Title
The Star Gazer and the Flesh Eater: Elements of a Theory of Metahistory

Journal
Cliodynamics, 2(1)

Author
Krakauer, David C

Publication Date
2011

DOI
10.21237/C7clio21207

Cliodynamics: the Journal of Theoretical and Mathematical History

The Star Gazer and the Flesh Eater:
Elements of a Theory of Metahistory

David C. Krakauer
Santa Fe Institute

> I have not as yet been able to discover the reason for these properties of gravity from phenomena, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterward rendered general by induction.
>
> —Isaac Newton. Philosophiae Naturalis Principia Mathematica. 1687.

> The Canaanites who fled from Joshua, retired in great numbers into Egypt, and there conquered Timaus, Thamus, or Thammuz King of the lower Egypt, and reigned there under their Kings Salatis, Bon, Apachnas, Apophis, Janias, Assis, etc. until the days of Eli and Samuel. They fed on flesh, and sacrificed men after the manner of the Phoenicians, and were called Shepherds by the Egyptians, who lived only on the fruits of the earth, and abominated flesh-eaters. The upper parts of Egypt were in those days under many Kings, Reigning at Coptos, Thebes, This, Elephantis, and other Places, which by conquering one another grew by degrees into one Kingdom, over which Misphragmuthosis Reigned in the days of Eli.
>
> —Isaac Newton. The Chronology of Ancient Kingdoms Amended. 1728.

Historical Modes: particular events and general trends

When considering these two quotes from Newton's early and late scholarship [22], we can discern a significant shift of interest and of approach or method. In the Principia, Newton sought to reconcile the regular motion through space and time of all massive bodies, regardless of size, position or composition. The tone is one of parsimonious reasoning coupled to a mild contempt for storytelling or "hypotheses." In the Chronology, Newton provides a list of names and places which he sought to tether to an objective astronomical calendar. There is no effort to discern regulatory, only a temporal sequence.

Corresponding author's e-mail: krakauer@santafe.edu

Citation: Krakauer, David C. 2011. The Star Gazer and the Flesh Eater: Elements of a Theory of Metahistory. *Cliodynamics* 2: 82–105

These two perspectives can be seen to constitute two poles of historical inquiry, one mechanistic and regular, and the other, incidental and particular. This tension lies at the core of most, if not all, historical inquiries. In this paper I want to outline briefly a few of the implications of these polarizing tendencies of history through the lens of evolutionary biology and complexity science, and search for a means of overcoming them through an appropriate trans-disciplinary language. The example of Newton serves to establish that these two approaches to dynamics can reside within the same research mind and program, and secondarily, serves to preemptively refute a few of the more tendentious dichotomies that arise in discussions between the "star-gazing" scientist and "flesh-eating" humanist.[1]

I take the position that historical explanation (as opposed to historical recreation or reconstruction in the form of systematic description and other forms of historical scene-setting and portraiture) seeks to account for some pattern of behavior in what we might call *the arbitrary present*. The arbitrary present (AP) in contrast to the chronological present (CP) – the temporal now. The arbitrary present is any date over the course of history for which we seek an explanation in terms of a series of antecedent events. The AP could just as well be 1492, 1687, 1914 or 2050. This idea was articulated, somewhat furtively, by Braudel when he suggested that "is it not the secret aim and underlying motive of history to seek to explain the present?" [2]. I allege that this is the primary aim of history, and that reconstruction of the past is a step towards this goal, and not the natural terminus of historical inquiry. I will have much to say about "events" in the course of this argument. My claim is that when a sub-population of historians moves towards the analysis of well-curated, quantitative, data sets in the near future, this concept will again become central, as it will be necessary to organize observations in a time series, and events will represent preferred and principled levels of granularity for these observations.

Newton's work reveals at least two tendencies, or modes of historical explanation (these are in contrast to non-historical means of accounting for the AP which I shall discuss shortly). One historical mode is to enumerate in as much detail as there are facts available, the causal sequence of events culminating in the desired variables describing the AP. Hence if we are interested in the colonial history of Mexico, to take one classic example [24]:

> While at Cempoalla Cortes received a message from Escalante, his commander at Villa Rica, informing him there were four strange ships hovering off the coast, and that they took no notice of his

[1] We typically think of Thales the "father of science" according to Bertrand Russell, who fell into a pit and died while contemplating the firmament, and the humanist, who has no appetite for nature beyond human nature.

> repeated signals. This intelligence greatly alarmed the general, who feared they might be a squadron sent by the governor of Cuba, to interfere with his movements. In much haste, he set out at the head of a few horsemen, and, ordering a party of light infantry to follow, posted back to Villa Rica. The rest of the army he left in charge of Alvarado and of Gonzalo de Sandoval, a young officer, who had begun to give evidence of the uncommon qualities which have secured him so distinguished a rank among the conquerors of Mexico.
>
> —William H. Prescott. *History of the Conquest of Mexico*

The AP in this case is Cortes in Villa Rica and the circumstance of his army at Cempoalla. The putative, local explanatory events required to account for this state of affairs consist in the implications of the four Cuban ships, and the trust Cortes placed in his officers. This passage, which I think is fairly typical of historical explanation, also illustrates the great complexity in seeking to establish plausible, causal events. The four ships stand-in for the scale of military intervention, and their effects are felt subsequently at the scale of individuals sensitive to geopolitical gaming. Prescott's passage provides an *explanation* only in so far as we share or trust his classification of the event sequence and the authority of his informal psychological insights contributing to the history.

If this all seems a little dated, exactly the same structure and logic of argument is made by contemporary historians,

> As before, events in Europe influenced the direction of events in New Spain. In May 1814, Ferdinand VII was restored to the throne and quickly reasserted his power. First he eliminated Cortes (a parliamentary body created to establish a constitution in the absence of monarchical rule when the French occupied Spain), and in Mexico, he named General Calleja the new viceroy. Calleja aggressively campaigned against insurgent sympathizers. Moreover, with stability reestablished in Spain, the Crown sent more troops to Mexico.
>
> —Burton Kirckwood, *The History of Mexico*

Once again, the argument invokes key events operating at multiple different scales, and appeals to individual psychological needs, such as the desire for power. And there is nothing at all wrong with this, it illustrates the complexity of historical argument, which we seek to unpack.

We might think about a history in terms of fitting a curve to time series data (time on the X axis and observations on the Y axis through which we draw a curve). So for example, if we choose an informative, quantitative variable in the present (size of population or army, birth rate, GDP, exchange rate, etc), then we could simply describe each event as it unfolds in time through a chro-

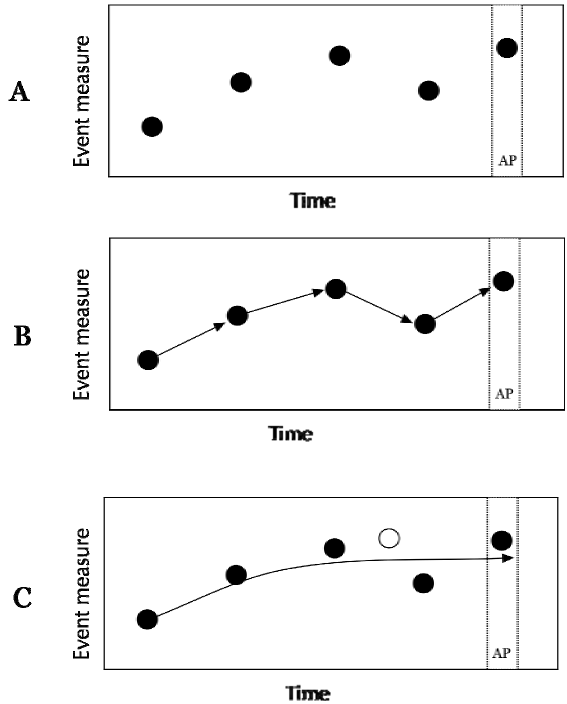

Figure 1. Descriptive, narrative and scientific models of historical sequences. In all three panels, salient events and their corresponding dates are illustrated with circles. The arbitrary present is represented by the final circle. (A). In a purely descriptive history, or chronology, events are reliably placed in temporal order according to a suitable calendar or clock. (B). In a narrative history, events are connected by a credible, causal mechanism (illustrated as an arrow connecting contiguous events). The mechanism represents a mapping from a previous event to a future event, and typically invokes processes for which there exists some informal consensus (psychological or economic theory for example). (C). A scientific history seeks to fit a dynamical system to the sequence, and is typically approximate, capturing patterns in the data, but failing to reproduce the particular character or value of an event. The value of the scientific history is that it can accommodate new observations (open circle) without having to provide an additional causal link and is less sensitive to noise in the sequence. The new observation (open circle) in panel C suggests that the causal link in B connecting the third and fourth event is spurious, as these events are contiguous by virtue of under-sampling of the historical time series, and not causally successive. In physical theory, the dynamics are often sufficiently simple that the dynamical system is as good as the narrative fit -- low residual variation. In biology, the social sciences and human history, this is almost never the case, and a good theory is often very weak when it comes to accounting for particular events. Thus the standard according to which we judge scientific history should be statistical rather than mechanical principles.

nology. This is a sequence that is interesting in itself. We can go one step further and "fit" a model through every point in the data set ending in the present. Statistically speaking, this is the best possible description of the current data. This is the essence of narrative history. Thus each chronological "event", or observation at a preferred scale of description, for which we have data is described, and provides the causal condition for subsequent events. However, if the data set is incomplete, this mode suffers from two critical weaknesses: (1) errors in the reconstruction of the sequence, and (2) over-fitting of the data. Errors in the causal sequence posit relationships among non-contiguous, temporally unrelated, events. Over-fitting the data risks inventing causal transformations for largely independent events, and obscures possible trends. Since our observations are incomplete, in both cases there is the risk that further observations (observations not used to reconstruct the observed sequence – observations out of sample) will fall a large distance from the narrative-arc that best describes the data we currently possess. Hence we have failed to account for the historical processes by adhering too closely to imperfect data.

The alternative historical mode, not typically associated with historians but with dynamical phenomena in the natural sciences, is to derive a compressed representation for regular sequences in the time series based on a mechanical model of putative variables. This was the achievement of Newton in the Principia, where among other things, he dealt with the problem of the path of a body subjected to a centrally directed force that varies as the inverse square of the distance.

In terms of data, this approach involves describing a small subset of the observations, and predicting a larger fraction of the data, rather than fitting the data, with as few parameters as is possible or recommended subject to some parameter cost.[2] Hence the motions of the planets can be described in terms of their initial positions and momenta, and the gravitational constant, rather than describing their orbits in detail. This law-like approach to history, which seeks to minimize the role of contingencies and narrative explanation, is a rather weak fit to history as currently practiced, but provides a useful reference point towards which a scientific history might move. Furthermore, this approach is a very natural complement to narrative and should in no way be thought of as mutually exclusive with it.

Positivism or phenomenology

Not all "scientific" descriptions of data – parsimonious and predictive – make use of mechanically informed models [20]. When a fit is performed without

[2] There is always a trade-off between the robustness of the fit and the number of parameters.

prior knowledge of mechanism, the model represents a phenomenological, and typically statistical (technically, frequentist) fit. And this is generally of less value than the mechanical fit. Hence we might fit circles or ellipses to the motions of the planets without invoking gravity as both Tycho Brahe and Kepler did with considerable success before Newton provided a principled explanation for elliptical orbits [9]. An obvious limitation of the purely statistical model, is that it does not suggest unifying mechanisms. Hence each orbit has its own independent description. The purely statistical models thus suffer from over-fitting of the data.

In practice, the degree of mechanical justification for a theory tends to fall on a continuum, including both free parameters for uncertain variables, and compressed formal relationships for the regular features. Even Newton was accused of a reliance on phenomenological regularity (gravity), which accounts for his somewhat defensive epithet, Hypotheses non fingo. This is because Newton was unable to provide a mechanical underpinning for the inverse square law.

When we turn to ahistorical theories, their primary character is to provide explanations for features of the AP that make limited use of inherited, or temporally sequential, processes with long memories. Rapid dynamics and boundary conditions are sufficient to guarantee the uniqueness of an AP when the initial conditions of the system are minimally predictive of the final state. Thus a process that has a single possible solution, or attractor state, regardless of what initial state the system inhabited, bears no trace of its origin. This is a very common feature of economic theory, such as game theory [12]. Economic theory is largely concerned with the optimal solution to conflicts of interest among two or more parties. Costs and benefits of coordinated behavior (such as a competition) are provided, and an optimal, stable, ahistorical strategy derived. It should be emphasized that this is a fault of a subset of economic theory and not of economics – an area of endeavor which certainly possesses significant historical regularities. So if we should ask why gold is favored over iron as a currency, we will find no answer to this question within economic theory. To begin to answer this question seriously, we will need a new field of ecological economics, to include substantial elements of economic history.

Darwinian selection as an ahistorical mechanism

Perhaps counter-intuitively, evolution by natural selection (in principle if not in practice) provides a fairly good example for an ahistorical process in biological history. When interpreting correlations among organismal characters and environmental features, analogous traits are those that manifest similar correlations for reasons other than history (where history here is thought of as common descent). The cause of these correlations is selection, which leads certain traits and their genetic complement to be perpetuated in accordance with their "fit" to the environment. Hence worms and snakes have morphologically converged from very disparate starting positions and through independent, historical processes. For this reason, natural selection is one of the major nuisance factors when trying to reconstruct an evolutionary history, or phylogeny. Natural selection tends to diminish the historical signal present in comparative-trait data, as regardless of where a trait starts, it tends to finish up in the same position. The creation of the neutral theory [17] – evolution by mutation and sampling drift rather than selection – was one of the major technical innovations that allowed for the reconstruction of biological history. This is because neutrality is permissive of historical changes that are selectively equivalent – mutations that generate phenotypes that are selectively indistinguishable. We might say that largely ahistorical selection mechanisms can erase historical patterns in evolution. The same intuition applies to language change. Language is a strong indicator of human history – patterns of migration – as long as independent language groups do not converge or acquire the same language through selective benefits, like conformity or economic opportunity – which lead populations to speak the same language when they have very different histories.

Complexity

The way we set about to explain regularity and randomness relates directly to the concept of complexity. The only time series without regular sequences, and thus requiring an interpolation (event by event description), is a random sequence. There is no trend in random data, and all new observations require a new description. By contrast, perfectly regular sequences permit a very short (compressed) description in terms of simple functions and processes.

These compressed descriptions of data can be either, mechanical explanations (along the lines of Newton's laws), or somewhat arbitrary, statistical explanations in terms of convenient data structures like decision trees. The natural sciences have been drawn traditionally to phenomena that have little randomness and permit highly parsimonious (elegant) representations of their regularities in mathematical or algorithmic languages. Einstein's field equations, Darwin's theory of evolution by iterated natural selection, Mendel's laws of segregation. The social sciences have been drawn to elaborate theoretical frameworks that seek too capture regularities at many scales of space and time with little explicit mention of random processes. Dialectical materialism, institutional economics, political sociology, and so forth. When we turn to history proper we identify the chronicle – largely lists of sequential events positioned on a reliable calendar – and the historical narrative. The historical narrative is a very complex representation of sequential events that seeks to fit detailed descriptions of people and places, within a series of nested regular processes– from psychology to ecology. For these reasons, narrative history subsumes the sciences, and therefore should in part, be founded upon scientific principles. The fact the historians tend to neglect the details of science in favor of qualitative allusions to germane scientific materials, is perhaps a commentary on the inaccessibility of much of science, and the time required to become familiar with it, rather than its relevance.

We can measure the complexity of a time series in terms of both its regular and random components. Complex time series traditionally have properties of both. This leads to two contrasting views of complexity, one emphasizing the random (Kolmogorov complexity) and the other, the regular (effective complexity) [13]. We might think of the complexity of a process as a function of the minimum number, of maximally compressed sequences of events, required to produce the observed pattern in the arbitrary present. A related problem has been approached formerly by attempting to calculate the "logical depth" of an object or process – the time required by a standard universal Turing machine to generate an output from an input that is algorithmically random [1].

Random events in an historical time series will tend to inflate the complexity estimate, as by definition, they have no structure. Thus we can either choose to filter out the random, incompressible events, leaving only the incompressible regular structure, or leave both in the data. A very useful approach is to calculate complexity measures for both, and thereby make a distinction between random events that constitute a legitimate part of the history, and regular mechanism through which random events are filtered and made consequential. The complexity of history then becomes a function of both of these measures, and is best thought about in terms of a two dimensional space of random and compressed regular contributions (see Figure 2). This provides us with an informal classification of historical time series which provides some insights into traditional, disciplinary preferences.

Critical events and critical systems

> I have already explained to you that what is out of the common is usually a guide rather than a hindrance. In solving a problem of this sort, the grand thing is to be able to reason backwards. That is a very useful accomplishment, and a very easy one, but people do not practice it much. In the every-day affairs of life it is more useful to reason forwards, and so the other comes to be neglected. There are fifty who can reason synthetically for one who can reason analytically ... Most people, if you describe a train of events to them, will tell you what the result would be. They can put those events together in their minds, and argue from them that something will come to pass. There are few people, however, who, if you told them a result, would be able to evolve from their own inner consciousness what the steps were

which led up to that result. This power is what I mean when I talk of reasoning backwards, or analytically.
—Arthur Conan Doyle. A Study in Scarlet. The Conclusion. [8]

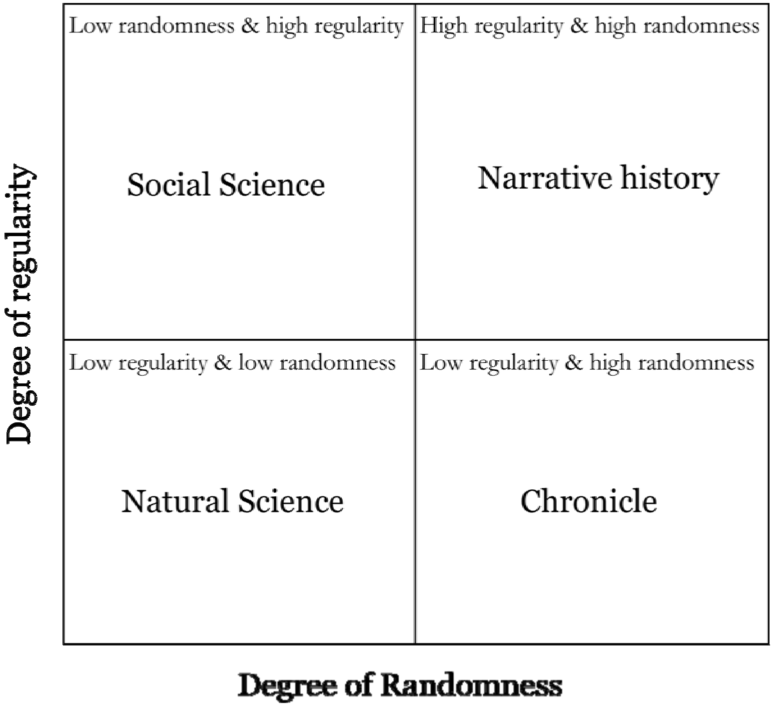

Figure 2. A classification of *traditional*, disciplinary approaches to dynamics based on the contribution of regular and random processes. Natural science, and physical science especially, has tended to consider systems with fairly clear-cut regularities and little in the way of randomness. The orbits of the planets, the mass of solids, the freezing temperature of liquids, the colors of the rainbow, etc. As a result, simple law-like expressions are capable of explaining much of the variability in the observations. This approach differs from the chronicle which focuses only sequences, treated as random events, with little or no attempt to provide an explanation for the sequence. The social sciences tend to provide elaborate, theoretical frameworks for events, neglecting random processes in data that lie outside of the purview of "theory." This is in part because data has made a small contribution to the formation of these fields, although this is rapidly changing. Narrative history attempts to provide various kinds of overarching theory to explain, or at least frame, a large quantity of particularist data. These are merely patterns of scholarship, and any comprehensive theory for a sufficiently complex phenomenon, will converge towards the upper right quadrant.

When we learn the "cause" of the first world war, we are told that this can be traced to June 28, 1914, and the assassination of Archduke Franz Ferdinand, heir to the Austro-Hungarian throne, by Gavrilo Princip, a Bosnian Serb citizen of Austria-Hungary and member of the Black Hand. The retaliation by Austria-Hungary against Serbia initiated a chain reaction of war declarations. Within a month, much of Europe was in a state of war. Historians explaining this event adopt either what Holmes describes as the synthetic mode of detection, where the outcome follows from the special properties of a sequence of events, or the analytic mode of detection, where the cause can be identified uniquely based on a careful examination of the outcome. The analytic mode relies on what we might call a critical event. A critical event is a perturbation of a system which preserves in the final outcome properties of the perturbation. Hence the system supports a long memory for an initial triggering-intervention. Alternatively, the system itself might be critical, in which case a larger number of unrelated events could all trigger a similar or identical outcome, and no unambiguous trace of the initial intervention would be preserved. The system loses its memory of the perturbation. The success of Holmes and his method of detection relies on the fact that all of his cases (at least those reported by Watson) involve critical events and not critical systems.

Thus on the one hand we stress the singular, random event, and on the other, the systemic properties that amplify events. The important task is to discriminate between critical events and critical systems in order to assign to each its relative causal contribution to history. In order to clarify this line of reasoning let me expand a little on the distinction between systems and perturbations.

1. System. There are a variety of related interpretations of a critical system. One possibility is that a system – a relatively densely connected network of variables – is positioned at, or tuned to, a threshold or phase transition. Beyond this point, the system will switch into a different state when perturbed regardless of the magnitude of the perturbation – the variables will adopt very different values. Alternatively, the system contains a contagion or chain-reaction mechanism which allows small perturbations to be amplified far from the critical point. An example for tuning to a critical point are systems with a property of self-organized criticality, whereas a good example for chain reactions are infectious diseases.

2. Perturbation. Most systems have a finite range of operation, and if a change in the value of a variable or change in the coupling of variables – perturbation – is sufficiently large, the system can be compromised. We can make an analogy with the elastic limit of a material – the point of deformation beyond which the material ceases to behave elastically and fails. For a given system we can characterize the distribution of perturbation magnitudes and frequencies. For example, the frequency of mutations in a lineage through generational time and the number of sites (magnitude) that are modified by the mutation.

We can monitor the perturbations without considering their consequence. We can ask how well do the perturbations, when considered alone, correlate with the distribution of salient variables in the system. When these two distributions are strongly aligned, then additional system dynamics can be ruled out.

3. Mixed cause. Most interesting examples from history have both properties. Infection with the right mutant form of an antigen allows for exponential growth of a pathogen. Infection with a pathogen to which the host is resistant, does not lead to proliferation. Contagion requires therefore a mechanism of complementation (recognition or non-recognition by the immune system and binding to a substrate, generated by random mutation events), and a mechanism for amplification based on a regular/predictable dynamical process. Many disagreements in the study of complex systems turn on the relative contribution of extrinsic perturbations versus intrinsic dynamics.

Thus the history of a system requires that we attempt to isolate random perturbations from their filters or amplifiers through an appropriate, regular system dynamics. This is logically, an elementary insight, but practically is very difficult without first having established a method for making this distinction possible, and even then might not be tractable. I suspect that not recognizing, or at least not treating this problem, has contributed to fanning the flames of the interminable debate in academic history between "laws" spoken of in terms of the generalities of system properties, versus contingencies, that would seem to require a "deep-description" of a system's particulars. Competing theories for the transformation of the Mayan society are illustrative of this tension. Ecological theories tend to emphasize common mechanisms of decline such as resource depletion and sustained drought. Intrinsic theories include social upheavals such as peasant revolt. The ecological theory presents itself as a rather general process capable of explaining a large number of unrelated collapses, potentially in a large range of species. The social theory involves a larger number of historical contingencies peculiar to Mayan society. In all likelihood, these factors have interacted in multiple ways, to accelerate the collapse, making a Holmesian elucidation of one guilty party rather difficult. Whatever the case may be, as Vilar wrote in defense of systematic attempts to "explain" history: "Today, too many theories in flight before history make the history of thought into a discontinuous series of singular totalities" [23]. Our efforts are directed at discerning generalities and singularities.[3]

[3] The protagonist of Poe's short story, *The Angel of the Odd*, complains along similar lines: "These fellows, knowing the extravagant gullibility of the age, set their wits to work in the imagination of improbable possibilities – of odd accidents as they term them…For my own part, I intend to believe nothing henceforward that has anything of the singular about it."

Coarse graining causal variables

When we attempt to account for features of the AP, we naturally need to choose some best scale, or set of scales, for the causal explanation. It is rare that we use the most fine-grained data (individual psychology for example), mainly because this is not available to us, or more interestingly, because it does not possess the strongest explanatory power. Aggregating or averaging over finer scales to generate average scales is called coarse-graining, and this procedure typically yields greater regularity in the averages. For an analysis of the value of the opposite procedure – the decomposition of events – see for example Krakauer [18], where I explain how the problem of uniqueness can be mitigated by recognizing common constituents of independent, aggregate events.

A familiar example is temperature, an average over the microscopic motions of single particles. Technically it is an average over the degrees of freedom of the particles (say translational and rotational motion) and is measured at a local equilibrium (we require this in order to calculate an average that applies globally).

Consider an example from physics. Rather than think about multiple individual particles in motion, we can think of a single quantity heat as a collective the variable, with transfer properties we think if as conduction, convection and radiation. These are all concepts constructed at the scale of an "effective" variable. Fourier's law of heat conduction can predict how temperature is transferred from hot to cold material without describing individual particles. This represents a statistical law or regulatory, expressed through an equation which predicts the average behavior of a system – an effective degree of freedom – without attending to the microscopic degrees of freedom of the system [19]. A more or less direct application of the heat equation formalism has proven to be of some utility in the economics of the market, where the heat equation is called, the Black-Scholes equation. Rather than heat we consider the diffusion of price. This model does not consider individuals moving the price, because at sufficiently large scales, these processes often appear random like the particles constituting heat in thermodynamics. It all depends on the level you are interested in.

Whereas these are examples of the direct application of formal concepts of effective variables, informal notions of causal aggregates pervades historical writing. Here is Edward Gibbon in chapter nine of The History of the Decline and Fall of the Roman Empire [14]:

> The comparative view of the powers of the magistrates, in two remarkable instances, is alone sufficient to represent the whole system of German manners. The disposal of the landed property within their district was absolutely vested in their hands, and they distributed it every year according to a new division. At the same time, they were not authorized to punish with death, to imprison, or even to strike, a private citizen. A

> people thus jealous of their persons, and careless of their possessions, must have been totally destitute of industry and the arts, but animated with a high sense of honor and independence.

And Lewis Namier, In the Margins of History [21]:

> Most nations are extremely touchy. "National Honor" and "National Prestige" were a fetish in this country in the eighteenth century, and are still on the European Continent; and the less honor nations observe in practice, the more sensitive are they to anything which might seem to question what amount of it they possess.

Both Namier and Gibbon ascribe psychological motivations to large aggregates, levels at which it is unclear what honor or sensitivity might mean. Yet as readers, we do not object, indeed seem to find coherent, the extrapolation of affective states to aggregates of individuals and institutions. I would like to suggest that there might be ways of increasing the credibility of these remarks; that in their current form perform as suggestive metaphors. It would seem to be a desirable goal of a meta-history to establish systematic approaches to identifying causal levels where possible.

Intensive and extensive historical dynamics

An important property of temperature is that is an intensive variable (IV), meaning that it does not depend on the system size – the temperature of two rooms can be the same temperature even when they are of very different sizes and hence contain different numbers of particles. This is also true for density and pressure. This is not true for mass, volume, energy, resistance or entropy that always grow in the number of components and are described as extensive variables (EV). Whether a variable is an IV or EV can reveal important details about the underlying mechanisms of mixing and sorting of the parts. When we bring together two sub-systems, each in equilibrium with respect to their intensive qualities, we observe flow between the systems measured in terms of variation in their extensive properties – energy in the case of variation in temperature.

If we consider our time series again, we can make partitions of the variables and calculate suitable averages. Many of these will be extensive quantities like the average size or strength of an army, or the purchasing power of a firm. However there are quantities that can be more intensive in the number of people, like the authority of the Parliament, which need not become more powerful with a larger number of members – a Monarch can, nominally, possess total power. When we want to calculate some global property of an aggregate, such as a nation, we need to be mindful of the distinction between intensive and extensive variables, as they will tell us how component properties combine. We do not assume that a history department is twice as interesting because we have two astounding medieval historians in residence rather than one, although the department might be twice as productive. How to assign to historically important events some measure of extensivity is far from trivial. Consider the following quote from John A. Crow's The Epic of Latin America [4]:

> James Truslow Adams, in his Epic of America, recalls that John Adams had said that only a third of the people wanted a revolution. A much smaller minority than this carried out the French Revolution of 1789, and the incredibly small minority of approximately fifty thousand "Reds" out of Russia's one hundred and fifty million brought about communism in the Soviet Union.

The degree of revolutionary force does not seem to scale in a simple way with the number of revolutionaries. Perhaps this potential for revolution, reasoning analogically, is more like pressure which can be measured as a local average, and is less like resistance, which always increases with area.

To ground these ideas in my own field let me turn to evolutionary biology. Perhaps the best-known, intensive, variable in biology is adaptedness – some measure of the information-flow or correlation, between an organism and its environment. Clearly something is not better adapted simply because there is more of it – larger population size or larger body size. The elephant is not better adapted to an environment than a flea. However, knowledge of the adaptive differences between two organisms is assumed to be predictive of flows of genetic information between generations. Hence better-adapted variants of a species experiencing competition tend to displace worse adapted variants by increasing preferentially the flow of their genomes into the population gene pool. This flow is typically measured as a function of the ratio of lineage biomass over time – a quantity evolutionary biologists refer to as fitness. Hence fitness is a rate of growth of a genome or biomass and scales with the number of genomes replicating in a population. This is an extensive quantity. Knowledge of these fitness gradients is assumed to be predictive of the distribution of adaptive traits into the future.

The intensive nature of adaptation is the essential idea behind the historical dynamics of invasive species. Whether native or non-native, these are species capable of heavily colonizing a given area by virtue of key traits rather then through force of number. Hence high dispersal, rapid replication, drought tolerance, and plasticity are a few characteristics of a species independent of their number that can promote invasion. The South American cane toad was introduced into Australia in 1935 to control the cane beetle. Its population has grown to an excess of 200 million through prolific rates of breeding. Similar Australian case studies include the red fox, feral cats, and European rabbits.

The total Australian biomass under the control of non-indigenous genomes has expanded several orders of magnitude over the course of only a few decades.

To the extent that evolutionary dynamics can provide insights into historical dynamics more generally, we need to be aware of these properties of explanatory variables. An area where these considerations might prove to be important is when cultures making use of different technologies come into contact – where technologies, behaviors and rituals, provide a considerable competitive advantage in a new habitat. This emphasis on intensive historical variables pervades world history, and is in stark contrast to say national histories, which tend to emphasize extensive variables, such as population size. Here is Jared Diamond from Guns, Germs, and Steel [7]:

> Writing marched together with weapons, microbes and centralized political organizations as modern agents of conquest. The commands of the monarchs and merchants who organized colonizing fleets were conveyed in writing.

And Hugh Thomas in The Spanish Civil War [26],

> This XIth International Brigade, however, probably comprised only about 1,900 men. The XIIth International Brigade, which eventually arrived at the Madrid front on about November 12, composed about 1600. This force was too small to have turned the day by numbers alone.

In the world history of Diamond, there is no need to mention numbers, as these are clearly of second tier importance next to the "modern agents of conquest." In the Thomas quote, numbers remain critical, even if they are not always simple predictors of outcomes. These are representative of what we might call intensive and extensive histories – histories whose coarse-grained variables are explanatory without recourse to magnitude (Diamond), and histories whose coarse-grained variables are only explanatory in so far as they account for details of relative magnitude between competitors (Thomas). There is in world history a hint of the possibility that history has itself undergone a change – from an extensive ancient world to an intensive modern world – a transformation in patterns of time, aided and abetted by technological innovation. It is as if technology has promoted a shift to forms of competition and cooperation that can operate more independently from population size.

Not all coarse-grainings, whether extensive or intensive, of observables are equally useful. I imagine historians disagree with both Diamond and Thomas over their choice of explanatory variables. In physics, a considerably simpler discipline that human history, the Fourier law of heat works because temperature is a demonstrably, effective coarse graining of the microscopic degrees of freedom of particles in motion. The test of the utility of a coarse graining, relates to a fascinating, quantitative property called statistical sufficiency. I shall briefly explain both the idea of a statistic and sufficiency. A statistic has been described as a well-behaved function of data. For example, the mean and variance of a Gaussian distribution of data is uniquely determined and finite. Statistics tell us something important about complicated data sets in a very simple way, and have the same meaning regardless of the data in question – averages for baseball statistics or stock prices. A sufficient statistic takes the statistical idea further. It is a function that is just as informative about a statistical parameter or variable as the complete data set. Put differently, it is as predictive of a variable or parameter as the complete data set. This implies that knowledge of this variable allows you to bypass tedious, microscopic scrutiny of data. Heat in the Fourier law, or price in the Black-Scholes equation, are treated as sufficient statistics in restricted domains of thermodynamics and economics

For the meta-historical sciences, finding sufficient statistics is a very challenging problem. However, this framework is often implicit in national comparisons based on mean levels of education, gross national product and related statistics, as these are meant to connote something of the future state of these variables. It would be of great interest, and perhaps importance, to determine how legitimate these approaches are. As an example, in evolutionary biology, the attempt to identify statistically sufficient aggregates has a long and contentious history. The debate typically centers about the concept of the levels of selection.

The levels of selection

Coarse-graining in evolutionary biology seeks to explain the individual in terms of levels of selection [16]. An individual is an aggregate of many microscopic degrees of freedom (molecules, cells, tissues etc), which nevertheless possesses average properties that remain informative. And perhaps most importantly, other organisms and the environment are capable of detecting these average properties, and this detection contributes to the survival the entire aggregate. Hence predators are not conspicuous to their prey by virtue of their cells, but through gross morphological properties comprised of cells. Likewise, prey are capable of escaping mortality through mass coordination of cellular aggregates, generating escape behaviors. The essential idea is that components come to possess a shared fate with selective consequences, and this encourages cooperative behavior causing components to become statistically `linked' rather than behaving independently, as expected in an equilibrium system.

This leads to a perspective in biology that permits multiple, simultaneous levels of description and explanation. Gould called this the "hierarchical theory of selection" [15], even though, strictly speaking, there is as yet no single, accepted theory. The implication of the hierarchical view, just like in physics, is that we can conceive of explanatory theories at the level of the emergent, "effective degrees of freedom." This endeavor is at the heart of complexity science, which emphasizes that there are fundamental principles of organization at multiple scales, and we do not always have to, or are capable of, reducing to the lowest common denominator of matter in order to understand a process. By this logic Historians have been practicing an informal complexity science for as long as there has been a history, switching between alternative coarse grains (individuals and groups) in search of effective explanation:

> "At the King's command, the Thasians tore down their wall and brought all of their ships to Abdera"
>
> —Herodotus. The Histories. Book Six. Hellas. Fifth Century BCE [3].

Herodotus shifts between an individual Monarch, a people and a machine, in order to explain an historical sequence of events. Herodotus does not find it necessary to describe each inclusive level by enumerating the individual contributors. While this linguistic and conceptual compression promotes an efficient delivery, it might conceal questionable assumptions. In evolutionary biology, such statements are often met with skepticism, as the statistical sufficiency of each member of the hierarchy has not been demonstrated. Perhaps the best-known example of this levels-positivism is Dawkins' concept of the selfish gene [5]:

A selfish gene is trying to become more numerous in the gene pool. It does this by helping to program the bodies in which it finds itself to survive and to reproduce. But now we are emphasizing it as a distributed agency, existing in many different individuals at once. The key point of this chapter is that a gene might be able to assist replicas of itself that are sitting in other bodies. If so, this would appear as individual altruism but would be brought about by gene selfishness. For example, if the gene for being an albino just happened to cause its bodies to behave altruistically towards other albinos, it would tend to become more numerous in the gene pool as a result.

Dawkins shifts causality to the lowest level in the statistical hierarchy, and describes bodies as emergent machines, capable of increasing the representation of certain genes in the gene pool. But genes are themselves aggregates of more fundamental chemical elements, which are in turn aggregates of fundamental, physical particles. Each level is "real" to the extent that it can operate as a sufficient predictor of its future state. Prediction however implies a time scale – predictions over short or long intervals of time. The source of the debate in evolutionary biology is not whether there are multiple levels of selection, but rather which ones possess long-term predictive potential. The continuous nature of time, and the relative quality of long and short, ensure that the argument continues. A comparable stance in history might be to assert that all true explanations for historical patterns need to be presented in terms of individual, psychological motivations, and that all larger scale aggregates are merely epiphenomena of individual behavior.

Major Transitions

A natural question to ask, is why do new levels, sufficient statistics, or effective degrees of freedom (all descriptions of essentially similar features), come into existence in the first place? Why do complex systems allow us to coarse-grain them into informative and sufficient statistics? Why might we have a history that goes beyond the psychology of individuals to allow for causal contributions from populations and nations? Is there some underlying dynamical process that ensures that this is possible, probable, and perhaps even desirable for a system itself? If the answer to these is positive, then historical explanations become more tractable, as we would have some basis upon which to ignore the multiplicity of detail at the lowest levels of organization and adopt an “emergence” perspective. For meta-historians, this question takes many forms. For the historian of human culture, it entails trying to explain transitions among, for example, nomadic pastoralists and settled urban populations. For the historian of the earth, the emergence of oxygenetic photosynthesis, and all that follows.

Evolutionary biologists answer this question by establishing the conditions promoting transitions from simple replicators to cells, to multicells through to colonies and societies [25]. And anthropologists like to ask similar questions about conditions relating to transitioning from families, to local groups, clans, regional polities, chiefdoms and through to states? From our perspective this question can be thought about in terms of those lower level mechanisms promoting the emergence of higher-level aggregates with novel functions. These emergent levels can then be understood in terms of new effective theories that are level specific, and are not explanations couched in terms of those levels below, while remaining fully compatible with them.

We might decompose this very difficult issue into a number of nested requirements for emergence: (1) A sophisticated memory mechanism, (2) a mechanism for generating, capturing and freezing accidents (learning, natural selection), (3) a construction mechanism – or a means of creating an aggregate, and finally we should like to (4) identify the dominant pressures or forces or norms driving the aggregation process. These requirements, I would argue are very general, and equally likely to apply to biological and cultural examples.

1. Memory. There is no history without memory. At its most basic, a memory is something like an attractor state of a dynamical system – a configuration towards which dynamical variables converge. Larger memories requires more, stable attractor states. Computer memory, like RAM, stores information in

binary, each bit is maintained in a preferred state through the flow of current from a power supply. Without power the memory effectively volatilizes and disappears. Hard drives offer non-volatile memories using magnetized ferromagnetic material. Brains make use of volatile protein densities to store memories, and humans traditionally make use of inorganic (iron gall or carbon ink) and organic (cuttlefish sepia) dyes to color surfaces with arbitrary symbols. These are also volatile, as attested to by the decay of over 25 per cent of the iron gall ink scores of J. S. Bach. In every case, there is some mechanisms for preserving a combinatorially large number of alternative states.

2. Freezing accidents. In order to build aggregates we need a way of writing symbols into stable memories. Not all events with significant consequences on the future are written into memory. Mass extinction events, which have a huge impact on the AP, do not necessarily get recorded into genetic memory. The KT extinction (around 65.5 million years ago), associated in the popular imagination with the loss of all non-avian dinosaurs, was the likely outcome an asteroid impact. This event left a long lasting trace but was not itself recorded. Contrast this germ-line mutations. In this case modest perturbations of a molecule can be "frozen" or fixed in covalent bonds, into sequence of DNA. In the long run these constitute the basis of new organismal features. It is the frozen accidents recorded in suitable memory materials that play the more important role in adaptive aggregation.

3. Construction. It is not enough to store events through time. In adaptive systems, these stored events play an important role in promoting the survival of their carriers. Whether organisms, groups, states, or civilizations. Just think of human languages and the memories that languages can preserve, both about humans and about the world. Language is constructed from neural impulses generating regular patterns of motor control, leading to speech or to writing. Without the construction process, the memory is effectively worthless. In biology the construction process is either called development, when describing how the egg to embryo transformation makes use of DNA memory in order to build cellular phenotypes, and is referred to as niche construction, when focusing on the organism to ecosystem, or social system, construction. The construction process takes the content of memory as a guide to building statistical aggregates.

With these requirements for emergence in hand, we are in a better position to discuss the regular processes that might be sufficient, that by exploiting these requirements, are able lead to successive aggregation. We should also consider those neglected processes promoting increasing simplicity without complete loss of function – when we observe disaggregation in favor of solitary habits.

Complexity Driving Processes

Let's consider three plausible, not necessarily orthogonal, candidates for increasing complexity: the minimization of energy dissipation, competition and entropy driven robustness mechanisms.

1. 1. Minimization of free energy. It has been suggested that simple biotic agents exist in order to more effectively transduce energy, and thereby alleviate the build up of free energy. Like lightning discharges, which arise following charge separation in the upper and lower atmosphere and cause a reduction in the atmospheric potential difference, organisms might be seen to constitute simple, enzymatic channels, in a chemical reduction potential. It is still not known whether chemically derived free energy stresses can force chemical order into complex biological states (memory with replication for example)) or stabilize these under chronic perturbations.

Another thermodynamic perspective is that complex delivery networks have evolved in order to more effectively supply large masses with essential energetic resources. The growth of mass and network hierarchy are driven by selection for more efficient metabolism. These energy transport theories can not in themselves explain the origins of very complex adaptive structures, but they can help us to explain why there might be an historical trend towards more efficient systems.

Both of these energetic, or thermodynamic, perspectives on historical trends towards hierarchy find variant forms in the study of Big History. The growth and fragmentation of cultures, or nation-states might be viewed through an appropriate lens of energetic efficiency.

2. Entropy and robustness. Once simple adaptive structures come into existence, their improbable configurations make them immediate prey to entropic processes of disordering – there are may more ways to be wrong than right [6].

This creates a strong selection pressure for mechanisms that stabilize these adaptive structures. However, these supporting structures are themselves fragile, and require additional mechanisms for support. The sources of instability can be both internal and external. The outcome is the creation of a hierarchy of error-correcting mechanisms, many of which do not serve the primary functional values, but are second and third order stabilizing mechanisms. This is a theory of telescoping bureaucracy.

3. Competition. Competition is a special form of dissipation resulting from the removal of energy for growth and maintenance following the depletion of scarce resources by other forms of life. Competition can lead to the exclusion of rivals, promoting a reduction of population diversity with an increase in individual complexity. Competition can also, under certain conditions, select for niche construction. In this scenario, competition promotes more effective mechanisms for harvesting and protecting scarce resources. There is an

ongoing effort to identify useful proxies for competitive superiority, including social power.

Simplicity Driving Processes

Not all of historical processes lead to increases in hierarchical complexity. Many, if not the majority, lead to greater simplicity. I consider two.

1. Mutation-selection ratios. When rates of change are significantly greater than rates of repair, or of freezing (fixation), there is no possibility of memory being preserved, and consequently no prospect for interesting structures to be built. The clearest exposition of this risk is the error threshold in genetics, which states that beyond a threshold rate of mutation (equal to the reciprocal of the coding genome size), all adaptive information will be lost. The same will be true of many cultural objects. If cathedrals are raised as frequently as they are built, there will be no enduring monuments to faith.

2. Coevolution, autonomy and minimality. When networks of mutual dependencies have been established (food webs) and resources are shared by co-evolving lineages, then individual simplicity is very likely to evolve. The preservation of a regular history in the form of a genome for example, is not required if that history is preserved elsewhere. This is the essence of parasitism, which is the purpose-full exploitation of the history of a competing lineage. Biological parasites do not need to encode proteins that are provided with high probability by their hosts. Cultural parasites do not need to work to generate an income that they can easily steal. This leads to minimality in the life or production cycle, as formerly essential proteins or products that served to increase the survival probability of the organism in uncertain environments, are dispatched. When uncertainty is great, then autonomy is favored, taking the form of a larger genome capable of generating a more secure number of input-output functions and returning us to those scenarios of increasing complexity.

The major transitions are thereby associated with the factors: memory, frozen accidents, and processes of construction. These factors when considered alongside energy minimization, competition, and robustness, may be able to promote the emergence of levels amenable to historical explanation. When rates of change are too high, or resources inadequately monopolized, then historical signals are expected to disappear, or least become highly simplistic, and biased toward descriptions of sequences of events at microscopic levels. In this way metahistory seeks not only to provide some formalisms for historical analysis, but to establish the conditions upon which an `interesting' history is expected to exist.

Conclusion

In this chapter, I have identified shared elements of historical explanations. Coming from a background in an historical, natural science, I have sought to describe a few key concepts that might prove of some value in an empirically-based historical analysis more generally. These include the concepts of regularity, complexity, criticality, coarse-graining, intensivity and extensivity, levels of selection, major transitions, and emergence. These are not in circulation in current historiography, which has tended to steer away from the analysis of large, quantitative data sets, but could provide new concepts for organizing phenomena when this tendency is overcome. In discussing these various mechanisms and principles, I have tried to establish the legitimacy of a meta-history – a field of history that encompasses elements of physics, biology, anthropology, archeology, and more recent human culture. This is distinct from the practice of Big History – seeking to explore grand narratives encompassing both naturalistic and cultural dynamics – and stresses a variety of problems, concepts and methods that might be applicable to all historical fields. This approach is viewed as both compatible and cooperative with more traditional, textual, narrative history, and might even provide a justification for narrative approaches when regularities are incompressible.[4] Inevitability, there will be humanists who find all of these ideas distasteful (or euphemistically -- useless), and would rather not wrestle with the problem of, for example, coarse-graining events, by asserting that only simple-minded, or naive history, deals with events. My hope is that by drawing out explicitly the analogies among histories, we stand to gain from the transfer of ideas formerly sealed into the tombs of disciplinary scholarship:

> "They who enter this sacred tomb shall swift be visited by wings of death."
>
> —The curse of Tutankhamun. 1323 BCE

References

[1] Bennett, C.H. "How to Define Complexity in Physics, and Why." In Complexity, Entropy, and the Physics of Information, Edited by W. H. Zurek, 137-148. Redwood City, CA: Addison Wesley, 1990.

[2] Braudel, Fernand. A History of Civilizations. New York, NY: Penguin Group, 1995.

[3] Herodotus. Translated by: Donald Lateiner and G C Macaulay. The Histories. New York: Barnes & Noble Inc., 2004.

[4] The Book of nature, like a merchant's ledger, might be kept in a double entry style, one column listing phenomena which can be quantified and another listing things which can be qualitatively known [10].

[4] Crow, John A. The Epic of Latin America, Fourth Edition. Berkeley, CA: University of California Press, 1992.

[5] Dawkins, R. The Selfish Gene. New York, NY: Oxford University Press, 1989.

[6] de Visser, J.A.G.M., J. Hermisson, G.P. Wagner, L. Ancel Meyers, H. Bagheri-Chaichian, J.L. Blanchard, L. Chao, J.M. Cheverud, S.F. Elena, W. Fontana, G. Gibson, T.F. Hansen, D. Krakauer, R.C. Lewontin, C. Ofria, S.H. Rice, G. von Dassow, A. Wagner, and M.C. Whitlock. "Evolution and Detection of Genetic Robustness." Evolution 57 (2003): 1959-1972.

[7] Diamond, Jared. Guns, Germs, and Steel, First Edition. New York: W. W. Norton, 1997.

[8] Doyle, Sir Arthur Conan. A Study in Scarlet. United Kingdom: Ward Lock & Co., 1887.

[9] Ferguson, Kitty. Tycho and Kepler: The Unlikely Partnership that Forever Changed our Understanding of the Heavens. New York, NY: Walker & Company, 2004.

[10] Fischer, David Hackett. Historians' Fallacies; Toward a Logic of Historical Thought. New York: HarperCollins, 1970.

[11] Frank, S.A., and M. Slatkin. "Fisher's Fundamental Theorem of Natural Selection." Trends in Ecology & Evolution 7 (1992): 92-95.

[12] Fudenberg, Drew, and Jean Tirole. Game Theory. Cambridge, MA: MIT Press, 1991.

[13] Gell-Mann, M., and S Lloyd. "Information Measures, Effective Complexity, and Total Information." Complexity 2(1) (1998): 44-52.

[14] Gibbon, Edward. The History of the Decline and Fall of the Roman Empire. Boston, MA: Adamant Media Corp., 2000.

[15] Gould, Stephen Jay. The Structure of Evolutionary Theory. New York, NY: Harvard University Press, 2002.

[16] Keller, Laurent. Levels of Selection in Evolution. Princeton, NJ: Princeton University Press, 1999.

[17] Kimura, Motoo. The Neutral Theory of Molecular Evolution. Cambridge, MA: Cambridge University Press, 1983.

[18] Krakauer, D. C. "Evolution, Complexity and Metahistoricism." Nouvelles perspectives en sciences sociales 4 (2009): 53-67.

[19] Lewis, G. N., and M. Randall. Thermodynamics, Second Edition. New York, NY: McGraw-Hill Book Company, 1961.

[20] Nagel, Ernest. The Structure of Science: Problems in the Logic of Scientific Explanation. New York, NY: Harcourt, Brace & World, 1961.

[21] Namier, Lewis Bernstein. In the Margin of History. Manchester, NH: Ayer Publishing, 1967.

[22] Newton, Isaac. Philosophiae Naturalis Principia Mathematica (1822). Whitefish, MT: Kessinger Publishing, 2007.

[23] Pierre, Vilar. "The Age of Don Quixote." New Left Review, I/68, 1971.
[24] Prescott, William H. History of the Conquest of Mexico. The Modern Library. New York, NY: Random House, 1843, 2001 Edition.
[25] Smith, J., and E. Szathmáry. The Major Transitions in Evolution. New York: Oxford University Press, 1998.
[26] Thomas, Hugh. The Spanish Civil War. New York, NY: Simon & Schuster, 1994.
[27] White, Hayden. Metahistory: The Historical Imagination in Nineteenth-Century Europe. Baltimore: The Johns Hopkins University Press, 1973