AN EVOLUTIONARY APPROACH TO MILITARY HISTORY[1].
UNA APROXIMACIÓN EVOLUTIVA A LA HISTORIA MILITARY.

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Abstract: This paper provides a new way of analysing the concept of change within the field of military history. The proposal is based on the use of complex adaptive systems and evolutionary theory. We introduce the concepts of selection, adaptation and coevolution to explain how war is managed in different societies, and game theory to explore decision-making processes of commanders. We emphasize the value of integrating formal modeling and computational simulations in order to apply the approach to real case studies. Our conclusions outline the advantages of an evolutionary military history in the difficult task of understanding the causes of transformation in past battlefields and armies.

Keywords: Military History, Evolution, Complex Systems, Game Theory, Agent-Based Modeling

Resumen: Este artículo explora una nueva forma de analizar el concepto de cambio en el campo de la historia militar. La propuesta se basa en el uso de sistemas complejos adaptativos y teoría evolutiva. Introducimos los conceptos de selección, adaptación y co-evolución para explicar cómo las diferentes sociedades humanas gestionan los conflictos bélicos, y la teoría de juegos para explorar los procesos de toma de decisiones de los comandantes. Se enfatiza el valor de integrar modelos formales y simulación computacionals a la hora de aplicar esta aproximación a casos de estudio reales. Las

conclusiones resumen las ventajas de una historia militar evolutiva en la difícil tarea de explicar las transformaciones de ejércitos y conflictos pasados.

Palabras Clave: Historia Militar, Evolución, Sistemas Complejos, Teoría de Juegos, Modelos Basados en Agente

Introduction.

Clearly the face of battle has changed over time, but do we know how? The ways in which humans attack their enemies (or show their capacity for exercising violence) have changed drastically over the last thirty centuries. These changes are partly the result of technological innovations, but this is not the whole story. Social change has a direct influence on military engagements since these are also, unfortunately, social activities. Current trends in military history recognize these concepts (technology and culture) as two of the main factors that we need to consider in order to understand the evolution of tactics and strategies. Finally, human constraints (both physical and psychological) also seem to be an important factor present in the battlefield. These three elements, filtered by the economic conditions of each separate scenario, form the umbrella under which history analyses warfare. Analysing these factors, and especially the dynamics generated between them, is difficult, and this daunting task is made even more complicated due to one particular property inherent in any system in which humans interact: complexity.

A system is defined as complex when we are unable to understand how it works by studying its parts. The classical scientific approach has been to solve problems by dividing a puzzle into smaller problems, usually simpler to tackle. This methodology is valid when each element has its own set of properties and rules, and the interaction between them is not especially important (if it exists at all). Complex systems show additional behaviors that are not detected in any individual part, but which emerge from the interaction of their components. These emergent properties are difficult to predict, but not chaotic. This means that the behavior must be robust enough to cope with small variations without portraying sensitive differences in the outcome[2]. These types of system are somewhere midway between those usually studied by science and others defined as chaotic. To summarize, we can state that complex systems are useful for studying problems where

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2 SAWYER, R.K. (2005). *Social emergence. Societies as Complex Systems*. Cambridge University Press, UK, p.3

any interaction between components must be understood if we want to comprehend them from an overall perspective[3].

Complexity is a property of a system and can be found in any type of problem and field, such as physics or biology. In biology, for example, we can compare the traits observed in ants and in the colonies formed by them. As a whole, the nest exhibits an extremely elaborate set of behavior that cannot be predicted if we study the individuals separately; we need a new perspective capable of analysing the interaction between them.

As we have said, complexity is present in various disciplines, but it is in the study of human society where it becomes most apparent. This is the case with social networks, where certain global events that change the social structure originate in a situation involving few individuals (known as the snowball effect). As other authors have pointed out, social emergence is the central phenomenon of the social sciences[4].

We will try to apply these ideas to military history. First of all, our intuition is justified in that we will not be able to understand the evolution of warfare by studying all the changes in weaponry, society, logistics, etc. separately. This framework provides the researcher with a holistic approach, capable of analysing not only the different factors involved in violent conflict but also the effects created by the interaction between them. Finally, the concept of complexity can be combined with another property: adaptation. The use of complex adaptive systems will enable us to study how these parts and their emergent properties change over time

The aim of this theoretical paper is to propose a new framework designed to study warfare from an evolutionary perspective. The objective is to provide military history with a new tool to make it easier to explain how the way battles are fought changes. The study takes various concepts created by the theory of evolutionary culture[5] and applies them to warfare. Interestingly, some of today's military historians already use this approach[6], although they do not explicitly use the mechanisms, just the general idea. We will try to show how using a richer theoretical framework can improve our understanding of transformations already detected by researchers. In order to accomplish this task we will go a step further and explicitly identify the processes that control

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3 MILLER, J.H., PAGE, S.E. (2007). *Complex Adaptive Systems. An Introduction to Computational Models of Social Life.* Princeton University Press, USA, p.5
4 SAWYER, R.K. (2005). ibid., p. 189.
5 BOYD, R., RICHERSON, P. (1985). *Culture and the evolutionary process*, University of Chicago Press, USA.
6 The authors even cite the concept of evolution in the title of their work, like: Heuser, B. (2010). *The Evolution of Strategy. Thinking War from Antiquity to the Present.* Cambridge University Press, UK
TELP, C. (2005). *The Evolution of Operational Art (1740-1813),* Frank Cass, USA.
LYNN, J.A. (2003). *Battle. A History of Combat and Culture.* Basic Books, USA, p. 34.

change in combat. A consequence of this approach is that we will be able to create formal models, a capacity rarely seen within other perspectives. This is a major advantage because these models will be helpful for any researcher interested in understanding a particular case study.

The following section describes how the concept of evolution is applicable to military history, and particularly as regards the development of tactical innovations. This basic framework will then be expanded in the next section, which discusses how can we use it to study campaigns and battles. Mathematical game theory will be used to analyse the commander's decision-making process. The following two sections will focus on the practical application of evolutionary military history to particular case studies, using formal modeling and computational simulation. Finally, we will conclude with an analysis of the risks and potential shortcomings of the framework along with a summary of its advantages and future research lines.

1. The evolution of battlefield tactics.

We are most interested in the study of change over time. The most interesting model to explain this is undoubtedly the theory of evolution by means of natural selection proposed by Charles Darwin. It was created for application in the field of biology, but over the last few decades a number of researchers have realized that its implications go far beyond this. Its scope has been expanded to deal with any scientific question related to transformations over time within a competitive environment. Darwinian theory has surpassed the limits of biology and has now emerged, at the beginning of the 21st century, as a universal theory capable of analysing change inside complex systems.

We should define what we mean by evolution before we start going into detail about how it affects our field. First of all, it is important to note that evolution is in no way related to the idea of progress. Some twentieth-century social scientists used a misunderstood version of Darwinism to justify their own political points of view about superiority, but the consequences of natural selection fall far from these ideas. The evolutionary approach does not point in any particular direction and neither does it specify that some traits are always superior to others. Quite the opposite; Darwinian ideas talk about entities (in the case of biology, individuals or genes) that are constantly adapting to changes in a given environment. Moreover, they interact with other entities which are also adapting, through different mechanisms such as competition, conflict and cooperation. The success of these

adaptations, known as fitness, is decided through the selection of certain traits that have a higher degree of survival and reproduction than others. These traits will gradually increase their presence within the population, while less successful ones will decrease, often to the point of disappearance.

From this perspective, no trait is intrinsically positive in itself. Depending on the situation they can be positive or negative, but also neutral as regards the entity's fitness. For this reason Darwinian evolutionary theory defines two basic types of change: selective processes and neutral processes. The union of both mechanisms can explain any change in a given environment and entity.

The selection of changes is based on two phases: the origin of the change and its reproduction. A change that enables an animal to improve its ability to obtain food will often provide better chances of reproduction. This transformation will have a positive impact on the selection of the individual if it is able to pass it on to other animals. In the case of genetic changes or mutations, sexual reproduction will be responsible for this process. The individual will have more offspring that will be able to reproduce better, and eventually the trait generalizes to the entire species. This, of course, will be the case if the environment does not change; if it does, the new scenario may not provide a positive selection for this trait and the entire situation could evolve in another direction.

Neutral processes have no real effect in terms of improving the fitness of the organisms. Genetic drift, for example, encompasses all the changes generated by sexual reproduction. This mechanism mixes the genes of two individuals, so traits present in only one of the parents are lost or transmitted without proper selection of their fitness.

These two mechanisms are not only applicable to biology. They help us to classify and understand any process of change, and for this reason they have been used in problems relating to culture and society[7]. We can use them to answer questions like why some ideas become popular when others that seem better fail, or whether some events are inevitable or, on the contrary, improbable, etc.

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7 For example: SHENNAN, S. (2002). *Genes, Memes and Human History. Darwinian Archaeology and Cultural Evolution*. Thames & Hudson, UK.
DEAN, J.S., GUMERMAN, G.J., EPSTEIN, J.M., Axtell, R.L., SWEDLUND, A.C., PARKER, M.T., MCCARROLL, S. (2000). "Understanding Anasazi Culture Change Through Agent-Based Modeling". *Dynamics in Human and Primate Societies.* Kohler, T.A., Gumerman, G.J. (eds.). Santa Fe Institute Studies in the Sciences of Complexity, USA.
BROWN, G.R., DICKINS, T.E., SEAR, R., LALAND, K.N. (2011). Evolucionary accounts of human behavioural diversity. *Philosophical Transactions of the Royal Society B,* 366, pp. 313-324.

This approach, like any other, has its detractors. A common criticism of the concept of evolutionary culture is that we do not know exactly how ideas are created and transmitted. There are different proposals as regards this problem, like the concept of 'meme'[8] and cumulative culture[9]. None of them are yet the equivalent of genes in biology, and the fact is that we do not know precisely what mechanisms underly selection within a cultural environment. Nevertheless, this does not invalidate the perspective as a whole. We can observe the results of selective and neutral processes in culture, and for this reason the theory stands as useful. Indeed Darwin himself did not know of the existence of genes when he wrote the Origin of the Species, but this did not decrease the validity of his hypotheses.

What we can certainly do is define which concepts play an important role in our story. Two different types of entity are observed: cultural elements (anything present in a human society: technologies, objects, ideas, etc.) and the relationships between them. These relationships will be understood in terms of selection, so an element *X* can ease, inhibit or be independent of the appearance of another element *Y*. The identification of elements and their relationships, combined with the detection of selective processes, will be the basis of our framework.

It is important to note that the use of this perspective is particularly promising in military history, given the particularities of the field. Applying an evolutionary theory is difficult if we cannot detect selective processes, and this is usually the case as regards human society. Identifying different cultural elements is difficult because they are intermingled and the speed of change is so fast in some cultures than observing positive selection is difficult if not impossible. However, the process is easier with military history because innovations (technological, tactical, strategic, etc.) can be isolated with greater confidence, and a notable segment of the discipline has focused on this task. Also, competition between cultural elements is fierce, and they even fight against each other on the battlefield; if one tactical system is clearly better than another in a particular environment, it will be selected and the other will become extinct.

To give a specific example, we will look at the transformations of the heavy infantry system in Europe during classical times. Independently of their origins, the best version of the hoplite phalanx was the one developed by Sparta, given its particular culture and society. However, the

8 DAWKINS, R. (2000). *El gen egoísta*. Salvat Editores, Barcelona.
9 ENQUIST, M., Ghirlanda, S., Eriksson, K. (2011). "Modelling the evolution and diversity of cumulative culture". *Philosophical Transactions of the Royal Society B,* 366, pp. 412-423.

Spartans were defeated by Theban forces at Leuctra (371 BC). The Theban commander, Epaminondas, managed to destroy the fearsome Spartan phalanx while adapting his tactics to exploit potential weaknesses in the enemy formation. The package of innovations developed by Epaminondas was defeated by another creation: the Macedonian phalanx. This new heavy infantry system annihilated the Theban formation at Chaeronea some decades after its victory over the Spartans (338 BC). It is worth noting that Philip II of Macedon's infantry tactics shared several characteristics with those created by Epaminondas. This case is a clear proof is that transmission of different innovations is possible as well as the creation of new ones. In the end the Macedonian phalanx system was repeatedly defeated by the Roman Republican legions within a period of 100 years, from the First Punic War (264-241 BC) to the Third Macedonian War (171-168 BC). We can detect the selective process of battle despite the fact that all these warriors (Spartans, Thebans, Macedonians and even Romans) are armed in a similar fashion, used equivalent technology and had the same origins. Nevertheless, we can clearly identify each of these formations (hoplite phalanx, Theban formations, Macedonian systems and Roman legions) and distinguish between them.

This small example shows why military history is a suitable field for exploring adaptive cultural processes. We will be able to identify evolutionary processes using textual sources and archeology, and also evaluate their fitness through actions on the battlefield.

The very same selective processes detected in tactical innovation can be used regarding technology. This element has a major impact in 20th-century conflicts, but we can also detect its importance in other periods (e.g. the Greek trireme, the horse stirrup and the socket bayonet).

It is important to clarify that we should not assume that a tactic or technology that is superior to another (from an independent point of view) will always be selected. Several processes play a vital role in the competition, and for this reason it is difficult to isolate a single factor as clearly superior. Firstly, random processes have a profound impact on selection, as in biology, and researchers have defined the concept of cultural drift[10] to deal with these mechanisms. Secondly, the way in which a warrior confronts enemies is very closely related to his own cultural package, because warfare is a part of it. The consequence of these two elements is that technological determinism[11] can seldom be accepted as a plausible explanation for change. The battlefield does not change because of slight variations in technology, and only huge differences will be of any

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10 BENTLEY, R.A., HAHN, M.W., SHENNAN, S.J. (2004). "Random Drift and Cultural Change" in: *Proceedings of the Royal Society B,* 271, pp. 1443-1450.
11 Lynn (2003). op.cit., p. 17.

importance, like the development of the atom bomb towards the end of the Second World War. At the same time we avoid the opposite position, where culture is the only important factor that drives the evolution of warfare, because other aspects (economic, random or even technological) can be equally important in the selection process. In this sense our approach is fully multidimensional, as evolution does not decide which factors are important by themselves to explain the outcome of a battle; it will depend on the environment created collectively by all of them.

Following this line of thought, the interaction between cultural elements can be even more important than the concepts themselves, and the emergence of an innovation may require changes at other levels (technology, society, etc.). A particular combination of concepts can amplify the effect of an element on the battlefield, and thus it is positively selected. This mechanism is known as coevolution and is seen when different entities adapt constantly to the changes in others.

The emergence of knights and feudalism in Europe is an excellent example of coevolutionary processes. The classic hypothesis that sees the introduction of the stirrup as the technological innovation that revolutionized Western European warfare and society[12] has been refuted by several recent studies[13]. From an evolutionary point of view we can state that heavy cavalry already existed in Europe before this time, in the form of cataphract units, so the main concept already existed and the stirrup probably improved the rider's performance on the battlefield. Nevertheless, other innovations and changes were needed to raise cavalry to its position as the central weapon of medieval warfare. Examples include the development of new lances and the breeding of a bigger horse capable of bearing heavier loads at a faster pace: the destrier. This combination gave a skilled rider superiority in individual combat against infantry. However, this supremacy in battle required one crucial social factor: the disintegration of the western Roman Empire. The reason for this is that the effectiveness of cavalry charges on the battlefield depends on psychological combat against infantry formations. If the enemy is capable of deploying large formations of organized veteran heavy infantrymen, cavalry will have a minimum impact because riders will not be able to pierce the wall of warriors unless these combatants panic. In the case of the Roman Empire, the centralization of resources allowed the creation of huge armies of infantry that were usually able to resist cavalry attacks successfully. The destruction of the political union removed this capacity, and therefore heavy cavalry became a powerful weapon thanks to the tactical

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12 WHITE, L. (1966). *Medieval technology and Social change,* Oxford University Press, USA.
13 AYTON, A. (2005). Armas, armaduras y caballos. In Keen, M. *(editor). Historia de la guerra en la Edad Media*. A. Machado Libros, Madrid, pp. 239-267.

and technological innovations mentioned above. We cannot say that the new type of warfare transformed society or that culture changed the armies because, in any case, all the concepts coevolved at the same time. It is pointless to argue about which cause was more important, because we should understand that each one interacted with the others and even minor events influenced the final result. Certainly the supremacy of the mounted arm slowly decreased towards the end of the Middle Ages and especially during the modern era. As always, historians have put forward various reasons for this, from socioeconomic changes (the rise of monarchies and the loss of power of the nobles) to technological changes (the development of cheaper armor for infantry) and cultural changes (the study of the classics during the Renaissance). In general terms, the progressive accumulation of resources in the hands of kings again enabled the deployment of large numbers of heavy infantrymen on the battlefield. Hence cavalry began to decline in European armies and the technological innovations of the Industrial Revolution condemned the concept of the war horse to extinction during the 20th century.

The rise and fall of western heavy cavalry shows the phenomenon of extinction and environmental change within our framework. Concepts that seem important at a given moment can disappear due to other innovations or changes. At the same time, ideas that already existed can suddenly dominate the battlefield thanks to their coevolution with other innovations.

The cases analysed so far require a large temporal scale to see coevolutionary mechanisms, but this is not always the case; the battlefield is such a competitive environment that we can identify these types of phenomenon on a smaller scale, such as years or even weeks. The Allied armies that disembarked on the beaches of France during Operation Overlord underwent a dramatic adaptation to the environment during the battle for Normandy (June-August 1944). The US First Army had little combat experience when they landed on the beaches, especially in a defensive landscape like the *bocage*[14]. The campaign saw a long list of military operations that met with limited success or even failure. Nevertheless, each of these actions allowed the commander and his troops to improve their fitness by adapting new technologies and tactics. The breaking point was Operation Cobra (25-31 July 1944), in which the Allied armies achieved material superiority in the western zone of the battlefield, exactly where the US First Army was deployed. The continuous process of adaptation undergone the previous weeks enabled the Allied troops to finally break through the German defensive system and advance into the interior of France. This victory was partly based on previous

14 BEEVOR, A (2009). *El Día D. La batalla de Normandía.* Editorial Crítica, Barcelon, pp. 304-317.

English attacks (like Operation Goodwood, 18-20 July 1944) that forced the German commanders to move their reserves to the eastern section of the combat area. But this is not the whole story, as the North Americans were able to achieve success where they had failed before. The evolution of Allied tactics are summarized in studies of the battle[15]. This is a good example of the fact that military historians have used the evolutionary perspective before, although almost subconsciously. Beevor explains several coevolutionary adaptations: the refinement of inter-arms cooperation, especially between land and air forcesarms[16], the modifications made to tanks for opening up gaps in the *bocage[17]*, the installation of phones behind armored vehicles to improve infantry-tank communications[18], etc. All of these were certainly used in other armies, but Operation Cobra was the first time that all of them were effectively applied on a large scale by the US army.

Now we have shown how this framework can be used on any scale, it will be interesting to take a look at how it deals with some of the classic debates that take place within military history. We will explain three of them, which can be found in any period: combat doctrine, the power of flexibility and arms races.

1.   We can define a new military system or doctrine as a package of cultural elements that, combining their effects, create a stable situation at a selective level. The ideas, tactics and technologies included in the package generate a feedback process that in this case improves their fitness. This is why they form a robust and identifiable group. Several examples of this process exist, from the hoplite phalanx[19] to combined arms[20]. These systems should not be seen as isolated packages, but as the aggregation of different concepts that were positively selected at a given moment. In the case of combined arms doctrine, it could be argued that this already existed before the contemporary era. Conditions, cultural variations and technologies were extremely different, but the basic concept can be identified in military forces ranging from Alexander's Macedonian army, through the Napoleonic *corps d'armée*, to the Red Army that captured Berlin in 1945 and the

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15 Ibid.
16 Ibid. pp. 449-468
17 Ibid. p. 323
18 Ibid. p. 361
19 HANSON, V.D. (2000). *The Western way of War: Infantry Battle in Classical Greece*. University of California Press, USA.
20 Also known as interarms cooperation doctrine: HOUSE, J.M. (1984). *Towards combined arms warfare: a survey of tactics, doctrine, and organization in the 20th century.* Command and General Staff College (CGSC) MMAS thesis, p.13, http://usacac.army.mil/cac2/cgsc/carl/resources/csi/House/House.asp

Coalition Forces that fought the First Gulf War in 1991.

2.   Flexibility is the ability of an army to adapt its behavior to new scenarios. This trait is particularly present in forces that need to fight multiple heterogeneous enemies. The Roman army is certainly one of the best examples in this respect. Several ancient military historians have focused on the advantages of the Roman legion system in pitched battles, even though many of these were lost. A new approach, defended by Adrian Goldsworthy, suggests that flexibility was precisely the determining factor in the legions' success[21]:

"*Not only had the Romans adopted the fighting methods of the local peoples, but their superior organization and supply system had given them major advantages over their opponents.*"

Roman armies were capable of adapting to new enemies and situations thanks to their inherent flexibility. They were equally capable of confronting a pitched battle as skirmish tactics, raids and sieges. At the same time, their experience fighting large-scale conflicts provided them with important advantages that improved their fitness in almost any environment.

3.   Finally, arms races are scenarios in which we can detect a continuous flow of improvements in the military potential of the two contenders. Each adapts to the innovation of the other and tries to improve its fitness. This situation produces an ascending spiral of innovations and new investments with no clear ending, and it is usually harmful to both sides. At the very least an arms race can generate a serious escalation in the possibility of conflict or even economic ruin for both sides. Interestingly enough, this social process is also observable in biology, where it is known as the Red Queen Principle[22]. This hypothesis states that entities competing within the same environment need to constantly improve their fitness in order to maintain their survival possibilities in relation to others. The situation can be identified as a coevolutionary process[23]. As Lewis Carroll's Red Queen says: "*...it takes all the running you can do, to keep in the same place.*".

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21 GOLDSWORTHY, A.K. (1988). *The Roman army at war 100BC-AD200*. Oxford University Press, UK,, p. 78
22 DAWKINS, R., Krebs, J.R. (1979). "Arms races between and within species". *Proceedings of the Royal Society B, 205,* pp. 489-511.
23 HEYLIGHEN, F. (1993). The Red Queen Principle. *Principia Cibernetica.*
http://pespmc1.vub.ac.be/REDQUEEN.html.

2. Decision-making processes: evolutionary game theory.

We cannot explain any type of change in war using ideas focusing on selection alone. Social interactions contain a crucial factor that biological studies do not need to consider: the human ability to evaluate situations and make decisions. Interestingly, we can also analyse decision-making processes from an evolutionary perspective, especially using the concept of coevolution.

Any commander will take possible enemy operations into account when deciding what actions his forces will carry out. As a result, any battle plan created by a commander takes into account the plans of the other commanders, and the decision-making processes of all these leaders coevolve in time.

From this point of view, we can expand the use of our evolutionary military history framework. It is not only useful for analysing transformations in tactics and technologies; we can also develop models capable of studying the decisions that a given commander made on a battlefield. However, the process is individual and extremely fast (compared to the other applications), so additional tools are required. We need to use a technique to apply the concepts of coevolution, selection and competition to scenarios in which there is a direct contest between individuals with decision-making capabilities.

Mathematical game theory appears to be the perfect answer. This set of tools enables a researcher to explore decision-making processes within a competitive human environment. The initial model formalizes situations with two protagonists (known as 'players') with completely opposing objectives (if one player wins, the other loses). This type of model, known as sum-zero games, is useful for studying strategies and battle plans created for a particular scenario. We can define the possible strategies of both sides and potential outcomes using several factors (army sizes, quality and morale, logistics, geography, etc.). The design of a game is useful due to the necessary discussion of variables, but in addition we can try to solve the model. The result will show which strategies were optimal for both sides under observed conditions.

Applying game theory to military problems is not new. It was extensively used during the Cold War, when several models were constructed for widely discussed topics such as nuclear weapon policies and strategic dissuasion[24]. In our case, the development of game theory models in

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24 BRAMS, S. J., KILGOUR, D.M. (1989). *Teoría de Juegos y Seguridad Nacional*. Ministerio de Defensa, Madrid.

military history must take into account a subtle difference: optimal strategies will not necessary be those chosen by the real commanders. These cases will be interesting from a scientific point of view, as they will portray situations in which the researcher has to find the reason for the divergence between optimal and real behaviour. This analysis will certainly increase the richness of the model, highlighting potential problems in information retrieval, situation awareness and army performance.

This first models proposed by game theory did not involve time or change: the game is played only once and strategies must be chosen at the same time and are implemented simultaneously. Nevertheless, a number of researchers saw the importance of introducing this concept. The approach they took was to repeat the game several times. At any moment players do not only evaluate the present situation, but also the relation between chosen strategies and results in past games. This modification enables players to adapt to the enemy through the design, modification or discarding of strategies. The proposal was an important achievement and created a new research line, known as evolutionary game theory[25], which was successfully applied to politics, sociology, economics and even evolutionary biology[26]. In the case of evolutionary biology, game theory was applied to understand how survival strategies are chosen through selective processes, thus strengthening the relationship between game theory and evolution. Obviously there are no individual decision-making processes involved in biology, but the process as a whole can be modeled on strategies and outcomes.

This is precisely the type of game theory model that may be interesting in our case. It enables the researcher to understand how humans make decisions and how these decisions can change over time in relation to enemy actions and past events. It is easy to deduce that this approach can be useful for military history, especially in the study of campaigns. We can imagine, for example, how it could be used to develop a model of two enemy forces that fight each other repeatedly over a brief period of time (months or years). Each engagement would serve to modify strategies in order to defeat the enemy, whose options are known from past combats. The Cold War between the USA and the USSR saw the first models of this type, such as those constructed by Dresher[27], who calculated the optimal distribution of tasks for an air force with fewer planes than the enemy.

As an example we will use this approach to analyse a famous set of campaigns: the Second

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25 AXELROD, R. (2006). *The evolution of cooperation*. Basic Books, USA., p.57
26 SMITH, J.M. (1982). *Evolution and the Theory of Games*. Cambridge University Press, UK.
27 DRESHER, M. (1981). *The Mathematics of Games of Strategy*. Rand Corporation, USA., pp. 145-156.

Punic War (218-201 BC). We know from Roman sources that, for Cannae (216 BC), the Punic commander Hannibal developed a battle plan specially designed to defeat the Republican Roman army. He based his strategy on knowledge extracted from past combats, especially the Battle of Trebbia (218 BC). In this engagement the Punic cavalry defeated their mounted enemies, but at the same time the Roman infantrymen broke through to Hannibal's center, this being the reason why the Roman legions were able to escape from a possible encirclement. The difference in the quality of infantry and cavalry was detected by Hannibal, who in Cannae deployed a flexible center, designed to retreat from the Romans without panicking. This solution gave the cavalry time to defeat their enemies, reorganizing and finally completing the encirclement of Roman infantrymen. Their situation became desperate and Hannibal was able to annihilate the enemy force and inflict a crucial defeat on the Republic[28]. Carthage was not alone in adapting to the enemy, and after the catastrophe a new Roman commander - Publius Cornelius Scipio - set out to modify Roman battle plans. His innovations exploited the capabilities of the Roman legions to the full and, combined with diplomatic opportunities, turned the war around. Scipio was finally able to defeat Hannibal at Zama, 16 years after Cannae[29]:

> «The deployment of both forces was very similar and showed how much the two military systems had learned from each other in the course of many years of war»

Scipio managed to defeat Carthaginian commanders including Hannibal without making any special changes in weaponry or tactics. The only thing he modified was the decision-making process of the Roman leaders, developing new strategies that were specially designed to defeat the Punic forces (exactly what Hannibal did in Cannae). It is worth noting that Hannibal tried, at the same time, to adapt to Scipio in Zama. He had lost the support of some of his allies, such as the Numidians, who had provided him with one of his best weapons: experienced light cavalry. As we have already mentioned, the use of an evolutionary approach does not imply a continued improvement in efficiency, but a constant adaptation to environmental change. Hannibal was aware that he would deploy an army of inferior quality to the forces operating in Italy, and for this reason he modified his tactics accordingly in order to improve the odds; the adaptation failed, and the result was decisive for the future of both sides.

Evolutionary game theory is not only useful for examining situations of repeated

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28 GOLDSWORTHY, A.K. (2001). *Cannae*. Cassell & Co., UK., p. 111
29 GOLDSWORTHY, A.K. (2002). *Las Guerras Púnicas*. Ariel Ediciones, Barcelona, p. 356

engagements. It can also help us to understand why a balanced scenario changes abruptly as a result of several small changes that are hard to integrate into a single explanation. The Balaguer campaign (1710), fought during the War of the Spanish Succession (1702-1715), is a clear example[30]. The paper explores an equilibrium of several weeks between a Bourbon army deployed outside the city of Balaguer and the Allied army defending the area. There was no pitched battle, and for several weeks the situation did not change. The worsening of health conditions in the Bourbon encampment along with rumors of Allied reinforcements and the geographical features of the area combined to alter the balance and change the perception of the Bourbon commanders. In the end they completely changed their operational strategy and retreated from the area. The final outcome was the Battle of Almenar, in which the forces of Charles III, the Hapsburg pretender, managed to defeat the Spanish army, leading to the offensive that conquered Madrid two months later.

3. Modeling military engagements.

In the previous sections we discussed how an evolutionary framework can be applied to understand and explore the concept of change in warfare. This is a multiscalar perspective that ranges from long-term transformations to individual decision-making processes. This seems useful enough as an underlying theory while examining history, but we are interested in applying these ideas in a practical way. We need to understand selective processes on the battlefield, using real case studies to detect particular adaptations and coevolutionary mechanisms.

The best way of dealing with this problem is to develop models. This scientific technique involves creating an abstract formulation of a situation. This construction, known as a model, can be of different types (mathematical, geographical, algorithmic, etc.) and will enable us to answer a particular question. The process is interesting because we will need to consider the most important variables that answer this particular question and how they interact with each other. The model will be simpler than in real life, and this property will make it easier to understand than real events. If the definition of the model includes the keys to answering the question, we will be able to give an outcome by resolving the system using analytical approaches, computational simulations, etc[31].

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30 RUBIO-CAMPILLO, X. (2009). "Teoria de jocs aplicada a la història de la guerra moderna. De Balaguer a Almenar". In: *Manuscrits. Revista d'Història Moderna,* 27, pp. 143-160.
31 RÍOS, S. (1995). *Modelización.* Alianza Universidad, Madrid, p. 17

This methodology, known as modeling, enables scientists to develop new theories that explain real observations such as, for example, the theory of general relativity proposed by Einstein or game theory itself. But it also has another use that is perhaps even more interesting for social scientists: the ability to experiment with scenarios impossible to create in the real world. A model can be used as a virtual laboratory, where working hypotheses can be tested and validated inside a controlled and simplified environment. If the model is correctly constructed, we will be able to extract knowledge that can be applied to real situations[32].

Modeling has been used extensively in most scientific disciplines and its application is currently increasing in human and social sciences. Some disciplines, such as economics and archeology, have already recognized the advantages of formal models. Unfortunately this is not the situation as far as history is concerned, and formal models are rarely seen in historical research publications. There are several reasons for this situation, but two of them stand out above the others: the poor training of historians as regards formal models (especially mathematics) and the difficulties involved in any attempt to model human society. The latter is very important, as any useful model should take into account decision-making processes as well as properties deriving from the complexity of the system.

Regardless of why, the fact is that few attempts have been made to use modeling to answer questions regarding human history. It is our belief that this situation should be addressed, as models are a powerful tool for the discipline because we are unable to experiment with past events, and so modeling is as close as a historian can get to a laboratory. He or she would be able to analyse a scenario by designing a model and testing whether the hypotheses formulated make sense in it.

It is worth noting that the only formal models published in historical research are related to military engagements. Most of this research, however, was published in journals seldom consulted by historians. Some examples of this are a mathematical model created to understand the Battle of Agincourt, 1415[33], a differential game approach to firepower at Bunker Hill, 1775[34], and the modeling of medieval logistics[35].

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32 For a more extensive explanation about this methodology see: EPSTEIN, J.M. (2008). "Why Model?" In: *Journal of Artificial Societies and Social Simulation, 11(4)12.* <http://jasss.soc.surrey.ac.uk/11/4/12.html>.
33 CLEMENTS, R. R., HUGHES, R. L. (2004). "Mathematical Modelling of a mediaeval battle: the Battle of Agincourt, 1415". *Mathematics and Computers in Simulation*, 64, pp. 259-269.
34 ISAACS, R. (1999). *Differential Games. A Mathematical Theory with Applications to Warfare and Pursuit, Control and Optimization.* Dover Publications, USA.
35 CRAENEN, B., THEODOROPOULOs, G., SURYANARAYANAN, V, GAFFNEY, V., MURGATROYD, P., HALDON, J. (2010). "Medieval Military Logistics: A Case for Distributed Agent-based Simulation". *Proceedings of*

This problem is symptomatic of another issue: the difficult communications between people with different backgrounds and languages, like modelers and historians. Fortunately, military historians have a midway alternative at their disposal: wargames. These formal models were created 150 years ago by soldiers and their main advantage is that they avoid complex mathematical formulations. A wargame can be defined as a game designed to explore a commander's role in warfare using an interactive approach similar to chess and other board games. One of the first wargames was *kriegsspiel*, an invention that the Prussian military staff developed after the Napoleonic wars. *Kriegsspiel* was used to train officers and improve their decision-making processes and cooperation between the staff. Its rules enabled simulation of the experience of a military campaign, integrating the strategies of both sides into the model, along with army capabilities and uncertainty.

Even though military training has used wargames for a long time, this tool has rarely been used in academia[36]. As a result, while soldiers have used formal models to study violent engagements, military historians did not consider the use of this technique even though they often have similar objectives.

The most interesting attempt to correct this situation is the *comparative dynamic model* published by Prof. Philip Sabin[37]. The aim of this is to explore the most important battles of ancient times using a wargame based on research hypotheses. The author uses the first section of the book to formalize his model, creating a set of rules capable of creating a battlefield with important geographical features (rivers, hills, woods, etc.). Sabin also uses textual classical sources to model the concepts of movement and combat for different types of troops (hoplites, heavy cavalry, archers and so on). The rules also include the differences in combat performance between the various types of warrior as well as the impact of quality, commanders and terrain on the outcome.

The second part of the text tests this model using several battles, from hoplite warfare between Athens and Sparta to the last battles of the Roman Republic, including Julius Caesar. The technique proposed is useful for finding errors in primary sources which are difficult to detect at first glance (e.g. deployment frontage, number of combatants, etc.). A second objective is the

the 3rd International ICST Conference on Simulation Tools and Techniques.
36 FOLEY, R.T. - Editor (2003). *Alfred von Schlieffen's Military Writings.* Frank Cass, USA, p. 119
37 See: SABIN, P. (2008). *Lost Battles: Reconstructing the Great Clashes of the Ancient World.* Continuum, UK.
 SABIN, P. (2012). *Studying Conflict through Simulation Games*, Bloomsbury Academic, UK.

comparative study of contradictory versions of the same engagement. These experiments enable the military historian to test which narratives seem more plausible from the model point of view. A third achievement is the capacity to portray the evolution of warfare over the course of the period studied. Sabin provides the researcher with a tool capable of modeling battles over four centuries, and therefore it is possible to analyse and compare the behavior and tactics of different armies. However, the most interesting idea arising from the project is that it enables the researcher to play the role of commander. It is a similar approach to game theory, as this experience is useful for understanding the decision-making processes using a simpler representation of a given battle.

The use of this model has achieved success within part of the military history community and has been accompanied by a conflict simulation course at King's College London.

These "manual" simulations provide a number of advantages for users, including the detection of important geographical features and the importance of cooperation between troops. An important result of this approach is that the models are fairly abstract in terms of tactics, types of troops and weapons. The reason for this is that highly detailed combat mechanisms should require additional quantitative data. This knowledge may be unavailable or unreliable and would introduce errors through the estimation of parameters with high uncertainty.

Nevertheless, it would be helpful to integrate this information into the model when it is available. This is one of the problems of "manual" simulations in that they are unable to solve complex interactive mechanisms with multiple actors (i.e. individual combats within a battle). The other major issue with this type of model is that a multiscalar approach is almost impossible. The combination of different levels of behaviors would complicate the resolution of the model, and most of them choose only one layer of combat (*Lost Battles*, for example, focuses on grand tactics).

These major problems make it difficult to use manual wargames to explore military engagements if we want to use a complex system perspective. As we mentioned earlier, certain properties observed on one level (heterogeneous behaviors, individual interactions, etc.) bring about the emergence of new patterns on larger scales. If we want to link small-scale processes with overall consequences we need to use computational science. Numerical simulations will be able to integrate quantitative and qualitative information at multiple levels, experiment with hypotheses and validate outcomes.

4. Agent-based modeling and warfare.

In this section we will show the benefits of developing computation simulations useful to military historians. The technique has interesting advantages but, like any other methodology, it can also involve problems and risks.

As stated earlier, the most powerful capability of computer simulation is the integration of multiscalar qualitative knowledge (tactics, behavior, culture of warriors, etc.) and quantitative knowledge (weapon lethality, proportion of casualties, etc.). Applying it to military conflicts seems an excellent idea because it is difficult to combine both types of knowledge in historical research. The study of warfare is currently divided into two different trends: individual qualitative studies analysing the experiences of soldiers[38] and the classical study of battles, centering on actions and closer to commanders[39]. Some historians are interested in closing the gap and some of them have even published studies focusing on this topic[40], but the reality is that it is a daunting task if we analyse combat using only textual sources and even archeology. This is because it is difficult to combine the commander's perspective with the experiences of the other soldiers due to the distance between both subjects.

Textual sources from ancient and medieval times are almost exclusively written by commanders, and the researcher has great difficulty in trying to detect the experiences of lower ranks. Archeological studies can be helpful in this respect, but the discipline has its own issues when trying to focus on particular individuals[41]. If we advance in time, modern and contemporary history provide us with primary accounts written by people with different roles, but their experiences are vastly different and it is increasingly difficult to integrate the whole plethora of different perspectives. Simulation can be a key tool in solving this dilemma, as it allows both visions to be integrated formally.

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38 See: KEEGAN, J. (1983). *The face of battle.* Penguin Books, USA.

DUFFY, C. (1998). *The military experience in the age of reason.* Wordsworth Editions, UK.

BISHOP, P. (2004). *Fighter Boys: The Battle of Britain.* 1940. Penguin Books, USA.

39 See: DUFFY, C. (2008). *By Force of Arms. The Austrian Army of the Seven Years War, vol. 2.* The Emperor's Press, USA.

HOCHEDLINGER, M. (1999). "Bella gerant allii...? On the state of Early Modern Military History" in Austria. *Austrian History Yearbook,* XXX, pp. 237-277.

40 KAGAN, K. (2009). *The eye of command.* University of Michigan, USA.

41 SHENNAN (2002). op.cit., p. 10

In addition, computer simulation breaks down the dichotomy between diachronic and synchronic perspectives. Some types of computer experiment are capable of integrating the analysis of a particular time (synchrony) with long-term pattern detection (diachrony). A major consequence is that researchers can apply the evolutionary perspective of simulation to link simultaneous and gradual transformations.

Agent-based models (ABM) are particularly successful in answering questions relating to social sciences and humanities. An ABM defines the behavior of any entity of a system that involves decision-making processes (known as agents). These agents interact within a controlled environment that can be a real landscape (with geographical features, vegetation, transport systems, etc.) or an abstract domain. The researcher creates an initial scenario, giving values to certain parameters according to certain hypotheses that need to be tested. The simulation now set up is executed in a set of regular time steps (an hour, a year, … whatever is most appropriate for the experiment). For each of these time steps the agents evaluate the situation, plan what actions they want to execute and interact with each other (and also with the environment). Finally, the results of several of these simulations are analysed in order to answer the questions set at the beginning of the research.

A paradigmatic example of this methodology is SugarScape[42], specially designed for social scientists. The authors build a virtual society from zero using simple, individual behavioral rules. The results portray the emergence of several universal rules that were not explicit in the initial model but which appeared out of the agent-agent and agent-environment interactions (migrations, conflicts, trade, hierarchies, cultural identities and so on).

It is worth noting that ABMs reproduce exactly the same situation as wargames: their use is considered in current military research[43] but almost unknown in military history. Nevertheless, some interesting experiments have been published in the last decade. One of the most interesting successes is the study of the WWII submarine campaign in the Bay of Biscay[44]. This project is an

42 EPSTEIN, J.M., AXTELL, R.L. (1996). *Growing Artificial Societies: Social Sciences from the Bottom Up.* The MIT Press, USA.

43 ILACHINSKY, A. (2004). *Artificial War. Multiagent-Based Simulation of Combat.* Center for Naval Analyses - World Scientific, USA.

44. See: PRICE, J. C. (2003). *Game Theory and U-Boats in the Bay of Biscay.* Master thesis, Air Force Institute of Technology.

HILL, R. R., Champagne, L. E., Price, J. C. (2004). "Using Agent-based Simulation and Game Theory to Examine the WWII Bay of Biscay U-boat Campaign". *Journal of Defence Modeling and Simulation*, 1(2), pp. 99-109.

HILL, R. R., CARL, R.G., CHAMPAGNE, L. E. (2006). "Using agent-based simulation to empirically examine search theory using a historical case study". *Journal of Simulation*, 1, pp. 29-38.

evolutionary analysis dealing with the tactical and strategic adaptations of both sides involved in this long battle. Technological innovations were constantly being developed in conjunction with tactical modifications. The spatio-temporal distribution of U-boats, the structure of Allied convoys and submarine hunter actions were radically modified over a period of almost six years.

This research proposed two different models that were combined in each time step:

–   An evolutionary game that models commander's decisions. This analytical approach explored the potential strategies of both sides using data from past and current time. For each time step, commanders choose a strategic plan that is implemented in the second model:

–   An agent-based model in which chosen strategies are applied. Submarines move and change their state (surfaced or submerged), while Allied submarine-hunter planes explore the sea day and night. In the end the probabilities of the success of attacks are calculated depending on the state of the agents. Information is extracted from the results and sent to the first model in order to execute a new iteration.

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There are other models constructed using this approach, such as Iruba, which explores the emergence of insurgence and guerrilla warfare[45], and EINSTein, which is designed to explore the dynamics of current battlefields[46]. However, all these works only analyse contemporary conflicts (20th and 21st centuries). There are only a couple of projects which study other periods, one of which is "Medieval Warfare on the Grid'. MWGrid models the entire logistic chain of an 11th-century army: the Byzantine force annihilated at the Battle of Manzikert, 1071[47]. The second example is a simulation of 18th-century infantry tactics, closely related to the study of material remains using battlefield archeology[48]. This is a comparative study of the fire systems available during the War of the Spanish Succession (1702-1715) and explores the evolutionary adaptations responsible for the diversity of tactics present in this conflict.

CHAMPAGNE, L.E., Hill, R. R. (2009). "A Simulation Validation Method Based on Boostrapping Applied to an Agent-based Simulation of the Bay of Biscay Historical Scenario". *Journal of Defence Modeling and Simulation*, 6(4), pp. 201-212.

45 DORAN, J. (2006). "Modelling a typical guerrilla war". *Distributed Intelligent Systems: Collective Intelligence and Its Applications*, DIS 2006, pp. 285-290.

46 ILACHINSKY (2004), op.cit.

47 CRAENEN, B et al. (2010), op.cit.

48 See: RUBIO-CAMPILLO, X., CELA, J.M., HERNÀNDEZ, F.X. (2012). "Simulating archaeologists? Using agent-based modelling to improve battlefield excavations". In: *Journal of Archaeological Science*, 39, pp. 347-356.

RUBIO-CAMPILLO, X., CELA, J.M., HERNÀNDEZ, F.X. (2013). "The development of new infantry tactics during the early XVIIIth century: a computer simulation approach to modern military history". In: *Journal of Simulation*, 7, pp. 170-182.

Conclusions.

This paper proposes a new approach to the history of warfare. We have shown that military history can enrich its discussions by analysing cultural change using Darwinian concepts. The evolutionary perspective is useful not only as a conceptual framework but also as a methodology capable of designing formal models that integrate data from various origins. It is currently being successfully applied in other knowledge fields involving human society, especially using agent-based models. Some of the reasons behind the spread of this technique are:

- Multiscale integration of qualitative and quantitative information

- Spatio-temporal analysis

- Detection of links between synchrony and diachrony

- It allows exploration of complex social systems in which overall behavior emerges from individual traits

We can say that computer simulation helps to solve some of the chronic problems of history, understood as a scientific discipline. However, any researchers that want to use it should be cautious because certain pitfalls and risks must be avoided in order to guarantee scientific quality. The most important point is that we should not accept the results of a simulation as directly applicable to reality. This problem is the result of misunderstanding the concept of modeling itself[49]. An excessive emphasis on individualism should also be avoided, a problem seen in badly designed agent-based models[50]. In a more practical sense, it is important that the models constructed are understandable and useful for humanists and social scientists. If this is not the case, these models will not be published in journals of the discipline and their impact on the community of historians will be insignificant however brilliant the design.

If we manage to combine this methodology within the theoretical framework currently used in history, the consequences could be important, as some of the works presented in this text prove. We should be able to gain deeper insights into human behavior, understood as a complex system. As a major result, any sense of historical determinism should disappear. This is an important point because it is present in certain aspects of the discipline, especially in military history. We can find

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49. GAFFNEY, V., BRADLEY, G. (2006). "Who's in command here? The digital basis of historical, military logistics". *General Issues in the Study of Medieval Logistics: Sources, Problems and Methodologies.* Brill Academic Publisher, pp. 37-69.

50 O'SULLIVAN, D., HAKLAY, M. (2000). "Agent-based models and individualism: is the world agent-based?" In: *Environment and Planning,* 32, pp. 1409-1425.

several examples that try to explain change using only a few causes without exploring the potential relationships between cultural elements or their relative importance as regards observations. Strictly speaking we need to be aware that simulating historical events does not prove anything, because we are exploring experiments using a virtual laboratory. Nevertheless, the design of a formal model forces the historian to explicitly list and justify the reasons why his or her hypotheses answer a particular question. The researcher must also define the importance of all parameters in relation to the others, and not just list them. In the end, simulation (both manual and computational) enables us to experiment with questions and hypotheses, and validate whether they are consistent inside a controlled environment.

Finally, the evolutionary framework demands that the discipline confront a crucial problem: the role of uncertainty in history. Multiple executions of a particular model enable us to understand the probability of a particular chain of events happening, unlike alternative scenarios. Past events were not inevitable and often they were not even the most probable outcome to a particular situation. Historians should realize that exploring other scenarios is interesting in itself and in addition provides us with a richer point of view about the past.

In short, the evolutionary perspective and formal models deriving from it generate a deeper and more complex interpretation of the elements that make up any event in society, and also their relationships. Using them would be a major contribution to the study of warfare, unfortunately one of the most important and constant of human activities.

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