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Accelerating Information Transmission in the Evolution of Intelligent Life

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1.   ABSTRACT

If *making tools by hand* was important in human evolution, was *the use of tools to make tools* just as important, or less so? As it happens, these two innovations each needed their own new method of teaching in order to pass them on to new generations. We could say that – from the teaching point of view – they are equal. We know of seven teaching methods from cultural evolution, all still in use, and each one associated with an evolutionary milestone (namely: *cumulative culture, tool use, toolmaking, tool-made tools, composite tools, new inventions* and *new livelihoods)*.

But there is something more that connects these teaching events. Together they form a simple geometric time sequence in which the time interval between successive events is shorter than the previous interval by the same factor, 4.6692… (the "Feigenbaum Constant δ"). The phenomenon of events accelerating by the Feigenbaum Constant δ is known in Chaos Theory as a "Feigenbaum Cascade" and is found in various non-linear dynamic systems, such as dripping taps, population dynamics, and various kinds of oscillator.

Cherry-picking of data to fit the time-pattern is avoided because the teaching levels were identified without reference to date other than in which order they appeared.

Teaching is **cultural transmission of information**. Extrapolating the Feigenbaum Cascade backwards in time indicates two events of **genetic transmission of information** (namely, *self-replicating cells,* and *sexual reproduction)*. Extrapolating forwards in time indicates events involving **writing-based transmission of information** (in the form of *written language, printing machines,* and *the computer)*.

The sequence suggests that there will be future events, due to reach a conclusion around the year 2200.

The hypothesis presented here is:
- that these information transmission events form a Feigenbaum Cascade.
- that each event is associated with a new means of adaptation.

It follows that the timing of the levels of evolution is predictable. I suggest a mechanism for the Feigenbaum Cascade and a tentative description of the evolution levels.

2. INTRODUCTION

Problem statement

One of the biggest mysteries in our knowledge of the universe is ourselves, and intelligent life in general. Did intelligent life evolve on Earth by pure luck, with the odds stacked against it? Or was it an inevitable result of whatever laws govern the universe? Cosmic evolution is a name sometimes given to studies aimed at creating a single, inclusive scientific narrative of the origin and evolution of all material things from the Big Bang to intelligent life. The objective of this article is to present a candidate for such a theory which can to some extent predict the development of the universe and intelligent life, together with evidence to support it, and an explanation that is based on well-known phenomena.

Avoiding Cherry-picking

The hypothesis presented in this paper is based on a sequence of events in the history of the universe and the mathematical relationship between them. A common problem with this kind of theory is that of *evidence-suppression* or *cherry-picking*. That is to say, choosing the events that suit the hypothesis and leaving out other events that disprove the hypothesis. I explain further down how this is avoided.

The Predictability or Otherwise of Evolution.

Another issue with theories which claim to have found a pattern in evolution, is that the "new evolutionary paradigm", which has been dominant in evolutionary theory for the past few decades, says that evolution is essentially unpredictable, both in direction and in speed. Sensitivity to initial conditions (the "Butterfly Effect" from Chaos Theory) is often quoted as one of the reasons for this. However, more recent research challenges the paradigm, with evidence that evolution may be more predictable than currently thought. (For more on this topic, see Appendix LB: Literature background.)

The other side of Chaos Theory

Chaos Theory is more than just the Butterfly effect. It can also explain order within chaos. Chaos Theory describes very common kind of chaotic system called "period-doubling systems". These are found in many natural phenomena. The remarkable thing about these systems is that they all have a distinctive signature pattern of shrinking "bifurcation intervals", and the intervals for *all* period-doubling systems shrink by a ratio that converges to 4.6692…, a number known as the "Feigenbaum Constant δ". I will try to show that life on Earth is a period-doubling system.

The Feigenbaum constant δ

Figure fei shows in more detail how the intervals between bifurcations are measured on a bifurcation diagram. A bifurcation diagram shows an "attractor", which means that it the shows equilibrium values that a system settles down to after a number of iterations. A typical example is a dripping tap, where the x axis is the amount of water flowing and the y axis is the time interval between drips. At a certain level of water flow, the time interval "bifurcates", which is to say, it splits into two values which alternate at every other drip. At higher flows the time interval bifurcates into 4 values repeating every fourth drip, then 8 values repeating every eighth drip, and so on. The diagram is not detailed enough to show more, but there are in theory an infinite number of bifurcations. The bifurcations converge quickly to the Accumulation Point, after which the cycles are aperiodic. This aperiodic or "chaotic" region is approximately the last 20% of this diagram.

The ratio of distances between consecutive bifurcations $L_i / L_{i+1,}$ converge to the Feigenbaum constant δ (4.6692…).
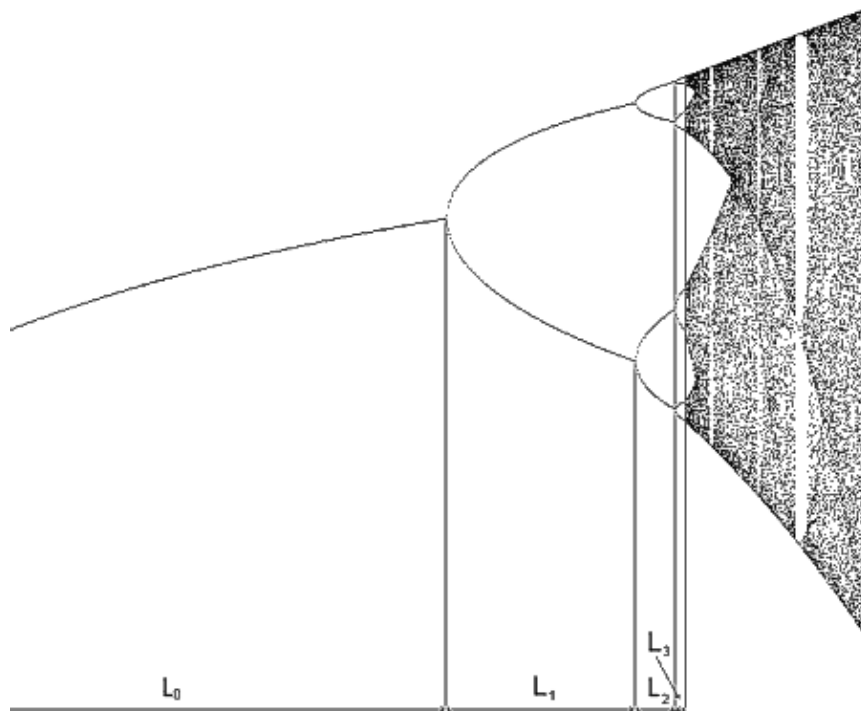
Figure fei: The simple logistic map, $x \rightarrow a.x(1 - x/K)$, when iterated, displays chaotic behaviour. The ratio of distances between consecutive bifurcations L_i / L_{i+1}, converge to the Feigenbaum constant δ (4.6692…). The bifurcations finish at the Accumulation Point, after which the chaotic region begins and cycles are aperiodic. This "chaotic" region is approximately the last 20% of this diagram.

Chaos Theory + Evolution = True?

A search of the literature reveals that Chaos Theory is almost never applied to the study of evolution. This is rather inexplicable, as Chaos Theory is the study of non-linear, iterative, dynamic processes, applying the same non-linear transformation again and again, the output of which is fed back into the input. This is exactly what evolution is, which makes it the ideal subject for applying Chaos Theory.

The importance of teaching

If making tools by hand was important in human evolution, was the use of tools to make tools just as important, or less so? As it happens, these two innovations each needed their own new method of teaching in order to pass them on to new generations. From the teaching point of view, they are equal. Perhaps we should be looking at what teaching – or, more generally, *information transmission* – can tell us about evolution.

A Brief History of Information Transmission

Information is of crucial importance to life and evolution. This paper is about *Information Transmission*. That is, how information is transferred from one generation to the next.

We shall initially focus on one type of information transmission (Intentional Teaching) and later consider the others.

First, an overview. Counting the physical evolution of the universe after the Big Bang, there have been 4 *phases* of evolution, each with one or more *levels*, including new levels of transmitting information to new generations:

110   The list below shows the different kinds of information transmission during the 4 phases of
111   evolution:
112
113   ▪   PHYSICAL EVOLUTION of the universe -   No transmission
114   ▪   BIOLOGICAL EVOLUTION -   Genetic transmission/DNA
115   ▪   BIO-CULTURAL EVOLUTION (culture-led) -   Cultural transmission/Intentional teaching
116   ▪   TECHNOLOGICAL EVOLUTION -   Writing-based transmission/ media
117
118   During Physical evolution there is no life and therefore no information transmission. The
119   information that living organisms use to reproduce themselves is passed on to the next generation as
120   DNA. But when complex animals evolved, they were able to discover useful behaviours that could
121   be passed on by imitation and social learning, instead of via DNA. This kind of information, if it is
122   passed on accurately, is called Cumulative Culture, or Bio-Cultural Evolution. Biological Evolution
123   was still significant, but biological changes selected were mostly those changes (for instance, larger
124   brains) that helped cultural innovation such as tool-use and language.
125   More recently, humans have invented writing-based information. That is, various ways of
126   storing information outside the body – like writing, printing and computing.
127   The newer transmission channels add to, rather than replace, earlier channels.

Cumulative Culture and Intentional Teaching

129   Cognitive scientist Peter Gärdenfors and archaeologist Anders Högberg argue that the most
130   important processes during Cultural Evolution were various forms of Intentional Teaching. The
131   young of many animals imitate their parents from the earliest age, but mistakes can be made during
132   the learning and these mistakes can accumulate down the generations. The intentional involvement
133   of experienced individuals, usually parents, in the teaching/learning process ensures that behaviour
134   is passed on as accurately as possible.

Known teaching methods and the innovations that need them

136   Gärdenfors and Högberg have concluded that:

137   1.   There are a number of teaching methods which appear at intervals when a new kind of
138   behaviour appears. A new teaching method arises because the existing teaching methods
139   cannot transmit the information about the new behaviour.
140   2.   The existing teaching methods are not abandoned but continue to be used.
141
142   From 1), it follows that the new information or behaviour is of a new kind, or is in a new format, that
143   cannot be transmitted. Also, the new behaviour and the teaching method must arise simultaneously
144   because each one needs the other and is useless without the other. The new behaviour cannot be
145   passed on without the teaching method and will be forgotten. Without the new behaviour, the new
146   teaching method will not be used.

The list of Teaching Methods

148   Gärdenfors and Högberg have identified 6 teaching methods, each associated with a class of
149   behavioural innovation. However, there is a documented teaching method, "Tool Transfer", which
150   is not on the list. Tool transfer simply means that the parent gives the tool to the youngster This
151   ensures that the youngster gets experience using a proper tool. This simple act fulfils all the criteria
152   for teaching: it occurs in a learner's presence, is costly to the teacher, and improve the learner's
153   performance. I add Tool Transfer to the list, which now has seven Teaching Methods, as follows:

154   i.   Intentional Evaluative Feedback;
155   ii.   Tool Transfer
156   iii.   Referential gestures (aka drawing attention);
157   iv.   Demonstration;

158   v.   Communicating concepts;
159   vi.   Explanation of relationships between concepts;
160   vii.   Narration.

161   *2.1. Original work in this paper*

162   In a nutshell, I attempt to show in this paper that:

163   -   The evolution of intelligent life on Earth has been governed by an accelerating series of 13
164   so-called bifurcation events from the Big Bang to the present day.
165   -   These events together form a Feigenbaum Cascade (that is, the intervals between successive
166   events get shorter by a ratio that converges to 4.6692…,the Feigenbaum Constant δ).
167   -   The 13 events are actually event pairs, each event pair consisting of a new way of adapting
168   to the environment and a new way to pass on (information about) the new adaptations.

169   Of the 7 teaching events, we know the dates of all except the first. I calculate the intervals
170   between the known dates and show that they form a Feigenbaum Cascade. Using the geometric
171   pattern of the cascade, I extrapolate further dates from this list to see if any events before or after
172   Cumulative Culture can be added. The results of this were at least 3, and up to 7 events similar to the
173   Teaching events.
174   After describing the events in more detail, I attempt an explanation of what causes the events. I
175   introduce some ideas from population dynamics, including the concept of bifurcations and why they
176   happen, the logistic map and its role in generating Feigenbaum Cascades, and similarities and
177   differences between population dynamics of livestock and evolution, and also how the methods of
178   population dynamics can be modified to explain the Feigenbaum cascade in evolution. I also try and
179   explain what the implications are.
180   At the time of writing this is a tentative hypothesis.

181   *Genetic assimilation of learned behaviour*

182   It is worth noting here that learned behaviour may become instinctive and no longer need to be
183   passed on by teaching because it is passed on by DNA instead. This is thought by some to happen
184   when the behaviour is established as part of the cumulative culture. Any genetic changes that aid this
185   behaviour may be selected. Indeed, the whole behaviour may eventually become instinctive. New
186   Caledonian Crows brought up in isolation from other crows make tools, but their tools are not as
187   sophisticated as the tools of the crows that learned the behaviour from other crows. This may be an
188   example of genetic assimilation of behaviour.
189   Genetic assimilation may make it more difficult to observe teaching processes as elements
190   become genetically assimilated and disappear from the teaching process.

191   *Cherry-picking avoided*

192   By starting with this list of Teaching levels, cherry-picking is avoided. The hypothesis depends
193   on the dates of the events in this list. The list was not compiled with dates in mind. It was simply
194   intended to be an exhaustive list of all the Teaching Methods used in Cumulative Culture.

195   ## 3.   *METHOD*

196   *Measuring the Teaching Events*

197   In Appendix FCCE "Dating and extrapolating the events" I show how I measured the intervals
198   between the teaching events. The ratio over all the events with known dates is between 4.26 and 5.23,
199   with an average of 4.76. The average value 4.76 is very close to 4.66920… , the Feigenbaum constant δ
200   and fits within the margins of error for the data.

201   In the same appendix, I extrapolate from the sequence of 7 teaching methods using the pattern
202 of the Feigenbaum Cascade to see if there are find more dates in the sequence both before and after
203 Cumulative Culture.

204 *New dates*

205   Between 3 and 7 new dates were found, depending on how one interprets the results. The
206 relative positions of the dates are as in this diagram:
207

← Event Dates extrapolated backwards in time				Original data set, Event Dates for the seven teaching methods							Event Dates extrapolated forwards in time →		
A4	A3	A2	A1	i	Ii	iii	iv	v	vi	vii	B1	B2	B3

208
209 *Dates from extrapolating forwards:*
210 Date A1.   251 million years BCE.
211   ▪   Matched event: **"Cumulative Culture": Date: *Unknown.***
212   ▪   This event is in the original data set. We still do not know the date, but we know it logically precedes
213   Tool-use, so we can say where we think it is supposed to be. That is to say, we now have a predicted
214   date.
215 Date A2.   1.22 billion years BCE.
216   ▪   Matched event: **"Complex multicellular organisms": Date: 1.0 to 1.2 billion years BCE [1] [2]** (-1.6%
217   error)
218   ▪   Adaptation: Complex bodies
219   ▪   Transmission: Sexual reproduction
220 Date A3.   5.7 billion years BCE.
221   ▪   Matched event: **"Single-celled life." Date: 4.28 to 3.77 billion years BCE [3]** (-25% error)
222   ▪   Adaptation: Self-replication and DNA mutation
223   ▪   Transmission: DNA copying in asexual reproduction
224   ▪   This is the nearest event to the predicted date, which is 1.5 billion years before life appeared on Earth.
225   But as we are near the beginning of the cascade, the date does not have to match, because it may not
226   have converged to the Feigenbaum constant δ yet. So I assume the beginning of life on Earth is the
227   correct event.
228 Date A4.   26.6 billion years BCE.
229   ▪   Matched event: **"Big Bang". Date: 13.77 to 13.82 years BCE [4]** (-52% error)
230   ▪   Adaptation: none
231   ▪   Transmission. None
232   ▪   This is the nearest event to the predicted date, which is more than 12 billion years before the Big Bang.
233   Again, as we are near the beginning of the cascade, the date does not have to match, because it may not
234   have converged to the Feigenbaum constant δ yet. Also, the difference between actual date and the
235   predicted date is bigger than for Single-celled Life, even when the logarithmic scale is taken into
236   account, which means that, taken together, the actual intervals are converging to the Feigenbaum
237   pattern, as expected.
238   So I assume the Big Bang is the correct event. The Big Bang has neither adaptation nor transmission,
239   but marks the start of the evolution of the universe and the process that leads to the first living cells on
240   Earth (unless one counts matter as an adaptation and persistent matter as some kind of transmission).
241
242 *Dates from extrapolating forwards:*
243 Date B1.   3160 CE.
244   ▪   Matched event: **"Written Language": Date: 3500 – 3200 BCE**
245   ▪   Adaptation: writing-based information storage
246   ▪   Transmission: via media.
247 Date B2.   1044 CE.
248   ▪   Matched event: **"Movable-type Printing", China. Date: 1039 - 1048 CE.**
249   ▪   Adaptation: Correctable typesetting

250 ▪ Transmission: mass replication of knowledge
251 Date B3.   1925 CE.
252 ▪ Matched event: **"The Computer". Date: 1948 CE**
253 ▪ Adaptation: Automatic processing of information
254 ▪ Transmission: User interface
255 ▪ The date is 23 years too early (950 years after the previous level, an error of 2.5%), but the computer
256 seems like the correct choice.
257
258 The next date after the invention of the computer is predicted to be more than 100 years in the
259 future.
260 The new dates found are not new teaching methods, but, like teaching methods, they are all
261 information transmission methods. I discuss the events in the Results section. A combined list of all
262 of the Adaptation/Transmission pairs (the original teaching events and the extrapolated events) is
263 shown in table ept1.
264
265

	Evolution phase & Information transmission channel	Level of adaptation (These are the things being varied)	Information Transmission Level
1	Physical/No transmission	None (Big Bang)	No transmission
2	Biological/DNA	DNA mutation	Copying DNA in cell division
3	Biological/DNA	Gene shuffling	Sexual reproduction
4	Bio-cultural/Teaching	Novel behaviour	Intentional evaluative feedback
5	Bio-cultural/Teaching	Tool use	Tool transfer
6	Bio-cultural/Teaching	Toolmaking	Referential gestures/Drawing attention
7	Bio-cultural/Teaching	Tool-made tools	Demonstration
8	Bio-cultural/Teaching	Composite tools	Communication of concepts
9	Bio-cultural/Teaching	New Inventions	Explanation of relationships between concepts
10	Bio-cultural/Teaching	New livelihoods	Final language level, narration
11	Technological/Writing-based	Documents of record	Transmission via writing
12	Technological/Writing-based	Long, accurate printed works	Mass replication of information
13	Technological/Writing-based	Software	Transmission via user interface

266 Table ept1. The original data set of Adaptation/Cultural Transmission (Teaching) event pairs (4 to 10)
267 together with the extrapolated Adaptation/Transmission Event Pairs (1 to 3 and 11 to 13). (Event 1 -
268 Big Bang – is not strictly an adaptation/transmission event, but it marks the start of physical
269 evolution.)
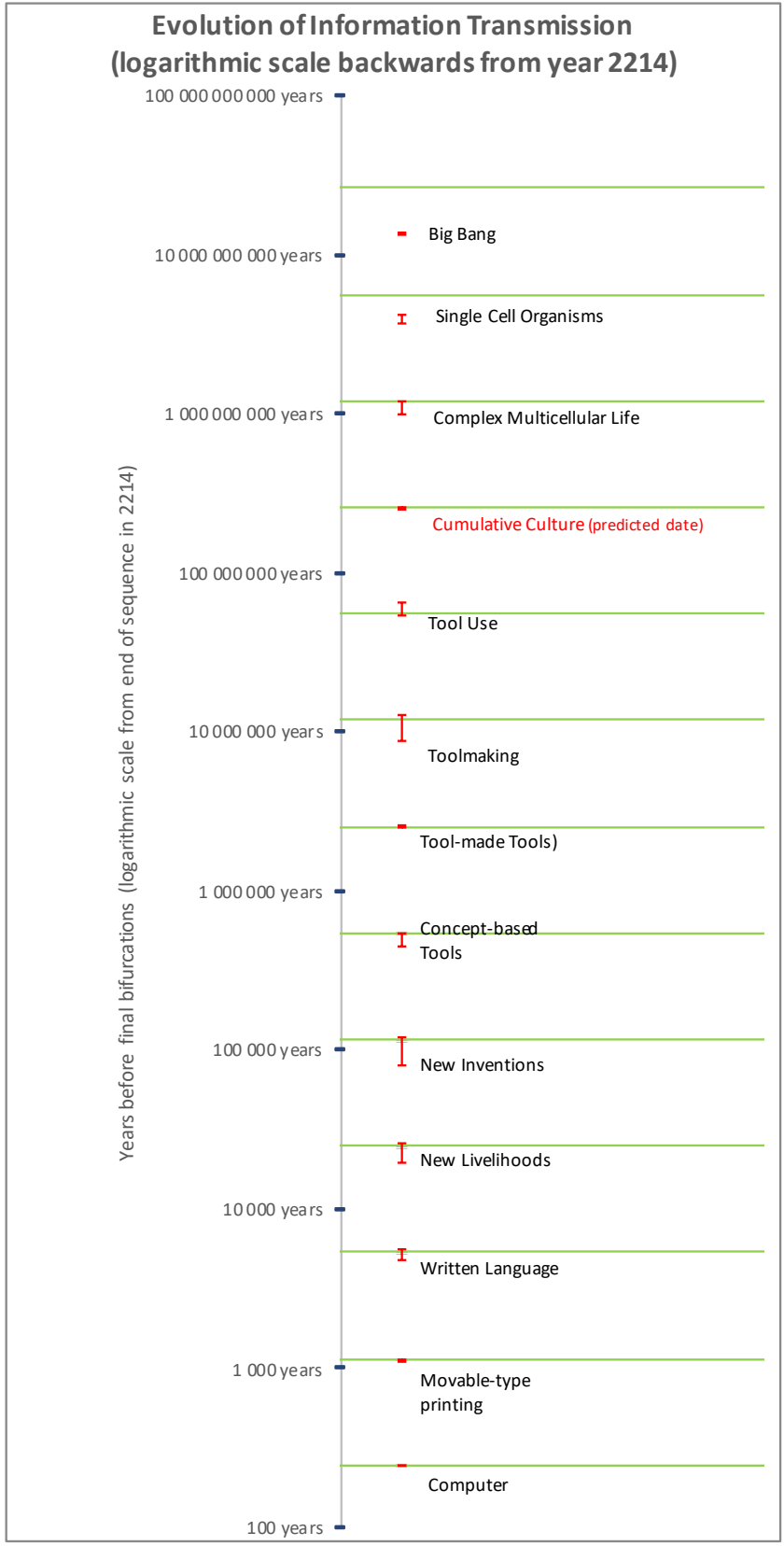
Figure 1. This is a timeline of the transmission events on a logarithmic scale, where the green lines mark the Feigenbaum-predicted dates, and the red error bars are actual dates. It can be seen that they intersect. Because it is a logarithmic scale, the green lines appear equidistant, although the time interval between the green lines decreases by the factor 4.6692 as one moves from the past to the present.

276   *The Timeline*

277   Figure 1 shows the timeline of the transmission events on a logarithmic scale, where the green
278   lines mark the predicted dates (as predicted by the Feigenbaum constant δ), and the red error bars
279   are actual dates. It can be seen that they intersect. Because it is a logarithmic scale, the green lines
280   appear equidistant, although the time interval between the green lines decreases by the factor 4.6692
281   as one moves from the past to the present. *(Dates are measured from where the bifurcations end around the*
282   *year 2196. **The actual date for the first occurrence of Cumulative Culture is not known (red text), so***
283   ***the predicted date is given.** The first two dates do not match the dates predicted by the Feigenbaum ratio.*
284   *However, in Chaos Theory it is nearly always the case that initial interval ratios do not match the Feigenbaum*
285   *constant δ, but rapidly converge to it, which is what we see here.)*

286   *The Events described*

287   The events are described in Table elm4. For further details of these events, see table el33 in
288   Appendix FCCE.
289   The large date error for the first two intervals is expected because the process needs time to
290   converge to the ratio 4.6692… .
291
292

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1.   Big Bang

Not strictly adaptation or transmission, but the Big Bang is the reference point where physical
evolution of the universe begins, and where eventually Biological evolution will also begin building
up to the time when the first cellular life reaches a Population Growth Rate greater than 1.0.
Adaptation: none at this stage.
Transmission: none at this stage.

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2.   Single-celled life   (predicted $4.6692^{12} \times 212$ years after previous event (-52% error))

The first self-replicating life on Earth.
Adaptation: Change is by random mutation in the DNA, and possibly Horizontal Gene
Transfer too.
Transmission: The DNA, including the changes, is copied and passed on in cell division.

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3.   **Complex multicellular organisms**   (predicted $4.6692^{11} \times 212$ years after previous event (-25% error))

Multicellularity with differentiated cells (e.g. muscle cells, brain cells, etc) – known as *complex
multicellularity* – is probably necessary for intelligent life to evolve. Plants and animals are
multicellular.
There is evidence that sex and multicellularity evolved at the same time in red algae found in
1.2 billion year old rocks [2]. The immune system of complex multicellular organisms depends on
every individual having a unique genetic identity. This is achieved by sexual reproduction, which
creates a unique genetic code for each offspring. The code is a random mixture of the genetic codes
of the grandparents.
Adaptation: Adapt quickly because genes are a random mixture of alleles from both parents.
99% of all species today reproduce sexually, so it is clearly advantageous [5].
Transmission: Multicellularity is apparently not viable without sexual reproduction. Sexual
reproduction also seems to evolve faster than simple self-replication (which is basically cloning).

4. **Cumulative Culture**:   (predicted $4.6692^{10} \times 212$ years after previous event (-1.6% error)

Adaptation: The adaptation innovation at this stage is novel behaviour (as opposed to instinctive, genetically programmed behaviour),

Transmission: Cumulative Culture survives best when social learning is corrected by experienced individuals.

5. **Tool Use:**   (predicted $4.6692^{9} \times 212$ years after previous event)

The use of tools is undoubtedly important in evolution.

Adaptation: In effect, a tool is an addition to the body. It instantly extends the body without waiting for biological evolution [10]. The tools in question would basically be sticks and stones that happen to be lying around on the ground and used without modification for a useful purpose.

56.6 million years ago, the first monkey had evolved. Monkeys use tools today [11], and it is not implausible to suggest that they were the first to use tools 56.6 million years ago.

Transmission: Chimpanzees have been observed imitating their mothers and learning how to place nuts on a so-called anvil stone and crack them open using a stone of suitable size and weight [25]. While they are learning, young chimpanzees are allowed to use their mother's tools. This is called "tool transfer" and even without additional teaching, it fulfils all the criteria to qualify as teaching on its own because 1) it has a "cost" (giving up the tool to the pupil), 2) the teacher is present, and 3) the pupil learns from practicing with the tool [26].

6. **Toolmaking:**   (predicted $4.6692^{8} \times 212$ years after previous event)

Adaptation: Making tools makes it easier to optimize and improve them. This is the time of the first great apes or hominids. Great apes have been observed making tools [16], so it is reasonable to suggest that they may have made tools back when they first evolved.

Transmission: Tools are made by humans, great apes and some birds of the corvid family. Humans, great apes, and ravens (corvid family) are also the only animals confirmed to use referential gestures [11] [17]. It is not unlikely that there is a connection between these two facts, namely that referential gestures are needed to teach tool-making.

7. **Tools made with Tools:**   (predicted $4.6692^{7} \times 212$ years after previous event)

Adaptation: Some kinds of tools were more effective if they were made of stone. They could be made sharper and more useful for cutting meat. But stone tools could not be made by hand. They had to be made using another stone tool to chip off parts of the tool being made.

Transmission: This event refers to the freehand knapping technique – also known as Oldowan technology – 2.6 million years ago. (There was another technique for making stone tools called the "bipolar" technique 700,000 years earlier [19]. The "bipolar" technique used an anvil stone. However, Gärdenfors and Högberg argue that Oldowan technology required a new level of teaching, but that the bipolar technique did not.)

8. **Composite and other concept-based Tools:** (predicted $4.6692^6 \times 212$ years after previous event)

Adaptation: One of the prime candidates for the first composite tool is the earliest known stone-tipped spear from 550,000-450,000 years ago [24][25][26]. It had a wooden shaft and a sharpened stone tip attached to the shaft using a method known as hafting.

Transmission: Composite tools require that the concepts of "whole" and "part" are understood. This would have required Gärdenfors's teaching method, Communication of Concepts[23], as do Late Acheulean tools which date from the same time.

9. **New Inventions:** (predicted $4.6692^5 \times 212$ years after previous event)

Adaptation: Boats, clothes, beads, harpoons, sewing needles, mortars and pestles, cloth, flutes, rope, pottery. These are just some of the new things that humans started to make, beginning around 114,000 years ago. It seems that humans suddenly gained the ability to invent new things. Everything that humans had made until this point were copies of the first tools used, which were originally stones, twigs and sharp sticks that were found lying around.

Transmission: These new inventions would also likely require a new form of teaching to explain the new invention to others. Gärdenfors' teaching level, Explaining Relationships between Concepts, would have been appropriate[23]. Of the earliest inventions are the first tools for making clothes (120,000 to 90,000 years ago[27]).

10. **New Livelihoods:** (predicted $4.6692^4 \times 212$ years after previous event)

Adaptation: Domestication of animals and plants, starting with the dog.

The Neolithic Revolution supposedly began 12,000 years ago with the domestication of sheep and various plants and led to the first agricultural civilization. However, the date predicted by the bifurcation pattern is 24,900 years ago. This agrees with the date of the first animal to be domesticated, which was the dog (26,000–23,000 years ago [30]). Dogs appear to have been an integral part of the Neolithic revolution [31]. It is believed that humans and dogs worked in a mutually beneficial partnership, initially in hunting [32], but later with herding. This partnership may have been important in the move away from hunting, scavenging, and gathering, to organize new livelihoods leading to agriculture and civilization.

Transmission: This innovation also seems to have come from crossing a cognitive threshold that may have been associated with an advance in language. This seems to have enabled the capacity to invent new livelihoods. Communication must have been important to make these new livelihoods work. At some point language seems to have given humans to the capacity for logical reasoning and problem-solving. From experiments we know that some kinds of problems can only be solved with the aid of language [33]. Certainly, some kind of logical reasoning and problem-solving ability must have been necessary for humans to abandon scavenging, hunting and gathering (which for tens of millions of years was the only thing they knew how to do) and invent new ways of living, ending up with civilisation and the specialisation of labour.

11. **Written Language**: (predicted $4.6692^3 \times 212$ years after previous event)

We know very little about the evolution of spoken language, but we do know a lot about written language. Much information is now being passed on by written words. The first writing was called Cuneiform and it was developed as a means to record trade, debt, and tax information

[34]. The written word is not just communication: it is a shared memory and reference. A handwritten document is a persisting object that can record things that two or more people have agreed upon. Such a document enables agreements to be made, accounts to be opened, and laws to be reliably documented. It became an essential part of society.

Adaptation:

Transmission: The two uses of writing – information storage and transmission are often intertwined. Storage allows growth of knowledge. As transmission, writing has the advantage that storage gives it – that the sender and receiver do not have to be in the same place at the same time for the message to be sent and received.

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12. Movable-type Printing. (predicted $4.6692^2 \times 212$ years after previous event)

Before printing, books were copied by hand, which made them very expensive and mainly owned by wealthy establishments such as religious authorities.

Movable-type printing had the effect of democratising knowledge, putting into the hands of many more people. Science and mathematics, which were revolutionised by the invention of writing, were again boosted by the ability of printing to spread accurately replicated knowledge, without the errors often caused by hand-copying.

Adaptation:

Transmission: The replication of texts enables large quantities of information to be sent cheaply. The movable type allows texts to be corrected after proofreading with minimal effort, enabling accurate texts.

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13. The Computer (predicted $4.6692^1 \times 212$ years after previous event)

Like spoken language, writing, and printing, the computer was an invention based on symbols. Indeed, writing and printing can both be seen as early forms of information technology.

Adaptation: Computers can handle information automatically. Information is handled according to instructions in computer programs.

Transmission: The human - computer interface is most often via a keyboard and symbols on a screen.

293   **Table elm4.** Description of each event pair.

294

295
296
297

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
…	…	…
Aperiodic level	2196 onwards	No more intervals

298   Table si1: Future bifurcation events

299   *Future bifurcations*

300   The pattern of bifurcations should, according to chaos theory, continue until the Accumulation
301   Point is reached. Theoretically there will be an infinite number of bifurcations and the interval will
302   shrink to zero, at which point in time the population will become aperiodic (aka "chaotic"). (The sum
303   of an infinite series can be finite, as in the case $1 = \frac{1}{2} + \frac{1}{4} + 1/8 +$ and so on.)
304   Future bifurcation events are shown in table si14. There are theoretically an infinite number of
305   bifurcation events before the Accumulation Point in 2196 CE (note that this date is not exact and may
306   change with new data). In reality, fractals do not continue forever, and we should aware of confusing
307   the map with the territory, so to speak.
308   The Accumulation Point may be what is commonly known as the Technological Singularity
309   where there is predicted by some to be a point of runaway development of technology.

310   *Effect of fossil fuels?*

311   For most of the history of most life on Earth, evolution has been powered by the sun only. It is
312   not inconceivable that evolution of humans has accelerated due to the consumption of energy from
313   fossil fuels, which became significant in the 20th century, and that this may cause the Accumulation
314   Point to come sooner than 2196.

315   *A Loose End*

316   The date of the first teaching event, "Intentional Evaluative Feedback" is not known as there is
317   no conclusive fossil record. Extrapolating the intervals according to the observed interval ratio gives
318   a date of 261 million years ago. Probably the most social of animals at this time were Cynodonts,
319   animals that were the ancestors of mammals. They lived in communal burrows with mixed
320   generations, which indicates that they may have been highly social, and therefore could have
321   practiced Intentional Evaluative Feedback and had Cumulative Culture.
322
323

324

4. DISCUSSION

326   *4.1. Summary of results*

327   *What was done?*

328   ▪ Staring with 7 dates from bio-cultural evolution, the dates were should to be consistent
329   with a Feigenbaum Cascade, indicating that evolution is a "chaotic" (in the technical
330   sense) process.
331   ▪ Using the Feigenbaum pattern to extrapolate from the original dataset, 6 or 7 more
332   events were found, showing that the Feigenbaum Cascade stretches from before the
333   beginning of life on Earth until today and into the future, the cascade due to complete
334   in 200 years or so.
335
336   The results are summarized in Figure 1, which shows all the events on an evolutionary timeline.
337
338
339
340   ▪ The extrapolations of the cascade sequence:
341   o positively identified 3 more events (Complex Multicellularity, Writing,
342   Printing)
343   o found 3 possible matches (Big Bang, Life, Computers).
344
345   ▪ Of the 13 events:
346   o 10 events match the dates predicted by the Feigenbaum Constant delta – that is,
347   their red error bars intersect the green lines representing the predicted dates.
348   o 1 event – Cumulative Culture – has a date that is not known, although we know
349   that it happened because it is still used today.
350   o 2 events – the first two, Big Bang and Single-celled Life – do not match the
351   predicted dates, but clearly look as if they are on a curve that is converging to
352   the predicted dates, which what one would expect of the first 1 or 2 dates in a
353   Feigenbaum Cascade. It is more likely that the model (the logistic map) that is
354   wrong, not the event dates.
355
356   1 more event . computer
357
358   The results support the existence of a Feigenbaum Cascade of Information Transmission
359   innovations.

360   *4.2. Theoretical Explanation*

361   If there is a Feigenbaum Cascade governing the evolution of the universe, what is the
362   explanation behind it?
363   The explanation for population bifurcations in evolution could be very similar to the reason for
364   population bifurcations in the study of Population Dynamics in livestock. I suggest an explanation
365   below. First there is a brief explanation in Box Z of the standard theory of bifurcations in Population
366   Dynamics. It explains how a group of animals in a limited ecosystem can consume too much, leading
367   to starvation the following year, if the Population Growth Rate increases – for whatever reason – and
368   happens to push the system over a bifurcation threshold.

369   Box Z. Bifurcations in Population Dynamics

Bifurcations in Population Dynamics

Before we look at evolution, we can look at how Feigenbaum Cascades work in Population Dynamics. Understanding this helps to understand how bifurcations may work in evolution.

Understanding Population Growth Rate

The three examples here give an idea of how the Population Growth Rate works:
- Population Growth Rate = 0.5 → population halves every year and will die out (equilibrium population = 0).
- Population Growth Rate = 1.0 → population stays the same every year.
- Population Growth Rate = 2.0 → population doubles every year. That is, it would double every year given an given an unlimited amount of food. That would be the case if the Population a → a.x, where a is population growth rate. But with limited resources modelled by, for example, logistic map, P → a.P(1 – P/K), where K = carrying capacity, the population rate slows until it reaches an equilibrium.
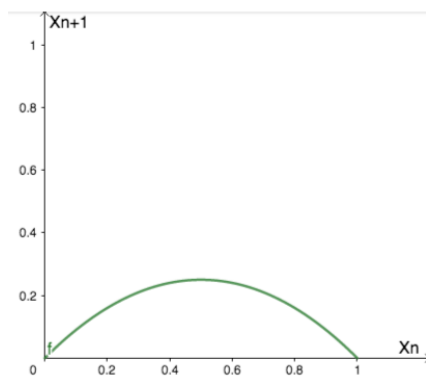

Figure log8. The Logistic Map P → a.P(1 – P/K), for Population Growth Rate a = 1, K = carrying capacity of the ecosystem for the species concerned.

The Logistic Map

Figure log8 shows the logistic map, P → a.P(1 – P/K), where P = Population, a = Population Growth Rate = 1, and K = carrying capacity of the ecosystem for the species concerned. This the simplest mathematical model of an ecosystem that has limited resources, and is used here, as elsewhere, for its simplicity. The curve is used to calculate next year's population from this year's population.
- At low population input, the population increases by approximately the Population Growth Rate.
- At high population input (Population, P nearly equal to the carrying capacity, K), next year's population will be nearly zero, because the food is nearly all gone.

Feigenbaum Cascades in Population Dynamics

Feigenbaum Cascades occur in the study of Population Dynamics. At least they do in some theoretical models of population fluctuation. Owners of livestock, for example, may find that the numbers of animals can drop unexpectedly compared with the previous year, particularly if they have just taken measures to increase the Population Growth Rate by artificial means, such as the use of antibiotics.

For example, if one had an ecosystem where a certain amount of food grew every year, an increase in the Population Growth Rate can paradoxically cause a drop in population because the faster-growing animals eat so much that they *eat some of the food that is needed for the year after*. When next year comes around, many animals will starve and the population drops.

If the increased growth rate persists, the situation will repeat, recovering every second year, only to starve again on alternate years.

If the Population Growth Rate increases even further, the animals eat into *two* years reserve of food. and the population levels bifurcate again, doubling to 4 levels which repeat every 4 years.

If the animals eat into *three* years food reserve, the levels double to 8.
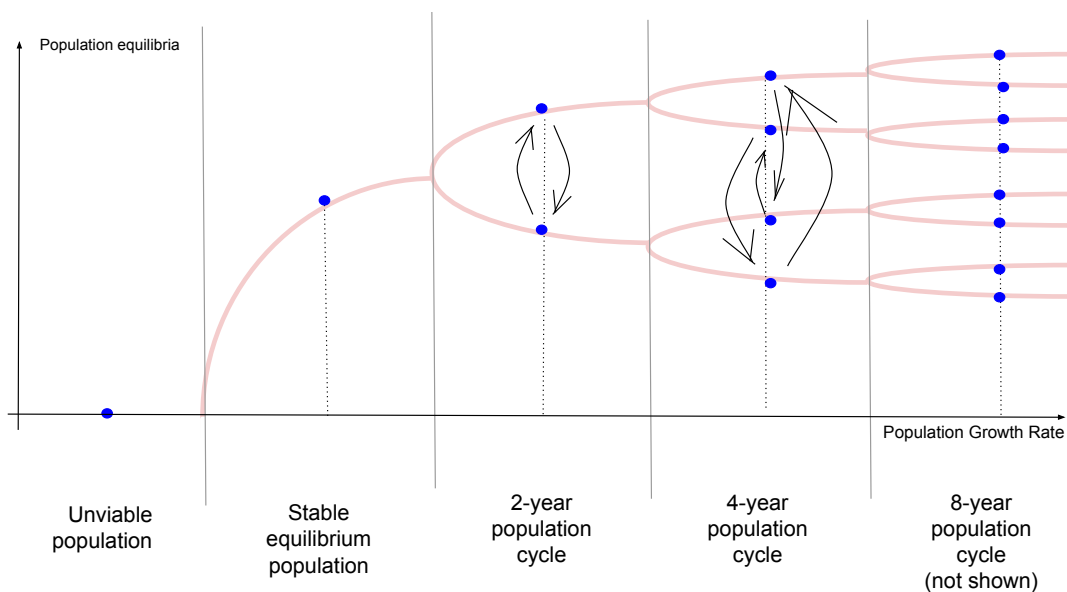
And so on.

Figure bif66: This schematic drawing of a bifurcation diagram shows the Equilibrium Population at various levels of Population Growth Rate (for organisms that breed once per year and grow to sexual maturity before the next breeding season).

Figure bif66 shows how bifurcations work in a simple population model. This schematic drawing of a bifurcation diagram shows the Equilibrium Population at various levels of Population Growth Rate and the 2 year and 4 year population cycles.

Figure bif66 is what is known as an "attractor", which means that it only shows the long-term values that the system settles down to, assuming no disturbances. In this case the red lines are attractors for the population level. When the red line splits into two values, it means that the population alternates between the two values, repeating every 2 years.
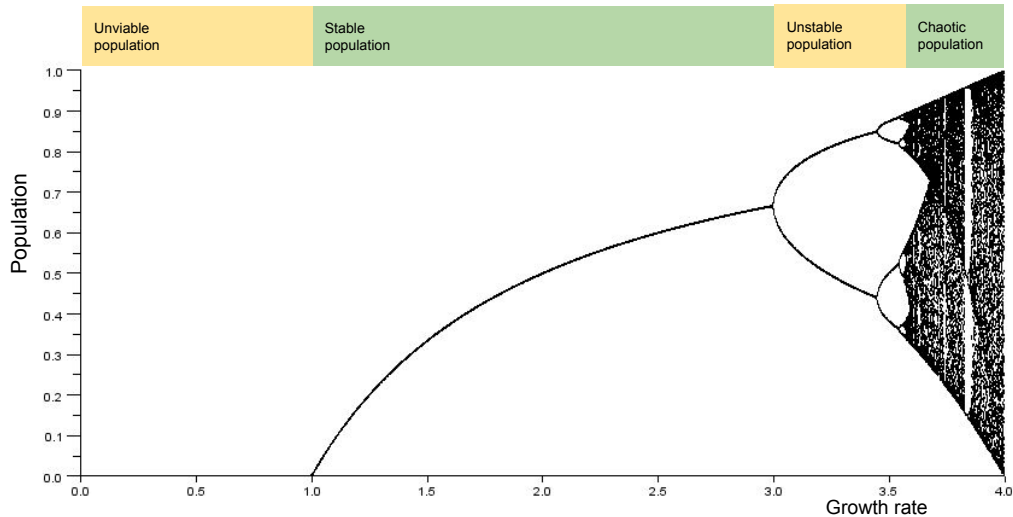
Figure jj4same. The attractor for iterations of the logistic map x → a.x(1 – x/K) for various values of population growth rate *a* from 0.0 to 4.0. (4.0 is the maximum for population growth rate for the logistic function. More sophisticated functions can handle higher growth rates, but all have bifurcations at intervals shrinking by the Feigenbaum constant δ.)

Actual bifurcation diagram

Figure bif66 is illustrative and not to scale. A "real" computer-generated bifurcation diagram for a period-doubling system with correct proportions for the bifurcations is shown in figure jj4same.

The diagram is an attractor. That is to say, it does not show all possible values, only the values that the population settles down to in the long term. One can see how the intervals grow rapidly shorter by the ratio 4.6692. The bifurcations converge quickly to the Accumulation Point, after which the variations in population do not repeat ("chaotic behaviour").

Figure jj4same shows the attractor for iterations of the logistic map *x → a.x(1 – x/K)* for various values of growth rate *a* from 0.0 to 4.0. (4.0 is the maximum for growth rate for the logistic function. More sophisticated functions can handle higher growth rates, but all have bifurcations at intervals shrinking by the Feigenbaum constant δ.)

The logistic map is often used for explaining bifurcation diagrams because it is perhaps the simplest possible bifurcation map.

Bifurcations

Figure jjsame shows the different regions of a bifurcation diagram based on the logistic map. (The thresholds may be different for other maps.) The regions are described here:

- At a Population Growth Rate below 1.0 the population will die out. (For example, with a growth rate of 0.99, next year's population will be 0.99 times this year's population. The population gets smaller every year and eventually becomes zero.)
- At a Population Growth Rate between 1.0 and 3.0, the population eventually settles to a stable level that remains the same year after year.
- At a Population Growth Rate between 3.0 and about 3.45, the population level becomes unstable as the equilibrium bifurcates into 2 levels, alternating between a higher and a lower population every 2 years.
- At a Population Growth Rate between about 3.45 and about 3.54, the cycle doubles into a 4-year cycle.

- At a Population Growth Rate between about 3.54 and about 3.58, Each bifurcation doubles the number of equilibrium levels and the number of years it takes to cycle through them.
- At a Population Growth Rate between about 3.58 (the "Accumulation Point") and 4.0, there are no more bifurcations and the variations in population are aperiodic (or "chaotic").

The diagram is for organisms that breed once per year and grow to sexual maturity before the next breeding season, but for our purposes the results work for overlapping generations too.

It also assumes sexual reproduction throughout.

370 *4.3. Bifurcations in evolution*

371   As mentioned above, the standard theory of bifurcations in Population Dynamics explains how
372 a group of animals in a limited ecosystem can consume too much, leading to starvation the following
373 year, if the Population Growth Rate increases – for whatever reason – and happens to push the system
374 over a bifurcation threshold.
375   It turns out that "whatever reason" can be evolution. Population Growth Rate increases as
376 organisms evolve, because that is what Darwin's Natural Selection does. Darwin's theory could have
377 been described as "survival of those with the highest Population Growth Rate".
378
379
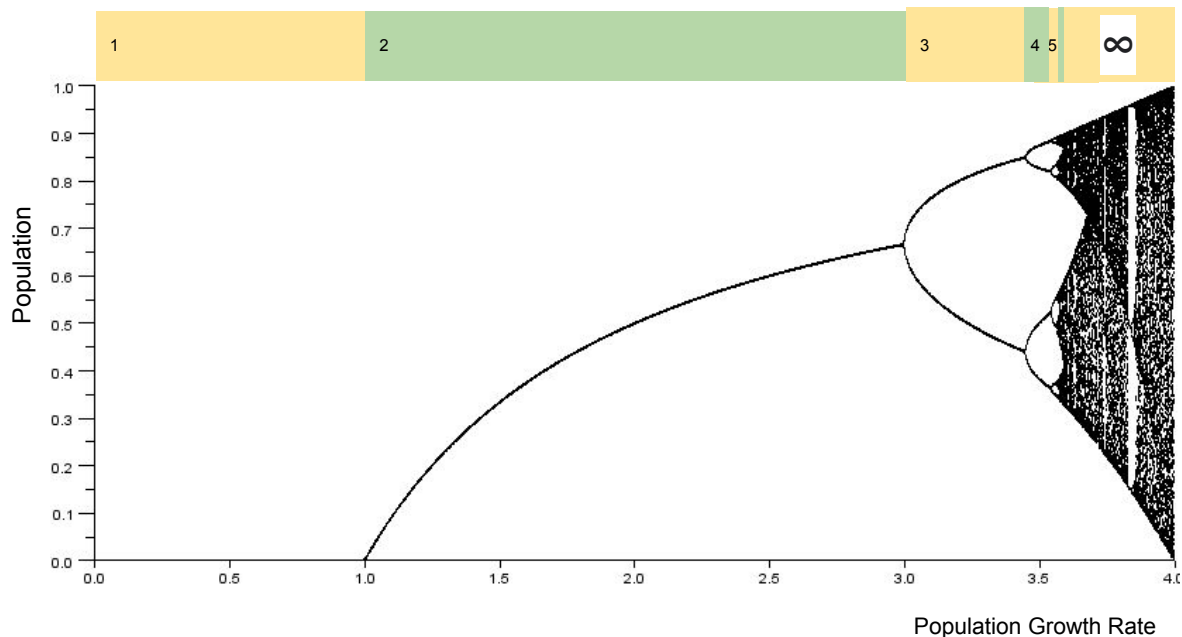
380

381 Figure jj3. Levels of evolution: 1. Big Bang; 2: Single-celled life; 3: Multicellular organisms; 4:
382 Cumulative Culture; 5: Tool Use; ∞: Accumulation Point and Aperiodic Population.
383 The attractor used is for iterations of the logistic map x → a.x(1 – x/K), matched with the levels of
384 evolution. Note: Not to scale. The logistic map has a much too short level 1 to fit physical evolution.
385 Population growth rate *a* from 0.0 to 4.0. (4.0 is the maximum for population growth rate for the
386 logistic function. More sophisticated functions can handle higher growth rates, but all have
387 bifurcations at intervals shrinking by the Feigenbaum constant δ.)

388 *The Bifurcation Diagram*

It is time to look at the Bifurcation Diagram for Evolution. I refer to figure jj3, to explain how evolution may match a bifurcation tree. The tree is derived from the logistic map, although it gives the wrong proportions, especially for the first level, level 1. But we don't have a correct map for evolution yet.

The x-axis is Population Growth Rate, but because Population Growth Rate increases with time, we can assume that the x-axis can also be time. The levels shown at the top pf the diagram are levels 1 to 5:

		Population	
1.	Big Bang	0 (no life)	
2.	Single-celled Life	Stable	
3.	Multicellular organisms	Unstable (growth at overconsumptionaa	Unstable
4.	Tool Use	Unstable	

The rest are too small to see. There are an infinite number of levels in theory (not necessarily in reality), which finish at the Accumulation Point, after which the population is aperiodic (the last yellow section marked "∞" in the figure.

405
406

Bifurcations in: `Population Dynamics among livestock`	*Bifurcations in:* `Evolution`
Increasing Population Growth Rate, caused by	*Increasing Population Growth Rate, caused by*
`The use of antibiotics, for example,`	`the effect of Darwinian Natural Selection in evolution,`
moves the position of the equilibrium point in the map, making the equilibrium point unstable. The tipping point tips over, creating a "disturbance" in the form of	*moves the position of the equilibrium point in the map, making the equilibrium point unstable. The tipping point tips over, creating a "disturbance" in the form of*
`too high a population,`	`a new adaptation level and transmission process,`
that grows in size, causing overconsumption and a population bifurcation	*that grows in size, causing overconsumption and a population bifurcation.*
	`The new process is a new adaptation level (such as complex multicellularity, or tool use, or the invention of writing), together with a transmission process. These processes may have already evolved and are just waiting for the tipping point where they will become self-sufficient in terms of net energy production and begin to grow.` `With evolution, the "disturbance" can take many millions of years, as the process of evolution progresses.`

407   **Table comp3:** The similar, but different case of bifurcations in in Population Dynamics and in
408   Evolution.

409   *What happens at each bifurcation?*

410   Table comp3 shows the description of a bifurcation in Population Dynamics, together with a
411   description of a similar, but different, scenario in Evolution. The difference is that:
412

413   ▪ In the Population Dynamics case, if there is a sufficient excess population to push the
414   population past the next overconsumption tipping point, this will cause a bifurcation.
415   No evolution takes place during this scenario. The excess population can be purely
416   temporary, perhaps due to immigration.
417

418   ▪ In the Evolution case, if the species has evolved to the next adaptation tipping point,
419   (or if we are looking at multiple species, or all species, then the first of these species to
420   evolve to the next adaptation tipping point,) then there will be a latent process already
421   in place (or one evolves very quickly) and the tipping point tips because the process
422   reaches a "break-even" point where the species gains more energy than it spends. This

423   will eventually lead to the same this as in the Population Dynamics case –
424   overconsumption and a subsequent population bifurcation.

425   *Relentless evolution*

426   It is altogether a slower process when evolution is involved. But overconsumption and
427   bifurcation in Population Dynamics that may happen in a livestock scenario are short-lived,
428   ephemeral, reversible events that can appear one year and disappear the next. But when evolutionary
429   bifurcations occur, they are – on the whole – here to stay. But even then, they may be false starts and
430   delays caused by disease, weather, and any number of natural reasons. But evolution is relentless, if
431   the Red Queen hypothesis is true (that all species have to evolve just to maintain the same position,
432   just as the Red Queen in Lewis Carroll's Wonderland ran fast but stayed on the same spot).

433   *The Time factor in Evolution*

434   Time is not really a factor in Population Dynamics. That is to say:
435   • The scenario of Population Growth Rate increasing with time is not a useful case to
436   study in practical situations.
437   • The Population Growth Rate in livestock scenarios is a question of doing things – like
438   adding antibiotics, that have immediate effect.

439   The same is true of the pattern of water drops from a dripping tap. The bifurcation parameter is
440   the rate of water flow, which is not usually coupled to time. In this case also, the change in the
441   bifurcation parameter rapidly moves the system to a new equilibrium.
442   In evolution, on the other hand, time is very much a factor. The level of complexity required for
443   life is so high that simply having a sun that provides sufficient energy to enable complex ecosystems
444   with intelligent life does not mean that they appear quickly, they take billions of years to evolve to
445   an equilibrium – an equilibrium that may not be reached for billions of years yet. That is the reason
446   why time is a factor in evolution.
447

448   *Characteristics of evolution*

449   Part of my hypothesis is that evolution is a period-doubling system. Other examples are
450   populations of species in a resource-limited environment, electronic and other kinds of oscillators,
451   and the pattern of water drips from a dripping tap. All these systems have in common that they share
452   a similar "single-hump" mathematical model. The iterations seem to wear away the differences so
453   that they all show the same ratio between bifurcations (4.6692…). Although evolution has given rise
454   to the most complex variations of life imaginable, it is all nevertheless subject to the simple rule of
455   Natural Selection which drives the slow increase in Population Growth Rate and the characteristic
456   bifurcations in population that occur as the mathematical sequence of thresholds are crossed. Just as
457   Natural Selection ultimately reduces all the dimensions of an organism to one dimension –
458   Population Growth Rate – and then to point along that dimension – survival or not, so the logistic
459   map (and maps in the same class) reduce everything to a 2-dimensional bifurcating attractor.

460   *Looking for traces of population fluctuations*

461   Looking for evidence of population fluctuations (bifurcations) in the past is not an easy task.
462   They have been observed in laboratory conditions. It is hard to find evidence of patterns of
463   bifurcations in a living ecosystem, because there are so many other parameters, like the weather, or
464   disease, affecting the population. Finding a population fluctuation pattern in an extinct population
465   will be even harder. If the period doubling pattern could be found in fossil evidence, it would
466   strengthen the hypothesis. Otherwise, indirect indications must be used.
467   But it is likely that the bifurcations have little effect on evolution and are just a possible
468   consequence. It is the *cause* of the bifurcations that is important, and the causes – the stone tools, etc.
469   – often do leave traces.

	New information transmission method	Failure of previous transmission method
1	None	None
2	**DNA copying and cell division** Self-replication	*The previous method, "None" was inadequate for **Single-celled Life** because* – there was no transmission method
3	**Sexual reproduction** Transmission by combining DNA from two parents.	*The previous method, **"DNA copying and cell division"** was inadequate for **Complex multicellular life** because* – it requires gene-shuffling to create a unique identity for the immune system
4	**Intentional evaluative feedback** Indication that the student is doing something wrong in their imitation of the parent's behaviour.	*The previous method, **"Sexual reproduction"** was inadequate for **Cumulative Culture** because* – the new behaviour cannot be converted to DNA
5	**Tool transfer** Giving the tool to the student, gives experience with a real tool, and fulfils the criteria to be classed as teaching.	*The previous method, "**Intentional evaluative feedback**" was inadequate for **Using tools** because* – feedback alone doesn't give experience with real tool.
6	**Referential gestures** Showing an object and making eye contact to tell the student to pay attention.	*The previous method, "**Tool transfer**" was inadequate for **Making tools** because* – with no way of drawing attention, teaching may not happen.
7	**Demonstration** "Demonstration" means that the task is performed deliberately slowly to allow the student to understand better.	*The previous method, "**Referential gestures**" was inadequate for **Using tools to make tools** because* – it is very difficult to imitate sophisticated methods unless slowed down.
8	**Explanation of concepts** Concept-based and/or composite tools. (Late Acheulean tech)	*The previous method, "**Demonstration**" was inadequate for **Composite and other Concept-based tools** because* – some tools require explanation of concepts.
9	**Explanation of relationships between concepts** Explanation of what the tool is used for..	*The previous method, "**Explanation of concepts**" was inadequate for **New inventions** because* – novel tools require explanation of what they are for, where improvements on old tools do not.
10	**Narration (which completes language)** Language used for organization and problem-solving.	*The previous method, "**Explanation of relationships between concepts**" was inadequate for **New livelihoods** because* – organizing new livelihoods requires a complete language.
11	**Written Language** **(Information storage)**	*The previous method, "**Narration (which completes language)**" was inadequate for **Written language (Information storage)** because* – narration has no memory function.
12	**Movable-type Printing** **(Correctable text)**	*The previous method, "**Written Language**" was inadequate for **Movable-type Printing (Correctable text)** because* – copying books by hand is unfeasible if everyone is going to read..
13	**The Computer** **(Information processing)**	*The previous method, "**Movable-type Printing3** was inadequate for **Computers (Information processing)** because* – printers cannot process information.

470 Table fail6: How transmission methods fail to transmit the latest adaptation, thus requiring a new
471 transmission method.

472   *The Importance of Transmission Failure*

473   Table fail6 shows how transmission methods fail to transmit the latest adaptation, thus requiring
474 a new transmission method.

475   ■   It is the requirement for and creation of new transmission methods that has created the
476   Feigenbaum Cascade in the evolution of human intelligence.
477   ■   The fact that these transmission methods are relatively easy to clearly identify and
478   distinguish from other events has enabled their discovery.
479   ■   That it is relatively easy to associate each new transmission event with an adaptation
480   innovation means that it has been possible to find the dates of 12 of the 13 levels of
481   evolution.
482   ■   It has been possible to use the cascade as a measure of the "importance" of each event,
483   and the sequence of levels seems to "Make sense" even if there is some work to be done
484   on understanding this sequence.

485
486
487

	New means of Adaptation	Control and Information – each level of evolution creates a new level of control using a new form of information
1	Big Bang & Physical evolution	Physical laws control matter
2	Single-celled Life	Cells manipulate matter using procedural information encoded in DNA
3	Complex multicellular life	Body controls cells, using Gene Regulatory Network information encoded in DNA
4	Cumulative Culture	Mind controls body using behavioural information passed on by Intentional Evaluative Feedback
5	Using tools	Mind controls use of found tools through behavioural information passed on by Tool Transfer
6	Making tools	Mind controls tool manufacture through behavioural information passed on by Referential Gestures.
7	Using tools to make tools	Mind controls tool chain through behavioural information passed on by Demonstration.
8	Composite and other Concept-based tools	Mind controls concept-based tool manufacture through concepts passed on by Communication of Concepts
9	New inventions	Mind invents new tools, passed on by explaining Relationships between Concepts.
10	New livelihoods	Mind solves organizational problems by referring to self in language
11	Written language (Information storage)	Writing-based information enables information storage, which gives control over important information
12	Movable-type Printing (Correctable text)	Writing-based information: correctable typesetting enables large, accurate information storage transmitted by automated replication, giving much more control of information.
13	Computers (Information processing)	Automatic processing of Writing-based information gives new control possibilities.

488   Figure mc1: A suggestion as to the way in which each bifurcation raises the level of control one step
489   further away (higher) from the physical level.

490

491   *Control at each level*

492   It seems to be a characteristic of the evolutionary levels that at each level there is something in
493   control, starting at the first single cell level as something like a pre-programmed unconscious
494   autonomous unit, and with complex multicellularity soon becoming a mind at various levels of
495   cognition, a mind that increases the reach of its control beyond the body. I suggest that the level of
496   control at each level of evolution moves one step higher from the physical level.
497   It does not feel too speculative to suggest – in Figure mc1 – what these levels of control look like.
498   The level of control moves one step further away (higher) from the physical level at each bifurcation.
499   Each level probably increases flexibility and adaptability as well as speed of adaptation. Each level
500   adds information in a new form.
501   We don't know what is next, but continued technology development seems likely.

502   *Natural Fit*

503   Evolution fits smoothly into the Feigenbaum Cascade. As evolutionary change accumulates in
504   every species, increased complexity improves the species in various ways, the result of which is to
505   improve the efficiency of the species, increasing in turn the Population Growth Rate.
506   At various points, determined by the Feigenbaum constant δ, the growth in complexity in the
507   species will have increased enough to have developed a new level of adaptability in the form of a
508   completely new process, which becomes energetically viable at the tipping point.
509   In the case where we interpret the population to be that of all species, the scenario will have
510   different parameters, but the universal behaviour will be the same.
511   As each new adaptive level is added, the population count becomes more unstable as the
512   population count cycling-period doubles. This mechanism works whether the new adaptation level
513   is multicellular organisms or written language.

514   *Does that mean we should have starved when the computer was invented?*

515   Do these bifurcations still work in the same way? We are not starving, and when people do
516   starve, it is because of lack of rain.
517   But the use of fossil fuels has changed the energy patterns. Life on Earth has been powered by
518   the sun until now. The Industrial Revolution saw the first large scale use of fossil fuels, but it is since
519   the middle of the 20th century that use of fossil fuel has dramatically risen, and that farming
520   worldwide has become almost completely dependent on fossil-based fertilizer.
521   But if we had not been using fossil fuels, maybe there would be much starvation today. It is not
522   a trivial matter to work out what the world food situation, or population situation, would have been
523   without fossil fuels.

524   *4.4. The limitations of the present study and new directions for futher research*

525   *Error estimations*

526   Error estimates for the extrapolated dates would be informative.

527   *Ways to disprove the cascade*

528   ▪   Find other events that seem to be similar to the events specified in this paper but which
529   do not match the time pattern.

530   *Ways of verifying the cascade*

531   ▪   Reliable and clear definition of each event
532   ▪   Metrics to verify, e.g. measurement of speed of adaptation at each level.
533   ▪   Other phenomena that support the cascade
534   ▪   Evidence of population bifurcations

535   ▪   Refining the theory to predict what each event should be (if prediction of the nature of
536   an event is possible)

537 *Anything else?*

538   There are bound to be many unanswered, and unasked, questions in a paper of this scope. If the
539 hypothesis survives scrutiny, it offers a new way of seeing the universe and everything that has
540 evolved in it.
541   And there is the question of the coming events. What will they be? What will happen after? Will
542 the process come earlier because of the use of fossil fuels in the past and the present, possibly
543 speeding up evolution?

5.   CONCLUSIONS

545   The result of this paper, if confirmed, could be the basis of a theory of Cosmic Evolution that
546 provides a framework for understanding Biological, Cultural, and Technological Evolution of life
547 and intelligence on Earth, and at least some, if not all of the Physical Evolution of the universe.
548
549   The following direct evidence speaks for a Feigenbaum Cascade in evolution:
550   ▪   The dates all fit, to a surprising degree.
551   ▪   The description of evolution as a Feigenbaum Cascade in section 4.3, is plausible.
552
553   The following circumstantial evidence speaks for a Feigenbaum Cascade in evolution:
554   •   Chaos theory is the study of nonlinear, dynamic, iterated systems, and evolution is a
555   non-linear, dynamic, iterated system.
556   •   Feigenbaum Cascades are found in many different kinds of systems of varying
557   complexity, such as electronic oscillators, to dripping water taps, to populations of farm
558   livestock.
559   •   The mathematical tools created to study Population Dynamics in ecosystems were easily
560   modified to explain the evolutionary pattern, simply by observing that Natural Selection
561   selects for the highest Population Growth Rate and that this rate therefore increases as
562   evolution proceeds, and evolution proceeds with time.
563   •   The relationships between time, complexity, and Population Growth Rate are probably
564   all monotonic, and do not need to be linear, or even known, to give the observed
565   Feigenbaum Cascade pattern, because of the shrinking intervals. Shrinking Intervals
566   have of themselves a linearizing effect.
567   •   The levels are plausible and explain a lot. And create a consistent, testable story.
568   •   The role of population and resources in the explanation echoes the role of population
569   growth in Darwin's theory. This does not feel like a coincidence.
570
571   The overall gist of the evolution of life could be expressed as "building knowledge about the
572 world by interacting with it", which describes the whole span from single-celled life randomly trying
573 mutations, to using computers to perform various tasks for us.
574   Evolution is continuous, but there are discrete adaptation levels, where the information changes.
575   Information starts as blind procedural knowledge in DNA to declarative knowledge. Senses
576 developed, creating a useful continuous, filtered experience of the world, then cognition evolved to
577 understand the experience, and technology to store, replicate, and process information. That is where
578 we are today, and within 200 years we shall have completed the cascade and arrived at a new state,
579 whatever that will be.
580
581   EMPHASIZE THE EXPLANATION. BOOM AND BUST BIFURCATIONS, ADAPTATION.
582

583 **Author Contributions:** NH wrote the paper.

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695

7. *Appendix LB: Literature background*

7.1. New evolutionary paradigm

In seeking a theory that can predict the evolution of the universe and intelligent life, I am going against the "new evolutionary paradigm", which says that evolution is inherently unpredictable. This paradigm was largely created by evolutionary biologist Stephen Jay Gould, who proposed the theory of "punctuated equilibria" together with Niles Eldredge. This states that evolution is a stop-start process that stops in periods of equilibrium, punctuated by short periods of evolutionary change[38]. In "Wonderful Life", Gould claimed that, if the "tape of evolution" on Earth were to be rewound and run again, that the result would be completely different, perhaps with no life developing at all[39]. The argument is that evolution is extremely sensitive to initial conditions, as illustrated by the Butterfly Effect from Chaos Theory. The paradigm of evolution unpredictable in speed or direction has influenced the theories of cultural evolution too.

However, the new paradigm has not been without its critics, and is being challenged by more recent research finding that mutation rates stay remarkably constant in spite of adverse conditions[reference], and that, although adaptation may start off in any direction, it can be quickly brought back to the same endpoint by natural selection[reference]. It would be premature to reject the 50 year-old "new" evolutionary paradigm yet, but perhaps it is healthy to be open to exceptions to the rule (of punctuated equilibria, for instance) and – as Gould once urged – to reconsider old facts in the light of new ideas.

8. *Appendix FCCE: Dating and extrapolating the events*

Association with Adaptation events

Gärdenfors and Högberg associate "Demonstration" with Oldowan tool technology and "Communicating concepts" with Late Acheulean tool technology. Otherwise they do not suggest a complete list to associate every teaching method with any particular events. Fortunately, it is not difficult to construct such a list:

- **Intentional Evaluative Feedback**. This can be used for any novel (non-instinctive) behaviour. This teaching could simply take the form of a signal of disapproval, a simple "grunt".
- **Tool Transfer**. Tool Transfer has been observed in chimpanzees teaching their young to use tools that are found lying around (rather than tools that have been made – toolmaking came much later when tool use had been well established), and so must be associated with the first use of tools.
- **Referential gestures** (aka drawing attention). This involves making eye contact and presenting an object, to ensure that the receiver of information is focused on the object. This method is found among animals associated with making tools, which apart from humans consists of various crow-related species. (COMPLETE THIS). It is useful to inform others when one is about to show something important, such as how to make a tool.
- **Demonstration**. Used to teach how to use tools to make tools. Demonstration is needed for more complex procedures, and involves making the tool so that the teacher can see that the student has understood, by doing things more slowly and repeating things that are not understood the first time.
- **Communicating concepts**. Used to teach how to make tools based on concepts, including composite tools (which require the concept of "whole" and "part" to understand). This level may have required simple language.
- **Explanation of relationships between concepts**. Examining the literature about the three preceding methods of toolmaking, it is clear that all three methods produced improved versions of the tools that were originally found lying around, but none of the methods produced tools with new functions, or what we may call "new inventions". Such new inventions, such as the

744   harpoon (with barbs for securing the fish), or a tool that was used for making clothes
745   (unfortunately, the clothes have not survived), would have required more explanation by the
746   inventor, namely "relationships between concepts".
747   ==REFERENCES TO PAPERS DESCRIBING THE ASSOCIATION==
748 **Narration**. The last level in the development of language, which enables organization of new
749 livelihoods and the ability to think about solutions to problems and to communicate the solutions.

750 *Dating the Teaching Methods*

751   ▪   The list of teaching methods was created by observing modern apes and humans. But
752   teaching has left no direct archaeological record and so the teaching methods cannot be dated
753   directly. As mentioned above, the use of new tool technology and the teaching of it to new
754   generations must have arisen simultaneously, as they both need each other. This means that
755   the teaching methods can be dated indirectly by association.
756 No archaeological findings to date the first event have been found, but 6 of the 7 events can be dated,
757 which also means that 6 teaching methods can be dated by association.
758 The dates of all of the Cumulative Culture events are shown in table GT1. The dates used are those
759 of the first known occurrence of the event or phenomenon, together with the error range estimated
760 for that measurement, or the known error range for the method used to determine the date.
761 I calculate that the intervals between successive Teaching Methods shrink by a ratio which (according
762 to the best measurements we have today) is between 4.26 and 5.23, with an average of 4.76. This is
763 consistent with period-doubling systems (also known as Feigenbaum Cascades), which have
764 intervals that shrink at a ratio of 4.6692…, the Feigenbaum Constant δ.
765 I extrapolate the dates of the Teaching Methods to generate more dates before and after the sequence
766 of Teaching Methods, and these dates seem to correspond events similar to the teaching events,
767 namely:
768   o   The events come in pairs.
769   o   One event is a new method of adaptation (such as mutation, gene
770   recombination, novel behaviour, tool use, etc).
771   o   The other event is a way of transmitting the information from the adaptation
772   event.
773   o   Both events occur simultaneously (for all intents and purposes) because one
774   doesn't work without the other.
775   o   Each event appears to be a new variation of a Darwinian process of
776   evolution.
777 The result of the extrapolation was:
778   o   The earliest 2 event dates did not match the date of any historical events, but
779   are assumed to be
780   ▪   the Big Bang (error 52%) and
781   ▪   Single-celled life (error 33%).
782   This is not a problem because it is commonly the case in Feigenbaum
783   Cascades that the ratio *converges* to 4.6692, and not equal to the Feigenbaum
784   Constant δ from the beginning.
785   o   The date of the first Intentional Evaluative Feedback is not known so could
786   not be verified.
787   o   The date match for the last event was 1924, which matched the first radio
788   broadcast. It was assumed wrong as it did not match the type of event pair
789   expected. It was assumed the computer (which matches the criteria above)
790   was the correct match at 1948, an error of 2.5% since the last event.
791 ● Figure cas5 shows all the events in one sequence, showing how the intervals between events
792   decrease.
793 Table tev1 shows all the events, with known intervals, and intervals calculated using the Feigenbaum
794 Constant δ, 4.6692…

795

796

Level of Intentional Teaching	Technology level	Date of technology level (years before 2000)
Intentional Evaluative Feedback	Cumulative Culture	*Unknown*
Tool transfer	Tool-use	65 to 55 million years ago [8][9]
Drawing Attention, aka Referential Gestures	Tool-making	13 to 9 million years[14][15]
Demonstration and Pantomime	Oldowan technology (making tools with tools)	2.60 to 2.55 million years [18]
Communicating Concepts	Late Acheulean technology (concept-based tools)	550,000 to 450,000 years [24][25][26]
Explaining relations between concepts	New inventions	Tools for making clothes (somewhere between 120,000 and 90,000 years ago[17]). Harpoons (somewhere between 110,000 and 80,000 years ago[18][19].
Narrating	New livelihoods (domestication)	Domestication (of the dog) 26,000–23,000 years ago[30]

797

798   **Table GT1**. Levels of Intentional Teaching and corresponding technology levels.
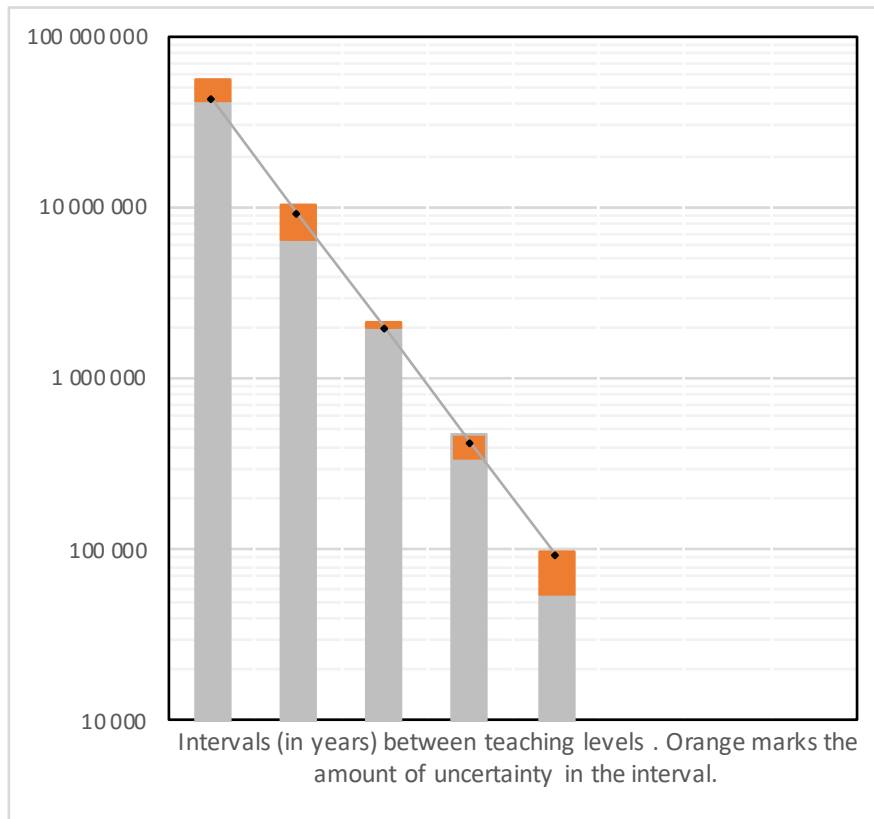
799   *The Cascade*

800   The Feigenbaum Cascade is about intervals rather than dates, so I have shown the successive
801   intervals between dates, using a logarithmic scale. The 5 intervals between the 6 known teaching
802   method dates are shown in figure gh2. (The first teaching method omitted because the date is not
803   known.)

804

805
806   **Figure gh2.** Intervals between the six consecutive teaching levels for which dates are known
807   became shorter at a uniform rate. The slope of the straight line is the rat
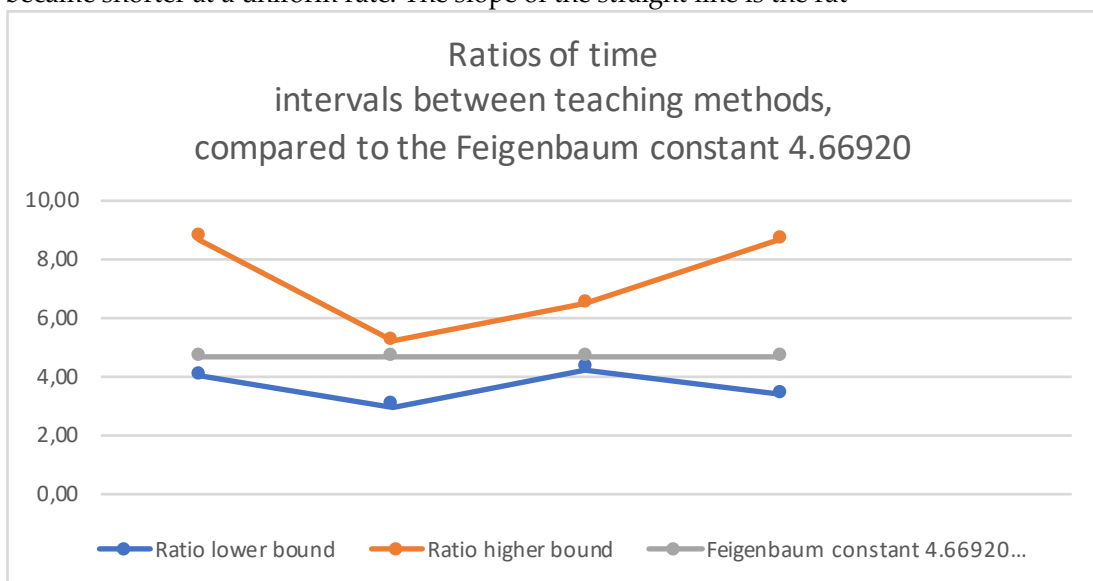
808
809   **Figure gh3.** The 4 ratios between the 5 time intervals between the 6 methods of teaching that
810   have known dates (that is, teaching methods 2 to 7).
811
812   Figure gh2 shows that the intervals between the methods get smaller. Not only that, but they
813   appear to get smaller at the same rate. In other words, they seem to form a one-dimensional fractal
814   in time.
815   Figure gh3 shows the ratio of each time interval (between teaching methods) to the next time
816   interval. The ratio between adjacent intervals varies from 3.58 to 5.82, with the average being 4.79.
817   (The uncertainty in the numbers is due to inaccuracies in dating methods and the incompleteness of
818   paleontological and archaeological records.) If there is a single ratio (the grey horizontal line) then it
819   is between 4.26 and 5.23, with an average of 4.76.

820 *The Feigenbaum Constant δ*

821   The average value 4.76 is very close to 4.66920... , the Feigenbaum constant δ. Using 4.66920 for
822 the interval ratio fits within the margins of error for the data, as shown in figure gh3.
823

824 *Event Pairs*

825   The complete list of events is shown in table GT1. About the events:
826 • What one sees in the table is that there are in fact 7 *pairs* of events.
827 • One of the events is a new way (behaviour or skill) of adapting to the environment, and the other
828   is a new way of teaching the new skill or behaviour.
829 • Both arise simultaneously, because each is useless without the other.
830 • Each new teaching event arises because the current teaching method is unable to convey the
831   information needed when teaching.
832 • It follows that each new teaching method transmits new information that was not transmitted
833   before.
834

835   As mentioned before, the ratio of the interval between events decreases by the factor 4.6692…
836 (the Feigenbaum Constant δ) every time, as shown in figure gh2.

837 *Expanding the Scope*

838   These events cover Cultural Evolution. There have been 4 phases of evolution of intelligent life
839 on Earth: 1) Physical Evolution of the universe; 2) Biological Evolution; 3) Cultural Evolution; 4)
840 Technological Evolution. Can the pattern from Intentional Teaching be extrapolated to the rest of
841 evolution? Doing so requires a redefinition of the events.
842   I used the following method to extrapolate the dates:
843

844 • Using the known dates of the events in Cultural Evolution, I used the least squares method to
845   extrapolate the sequence of Teaching methods. I did this manually using a heat map to find the
846   best result. I did no error estimates for the accuracy of the found dates An error range would be
847   informative.
848 • I extrapolated the event pairs one at a time. After deciding what the event pair was, the correct
849   dates for the event pair were added to the sequence, before extrapolating the following event
850   pair.
851 • I started with the events after Cultural Evolution, because the cascade ratio for later events would
852   be well and truly converged to the Feigenbaum Constant δ, in contrast to the events before
853   Cultural Evolution.
854

855   Three events could be predicted this way, bringing the list up to the present day. The next event
856 after that is predicted to be more than a hundred years in the future.

857 *The predicted later events*
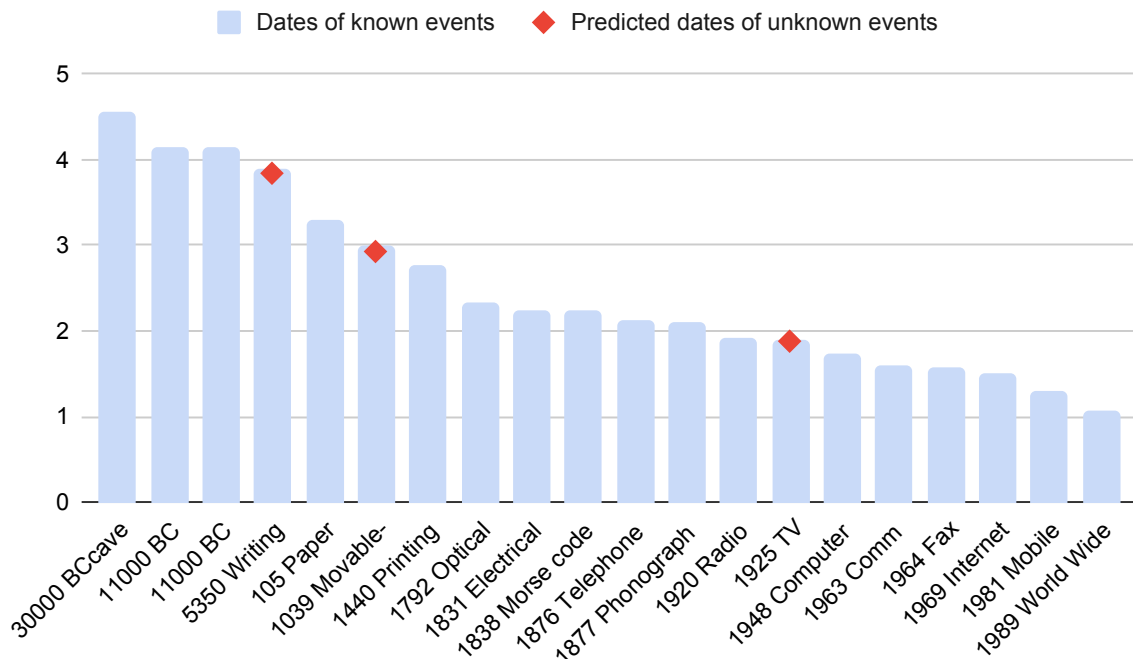
Figure pdt: The three red dots are the three dates extrapolated from the Cultural Evolution sequence of Teaching Methods, shown against a list of events in the history of communication. (The scale is 0 to 5 powers of ten (that is, 1 to 100,000) years between each event and the year 2000 (which is used as "now" in the article).

Figure pdt shows the result of the extrapolation. The events seem to coincide with the following historical events. They also seem to be event pairs, like the Teaching Methods, and also pass on information intentionally.

14. **Written Language**:
    1. **Predicted date**: 3160 years BCE
    2. **Known date**: 3500 – 3200 BCE.
    3. **Adaptation event:** Means of information storage
    4. **Transmission event:** Indirect information transmission, without meeting.
    5. **Intentional:** All writing is written with the intent of passing on information.
    6. **Mutually dependent events?** Yes. The indirect transmission needs the storage and the storage is meaningless without being read at some point.

    Following on from the last event in cultural evolution – the beginning of domestication and the completion of spoken language – the next date predicted by the Feigenbaum ratio is in the range 3100 – 1353 BC. This just matches Written Language, 3500 – 3100 BC. This is appropriate because the preceding events in cultural evolution were all about transmitting new kinds of information.

15. **Movable-type Printing.**
    1. **Predicted date**: 1044 CE.
    2. **Known date**: 1039-1045 CE.
    3. **Adaptation event:** Page composition with reusable type, with means of correction.
    4. **Transmission event:** Automated information replication.
    5. **Intentional:** All printing is written with the intent of passing on information.
    6. **Mutually dependent events?** Yes. The replication requires a composited page, and the composited page needs the replication to reach readers.

Movable-type Printing was invented by Bi Sheng[REFERENCE] in China, 450 years before it appeared in Europe.. This was a machine for replicating information. Movable-type Printing allowed long written works to become viable, because the resulting work was relatively inexpensive but with high accuracy, and it was relatively easy for the author to check the result and correct errors before the work was published. The invention of Movable-type Printing is related to teaching insofar as it is concerned with the transmission of knowledge, as is teaching. However, printed literature is predominantly used for self-teaching, and belongs to a new mode of information transmission.

16. **The Computer.**

1. **Predicted date**: 1925.
2. **Known date**: 1948.
3. **Adaptation event:** Automated Information processing.
4. **Transmission event:**. User interface.
5. **Intentional:** All transmission is done with the intent of passing on information.
6. **Mutually dependent events?** Yes. The processing requires a user interface, and the user interface requires that something useful is available.

Although the date matches the first television broadcast in 1925, it is very close to the date of first computer in 1948 (using the date of the first stored-program – and therefore Turing-complete – computer, the Manchester "Baby"), which is a more significant event in information history. An error of the order of 23 years, approximately 950 years since the previous event, which would be an error of about 2.5%, which probably within the error margin.

918

919   *Writing-based information*

920   These events together might be called writing-based information. The events are shown in
921   table 1t3.
922

Event	Adaptation Innovation	Innovation in transmission of information	Date predicted by Feigenbaum constant δ	Actual date of innovation
Written Language	Information storage	Indirect information transmission, without meeting.	3160 BCE	3500 to 3200 BCE [40][41]
Movable-type Printing	Page composition with reusable type, with means of correction.	Automated information replication	898 CE	1039-1048 CE [35]
Computers	Automated Information processing	User interface	1924 CE (error = 24 years in 900[36][35]	1948 CE [36]

923
924   **Table it3**. Writing-based information

925   *8.1. Extrapolating backwards*

926   Following the bifurcation pattern backwards, finds the following events:
927
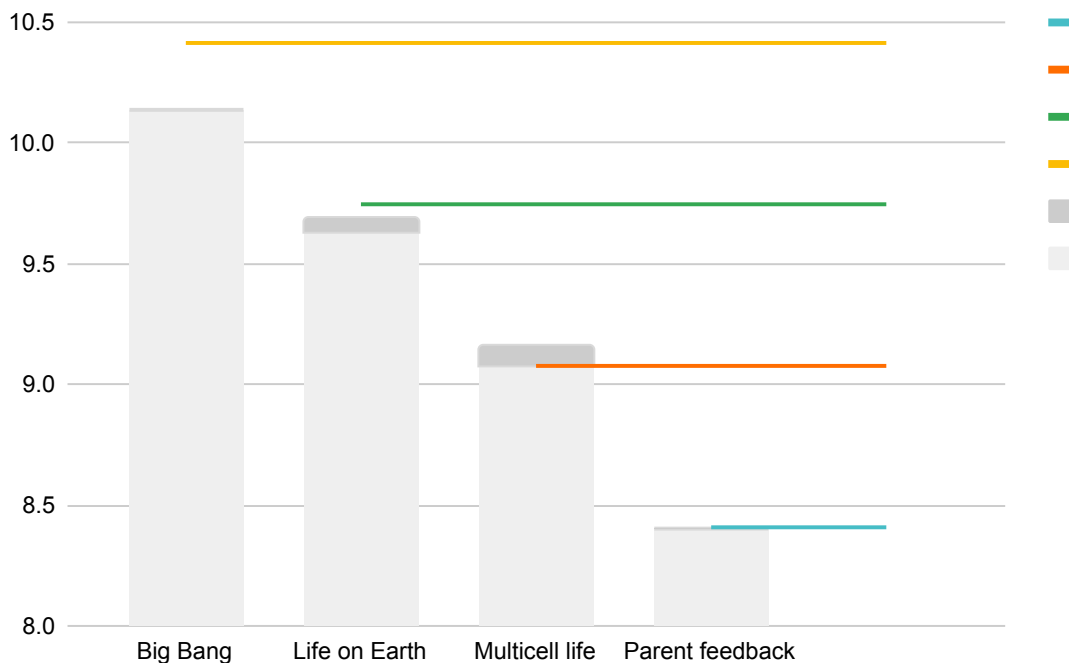
928

929   **Figure uniV**: This shows the dates extrapolated backwards from Cultural Evolution (the colored
930   lines) together with known events dates (the columns. The grey area at the top of the column is the
931   margin of error.

932

Adaptation Event	Information Transmission	Date calculated from Feigenbaum constant δ 4.66920…	Best known date from the historical record (upper and lower limit)	Deviation of known date from Feigenbaum constant δ
Big Bang	No information transmission (Big Bang)	26.6 billion years BCE	13.82 to 13.78 billion years BCE [4]	-52%
Single-celled life.	Asexual Reproduction of Single-celled Organisms.	5.70 billion years BCE	4.28 to 3.77 billion years BCE [3]	-25%
Complex Multicellularity	Sexual Reproduction	1.22 billion years BCE	1.0 to 1.2 billion years BCE [1] [2]	-1.6%
Cumulative Culture	Intentional Evaluative Feedback (Intentional Teaching)	251 million years BCE	No record	Unknown

933   Table bac1:

934   Table bac1 summarizes the events extrapolated to the time before Cultural Evolution.

935   Figure uniV shows the dates extrapolated backwards in time from Cultural Evolution. There are
936   4 dates:

937   • shortest column is the earliest Teaching Method of Cultural Evolution, "Intentional Evaluative
938   Feedback", for which we don't know the actual data, so this is a prediction and a placeholder for
939   any future evidence of the event.
940   • The next event matches the known date of Complex Multicellular Life.
941   • The next event nearly matches the date of Life on Earth.
942   • The final event corresponds to a time long before the Big Bang.

943   Given the importance of the Big Bang and Life on Earth, it is highly likely that these last two
944   events are the correct events, but the evolution of the universe has not yet converged to the
945   Feigenbaum constant δ. This initial difference followed by rapid convergence to the Feigenbaum
946   constant δ is the rule rather than the exception for period-doubling cascades.
947   Again, these events are different from teaching, although Information Transmission is still
948   central to these processes. The Big Bang is the beginning of the whole process, the starting point of
949   the physical evolution of the universe, culminating in stars, planets, and complex molecules which
950   are gradually evolved into life on Earth (and perhaps in space).

951   *The whole cascade*

952   The whole Feigenbaum cascade is that shown in the Introduction in figure cas5. Table tev1
953   shows the details of all the events.
954   The events are described in Table elm4 in the main article. Further details of the events, are in
955   table el33 here.
956

> 1. **Big Bang**
>   1. **Date predicted using Feigenbaum Constant δ**: 26.6 billion years BCE (-52% error)
>   2. **Known date**: 13.77 to 13.82 years BCE [4]
>   3. **Adaptation event:** No transmission
>   4. **Information Transmission event:** No transmission
>   5. **Actively pushed transmission:** No transmission
>   6. **Mutually dependent events?** Yes
>   7. **Selection:** Extrapolation: assumed to be part of the sequence in spite of the date discrepancy.

Details: The Big Bang is the reference point where physical evolution of the universe begins, and where eventually Biological evolution will also begin building up to the time when the first cellular life reaches a Population Growth Rate greater than 1.0.

Starting from a state of low complexity, the state of the universe increased in complexity through various processes until organic molecules developed and, after about 10 billion years, self-replicating life.

2. **Single-celled life**
   1. **Date predicted using Feigenbaum Constant δ**: 5.7 billion years BCE (-25% error)
   2. **Known date**: 4.28 to 3.77 billion years BCE [3]
   3. **Adaptation event:** Random mutation
   4. **Information Transmission event:** DNA mutations passed on
   5. **Actively pushed transmission:** Yes. DNA is actively copied and passed on to both cells on cell division
   6. **Mutually dependent events?** Yes
   7. **Selection:** Extrapolation: assumed to be part of the sequence in spite of the date discrepancy.

Details:

3. **Complex multicellular organisms**:
   1. **Date predicted using Feigenbaum Constant δ**: 1.22 billion years BCE (-1.6% error)
   2. **Known date**: 1.0 to 1.2 billion years BCE [1] [2]
   3. **Information Adaptation event:** More complex physical form
   4. **Transmission event:** Random Gene Shuffling/Recombination
   5. **Actively pushed transmission:** Yes
   6. **Mutually dependent events?** Yes.
   7. **Selection:** Extrapolation from original data set, using date.

Details:

4. **Cumulative Culture**:
   1. **Date predicted using Feigenbaum Constant δ**: 251 million years BCE
   2. **Known date**: *Unknown*
   3. **Adaptation event:** Novel behaviour (as opposed to instinctive behaviour).
   4. **Information Transmission event:** Intentional Evaluative Feedback
   5. **Actively pushed transmission:** Yes
   6. **Mutually dependent events?** Yes.
   7. **Selection:** In the original data set (Teaching Methods during Cumulative Culture).

Details: We have no evidence of when Intentional Evaluative Feedback began, but Cynodonts appeared about 260 million years BCE. They were immediate precursors of mammals and lived in borrows underground, which means that they were social animals. There is evidence of parental care for their offspring, which suggests that it is not impossible that they could have practiced teaching too.

5. Tool Use:
   1. **Date predicted using Feigenbaum Constant δ**: 54.4 million years BCE
   2. **Known date**: 65 to 55 million years BCE [8][9]
   3. **Adaptation event:** Extending the physical body with found tools
   4. **Information Transmission event:** Tool Transfer
   5. **Actively pushed transmission:** Yes

      6. **Mutually dependent events?** Yes.
      7. **Selection:** In the original data set (Teaching Methods during Cumulative Culture).

Details: Cumulative culture can be due to learning or teaching. It seems that social learning has been around at earlier stages of evolution and that the innovation in this stage is Intentional Teaching. According to Gärdenfors and Högberg, teaching can be a simple "grunt of disapproval".

(Social learning, whereby young animals learn imitating others seems date back to the beginning of sexual reproduction or even earlier. Social learning is very widespread, as most species interact with their young at the beginning of their lives [6] and it covers a whole spectrum of situations, including learning prior to birth. For example, the fact that new-born rats respond positively to foods that the mother ate during pregnancy is counted as social learning [7].)

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6. Toolmaking:
      1. **Date predicted using Feigenbaum Constant δ**: 11.7 million years BCE
      2. **Known date**: 13 to 9 million years BCE [14][15]
      3. **Adaptation event:** Improving tools
      4. **Information Transmission event:** Signaling information transmission saves time.
      5. **Actively pushed transmission:** Yes
      6. **Mutually dependent events?** Yes.
      7. **Selection:** In the original data set (Teaching Methods during Cumulative Culture).

Details:

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7. Tools made with Tools:
      1. **Date predicted using Feigenbaum Constant δ**: 2.59 million years BCE
      2. **Known date**: 2.60 to 2.55 million years [18]
      3. **Adaptation event:** Coordinated hand movements.
      4. **Information Transmission event:** Demonstration, that is slowing down movements, and other ways of making learning easier for the learner.
      5. **Actively pushed transmission**: Yes.
      6. **Mutually dependent events?** Yes.
      7. **Selection:** In the original data set (Teaching Methods during Cumulative Culture).

Details:

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8. Composite and other concept-based Tools:
      1. **Date predicted using Feigenbaum Constant δ**: 534,000 years BCE
      2. **Known date**: 550,000 to 450,000 years [24][25][26]
      3. **Adaptation event:** Composite tools, making better use of materials
      4. **Information Transmission event:** Communicating concepts
      5. **Actively pushed transmission:** Yes.
      6. **Mutually dependent events?** Yes.
      7. **Selection:** In the original data set (Teaching Methods during Cumulative Culture).

Details: From this point onwards, early humans had the ability to conceive of a human-made object made of more than one component and were able to construct one.

Note that this is not a new tool, because spears had already been in use for a very long time, but making a tool by making separate parts and joining them together is a new and important concept for making things.

9. New Inventions:
    1. **Date predicted using Feigenbaum Constant δ**: 114,000 years BCE
    2. **Known date**: Tools for making clothes, 120,000 to 90,000 years BCE[17]).
    3. **Adaptation event:** Imagining tools with new functions and making them.
    4. **Information Transmission event:** Explaining relationships between concepts.
    5. **Actively pushed transmission:** Yes.
    6. **Mutually dependent events?** Yes.
    7. **Selection:** In the original data set (Teaching Methods during Cumulative Culture).

Details: The previous pinnacle of human technology - the stone-tipped wooden spear - was a just superior version of a sharp stick that was first found and used perhaps tens of millions of years before.

This new ability for invention did not seem to require much advance in manual techniques so much as a new creativity or problem-solving ability.

Another new invention was the harpoon (110,000 to 80,000 years ago[28] [29]

10. New Livelihoods:
    1. **Date predicted using Feigenbaum Constant δ**: 24,300 years BCE
    2. **Known date**: 26,000–23,000 years ago[30]
    3. **Adaptation event:** Finding new ecological niches.
    4. **Information Transmission event:** Narration – talking about the self, the final step in language and to organization.
    5. **Actively pushed transmission:** Yes.
    6. **Mutually dependent events?** Yes.
    7. **Selection:** In the original data set (Teaching Methods during Cumulative Culture).

Details:

11. **Written Language**:
    1. **Date predicted using Feigenbaum Constant δ**: 3160 years BCE
    2. **Known date**: 3500 – 3200 BCE.
    3. **Adaptation event:** Means of information storage.
    4. **Information Transmission event:** Indirect information transmission, without meeting.
    5. **Actively pushed transmission:** All writing is written with the intent of passing on information.
    6. **Mutually dependent events?** Yes. The indirect transmission needs the storage and the storage is meaningless without being read at some point.
    7. **Selection:** Extrapolation and date match: Following on from the last event in cultural evolution – the beginning of domestication and the completion of spoken language – the next date predicted by the Feigenbaum ratio is in the range 3100 – 1353 BC. This just matches Written Language, 3500 – 3100 BC. This is appropriate because the preceding events in cultural evolution were all about transmitting new kinds of information.

Details: It also enabled the recording of religious knowledge, literature, and medical texts. Without the aid of writing, humans would have had to evolve much increased memory abilities which, even if possible, would take a long time to evolve.

The invention and use of new kinds of documents became the main source of variation and entirely new source of human society, taking over the role of the main driver of evolution of intelligent life on Earth. Various types of handwritten documents quickly became established, such as contracts, accounts, and descriptions of laws. Such documents enabled the organisation of groups of people on a larger scale and led to what we know of as cities and civilisation and an even greater degree of labour specialisation.

Writing is a form of information technology. The gestural and vocal parts of spoken language are translated into visual symbols on clay tablets or paper-like sheets of papyrus. Where spoken language is ephemeral, written language is persistent. Information in written form does not have to be remembered in detail. It can be referred to when necessary. It effectively forms a storage medium that extends the storage capacity of the mind.

Writing consists of a common, mutually understood core, but often extended with specialist languages for such things as mathematics, as well as with other media, such as pictures. But writing is essential, unlike pictures. Pictures without writing have ambiguous meaning unless we know the context.

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12. **Movable-type Printing.**
   1. **Date predicted using Feigenbaum Constant δ**: 1044 CE.
   2. **Known date**: 1039-1048 CE[35].
   3. **Adaptation event:** Page composition with reusable type, with means of correction.
   4. **Information Transmission event:** Automated information replication.
   5. **Actively pushed transmission:** All printing is written with the intent of passing on information.
   6. **Mutually dependent events?** Yes. The replication requires a composited page, and the composited page needs the replication to reach readers.
   7. **Selection:** Extrapolation and date match

Details: Movable-type Printing was invented by Bi Sheng [REFERENCE] in China, 450 years before it appeared in Europe.. This was a machine for replicating information. Movable-type Printing allowed long written works to become viable, because the resulting work was relatively inexpensive but with high accuracy, and it was relatively easy for the author to check the result and correct errors before the work was published. The invention of Movable-type Printing is related to teaching insofar as it is concerned with the transmission of knowledge, as is teaching. However, printed literature is predominantly used for self-teaching, and belongs to a new mode of information transmission.

An important entirely new source of the transfer of information that happened after the invention of written language, was the invention of a machine to replicate information. To be more precise, the invention of movable type printing in 1039-1048 CE. This was perhaps the first machine to handle symbols. Movable-type printing had small printing blocks for each character which could be assembled together in a frame and used to print text onto paper. The movable type made the process of composing a page of text very quick compared with the previous technique of carving wood blocks for printing. Movable type printing was invented in China and later spread to Europe. The 400-year delay before it spread to Europe could be thought to have slowed European development. When movable type printing arrived in Europe, it was an instant success and may have made up for lost time by incorporating new technological developments that had taken place in the meantime. Printing was banned by the authorities in China after a while, but thrived when it arrived in the small states that are now Germany where the church was not powerful enough to ban it.

13. The Computer.

1. **Date predicted using Feigenbaum Constant δ**: 1924. CE (24 year error since last even 990 years ago. Error = 2.5%)
2. **Known date**: 1948 CE [36]
3. **Adaptation event:** Automated Information processing.
4. **Information Transmission event:**. User interface.
5. **Actively pushed transmission:** All transmission is done with the intent of passing on information.
6. **Mutually dependent events?** Yes. The processing requires a user interface, and the user interface requires that something useful is available.
7. **Selection:** Extrapolation: Although the date matches the first television broadcast in 1925, it is very close to the date of first computer in 1948, which is a more significant event in information history. An error of the order of 23 years, approximately 950 years since the previous event, which would be an error of about 2.5%, which is probably within the error margin.

Details: Information technology began with the creation of the first working computer. There are many candidates for this, but the Manchester Baby, 1948[37], was the first stored-program (and therefore the first Turing-complete) computer, programmed with software rather than by plugging wires into sockets.

Computers can also be used to extend the human mind by running simulations of scientific models of various phenomena. Such computer simulations are recognized as a new way to run scientific experiments. Networks of computers, such as the Internet, allow information to be exchanged virtually instantly between any locations. All knowledge is currently being transferred from books to the Internet.

957   **Table el33.** All the events in detail.

958