The Problem with the Concept of Complexity

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Abstract: The concept of complexity is one of the most fundamental of big history fundamentals. The concept of complexity has great potential for understanding the shared qualities of otherwise disparate systems, explaining large-scale change, and comparing different types of complex systems, including human societies. Given this potential, it seems extraordinary that the concept has not penetrated the academic zeitgeist more thoroughly. I argue that four key roadblocks are holding the concept of complexity, and by extension, big history, from broader acceptance in the academy: first, the term "complexity" in its technical usage is not intuitive to people outside the fields of big history and complexity science; second, there is a lack of consensus even among big history scholars on the definition of complexity; third, measuring large-scale change over thousands, millions, or billions of years may lead to imprecision and oversimplification; and fourth, complexity, while an objective indicator of change, is closely tied to contested, subjective, culturally-specific notions of human progress. This paper argues that the concept of complexity, despite these roadblocks, has significant utility in fields that consider large-scale change. Ultimately, this paper aims to provide more clarity and precision around the concept of complexity to strengthen one of the key foundations of big history.

1. Big History's Biggest Problem?

Big history has a problem with the concept of complexity. Working at Macquarie University, I am fortunate to be surrounded by a department of colleagues who, whether sympathetic to the aspirations of the big history project or not, are familiar with the field. This article emerged from a discussion with a colleague, an eminent historian who shall remain anonymous, about the 30-year legacy of big history within broader academia. Big history is a deeply interdisciplinary field with significant potential to impact both secondary and tertiary curricula in a period where interdisciplinary research has been promoted by universities worldwide. Nevertheless, big history has remained on the fringe of university research. My colleague argued that the core of the problem was that the concept of complexity simply "had not gained traction". Yet, complexity has emerged as a central concept in the big history story, arguably THE core concept. The reason for complexity's centrality is that most big history narratives involve telling how complexity has increased from "Big Bang to modern human society". Even when the Big Bang-to-humans narrative is not the focus, complexity provides one of the most useful tools for comparing the nature and size of complex systems that might otherwise seem to have little in common. Given the importance of the concept of complexity, any failure for it to gain wider acknowledgement and understanding will likely keep big history at the margins of academic research. This article investigates this complexity problem and aims to provide some resolutions to key issues surrounding the concept of complexity.

The concept of complexity has been well-debated among big historians and complexity scientists. The goal of this article is not to provide a single unifying definition of complexity – the Santa Fe Institute and the field of complexity science have been attempting that for decades without much success – rather I aim to clarify some of the possible meanings of the concept of complexity in big history.[1] Almost any system can experience measurable changes in complexity but not all systems are the focus of big history. Instead, big history primarily focuses on those systems which are relevant stepping stones from the Big Bang to human societies. What big history really means by complexity, then, is *useful* or *meaningful* complexity, that is increases in complexity that have meaningfully contributed to the emergence of a complex society of advanced sentient beings. While this story appears anthropocentric, there is no reason why this practical discussion of the emergence of humans cannot be applied to SETI (the Search for Extra-Terrestrial Intelligence) or to discussing potential futures for even more complex societies.[2]

So, is it a futile task then to attempt to define and develop a large-scale metric like complexity in a sufficiently precise way that meaningful conclusions can be drawn? The task is not a futile one but, given the large scale on which big history works, it is important to clarify that the level of precision which can be achieved is limited by the amount of information the authors or even a computer can gather and process. For highly complex systems like human societies, the level of precision is going to be much lower than for simple systems like molecules. For example, it is difficult to judge whether the Roman Empire was more or less complex than Ming Dynasty China or to measure small changes in complexity in a stable agrarian society over the course of a week or decade. What complexity is good for is tracking large-scale change and for comparing systems that are otherwise very different, such as a star to an ant colony, or a foraging society to an industrial one. Having a mechanism for large-scale comparison is important *because* complex systems are unpredictable; they have so many moving parts that even a small change, such as that wrought by a particularly charismatic individual or the presence of a certain type of edible plant, can disproportionately impact a society's history.[3] In practice, then, an outcome may be true or likely for complex system but so for another similar complex system; if however, a trend occurs in every or many systems of different levels of complexity, then that trend is much more likely to occur regardless of the system's complexity. Consequently, It is both reasonable and useful to track complexity on the scale of big history as it provides both a more coherent understanding of the past and a more solid foundation from which projections about future changes in complexity can be made. This is why big history's particular framing of complexity is so important. By building a framework for identifying and mapping changes in useful complexity, big historians have a unique tool for sifting through the universe and finding the systems which are most relevant to the human story. The concept of complexity provides a mechanism for binding the otherwise utterly different systems of atoms, stars, bacteria, and human societies together into a coherent narrative. Ultimately, I will argue, the concept of complexity uniquely allows big historians to not only objectively map something very close to progress but also to make normative judgements about whether complexity and progress should continue to be pursued in human societies.

Then why has such a useful tool failed to gain broad acknowledgement and understanding in the academy? I argue that big history's problem with the concept of complexity is four distinct, but interlinked problems which I outline in turn. Many of these issues are fundamental to the field and are unlikely to ever be resolved completely although there is certainly room for more clarity and precision; indeed, they should remain open questions subject to robust academic debate. Rather than seek to solve the complexity problem, I seek to provide a framework for confronting the core issues of complexity in a way that allows academic discussions within the field to move past the roadblock current definitions of complexity often create, while also allowing for communication of the concept of complexity beyond the field of big history. Ultimately, I argue that big historians need to use the concept of complexity in consistent, well-defined ways and discuss complexity with sensitivity to the potential unfamiliarity of readers outside of big history. A blessing or a curse, it may be necessary for big history authors to briefly define and justify their use of the concept of complexity in each text to ensure clarity and broader understanding.

The first of the four problems with the idea of complexity is that, in its technical usage, complexity is a term unfamiliar to many scholars in the humanities and many of the sciences. Its ordinary and natural meaning is substantially different from its technical meaning. This problem can be best confronted by both clear definitions and consistent usage of the word "complexity" within each work of big history. This should be accompanied by an assumption that the reader may not be fully aware of the important differences between common-sense uses of the term and more technical uses. Second, even within the field of big history, there is a lack of consensus about what complexity means and how it should be measured. Robust debate about the nature and features of complexity is a central part of the big history research agenda, and this debate should continue. However, most authors agree that energy flows, interconnectivity, and emergence are key aspects of "useful" increases in complexity.[4] The debate is typically about the degree to which each of these three metrics is relevant. Rather than attempting to resolve the debate, authors should acknowledge the common ground and situate their work within it. Third, the large scales of big history can lead to imprecision and oversimplification of complicated problems. This is less a problem and more a methodological question that needs to be addressed in each work of big history. It is important to acknowledge both the benefits and the limitations of the large-scale approach and to emphasise that, by taking a wide lens, the interdisciplinary view may provide further clarity into how each field of knowledge fits into the broader story of the universe. Finally, complexity is closely tied to subjective, culture-bound, and often deeply problematic notions of human progress. I argue that there are some commonalities between the many different conceptions of progress and that complexity is, or is very close to, an objective representation of these common elements. It is, therefore, important for all big historians to note that increased complexity does not necessarily lead to outcomes that will universally be regarded as positive. In the past 30 years, big history has done an excellent job of describing changing complexity but has untapped potential in normative discussions about whether complexity *should* continue to increase. I argue that a shift towards this more analytical framework allows big history to engage in deeper normative conversations with other fields.

2. The Definition Problem

The first core aspect of the complexity problem is that "complexity" is often used informally as an adjective to describe a difficult problem or situation. More precisely, the technical definition of complexity in big history and complexity science does not intuitively follow from the more vernacular usage of the word. In general parlance, complexity means "the state of being intricate or complicated".[5] There are four points of difference between the technical and vernacular definitions that are non-intuitive and therefore may create confusion. First, in technical parlance, "complex" and "complicated" are not the same thing; both complex and complicated systems have many interconnected parts, but complex systems have *emergence*.[6] Emergence occurs when a system develops a property because of its specific arrangement of parts. For example, there are multiple ways to arrange hydrogen and oxygen molecules but only in the L-shaped form of H_20 do the extraordinary bonding properties of water emerge. So, any academic definition must include the concept of emergence – although, as I argue in part 3 of this paper, emergence alone is not sufficient to define the concept of complexity.

The second point of confusion relates to the types of systems that can have complexity; a system can have complexity even if it is very simple, while a very complex system can be made up of parts that are complex systems in themselves. It does not intuitively follow that a water molecule, which is stable and comprised of a few atoms with no concept of agency, can be meaningfully compared to a human society, which is made up of conscience, complex beings each with their own agency. The former is a Complex Physical System (CPS) which derives its structure from the physical arrangement of its parts, while the latter is a Complex Adaptive System that consists of physical arrangements that can actively respond to external conditions.[7] A CPS is passive and cannot actively respond to external changes while a CAS is active and can respond – in practice living systems and non-living systems like economies which derive from human systems are CASs and all other non-living systems are CPSs.[8] Importantly a CAS must be comprised of CPSs like atoms and molecules and can be comprised of other CASs such as individual humans forming part of a human society. The unifying thread between these apparently disparate systems is that they all have complexity, albeit to different degrees.[9] Part of the value of the concept of complexity, then, is that it reveals the commonality and connections between these otherwise disparate systems in the Universe.

The third aspect of confusion is that, in CASs, parts are so intricately connected that the properties of the whole can no longer be predicted by linear equations.[10] It is reasonable for someone who has never engaged with the academic usage of complexity to ask: "why does having more moving parts make a system more unpredictable? Yes, more moving parts means inputting more initial conditions into the calculation but why is there a point where the number of initial conditions hits a critical mass whereby the calculations no longer work?" The short answer is that large numbers of initial conditions mean large numbers of possible interactions between each initial condition; two systems that are initially the same except for one small difference in a single initial condition could quickly become significantly different.[11] In this way, CASs behave like chaotic systems. For example, try to imagine the consequence of the horse – an animal key to efficient agriculture, transport, and warfare – becoming extinct in Eurasia instead of the Americas. How would human history look in the 21st century? One could make projections about faster growth in agrarian societies in the Americas, increased power of a China not harassed by horse-riding nomads from the Steppe, and significantly reduced range of movement in Eurasia limiting the exchange of goods and ideas. One could also suggest that changing the history of the horse would have had minimal impact due to other factors like geography, culture, or suitable alternatives. The most correct answer is also likely the intuitive one: that making predictions about alternate realities for modern human societies is a fraught task that requires a considerable amount of guesswork. Yet, it is possible to calculate what will happen to most chemical reactions if the initial condition of a catalyst is not present: the reaction occurs much more slowly or not at all.[12] The chemical system has a predictable outcome because it is a CPS with a limited number of initial conditions. The human system has an unpredictable outcome because it is a CAS and has many possible initial conditions. Both systems have complexity, but one is much simpler than the other and that shapes our understanding of the capabilities and limitations of each system.

So far, I have clarified the technical definition of complexity in three ways: first that any technical definition of complexity must include the concept of emergence in addition to many connected parts; second that both CPSs and CASs can have complexity; and third, that CASs are, by virtue of having many possible initial conditions, always contain some element of unpredictability which cannot be perfectly captured by quantitative modelling. I now move to the point of confusion which relates to big history's specific concept of complexity which is meaningful in the context of the "Big Bang to modern humans" story.

3. The Consensus Problem

The second aspect of the complexity problem is that there is no consensus, even within big history or complexity studies, around the definition of complexity. There are more than 40 different ways of measuring complexity, but big history has focused on four key areas: energy, interconnectivity, emergence, and information.[13] Most authors adhere closely to one of the four but I argue here that there is common ground to be found by accepting that all play a role in increasing complexity. I discuss the three first three components of complexity in turn then argue that they should be considered as inextricably linked parts of a single whole rather than being able to provide a single unifying theory on their own. I further argue that information does not need to be considered as a separate metric because, while may be an important feature of complexity, it can be effectively represented by the fundamental components of energy, interconnectivity, and emergence.

Within big history the debate about what complexity is and how to measure it is typically focused on four concepts: energy flows, interconnectivity, emergence, or information. Big history authors have typically focused on one of these four concepts as the core indicator of levels of complexity, although it is worth noting that the other three features are rarely ignored. Indeed, I argue here that any definition needs to include, at the very least, energy, interconnectivity, and emergence to effectively capture big history's concept of "useful" complexity. As stated above, information is extraneous because it can be captured by the above three elements. I argue that complexity increases when a complex system's free energy density (the amount of "useful" energy flowing through a gram of a system per second) increases, the number and diversity of interconnections rise, and new emergent properties arise. The size of the lens matters here. Shifts in these three metrics may not be visible in granular, small-scale changes in complexity but typically crystallise in large-scale leaps forward. This is why the concept of complexity is so useful in big history; when applying a lens that encompasses the history of the universe, complexity provides a way of identifying which changes matter. In other words, debate can exist as to the weight which should be given to each attribute, but the above three concepts in the concept of complexity, taken together, provide a good starting point for clarifying the concept of complexity in big history.

Interconnectivity:
Spier and Interconnected Building Blocks

Spier argues that the complexity of a system can be defined in terms of the number and diversity of its building blocks and the number and diversity of connections between those building blocks.[14] The great value of this definition is that it is probably the closest to common-sense notions of complexity. Spier proposes that complexity should be measured using four criteria: 1. The number of building blocks, 2. the number of different types of building blocks, 3. the number of interconnections between building blocks, and 4. the number of different types of interconnections between building blocks.[15] While he acknowledges that emergent properties and increased free energy density may arise as a result of the increased interconnections, Spier argues that these outcomes are correlative indicators rather than direct measures of complexity.[16]

There are two central challenges with Spier's approach. The first is acknowledged by Spier himself as being the difficulty with which the number and the diversity of building blocks in interconnections can be measured, particularly as the complexity of the system increases.[17] In a water molecule, each of Spier's criteria can be easily determined. There are three building blocks, two different types of building blocks, hydrogen, and oxygen atoms, and two interconnections, each linking a hydrogen and oxygen atom. In a more complex system like a human society, with its enormous number and diversity of building blocks and interrelationships, it is difficult to envisage how each of Spier's criteria could practically be measured. This is compounded by the unresolved question of how much weight should be given to each of Spier's four criteria. A problem may be, for example, that a system with many building blocks, like a star is less complex than a single-celled living organism, which has greatly fewer building blocks but a greater diversity of building blocks and a greater diversity of relationships within itself, and with its surroundings.

The second problem is increasing the number, diversity, and interconnectivity of building blocks alone does not always lead to increased "useful" complexity. For example, if one broke a human body down into its constituent parts, tossed them around in a giant mixer, and then attempted to reassemble that same number and variation of parts together ensuring the same number and diversity of interconnections, it is more likely than not that the reassembled set of parts would be a jumbled mess with little prospect of movement or conscious thought. In both circumstances, complexity may have increased by Spier's but only one version is useful: where those building blocks are arranged in a precise way to produce the emergent property of flight and lead to meaningfully increased complexity. The success with which the building blocks were arranged in a precise way to create greater meaningful complexity can be estimated by examining whether the arrangement has led to the production of greater free energy density and emergent features, both considered below.

Energy: Chaisson's Free Energy Rate Density (FERD)

Chaisson's Free Energy Rate Density (FERD) approach is much less intuitive but likely provides the best approximation of complexity using just a single metric. In practice, the same as power density in physics except using different units of measurement, FERD measures the amount of free energy that passes through a gram of a system each second (erg/s/g).[18] Complex systems are organised clumps of matter in an otherwise nearly empty universe. The second law of thermodynamics state that entropy will always increase. Entropy is the universe "trying" to spread all matter and energy evenly, dismantling any clumps or imperfections. The denser the clump, the more entropy will "try" to pull it apart. What this means in practice is that more complex systems tend to need to expend more energy to combat entropy as well as maintain its essential functions.[19]

If more energy becomes available, either due to increased natural supply or an evolution within the system to allow more efficient harvesting of energy, each of Spier's four features may increase.[20] Conversely, if a system is faced with a sustained decrease in energy availability, the intricacy of the system must also decrease unless the system evolves to use energy more efficiently.[21] In short, because entropy makes all forms of complexity precarious – complexity may, at best, allow a system to "evade locally and temporarily the usual entropy process." The availability of energy flows is a key factor that impacts a system's capacity to generate and sustain complexity.[22] "Energy flow regulation" – the more efficient use of existing energy flows – is also likely "a necessary part" of complexity maintenance and growth. However, figure 1 seems to indicate that systems that have made significant leaps in energy flow regulation still increase their FERD over time.[23] The great benefit of FERD is that energy can be much more easily quantified than the other metrics discussed in this part.[24] As such, FERD may provide a solution to the central challenge facing Spier's method, finding the exact ratio (if a single constant exists) by which the four features must increase for greater complexity to form.

However, measuring FERD precisely and consistently across all systems in the universe remains a challenging prospect and it is on this point that Spier is most critical of Chaisson's approach to quantitively measuring complexity.[25] The first challenge to measuring FERD relates to which part of the system the measurement should be taken from. Non-equilibrium systems, that is systems that have positive entropy, are rarely in a steady state where energy is flowing consistently and equally throughout all parts of the system. Instead, systems are in a constant state of flux, with energy flowing unevenly to different parts of the system as it is needed. This unequal spread of energy flows becomes more pronounced as the complexity of a system increases because different building blocks may require energy to perform their relevant functions only when those functions are required. For example, a cheetah's legs only require significant energy when the cheetah is moving; when the cheetah is at rest, the energy flows directed to the leg diminish. This means that a sample taken from a small part of a system may not provide an accurate indication of either FERD or complexity. The second challenge considers the point in time that the

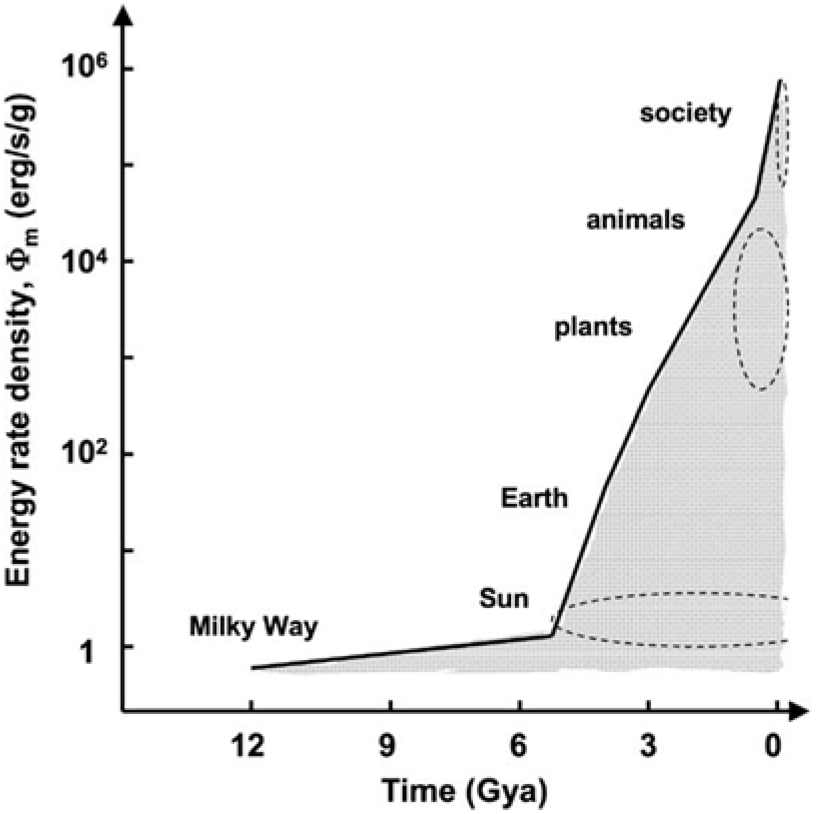

Figure 1: Chaisson's semi-logarithmic representation of FERD in select systems in big history.[26]

measurement is taken. As well as energy flows being in constant flux across different constituent parts, so too do non-equilibrium systems' energy flows trough and spike at different points in time. Periods of volatility in energy flows can be particularly violent during periods of creation or destruction of complexity. When a protostar finally gains enough mass to begin nuclear fusion and become a star, there is a massive spike in energy that blasts the protostar's gas and dust envelope away. Similarly, when a star dies through a supernova, the explosion creates a sudden spike in energy flows many orders of magnitude greater than that same star's average FERD before the supernova, yet it makes no sense to regard that spike as evidence for an increase in "useful" complexity. Even during periods of relative stability in a system's complexity, energy flows may differ if there is a need to do so. A cheetah chasing after its prey momentarily has much greater FERD than it would at rest, while a hibernating bear has a much lower FERD than when it is active. So, both the "where" and the "when" of the FERD measurement can potentially produce wildly different results.

There are multiple potential solutions to the challenges of measuring FERD. The first is to measure the system's FERD at its highest point, which should, theoretically, indicate the highest level of complexity that system achieved. This method is flawed for two reasons. First, a system's highest FERD often occurs during the power spike that arises when complexity is created or destroyed. The burst of energy that often accompanies the creation of greater complexity typically subsides quickly and the system settles at a lower, but more stable, FERD. Even more misleading would be a measurement at the moment of destruction. A supernova, an animal fighting to the death by exhaustion to protect its young, or a megalomaniac using humankind's stock of nuclear weapons to wipe out the human species would all represent the highest FERD which that star, animal, or society had ever achieved, but it would not provide a useful representation of that system's complexity. Consequently, this paper posits that FERD measurements should be taken only from stable, "controlled" uses of energy, that is from energy flows that are necessary to maintain the system's normal level of complexity.

The second method of measuring FERD is perhaps the more obvious one, and the most ideal in theory: to take an average of the energy flowing through all parts of the system over an extended period. While FERD fluctuates significantly during the creation and destruction of complexity, there is a period between the initial increase in the system's complexity and the moment when that complexity is either increased further or destroyed, where FERD remains relatively stable and energy flows are "controlled".[27] It is during this period that an average measurement for FERD should be measured. From this base measurement, it is then possible to gauge the effects of a period of increased or decreased energy flows on a system's complexity. The main practical challenge of measuring FERD based on a long-term average is the sheer amount of data required to do so with any level of accuracy, a problem that magnifies as the system becomes more intricate. It is reasonably simple to provide an accurate FERD measurement for less complex systems as both the building blocks and the interconnections between them tend to be largely uniform. For example, the FERD of stars and galaxies can be calculated by the luminosity-to-mass ratio, which indicates how much energy, in the form of light, per gram of the star is being emitted per second.[28] Similarly, the FERD of a biological system, like an animal or plant, can be measured by its metabolic rate, how quickly an organism breaks down fuel into energy that keeps the organism alive.[29] Measuring the FERD of a human society becomes much more complicated primarily because human societies tend to draw energy from an increasing diversity of sources as their complexity increases. Hunter-gatherer societies rely primarily on human food consumption to obtain the energy required to sustain their complexity, but this may be supplemented with the use of other natural energy sources like fire. Agrarian societies' FERD must not only reflect the food consumed by the human inhabitants, but also the fodder eaten by domesticated animals, and any natural energy produced by non-industrial technologies that use natural resources like water and windmills, thermal baths, kitchens, sail ships, and blacksmith's forges. Modern industrial societies have the greatest diversity of all, utilising all the energy sources of an agrarian society along with fossil fuels, nuclear, and renewable energy to create an extremely complicated network of energy usage. As a result, while it is possible to obtain data from a wide range of historical and archaeological sources to form well-informed and plausible estimates of how much energy a human society draws from each resource, it may not be possible to measure the FERD of human systems with the same precision as non-human ones.

While measuring FERD across different systems with varying levels of complexity may require diverse methodology, there remain three core principles that should be applied in each case, but particularly in systems of greater complexity, to provide optimal accuracy. First, the number of energy flow measurements should be as high as possible because, like any measurement of the interactions between matter, repeated tests tend to produce more accurate results. Second, for a general representation of a system's complexity, energy flow measurements should be taken at different points over a long period to better account for short-term spikes and troughs in energy use, although these fluctuations can be used to identify and analyse significant moments in a system's history. Third, where there are multiple different types of building blocks, energy flow measurements should be taken from as wide a variety of these building blocks as possible. So, while measuring the energy flows of a modern fighter jet in flight may produce an erroneously high representation of the FERD of a modern society, measuring many fighter jets, both in flight and at rest, along with a wide variety of other parts of that society will produce a much more accurate representation of FERD and complexity. Despite the challenges of measurement, FERD remains possibly the most effective means of quantitively measuring complexity.

Emergence

Emergence is a key part of the concept of complexity in big history because it adds further clarity to discussions around energy and interconnectivity. It is possible to have a system with the same number of interconnections and energy flows but different levels of complexity. To return to a previous example, the constituent parts of a jet plane can be connected in an infinitesimally large number of ways, but these parts must be assembled into a specific structure to generate the emergent property of being capable of flight. Each arrangement would have a similar number and diversity of interconnections and could each sustain the same amount of energy flowing through the engines. The difference between the jet plane which produces flight, and all other arrangements of the same constituent parts is not energy flows or interconnectivity, it is emergence. Emergence is a way of capturing the idea that more complex things may have novelty, and new qualities, and in this sense, tracking increasing complexity is a way of discussing the creation of the universe, and its ability to generate new types of entities. Emergence is the new features that are created because of the parts of the system being arranged in a specific way – in this case, the ability to fly in a controlled manner. It cannot be calculated by simply adding the sum of all the parts together rather, using somewhat circular logic, emergence is generated by a complex system becoming more complex. Put another way, increasing interconnections and energy density are *causes* of rising complexity while emergence is an *effect.* Emergence, then, is not a metric of increasing complexity, but rather a qualitative way of determining whether a particular event of rising complexity – the increase of energy density and interconnectivity – matters in the context of the big history story. Emergence can be used to distinguish relevant increases in complexity from amorphous explosions of energy that amount to the equivalent of evolutionary dead ends on the cosmic scale.

Emergence is an effect of rising complexity, rather than a cause, so it can only ever be used retrospectively to indicate complexity in the past. It cannot effectively be used to forecast future changes in complexity. Emergent properties cannot be predicted from the sum of parts of the system; they only exist because the system is arranged in a specific way - what Baskin (2022) terms "systemic causation".[30] To achieve this specific arrangement in highly complex systems, a significant number of exact conditions may need to be met – these exact conditions are often called "Goldilocks Conditions".[31] Until that specific arrangement has been made it is impossible to know whether emergent properties will occur and what those properties may be. Indeed, emergent properties may share some common elements but they are each unique. This is why it is crucial to include discussions of emergence when talking about rising complexity in the past: emergent properties explain the unique changes wrought by higher levels of interconnectivity and energy density at each new level of complexity. Further, while interconnections and energy density increase in line with rising complexity, emergence also occurs in clumps, appearing only when certain levels of complexity are reached. What this means in practice is that, beyond the conclusion that new emergent properties will appear with rising complexity and the right specific arrangement of constituent parts, emergence is impractical for forecasting the impacts of future rises in complexity. It also means that emergence is ineffective at tracking past changes in complexity except on a very large scale, where a new threshold, epoch, or level is crossed. It is, however, particularly useful for describing major technological transitions in human societies. At this historical moment in the transition to the Anthropocene where complexity is potentially rising faster than ever, the concept of emergence may provide much-needed clarity to the rapid changes humankind has experienced in the last 50-200 years and act as signposts for lasting changes in complexity in the present.

What about Information?

Information has been presented as a core element of complexity or even as a standalone metric of complexity. There is little doubt that information and complexity are closely connected but the exct nature of their relationship remains unclear and subject to debate. I have argued above that energy, interconnectivty, and emergence provide a quite complete estimation of a system's complexity's and I posit below that information is an unnecessary fourth component because its facets are effectively captured by the other three metrics of complexity. This is not to say that the relationship between information and complexity is unimportant but rather that one should not be considered as a metric of the other.

Information theory is a huge and complicated field on its own, but Ken Solis (2022) has noted that definitions of information get muddied by there being three different kinds: syntactic, semantic, and surprise.[32] Syntactic information is how the universe is physically arranged, semantic information is relational, arising only once it has been processed by agents, and surprise information captures unknowns that are discovered as information gathering "reduces uncertainty."[33] While more clarity is needed around information, there appear to be some similarities between syntactic information and Complex Physical Systems, between semantic information and Complex Adaptive Systems, and between surprise information and the principle of emergence. In terms of syntactic information Solis has echoed Norbert Weiner's argument that "information is fundamentally a measure of order".[34] Deacon (2011) argued that emergence and information are not only connected but part of the same process.[35] Increasing complexity generates emergent properties which generate new ways of creating, storing, and using information. Despite the diversity of emergent properties across different systems, information is often a common element. Certainly, in more complex systems, many emergent properties that are relevant to complexity involve some kind of improvement in the way information is stored and transferred. This can range from the genetic information storage in DNA in biological systems or writing and the internet in human systems. Gleick argues that "information is what the world runs on: the blood and the fuel, the vital principle" and that even a system as small as an atom contains a measurable amount of information in the form of bits.[36] So there seems to be some good basis for using information as a mechanism for measuring emergence and therefore changing complexity. Yet, there is tension here. In 2013, D W McShea argued that "information should be banned from interdisciplinary discussions of complexity in the history of the Universe" – the inclusion of information as a tool for measuring complexity is by no means agreed upon.[37]

Some of the challenges facing the use of information as a metric of complexity and emergence are the lack of definitional clarity and the lack of a consensus on how to measure it. How should uncertainty reduction be measured? Information theory scholars such as Gleick (2011), Loewenstein (1999), and Wheeler (1994) have suggested that bits, the unit of information used in computers, can be applied to other systems like atoms.[38] Recent progress in quantum computing has meant that an even smaller unit of measurement, qubits, can be used to measure information on very small scales. This method of measuring is by no means agreed upon as effective even within information theory.[39] An alternative model is information as negentropy or increased order as discussed by Solis (2022). If this model is viable then energy flows and information fit together very nicely and indeed may be measurable using the same metric. What neither the bits nor negentropy methods account for, however, is the nature of emergent properties. Instead, they record only the effect which FERD arguably does anyway; a society with new emergent properties is going to be more complex which means that FERD will increase. The importance of emergence is in describing the unquantifiable effects of increased complexity, those emergent properties that cause energy, information, and interconnectivity to leap unpredictably forward in clumps. Emergence also provides a qualitative indicator of whether a system's increase in energy density and interconnectivity is meaningful in the context of the big history story.

A Unified Approach

Energy, interconnectivity, and emergence considered together rather than in isolation present the most workable picture of complexity. Any measure of complexity cannot be wholly quantitative because knowing the initial conditions of very complex systems in their totality is impossible. Qualitative indicators, particularly that of emergence, provide clarity where the quantitative indicators fail, such as where there are large explosions of energy flows. There is enough common ground between the three main metrics of complexity in big history for them to be considered together; Indeed, it may be a more difficult task – and an unhelpful one for the field – to disentangle them from each other.

4. The Scale Problem

The third aspect of the complexity problem is the imprecision created by a large-scale approach. A favourite metaphor of David Christian's is that "from the top of a mountain, you can see the forest rather than just the trees". A former colleague of mine who worked on much smaller scales pointed out that a whole army could be dead in that forest, and you would not know from the top of the mountain. This summarises a common critique of big history and its discussions of large-scale changes in complexity: the bird's eye view approach is too imprecise and leads to problematic oversimplifications. So, is big history too big? No, but it is important to acknowledge the limitations of the approach. Big history is not, should not, and cannot be a universal descriptor of everything that ever happened and will happen – and no other subfield of history is or should be held to such a standard. It can provide large-scale insights and identify trends that smaller-scale approaches cannot; from inside the forest, one cannot see the whole forest. To gain the deepest understanding of the forest, the universe, or human history, one must look at it on a large scale and a small scale. Of course, a large-scale approach will miss details, just as a very small-scale study of a single person's life, or a certain type of frog, an interaction between two specific molecules will miss the implications of each of those stories for the larger whole. The interdisciplinary nature of big history is meant to be collaborative and to draw on a range of sources from other fields. It is not, and I think this should be emphasised in every work of big history, meant to replace those individual fields.

big historians are often interpreters that can facilitate a conversation between many diverse fields. It is, however, important to emphasise that big history research is not simply an act of making these connections but also providing valuable and unique insights based on them. The future is difficult to forecast and, as the discussion about emergence above demonstrates, every new level of complexity leads to new and unique emergent properties. There is, then, a risk that the Anthropocene is so unprecedented that the lessons of the past can no longer be applied. There is a real risk, for example, that the lessons drawn from the rise and fall of a certain society, say the Roman Empire, cannot be applied to modern techno-industrial societies – they are just too different in size, technology, culture, and organisation. This risk is reduced in the large-scale comparison of the rise and fall of different agrarian societies because the diversity of structures means that the results are more likely to apply when circumstances are different. However, a study of agrarian societies is most likely to produce results applicable only to agrarian societies. What big history does is consider the common trends between all human societies, regardless of their structure, and even all complex systems. If many highly diverse systems produce similar results, then it is much more likely that those results will be applicable across all complex systems, including future human societies (Fig 2). Put another way, the study of each complex system can be treated like a laboratory experiment. If each experiment produces the same results despite having widely different variables, it is much more likely that the results will be the same *regardless* of the variables.

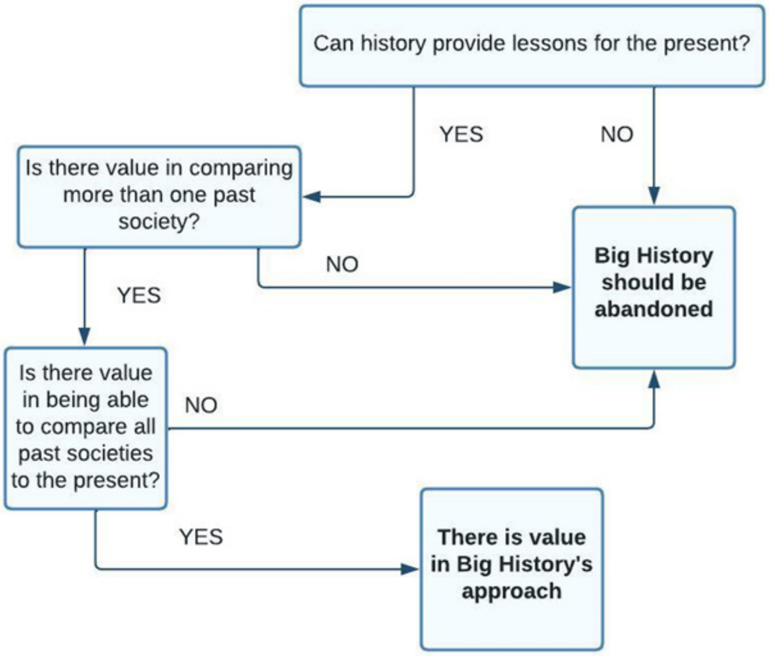

Figure 2:
The Value of Large-Scale Comparative Approaches.

5. The Progress Problem

The final aspect of the complexity problem relates to using complexity to make normative judgements, rather than just as a descriptor, to answer the question of whether increasing complexity aligns with the betterment of human societies. big historians are no strangers to discussing normative questions about the present and future of humankind and beyond. In the past five years, big historians have used complexity theory to foray into discussions about ethics,[40] SETI,[41] the singularity,[42] and the Anthropocene.[43] It is, in practice, very difficult to disentangle describing increasing complexity from value judgements, express or implied, about whether rising or higher complexity is a positive outcome for a system. It is a dangerous assumption indeed to say that because increasing complexity led to our present human society, increased complexity should be pursued in the future. I argue here that complexity is, or is very close to, an objective measure of 21st-century conceptions of human progress. Acknowledging this close relationship and engaging with it has two potential benefits for big history. First, it directly confronts the potential critique of big history from humanities scholars that the field uncritically advocates for human progress. Second, it creates a foundation from which big history can have a meaningful and nuanced conversation about whether complexity should be maintained and pursued. This question is very relevant to recent discussions by Graebar and Wengrow about whether a better future may not be a simpler future,[44] and it is in answering this question that some of big history's biggest untapped potential lies.

Enlightenment Notions of Progress

Progress, particularly when used in the context of the 'betterment' of society, is a slippery, subjective, and highly contested term. Progress has problematic roots, being used to justify imperialism, colonialism, and racial discrimination throughout the 18th, 19th, and 20th centuries. By the 19th century, the ideas of Hobbes and Rousseau had both been co-opted into justifying the necessity of human progress. Hobbesians believed that life in a "state of nature" – life without the structures of the nation-state, life in a society of low complexity – was "nasty, brutish, and short";[45] people could not be trusted to act selflessly, so needed the state, needed complex structures, to regulate their behaviour. Rousseau's view on the state of nature is of humans as idyllic, gentle dreamers but he nevertheless argues that "civilisation" becomes necessary for confronting economic hardship.[46] The Hobbesian and Rousseauian views about the state of nature, apparently diametrically opposed, have formed the basis of narratives of progress for the past 200 years, although Graeber and Wengrow (2021) have recently argued against this dichotomy, suggesting that it only applies if one assumes that increasing complexity is inevitable.[47]

The real problem with the use of the word "progress" is that ideas of betterment became linked with the concept of ‘civilisation’ and social Darwinism in European colonialism. These ideas were then employed used as a justification for colonial oppression by white ‘civilised’ Europeans against a non-white ‘savage’ or ‘barbarian’ other. [48] In the West, the racial dimension persisted at least until the Post-War period, where the aftershock of the Second World War, decolonisation, and civil rights movements forced a rethinking of the relationship between social Darwinism and progress. The result was the more amorphous, flexible modern notion of progress as a desirable societal improvement.

It is important then, for big history to be sensitive to how enlightenment conceptions of progress were used to justify colonialism, racial policy, and other atrocities. Claims, or even implications, that being more complex is better has dangerous connotations. Is the more complex society of 21st-Century USA superior to the less complex, pre-colonial indigenous societies? When the question is posed so directly, few authors would answer yes, but the danger is the implication of “more complexity = better” creeping into discussions about increased complexity.

The “Modern” Notion of Progress

So how can big history engage in discussions of progress and complexity in a sensitive and productive way? A good place to start is by considering modern conceptions of “progress”. The nebulous, elastic nature of the word progress makes it easily manipulated to serve the user’s ends. For this reason, it remains a favourite of politicians the world over. Democracy or dictatorship, monarchy or theocracy, leaders can and do employ ‘progress’ to imply they are improving the lives of their citizens and thus court public opinion. One does not have to dig deeper to find mentions of progress by politicians on all sides of the political spectrum. A brief survey of political speeches by different politicians across the world since the 1950s finds progress employed by leaders across the political spectrum – from Stalin to Obama, Mugabe to Nehru.[49] Despite all employing the word ‘progress,’ each leader has a different outcome in mind when using it, typically coloured by national interest and ideology. For example, where Stalin employs it to mean the continued spread of communism, Barack Obama uses it to mean continued economic growth and democratisation under Western liberal capitalism. With such diverse, often directly conflicting conceptions of what progress might look like, is it possible to draw out any commonalities beyond a vague, subjective sense of ‘moving forward towards something better’?

While individual interpretations of progress are varied, these are not so varied to render the term ‘progress’ meaningless. Coccia and Belitto (2018) argue that the concept of progress in the 21st century has five central driving forces: scientific advancement, technological advancement, energy control, economic growth, and democratisation.[50] While the authors do not claim to be providing a comprehensive list of possible features – this would be impossible given that progress means something different to each individual – they do claim their list encompasses the main driving forces behind modern progress.[51] That democratisation is tied to progress is their most controversial claim, which the authors acknowledge: “In principle, with due caution, it can be said that the economically healthier societies, with higher innovative outputs, are also the most democratic.”[52] While generally the case, the economic giant that is modern China would suggest that Western democracy is not the only way to achieve the socio-economic dimensions of progress. Indeed, it is important to be open to the possibility that new or different forms of social organisation may be necessary for managing challenges facing human society in the future.[53]

The other four elements are less controversial – there are, few political leaders that would argue that ‘progress’ means less scientific knowledge, less technology, less economic growth, and reduced energy use (although there are plenty that would argue for less democracy). Excepting democratisation, the other four driving forces link closely to complexity. They form part of an interlinked process of cause and effect: scientific and technological advancement stemming from emergence creates improvements in energy harvesting, efficiency, and storage, generating greater energy flows and economic growth which in turn creates more opportunities for more emergent scientific and technological advancement. When stable energy flows increase in human societies, a greater number and diversity of economic, social, and political interconnections form to manage them. In short, a call for ‘progress’ typically implies a package of improvements to economic, social, cultural, and political life. Depending on the context of the speaker, the contents of that package may vary significantly. Nevertheless, an increase in complexity, through increased energy flows as economic growth, greater interconnections as socio-economic and political structures, and emergence as scientific and technological innovation, almost always forms a key part of that package. As such, while progress and complexity are different concepts, the two cannot be easily disentangled because a call for progress almost always involves a call for increased complexity.

Human Development as a Pathway to Normative Discussions of Complexity

I have presented above a way to connect big history discussions of complexity to modern conceptions of progress in a way that avoids the value-laden judgements about whether increasing complexity and progress is a good outcome. Yet, earlier in this paper, I argued that big history can, and indeed should, use its findings about the impacts of increasing complexity to make normative "should" arguments. To do this, a framework for positive progress is needed. As I have discussed already, the idea of progress is highly subjective but there is a framework that has, at least in principle, agreement from nearly all nations in the world: human development. The term development emerged in the 1970s first from scholars in the Global South critiquing the use of economic growth in the form of GDP as the primary measure of human progress. Development economists Mahbub ul Haq, Üner Kirdar, and Amartya Sen argued that economic growth alone failed to adequately capture whether the lives of people were improving and proposed the more wholistic approach of human development.[54] As of 2015 193 UN member states are signatories to the Sustainable Development Goals (SDGs) making them the closest global human society has come to a consensus on the shape of positive human progress.[55] Human development has three core metrics as set out in the Human Development Index (HDI): longevity, education, and control over resources to achieve a basic standard of living.[56] The methodology for measuring these metrics has between refined over the past 30 years but the principle behind them remains the same: it is difficult to argue against the idea that living longer, having better access to education, and having more resources are measures of betterment.

While the metrics of the HDI are not directly in line with the complexity metrics discussed in this paper, there is some basis to suggest that increased complexity may lead to greater development. There is, at the very least, a close correlation between the control of resources and per capita energy density. Resources are either energy – in the form of food or electricity – or things that require energy to produce. Greater interconnectivity results in more elaborate systems including education systems and, because emergence very often relates to innovations in information storage and transfer, increased complexity results in higher levels of education. Finally, increased complexity leads to greater resource availability, access to services, and technological innovation, all of which contribute to increased life expectancy. In short, while development and complexity are not interchangeable concepts, increased complexity seems likely to lead to increased development.

Development may be the closest global human society has come to a consensus on the meaning of positive progress. If this is the case, then any normative discussions which stem from the concept of complexity should be done with reference to human development. Making clear connections between complexity and human development allows big history to provide practical advice and solutions around increasing development. Discussion of complexity and its impacts, which are less value-laden than progress and development, can then be used to engage in normative discussions about whether progress, complexity, and development should be pursued.

6. The Way Forward

Considering how the concept of complexity in big history fits into the broader academic discussion of complexity provides both useful clarity for the field and an opportunity to consider how big history can gain deeper academic traction going forward. I have presented four potential roadblocks which I have suggested have been preventing the concept of complexity from gaining traction and I have provided four potential paths around the roadblocks. First, it is important for works of big history to clearly articulate how they are using complexity. Not only does the big history definition differ from the intuitive concept of complexity but it is also much narrower than that of complexity science. While it acknowledges that there are many forms of complexity, big history focuses primarily on those forms which are relevant to the "Big Bang to modern society" story. I have referred to this narrower conception of complexity as "useful" or "meaningful" complexity. Second, much time and effort has been devoted to defining complexity clearly within the field of big history. The debate around precise metrics of complexity will (and should) continue, but it is important to acknowledge some common ground. Discussions of complexity in big history almost always include three features: energy density, interconnectivity, and emergence. I have argued here that these three features must be considered together, and given similar, if not equal, weight in determining a system's level of complexity. Third, I have provided a brief defence of the utility and relevance of the large-scale approach in the modern academy. In particular, I have argued that complexity is an effective tool for making comparisons of vastly different systems in order to provide relevant conclusions for present and future human societies (themselves vastly different from anything that has come before). Finally, I have argued that complexity has very close correlations to subjective notions of progress and development, and that this close correlation should be used by big historians to provide useful and unique insights into normative discussions about whether complexity, progress, and development should be pursued.

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