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RASHEVSKY'S DREAM

A physico-mathematical foundation of history and culture

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The popular science fiction series *Foundation* penned by Isaac Asimov explores the idea that the course of the future of societies is not only predictable but can be engineered as well. In Asimov's fictional world, a multidisciplinary science called *psychohistory* combines mathematics, psychology, and history to predict future events. Nicolas Rashevsky, the father of mathematical biology, lent credibility to the existence of universal principles underpinning human cultural evolution using mathematical models. His vision remains to be fully realized, as our capacity to predict and even engineer is very fragmented. Two main obstacles are a misunderstanding of the role of mathematical models and the limitations of current datasets. Recent advances in complex systems research, computer-based simulations, and large-scale databases, are paving the way towards fully developing a mathematical theory of human history.

Keywords: **psychohistory**, **cliodynamics**, **culturomics**.

■ INTRODUCTION

Sociocultural evolution has been documented throughout the history of humans and earlier hominins. This evolution manifests itself through development from tools as simple as a rock used to break nuts, to something as complex as a spaceship able to land on other planets. Similarly, we have witnessed the evolution of the human population towards complex multi-level social organisation (e.g., chiefdoms and states). Although cases of decrease and loss of social complexity have been reported, in global terms complexity tends to increase with time. Despite its significance, the conditions and the factors driving complexity fluctuations are still poorly understood and subject to debate.

In the past, we have approached the study of history from a mainly qualitative perspective. Traditionally, many competing verbal *ad hoc* explanations have been proposed. For example, a German historian reported 210 alternative explanations for the fall of the Roman empire but, clearly, not all of them can be correct. Societies are dynamical systems with many interacting elements. Mathematics formalizes these complex feedbacks and allows us to extract reliable conclusions from these models, which cannot be arrived at intuitively. This approach has been immensely successful in physics and biology. Can something similar be done to understand historical dynamics?

«Societies are dynamical systems with many interacting elements»

When Hari Seldon, the discoverer of psychohistory in Asimov's story, finds that their galaxy spanning society is on the verge of collapse, he realizes the public will have a hard time believing him (Asimov, 2010). After all, their empire is fully functional and humans, in general, cannot wrap their heads around

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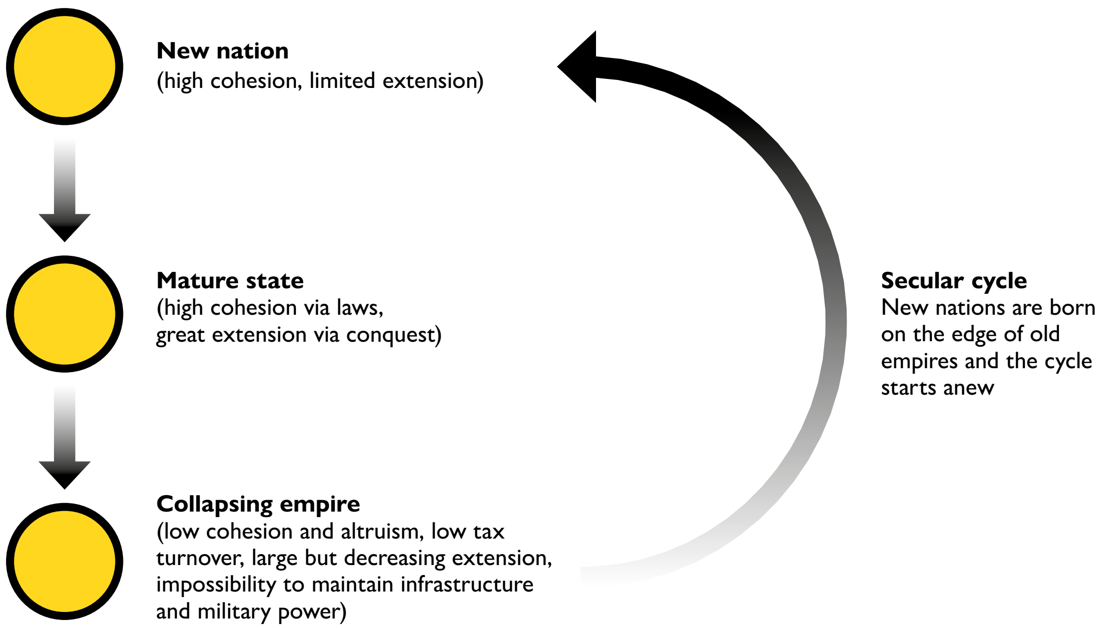
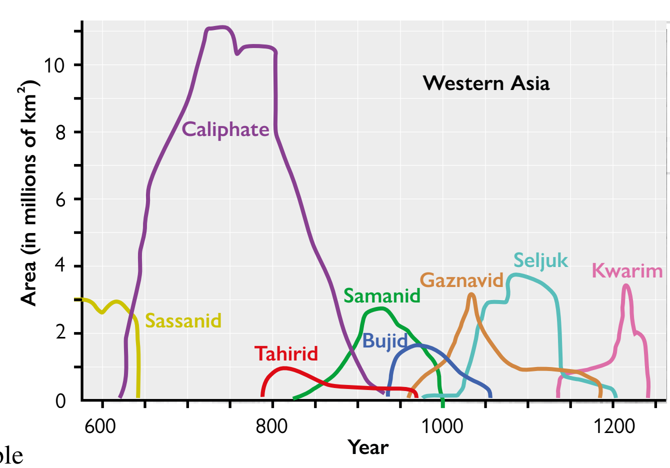


Figure 1: Cliodynamics. Above: The lifecycle of societal evolution («Secular Cycles Model») according to Peter Turchin, long-term historical trends are not the inexplicable consequence of «exogenously-driven reverses in population trends», but «the result of feedbacks operating with substantial time lags». Turchin analysed the global trends in the rise and fall of empires and nations, and he observed that there are regular patterns, which he calls secular cycles: dynamic similarities in the way nations are created, grow in power beyond what they can handle, and enter into territorial and population collapse over the course of a few centuries. Below: Example of empire historical dynamics in Western Asia. Several polities were born over the course of six centuries, rising, maturing and then collapsing (being substituted by newer nations).

SOURCE: Redrawn from Taagepera (1997)



non-linear and sudden changes in behaviour. Beyond the scepticism for his predictions Seldon faces danger, as many within the galactic empire see his work as a threat to the status quo of the social structure. In the real world, those proposing that mathematical theories could be used to predict human behaviour at the larger scales have sometimes faced similar responses.

Popular until the mid-20th century, the great man theory proposed that historical events are shaped by extraordinary individuals, whose leadership and resourcefulness transcends the limitations that the environment imposes on them and give rise to transformational events in societies and cultures. Such perspective can be found in many historical texts from antiquity to more modern times, in a reciprocating relation between the divine right to rule and those who codify history in human societies. This view was substituted for a more reasonable perspective of «things are complicated», where numerous competing factors (from demography to religion) can have an impact on pivotal periods of history and constitute their own microcosms with idiosyncratic rules and explanations. It is this overarching perspective that things are complicated and largely unpredictable that permeates the criticisms of mathematical theories of history.

In the fictional psychohistory, successful prediction depends on two main prerequisites or axioms. First, the population on which the behaviour is to be modelled must be large enough (approximately 75 billion) and second, individuals should remain ignorant of the application of psycho-historical analysis. These assumptions reinforce the idea that, while one cannot foresee the actions of a particular individual, in large societies individual activities «even out» and the general flow of future events becomes predictable. This very same development can be found in the transition from Newtonian physics (where predictability hinges on the ability to quantify the position and velocity of every object in a system) to Lagrangian physics (where the focus of the theory doesn't lie on individual particle motion but instead on system-level quantities and their evolution, like kinetic and potential energy). Critics of mathematical approaches to history have complained that humans are not like billiard balls, which when arranged in certain configurations and struck with the right amount of force, will inevitably roll down towards war or peace. Whether individual human psyches and behaviour can be predicted is a moot point, it only matters that in sufficiently large numbers of collections of humans have system-defining properties (like pressure or temperature in a collection of particles making up gas) that can be predicted and correlate to war or peace. However, this perspective that the human details do not matter, is diametrically opposed to the prevalent view in the West of human value found in uniqueness and individuality.

«The mathematical approach to history was dismissed as a niche topic for a few decades»

TOWARDS A MATHEMATICAL THEORY OF HISTORY

Different frameworks have been used to explain the rise of sociocultural complexity in human societies (in terms of demographic factor, cognitive component, historical contingency), but so far, no consensus has been reached.

Nicolas Rashevsky

Mathematical approaches to history have been inextricably linked to developments in mathematical biology. Many notable researchers in this area have been influenced by evolutionary theory and the multiple attempts to connect mathematics and evolution. Some were trained as biologists or started their careers in the life sciences (see below). This was the case of Nicolas Rashevsky (1899–1972), one of the fathers of mathematical biology and cliodynamics (Rashevsky, 1968). Initially a theoretical physicist, he crossed over to biology and quickly became interested in translating theoretical ideas into a full research program for mathematical biology. Humans are part of the natural world, and like many other species, their actions can shape the surrounding environment, which indirectly influences the actions of others (e.g., by means of technology). This suggested how mathematical models of individual behaviour could be extended to social interactions. Work done by Rashevsky and others in mathematical sociology demonstrated the feasibility of this approach, which paved the way for a more ambitious (and controversial) plan.

In Rashevsky's book *Looking at history through mathematics* (Rashevsky, 1968) an attempt to bridge mathematics and history was outlined. The book described a collection of elegant mathematical models for a wide range of historical processes. For Rashesvky, mathematics underpinned the search for any general principles, i.e., the «laws of nature». The existence of general laws governing both living systems and human societies was already proposed by Felix Auerbach, in 1913 *Das Gesetz der Bevölkerungskonzentration* (The Law of Population Concentration), and the book of George K. Zipf, *Human Behavior and the principle of least effort*, published in 1949. Rashevsky's plan followed this tradition but was met with scepticism and resistance by historians and philosophers, and it was dismissed as utterly simplistic. Rashevsky made clear that his intention was not to fit any specific system, but to develop the mathematical foundations for a science of history. However, historians have been doubting the existence of universal laws for some time, arguing that stylized models could not possibly explain the intricacies and uniqueness of human societies. Misunderstood, Rashevsy's book was largely forgotten, and the whole mathematical approach to history dismissed as a niche topic for a few decades.

Turchin and cliodynamics

A modern champion of the mathematical view of history is Peter Turchin, a former ecologist who draws some parallels between Hari Seldon and himself in his book, published in 2000, *War and peace and war* (Turchin, 2005). Turchin acknowledges strong influences beyond the literary domain, for instance classical works in ecological theory and dynamical systems, but also the fourteenth century Arabian philosopher Ibn Khaldun, often credited with founding various scientific disciplines including: historiography, sociology, and demography. In *War and peace and war*, Turchin defines a mathematical framework (cliodynamics) using tools from population biology to study and predict various social phenomena, from geopolitics to ethno-kinetics. Named after the Greek muse of history, Cliodynamics establishes a two-step approach to large-scale human history combining mathematics with rigorous empirical analysis.

First, Turchin establishes the need to translate verbal theories into mathematical models. This way causal links between variables can be formalized, allowing us to make testable, quantitative predictions and reach conclusions regarding the fabric that binds us to social structures. Furthermore, this wealth of theory and models needs to be tested against a robust dataset of coarse-grained historical variables, like demography and nation size. In particular, Turchin analizes global trends of rise and fall of empires and nations and realizes that there are regular patterns he calls secular cycles: dynamical similarities in the way nations coalesce, grow in power into overextension, and collapse in extension and population over the course of a few centuries (Figure 1). These cycles are not the result of exogenous causes acting on political, economic or social dimensions, but endogenous processes with feedback operating and very long timescales.

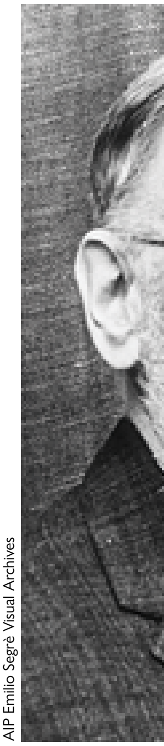
«A modern champion of the mathematical view of history is Peter Turchin»

To further our understanding of historical dynamics, Turchin and collaborators (2015) have established the Seshat: Global History Databank (named after the Egyptian goddess of knowledge and writing), as an invaluable resource of historical data across the ages, from cultural complexity, nation extension and population. This rich dataset should help social scientists around the world develop testable theories towards a formal understanding of cliodynamics, i.e., the creation of a true psychohistory. Seshat is theory-neutral, and it has been used to study a diversity of themes including the evolution of social complexity, the role of religion in promoting social cohesion, the rise and fall of empires, and many others. However, Turchin and collaborators have faced some strong criticism by offering only curated (coarse-grained) indicators instead of raw data. According to Spinney (2016), aggregated complexity is often not enough to establish causal inference and lower-level variables should be used instead, although she recognizes that Seshat should at least allow us to discard many verbal theories in sociology that have never been confronted with comprehensive datasets to fit.

Digital humanities, culturomics and Big data

An alternative to Seshat can be found in extensive datasets produced by the digital humanities. From the production of books to economic performance to social media messages, our civilization has turned into an «algorithmic society», generating about 2.5 quintillion bytes of data per day according to current estimates. To process these large amounts of information, big data approaches are necessary to sort and act on this data (both in the private and the academic domains).

In the case of literature, books provide a unique window into cultural evolution, back to the origins of writing. By looking at the collection of written records, we can hopefully reconstruct long-term historical patterns. But large-scale textual analysis is not free of difficulties. First, a longitudinal analysis of language is challenged by the fragmentation of information into individual books (Moretti, 2013). And second, data completeness (especially for ancient texts) creates a sizable void in our understanding, making a comprehensive theory very challenging. A new discipline, the digital humanities, has emerged to deal with this wealth of information. In this context, large-scale book digitization projects represent an essential component of the quantitative approach to humanities. One of the forerunners was the book digitization project at Google, and the associated field of culturomics: the study of cultural trends through the quantitative analysis of large collections of digital media. A collaboration between Google and Harvard University scanned approximately 12 % of all books ever published (around 15 million printed books). This massive collection (which can be freely accessed through google n-gram) (Michel et al., 2011) is used to trace long-term trajectories of word frequencies in printed books (see Figure 2). It was proposed that culturomics maps collective behaviour in the big-data era, but it is not well-understood how universal word trajectories are, and if they can be used to predict future trends.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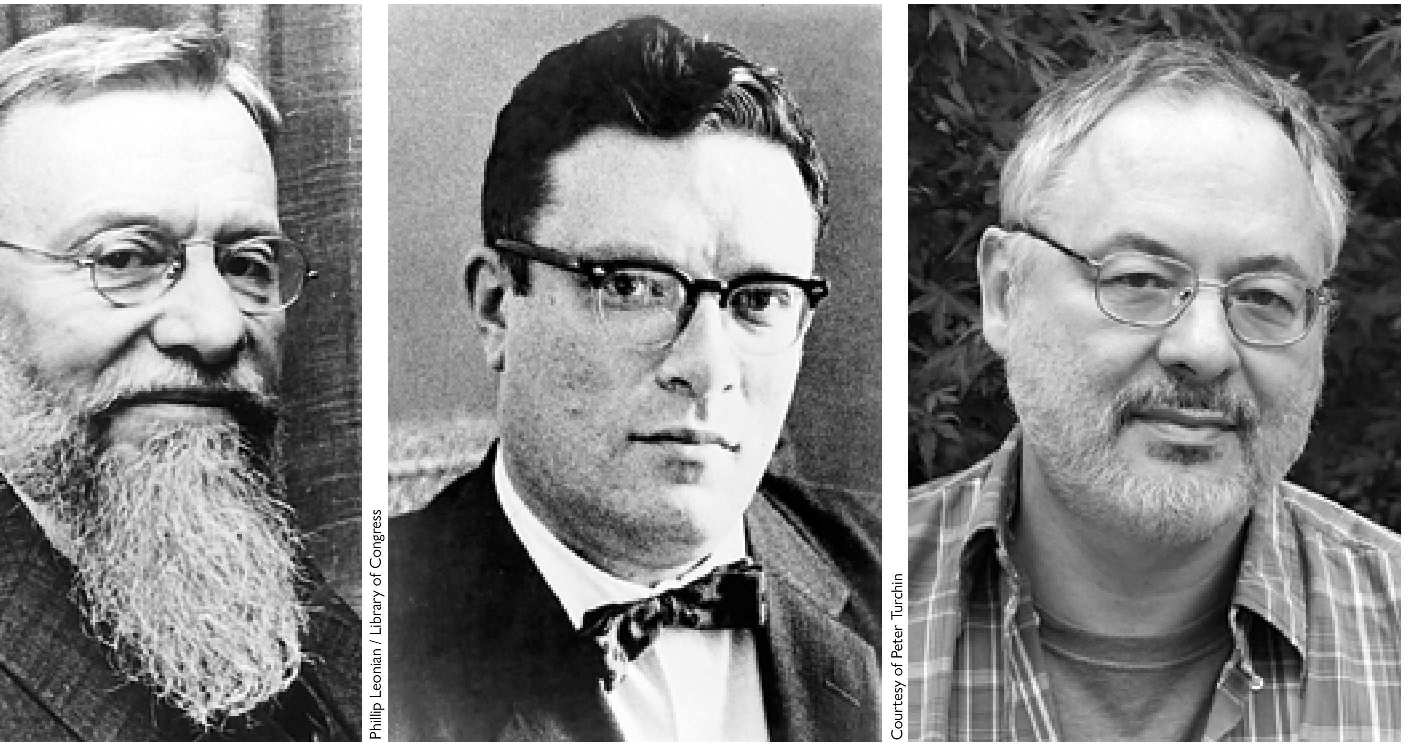
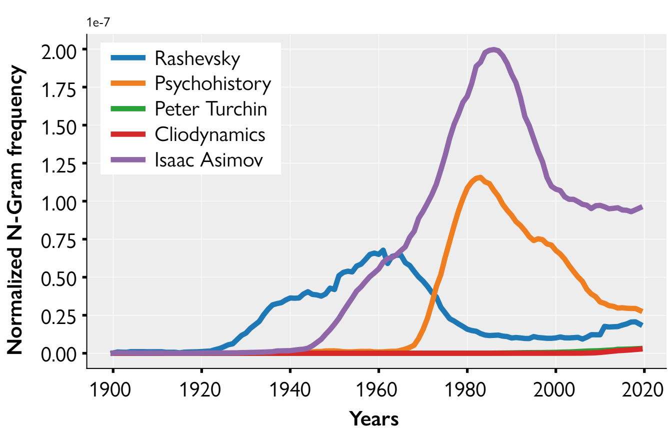


Figure 2: Culturomics and big data. Books provide us with unique insight into cultural evolution from the origins of writing, and their digitisation allows us to trace conceptual evolution and usage across printed literature. Above, from left to right: Nicolas Rashevsky (1899–1972), Isaac Asimov (1920–1992) and Peter Turchin (1957), the three champions of the mathematical approach to history. Below: Usage frequency over time of Rashevsky, psychohistory, Peter Turchin, cliodynamics, and Isaac Asimov in millions of printed books (1900–2019). Thanks to digitised data, we can observe the periods in which these concepts were most used in literature.



A limitation of such big data approaches is the lack of control over theoretical variables. By focusing on what has already happened, we limit our theories and predictions to outcomes already observed. A difference lies in devising real-world experiments that address unobserved scenarios. For instance, researchers have explored the role of group size in collective decision making. It has been found that individuals with partial understanding of a problem can team together to become better at collective decision making (Prelec et al., 2017). Other works have explored the role of leadership positions among groups, finding that even individuals in non-leadership roles can have a lasting impact in collective decisions if their decision is communicated early. This has been justified by a basic human psychological drive to conform to previously expressed emotions and beliefs. These results give context to the population threshold of 75 billion proposed by Asimov, suggesting that cultural evolution in small groups is subject to individual decisions that can become disproportionately important.

DISCUSSION

Historians and philosophers have been reluctant to accept the mathematical approach to history. Underlying their criticisms underlies the assumption that history is a chaotic mess of interrelated events that no one can possibly disentangle. As the study of complex systems has shown us, it is precisely in this context where mathematical models are not only useful, but an indispensable tool to make sense of a complicated world. Such models are necessarily simplified versions of reality, a model as complicated as the real world is non-actionable. The alternative perspective where human histories are not the subject of mathematical models, means that all verbal theories are possible and cannot be confronted with real world data.

A simplification that historians have found particularly hard to accept is the irrelevance of the individual choices at the largest scales of societal evolution. Experimental psychology has corroborated that, at least in small groups, individuals and leaders can steer collective dynamics. In the real societies of the past, collective dynamics emerged through the interactions of many individuals, driven by cooperation and conflict. Nowadays, electronic communications have brought important social, behavioural, and economic changes. Modern post-industrial states display growing individualism, which can paradoxically push them closer to the physics of billiards by removing social interactivity. This isolation in modern societies poses numerous global challenges, including increasing xenophobia, reactionary politics and autocratic threats to democracy as evidenced by recent events (Bak-Coleman et al., 2017).

Rashevsky's vision of a mathematical theory of history remains to be fully realized. Such a theory hinges on our ability to sift through enormous datasets being continuously generated and finding the proverbial needle in a haystack. Strikingly, data completeness (the possibility that our knowledge is incomplete) is also a real challenge in all historical sciences, including evolutionary biology. This is especially true in archaeology, but also in the digital era: not everything that humans do is preserved and there is a real danger of losing important bits of historical information. This threat has been identified in fields that we typically think of as secure, like innovation (patent data, scientific publications) or historical context (news). Just as an organism decays with age, so too does the body of knowledge accumulated in our society. Without properly preserving information and a coherent theoretical framework that recapitulates historical trends, we are condemned to live in a universe where we will never fully understand the social nature of human history.

«A mathematical theory of history hinges on our ability to sift through enormous datasets being continuously generated»

But we do not need to despair. A Rashevsky in the time of Big Data and the Internet would probably have gone further. Rashevsky struggled to establish a mathematical approach to biology and history. Today, large-scale data collection projects are underway, together with many efforts in theoretical and computational modelling of history and cultural evolution. The time is ripe for recovering Rashvesky's dream towards a psychohistory 2.0 that will allow us to model cultural and historical dynamics upon the existing wealth of data. ⊕

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