Such passages are common in the annals of Roman history. Each one describes the extermination of various members of the city’s elite, as one or more of Rome’s factions vied for power. In this article I present an agent-based model called PatronWorld. PatronWorld explores how and why such episodes emerged in Roman society, and it provides a means to explore the consequences of social conditions actually and potentially extant at the time. Under what circumstances did Roman patronage networks survive? Collapse? Transform? And what do the results obtained from PatronWorld models imply for our understanding of Roman culture?[1]

For historians, agent-based modeling (ABM) methodologies allow us to formalise our thinking about how the past worked and explore those assumptions in a way previously limited to thought-experiments. In ABM, numerous autonomous, heterogeneous agents are allowed to interact in a digital environment according to rules of behaviour directly drawn from the historical event the researcher wishes to study. The exact number of agents is dependent on the given event, but they should be appropriately scaled to that situation (where "appropriate" is determined on statistical or other clearly defined criteria). This technique allows the researcher to determine the range of possible outcomes – in terms of emergent structures and behaviours – that can be obtained given the specified rules for agent interaction. The purpose of this exercise is to determine whether the model can produce an outcome similar to what has been observed historically, through an adjustment of the model’s parameters. If the model does produce a match, then the historian has a basis to claim that he or she has discovered something new about the conditions that underpinned that historical moment. In a sense, ABM allows the historian to systematically and formally explore a series of counterfactuals based on the historian’s own understanding of the past. The historian becomes the geographer of behaviour space.

1.0 Modelling an Economy of Friends

Roman historians have often drawn attention to the important role that friendship and patronage networks played in sustaining Rome’s economy. Koenraad Verboven, for example, recently characterized the Roman economy as the economy of friends (2002). These networks, it has been argued, complemented and extended the market economy of Rome, fulfilling the role that banking and the transfer of financial capital played in modern economies. The pivotal figure in all of this was the patron, the man whose contacts, fides, and personal power allowed him to protect and promote the financial and social welfare of his clients. Patronage is an asymmetrical friendship between individuals who have differing levels of social power. The practice bound different levels of Roman society together by creating networks of financial and political support, and imposing social obligations and debts that its members were required to pay. Each
network revolved around the linchpin of its patron (Verboven; cf Wallace-Hadrill; Saller). Patronage and its resulting networks was the animating force of Roman society from its earliest days. The study of patronage practices, and their consequent impact on Rome’s social networks, offers one way to explore the underlying DNA of Roman society.

This issue is important because Roman history is replete with instances in which the city’s elite engaged in a process of self-extermination, a practice that seemed to present no fundamental consequences for Roman society at large. What was it about the structure of Roman society that allowed it to endure the loss of major figures in social and economic life? In a culture where the economy was embedded in social and political networks, the development and changing pattern of those networks has important ramifications for understanding historical change.

In addition to their intrinsic interest, the answers to these questions have wider implications for the social sciences and, in particular, for debates touching on agency and its relationship to the emergence of society, an agenda championed by the sociologist Anthony Giddens in his “structuration theory.” Roman archaeology is seldom studied for its relevance to wider issues in the social sciences despite the wealth of material remains and literary sources from the period that could be investigated. In this regard, this work represents an important first step. This project takes the archaeological evidence from one particular set of patronage relationships – the ties between landowners and brick makers in the Tiber Valley, north of Rome (relationships that were recorded by stamps on bricks) – and uses these as the framework for "reanimating" one sector of the Roman economy (Graham). I use the same number of agents in the model as can be attested archaeologically in the brick stamps, namely 234.

In order to explore this "economy of friends", I have built a model of Roman social life, whose fundamental "procedure" is the morning ritual of the salutatio, the morning greeting clients gave their patrons. This ritual cemented the patronage networks underlying Rome’s economic life, and it was one of the city’s most ancient social rituals. Here I explore what such an economy might have looked like. I describe how spontaneous purges and proscriptions can be modelled and the circumstances under which they are generated. The initial results from this model point to gift-exchange as a key factor in the emergence of civil violence in ancient Rome. The finding casts the competitive building projects of the Late Republic, which were enormous gifts to the people of Rome, in a new light, since it was a period of extreme violence. [2]

Agent-based modelling of the Greco-Roman world is still something of a novelty. The method, however, is gaining momentum in research domains devoted to European pre-history. (See for instance Connolly et al., 2008). It is a research tradition with roots extending back to the 1970s (cf. Kohler; Kohler et al.; Doran et al.; and Cherry). Recent notable applications of ABM in archaeology include projects devoted to studying the collapse of the Anasazi in the American South-West (Dean, Gummerman et al.) and the colonisation of the archipelagos situated between New Guinea and Samoa (di Piazza and Pearthree). I have also used ABM to study the diffusion of information through the Roman Empire, and the emergence of settlement structures and political jurisdictions from social interactions in pre-Roman Italy (Graham; Graham and Steiner). My simulations are based on the Netlogo modeling environment, freely available from NorthwesternUniversity’s Center for Connected Learning (Wilensky).
I turn first to a description of agent-based modelling, and more specifically to a description of what it can and cannot do. I discuss next the foundation and implementation of the agent model presented here and present a preliminary analysis of its results. I will conclude by offering suggestions for further extensions of the model.

2.0 Agent Based Modeling and Complexity

In any given social situation there are a number of behavioural options an individual may choose. The one chosen becomes “history,” the others become “counter-factual history.” As archaeologists, we find the traces of these individual decisions. In literature we read of Cicero’s decision to help his friend with a gift of money. What is the importance of the decision that Cicero did not make to not help his friend? How can we bridge the gap between the archaeological traces of an individual’s decision, and the option he or she chose not to pursue in order to understand the society that emerged from countless instances of individual decision-making? Compounding the problem is that the society that emerged influenced individual decision-making in a recursive, iterative fashion. The problem, simply stated, is one of facing up to complexity. A major tool for this problem is the agent based simulation.

Agent-based models (ABM) are emerging as the main technique for studying complex systems because they do not specify the macro-scale behaviour of the systems they model. Research in archaeology at one time described society much like a machine. Cultures were comprised of different systems and subsystems, all operating in balance (Aldenderfer91-120). However, chaos and complexity theories indicate that most natural and social phenomena do not exist in a state of equilibrium. The consequence of this realization is that the interrelationships between the components are unstable, non-linear, and often cannot be discovered (Aldenderfer104; cf Cilliers; Lewin). Further, complexity theorists argue that the large scale structures we identify with “society” emerge because of individual interactions on the ground (Barrett155). What ABMs do – and do well – is model the interactions of individuals so that emergent phenomenon may be studied. It is a generative rather than reductionist approach. (Epstein, Why Model?; Generative Social Science 41-2). It builds from the ground up, rather than reducing from the top down.

An ABM works by modeling phenomena in a computer using “self contained programs ['agents'] that can control their own actions based on their perceptions of their operating environment” (Huhns and Singh quoted in Gilbert and Troitzsch 172). It is explicitly built on the premise of individual actions, not systems. It is thus sometimes also known as individual-based modelling (Gimblett 5). The agents in the model are usually autonomous: they have social ability; they can perceive and react to their environment; and they can engage in goal-oriented behaviour (Gilbert and Troitzsch 73). They have basic operating instructions (rule-sets) to govern their decision making. A certain anthropomorphism is hard to avoid when speaking of “agents.” It is more correct to say that the agents represent simulated individuals, where the simulacra are autonomous pieces of software that are allowed to interact with each other and their environment. Each agent is its own bounded heterogeneous object. While every agent may have the same suite of variables, the combination of values for each agent is unique. The agents
are given simple rules of behaviour drawn from whatever phenomenon we wish to study. How each individual agent implements the rules depends on its combination of characteristics and its situation vis-à-vis its local environment and neighbouring agents. The focus is on the particular. From these interactions, an artificial society begins to emerge. While the model featured here emphasizes the individual, other agent-based models can and do feature emergent levels of society which interact with the individuals from whom they emerged. Creating an ABM requires clarity. We have to specify exactly what we think, and why, in order to translate our understanding of a phenomenon into code.

Joshua Epstein argues that this in fact is the principal strength of agent-based modeling: it requires modellers to make explicit their assumptions about how the world operates (Epstein). This is the same argument made by Bogost for the video game: it is an argument in code, a rhetoric for a particular view of the world. As historians, we make our own models every day when we conceive how a particular event occurred. The key difference is that the assumptions underlying our descriptions are often implicit.

The rules that we used to encode the model are behaviours derived from archaeology, from the discovered traces of individual interactions and the historical literature. Once the rules for agents in this model and others are encoded, the modeller initiates the simulation and lets the agents interact over and over again. As they interact, larger-scale behaviours – an artificial society – begins to emerge. In using an ABM, our central purpose is to generate the macro by describing the micro (Epstein, Generative Social Science 42).

3.0 Netlogo and the Black Box Syndrome

While agent modelling makes its assumptions explicit in the code for the model, the method is still vulnerable to the danger known as the “black box syndrome” (cf Turkel and MacEachern). For those of us who are not programmers, it is worrisome to put so much faith in an approach where we cannot see what is happening, and where we cannot even understand the language used. This is a valid worry. If the rule-sets are not carefully defined and cannot be verified by a knowledgeable observer, it might be that we do indeed have an interesting artificial society, but one without relevance to the original society from which the model is ostensibly drawn. Even worse would be a scenario in which a relevant model, one with important things to teach us, is rejected by the academic community because its workings are murky and not susceptible to critical evaluation.

Most historians do not have the computer science or mathematics background to program their own models. [3] Even if a given historian had access to a sympathetic computer-science department at a university to assist in the development of a model, he or she would still find it difficult to convince archaeologists or historians of the relevance of their work due to his or her ignorance of the underlying code. Fortunately, the agent-based modeling authoring environment Netlogo is designed for the precise purpose of supporting researchers who do not have a computer science background (Wilensky). Netlogo is a descendent of the Logo programming language, and for which reason its agents are known as “turtles.” Models created with Netlogo
are written in a “near-English” syntax that is easily understandable and adaptable. It is an object-oriented approach. Each of the particular behaviours is modeled as its own object. Then the various objects are arranged in a specified order for the agents to perform. When the simulations runs, each individual agent performs the rule-sets, the strategies for behaviour listed in the objects, at the same time as every other agent. Netlogo is simple enough to master that complicated models can be created by the user after working with a day-long tutorial, yet powerful enough to create simulations devoted to crowd dynamics and the emergence of cities in the third millennium BC (Heinen and White) (Ourednik and Dessemontet). A number of tutorials and sample models come bundled with the program.

For instance, one might create a model where agents are supposed to negotiate a best price for a product. The model might look like this:

to go ;; 'go' is a procedure that sets the model running
Am-I-a-buyer-or-a-seller
Search-for-a-partner
Set-my-price
Negotiate-the-sale
Do-my-accounting
end
to Am-I-a-buyer-or-a-seller ;; this is the first procedure
if resource < 0 [set status 'buyer']
if resource > 0 [set status 'seller']
end
[… and other procedures follow …]

Then, to run the model, the user simply types, "go". Each line in the model refers to an "object" or in Netlogo-speak, a procedure. Each agent in the model simultaneously follows the instructions in each procedure. And since events in the model are historically contingent, agents, depending on the given circumstances of the given run, may select different roles. In one round, an agent might be a buyer; in another, it might be a seller if it has the required “resource.” This resource could be “harvested” from the environment where the agent operates, or it could be assigned at random depending on the objectives of the model. The entire model can be monitored for emergent properties. In our buyer-seller model described here, we might include a graph to monitor the flow of money –one that would indicate important developments such as a price-crash.

Netlogo militates against black-box syndrome because every part of a model is put on display, and the programming language associated with the application is simple to learn. Indeed, Netlogo was first developed as a teaching tool for secondary level students to learn about complex phenomena (Wilensky). In the intervening decade, it has attracted a large community of researchers. Its ease of use and power makes it a feasible option for investigators with an average level of computer literacy.

Scholars who use Netlogo face the problem of developing appropriate rule-sets to govern social behaviour and then encoding them. One important guideline to remember here is not to become
fixated on the process of assigning a numerical value. The numbers themselves are significant only because they allow a certain range of behaviours. In a model devoted to assessing the prestige to an individual Roman, and its impact on the economy, we might develop a scale of “prestige importance” running between a range of 1 to 100. The importance of the numbers is simply that “100” signifies “very” and “1” signifies “not much at all.” Once the model was constructed, it would then be possible to run the simulation multiple times, with each run altering the “prestige importance” parameter in increments of ten in order to see if there is a point where some new behaviour of interest emerges (Agar 4.16-4.18).

With agent-based models, it is possible to run an artificial society – such as the model of Rome described here – through a series of artificial histories. After the set of simulations has been completed, the historian’s next task is to select the runs that best correspond with history as it actually occurred. Here the primary task is to determine the parameter settings for the best runs. If the model has been carefully designed and validated, the historian will have learned something new about the original society, namely the parameter settings, and the agent behaviours indicated by the parameter settings. That is the power and promise of agent-based modeling.

It is worth repeating that agent-based modelling forces us to formalise our thoughts about the phenomenon under consideration. There is no room for fuzzy thinking. We make the argument in code. Doing so allows us to experiment with past and present human agents in way that could never be done in the real world. Some ABMs, for example, infect agents with a “disease” to determine how fast it spreads. An ABM allows us to connect individual interactions with globally emergent behaviours. It allows us to create data for statistical study that would be impossible to obtain from real-world phenomena.

4.0 Salutatio

The morning salutatio was one of the most ancient traditions in Rome. The word “salutation” is derived from the tradition, and it refers to the custom whereby the clients of a patron would formally greet the patron at the start of each day. The order in which a client was received stemmed from the status and esteem wherein he was held by his patron. An essential feature of this tradition was that outsiders saw it, and more specifically saw the numbers of clients paying their morning respects to their patron (cf. Wallace-Hadrill 83). After the salutatio, the patron and his attending clients then proceeded to the Forum to conduct the day’s business. The procession and activity at the Forum provided another opportunity for outsiders to assess the patron’s prestige and status, through observation of the number and quality of his clients. [4] The patron relied on his clients for political support. The client relied on the patron for financial, legal, or other kinds of support.

It is important to note that the template of personal relationships described here was the template that Rome applied to govern its relationships with its conquered cities and peoples, a template embedded in the language of patronage. Indeed, it could be argued that this practice was a formative cause of the late Republican civil wars. When new peoples were incorporated into the Roman system, they were described as clients of individual Roman statesmen, not the Roman state. It was a practice that upset the balance of power among Rome’s elite: more clients equalled more power. A model of the salutatio, therefore, is not just a model of individual activities; it
also represents in a larger sense a model of how Rome managed its Mediterranean empire. It is impossible to understand Roman antiquity without viewing it through the lens of patronage.

Patronage, at its most fundamental level, can be understood as an asymmetric relationship between two people of unequal social status where there is a reciprocal, or two-way, exchange of goods and services. The relationship is not transient, as it would be in a modern commercial transaction, but instead is maintained by both parties for an extended duration of time and is distinguished by its personal quality (Saller 49). Patronage is a relationship, which may be entered into voluntarily; a client may withdraw his allegiance and may have more than one patron (Garnsey and Woolf 154; Drummond 101). The central purpose of patronage, as Wallace-Hadrill (72-3) shows, is to control access to resources. Power is derived from knowing the right people, from giving and receiving favours. Archaeologically, we find evidence of this practice in the construction of the Forum Baths at Ostia by Gavius Maximus, Praetorian Prefect of Antoninus Pius. Over 90% of the stamped bricks in this complex were supplied as a result of the contacts Gavius maintained with the Imperial family, and with Asinia Quadratilla and Flavius Aper (DeLaine, Ostia). In the ancient Roman economy the products of one’s land were not things that one simply sold. Rather, they were “bargaining chips” in a great game. Rome’s economy was not a market economy; it was an economy of friends, a network of patronage relationships maintained through interlocking rings of well-connected people. In such a context, it was important to ration one’s knowledge and resources carefully. Important economic opportunities were available – numerous private and public building projects were constructed in the second century – but to prosper in such an economy it was important to know when to supply and when to Baths of Caracalla shows the enormous impact that the baths’ construction exerted on Rome’s economy. Her work also indicates, however, that the economic impact of their construction was not evenly distributed (DeLaine). Patronage was a given to be given to the right people.

“Salutatio” is the crucial behaviour that is modelled in the PatronWorld model. In principle, there are two ways that the historic impact of this practice can be explored. The first is to incorporate the practice into a randomly generated social network, and then see how the simulated network evolves over time. The second method – which was applied in PatronWorld – was to incorporate the behaviour into a network of two hundred thirty-four individuals whose identities were derived from archaeological evidence; these individuals were associated with a patronage network responsible for providing building materials to the City of Rome in the second century AD (Graham).

The brick industry in central Italy was a major component of Rome’s economy. The extraction of clay for brick was considered an agricultural enterprise, and thus many landowners participated. The Roman practice of stamping bricks with the name of the estate, landowner, and brick maker provides important evidence that enables contemporary archaeologists to reconstruct the second century social network then associated with land exploitation and brick making. In archaeology, it is rare that the names of so many individuals affiliated with a network and the web of connections between them can be drawn out. However, what is extremely important about these individuals was not so much their number, but their social station. They were major landowners situated around Rome and hence the people closest socially and politically to the seat of power.
Importantly, individuals from every stratum of Roman society were also participants in this network, from the Emperor and his household on down.

This network therefore – derived from brick stamps – provides a glimpse of Rome’s social structure (Graham and Ruffini; Graham; Graham). The City of Rome in this period had a population of around one million people. A sample of two hundred thirty-four individuals from a population of one million, at a confidence level of 95%, has a confidence interval of just over 6%. Other more limited representations of Roman patronage networks can be discerned in the writings of Cicero, such as in his letter to Atticus “On Friendship.” Both sources provide the data to reconstruct Roman social networks and explore the impact of patronage on their functioning and evolution. Both sources also provide the means to re-animate Roman social life through agent-based modelling.

5.0 Network theory and Patronage

The number of actors in a network is not the only important variable. The nature of their relationships was also a crucial concern. The dictates of patronage suggests that the relationships between individuals were unequal: Fortunatus’ relationship with Quadratilla was not the same as Quadratilla’s relationship with Fortunatus. Due to its unequal nature, their relationship, in a network model, would be expressed as two links. For the two hundred thirty-four individuals represented in our model, however, it was not always possible to determine the exact nature of the relationship between two given individuals. In such circumstances, one had to be content with the knowledge that a relationship had existed. Analysis of the network’s changing shape and constitution, however, required some expression of the relationship, and in such circumstances relationships for the entire network were therefore expressed as single linkages.

There was a theoretical maximum of twenty-seven thousand links for this network if every individual was completely linked to every other participant. However, there are only eight hundred seventy ties, or just over 3% of the potential maximum, in evidence. The standard deviation of these ties, a measure of the variation between one actor’s ties and those of a counterpart, is 13%, a characteristic that suggests there were a number of subgroups within this network. Further investigations of the topology of this network show that the historic patterns of clumping in evidence strongly correlated with changes in Rome’s Imperial dynasties: when a new family took power, new patronage connections emerged (Graham97-8).

The number of ties in evidence is only the first step in exploring how individuals were connected. In their work, Duncan Watts and Steven Strogatz have demonstrated the conditions under which a network can be considered a “small-world” (Watts and Strogatz). Determining whether or not a network is a small world is important, because it carries implications for how information, however it is defined, is transmitted through that network. A small-world network is one wherein a majority of its inhabitants are clustered together into small groups with their nearest neighbours. A few individuals exist in the group, however, who provide links with remote clusters and remote neighbours within the network. These individuals can be very useful for disseminating information within the network. Without them information might have to
travel between, say, ten or more links in order to traverse from one side of a given network to the other. With them the number of links drops to a mere handful (Barabási51-53). Small world networks are capable of generating emergent phenomena from their own dynamics, in large measure because the long-distance connections afforded by the select few in the network function as non-linear feedback loops.

The network associated with Rome’s brick industry matches the small world characteristics defined by Watts and Strogatz and the later refined by Barbási, particularly the characteristic known as preferential attachment (Graham100-1). “Preferential attachment” is a concept that explains the dynamics underlying the growth of small world networks. It posits that an agent’s chance of joining an actor heading a network is a function of the number of connections which that actor already has. In this conception, the rich get richer. Those individuals who are well connected find it easy to generate still more connections (Barabási90-91). It is evident that the concept of preferential attachment matches well with our understanding of how patronage worked in Roman society. There was no point for most Romans in becoming the client of a man who had few connections himself.

6.0 Behaviour into code

Prestige and status were pervasive features of social life and the ancient Roman economy. Everything was filtered through the lens of prestige and status. Transactions were not framed in terms of pure economic exchange. Therefore, in our model I encoded the following behaviours into our agents:

1. Agents were required to examine their own status level, which initially was a function of how many people they knew, and then pay respects to individuals whom they knew who have a higher status than themselves.
2. Agents knew that it was in their interest to receive high status "clients", and accordingly were programmed to receive them when the potential client's status was relatively high to its peers.
3. Agents were programmed to seek an audience with a high status patron, since they knew such visits would enhance their status.

These three rules constituted the fundamental procedures for agent conduct in the model. Together, they recreated the ritual of "salutatio," the ritual of paying respects to one’s social superiors. Two other rules were also incorporated into the model.

4. Agents were required to exchange gifts when paying respects. In the ritual of “salutatio” gift exchanges served to cement the relationship between patron and client. They also facilitated the redistribution of wealth.
5. Agents were programmed to trade with counterparts at similar status levels, though trade was not contingent on each party belonging to the exact same rank.
After paying their respects, agents in the model manoeuvre through their world, and seek to trade – to play the game – with others of similar status. I have opted to model the basic mechanism of trade in my model as a type of game where the agent’s chances of gaining a favourable outcome depend on its social status. The mechanism is not a zero-sum game, wherein if one agent wins, the other must lose; rather, success depends on the agent’s status level and the probability of a successful outcome imposed by a particular economic “climate,” which is set by the model’s user. Both agents could win, only one could win, or both could lose. The “climate” represents a host of individual, historic, and economic contingencies. When two agents meet to trade, the “climate” indicates whether the agents have good market information, whether they are good dealers, whether one is having an off-day, or any one of a potential number of competing factors that can influence whether an agent gets the best of any particular deal.

In the simulation, no specific good or service is “traded” *per se*. Instead, I model the outcomes of economic exchanges based on the assumption that the more prestigious an agent is, the more likely he is to receive the best result from any particular encounter. If an agent wins, his money is increased by the “risk-factor,” a variable that determines how much an agent stands to win or lose from a given transaction. Similarly, if the agent loses, his money is decreased by the same “risk-factor.” Profit from a transaction can increase the agent’s status in the simulation, but not necessarily. A great deal depends on the agent’s status in the first place. Consider, for example, the fate of the wealthy freedman Trimalchio, a literary creation of Petronius. Despite his enormous acquisition of wealth, he gained very little status. Giving gifts can also enhance an agent’s prestige in the simulation. While the act initially decreases the patron’s wealth, it increases his chances of achieving greater economic success in the long-run.

This simple model of Roman social organisation displays interesting behaviours that may cast new light onto Roman history. When the model runs with only rules one through three, enormous disparities in status level emerge. When rules four and five are applied, the trading mechanism allows agents to make new acquaintances and learn of the existence of higher status agents previously unknown to them. Through trade, agents gain opportunities to join new chains of patronage. The trading mechanism therefore opens up the possibility for social mobility. It is not success in trade that creates this possibility. Rather, it is the process of becoming known to new individuals. If the trade mechanism is turned off, the process of paying respects alone causes the overall social structure to ossify.

### 7.0 Generating Civil Violence

In early versions of the model, investigators were afforded the capacity to explore the effects of "shocks" to the system through activation of a *deus ex machina* button, one that would randomly kill high status agents. If the overall difference in social status between “high” and “low” agents in the artificial society was not great, social life continued – with agents at each rank ascending to the next level vacated by their dead predecessors. If the initial distinction in social status was great however, the artificial society quickly evolved into a despotic society, one headed by one high status individual and populated by individuals of extremely low status. Agents ceased to pay respects to one another, and the society collapsed. In the emergent despotic society, random
killings of agent seemed to have no effect, since all agents were equal in status – no one paid respects to counterparts or superiors; therefore, there was no possibility of changing status and ascending to a vacant social niche.

Obviously, the shock button was not a satisfactory long-term solution for the model. Work by Joshua Epstein on modeling political violence suggested a mechanism for allowing purges to emerge spontaneously from the model itself (Epstein). In Epstein’s model, agents rebel if government legitimacy is perceived to drop below an agent’s tolerance for bad government. They only spring into action, however, when other, similarly rebellious agents are situated nearby. Action in Epstein’s model depends not only on an agent’s internal state, but also on its social context. The social context for rebellion can be dampened by having “police” agents who wander the world. In such a scenario, agents who fear arrest are less likely to rebel.

Epstein’s mechanism then depends on agent’s responding to their internal states and to environment cues. I translated this mechanism into PatronWorld first by giving each agent a capacity to hold a grudge. Remember that a patron’s status was enhanced by the social standing of those who visited him. It was therefore in the interest of patrons to ensure that their clients were suitably notable themselves before allowing them to participate in the salutatio. In the model, a patron’s decision to deny agents the opportunity to pay respects due to their low social standing, thereby limiting their access to patronage networks, creates a state of “grievance” in the affected agents, and eventually lays the basis for political violence. Agents remember who has denied them the opportunity to participate in the salutatio. In the model, a patron’s decision to deny agents the opportunity to pay respects due to their low social standing, thereby limiting their access to patronage networks, creates a state of “grievance” in the affected agents, and eventually lays the basis for political violence. Agents remember who has denied them the opportunity to participate in the salutatio. Each individual agent has its own randomly set tolerance for rejection, its own specific “grievance” level. Its action on that grievance, however, depends on whether its neighbouring agents are also prepared to act. When does PatronWorld tip into violence? It does so when the global measure of patrons’ legitimacy, their capacity to “oppress” the clients over which they have charge, is exceeded by the number of agents ready to become violent. For each individual agent the measure of legitimacy is called auctoritas, or authority. Auctoritas is the measurement of an agent’s wealth and prestige.

When agents become violent, death ensues. Agents in the simulation do not kill randomly. Instead, they target other agents against whom they have a grievance. Such targeted killings, however, can set off cascades of killing, since the removal of individuals alters the social environment for the salutatio by changing the levels of social prestige for the survivors, thereby changing the chains of connected individuals and altering the overall level of auctoritas governing PatronWorld.

8.0 The sources of civil violence in the Roman world

The concern here is to identify a mechanism that could have generated civil violence from the normal operations – or failures of – the patronage system in Rome. The greatest expressions of civil violence – the late Republican civil wars – can be viewed in this light as the competition between three or four “great men:” Caesar, Pompey, Antony, and Octavian. Each man at different points in time attempted to expand their control beyond their own respective chains of patronage in order to incorporate all of Rome’s patronage networks. The civil wars were a failure
of patronage in that in the good of the state, the res publica became identified with the good of
the individual general. Generals were permitted to oversee the pensioning and support of
demobilized soldiers, and the allegiance of soldiers accordingly was transferred from the state to
the person of the general. The arrangement permitted victorious generals to translate their
military strength into political strength and subvert the normal workings of state machinery.
Generals – as competing politicians – used the patronage system to stimulate urban riots, calling
on their respective followers to contest legislation or elections through violence (Aldrete).

Famines were another factor that precipitated civil violence in the Roman world. They also have
been shown to be failures of the patronage system and political will, since they exacerbated crop
failures and transformed them into the social disaster of a famine (Laurence 135). Ultimately,
when Rome's political elite was confronted with environmental or political challenges, their
response was consistently filtered through the lens of patronage. Technological change was
rarely a disruptive factor in ancient Rome, largely due to the inherent conservatism of Roman
patrons and their dependence on a slave economy. Vespasian reportedly dismissed a labour-
saving device so that “he might be able to feed the mob.”[5]

At the individual level, Gregory Aldrete demonstrates that the mechanics underlying riots in
Rome in the late Republic and Early Imperial ages were generally not spontaneously generated
(Aldrete); rather they were often the product of professional agitators. The profession of agitator
had its origin in the theatre. Individuals were hired to start the applause for a particular actor or
performance. These "claquers" – as they were also known – were subsequently appropriated by
Rome’s elite for political purposes, namely to provide “spontaneous” support at orations and
other political events. They were also hired to start demonstrations, demonstrations that
potentially could tip into riots. When initiating a mass event, it was crucially important for the
agitator to make the demonstration or riot appear as if it emerged spontaneously. The act of
agitation required the presence of individuals who could be induced to riot if someone else
appeared ready to do so: to initiate a band-wagon effect. This is in fact the precise mechanism
that was suggested by Epstein, and used in the modeled described here (Epstein).

9.0 Running the model

Figure 1 is a screen shot of the model interface. A single model run plots the outcomes of the
interactions of agents who use as starting positions the variables indicated at the top left. These
are the initialization variables. They set the number of agents, the average number of people each
agent can “know,” and the initial distribution of prestige around an average value. When the
model is started from random, the attribute values for the artificial society are distributed
normally. When the model starts from a specific point in history, the simulation’s initialization
variables are derived from archaeological or historical data. In this model, a well-connected
historical actor is assumed be more capable of managing social knowledge and maintaining a
concomitant level of prestige.

The “run” variables are gathered under the label “economic climate.” “Harshness” refers to the
severity of the economic climate and the corresponding probability of completing a beneficial
transaction. The variable is specified by attribute values ranging from 1 to 100. The higher the value, the lower the probability that a given agent will be able to complete a beneficial transaction. “Risk-factor” is a multiplier used by agents to determine what proportion of their wealth they are willing to risk for any given transaction. The maximum risk factor setting permitted in the model is one third of an individual’s wealth, a requirement that reflects the inherent conservatism of Roman investment practices. Finally, “sportulae” – the Latin term for a gift given by patrons to clients – refers to the maximum gift size that can be given by a patron to his client. It is specified as a fraction of the patron’s wealth.

The remaining “on/off” switches are used to test the various components of the model, to permit, for example, the model to run with its violence routines switched off. Exact instructions for running the model – including instructions enabling users to adapt, expand, or alter it – are packaged with the model itself, and can be accessed via the “information” tab. The code itself may be found under the “procedures” tab.

As the model runs, “reporters” record the number of patrons and clients, the amount of money in circulation, and the division of the population into three classes, based on status level. The “reporters” also show the emergent alliances between agents. These alliances are referred to as “houses.” Initially, at the start of each run, each agent is assigned a unique colour. Once the agent joins a particular network his colour changes to that of his patron. As the simulation progresses, the population often stabilizes into a handful of colours. “Mobsize” and “oppression” (the collective auctoritas of the patrons) are variables that are also plotted over time. They enable the modeller to determine when the population has tipped over into violent behaviour.
Figure 1: This is the PatronWorld model running in Netlogo. In this model run, a small artificial society with forty-nine agents was created, tied together in a randomly generated social network. As the model progressed from an initially egalitarian state, a division into high-medium-low classes emerged (as measured by the agents' prestige values). At the same time, these fewer and fewer high class individuals were unable to keep others' grievances under control, and violence emerged. At the point where the model was stopped, seventeen agents had been 'killed'. The 'Houses Histogram', which gives a rough estimate of the number of chains of patronage present in this society, shows that the majority of the existing agents have connected into a single chain. To see the model in action, please go to http://graeworks.net/abm/PatronWorld.html.

10.0 Visualizing Behaviour Space

“Behaviour Space” is a graphical representation of all possible outcomes given all possible combinations of variables for the model. The purpose of using it is not to look at the detailed and contingent events of a single model run, but rather the aggregate behaviour of several model runs.

We now are in a position to ask two questions. Given the above understanding of “Behavior Space,” and the assumptions about agent conduct described above and expressed in code, we can now ask:

1. Under what economic circumstances will civil violence emerge?
2. If we run this model using archaeological or historical data (an ancient social network) to configure our starting point, which set of initiating circumstances will produce outcomes that best match what we know historically to have been true, and...
   a. ...what implications can we draw from model outcomes that diverge from actual historical outcomes?

In order to answer these questions, we ran the model through a parameter sweep of all possible combinations of variables twice, with the first sweep starting from a purely random starting position and the second derived from historical data from the first and second centuries AD (Graham). In both cases, the number of agents was two hundred thirty-four, reflecting the number of individuals drawn from brick-stamp data.

Each parameter sweep took six to seven hours to run, and involved twenty-seven “runs” of the model. Each run lasted for one hundred model “days,” with each “day” defined as one full cycle of the salutatio procedure, or thirty-five ticks of the Netlogo clock. The three variables that were modified each run were harshness, risk-factor, and sportulae; over the course of the parameter sweep each variable was set first at its lowest setting, then its middle setting, and then its highest setting: 3 x 3 x 3 = 27 runs. The state of the model at each tick of the Netlogo clock was recorded on a spreadsheet. Descriptive statistics for each “reporter” were calculated, including the coefficient of variation, using the University of Reading’s Statistical Services Centre software Instat+ for Windows. The variation was normalized for “mob size” and “oppression.” Deaths were simply counted, and then normalized against the highest number of deaths. A pseudo-3d
surface for these variables by model run was created using MS Excel, where peaks represent
high variation. When a “reporter” indicated a high degree of variation, the finding indicated that
the particular model run was extremely dynamic, while findings with a low degree of variation
indicated that the given run was stable.

Complex systems are extremely sensitive to initial parameter settings. Without performing a
parameter sweep of all possible combinations, it is not possible to identify which combinations
of variables might create “tipping points” – interesting emergent behaviours – or in turn prompt
wildly divergent outcomes. As an initial exploration of this geography of behaviour space, I
chose to begin the parameter sweep with the coarse-grained setting of three settings per variable.
If particular combinations, at this low level of fidelity, seem to produce interesting results, then
subsequent explorations should enable the researcher in future runs to zero-in on particular
regions of behaviour space in order to run finer-grain explorations. For my purposes here, the
key distinction of interest is the emergent outcome resulting from a random, computer generated
network and the emergent outcome of a small world network known derived from history. Given
these objectives, the twenty-seven possible combinations of parameters were sufficient to
generate interesting data.

### 11.0 Gifts between friends

Table 1 shows the variation in settings for each model run. Figure 2 shows the Behaviour Space
for the fully artificial Roman society, where the patterning of connections emerged from the
randomly generated social network. Two results are immediately striking: the eight background
peaks, indicating a run with high variability in emergent mob sizes; and the four areas of empty
white space in the foreground, indicating a high number of deaths.

<table>
<thead>
<tr>
<th></th>
<th>Harshness</th>
<th>Risk-factor</th>
<th>Sportulae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>10</td>
<td>0.1</td>
<td>0.005</td>
</tr>
<tr>
<td>Run 2</td>
<td>10</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>Run 3</td>
<td>10</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Run 4</td>
<td>10</td>
<td>0.25</td>
<td>0.005</td>
</tr>
<tr>
<td>Run 5</td>
<td>10</td>
<td>0.25</td>
<td>0.01</td>
</tr>
<tr>
<td>Run 6</td>
<td>10</td>
<td>0.25</td>
<td>0.1</td>
</tr>
<tr>
<td>Run 7</td>
<td>10</td>
<td>0.33</td>
<td>0.005</td>
</tr>
<tr>
<td>Run 8</td>
<td>10</td>
<td>0.33</td>
<td>0.01</td>
</tr>
<tr>
<td>Run 9</td>
<td>10</td>
<td>0.33</td>
<td>0.1</td>
</tr>
<tr>
<td>Run 10</td>
<td>50</td>
<td>0.1</td>
<td>0.005</td>
</tr>
<tr>
<td>Run 11</td>
<td>50</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>Run 12</td>
<td>50</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Run 13</td>
<td>50</td>
<td>0.25</td>
<td>0.005</td>
</tr>
<tr>
<td>Run 14</td>
<td>50</td>
<td>0.25</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Table 1: Variable settings for model runs

<table>
<thead>
<tr>
<th>Run</th>
<th>50</th>
<th>0.25</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 6</td>
<td>50</td>
<td>0.33</td>
<td>0.005</td>
</tr>
<tr>
<td>Run 7</td>
<td>50</td>
<td>0.33</td>
<td>0.01</td>
</tr>
<tr>
<td>Run 8</td>
<td>50</td>
<td>0.33</td>
<td>0.1</td>
</tr>
<tr>
<td>Run 9</td>
<td>99</td>
<td>0.1</td>
<td>0.005</td>
</tr>
<tr>
<td>Run 10</td>
<td>99</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>Run 11</td>
<td>99</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Run 12</td>
<td>99</td>
<td>0.25</td>
<td>0.005</td>
</tr>
<tr>
<td>Run 13</td>
<td>99</td>
<td>0.25</td>
<td>0.01</td>
</tr>
<tr>
<td>Run 14</td>
<td>99</td>
<td>0.25</td>
<td>0.1</td>
</tr>
<tr>
<td>Run 15</td>
<td>99</td>
<td>0.33</td>
<td>0.005</td>
</tr>
<tr>
<td>Run 16</td>
<td>99</td>
<td>0.33</td>
<td>0.01</td>
</tr>
<tr>
<td>Run 17</td>
<td>99</td>
<td>0.33</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Figure 2: a pseudo-3d surface created in MS Excel, shows the normalized co-efficient of variation for three variables Harshness, Risk-Factor, and Sportulae per model run settings, corresponding to the runs shown in Table 1. The social network shown here emerged from a
randomly generated artificial society. The number of connections per agent for the society approximates a normal distribution.

Of the eight mob size peaks, six emerged when sportulae was set at 0.005, that is, when gift-giving was set at its minimum. Keeping in mind that the size of the gift is a proportion of the patron’s wealth, and that wealth is a function of the economic environment, it comes as no surprise that the fourth through eighth peaks shown here, all with sportulae = 0.005, emerged in conjunction with a spike in killing. The economic environments of runs 10 through 18 were set at 50, while runs 19 through 27 were set at 99. However, run 15, 18, 20 and 21 seemed to avoid tipping into violence. Each of these runs, save for run 20, had gifts set at .1 of wealth.

Oppression – the ability of patrons to keep a lid on violence – seemed to increase in conjunction with the risk-factor – that is, the proportion of their fortune that each patron was willing to risk in an economic exchange. The possible reason for this correlation might be the gentle economic climate that pertained during these runs. Given the promising chances of a good economic outcome, and the potential rewards available to risk takers – the risk factor was set at .25, or .33, a bet of 25% or 33% of total wealth – it is possible that prestige and auctoritas grew exponentially as a result of consistently high returns on investment. It was only in poorer economic conditions that risk-factors started to play merry havoc with the variation in oppression for a given run. Add to this the complex interplay between sportulae and the patron’s risk-factor and it is no wonder that violence and death increased with greater regularity and force under runs with harsh economic conditions.

The harshest economic climates are shown in runs 19 through 27, where the chance of a favourable outcome was one in one hundred. Clearly, these runs were not reflections of a realistic economic environment. What is more curious are the results obtained from the middles runs, 10 through 18. Economic conditions here were hard, but not too hard. The results here suggested that, under the framework of this model, it was possible for patrons to keep violence under control, even in bad times, and even when they took big risks with their money, so long as they re-distributed their wealth in the form of significant gifts. The deep valleys shown in runs 15 through 18 correspond with the highest possible settings for sportulae. Bread and circuses really worked. Curiously, the impact of the same strategy in runs 1 through 9, where economic conditions were relatively easy, was marginal. In these instances, giving a big gift decreased a patron’s wealth but did not provide a corresponding gain in added prestige, since everyone was winning at the economic game.

When we run the model through its second parameter sweep, based on a starting position determined by historical data, we are presented with a very different Behaviour Space (see Figure 3). The only difference between the two sweeps was the pattern of social connections that applied in the randomly generated network versus the historical network derived from Roman brick stamps. In the first, it was a normal distribution insofar as the majority of agents all had roughly the same number of connections as their counterparts, with small numbers of agents at each end of the distribution having either a very few connections or many. In fact, such a distribution is an atypical pattern for most real-world social networks. Most networks follow a power-law distribution – the most important indicator of a small-world network; this distribution
can be defined as a scenario in which a few individuals enjoy a high number of social connections, while the majority connect to very few of their counterparts (Barabási 67) (Barabási, personal communication).

However, in the second sweep the *sportulae* again appeared to be a major factor in determining whether or not violence erupted. Peaks in mob size variability tended to occur when the *sportulae* variable was set at 0.005. The ability of patrons to keep violence down – oppression – seems to be an area where network topology makes a major difference. This finding may be due to the fact that in the first sweep based on the random network oppression was distributed evenly throughout the artificial society, while in the second sweep it was concentrated along particular strands of the network. While one can reasonably expect violence to occur when economic harshness is set at 50 or 99, it is interesting to note that two rounds of violence emerged during the easiest economic climate, during runs 3 and run 8. Run 3 produced a greater number of deaths than run 8, as well, while the risk-factors in run 3 and run 8 were .1 and .33, respectively. *Sportulae* for run 3 and run 8 were .1 and .01, respectively. Mobsise variability for both of these runs was much lower than in Figure 2.

![Figure 3: this image shows a pseudo-3d surface created in MS Excel, showing the normalized coefficient of variation for three variables Harshness, Risk-Factor, and Sportulae, by model run settings as in Table 1. The social network in this artificial society is derived from stamped brick data described in Graham for the late first and early second centuries. Each agent has connections of a known historical actor. The number of connections per agent for the society approximates a power law distribution.](image-url)
Why is there greater violence in the easiest, least risky scenario? An explanation lies in the power law distribution of connections: only a well-connected few enjoyed the benefits of social connections and economic gain. While mob size never varied much, oppression was never equally distributed. Similarly, *sportulae* were not equally distributed around the network, which enabled some agents to gain prestige at a rate that precluded other agents from making new connections. Essentially, the practice of giving big gifts and easy economic returns to a select few effectively shut out low-status individuals from the patronage network and economic gain. The same pattern emerged in run 8, but to a lesser degree because the risk-factor permitted the occasional agent to lose large amounts of money and prestige, thereby enabling new social patterns to emerge.

### 12.0 Pax Romana

One interesting outcome of the *PatronWorld* model – which was designed to explain the spontaneous emergence of civil violence – was the emergence of counterfactual “histories” – model runs – where violence did not emerge. The Roman Empire enjoyed a period of comparative peace and prosperity – often called the *Pax Romana* – from the reign of Nerva to the end of the reign of Marcus Aurelius, a period of roughly one hundred years. The model-runs that best matched this period were those captured in the Behaviour Space from runs 9 through 11. In history and in the model, it was a period of increasing economic hardship, starting in a period of economic stability induced in part by the expansion of the Empire under Trajan, and culminating in a period of stress, with the abandonment of provinces and exposure to severe plagues that decimated the population under Marcus Aurelius. The period, however, was also characterized by caution in risk-taking. *Sportulae* was extended in the manner described at the start of this article, with the elite distributing public building contracts to their friends.

The social network that emerged in the model and in history was the same. The transition from run 11 to the space occupied by runs 12 through 18 suggests that Roman social networks were susceptible to crashing into a fit of violence if risk-taking or gift-giving, or both, increased. In the change from the Antonine to the Severan dynasties, civil violence was accompanied by enormous spending increases in public works – most notably, the Baths of Caracalla – and by the extension of Roman citizenship throughout the Empire by Emperor Caracalla. One consequence of this extension was that it created new openings in patronage networks, and created in particular hundreds of thousands of individuals in personal debt to the Emperor. In the aftermath of these initiatives, the third century was racked by civil war and periodic fits of severe violence.[6] The outcome of the interplay between risk-taking, gift-giving, and patrons’ ability to channel authority through changing networks presented here suggests that Roman scholars in the future would do well to focus their attention on public building projects as a potential indicator for the emergence of civil violence.

The geography of Behaviour Space provides a vantage point to consider not only competing hypotheses regarding history as it occurred, but also possible counterfactual histories using historical data as a starting point. For instance, what might have happened to Cicero’s patronage network – described in his letter to Atticus “On Friendship – if it had been set in different
economic circumstances? If we run the model under the assumption of an extremely harsh economic environment, with a parameter setting at 90, representing a 90% chance of not gaining favorable terms from an economic exchange, Cicero’s circle of friends—with thirteen patrons and thirteen clients quickly collapses from twenty-six to seven individuals. At that point, the network enters into a state of equilibrium with no more killings. Four of the survivors play the role of patron, while three play the role of client. While this finding is the product of a counter-factual analysis, it is nevertheless interesting because it corresponds with much of what actually occurred in Ciceronian Rome. The Late Republic experienced a transformation similar to the one shown by our counter-factual model, with only a small circle of powerful families situated at the top of Rome’s hierarchy. By the end of the Republic, of that small circle only one man remained at the pinnacle of power: Octavian—better known as Augustus—who gained a status by dint of his prestige, wealth, and social connections, and his formidable military nous.

Rome was not a static society. New peoples were added to the state constantly over time, and each new group or individual ideally was integrated into the existing networks of patronage, such as when Caracalla extended citizenship. When we add the possibility of new people joining the artificial society in our model, the situation changes dramatically. Newcomers try to join the game—find a patron, be received, and enjoy the associated prestige and status—but opportunities are limited since, as new subjects of the empire, they carry little inherent prestige of their own. No patron wants the new clients. Consequently, grievances grow faster than the abilities of patrons to contain or mitigate them, and this leads to violence. However, the violence and killings open up new niches in the existing networks, thereby permitting the former newcomers to find roles. The problem is contained until the next generation of newcomers arrives. Starting with a network based on the pattern of friendship described by Cicero, and allowing for new individuals to join this society, the simulation eventually balances out with only marginally fewer people than when it started. The simulation produces a society that is top-heavy, one that is a close analogue to the state of Roman society at the end of the Republic and the beginning of the Early Empire. In history and in our simulation, Rome was the center of a cycle where patronage networks were exposed to waves of killings and followed by the incorporation of new people who filled the network’s empty niches; this surge of new people in turn set off another round of killing until a new society emerged.

13.0 Complexity Theory and PatronWorld

One interesting by-product of the simulations produced in PatronWorld is the consistency with the theoretical findings generated by the science of complexity. Researchers in this interdisciplinary science study complex adaptive systems—systems comprised of multiple agents which interact. That interaction leads to the emergence of new patterns, patterns which in turn constrain the actions of the system’s constituent agents. Societies, to name one example, are complex emergent systems. They emerge because of the interactions of individuals, and consecutively constrain the actions of their constituent individuals, by defining the range of possible actions that are open to them (Waldrop; Cilliers). Complex systems are also capable of undergoing “phase changes,” a process wherein the complex system dissolves and self-organizes again into an even more complex entity. Phase changes are stimulated by feedback from the
environment. They can only take place in a state complexity researchers refer to as “the edge of chaos,” a meta-stable state in which the system is situated half-way between a full state of entropy, or randomness, and a full state of order, or stasis. Systems that are situated between these two extreme states retain the capacity to self-organize into new and more adaptive configurations.

In network terms, a complex system at the edge of chaos has a networks structure much like a small world (Barabási 90-91). Researchers affiliated with the science of complexity have discovered that there are control parameters that determine if a system can remain at the “edge of chaos” and self-organize into new configurations as and when needs require. In *PatronWorld*, one important control parameter was the density of connections between individual members of Rome’s elite. The findings in our simulation mirror research by Stuart Kauffman and others relating to the behaviour of neural networks. When the neurons in Kauffman’s artificial network were exposed to too many connections, the entire network descended into a state of flux. The network was unable to generate meta-stable, emergent patterns (Waldrop 109-112).

Complexity research, therefore, suggests that the density and topology of connections can prove to be an Achilles’ Heel for networks. In a small world network, the patterns of local and long-distance connections are such that the network generally proves robust in the face of random attack. When a network is subjected to external stress, the constituents responsible for maintaining long-distance contacts within a network, and between networks, are generally not severed since there are relatively few of them. However, if an attack does succeed in severing one of these key agents, then the network may fragment. Agents who possess dense, long-distance connections with counterparts in a given network are able to support the establishment of multiple pathways for contact within a given network. If these are removed, however, new pathways for contact have to be established, which forces the network to attempt to sustain its operations using a reduced number of links. If a key agent is removed, then its removal may initiate a cascading failure within the network. Some surviving constituents will fail due to the reduced number of connections within the network, a failure that will initiate a second cascade. The extent of the cascading failure is determined by the importance of the first key agent to fail (Barabási 119-120).

Translating these insights into human terms, it suggests the central importance of the patrons in maintaining their social network. The obligations of patronage did not disappear when a head of household died, was exiled, or murdered. Instead, his functions simply devolved to the new head of household. If the new head proved unable to meet his obligations, by creating new links with clients and finding powerful patrons for himself, then there was a strong possibility that that failure would initiate a cascading process that would destroy his network in the end. The waves of killings generated in *PatronWorld* were also cascading failures, potentially initiated by the density or topology of the networks that were modeled. This is a new way of thinking about social change in the Roman world, and one that bears closer investigation.

14.0 Conclusion: The Digital ‘What if…’
*PatronWorld* is still an on-going process. It is like studying a living system, one that continually produces new surprises. The results presented here may be considered as be preliminary. In future work, the *PatronWorld* model will be applied to a suite of networks drawn from historical and archeological data. Future analyses will compare geographic regions, different cities, and different eras in Roman history, all in a broader attempt to understand Roman society (or societies) as dynamic entities.

Until the advent of agent-based modeling, counterfactuals were nothing more than thought experiments. The advent of this methodology, however, enables us to raise counterfactual analyses to a whole new level by articulating our model with the rigor demanded by a computer. The models, and the process of building the model, are important in themselves for what they can show us about how our ideas interact. It is an argument constructed in code and a procedural rhetoric. For this reason alone historians should be interested in building agent-models: “If this model clearly reflects my understanding of historical process X, then these are the natural consequences of that understanding”. Agent-based simulations force assumptions to be made explicit. Such models can be made to reflect not only our assumptions about the past, but also information derived from historical data. In the latter case, providing our assumptions are valid, there are grounds to suggest that the emergent results of such models must necessarily have some historical truth to them.

**Acknowledgments**

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**Works Cited**


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**Endnotes**


[2] My models are available for study and for adaptation. They are published on the Internet under a Creative-Commons license, to allow interested readers to better understand my argument and indeed, to argue against my conclusions and provide better simulations of the Roman social and economic world in turn. The models may be downloaded at http://home.cc.umanitoba.ca/~grahams. I maintain a research blog with further links to agent modeling resources at http://electricarchaeologist.wordpress.com.

[3] For an argument indicating why historians should learn to program, see (Turkel) and (Turkel and MacEachern)


[5] Suetonius, *De vita Caesarum*, *Vespasianus* 18

[6] See (Graham 92-114) for an argument on how changing network topology might be a possible foundation for civil violence.