two categories done by Maxwell's demon. It isn't clear to me whether the comparison is violated by the fact that processes in an egg may have two sources of energy, that might be used to drive the sorting process, namely (a) external heat provided by the environment (e.g. if a parent sits on the egg) and (b) chemical energy that may be released by breaking down some of the molecules provided in the egg by the mother.

Another difference between the task of Maxwell's demon and the task of assembling a new animal in an egg is that the task of the in-egg assembler constantly involves new subtasks, involving increasing amounts of parallel processing going on in high-precision atomic-scale disassembly and assembly processes happening at sub-microscopic levels as the molecules provided in the egg by the mother are disassembled and reassembled in increasingly complex ways with constantly increasing parallelism, constantly increasing diversity, and increasing requirements for sub-microscopic precision during assembly of all the required physiological structures.

Not only in egg assembly is required

The in-egg assembly processes also use information in DNA not only to control assembly of all the molecular scale and larger substructures forming the complex physiology of the emerging hatchling, but also to provide usable information structures and mechanisms required to enable the new hatchling to perform the post-hatching actions, as illustrated by sea-turtles and avocets shown in videos below.

It isn't obvious to me that the mechanisms currently known to physicists suffice to explain all of that increasingly highly parallel high-precision molecular disassembly and assembly so as to create not only a complete new biological organism (the new animal), but also internal post-hatching control mechanisms able to control many muscular processes aided by information about the environment obtained using recently assembled sensory organs.

At present I am guilty of much hand-waving, but perhaps someone can either turn this into a precise argument, or refute the challenge to physics by showing that everything that happens during the processes of disassembly and assembly, including the mechanisms that control the process, are already explicable by current theoretical physics, or could be after minor additions to current physical theory.

The remainder of this document attempts to fill out more details of the problem and provide more biological and philosophical context.

Most of the material summarised here cannot be included in a single talk.

The above diagram does not incorporate the processes involved in invertebrate reproduction, using cocoons, etc. mentioned above. Invertebrate reproduction processes and mechanisms provide additional challenges for fundamental physics.

[End of extended abstract]

Previous work by other researchers:

Much related work has been done by other researchers, but I have not found another researcher who has attempted to formulate, and begun to answer, the specific collection of questions and conjectures discussed below, including the precise questions about interactions between evolution and development, especially evolution and development of information processing mechanisms required to control development of members of a vertebrate egg-laying species.

However, the ideas of Lynn Margulis seem to me to be very relevant to questions about how such species evolved, although as far as I know she did not mention my examples explicitly.

Stuart Kauffman ([2019](#)) makes closely related points, He doesn't seem to be aware of the closely related work of Margulis cited here. I also have the impression that he has understood some, but not all of the problems involved in explaining how hatching processes work, especially their ability to produce complex unlearned cognitive competences available for use shortly after hatching, and the changing, increasingly demanding, multi-stage, problems of control of further construction during hatching processes, crudely indicated in diagrams below, especially the last and most complex diagram shown above and repeated [below](#).

The pioneering work of [Tibor Ganti](#), celebrated in Korthof's web site <https://wasdarwinwrong.com/kortho13.htm>, pointed out many other requirements for various forms of life capable of reproduction.

An important omission in other work:

Nothing that I have encountered in web searches for information about control of hatching attempts to explain how the in-egg construction processes can produce significant post-hatching behavioural competences that don't require any post-hatching training, as shown by the [sea-turtles](#) and [avocets](#) mentioned below.

The in-egg processes include biochemical disassembly and assembly processes that transform relatively unstructured chemical biomasses in a new-laid egg into an intricately structured new vertebrate animal, e.g. a baby chicken, duck, swan, alligator, crocodile, turtle, python, etc. etc. -- that **also possesses unlearned knowledge about how to act in the environment after emerging from the egg.**

How are those in-egg transformations achieved?

How can highly parallel, multi-layered, constantly branching, chemical processes in an egg produce

not only

extremely complex, intricately related, physiological structures and mechanisms of many kinds, all required for post-hatching functioning of the new animal,

but also

post-hatching species-specific behavioural competences, i.e. abilities to act appropriately (for organisms of that type), in their environment, e.g. moving around, avoiding obstacles, feeding themselves and in some cases, but not all, following parents?

Sea-Turtles

The problem I am discussing is illustrated very clearly by the behaviours of newly-hatched sea turtles that fend for themselves after hatching, with no parents to look after them. When the turtles hatch, they have to crawl and swim out to sea and feed themselves, as explained in this tutorial video <https://www.youtube.com/watch?v=C9VydNhr35Y>.

Newly hatched avocets provide another type of example.

Recently hatched avocet chicks leave their mother to walk towards nearby water in which they catch food, in this 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>.

The full Springwatch episode, showing the avocet hatchlings, is on Youtube at: <https://www.youtube.com/watch?v=FV6ZHe0CiHw>

The section on "Avocet Island" starts at about 12min 23sec. The above 35 second extract, showing competences of newly hatched avocets, starts at about 12mins 30secs.

The video shows new avocet hatchlings engaged in rich interactions with a complex environment, including walking to a river and "fishing" for food, all done long before they have had time to train neural networks for the purpose.

There is a huge variety of different examples of hatching processes on this planet that produce both new bodies and new competences in those bodies, including vertebrate and invertebrate species.

All those new hatchlings need to use fairly complex competences before they have had time, or opportunity, to acquire the competences by training neural networks.

Neural networks do not exist during early phases of hatching, and when they do develop they cannot be trained, within the egg, to control behaviour in an inaccessible environment outside the eggshell!

The only possible source of competences of such newly hatched animals is the genetically (biochemically) controlled hatching process within the eggshell, as they need to use their competences before they have had an opportunity to train their neural networks after hatching.

Neural nets cannot explain detection of necessity or impossibility

I have the impression that very few researchers understand that the vast amount of recent research on statistics-based neural networks cannot explain ancient human (and some non-human, e.g. squirrel) abilities to detect and make use of spatial **impossibility** or **necessity**.

Immanuel Kant's insights

And few seem to understand Immanuel Kant's point in his ([*Critique of Pure Reason 1781*](#)) implying that statistics-based mechanisms cannot explain mathematical discoveries concerning impossibility and necessity (e.g. in geometry and topology) -- including discoveries that we now know were

made centuries before well known ancient mathematicians such as Pythagoras, Euclid and Archimedes were born, and even longer before logic-based reasoning mechanisms were invented and used by humans.

Necessity and impossibility are not high and low points on a scale of probabilities. They have totally different origins from probabilities, and, as Kant realised, neither impossibility nor necessity can be derived from statistical evidence supporting probabilities.

He also noticed that ancient precursors of such mathematical competences are essential for many non-mathematical spatial competences. Examples include avoiding obstacles, making tools, moving complex objects through narrow openings (e.g. a table too wide to fit through a doorway, but capable of being rotated in 3D space), building nests, and caring for offspring. (He had other examples.)

So, impossibility and necessity -- key features of mathematical discoveries in past millennia, and also relevant to intelligent selection of actions to achieve goals -- cannot be detected using statistics-based neural network mechanisms, a point that seems not to have been understood by the vast majority of contemporary researchers working on natural and artificial neural networks that collect statistical evidence and derive probabilities!

Presumably, those researchers have not read and understood Kant's claims made in 1781 (mentioned above).

And for the huge majority of current researchers (as far as I can tell) their school education in mathematics did not include geometrical and topological spatial reasoning of the types referred to in various places in this document, as well as in Kant's work.

Note:

Many philosophers, and perhaps other thinkers, now accept the erroneous belief that Kant's views on mathematical discovery had been refuted by Eddington's observations of a solar eclipse in 1919, confirming Einstein's claim in his theory of General Relativity that physical spaces are not necessarily Euclidean.

Discussions of that claim usually ignore the fact that non-Euclidean structures have been commonplace, since long before Einstein was born, e.g. the surface of a ball, or a kettle, and the surfaces of most human body-parts.

The existence of such non-Euclidean structures does not refute ancient mathematical discoveries about properties of Euclidean structures, and does not remove the need to explain how human reasoning mechanisms make such discoveries possible, and how those mechanisms are produced by a combination of evolutionary and developmental chemistry-based processes!

The ideas presented below provide steps toward a defence of Kant's views on mathematical discovery that nobody could have thought of in Kant's time.

Is our planet unique?

Does anyone reading this know whether any other parts of the universe include similar forms of biological reproduction and evolution? Could evolution of vertebrate animals and/or mathematicians able to make discoveries about topological or geometric necessity or impossibility be unique to this planet? Do organic molecules found in meteorites suggest an answer?

Competences of new hatchlings

My attempts to link these old investigations to hatching processes in eggs of vertebrates began in 2020, extending previous research with students and colleagues in Philosophy/AI/Cognitive Science since 1959. This was triggered by reflecting (for the first time) on the well known (but widely ignored?) fact that there are many species of vertebrate hatchlings that emerge from eggs, not only possessing bodies that contain a huge variety of extremely intricately interconnected internal physiological substructures and mechanisms, but also possessing important species-specific spatial competences combining complex perception and action mechanisms, that are used before the new hatchling has had time or opportunity to train neural networks after hatching.

These mechanisms are used in performing tasks such as breaking out of the eggshell, following a parent, or going to food and eating it, all done without prior learning or training, as illustrated by the above [avocet video extract](#) and the [sea-turtles](#), both showing competences of new hatchlings.

There seems to be evidence of similar precociality in hatchlings of a long extinct dinosaur species, referenced [below](#).

Do mechanisms underpinning competences of new hatchlings challenge current physics?

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

My (partial, tentative, and hard to digest(!)) answer outlined below attempts to link products of processes on many different time scales within and across species, produced by branching and converging evolutionary histories.

The answer seems (to me) to challenge current fundamental physical theories (as has happened repeatedly in the history of physics), though my original aim was not to [challenge](#) fundamental physics but to [use](#) fundamental physical theories (with expert help from theoretical physicists).

The challenge is this:

[The fact that evolution by natural selection in a chemical universe can produce such consequences, including finding ways of chemically encoding such rich semantic contents, is astounding.](#)

[Moreover such mechanisms are used in thousands of very different species of egg-laying vertebrates with details that partly overlap with phenomena in other species \(e.g. mammals and insects\). This suggests that there are deep facts about the physical universe which make those forms of reproduction possible and which have so far mostly gone unnoticed and unexplained. Many of those features were noticed by Lynn Margulis and are included in her ideas about symbiogenesis referenced \[below\]\(#\).](#)

If it turns out that physics needs a new revolution, in order to explain hatching processes in eggs, it won't be the first revolution in physics triggered by new empirical discoveries. For example, the discovery of magnetism, centuries ago, and the discovery (many centuries later) of connections between magnetism and electricity, led (via Oersted, Ampere, Faraday, Maxwell, and others) to major changes in fundamental physical theories, as well as many engineering applications of electromagnetic mechanisms.

Could understanding hatching processes also lead to currently unexpected (unbelievable?) new developments in science and engineering?

Relevant well-known facts

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 by acting in the environment.

Not so well-known facts/conjectures

Hatching processes depend on both general and species-specific chemical disassembly and assembly competences used inside eggs during hatching -- competences with their own developmental and evolutionary histories.

(Messy diagrams below are my attempt to depict some of the interactions between evolution and development.)

Some facts about hatching processes in the eggs of such species:

- They transform the original relatively small variety of chemicals in new-laid eggs into a much larger variety of chemicals used in multiple, more recently evolved, intricately interrelated, body-parts of the new hatchling, with many different functions.
- Less obviously, they repeatedly have to [extend the available in-egg mechanisms](#) for performing the above tasks, i.e. mechanisms for dismantling existing molecules and re-combining the components to form new increasingly complex structures and also new more complex, more recently evolved disassembly/assembly mechanisms required for later stages of the hatching process;
- and the in-egg hatching processes also construct in-egg mechanisms that provide several species-specific [post-hatching spatial competences](#), used after hatching without requiring any training, as illustrated by the [avocet hatchlings](#), and [sea-turtle](#) videos.

E.g. new hatchlings of many species can perceive objects in the environment, select goals, plan and execute suitable actions, including following a parent, moving toward, or avoiding, objects in the environment; and feeding themselves. or (like the sea-turtles referenced above) travelling unaided to a new location.

However, those observable competences are far simpler than the competences required to construct the organisms inside eggs.

Moreover, during hatching there are repeatedly branching varieties of new physiological substructures, requiring a repeatedly branching variety of new construction-control mechanisms for constructing new construction-control mechanisms!

[Earlier ancestors of such species would have had fewer developmental phases and would have needed fewer construction-control processes during hatching.](#)

**Note about invertebrate species:
(Expanded 6-14 Jun 2023)**

Related phenomena occur in insects that start life as grubs that grow for a while by feeding themselves (e.g. on plant matter, or dead animals), then produce cocoons in which processes of metamorphosis occur that transform the grub 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. In some insects the transition to a new form with new behaviours, e.g. growing wings and flying, happens without a cocoon stage.

The insect examples may later provide evidence that can suggest or test answers to my questions about processes in vertebrate eggs.

Use of cocoons:

In my previous presentations on hatching mechanisms and in my online documents, I mentioned only developments in eggs of vertebrates. However, since then I have been reminded of the fact that many invertebrate species hatch from eggs as grubs or caterpillars that forage for a while, then create a cocoon or chrysalis in which a process of *metamorphosis* occurs, during which they transform themselves into an entirely new species-specific physiology, often with wings, e.g. wasps, butterflies, moths, etc., where the physiology, forms of motion, and preferred foods are totally different from the earlier versions, when they were grubs/caterpillars.

A complete theory about biological morphogenesis must explain the astonishingly varied types of insect metamorphosis, all of which involve (at least?) two very different processes of gene expression in the same individual, to assemble a new animal, *i.e.* first producing the grub or caterpillar form, then later during metamorphosis producing the adult form, in many cases with wings and abilities to fly, including finding and consuming new types of nourishment (e.g. nectar instead of solid plant matter) and also abilities to mate, in some cases even while flying.

After metamorphosis, males and females emerge from cocoons with different physiologies and complementary mating behaviours, followed, in the case of females by species-specific egg-laying behaviours (e.g. see <https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/insect-eggs>).

They also have new feeding behaviours, e.g. in some cases, flying to obtain nectar in flowers, which they may consume using a long proboscis, which did not exist before metamorphosis.

The sequences of transformations using metamorphosis in insect species are in some respects more spectacular than the transformations that occur in eggs of vertebrates, where chemicals provided by the mother, while the egg is assembled, are transformed to form the new physiology, of chicken, duck, alligator, turtle, etc.

During the process of metamorphosis of invertebrate species, inside the cocoon or chrysalis, many of the chemicals used to produce the final form of the new organism (e.g. butterfly, moth, dragonfly, etc.) were not provided by the mother, in the original egg, as in vertebrate egg-layers, but have to be acquired during a substantial feeding process, after initial hatching as a grub or caterpillar.

During metamorphosis, the new organism is created by disassembling complex physiological structures in the previously hatched grub or caterpillar much enlarged by feeding after hatching. The disassembled physiological structures, are replaced inside the cocoon by recombining the

chemicals in the cocoon to form an entirely new animal with new physiological structures, e.g. a moth or butterfly in some cases, which emerges from the cocoon with wings which did not previously exist, also possessing entirely new unlearned abilities to fly and to feed, using new forms of action control, e.g. landing on flowers and sucking nectar, instead of feeding by chewing parts of plants or other solid matter, as they did before the cocoon stage. There are also new abilities to mate with a conspecific of the opposite sex, a process in which males and females have very different roles, with very different consequences.

Note: I am ignoring many detailed differences between insect species -- on which my knowledge is currently very meagre compared with what has already been discovered about the huge variety of life-cycles in insects.

However, what is common is that all the information required for producing the physiology and the behavioural competences of a newly hatched animal, and also the information required for producing the behavioural competences required at later stages of development, including male and female mating behaviours, and the various egg-laying strategies of insect females, must have existed in the original fertilised egg from which the animal emerged, but remained unused while the newly-hatched grub or caterpillar crawled over plant matter, feeding and growing, until ready to stop and transform itself inside a new shell (chrysalis or cocoon) into a new animal with new physiology, new needs, and new behaviours.

[Is that last sentence too complex to be understood??? Suggestions for improvement welcome!!]

Genetic information about the later stage (e.g. butterfly stage) must be present throughout the earlier stages, but is not used until enough chemical matter has been assembled to start the transformation to the winged, flying, form.

This (still very superficial) comparison of vertebrate and invertebrate hatching processes was not mentioned in any of my presentations or papers before 2023, which focused only on vertebrate egg-layers, such as birds, tortoises, lizards, etc.

This information about invertebrates adds significant details to the top level project: trying to understand varieties of information processing that can occur in this universe and what fundamental physical features of the universe make them possible.

Main conjecture

There must be multi-layered answers to these questions:

How can so much extremely complex, increasingly species-specific, 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 physical mechanisms in this universe support the even larger variety of forms of self-reorganisation of physical matter in invertebrate species, producing a huge variety of physiological transformations of individual organisms, and of internal and external behavioural competences at various stages of development?

Discussion and questions

Some of the above questions are concerned with production of both physical structures and mechanisms inside eggs and unlearned species-specific behavioural competences in newly hatched animals produced by those mechanisms.

How can chemical processes in eggs produce competent new animals with a combination of enormously complex and varied species-specific internal physiological structures and processes, and also unlearned behavioural competences, like the competences of newly hatched avocets and sea-turtles mentioned above, and the hugely varied insect competences used at different stages of development both in eggs and after post-hatching feeding and growth?

The main idea proposed here is that the abilities of biochemical processes in eggs to produce both post-hatching **behaviour**, and the less obvious processes of assembling increasingly complex **physical structures within the egg**, are recent extensions of evolutionarily older classes of biochemical mechanisms that contribute to development of additional physiological complexity *in the hatching process* while they are controlling physical assembly processes by rearranging chemical substances within the egg.

The older mechanisms were also presumably once relatively recent extensions of even older classes of mechanisms and competences inherited via backward branching routes (coming from male and female parents, and their male and female parents, etc.)

Note that discontinuous processes are intrinsic to this area. Biological evolution is not and cannot be a continuous process in any species that uses existing individuals to produce new members of the species.

Insofar as the processes of development in an egg involve removal and formation of chemical bonds they also cannot be continuous processes -- they include discrete changes. This is explicit in Schrödinger's discussion of biochemical reproductive processes in *What is life?* (1944).

What I am now suggesting is that abilities of chemical processes in eggs to produce competences for use by an animal after hatching, are later developments of much older abilities of chemical processes occurring during a particular phase of assembly inside the egg corresponding to a certain period in its evolution, to produce the assembly control mechanisms required for the next stage of development inside the egg. Important later processes and mechanisms of development in eggs are products of more recent evolutionary processes.

So each phase of assembly produces or modifies new physiological structures and also creates new control mechanisms required for assembly processes during later phases of development, corresponding to more recent evolutionary developments.

The above line of thought leads to the conjecture that the mechanisms producing competent post-hatching behaviours are relatively recent evolutionary products, following a collection of earlier evolutionary products. The earlier developmental behaviours (i.e. separating and re-using components of biochemical molecules provided in the egg by the mother) occur during, not after, hatching, whereas the more recent evolutionary products in insects produce behaviours after hatching such as feeding and mating.

But perhaps the earliest extensions of in-egg construction processes evolved after earlier external behaviours had evolved -- which were then incorporated into the internal construction behaviours required for evolution of physically more complex species with more complex behaviours?

So perhaps 'recapitulation theory' (the theory that ontogeny recapitulates phylogeny) is true of some of the earliest species?

There remain 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 Emily C. Dooley).

My main claim is that answers to these questions, i.e. explanations of the evolutionary and developmental phenomena relevant to assembly of new structures in an egg, depend on multi-stage processes of development in eggs, using increasingly complex biochemical developmental control mechanisms specific to eggs of that species.

The in-egg mechanisms "bootstrap" construction of both

-- increasingly complex physiological structures in eggs, corresponding to different stages in evolution of the species,

and also construction of

-- increasingly complex forms of new virtual (non-space-occupying) machinery, that control additional intricate, multi-strand, highly parallel, chemical assembly processes inside the egg.

As a result, those in-egg processes are also able to produce mechanisms that control species-specific post-hatching behavioural competences, illustrated by the behaviours of newly hatched avocets, and many other egg-laying species.

How is all that possible?

Increasingly complex, incomplete answers have been sketched in my talks and online notes on this topic, since late 2020, involving (among other features) hypothesized use of a previously unnoticed [], parallel, branching, growing collection of increasingly complex, increasingly species-specific, in-egg "Maxwell demons" disassembling and assembling complex biochemical structures, controlled by conjectured increasingly complex multi-layered forms of virtual machinery operating at different stages within the eggs, but without occupying physical space in the eggs, since no spare space is available!*

[]. If anyone knows of related work on hatching mechanisms, I'll be grateful for information (using contact address [above](#)).*

*Could all that be achievable during hatching by using increasingly large collections of **simultaneously active** electromagnetic signals, some of which trigger production of both new physiological structures and also new control machinery required for later stages of assembly?*

What mechanisms could enable increasingly 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>

In short: I conjecture that successive collections of virtual machinery in the egg control constructions in different developmental stages during hatching, by controlling chemical processes that produce new, increasingly complex, species-specific **physiological structures**, and also species-specific controlling processes that produce the next level, species-specific, more recently evolved, **successor control machinery**, i.e. more recently evolved (virtual) assembly demons!

(All this seems to contrast with [Levin's excellent work](#), which, as far as I know, has not mentioned, or attempted to explain, production of unlearned, post-hatching behaviours of birds, alligators, turtles, and many other species.)

These ideas are crudely depicted in what was referred to above as [the "final" diagram](#), whose explanation was an important part of my recent talks, which I fear most people found too difficult to follow.

[End of extended abstract]

DRAFT NOTES FOR PRESENTATION,

(I apologise for unclarity, verbosity, duplication, and other flaws. Please send comments and criticisms to contact address [above](#).)

This document presents still evolving work-in-progress, is very chaotic, and is liable to change. Suggestions for improvement are welcome. I'll also be grateful for information about relevant mechanisms not mentioned here, and also for corrections.

For the workshop presentation, I'll select a subset of the contents below, depending on the audience and the time available, usually including a discussion of the main evo-devo diagram [below](#).

RELATED WORK BY OTHER RESEARCHERS Related work done elsewhere?

I would be interested to hear about any researchers attempting to explain the combined, detailed, problems of [parallel construction, within an egg, of a very broad and varied, intricately interrelated, collection of physiological structures](#), while also producing [significant species-specific competences that are required soon after hatching, for interacting appropriately with structures in the environment -- including abilities to detect impossibilities](#), or to perform actions with useful **necessary consequences**.

There are many researchers working on self-organising, chemistry-based mechanisms, e.g. in slime moulds, but I have not encountered any that meet the above requirements.

The work of [Mike Levin](#) at Tufts University (another invited speaker at this workshop) is particularly impressive, but the work I have seen also addresses only a subset of the problems discussed here. As far as I know he has not discussed mechanisms that are able to detect impossibility or necessity (which are not degrees of probability) or tried to explain [the parallel assembly of a huge variety of different but intricately interrelated physiological structures inside an egg, or the ability of](#)

biochemical hatching processes in an egg to produce useful knowledge and skills available for use very soon after hatching.

I apologise to any researchers whose work does address the issues mentioned here. I'll be pleased to add references to such work in the online version of this document.

There was more or less closely related work by many other researchers, notably research by Mike Levin and collaborators mentioned above, presented at the same workshop 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, producing increasingly many, increasingly complex, increasingly intricately interrelated structures, 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](#), or the [sea-turtles](#).

Many more details and more questions related to this project are linked, above and below, on this web page, i.e.

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

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

This document is a product of a different kind of multi-stage hatching process (thought-hatching?) that has been growing increasingly complex since I first began thinking about the problems in 2020. as I repeatedly became aware of new complexities to be addressed! (The closest parallel that I am aware of is the work of Lynn Margulis referenced in several places in this document.)

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.

(End of note)

Selections from this document may be used for future conference/workshop presentations. The latest was in January 2023, referenced [above](#), since when there have been several changes, as the ideas developed.

Location of This Document

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.

Since 8th Nov 2022, changing versions of this document have been available at:

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

Older versions of presentations on this topic are now out of date, as they are superseded by this one. This page will continue being modified, including addition of more references.

NB: THIS IS STILL UNDER CONSTRUCTION AND LIKELY TO CHANGE

Some of the major changes are listed above and below!

9 Sep 2022: Added [link to avocet video](#).

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>,

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](#).

Nov 2022 to Jan 2023: There has been continuing development of the ideas presented in a series of (mostly dated) modifications of this document. As explained [above](#), it was originally developed for a (remote) presentation on 21st Jan 2023, for the

14th International Workshop on Natural Computing, Tokyo January 20-22, 2023

Modified versions of this document may be used for later presentations.

[] 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](#) on chemistry-based morphogenesis seems to make similar assumptions, and also Schrödinger in *What is life?* ([1944](#)).)

Another advantage of chemistry, compared with digital circuitry, is its ability to enable [hugely complex](#) interacting physical structures and processes occupying [minute](#) spaces: the digital technology developed in the last 70 years by human engineers is totally incapable of matching the degree of complexity achieved by chemical mechanisms in very small spaces although it has produced very complex interacting virtual machines on a much larger physical scale, for example online banking systems, flight reservation and control systems, and, more recently, mechanisms like Zoom, supporting distributed conferences linking changing collections of physical participants using computers that are not physically connected.

I'll try to show why extremely complex, but largely unnoticed, chemistry-based 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 -- a fact that cannot be explained by currently fashionable neural network models of reasoning or current logical/symbolic models of reasoning, since there's no evidence that they were used by ancient humans or other intelligent animals.

The proposed (but still under-specified) chemistry-based mechanisms are also related to the ideas about ["Meta-Configured" genomes](#), developed initially in collaboration with Jackie Chappell, as mentioned above.

The meta-configured-genome mechanisms motivate young animals to perform actions not because they meet some current need or provide some immediate reward, but because they provide information that can be used by later processes of gene expression in members of that species, because some genes are under-specified, or have gaps, to be filled by information acquired earlier by the developing individual.

Readers who have never encountered the label, should nevertheless immediately be able to think of familiar examples, for example in child language development. Some of the most important examples occur in language development where modifications of previously acquired information, e.g. adding plural forms of nouns, or future tenses of action verbs develop through later gene-expression processes, some time after the child has learnt about nouns and action verbs to which the new modifications become available.

Although the proposed mechanisms are implemented using [chemical structures and processes](#), they can use and produce [information contents](#) that refer to actual and possible physical structures and processes in the environment, e.g. possible future processes of construction of species-specific nests, in trees or on the ground.

I suggest that more complex versions of such mechanisms, that evolved much later, are 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 mechanisms and temporary structures used to aid construction of much larger objects).

Some of those ancient designers did not merely think about each individual item as it was being constructed. They were also able to think about possible future construction processes, and perhaps also past processes that went wrong in some way, or revealed new useful construction possibilities.

In addition to using such processes for their own future benefit, products of human evolution enabled them to transfer results of such learning to other individuals, effectively turning learning into a collaborative process, though collaborative symmetry is reduced in most teacher+pupil learning processes.

If these conjectures are correct, those ancient humans (unlike other intelligent species -- unless there are exceptions about which I have not been informed) made general discoveries in geometry and topology about which they could think (and in some cases discuss with others) while not actually involved in the construction processes, though the results of such thoughts could later be used for practical activities, such as building shelters, machines or clothing, or even giant pyramids and temples.

No similar processes occur in any other intelligent species, although many non-human animals (e.g. squirrels, nest-building birds, orangutans, and many others) seem to be able to acquire re-usable general information about physical possibilities and constraints from observations of particular cases.

Learning by understanding how something new (and possibly unexpected) happened is completely different from learning by collecting statistical evidence and computing probabilities, as is done in artificial neural network machines. (There's a lot more to be said about limitations of AI based on neural networks.)

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: there's no help or new material available from the mother during body construction, as occurs in wombs.

But the processes isolated in eggs are 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!

I hope that later work will 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* (including 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.

The work presented here can therefore be thought of as work in biology, or theoretical biochemistry or theoretical physics or philosophy of mind or philosophy of mathematics or philosophy of ... illustrating 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 on different occasions, in different evolutionary histories.

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, producing his work on chemistry-based morphogenesis as a side-issue.

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 during and after hatching processes. Unfortunately, since mid-20th Century, many highly intelligent researchers have had an education in mathematics that does not include relevant aspects of geometry and topology originally discovered long before now famous geometers were born.

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.:

<https://www.cs.bham.ac.uk/research/projects/cogaff/misc/hatching-talks-2022.html>

(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 have been trying to describe some recent steps toward answers 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 external controlling mechanism outside the egg (e.g. the mother's physiology) to control details of processes of development inside the egg. So all the details, e.g. initiating and guiding growth of blood vessels and 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, must all be controlled by mechanisms within the egg-shell.

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!)

END OF BACKGROUND INFORMATION

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_\(software\)](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 more changes in control mechanisms for assembling various parts of the new organism during the hatching process than members of species that evolved much earlier (along the same or a similar trajectory).

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.

(Information about varieties of virtual machinery should by now be a standard part of education in philosophy, biology, psychology, neuroscience, social science, as well as computer systems engineering. But that has not happened.)

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

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 last 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)

XX

Figure Evo-Devo-b (later evolution)

More than one stage of development.

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

XX

Figure Evo-Devo (latest stage of evolution)

Including more layers of evolution, and corresponding new layers of development, combining stages depicted above.

XX

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 could 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 further 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.

Correcting or compensating for abnormal development

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, e.g. conjoined twins in humans, mentioned above.

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.

I am not claiming that ontogeny recapitulates phylogeny: a new-born human has not gone through developmental stages corresponding to complete animal ancestors of humans. The relationship between developmental processes and evolution presented above 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. The differences in products of gene expression mechanisms are very obvious for species that emerge from their eggshells with very different outer coverings e.g. feathers, shells, scales, etc. and very different post hatching behaviours (e.g. walking, crawling, swimming).

In contrast, the similarities in mechanisms of gene expression are unobvious, partly because the mechanisms are not directly visible at any stage and partly because the similarities are very abstract features of developmental processes.

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. This must be a result of previously unnoticed differences in the earlier stages of hatching, including subtle differences in structures of the initial DNA.

One of the aims of this presentation is to draw attention to that divergence, in developmental processes, its origins, and its implications, and to defend a claim that although the processes of development differ widely across species there are some higher order common patterns in that divergence, shown relatively clearly 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 (e.g. the avocets mentioned above).

This claim about very complex, highly abstract common "evo-devo" patterns is illustrated in the most complex figure above, summarising relationships between evolution and development in many species, i.e.

<http://www.cs.bham.ac.uk/~axs/fig/evo-devo/evo-devo-final.jpg>

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 the 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 individual learning or training.

These hatchling competences include perceptual competences, goal formation competences and goal achievement competences, all of which can be observed in the behaviours of newly hatched members of many different vertebrate species. There are also competences that arise at later stages of gene expression, e.g. mating competences and the other meta-configured competences mentioned above.

Can current physics explain competences of newly hatched avocets and sea turtles?

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 the newly hatched avocets or the sea turtles, illustrated above.

What sorts of chemical assembly processes in an egg can produce an animal that has not only a species-specific collection of 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.

Those theories were, in effect, refuted long before they were formulated, 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 mistaken 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.

The in-egg chemical assembly mechanisms are much more powerful than trainable neural networks, insofar as they are able to produce both a huge variety of physical/physiological structures, and 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.

The generality of these mechanisms is illustrated by the fact that there are 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 birds, alligators, turtles, snakes, ... and many more.

At present I know of no attempts to describe developmental mechanisms that could explain how all those structures, mechanisms and 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 let me know 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. I'll use such information to extend appropriate lists of references in this or related documents.

Note on incompetent or less competent hatchlings:

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. (Other less obvious forms of development may also be required, e.g. specially evolved bone structures and brain mechanisms.)

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; while the in-egg demon-equivalents introduce many kinds of structural and functional differentiation, and (b) the demon or demons that are active at any stage during hatching, somehow also produce the more sophisticated demons required to control later, more recently evolved, stages of assembly in the egg.

The diagrams above very crudely (and perhaps too obscurely to be useful?) represent such multi-layered, multi-branching 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. These developments are all parts of larger processes of development within the egg, each of which forms a subsystem that requires coordination of its own components, as well as coordination between systems. Examples of such constructed sub-systems 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 they provide 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.
- glands of various sorts producing chemicals used in other parts of the body, to which they are transported, along with other materials, mainly by blood vessels.
- others ...

The diagrams above very crudely (and perhaps too obscurely to be useful?) represent such multi-layered, multi-branching ("ML-MB") processes of gene expression.

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*, including *rates of change of rates of change*, etc. But such mathematical forms 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 when a level-N demon begins to operate during the hatching process, it cannot already have the knowledge required for the level-N+1 assembly task. The information is presumably available *implicitly* in portions of the DNA that have not yet been used to control assembly, but will be used during level-N assembly, although that would not have been done by earlier ancestors of the level-N assembly controllers.

A new, more sophisticated, more recently evolved, control process for the level-N+1 task has to be triggered by the level-N demon. That requires level N demons to be modified (during evolution) so that they "know" how to perform actions that will create the level-N+1 demons that will have the competences required to control the next-level assembly processes. But the level-N demon does not know that what it does will produce such competences!

The comparison with Maxwell's demon is misleading insofar as Maxwell's demon does not create new demons. Moreover, unlike Maxwell's demon, the mechanisms controlling increasingly complex forms of differentiation in an egg can use chemical energy liberated when complex molecules provided in the new-laid egg are decomposed to provide the fragments needed to construct new components in the developing embryo. The chemical decomposition process may produce both new fragments and new energy required for subsequent assembly processes.

(It's likely that I am revealing my limited understanding of current theoretical physics?)

Is it possible that the standard laws of thermodynamics do not apply to biological mechanisms of gene expression? Supposed laws of nature have in the past turned out to have counter-examples, when previously unknown phenomena were discovered.

A question about post-hatching results

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?

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: varieties and sources of knowledge

David Hume and Immanuel Kant (from Wikimedia)



David Hume famously criticised theological and related metaphysical discussions by making a distinction between significant kinds of knowledge, which he divided into two major categories, and spurious knowledge claims that he described as "sophistry and illusion".

-- He claimed that important kinds of knowledge are either (a) about "matters of fact" or (b) about definitional "relations between ideas" and their consequences,

which he contrasted with

-- supposed types of knowledge that are neither of type (a) nor type (b), which Hume claimed to be "mere sophistry and illusion", including theological claims and possibly other metaphysical claims.

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

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: it is non-empirical (*a priori*) and synthetic.

So such discoveries are not about contingent truths or falsehoods but about **necessary** truth or falsehood.

Examples include many different proofs of Pythagoras' theorem and other discoveries in geometry and topology made centuries before well known ancient mathematicians such as Pythagoras were born. An example is the discovery that *one-to-one correspondence* between sets is necessarily a transitive relation: if S1 and S2 are in one to one correspondence and S2 and S3 are in one to one correspondence, then **necessarily** S1 and S3 are also, a fact that is implicitly presupposed by our uses of the natural number series. Piaget discovered that necessary transitivity of one-to-one correspondence is not normally understood by humans until they are five or six years old [Piaget\(1952\)](#). I don't think any living psychologist or neuroscientist knows how brains recognize such examples of **necessary** transitivity.

Training a neural network cannot produce such a discovery because trained neural networks merely derive probabilities from statistical evidence: that cannot lead to recognition that something is necessarily true or necessarily false (impossible). Something completely different must be going on in brains of young children who acquire that understanding -- perhaps using **chemical** rather than standard **neural** forms of information processing.

Kant pointed out, in his critique of Hume, that such discoveries are

- synthetic, not analytic, i.e. not simply based on logic and definitions,
- non-empirical (i.e. *a priori*) but not innate, since active effort is involved in discovering them, and different subsets are discovered in different communities, or at different times in old communities, 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. They therefore cannot explain ancient mathematical competences.

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.

The *key idea* presented above is that hatching processes in eggs of vertebrates involve complex, varied, processes and mechanisms that evolved at various times, producing new levels of increasingly complex types of gene-expression. More details including discussion of insect metamorphosis and many other biological phenomena are presented in this more recent document (work in progress):

<https://www.cs.bham.ac.uk/research/projects/cogaff/misc/metamorphosis.html>

Background 2: The Meta-Morphogenesis project

As mentioned above, the ideas presented here are closely related to, and emerged from, the *Meta-Morphogenesis* (or *MM* project, which was inspired by some of Turing's ideas on chemistry based morphogenesis (published in 1952).

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 his well-known 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, which I suspect 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. (Perhaps his unpublished work anticipates all the ideas in this paper. Compare my paper on the irrelevance of Turing Machines to AI [below](#).)

These ideas are also relevant to spatial intelligence in many non-egg-laying species and are closely related to earlier work with Jackie Chappell on "Meta-Configured" genomes, referenced [below](#).

Flaws in fashionable neural-network-based explanations of intelligence

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 [above](#)) display important competences that they have not had time to acquire by training neural networks, and more importantly 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. As noted above (and implied by Kant's ideas, around 1781), impossibility and necessary truth cannot be detected by neural net based mechanisms that collect statistical evidence and compute probabilities.

These limitations of neural networks seem not to be understood by most researchers who investigate learning and reasoning mechanisms based on trainable NNs. I suspect many of them have never studied geometry and topology using diagrammatic proofs, because of disastrous changes in mathematical education around the middle of the 20th century mentioned [below](#).

What about Logic-based reasoning?

The most popular alternative to both diagrammatic reasoning and empirical learning in mathematics is use of symbolic reasoning based on logical and algebraic mechanisms involving manipulation of discrete symbols. This has led to many deep mathematical results and development of computer-based mathematical reasoning systems. These are developments during recent centuries.

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 (including squirrels shown defeating "squirrel-proof" bird feeders in several online videos), many nest-building birds (e.g. weaver birds), elephants, orangutans, aquatic mammals, and many more.

Note on logic

A conference announcement for World Logic Day 2023 included this claim

Logic is not one field among others because it is universal, it encompasses everything: reasoning is fundamental for the development of any science, to guide our mind, to direct our actions.

and the conference web site, <https://www.logica-universalis.org/wld5>, states:

Logic is not one science among others. It is a very special science and it is not only a science, it is an extraordinary capacity that human beings have, called in Latin "reasoning". Logic is the art of thinking that allows us to understand, master and transform reality. Logic is not one field among others because it is universal, it encompasses everything: reasoning is fundamental for the development of any science, to guide our mind, to direct our behavior.

Claims like that ignore the well-known examples of non-human spatial intelligence mentioned above.

Moreover, there is no evidence that anything remotely like human uses of logic is involved in, or required for the stupendous variety of spatial control tasks involved in converting the contents of a new-laid vertebrate egg into any of the many varieties of animals produced by such eggs. There is no evidence that anything remotely like logic is used either for controlling the extraordinarily complex chemical assembly processes during hatching, or the post-hatching competences (e.g. abilities to find and consume food in the environment) produced by those in-egg biochemical

processes, illustrated by the avocets in the video above, and also sea-turtles that find their own way out to under-water feeding places after hatching on sandy beaches.

So why should we assume that logic is *required* for all human forms of reasoning or intelligent control of behaviour? The biological evidence challenges such claims.

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 in this document.

(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, documented in increasing detail during 2021-2022. After the January workshop new ideas emerged especially ideas about insect metamorphosis, referenced above.

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 there are others, please send me details (a.sloman AT bham.ac.uk). Perhaps collaboration will be fruitful.]

The restriction to vertebrate species does not imply that the ideas are not relevant to eggs of non-vertebrates, such as insect eggs, or even 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 a series of "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, 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 researches 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 newly hatched individuals of many different 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 the video-clip [above](#).

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

<https://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo-stepney.html> itself based on my talks about evolution, development and eggs during early 2022.

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 and sea-turtles 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., and, in the case of young horses, running with the herd to escape predators.

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 for a time I 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 hatch bird or other reptile. (Some biologists now classify birds as types of reptile.)

Previous presentations (when the ideas were a bit simpler)

Since the middle of 2022, I have used the title: [Recently hatched ideas about hatching and intelligence: using very low energy physics and chemistry at 'normal' temperatures in egg-laying vertebrates.](#)

An important and for me very useful occasion was an invited talk to a group of biomedical engineering researchers in Singapore, with philosophical interests (on 21st June 2022) with a 2 hour 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-wBEx7zIir_8TNRbYF14vddsNZa/edit

Most conferences are less generous with time for talks on complex new topics!

A later talk given on 20th August 2022 to the International Society for Philosophy of Chemistry (ISPC) was much shorter -- possibly too compressed. The recording is available here

<https://www.youtube.com/watch?v=m2FnBnlfqns>

Another relevant, older, thread: Meta-Configured Genomes

A collaboration with Jackie Chappell (Biosciences, University of Birmingham, UK)

(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 "late" 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.

I am very grateful to Peter Tino

The Meta-configured Genome and Hatching

Updated 25 Apr 2023

Those early MCG ideas were never applied to hatching processes, but I think they provide a useful background to the more recent ideas I presented (remotely) at the 2023 Tokyo workshop and at other venues, proposing interactions between species-specific stages of gene expression during hatching in eggs, that are partly analogous to interactions between culture-specific stages of language development, that seem to have inspired some of Chomsky's ideas about a hierarchy of types of generative grammars acquired and employed by language users, as they develop:

https://en.wikipedia.org/wiki/Chomsky_hierarchy

Chomsky's anti-empiricist work e.g. in Aspects

The important role of Chemistry in meta-configured genomes.

Some of the later threads connecting the Meta-Configured genome theory with biochemical details were suggested by Prof Peter Tino (mentioned above) 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. There are many online discussions and/or presentations of her work.

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 "explicit" 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 full details, but I suspect that when we understand a lot more about how hatching mechanisms in vertebrate eggs 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. That may even help to illuminate (for example) linguistic and mathematical competences in humans.

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, that 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/discoveries, and I know of no evidence that they were used consciously or subconsciously by the ancient mathematicians who first discovered theorems and proofs in geometry or the ancient engineers who used informal versions of such reasoning in their practical activities (e.g. devising ways of transporting very heavy objects and constructing (and maintaining?) very large objects such as pyramids and temples. I suspect other ancient forms of engineering, including construction and use of tools, and modes of transport on land or on water, will also turn out to be relevant,

Some online geometry/topology tutorials

-- Readers who were deprived of traditional mathematical education including use of geometric reasoning may find the following useful:

"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>

Now at University of Sydney

<https://www.msri.org/people/12337>

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

-- 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>

MATH 373 - Geometry I - Lecture 1

<https://www.youtube.com/watch?v=1hNR-iCuw7g>

MATH 373 - Geometry I - Lecture 2

[There are many more online geometry and topology tutorials.]

RELATED WORK

Earlier work leading up to this

The above significantly extends the ideas presented in my [2020 paper](#) on evolution of consciousness.

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.

Earlier versions of the key ideas were presented in 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.

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@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 processes 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. A similar comment is made in the document about insect metamorphosis referenced above.

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.

Michael (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>. They don't seem to me to have attempted to explain how hatching processes can produce the post-hatching competences described above (e.g. sea-turtles, avocets and other species).

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, he seems to have offered 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 Levin 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:

https://www.youtube.com/watch?v=kgMFnfB5E_A

It 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, especially, [post-hatching forms of intelligence](#).

Note added: 12 Jan 2023

See Also [Manicka et al.\(2023\)](#)

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, including insect eggs, cocoons, germinating seeds, etc. Such discussions will be left to other researchers for now.

In principle it would be desirable to produce a survey of attempts to explain how hatching mechanisms work across a wide range of species. Most of the explanations produced so far regarding hatching processes refer mainly to the relatively early stages of gene-expression that are common to a wide variety of species, before highly species-specific structures and mechanisms are produced in the eggs. And I haven't seen attempts to explain details of post-hatching competences. It's possible that there is relevant research on hatching processes that I have not yet encountered.

I would be grateful for references to research on how later species-specific mechanisms of hatching are bootstrapped during earlier stages of hatching/gene-expression in a variety of species.

I have hinted at the possibility that this work may have implications for theories of fundamental physics. That's partly because the processes discussed above require increasingly rich combinations of control of detailed microscopic physical changes of increasingly varied physiological structures and mechanisms, and most of the new mechanisms are constructed while older mechanisms are already running and contributing to the new processes. The number and variety of such mechanisms and processes "bootstrapped" inside an egg that is much smaller than most machines produced by human engineers is unmatched in products of human engineering.

I suspect that no human designed machine starts with so few types of chemical substance and within a few weeks creates such a large variety of types of chemical substance performing such a large variety of increasingly species-specific functions within the original space.

During the hatching process there is a great deal of replication of evolutionary history, namely, replication of types of assembly process and assembly mechanism, including mechanisms that bootstrap production of later assembly mechanisms, but not replication of adult stages of the organisms, as claimed by so-called "replication theory".

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 mammalian mothers at different stages of development in the uterus, whereas the egg-laying mother has to provide all the chemical resources required when the egg is formed, before it is laid, and cannot directly control any of the later chemical assembly processes in the egg.

Information about the mammalian case is provided (for example) 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 *Consciousness and Cognition* Volume 91, May 2021.

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, or even asks, all 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 may be added here later.

Note on recent "shock" announcement by Geoffrey Hinton

(Added: 4 May 2023)

A well-known AI researcher, Geoffrey Hinton, <https://www.cs.toronto.edu/~hinton/> has recently made a very widely reported "shock" announcement about dangers of "hype" about neural-network based AI. In reports of this announcement he is mis-described by idiotic/ignorant BBC reporters (and others) as "The Godfather of AI", a title I am sure he would firmly reject, and which will annoy those who are well-educated regarding the history of AI, which has origins long before Geoff began to work in AI as a PhD student, in the early 1970s.

He is an old friend and colleague who worked with me for a while in the 1970s, for which he was thanked in the preface to my [1978 book](#) *The Computer Revolution in Philosophy*. He later went on to work on major projects extending the science and technology of artificial neural networks -- which I always thought had very little connection with natural forms of intelligence!

Note:

Use of the "Godfather" label is an example of very poor, though unfortunately not uncommon, science journalism, even at the BBC. It probably also reflects poor teaching in science and engineering which over-emphasises currently fashionable developments, ignoring their limitations and alternative theories of intelligence.

I have tried, and completely failed, to understand what information about any of the history could have led journalists, or anyone else, to use the epithet "Godfather" in this context. A bizarre episode in the sociology (??) of science.

He was interviewed on this topic in this video: <https://www.youtube.com/watch?v=qpoRO378qRY>

Note:

Although Geoff and I always got on very well personally, we have always disagreed regarding the relevance and power of statistics-based neural networks to explanations of human and non-human intelligence, including forms of spatial intelligence involved in ancient discoveries in geometry and topology, e.g. discoveries made in India, China, Babylon and elsewhere, centuries before well known ancient mathematicians such as Pythagoras, Euclid, and Archimedes, were born.

Those and other discoveries about geometric or topological impossibility or necessity cannot be based on collecting statistical evidence and then calculating probabilities. Impossibility and necessity are not low and high degrees of probability!

I have mentioned this because our disagreement is relevant to the main thread of this document, and also reflects my disagreement with the vast majority of (perhaps all??) well-known researchers who focus on natural or artificial *neural network* mechanisms, apparently unaware of the inability of those mechanisms to explain or model detection of spatial *impossibility* or *necessity*, which are key features of ancient discoveries in geometry and topology, and, less obviously, are involved in various non-human forms of spatial intelligence, e.g. in squirrels, apes and elephants.

Mechanisms that collect statistical evidence from which they derive probabilities are incapable of explaining forms of human and non-human intelligence based on recognition of spatial necessity or impossibility, e.g. in squirrels, many nest-building birds, various types of apes, and aquatic mammals, along with pre-verbal humans. (Examples are presented in a discussion of [toddler-theorems](#), and other online documents linked there.)

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>

(Personally very relevant because Kant's claims first attracted my attention (around 1957-8) away from mathematics to questions about the philosophy of mathematics and origins of human mathematical competences.)

Jackie Chappell and Aaron Sloman, (2007), Natural and artificial meta-configured altricial information-processing systems, *International Journal of Unconventional Computing*, 3, 3, pp. 211--239,

<http://www.cs.bham.ac.uk/research/projects/cogaff/07.html#717>

Jackie Chappell first drew my attention to flaws in the Waddington's idea of an epigenetic landscape after she moved from Oxford to Birmingham in 2004.

Our subsequent discussions over several years led to the still evolving idea of a "Meta-Configured Genome", which, as far as I know, has no parallel in other work, although there are important connections with ideas about Symbiogenesis in the work of Lynn Margulis -- connections which I did not notice I re-read some of her work in 2023!

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>

(Also included in the Elsevier Commemorative volume, below.)

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.

Older publications that provide some of the ideas that are relevant to or motivate recent work on mechanisms of life and their origins include the following (a tiny sample):

- P.W. Anderson, More is different: Broken symmetry and the nature of the hierarchical structure of science, 1972, *Science, New Series*, Vol 177, No 4047, pp. 393-396,
https://www.tkm.kit.edu/downloads/TKM1_2011_more_is_different_PWA.pdf

- Daniel C. Dennett, *Darwin's Dangerous Idea: Evolution and the Meanings of Life*, 1995, Penguin Press, London and New York,

- Recent work by theoretical physicist David Deutsch and his collaborator Chiaro Marletto on what they refer to as "Constructor theory" is also relevant but, unless I have missed something, the theory doesn't develop details that help to extend the ideas above. See, for example:

- <https://www.youtube.com/watch?v=d8KCXgzqhsQ>

David Deutsch on 'Constructor Theory' with Chiaro Marletto, interviewed by Joe Boswell.
I don't think they address the hatching problems explicitly.

- Tibor Ganti (1971, translation 2003) *The Principles of Life* OUP, Eds. Eors Szathmary & James Griesemer, Translation of the 1971 Hungarian edition,
http://chemoton.com/images/pdf/GantiTiborEletmu_14.pdf

- Stuart A. Kauffman (2019) *A World Beyond Physics: The Emergence and Evolution of Life*. Oxford and New York: OUP

- Manicka, Santosh and Pai, Vaibhav P. and Levin, Michael (2023), *Information integration during bioelectric regulation of morphogenesis in the embryonic frog brain*, DOI, 10.1101/2023.01.08.523164, Cold Spring Harbor Laboratory,
<https://www.biorxiv.org/content/early/2023/01/10/2023.01.08.523164.full.pdf>

- Two books on the Symbiogenesis theory of Lynn Margulis

Lynn Margulis, *The Symbiotic Planet: A New Look at Evolution*, 1998, Weidenfeld and Nicholson, London

Lynn Margulis and Dorion Sagan, *What is life?*, 1995, Simon and Schuster, New York

- Jean Piaget, *The Child's Conception of Number*, 1952, Routledge and Kegan Paul, London

- Hermann Rahn, Amos Ar and Charles V. Paganelli, (1979), How Bird Eggs Breathe, *Scientific American* 1979, 240, 2, Feb, pp. pp. 46--55,
<https://www.jstor.org/stable/24965119>

- Rapaport-Sloman-Books and Papers:

Online collection of linked documents related to mutually cross-referenced work by

-- William Rapaport <http://www.cse.buffalo.edu/~rapaport>

and

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

Can be accessed from this document:

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

(also see the next item by Rapaport).

- William J. Rapaport (2023),

Philosophy of Computer Science: An Introduction to the Issues and the Literature

<https://www.amazon.co.uk/Philosophy-Computer-Science-Introduction-Literature/dp/1119891906>

(Also available in other countries and in other formats: Paperback from Wiley-Blackwell)

- Marco Schade, Nils Knötschke, Marie K Hörnig, Carina Paetzel, Sebastian Stumpf, (2022)

Neurovascular anatomy of dwarf dinosaur implies precociality in sauropods. See

<https://elifesciences.org/articles/82190>

- Erwin Schrödinger, *What is life?* 1944, CUP, Cambridge,

(Later reprinted in a different format, with additions.)

- Neil Shubin, Cliff Tabin and Sean Carroll, Fossils, genes and the evolution of animal limbs, 1997,

Nature, 388, pp. 639-648, <https://doi.org/10.1038/41710>

- Herbert A Simon, *The Sciences of the Artificial* (3rd Edition), MIT Press, 1996

- Aaron Sloman, *The Computer Revolution in Philosophy: Philosophy, Science and Models of Mind*, Harvester Press (and Humanities Press), 1978, Hassocks, Sussex,

Now freely available online (html and PDF), with additional notes and some corrections:

<https://www.cs.bham.ac.uk/research/cogaff/62-80.html#crp>

- Aaron Sloman, The Irrelevance of Turing Machines to Artificial Intelligence, in *Computationalism, New Directions*, ed., Matthias Scheutz, MIT Press, 2002, pp.87-127

<https://www.cs.bham.ac.uk/research/projects/cogaff/sloman.turing.irrelevant.html>

(Invited chapter. Also pdf)

- Aaron Sloman (2020), Varieties Of Evolved Forms Of Consciousness, Including Mathematical

Consciousness, in *Entropy*, MDPI, 22(6:615), <https://doi.org/10.3390/e22060615>, or

<http://www.cs.bham.ac.uk/research/projects/cogaff/sloman-moc-entropy.pdf>

- Aaron Sloman (2011), Meta-Morphogenesis and Toddler Theorems: Case Studies

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

- Aaron Sloman (1965), 'Necessary', 'A Priori' and 'Analytic', in *Analysis*, Vol 26, no. 1, pp. 12--16,

<http://www.cs.bham.ac.uk/research/projects/cogaff/62-80.html#1965-02>

(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?

Commentary on three articles by Premack, D., Woodruff, G., by Griffin, D.R., and by Savage-Rumbaugh, E.S., Rumbaugh, D.R., Boysen, S. in *Behavioral and Brain Sciences Journal* 1978, 1 (4),

<http://www.cs.bham.ac.uk/research/projects/cogaff/62-80.html#1978-02>

- Towards a grammar of emotions, in *New Universities Quarterly* 1982, 36, 3, pp. 230--238,

<http://www.cs.bham.ac.uk/research/cogaff/81-95.html#emot-gram>

- C. H. Waddington, (1957), *The Strategy of the Genes. A Discussion of Some Aspects of Theoretical Biology*, George Allen & Unwin

NOTE

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

THANKS OWED TO MANY OTHERS

Over many years I've received an enormous amount of help, encouragement, constructive criticism, replies to my questions, and pointers to relevant information. This includes comments from colleagues, students, people who have read some of my work and written to me (not always in agreement).

A probably incomplete list:

Most recent influencers:

Anthony (Tony) Leggett (thanked above also), Jackie Chappell (close collaborator, since late 2004, with whom ideas about "meta-configured" genomes were developed).

Also (order partly random):

- Achim Jung,
- Alan R. White,
- Alison Sloman,
- Daniel Dennett,
- Eva Hudlicka,
- Herbert Simon,
- Iain Styles,
- Ian Wright,
- Jeremy Wyatt,
- Luc Beaudoin,
- Margaret Boden,
- Mark Ryan,
- Max Clowes,
- Max Wertheimer,
- Mike Ferguson,
- Mohan Sridharan,
- Nick Hawes,
- Simon Bowes,
- Stephen Isard,

- Tom Khabaza,
 - Visvanathan Ramesh,
 - William Rapaport
- and totally unwitting deep influencers:
- Lynn Margulis -- who (like Immanuel Kant, among others) influenced my ideas in a deep way, without ever being aware of my existence, although I was in the audience at her presentation in Oxford!
 - Immanuel Kant, in his [Critique of Pure Reason \(1781\)](#).
 - Noam Chomsky -- I shared his disagreements with behaviourists, but felt that he should not have ignored Kant's ideas about ancient forms of geometry and topological knowledge. See also <https://web.stanford.edu/~siegelr/england/margulis2009.html>
...(I think I was near the back of the audience in one of those pictures.)

[The above list was constructed when memory functions were going downhill, and there are likely to be important omissions. Feel free to write to me pointing out gaps and errors that need to be corrected -- also in the rest of the document!]

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