

From Big Bang to Chaotic Complexity: A Theory of Big Evolution

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Abstract

One of the mainstays of modern evolutionary biology is that evolution is highly sensitive to initial conditions and that, according to the Butterfly Effect from Chaos Theory, it is impossible to predict evolution in any way. But Chaos Theory is more than the Butterfly Effect, and there are aspects of chaos that - in complete contradiction to the Butterfly Effect - are *insensitive* to initial conditions. Also known as Universality within Chaos Theory, there is a phenomenon known as a Period-Doubling Cascade, or Feigenbaum Cascade, which is ubiquitous in iterative non-linear dynamic processes with limited resources. And iterative non-linear dynamic processes with limited resources are not exactly uncommon in the universe. Evolution is just such a process.

This study examines the spontaneous creation of innovations in Intentional Teaching among animals and early humans. Such innovations occurred during Cultural Evolution, which followed Physical and Biological Evolution. Each of the teaching innovations represents nothing less than a new form of evolution. If one accepts that transmission of cultural information is as legitimate a form of transmission of acquired information as transmission of DNA during biological reproduction, then the innovations in teaching methods are potentially highly significant. There are seven new teaching methods identified by cognitive archaeologists. Each of them transmits a new kind of information that is on a higher cognitive level than previous methods. The co-evolution of tool technology, teaching, and biology, led eventually to spoken language.

Examination of the time intervals between these seven evolutionary stages shows that they are compatible with a Feigenbaum Cascade from Chaos Theory. Physical and Biological Evolution also converge to the time pattern of the Cascade, as do the development of information technology in the form of written language, the printing machine, and the computer. This forms the basis of a theory of Big Evolution, which - like Big History - covers the whole of time.

Key Words: Chaos Theory, Human evolution, Feigenbaum constant, singularity, acceleration

Big History and Evolution

Big History is the discipline of studying the past all the way back to the beginning of the universe from the human point of view to understand what happened. Ideally, we would like to have a single theory of evolution that covered the whole of Big History. The methodology used in most theories is to estimate the rate of increase of one or more evolutionary factors that have existed throughout big history, such as growth in energy, complexity, information, etc. There are a few theories around, but none that have yet attracted much support apart from Eric Chaisson's proposal of a common measure of complexity, Free Energy Rate Density (FERD). This is useful, because there is no generally agreed definition or measure of complexity. FERD has been praised as a metric, but Chaisson's claims for it have been criticized (Solis, Ken, 2023).

Many of the theories claim that evolution is accelerating. Some of them also include the idea of a technological singularity – defined as a point in time where technology is able to evolve itself faster than humans can develop it, and that the speed of evolution becomes very fast, very quickly (Kurzweil, 2014).

Chaos Theory and Evolution

This paper proposes a theory based on information and complexity examined through the lens of Chaos Theory – also known as Non-linear Dynamics. Chaos Theory has a feature called Universality whereby various processes modelled by different mathematical functions can give exactly the same results (Feigenbaum, 1983). In Linear Dynamics, the exact functions used in mappings is important. Not necessarily so in Non-linear Dynamics, where iteration of functions often obscures the differences between functions and it can be enough to define relationships between variables as monotonic (“always increasing”, or “always decreasing”) and still get the same qualitative and quantitative result.

An interesting application of Chaos Theory Universality would be if we could use it to show that the entire span of evolution – from the physical evolution of stars and planets, to the evolution of life, culture and technology – were all different phases in the same process, superficially different, yet all obeying the same mathematical rule. Chaos Universality may mean that such a theory is possible. All we have to do is to find the evidence.

But there is another thing we would have to do as well – convince the scientists. When Chaos Theory was discovered in the first half of the twentieth century, “what made universality useful also *made it hard for physicists to believe*. Universality meant that different systems would behave identically” (Gleick, 1987). When Gleick wrote that in 1987, one may have thought that today, 35 years later, the mathematics of Non-linear Dynamics would be as widely used as Linear Dynamics was back then. Yet it seems that today there are still aspects of Non-Linear Dynamics that are not as well-known as they could be. Evolutionary Biologists today quote elementary Chaos Theory to “prove” that a universal theory of evolution is “not possible”, because “sensitivity to initial conditions makes evolution completely unpredictable.” This is a very limited interpretation of Chaos Theory, where under some conditions there is the very opposite, namely the *complete insensitivity* to initial conditions.

The unpredictable rate of evolution. As well as unpredictability, Gould and Eldredge proposed that evolution is also unpredictable in speed, with their theory of punctuated equilibria. (Eldredge & Gould, 1997; Gould, 1990). However, more recent research challenges the paradigm, with evidence that evolution may be more predictable than currently thought (Kryazhimskiy et al., 2014) .

Evolution as the accumulation of information. The events on which this paper is based concern the evolution of information. Big History theories often talk about the phases of evolution – especially Physical, Biological, and Cultural. Technological Evolution, starting with the evolution of Tools, is sometimes separated from Cultural Evolution, sometimes considered a part of Cultural Evolution. Carl Sagan wrote a book showing how that information was a common thread throughout evolution (Sagan, 1977). The information in question is information about how to survive and prosper. From an information perspective it can be useful to refer to Information Technology Evolution, which begins with Written Language. This means that Information was stored in a different way for each phase of evolution. This paper uses the following classifications of knowledge.

- **Physical evolution** saw the evolution of the universe, stars and planets, eventually resulting in cell-like molecular structures. These structures "knew" how to survive, but there was no information other than the structure itself.

- **Biological evolution** saw the first living cells that could replicate themselves, or modified versions of themselves, from coded instructions (coded, for example, in DNA). From this point the prime mechanism of evolution was no longer direct change to the cell but change to the coded instructions in the cell's DNA.
- **Cultural evolution** began when animals had sufficient awareness that they could recognize others of the same species and imitate and learn their behaviour and skills so that these useful skills can be passed on to future generations (Huber et al., 2009). Any useful behaviour that results is stored in the phenotype (i.e. in the body – for example, in the brain) but not in genotype (DNA). Learning led to teaching, which then co-evolved with tool development and language, all of which was a significant driver of biological evolution (Morgan et al., 2015).
- **Information Technology Evolution** began when information was stored "extrasomatically" ("outside the body") as written language.
(Note that this paper refers to evolution of *Information Technology* as separate phase after Cultural Evolution, and distinct from other kinds of technology such as Stone Tools, which evolved during Cultural Evolution together with communication and language.)

None of these phases of evolution have actually ended – all of them are still ongoing.

Looking at where humans are now, we can see that the accumulation of knowledge to survive and prosper is similar, if not identical, to the scientific search for knowledge in general as well as the knowledge to create useful things. The more knowledge we have, the more we can predict and avoid future problems. And the more useful things we can create, and the more able we are to deal with problems that cannot be avoided.

Why 4.669? Some authors have concluded that there is a characteristic rate of acceleration of evolution which can be expressed as events occurring at time intervals which become smaller. This paper also proposes an acceleration rate, equal to 4.669. This number does not originate from an empirical study of history, but comes from the study of Non-linear Dynamics, also known as Chaos Theory. In particular it comes from a very common phenomenon known as a "Period-Doubling Cascade" or "Feigenbaum Cascade" (Cheung & Wong, 1987).

Feigenbaum Cascades are found in iterated nonlinear dynamic systems with limited resources. They are modelled using maps like the one in figure 1.1. At first the output increases as the input increases, but as the input increases to its maximum value, the output goes back down to zero and all the resources are consumed (Chen et al., 2021).

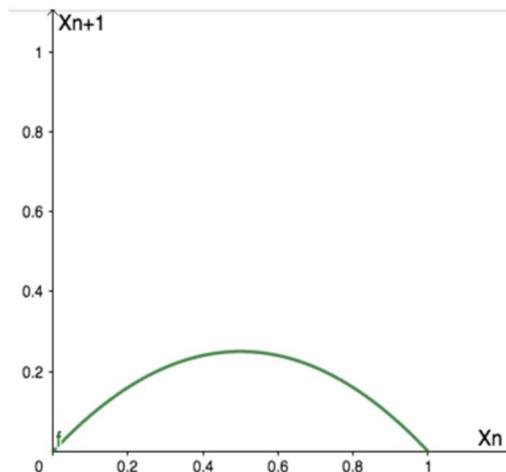


Figure 1.1: The logistic map, often used to model systems with restricted resources.

Figure 1.2 shows the "attractor" for a typical limited-resource map. The attractor shows the equilibrium value of x after many iterations as parameter r increases. At a certain value of r the output value x bifurcates into two values and oscillates (alternates) between the two values. Each bifurcation is usually accompanied by discontinuous changes in the process.

Resource-Depletion Bifurcations occur in systems with limited resources, which is a substantial proportion of all systems. The bifurcations occur because a resource consumption threshold has been crossed, causing resources to be depleted to the level where starvation occurs, resulting in oscillations in the population level.

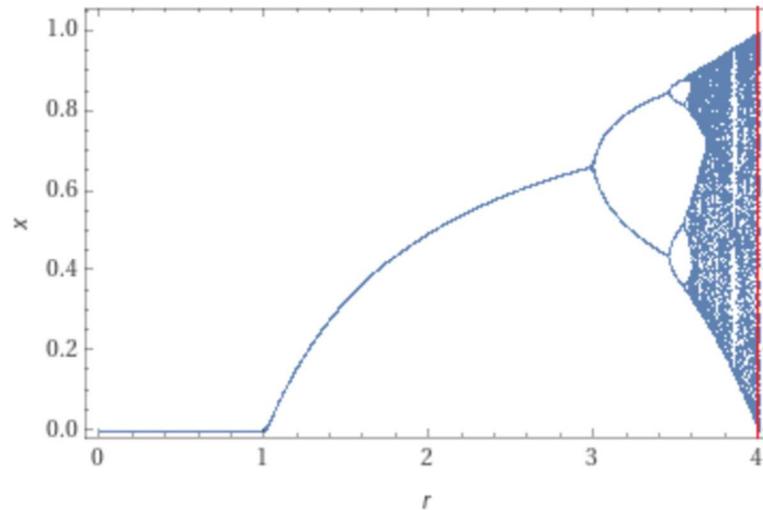


Figure 1.2: Feigenbaum Cascade. The simple logistic map, $x \rightarrow r.x(1 - x)$, where r is birth rate, x is population (maximum is 1.0). When iterated, it displays chaotic behaviour, as shown. The ratio of intervals on the r axis between consecutive bifurcations converges to the Feigenbaum constant δ (4.669...). (Only the first two bifurcations can be seen on this diagram.) The bifurcations finish at the Accumulation Point (which, on this diagram, is approximately at $r = 3.6$) after which the chaotic region begins and cycles are non-periodic.

Very similar attractors can be found in, for example, 1) the pattern of drips from a dripping tap (where the parameter on the x-axis is water flow); 2) oscillations in neural networks; and 3) fluctuations of predator population in an ecosystem (where the parameter is birth rate) (May, 1976). A remarkable feature of these bifurcations is that the ratio of distance between each resource-depletion bifurcation is always the same – namely 4.669, known as the Universal Feigenbaum Constant Delta. (Figure 1.2). One gets the same result from a single “hump” almost no matter what the exact function is. The only requirement is that the map used has a single “quadratic peak”.

The point here is that we could model say, a fish farm, using the simplest restricted-resource map – the Logistic map. Or we could study fish behaviour very closely, and make models – far more sophisticated than the Logistic Map – of how treatment with antibiotics increases the birth rate in a fish farm. But the end result would still be a Feigenbaum Cascade with an acceleration that converges to 4.669.

Original work in this paper

Because Feigenbaum Cascades are so common, there is the possibility of finding them in Evolution, which seems to fulfil the relevant requirements of being an iterated non-linear dynamic process. The goal of this paper is to confirm that Feigenbaum cascade has occurred during evolution resulting in its characteristic signature, the Feigenbaum constant Delta. This investigation begins with set of 6 methods of Intentional Teaching proposed by cognitive scientists for Information Transmission (aka Heredity) during Cultural Evolution (Gärdenfors, 2021; Gärdenfors & Högberg, 2017). These methods appear to follow a pattern similar to that of a Feigenbaum Cascade. Further investigation found 7 more events of the same kind stretching over the history of the universe, resulting in the hypothesis below.

The hypothesis.

- The evolutionary record shows evidence of what I have called “**Heredity Transmission Channels**” or “**Heredity Channels**” for short. Each of these events gives rise to a new process which transmits a new kind of hereditary information in a new format.
- The Heredity Channels appeared at successive time intervals that decreased by the factor 4.669 – the universal Feigenbaum Constant – thus forming a Feigenbaum Cascade. The first interval was several billion years and the latest completed interval about 1,000 years.
- This new information is about a new Means of Modification. Every new Heredity Channel is namely linked to a new Means of Modification. (An example of a new Means of Modification is Making Tools.) The new information about tools cannot be transmitted (taught) using existing Heredity Channel, and this gives rise to the new Heredity Channel. Each new Means of Modification was so innovative that they could not be sent on existing channels to new generations, and required a new Heredity Channel to be invented. (An example of a Heredity Channel is Demonstration.)
- Each new Means of Modification is faster than the previous Means of Modification.
- There are 13 of these Modification-Means/ Heredity-Channel pairs. These are shown in table 1.1.
- (This can be compared with mainstream evolutionary theory, which has the same 2 Modification-Means /Heredity-Channel pairs in Biological Evolution (but treats them as one) and it is debated whether Cultural Evolution as a whole counts as a third Modification-Means /Heredity-Channel pair).
- Each new Modification-Means/Heredity-Channel pair adds to, and does not replace, previous Modification-Means/Heredity-Channel pairs.

The sequence seems set to reach an “accumulation point” and a transition to a chaotic phase around the year 2196. The nature of the transition and the chaotic phase are unclear.

Methods

Confidence levels

We are interested in the date of the earliest example of each object, which is the oldest date. Each date is in fact 2 dates representing an interval of 95% confidence. 95% is assumed unless explicitly stated, and all dates here are 95%. However, some dates are known very accurately (small interval) and many less accurately (larger interval).

Logarithmic Scaling to view the whole timeline at once

The Feigenbaum Cascade is a geometric progression. This means that it has a wide range of scale where the size of an interval ranges from 200 years now to several billion years at the start of the universe, a range of about 100,000,000 to 1. This is far too large a range to show on a linear diagram, but we can instead rescale every interval so that every interval is the same size. We can do this using logarithms (Lewis, 1960). This means we can see, for example, the difference between the theoretical and the actual values for all 13 intervals on the same diagram. The Timelines in Figures 1.3 and 1.4 both use this technique.

Overview of Methods

This section describes the methods used for analysing the available data. There are two methods:

- **Methods Part 1: Looking for the Feigenbaum Cascade in Cultural Evolution.** The method used to find the dates for when each Heredity Channel arose is explained. This is to be applied to Heredity Channels in Cultural Evolution proposed by Gärdenfors and Högberg to see how well they fit a Feigenbaum Cascade.

- **Methods Part 2: Looking for the Feigenbaum Cascade outside Cultural Evolution.** Then there is an explanation of how the pattern is extrapolated forwards and backwards in time to see if the pattern indicates any more Heredity Channels before or after Cultural Evolution.

Methods Part 1: Looking for the Feigenbaum Cascade in Cultural Evolution

Gärdenfors and Högberg (G&H) propose:

- That Information Transmission methods during Cultural Evolution – at least among human ancestors – were all forms of Intentional Teaching of offspring by parents. This was because Intentional Teaching provided the necessary fidelity for the acquired skills to be accurately passed on for an indefinite number of generations.
- That each new Teaching Method was added to the toolbox of methods and did not replace any earlier Teaching Methods, all of which remain active to this day.
- That there are six of these well-defined teaching innovation events during Cultural Evolution.

The intervals between the events in this sequence of events that appear to be close to the interval ratio 4.669. However, the question of dates is not simple.

Teaching techniques do not usually leave archaeological remains that can be dated. G&H state that two of the teaching methods (“Demonstration” and “Communicating Concepts”) enabled two important advances in toolmaking techniques (“Oldowan” and “Late Acheulean”) to be taught. This implies that the teaching methods may have appeared some time before, and applied to the tools later.

However, if this assumption is true, it is incompatible with the hypothesis in this paper, because the dates will not agree with predicted dates. On the other hand, it is reasonable to make the assumption that the Means of Modification and the teaching method appeared simultaneously, as they are mutually dependent.

A likely scenario that one or both lay dormant until conditions reached a tipping point where they both became active – for example, when the net energy produced crosses the threshold from negative to positive). This is the way that flip bifurcations work. It is the date of the tipping point, when the processes become active, that is the date of interest.

Of course, seeing modification and teaching as two separate things is a human way of understanding them. They could be seen as one thing with two parts, and each of them can probably be divided into several parts in more ways than one. Evolution, which produced them, does not “think” about them at all. In reality there are lots of parts and nothing works until the last piece is in place and the conditions are right.

Assuming the teaching and Means of Modification have the same date, then we just have to associate each Means of Modification with a teaching method – justifying each association by referring to G&H’s papers or to other sources – and then find the date when the Means of Modification first appeared.

Methods Part 2: Looking for the Feigenbaum Cascade outside Cultural Evolution

Extrapolation Method

When we have the dates of the seven Teaching Methods of Cultural Evolution and have confirmed that they are part of a Feigenbaum Cascade, we can extrapolate the sequence backwards and forwards in time to find new dates where would expect to see more Heredity Channels created. The method for doing this is as follows:

1. Begin with the dates of the Cultural Teaching Methods (Heredity Channels)
2. Create a best-fit timeline

3. With the Timeline, we can extrapolate in two directions. Extend the Timeline at each end by one event, using the Feigenbaum Constant 4.669 to scale the interval (multiply the time interval by 4.669 when going back in time, and dividing by 4.669 when moving into the future,
4. Look at each of the predicted dates and see if either of them corresponds to a Heredity Channel.
5. If any are found, add them to the Timeline.
6. Some of the event dates may need adjusting. Work out a new best-fit timeline.
7. Go back to step 3, and repeat as needed.

Results

Results Part 1: Looking for the Feigenbaum Cascade in Cultural Evolution

Cherry-picking avoided by absence of information. The initial attempt to match G&H's Teaching Methods to a Feigenbaum Cascade failed because one of the intervals was too large, by a factor roughly equal to $\Delta + 1$. This gap indicated that there may be a Teaching Method missing from G&H's list.

The gap also indicates that events have not been cherry-picked to fit the interval ratio 4.669. Indeed, the authors do not mention any mathematical rule for the events. And there is nothing in any literature about the Feigenbaum Constant Δ in evolution at the time their paper was published. It follows that the authors were unaware that a mathematical analysis of the sequence indicates that one event is missing.

Saved by Tool Transfer. This gap in the sequence is after the first teaching technique, Parental Approval/Disapproval. This technique is applicable to both behaviour without tools and behaviour with tools. The next teaching method, Drawing Attention (to an object), is used to indicate to the student that they are about to be shown something important, such as how to make a tool. In retrospect it seems obvious that the missing behaviour should be to do with learning how to use a found tool, because it seems obvious that Tool Use is a higher cognitive threshold than Behaviours Without Tools, and lower than Making Tools.

However, the behaviour in question (Tool Transfer, which is when the parent gives a tool to their young) does not involve teaching in the way we think of it. But Tool Transfer nevertheless fulfills the definition of a teaching method — that the student leans, that the teacher is present, and that the process involves a cost for the teacher (in this case the time and energy to acquire the tool) (Hunt & Gray, 2007). But Tool Transfer is necessary for learning Tool Use because the student needs to practice with a suitable tool before they can learn the next part of Using Tools, which is to find a suitable tool.

Also, Tool Transfer is not observed in, for example, all groups of chimpanzees (Musgrave et al., 2016). possibly because of Genetic Assimilation of Behaviour, whereby acquired behaviours can become instinctive after many generations and therefore no longer need to be taught (Tierney, 1986).¹ .

¹ Genetic Assimilation of learned behaviour is a process by which learned behaviour may gradually become instinctive and no longer need to be passed on by teaching because it is passed on by DNA instead. This is thought by some to happen when the behaviour is established as part of the cumulative culture. Any genetic changes that aid this behaviour may be selected. Indeed, the whole behaviour may eventually become instinctive. New Caledonian Crows brought up in isolation from other crows make tools, but their tools are not as sophisticated as the tools of the crows that learned the

Tool Transfer is still necessary for evréry tool that is taught, even today when a tool might be a Large Hadron Collider. All the other methods are still in use too, although perhaps updated.

Fortunately, as well as fitting the cognitive gap, Tool Transfer also also fits the mathematical sequence using the Feigenbaum Constant Delta.

The Heredity Channels of Cultural Evolution. The seven Heredity Channels that arose during Cultural Evolution are described below, with the Heredity part and the Modification part and a brief explanation of why the Heredity Channel and the Means of Modification are associated with each other.

We start the numbering of the Heredity Channels with number 4, because we will see later that there are 3 Heredity Channels before Cultural Evolution..

HEREDITY CHANNEL 4	
Parental Approval	
Means of Heredity: Parental Approval	Means of Modification: Parental Care
What are the Means of Heredity and Modification? Parental approval or disapproval is when a parent signals to their offspring that their behaviour is correct or incorrect. Intentional teaching can be a simple “grunt of disapproval”. It improves the fidelity of their learning so that it is sufficiently to be passed on indefinitely (Gärdenfors & Högberg, 2017). Teaching requires learning of course. The theory of Social Learning in humans concerns how humans learn from each other. Social Learning is thought to occur by observation and imitation. Imitation requires the evolution of vision. Parental Care is adaptive as it can increase offspring fitness.	
Why did they appear together? Parental Care is needed for teaching by Parental Approval/Disapproval. The earliest teaching among animals is not known, but from an energetic point of view it is reasonable to assume that would have arisen at the same time as parental care, because looking after offspring must in the long term take more energy than teaching them to look after themselves (Gärdenfors & Högberg, 2017).	
Date? There are two possible fossil candidates:	

behaviour from other crows (Hunt & Gray, 2007). This may be an example of genetic assimilation of behaviour. Genetic assimilation may be a reason why teaching steps may not be observed – in some populations of some species.

Parental care in reptiles 309 million years before 2000 (Maddin et al., 2019), and parental care in Cynodonts (precursors to mammals), known to live in burrows, and therefore probably social, 251 million years before 2000 (Damiani et al., 2003).

Table 2.4: Heredity Channel 4.

HEREDITY CHANNEL 5

Using Tools

Means of Heredity: Tool Transfer	Means of Modification: Using Tools
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What are the Means of Heredity and Modification?

Use of tools refers to Found Tools, objects found and used as tools. But a tool is not just an object that it is found or made by an animal. A tool is an extension to the body that is used to manipulate the environment, although there are alternative definitions (Cabrera-Álvarez & Clayton, 2020). Many animals are thought to have a Body Schema which tracks the body and limbs in 3D space. Tool-users are thought to have a flexible Body Schema that can incorporate tools and, for example, track the working tip of the tool in three-dimensional space.

Using tools is a Means of Modification without DNA changes. Tools can be added and discarded at will and in real time. They break the Parental Approval heredity path, because offspring need to be given an appropriate tool for the task being taught. The giving of the tool is called Tool Transfer. Only after mastering the tool can the student find their own tools.

Why did they appear together? Tool Transfer is the most basic of the tool actions and naturally belongs with the first use of tools (Musgrave et al., 2016). Tool Transfer is the most basic of the tool actions (Musgrave et al., 2016).

Date? Tool use with found rocks and twigs has left no trace. Most likely after the first primates appeared 56 million years before 2000, because many, though not all, primates use tools today (Steiper & Seiffert, 2012). Most likely before the Latest Common Ancestor of tool-using new world capuchins and old world tool-using macaques, 40 million years before 2000 (Dunn

& Cristobal-Azkarate, 2016). (Evidence, if available, of which primates used tools, and which tools, might improve this estimate.)

Table 2.5: Heredity Channel 5.

HEREDITY CHANNEL 6	
Making Tools	
Means of Heredity: Drawing Attention, aka Referential Gestures	Means of Modification: Making Tools
What are the Means of Heredity and Modification? Young are naturally curious when they see their parents using tools to get food, and naturally try to join in. Seeing the parent making a tool does not elicit the same interest. The parent must draw their attention, indicating that they should watch how to make a tool (Locke et al., 2011).	
The Means of Modification are the making of, and improvement of, tools.	
Why did they appear together? Both are concerned with the simplest means of making tools).Teaching how to make tools belongs naturally with Making Tools (Gärdenfors & Högberg, 2017).	
Date? 16-12 million years before 2000. Last Common Ancestor of toolmakers orangutans ((Laumer et al., 2018) and humans: (Locke et al., 2011)	

Table 2.6: Heredity Channel 6.

HEREDITY CHANNEL 7	
Making Tools With Tools	
Means of Heredity: Demonstration	Means of Modification: Making Tools with Tools
What are the Means of Heredity and Modification? Hands can strip leaves from a twig, but they cannot make a sharp stone knife. Another tool is needed that is harder than the tool that is being made. Also, a tool is made at the same time as a tool used	
These tools need to be taught by demonstration. In other words, the teacher slows down and repeats	

actions, for example (Gärdenfors & Högberg, 2017).

Why did they appear together? Gärdenfors & Högberg explain why demonstration is used to teach Oldowan stone technology.

Date? 2.60 to 2.55 million years before 2000.

Table 2.7. Heredity Channel 7.

HEREDITY CHANNEL 8

Tools with Concepts

Means of Heredity: Communication of Concepts	Means of Modification: Tools with Concepts
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What are the Means of Heredity and Modification?

The use of tools that have a concept that needs explaining gives a competitive advantage (Gärdenfors & Högberg, 2017). Having tools made up of different materials is also a concept, and timewise, the first composite tools (wood spears with a stone head) also appeared at this time (Wilkins et al., 2012).

Why did they appear together? According to G&H, late Acheulean tools incorporated concepts that needed communication, either by gesture or by speech.

Date? Composite tool, 550,000 to 450,000 years before 2000 (Wilkins et al., 2012).

Table 2.8: Heredity Channel 8.

HEREDITY CHANNEL 9

Tools with new functions

Means of Heredity: Explaining Relationships between	Means of Modification: Tools with new functions
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What are the Means of Heredity and Modification?

Heredity Channels 6, 7, and 8 improved on the original Found Tools, but this event saw the beginning of “Complex Culture and Cognition” and tools that had new functions (Hallett et al., 2021).

The first definite example was a tool for making clothes, although no clothes survive from this time. The harpoon – a spear with barbs for catching fish –

<p>appeared thereafter, followed by more and more inventions.</p> <p>This stage would have required speech to explain the usage of the tools (Gärdenfors & Högberg, 2017).</p> <p>Why did they appear together? New inventions required more explanation than improvements on existing tools (Gärdenfors & Högberg, 2017).</p> <p>Date? Tools for making clothes. 120,000 - 90,000 years before 2000</p>
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Table 2.9: Heredity Channel 9.

HEREDITY CHANNEL 10 Domestication	
<p>Means of Heredity: Narration (Complete Language)</p>	<p>Means of Modification: Domestication (New Livelihoods)</p>
<p>What are the Means of Heredity and Modification? The new Means of Modification is the creation of new livelihoods, beginning with the domestication of animals and plants. And the first of these was the domestication of the dog (Perri et al., 2021). Narration is the last stage of language development in Gärdenfors’ hypothesis (Gärdenfors & Högberg, 2017).</p> <p>Why did they appear together? The challenges of a change of lifestyle from the instinctive forager-scavenger lifestyle require a complete language to enable logical thought in order to solve problems (Gärdenfors & Högberg, 2017).</p> <p>Date? Domestication (of the dog) 26,000–23,000 years before 2000.</p>	

Table 2.10: Heredity Channel 10.

Dates of the Teaching Methods during Cultural Evolution. Table 1.2 shows the dates of the Means of Modification during every stage of evolution, including Cultural Evolution with actual dates and theoretical dates (best-fit Feigenbaum Cascade).

Figure 1.3 shows the Cultural Evolution events on a timeline. The graph is scaled so that successive intervals with the same ratio have the same length on the graph. The dates match the pattern of a Feigenbaum Cascade, where successive intervals are shorter than the previous interval by the factor 4.669. The dates of the best-fit Feigenbaum Cascade are shown by the horizontal lines. The actual dates of the events are shown as error bars, which show the upper and lower bounds of the known dates. The horizontal lines are within the limits of the error bar for every Heredity Channel (i.e.

Teaching Method), confirming that the seven Teaching Methods match the Feigenbaum Cascade. The dates are relative to the year 2196, which is the Accumulation Point where the size of the events become infinitely small (in theory) and there is a transition to infinite-period or chaotic behaviour.

	Means of Modification	Date of Means of Modification (years before 2000)	Predicted date (years before 2000)
PHYSICAL EVOLUTION			
1	Big Bang	13.82 to 13.77 billion years before 2000 (-51% deviation from prediction)	26 601 260 577
BIOLOGICAL EVOLUTION			
2	Single Cell Organisms	4.28 to 3.77 billion years before 2000 (-25% deviation from prediction)	5 697 177 216
3	Multicellularity (differentiated cells)	1.2 to 1.0 billion years before 2000 (1.6% deviation from prediction)	1 220 161 162
CULTURAL EVOLUTION			
4	Parental Care	309 to 251 million years before 2000	261 321 092
5	Tool use	56 to 40 million years before 2000.	55 966 841
6	Tool making	16-12 million years before 2000.	11 986 234
7	Making tools with tools	2.60 to 2.55 million years before 2000	2 566 931
8	New concepts in tool making (e.g. Composite tools)	550,000 to 450,000 years before 2000	549 604
9	Tools with new functions	120,000 - 90,000 years before 2000	117 555
10	Domestication	26,000–23,000 years before 2000	25 023
INFORMATION TECHNOLOGY EVOLUTION			
11	Written Language	5,269 years before 2000	5,205
12	Movable-type Printing	959 - 952 years before 2000	961
13	Computers	52 years before 2000	52

Table 1.2. Means of Modification with actual dates and theoretical dates (best-fit Feigenbaum Cascade). All dates relative to year 2000. The theoretical dates are final values after all of the extrapolated events have been found and incorporated.

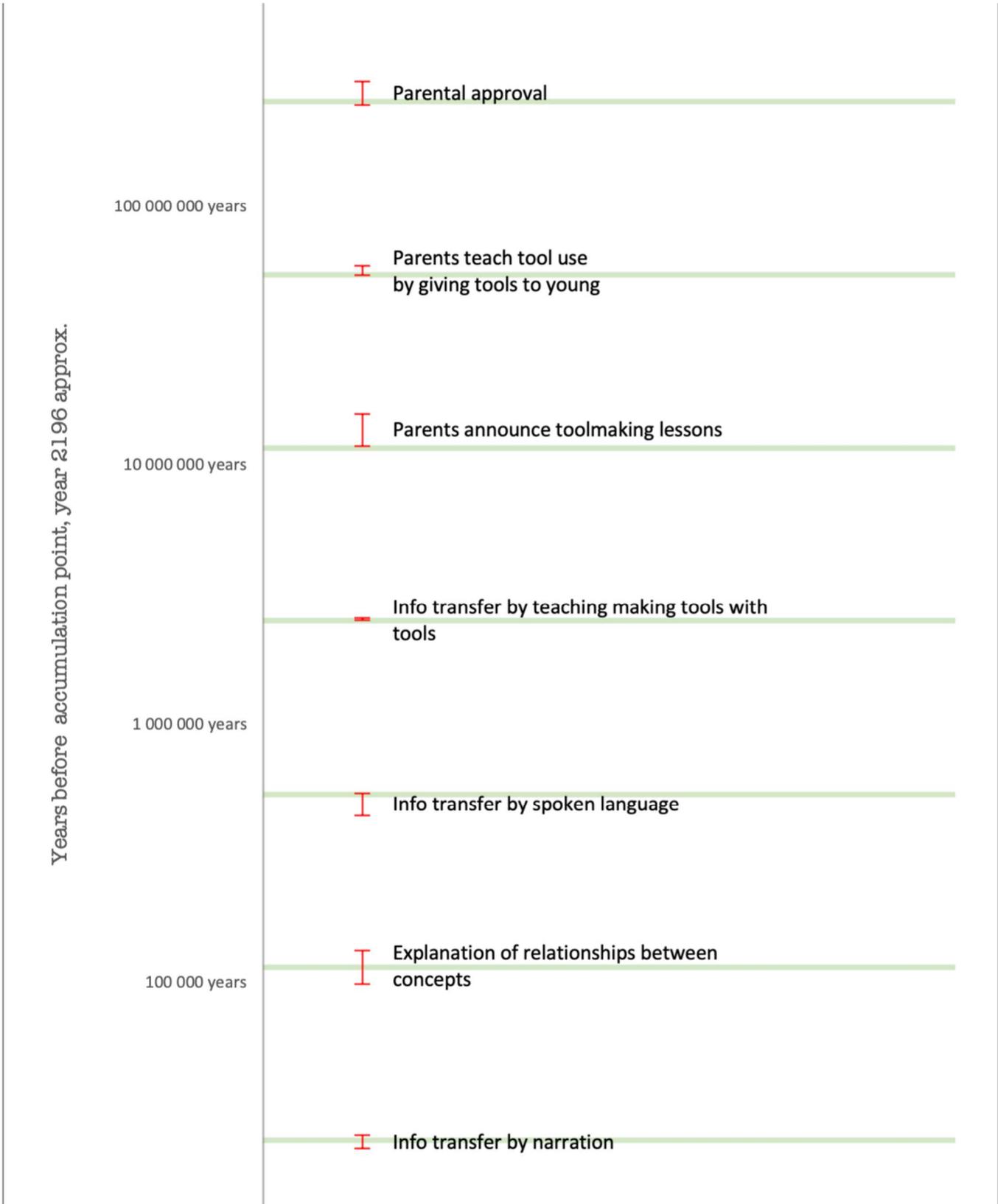


Figure 1.3. The seven Teaching Methods that arose during Cultural Evolution match the pattern of a Feigenbaum Cascade, where successive intervals shrink by the factor

Table 1.1 *Heredity Channels and Means of Modification during Physical, Biological, Cultural, and Information Technology Evolution. During Cultural Evolution all Heredity Channels are Intentional Teaching methods.*

	Heredity Channel - Means of Heredity	Means of Modification	New type of Useful Heritable Information (the new Variable or Dimension)
PHYSICAL EVOLUTION			
1	None	Big bang	None
BIOLOGICAL EVOLUTION			
2	DNA copying during cell division	DNA Mutation (All life is Single-celled)	Random DNA mutations cause phenotype changes
3	Sexual Reproduction	Gene Shuffling (Multicellular organisms)	Random gene allele combinations cause variations in traits.
CULTURAL EVOLUTION			<i>N</i>
4	Intentional Evaluative Feedback (aka Parental Approval and Disapproval). Offspring learn by imitating their parents, but often need correction	Parental Care	New (non-instinctive) behaviours and skills
5	Tool transfer. The parent gives a tool to their offspring. This fulfils the definition of teaching,	Tool use	Various found tools. (A tool is an object used to manipulate another object.)
6	Referential gestures (aka Drawing attention to an object) to signal that a tool-making lesson is to start.	Tool making	Tools made by hand
7	Demonstration Teaching tasks slowly and with repetition	Making tools with tools	Tools made from hard materials using found tools of harder material
8	Communicate concepts (gesture or speech)	New concepts in tool making (e.g. Composite tools)	Tools made according to new concepts, such as assembly
9	Explain relationships between concepts (speech)	Tools with new functions	Tools invented for new purposes (that are not just improved versions of found tools)
10	Narration (Complete language)	Domestication (and other new livelihoods)	New livelihoods (starting with Domestication)
INFORMATION TECHNOLOGY EVOLUTION			
11	Storage of information as visual symbols	Written Language	Simple information (laws, contracts)
12	Mechanical replication of information	Movable-type Printing	Complex information (books, science)
13	User Interfaces	Computers	Online information and software

Results Part 2: Looking for the Feigenbaum Cascade before or after Cultural Evolution

After the Cultural Heredity Channels, a search is made to see if more Heredity Channels before and after Cultural Evolution can be pointed out by the Feigenbaum Constant Delta, 4.669.

The details are shown in appendix 2. Here are the results.

Three Heredity Channel/ Means of Modification pairs found before Cultural Evolution. The first Heredity Channel/ Means of Modification pair found by multiplying the interval by 4.669 is Sexual Reproduction/ Multicellularity. The difference between the actual and theoretical dates was 1.6%.

The next two extrapolations at 5.70 and 26.6 billion years before 2000 were nowhere near any events of interest, although we might expect them to match the two most important events, the first life on Earth and the Big Bang. The theoretical interval to the first life is long before the first life on Earth. We do not know if life actually started on Earth or in space before the Earth was ready for life, although clearly pre-biotic evolution has been going on since the Big Bang.

The theoretical date for the Big Bang is twice the currently accepted age of the universe. The age of the universe is currently in question given results from the James Webb telescope and may be much older than thought. The Big Bang has no means of inheritance or Means of Modification other than the persistence of matter and its ability to change. It is however the starting point for Physical Evolution.

The three events are listed here with the deviation from the Feigenbaum Constant 4.669:

- 1 Big Bang (deviation from theoretical date 50%)
- 2 Single-celled Life (deviation from theoretical date 26%)
- 3 Multicellularity (differentiated cells) (deviation from theoretical date 1.6%)

The discrepancies in the initial bifurcation are in fact perfectly normal for Feigenbaum Cascades, as long as there is rapid convergence to 4.669. We can see clearly in figure 1.4 that this is the case. The sequence 50%, 26%, 1.6% is a rapid convergence.

Heredity Channels 1 to 3 are detailed below.

HEREDITY CHANNEL 1	
Big Bang	
Means of Heredity: None	Means of Modification: Undefined
What are the Means of Heredity and Modification? Neither exist at this point. The Big Bang is thought to be the beginning of the universe and is used here as a reference point. There is no life, self-replication, heredity, or modification. But there is Physical Evolution which will eventually produce these things (Lazcano, 2018).	
Why did they appear together? (Neither exist at this point.)	
Date? 13.77 to 13.82 years before 2000 (Planck Collaboration et al., 2020) (-50% compared to predicted interval)	

Table 2.1: Heredity Channel 1.

HEREDITY CHANNEL 2	
Single Cells	
Means of Heredity: DNA Copying	Means of Modification: Mutation
<p>What are the Means of Heredity and Modification? Heredity: DNA copying during cell division (Lemmens & Lindqvist, 2019). Modification: DNA mutation (Griffiths,Anthony, 2023).</p> <p>Why did they appear together? Self-evident.</p> <p>Date? 4.28 to 3.77 billion years BCE (Dodd et al., 2017) (-25% compared to predicted interval).</p>	

Table 2.2: Heredity Channel 2.

HEREDITY CHANNEL 3	
Multicellularity (differentiated cells)	
Means of Heredity: Sexual Reproduction	Means of Modification: Gene shuffling
<p>What are the Means of Heredity and Modification? Heredity: Sexual Reproduction. Modification: Recombination of genes. (Britannica editors, 2023).</p> <p>Why did they appear together? Self- evident.</p> <p>Date? 1.2 billion years BCE (Butterfield, 2000)</p>	

Table 2.3: Heredity Channel 3.

Three Heredity Channels found after Cultural Evolution. Extrapolating from Heredity Channel/ Means of Modification pair 10 “Narration/ Domestication”, dividing the intervals by 4.669 we find very interesting results. namely:

- Written Language (error 0%)
- Movable-type Printing (error 0.14%)
- The Computer (error 0,5%)

Each of these Heredity Innovation events is a way of improving the inheritance of information between humans by using human-made technology.

- 11 Written Language stores information “extrasomatically (outside the body) so that the brain does not have to remember the information. Also information can be transferred without the sender and receiver needing to be at the same place at the same time.
- 12 Moveable-type Printing makes it possible to spread large amounts of information by using mechanical replication. This makes it possible to replicate information at greater than reading speed rather than at writing speed.
- 13 Computers can find and deliver information around the world almost instantly.

The fact that the dates of these three Information Transmission innovations were picked out as Heredity Channels by the extrapolation of the Feigenbaum Cascade is highly significant, as it adds extra weight to the hypothesis that evolution of intelligent life is a Feigenbaum Cascade.

Heredity Channels 11 to 13 are detailed below.

HEREDITY CHANNEL 11	
Writing	
Means of Heredity: Visual Symbols	Means of Modification: Public Records
What are the Means of Heredity and Modification? Heredity: transmission of information is by visual symbols. Modification: information is stored “extrasomatically” (outside the body) on clay tablets or paper, which means the human memory capacity no longer restricts the amount of knowledge that can be accumulated.	
Why did they appear together? Self- evident.	
Date? 5500 to 5200 years before 2000 (3500-3200 years BCE)(Schmandt-Besserat, 1980).	

Table 2.11: Heredity Channel 11.

HEREDITY CHANNEL 12	
Movable-type Printing	
Means of Heredity: Mechanical Replication of Information	Means of Modification: Newspapers, Books.
What are the Means of Heredity and Modification? Heredity is by reading printed matter. Modification occurs when the information is put into practice.	
Why did they appear together? Self-evident.	
Date? 959 – 952 years before 2000 (1041 – 1048 CE) Invented by Bi Sheng, China. (Needham & Tsien, 2001). (Error estimate = $14 / (3200 + 1025) = 0.14\%$).	

Table 2.12: Heredity Channel 12.

HEREDITY CHANNEL 13

Computers

Means of Heredity: User Interfaces	Means of Modification: Information processing
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What are the Means of Heredity and Modification?

Modification: Programmable information processing.

Heredity: information presented via user interfaces.

Why did they appear together? Self-evident.

Date? 52 years before 2000 (June 1948 CE)
(Copeland, 2011)

Table 2.13: Heredity Channel 13.

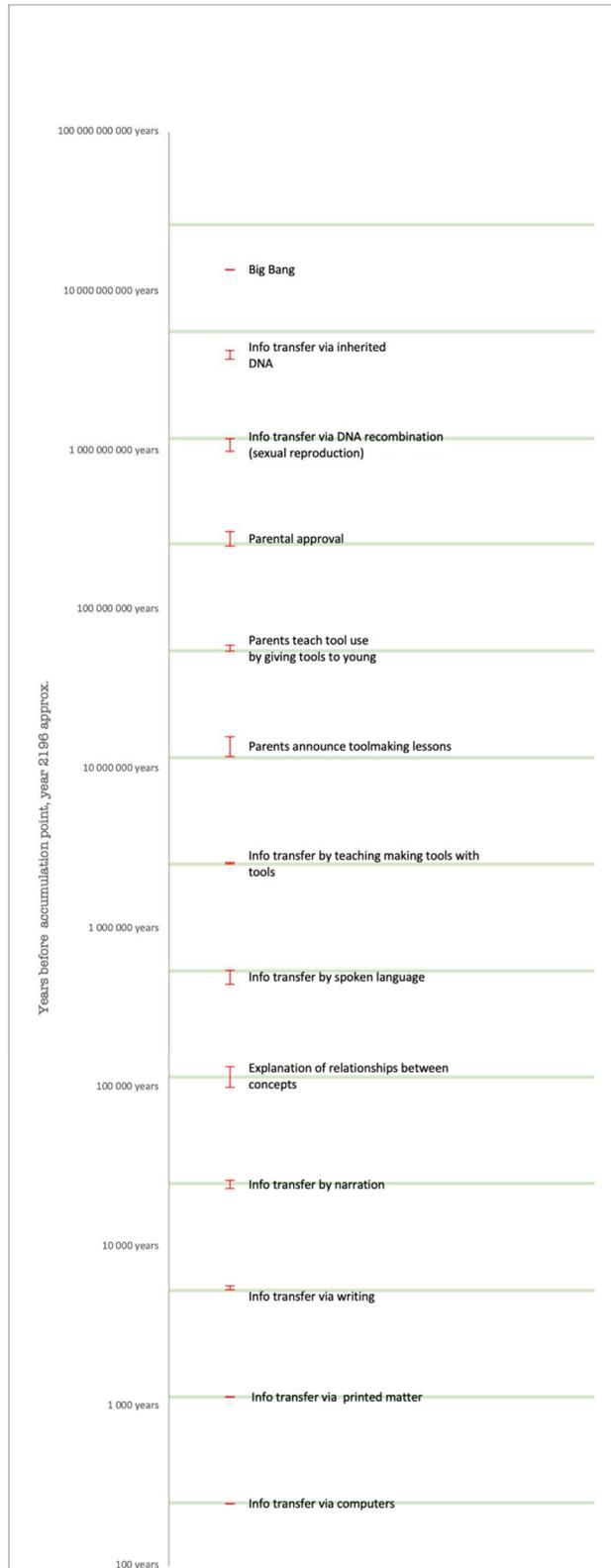


Figure 1.4: The Timeline for all Heredity Channels

The Timeline (figure 1.4). We now have 13 Heredity Channels. Seven of them (“Parental Approval” to “Narration”) are the Teaching Methods from Cognitive Science research, and the remaining six are extrapolations of that sequence using

the Feigenbaum Constant Delta. That is to say, they are decreasing by the factor 4.669. All 13 events are shown on a timeline in figure 1.4. It can be seen that the first two events do not match the Feigenbaum dates, but the events converge to the Feigenbaum dates by the third event “Sexual Reproduction”. The initial error and rapid convergence are normal for Feigenbaum Cascades.

Event	Year of event	Interval until next event
13 (The computer)	1948	195 years
14	2143	41.7 years
15	2184	8.93 years
16	2193	1.91 years
17	2196	150 days
18	2196	32 days
19	2196	6.9 days
...
Non-periodic level	2196 onwards	No more intervals

Table 1.3: Feigenbaum Cascade. Predicted future Heredity Channel creation events

Future events. The pattern of bifurcations should, according to chaos theory, continue until the Accumulation Point is reached. Theoretically there will be an infinite number of bifurcations and the interval will shrink to zero, at which point in time the population will become non-periodic (aka “chaotic”). (The sum of an infinite series can be finite, as in the case $1 = \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \dots$ and so on.)

Future bifurcation events are shown in table si14. The Accumulation Point will be in 2196 CE (note that this date is not exact and may change with new data). In reality, there will be a physical limit to how short a bifurcation event can be and

there will probably be an undramatic transition to the chaotic phase after the accumulation point..

The Accumulation Point would seem to correspond to what is commonly known as the Technological Singularity where there is predicted by some to be a point of runaway development of technology. It is possible that there will be such a singularity. Or it may be something else.

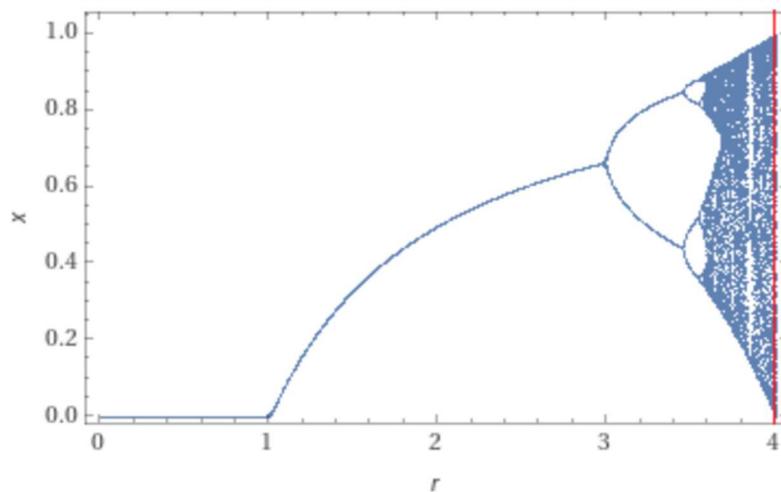


Figure 1.5. Stages of evolution:

r = 0: Stage 1: No heredity/Big Bang;

r = 1: Population rises above zero. Stage 2: Cell division/Single-celled life;

r = 3.0: First bifurcation: Stage 3: Sexual reproduction/Multicellular organisms;
r = 3.45 approx.: Second bifurcation: Stage 4: Parental approval & disapproval/Parental Care;
r = 3.5 approx.: Third bifurcation: Stage 5: Tool Transfer/Tool Use;
r = 3.5 to 3.55 approx.: Remaining stages.
r = 3.55 approx.: Accumulation Point and start of chaotic (non-periodic) population fluctuations.
(Note: the interval between the Big Bang and the first living cells is too short, which means that the logistic map is unsuitable for modelling evolution)

Discussion

Summary of original work.

This hypothesis concerns Heredity Channels, that is to say the appearance of new processes whereby information is passed on to new generations. They have appeared at time intervals defined by a simple mathematical ratio.

They also arise simultaneously with new Means of Modification, which increase the rate of evolution by having a novel source of variation which cannot be inherited by previously existing Heredity Channels, hence the creation of the new Heredity Channel.

These events occur as complexity gradually increases and reach a threshold when the net energy gain of the new process becomes positive, coinciding with a flip bifurcation in the bifurcation diagram.

This pattern agrees with the 7 Heredity Channels (Intentional Teaching Methods) during Cultural Evolution proposed by Gärdenfors and Högberg (Gärdenfors & Högberg, 2017) and (Gärdenfors, 2021) (6 events) and Musgrave et al. (Musgrave et al., 2016) (1 event). Cherry-picking of data is clearly ruled out. All known Heredity Channels are included.

Extrapolation of the timeline before and after Cultural Evolution reveals a total of 13 events and shows that the time interval ratio rapidly converges to the Feigenbaum Constant 4.669, which is a Universal Constant for all period-doubling non-linear dynamic processes.

The bifurcation diagram for Evolution

Figure 1.5 shows how a bifurcation diagram from a Feigenbaum Cascade corresponds to the creation of Heredity Channels. Because we don't have a correct Map function for evolution, we are using a diagram derived from the Logistic Map. It gives the wrong proportions for the first two events, but as we have seen, there is rapid convergence to the Feigenbaum Constant 4,669 by the third event (= first bifurcation). The Logistic Map was designed for modelling population dynamics. Normally one would draw a diagram for a single species, with r = birth rate and X = population. But in this case the diagram shows all human ancestors as they evolve. To allow for single cells and multicellular organisms, the y-axis is not population, but biomass per unit area.

Instead of birth rate, the x-axis is Biomass Growth Rate, which is assumed to increase with complexity, which is assumed to increase with time. It is in the nature of the bifurcation diagram that the exact relationship between variables such as time, complexity, population growth rate, etc., do not have to be linear – it is enough that they are monotonic (roughly, that they increase together).

The stages shown in the diagram are stages 1 to 5 in evolution. The rest are too small to see in the figure. There are an infinite number of levels in theory (not necessarily in reality), which finish at the Accumulation Point, after which the population is non-periodic (that is, non-repeating, or in other words, with an infinite period).

Bifurcations of permanent advantage

Every new Means of Modification increases the rate of modification. Assuming an ecosystem where some species have a new Means of Modification but others do not, the ones with the new Means of Modification will have a permanent advantage. I propose that this mismatch causes a permanent alternating population bifurcation among the species involved, as in a Feigenbaum Cascade. This is partly corroborated by Adams & Matsuda who find that differential modification rates cause permanent population oscillations, even when different parameters would result in a steady state (Abrams, Peter & Matsuda, Hiroyuki, 1997). That these are period-doubling bifurcations is not confirmed.

Population bifurcations in the distant past are likely to be very hard to detect. But if we want to determine the date of the bifurcation, in most cases we won't need to look for records of population oscillations, because already know the dates of the new Means of Modification that are the immediate cause of the population oscillations.

New Means of Modification means a new parameter. New Means of Modification are not just things that have evolved, they are new ways of evolving.

New Means of Modification have a new "thing" (parameter, dimension, variable, tool, etc) to create evolutionary variation before the process of Natural Selection. This parameter is the new information that could not be transmitted using the existing transmission methods. Table 1.1 shows the Means of Modification, the corresponding Heredity Channels and the new variables.

The Accumulation Point

The pattern predicts one event in each of the years 2143, 2184, 2193, and then a final cascade of events in 2196 ending with a transition to a new phase of evolution. This is assuming the dramatical increase in fossil fuel in the 20th century does not make it happen earlier. What will happen at these remaining events is outside the scope of this paper.

Cognitive levels

G&H associate each Teaching Method (i.e. Heredity Channels 4 to 10) with a new cognitive levels, requiring increasing levels of mind reading, cognition and communication. This raises the question of whether the other stages (1 to 3, and 11 to 12) can be considered to have increasing level of these attributes (mind reading, cognition and communication), or whether equivalent attributes can be defined.

Computational Biology

As we have seen, information is the common thread throughout evolution. Individuals that survive get to pass on their personal information for replication in following generation.

This process is emulated by humans using computers to search for optimum solutions for engineering or scientific research. One such technique is the Genetic Algorithm. Biological evolution elements are used - heredity, mutation and/or recombination, and selection. Using a Genetic Algorithm to use random change and selection to search the fitness landscape for the best result (for example, the optimum shape of an aircraft wing) is essentially identical to the process of evolution to search and explore the fitness landscape with real phenotypes.

The algorithms used in the computer technique perhaps differ somewhat from the real thing, But with 13 levels of evolution, they may vary a bit too)

But they share essential features. It is very interesting, therefore, to know that Collard & Clergue have induced Feigenbaum (period-doubling) Cascades in Genetic Algorithms (Collard & Clergue, 2000).

Stage by Stage, Boxes of Modifications, and the Cost of Complexity - this is how Big Evolution might work.

Species adapt and evolve by collecting modifications and growing in complexity. But as the organism grows more complex, and the number of modifications grows bigger, the less the effect of a new modification. Increasing the complexity of the organism results in ever smaller increases in birth rate and population.

But other kinds of modification wait in the wings. There is always some other process, based - not on the current variable, but on some new variable that is one of the products of the evolution. It wasn't there at the last bifurcation, but has been evolving in the background until it becomes viable - that is to say, when it produces most energy than it uses.

Outside the Box - the Next Box. Suddenly, this new kind of modification arrives, outside the box, so to speak. Instead, it arrives in a new box, a new kind of modification that is a new ability. And which needs a new Heredity Channel. The new variable takes over from the previous variable. The speed of adaptation increases dramatically, because the new box is empty at first, and modifications of the new kind can have a big impact. Later on, this box too will become full, as modifications exhaust the new evolution space. And the scenario repeats, following the universal mathematics of Feigenbaum Cascades, which always have the same maths, even though the processes are always different, because they all look more or less like the logistic map - are all single-hump curves, which is the shape of limited resources, which is so ubiquitous, so universal because resources are nearly always limited in whatever process you look at in this universe.

The old variables continue. When a variable hands on the baton of evolution to another variable, it does not stop operating. It continues in co-evolution with the new variable. The new variable determines the direction of evolution, and the old variables follow.

How did this pattern not show signs of shocks by meteorites, epidemics, climate change, etc?

Random external mass-extinction events, such as the extinction of dinosaurs by meteorite, is an oft-quoted reason for unpredictability. However, Natural Selection is constantly removing species, usually those species that are at the bottom of the scale of adaptability, allowing the more adaptable species at the top of the scale to live on. Whether circumstances and conditions remove the bottom 1% of species or the bottom 99%, the most adaptable and most evolved species are more likely to survive.

The theory presented is largely about organisms that are the most advanced and most adaptable, those at the cutting edge of evolutionary complexity and have advanced furthest along the proposed 13 stages.

Also, the theory is about stages of evolution, not population levels, so evidence of low population level does count as disruption unless it led to delays.

There is every reason to believe that it is possible for even the most resilient species to be disrupted, there was no obvious evidence to that effect.

Limitations of the study

- Lack of specification of Means of Modification in G&H's paper.
- Lack of associations between Teaching Methods and Means of Modification in G&H's paper.
- The following assumptions have been made:
 - i. That Means of Modification and new Heredity Transmission channels appear at the same time

- ii. That sex and multicellularity are mutually dependent
- iii. That the worked stones found at Lomekwi3 are not tools, but were used as a mineral diet supplement as modern capuchin monkeys do.
- iv. Full Modern Language and domestication 26,000 to 23,000 years before 2000 are mutually dependent.
- v. That future improved estimates of the dates of various events continues to agree with the theoretical dates.

● The theory rests rather heavily on Gärdenfors' papers. It would be helpful to find some other sources of support for the theory.

Conclusions

This study began as an investigation into whether it was significant that the sequence of new Information Inheritance processes (which during Cultural Evolution took the form of new methods of Intentional Teaching, proposed by Gärdenfors and Högberg) seemed to follow the same pattern found in so many chaotic processes.

The result is a hypothesis that proposes that the entire history of evolution is a Feigenbaum Cascade of 13 new Information Transmission processes (Heredity Channels), each of which was needed for passing on 13 innovations in the way organisms adapt and evolve, from DNA mutation, through tool development, to information technology (writing, printing, and computing).

The hypothesis follows Carl Sagan's insight that information unites the different phases of evolution. It supports the idea that the evolution of life, once started, is compelled to evolve intelligent life. Cells began by exploring which random sequence of instructions in DNA survive best. Each subsequent stage of evolution accumulates more information for the same reason.

Evolution has followed a mathematical series, which suggests that the milestones of evolution – such as tool-use or language – are generated by the evolution of life, not by external events. It follows that evolution is a result of the increasing complexity of life. As each stage slows, it supports, and is revitalized by, newer stages. These new stages are the result of new Means of Modification at complexity thresholds. These Means of Modification are passed on by new transmission methods (Heredity Channels).

Despite the fact that the evolution process changes at every stage, the process apparently fits in the Feigenbaum Cascade. The first two dates have the biggest deviation from the logistic map, but we don't know whether the logistic map is the best model for Physical evolution and single-cell evolution. Neither do we know how much of the first two stages took place on Earth, which may have different rate of evolution. However, the remaining stages (Stage 3 to stage 13) fit the Feigenbaum Cascade very well.

If the hypothesis is proved correct, it will have a significant effect on the debate about humankind and our place within the universe. It goes against the current paradigm that evolution is unpredictable and has no direction. It also potentially offers a simple yet rigorous theoretical framework for understanding Big History.

While not being a proof, the universality found in Chaos Theory explains how it is possible that each stage of evolution can exactly fit into a Feigenbaum Cascade. However, Chaos Theory is so different to Linear Dynamics that "[...] what made universality useful also *made it hard for physicists to believe*. Universality meant that different systems would behave identically" (James Gleick, *Chaos – Making a New Science*). If this is true of physics, how much more this must be true of an endlessly complex discipline like Evolutionary Biology. If the conclusions of this paper seem far-fetched, this may be due to Chaos Theory as much as the hypothesis presented.

New directions for further research

- Develop a reliable and clear definition of important events that fits only the events we have looked at and excludes all other events.
- Find theoretical predictions or metrics that can be verified. For example, the speed of modification or speciation at each level, or any other quantitative metrics.
- Look for evidence of alternating population oscillations due to the stage of evolution, possibly under laboratory conditions.
- Refining the theory to predict what coming events should be (if prediction of the nature of an event is possible)

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