13

Human History: A Science Matter

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Human history is the most important discipline of study. The complex system under study in history is a many-body system consisting of *Homo sapiens*—a (biological) material system. Consequently, history is a legitimate branch of science, since science is the study of Nature which includes *all* material systems. A historical process, expressed in the physics language, is the time development of a subset of or the whole system of *Homo sapiens* that happened during a time period of interest in the past. History is therefore the study of the past dynamics of this system. Historical processes are stochastic, resulting from a combination of contingency and necessity. Here, the nature of history is discussed from the perspective of complex systems. Human history is presented as an example of Science Matters. Examples of various scientific techniques in analyzing history are given. In particular, two unsuspected *quantitative* laws in Chinese history are shown. Applications of active walks to history are summarized. The "differences" between history and the natural sciences erroneously expressed in some history textbooks are clarified. The future of history, as a discipline in the universities, is discussed; recommendations are provided.

13.1 What is History?

Human history is the most important discipline of study [Lam, 2002]. Yet, human history, or history in general, as a science is rarely discussed [Lam, 2002; Krakauer, 2007].

Science is the study of Nature and to understand it in a unified way. Nature, of course, includes all material systems. The system investigated in history is a (biological) material system consisting of *Homo sapiens*. Consequently, history is a legitimate branch of science, like physics, biology and paleontology, and so on. In other words, history is not a subject that is beyond the domain of science. History can be studied scientifically [Lam, 2002].

By definition, history is about past events and is irreproducible. In this regard, it is like the other "historical" sciences such as cosmology, astronomy, paleontology and archeology. The way historical sciences advance is by linking them to systems presently exist, which are amenable to tests. For example, in astronomy, the color spectra of light emitted in the past from the stars and received on earth can be compared with those observed in the laboratory; the elements existing in stars is then identified. Similarly, the psychology, thoughts and behaviors of historical players can be inferred from those of living human beings, which can be learned by observations, experimentations and neurophysiologic probes [Feder, 2005].

The system under study in history is a many-body system. In this system, each "body" is a human being, called a "particle" here; these particles have internal states (due to thinking, memory, mood and so on) which sometimes can be ignored. Each constituent particle is a (non-quantum mechanical) classical object and is distinguishable; that is, each particle in the system can be identified individually. This many-body system is a heterogeneous system, due to the different sizes, ages, races…of the particles.

A historical process, expressed in the physics language, is the time development of a subset of or the whole system of *Homo sapiens* that happened during a time period of interest in the past. History is therefore the study of the past dynamics of this system. *Historical processes are stochastic, resulting from a combination of contingency and necessity*.[1] Here, necessity is an assumption, which could only be confirmed by results showing that it really exist; contingence is due to the many other factors not included in the system under study—as usually is the case in many complicated situations—and could be represented as noise in the study of stochastic systems.

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[1] "Stochastic" is a technical word in physics, meaning that probability appears somewhere in the process; a random process is a special case [Paul & Baschnagel, 1999].

In modeling, contingency shows up as probability and necessity is represented by rules in the model. The situation is like that in a chess or soccer game. There are a few basic rules that the players have to obey, but because of contingency, the detail play-by-play of each game is different. In principle, someone with sufficient skills and patience can guess the rules governing historical processes, like those in a chess or soccer game.

In some cases, these two ingredients of contingency and necessity, through self-organization, may combine to give rise to discernable historical trends or laws. In other cases, either no laws exist at all or the laws are not recognized by whoever studying them. Whether there actually exist historical laws cannot be settled by speculations or debates, no matter how good these speculations or debates are. *A historical law exists only when it is found and confirmed* (as indeed is the case as shown in Sections 13.2.1 and 13.2.4). Furthermore, any historical law—like that in physics—has its own range of validity, which may cover only a limited domain of space and time. Yet most people, including many historians, do not believe that any historical law could exist [Gardiner, 1959]. They are wrong.

13.2 Methods to Study History

An important step towards the scientific study of any subject is to pick the right tool to tackle it. Historical processes are stochastic. The kind of physics suitable for handling many-body systems ingrained with contingency is statistical physics. Furthermore, the historical system is an *open* system with constant exchange of energy and materials with the environment and is never in equilibrium. Thus, for history, an appropriate tool is the stochastic methods developed in the statistical physics of nonequilibrium systems [Lam, 1998; Paul & Baschnagel, 1999; Sornette, 2000].

However, there are other tools, too. In fact, there are at least four different approaches applicable in understanding history. Examples are given below, with each reflecting either the *empirical*, *phenomenological* or *realistic* level commonly found in the scientific development of any discipline [Lam, 2002].[2]

13.2.1 *Statistical Analysis*

Statistical analyses of data are at the empirical level, without knowing the mechanism of the processes involved. Two examples are given here.

1. Power law in the distribution of war intensities

Figure 13.1a shows a historical law of statistical nature; historical laws do exist. The statistical distribution of war intensities obeys a power law[3] (Fig. 13.1a), first discovered by Richardson [1941] and confirmed by Levy [1983] using a different data set covering 119 wars from 1495-1975. In this new study, war intensity is defined by the ratio of battle deaths to the population of Europe at the time of the war. (Europe is used because for the earlier wars, estimates of the world population are unreliable.) More recently, this conclusion is interpreted by Roberts and Turcotte [1998] in terms of a forest-fire model. Similar power law is found in the distribution of earthquake intensities, called Gutenberg-Richter law (Fig. 13.1b), in the ranking of city populations, and in many other systems [Zipf, 1949]. The fact that human events like wars obey the same statistical law as inanimate systems indicates that the human system does belong to a large class of dynamical systems in Nature, beyond the control of human intentions and actions, individually or collectively.

2. Power law in the distribution of Chinese regime lifetimes

Another example is provided in the case of Chinese history. China has a long, unbroken history, which is probably the best documented [Huang, 1997]. The dynasties from Qin to Qing ranges from 221 BC to 1912, with 31 dynasties and 231 regimes spanning a total of 2,133 years [Morby, 2002]. (A regime is the reign of one emperor; a dynasty may

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[2] For history, there is also the *artificial* level—artificial history [Lam, 2002].

[3] In a power law, two variables x and y relate to each other through $y = Ax^{\alpha}$, where A and α are constants. Equivalently, the plot of log x *vs*. log y shows up as a straight line.

consist of several regimes.) Some of these dynasties overlap with each other in time.

Let τ_R be the regime lifetime, an integer measured in years. The histogram of τ_R is found to obey a power law (Fig. 13.2), with an exponent equal to -1.3 ± 0.5 [Lam, 2006a; 2006b]. This result implies that the dynamics governing regime changes is not completely up to the emperors, statistically speaking, but share some common traits with other complex systems such as those displayed in Fig. 13.1. To the best of our knowledge, this is *the first quantitative law concerning Chinese history*.

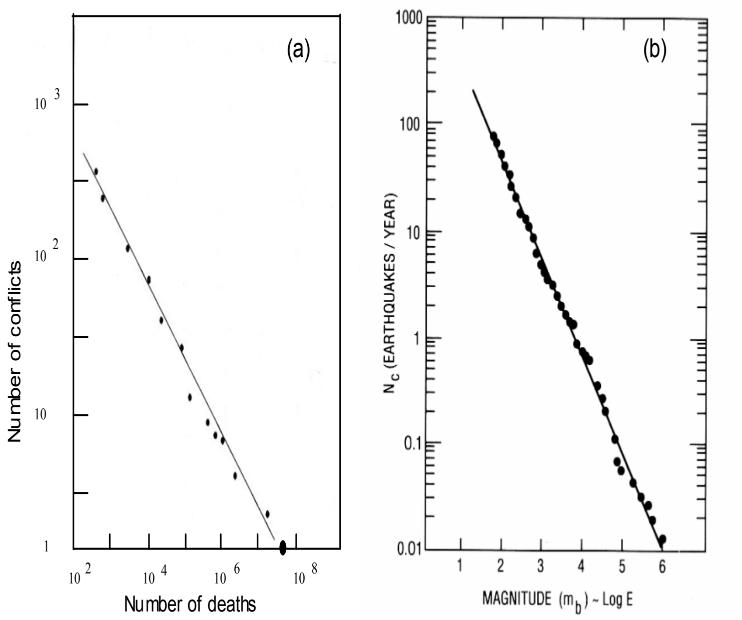

Fig. 13.1. (a) Statistical distribution of war intensities. Eighty-two wars from 1820 to 1929 are included; the dot on the horizontal axis comes from World War I. (b) Distribution of earthquake sizes in the New Madrid zone in the United States from 1974 to 1983 [Johnston & Nava, 1985]. The points show the number of earthquakes with magnitude larger than a given magnitude *m*. The graphs in (a) and (b) are log-log plots; a straight line indicates a power law.

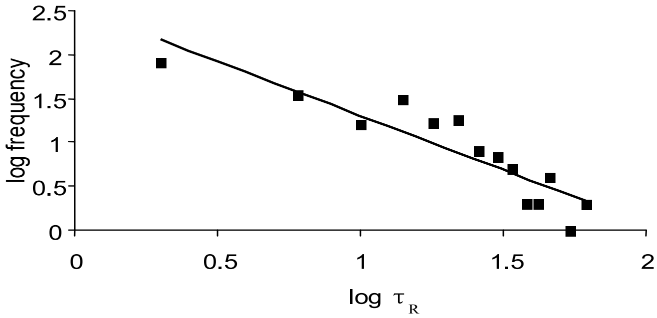

Fig. 13.2. Log-log plot of the histogram of Chinese regime lifetime τ_R, covering the years from 221 BC to 1912. (Bin width of the histogram is 4 years.)

13.2.2 *Computer Modeling*

A common metaphor for history is that it is like a river flowing; people talk about the "river of history." This metaphor is not so off mark if the water flowing in the river is able to reshape the landscape as it flows, and the river is allowed to branch from time to time under certain conditions. Active walk (AW) [Lam, 2005a; 2006b] is a natural in matching such a metaphor. It is then no surprise that a whole class of probabilistic AW models are found to be relevant in studying history [Lam, 2002].

Active walk is a paradigm and method introduced by Lam in 1992 to handle self-organization and pattern formation in simple and complex systems. In AW, a particle (the walker) changes a deformable potential—the landscape—as it walks; its next step is influenced by the changed landscape. For example, ants are living active walkers. When an ant moves, it releases chemicals of a certain type and hence changes the spatial distribution of the chemical concentration. Its next step is moving towards positions of higher chemical concentration. In this case, the chemical distribution is the deformable landscape. Active walk has been applied successfully to a number of complex systems in "natural"[4] and

[4] In this chapter, "natural science" with quotation marks is defined as the science of mostly simple systems [Lam, 2008a].

social sciences. Examples include pattern formation in physical, chemical and biological systems such as surface-reaction induced filaments and retinal neurons, the formation of fractal surfaces, ionic transport in glasses, granular matter, population dynamics, bacteria movements and pattern forming, food foraging of ants, spontaneous formation of human trails, oil recovery, river formation, city growth, economic systems, parameter networks [Han *et al*., 2008] and, recently, human history [Lam, 2002; 2004; 2006b]. Here are some examples of application of AW in history—modeling at the phenomenological level.

1. Modeling economic history: why an initially disadvantageous product can catch up and win out in the market?

A Florence cathedral clock, built in 1443, has hands that move *counterclockwise* around its dial [Arthur, 1990]. Consequently, two types of clocks, with hands moving in different directions, could be in the market in those early years. However, since sundials, the timepiece before the invention of clocks, in the north hemisphere have the pointer's shadow moving clockwise, people in Europe are more comfortable with clocks having hands moving clockwise, too. Those "counterclockwise" clocks, like the Florence cathedral clock, are thus "inferior" products and they are soon run out of the market. That is why we are now left with only one type of clocks, those having hands running clockwise. This is the case of an inferior product losing out, which is not at all surprising. What is surprising is the case of an inferior product winning out. The "QWERTY" keyboard, the type we are using today, is such an example [David, 1986]. Invented in 1867, this keyboard is designed to slow down our typing so the mechanical parts will not be jammed that easily. Other superior designs, such as the Maltron keyboard—with 91% of the letters used frequently in English on the "home row" compared to 51% for the QWERTY design—coexist in the market but all lose out. Why?

The two-site AW model [Lam, 2005a] is able to explain this and other real cases[5] in economic history that an inferior product can actually win out in the market [Lam, 2002].

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[5] Other examples are the competition between Apple computers and the PCs, as well as Beta and VHS videotapes. In each case here, the second product is the inferior product.

2. Modeling evolutionary history: rewinding life's "tape," or how important is contingency in survival?

In 1989, Stephen Jay Gould (1941-2002) [1989] publishes the book *Wonderful Life*. From the fossil record found outside of Vancouver, Canada, it seems that some "advanced" organisms (with many legs, say) that should survive are wiped out suddenly. From this one data point, Gould concludes that contingency is extremely important, that is, not the fittest will survive, contrary to what Darwin's evolution theory asserts. He asks: If life's tape is replayed, will history repeat itself and humans can still be found on earth? His own answer is "no." Debates go on but nothing is done seriously and scientifically. Worse yet, there is no second data point forthcoming. Our active-walk aggregation (AWA) model [Lam & Pochy, 1993; Lam, 2005a] is able to shed light on this debate. The AWA model says "maybe" in answering Gould's question [Lam, 1998]. It is "maybe" because if the world lies in the "sensitive zone",[6] then the growth outcome may not be repeatable; otherwise, it is repeatable, more or less. The problem is to know where our world sits.

3. Modeling social history: will all societies end up as liberal democratic societies?

Francis Fukuyama, considered one of fifty key thinkers on history, publishes in 1989 an article, "End of History?" [Fukuyama, 1989]. He asserts that every human being needs two satisfactions, namely, economic well being and "recognition," with the latter meaning respect by others. He argues that since the liberal democratic society is the only one that can satisfy its citizens on these two basic needs, consequently, given enough time, all societies will end up as liberal democratic societies. And that will be the end of history, if history is understood to be the directional change in societal forms. Misunderstandings of Fukuyama's thesis ensure and debates go on in the history profession. Nothing is done scientifically to settle the issue.

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[6] The sensitive zone is a region in the parameter space, within which, for the same set of parameters, different runs of the computer model may result in different patterns due to the use of a different sequence of random numbers in each run.

In our view, the two human needs suggested by Fukuyama should be generalized to "body satisfaction" and "soul satisfaction." After all, body and "soul" (or spirit) comprise the whole of a human being. And we know for sure, for example, when someone joins a revolution to change the society, the person may give up her or his life before the revolution succeeds, if at all—and recognition is not in the person's mind. The degrees of satisfaction of "body" and "soul" in each society can be quantified by two indices, obtained from a survey of its citizens. To test Fukuyama's thesis, one can represent each society as an active walker, a particle, moving in the two-dimensional space of "body" and "soul" indices (see Fig. 13.3) [Lam, 2002]. At each point in this space, a "fitness" potential can be defined. The movement of each particle (usually, but not always, up the scales) will change the fitness landscape and influence the movement of other particles. The problem will be to find out, under what circumstances, all the particles will cluster together at the location corresponding to a liberal democratic society. It is thus a problem of clustering of active walkers in a two-dimensional deformable landscape.[7]

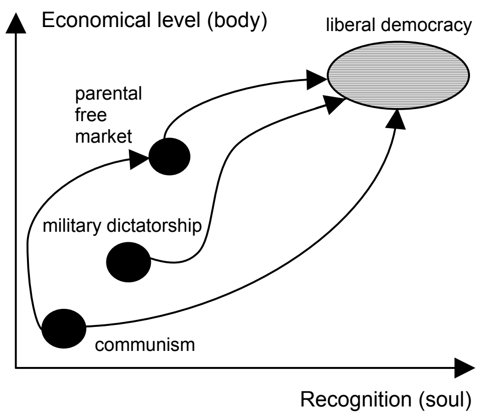

Fig. 13.3. Sketch of an active walk model for the evolution of political systems.

[7] The model can be generalized to include the possibility that two particles may combine into one, and some particles may split into two or three—some kind of chemical reactions—corresponding to the case in history that countries may get unified or fragmented in time.

Such a problem has been studied before in physics in another context, and clustering of active walkers indeed occurs [Schweitzer & Schimansky-Geier, 1994]. The corresponding investigation in history as outlined above will bring Fukuyama's historical study one level up, as scientific level is concerned, and serve as an example in other cases.

Note that AW is not the only paradigm possible in modeling history. And, in rare occasions, modeling of a system can be done analytically without the use of computers.

13.2.3 *Computer Simulation*

Another approach is the method of computer simulations, which usually are at the realistic level—with the mechanisms incorporated, even only simplified mechanisms. Here is a very interesting example.

<u>Simulating the growth of a historical society</u>

A simulation of the development of a society in the Long House Valley in the Black Mesa area of northeastern Arizona, USA, was carried out by Axtell *et al.* [2002]. The simulation results show agreement with the quantitative historical data, which are reconstructed from paleoenvironmental research based on alluvial geomorphology, palynology and dendroclimatology. For example, between the years *anno Domini* 400-1400, the number of households has two peaks; this is reproduced in the simulation. So is the evolution of the spatial distribution of settlement. In this study, heterogeneity in both agents and the landscape, hard to model mathematically, is found to be crucial. The modeling starts with a landscape reconstructed from paleoenvironmental variables, which is then populated with artificial agents representing individual households. Five household attributes are specified, together with household rules guessed from historical data. The model involves 14 reasonably chosen parameters, plus eight adjustable parameters for optimization. The model is very detailed. It is interesting to see whether the model can be simplified to its bone, with fewer parameters, that can still produce essentially the same results.

13.2.4 *The Zipf Plot*

Sometimes, very interesting results can be obtained from some very simple techniques which are quite well known in the field of complex systems. An example is the use of *Zipf plot*, which is at the empirical level. To obtain this plot for a given sequence of numbers, there are four steps:

1. The sequence of numbers is rearranged in a decreasing order.
2. Redundancy is removed by keeping only one number among those of same magnitude, resulting in a sequence of monotonic decreasing numbers. [8]
3. The largest number is assigned rank 1, the second largest rank 2, etc.
4. The Zipf plot is the curve appearing in the plot of the number *vs.* rank (with rank as the horizontal axis).

Here is an example concerning the Chinese dynasty lifetimes [Lam, 2006a; 2006b]. The lifetime of a Chinese dynasty τ_D is the sum of regime lifetimes τ_R, corresponding to all the emperors within the same dynasty. The Zipf plot of τ_D is given in Fig. 13.4, with the presence of 26 data points, less than 31 (the number of available dynasties), due to the adopted procedure of removing redundancies in the data sequence. The data points fall on two straight lines—a result named the *bilinear effect* [Lam, 2006b; Lam *et al*., 2008]. It implies that

1. The "curse of history," as Chinese dynasties are concerned, does exist.
2. A dynasty can survive every 3.5 ± 0.1 years if it lasts 57 ± 2 years or less; beyond that, every 25.6 ± 0.1 years—dynasty lifetime is discrete, or "quantized."
3. There is a transition point separating these two different behaviors.

[8] Other people might retain all the numbers of the same magnitude in the sequence, resulting in a Zipf plot which could contain horizontal parts. Our version here is more reasonable, because one would like to fit the plot to a smooth curve.

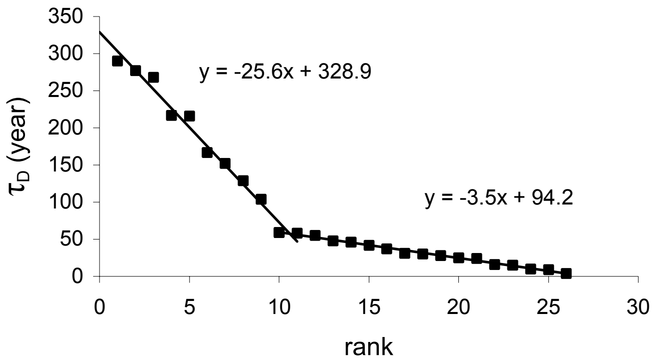

Fig. 13.4. The Zipf plot of Chinese dynasty lifetime τ_D, an example of the bilinear effect.

This is *the second quantitative law concerning Chinese history*. Whether the discreteness in τ_D results from some periodic external conditions in the Chinese history or is a self-organizing phenomenon resulting from some nonlinear dynamics remains to be investigated.

The bilinear effect is the phenomenon that an adaptive system becomes stronger after existing for a period of time. The mere fact of survival reinforces its strength, through learning, restructuring, and so on. Similar behavior is known to exist in the case of restaurants, corporations or biological species. What is surprising here is the presence of two linear lines and a sharp transition point (in the Zipf plot).

A *quantitative* prediction could be inferred from Fig. 13.4. Under the *assumption* that Chinese dynasties remain in the bilinear-effect class, any dynasty after Qing, if exists, will either

1. last 303 ± 1 years or less, and fall more or less on the two lines in Fig. 13.4; or
2. end definitely and exactly in its year 329 ± 1.[9]

[9] The number 303 is the height at rank 1 on the straight line in Fig. 13.4; 329, that at "rank" 0.

Note that the second law, corresponding to Fig. 13.4 (in contrast to the first law in Fig. 13.2), is *not* statistical in nature; and this prediction is not a statistical prediction. These two laws and the prediction concerning Chinese history are both quantitative and model independent. As far as we know, no other quantitative, non-statistical historical laws and predictions are known, to the historians or others.

The essence of a dynasty is not much the succession mechanism within a family, but the way of governance resulting from that mechanism. The "curse of history" spelled out here in Fig. 13.4 can be avoided only if one is willing to move the country away from the trajectory of the two straight lines, by abandoning the old ways of doing things.

It turns out that this regularity in Chinese history is only a particular case of the bilinear effect; more examples are subsequently found in other human affairs and complex systems (Fig. 13.5) [Lam *et al*., 2008]. Figure 13.5a is the Zipf plot of the number of votes for Chinese *xiaopin* actors.[10] Figure 13.5b comes from the airline quality ratings in the year 2005.[11]

In other words, the bilinear effect is a *new* class of Zipf plots, apart from the other two well-known classes—power laws [Newman, 2005] and stretched-exponent distributions [Laherrère & Sornette, 1998].

The generic mechanism behind bilinear effect is not yet understood. But we do know more than one way to obtain the bilinear effect [Lam *et al*., 2008]. For example, first pick N_p number of points according to a one-peak probability distribution function $p(x)$, say, to obtain a sequence of numbers $\{x_i\}$, with $i = 1, 2, \ldots, N_p$. That is, the probability that x_i being picked is proportional to $p(x_i)$. A Zipf plot is then performed with this sequence $\{x_i\}$. With luck, the Zipf plot is bilinear.[12] The chance of obtaining bilinear effect increases as N_p is increased. Such a mechanism is applicable to the case in Fig. 13.5a, wherein, the votes were cast

[10] ent.sin.com.cn/2004-09-30/1050521359.html (Oct. 7, 2004). *Xiaopin* is a popular form of short drama performed by a cast of usually two actors in China.

[11] www.aqr.aero.

[12] Experience shows that the one-peak shape of $p(x)$ is not a necessity in obtaining bilinear effect this way. Sometimes, a monotonic decreasing $p(x)$ also works; but so far, a decreasing power-law $p(x)$ does not seem to work.

independently by people on the Web from a *xiaopin* list. It is not applicable to the Chinese dynasties, the lifetimes of which are obviously correlated.

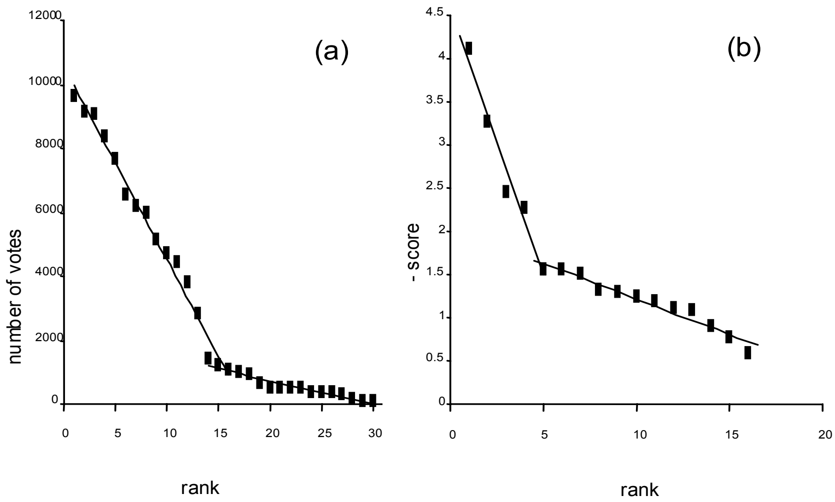

Fig. 13.5. Two additional examples of the bilinear effect. Zipf plots of (a) popular votes for *xiaopin* actors, and (b) airline quality data.

13.3 History in the Future

The importance of history can be seen, for example, through its negative impact on human lives. Powerful political leaders could mistake an unproven historical hypothesis as firm theory, apply it to a confined population and cause millions of death in a few short years [Lam, 2002]. Another example is the massive protests in China few years ago, due to different interpretation of past history involving two countries (Fig. 13.6). Yet, in spite of its importance, the physical basis of history is unrecognized by most historians. For instance, in the historiography textbook *The New Nature of History* [Marwick, 2001] the alleged "fundamental differences" between history and the sciences are listed:

Fig. 13.6. Protests in China, April 2005. (a) “FACE HISTORY” is the slogan on the left placard. (b) “PROTECT DIAOYUDAO” is a historical issue also raised in the protests. Diaoyudao, or diaoyutai, is a group of tiny islands in the East China Sea. The “protect diaoyutai” movement was started by oversea Chinese students in the United States at the end of 1970 [The Seventies Monthly, 1971].

1. Fundamental difference in the subject of study: natural sciences concern natural world and physical world; history concerns human beings and human society, very different in character.
2. No controlled experiments by historians.
3. Historians develop theories and theses, but not concerned with developing laws and theories like that in sciences.
4. History studies do not have prediction power.
5. Relations and interactions in history studies are not expressed mathematically.
6. Historians report their findings in prose (articles or books), not in terse research articles.

Unfortunately, all six points are wrong, for the following reasons.

1. As explained in Section 13.1, human beings and thus human society are material systems, which are part of the natural sciences. Human society share same characteristics as other inanimate complex systems, as demonstrated in Figs. 13.1, 13.2, 13.4 and 13.5.
2. Some physical disciplines like astronomy and archeology also do not have controlled experiments.
3. It is untrue that all historians are not concerned with developing laws and theories in history. Some tried, not very successfully, partly due to their inadequate training in using scientific tools. Historical laws do exist, as shown in Sections 13.2.1 and 13.2.4 and in Figs. 13.1, 13.2 and 13.4.
4. History studies, like that in Section 13.2.4, do have prediction power.
5. Relations and interactions in history studies can be expressed mathematically. An example is the landscape theory of Axelrod and Bennett [1993] to show how and why 17 European nations in World War II aligned themselves into two large groups. The pairwise propensities between nations are assigned numerical values, and the configuration energy in the (fixed) landscape is given in equations.[13]

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[13] See [Galam, 1998] for a comment on this work, and the following response by the original authors.

6. Historians do report their findings in research articles, terse or not. That is why there exist quite a number of history journals, such as *History and Theory* and *American Historical Review*. It is true that many historians still skip the peer-reviewed journals and directly report their findings in books—not a healthy thing for the history discipline, epistemologically speaking [Lam, 2002]. These are actually popular history books, like the popular science books written by physicists.[14] In the case of the history profession, there are at least three reasons behind this practice. (1) Many research results in history are still at the data gathering and empirical analysis stage, not very technical and can be presented in narratives. (2) There is enough number of readers out there who is willing to pay to find out what happened to their ancestors or their own kind in the past. In contrast, not that many will pay to learn what happened to the electrons. Bad for physics. (3) Historically, before history became a professional discipline in the universities in the second half of the nineteenth century, historians had to earn their living by writing books that are readable and salable to the public [Stanford, 1998]. In other words, writing popular history books was a survival need for historians, a tradition carried over up to now.

These errors are due to misunderstanding of the nature of science, and the neglect of the material basis of the historical system itself. The inadequate science training received by historians, past and present, explains why they failed to find historical laws. For example, the Chinese dynasty data have been lying there after 1912; the plots in Figs. 13.2 and 13.4 could be carried out by hand without computers, and even by high school students. But unless one knows about power laws and the existence of the Zipf plot, there is no motivation to do so. And these are current topics in the study of complex systems. Ironically, Zipf plots were first done by George Zipf (1902-1950), a Harvard linguist, with data from the humanities and social sciences.

[14] The unique characteristics of popular-science books and how to integrate them into science teaching are discussed in [Lam, 2001; 2005b; 2006c; 2008b].

Quite recently and surprisingly, while the importance of history is well recognized in Hong Kong, the history department of the University of Hong Kong is threatened with closure because it fails to attract enough number of students [Xie, 2005]. Anyway, it is time for all history departments to revamp their curriculum, by increasing the mathematical skills of their students, going beyond story telling and making history research more technical and scientific, and creating a course on the physics of history (or *histophysics* [Lam, 2002; 2004]). This revamp will help current students to become better historians after they graduate, and may appeal to a new class of incoming students who have a technical background but feel attracted more to the humanities than the traditional sciences.

13.4 Conclusion

As shown above, human history can indeed be studied scientifically, using techniques borrowed from physics and complex systems. Human history is thus a true example of Science Matters (SciMat), the new discipline that treats all human-related matters as part of science [Lam, 2008a; 2008c]. This, of course, does not imply that the conventional studies by other historians or the existing history departments should be abolished. On the contrary, they are very valuable. They are doing splendid jobs at the *empirical level*, the first level in the scientific development of any discipline, which is to collect data, analyze and summarize data, and come up with "explanations" in understanding them. Yet, the explanations are usually educated guesses—"hypotheses" but not yet "theories," in the sense that a theory is a confirmed hypothesis. The single-event, unrepeatable nature of history makes the direct confirmation of a hypothesis very difficult, unlike the case in many "natural sciences." It is at this point that history as a SciMat enters, as illustrated in Section 13.2.

As demonstrated, with a little bit of luck and the right perspective and right tool, a hidden historical *law* (not merely a historical trend) might suddenly jump out and meet the eyes of the investigator. With a lot of luck, this historical law might even lead one to the discovery of a general principle in Nature (such as the bilinear effect).[15]

What we try to do is to raise historical studies to a higher scientific level—to the phenomenological and realistic levels. To this end, collaborations between traditional historians and physicists are strongly urged. And everybody gains.

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[15] Starting with a particular case and ending with a general principle is the common route of discoveries in physics and other disciplines. We ourselves have experienced this before: the modeling of filamentary patterns found in thin cells of electrodeposit experiments led us to active walks, a general paradigm for complex systems [Lam, 2005a; 2006b]. Similarly, that was how Charles Darwin (1809-1882) found his evolutionary principle for living systems.

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