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Abstract

A dynamic distributed model is presented that reproduces the dynamics of a wide range of varied battle scenarios with a general and abstract representation. The model illustrates the rich dynamic behavior that can be achieved from a simple generic model.

1 Introduction

Studies of biological computation and neural activation have revealed mechanisms that are spatially distributed and essentially dynamic in nature. The dynamic nature of neural representation should not be surprising, since the external world which is modeled by such internal representations is itself fundamentally dynamic, as evidenced by the growing popularity of chaos and dynamics in models of natural systems. Nowhere is nature more dynamic than in situations of competition and conflict, where the struggle for resources often leads to large and erratic swings of fortune that are impossible to model with simple linear models.

In the case of human conflict, certain nonlinearities dominate the dynamics of battles and wars. Local superiority of force provides a nonlinear advantage in a battle, making it a primary concern of the military commander to concentrate strong forces against enemy weak points. The issue of resupply to units in action embodies yet more nonlinearities, since smaller forces can defeat larger forces by cutting off their supply lines. On a larger scale of strategy, the sources of supply of war materiel are also a prime target, which contributes another nonlinearity since the capture of such supply sources simultaneously increases your own supply while reducing that of the enemy. Furthermore, a source that is capable of producing a steady supply of some commodity is immeasurably more valuable than a fixed quantity of such a commodity since a source represents a potentially endless quantity. All of these nonlinearities (and many more) result in a dynamic situation that can be extremely labile and sensitive to initial conditions. Skilled commanders must be able to function in such an environment, allocating resources to critical areas, providing sufficient defense while pressing home an aggressive offense. The commander must understand the dynamics of the situation with a mental model, in order to make critical predictions on the basis of limited knowledge and in the face of many layers of uncertainty. The fact that commanders can operate successfully in such demanding circumstances suggests a general purpose dynamic modeling mechanism as being a fundamental part of their mental processes.

Many dynamic systems are mathematically equivalent, and exact analogs have been established between the dynamics of electrical, mechanical, acoustical and hydraulic systems (Olson, 1943). Neural systems must exploit this commonality by reproducing the same dynamics in a generic neural circuit. The xbattle project is an effort to explore the properties of this kind of generic dynamic model, by illustrating how such a simple but general dynamic representation is able to capture the essential dynamics common to a large range of widely varied battle technologies. In doing so, xbattle illustrates that a detailed modeling of individual facts and functions specific to a particular technology is not essential to an understanding of the top level or abstract overview of the battle strategy, and that this kind of abstract representation would likely play an important part in the mental visualization of the battle commander.

2 Elements of the Model

The xbattle simulation consists of a two dimensional array of neural elements representing the battlefield, whose activation represents a military presence. This presence can be interpreted as the presence of troops, ammunition, supplies, food, or other requirements of an army in combat. For convenience, we will call this quantity "troops", although the exact nature of the quantity is an abstract value, representing military effort in any of the many forms that it may take. The elements can be connected to their four orthogonal nearest neighbors to represent troop movement from one element to the next. In each update cycle, the value of each element is computed from its inputs and the activation function. A variation of the Grossberg shunting equation (Grossberg, 1968) was used as a generalized dynamic neural model, which grows exponentially with input while remaining bounded to a maximum saturation value by the shunting term. This represents a maximum limit to the number of troops that can be stationed at one location, and the shunting term simulates the time taken to dig in and build up to that maximum value. A decay term simulates the consumption of supplies at each location, and is proportional to the number of troops at that location. A supply source can be input from either a neighboring element, or from an external supply source which is available at some locations. The details of the dynamics are described in the appendix.

The array is displayed graphically on a computer screen as a grid, where a human operator can issue commands by clicking on the grid with a mouse, and a battle simulation is achieved by displaying the same grid on other displays where other operators control the opposing armies. Opposing armies are displayed in different colors on the screen, and the armies can be commanded to move by making or breaking the links between adjacent squares. Figure 1 shows a typical display during a battle simulation. Unlike conventional neural activation, in this model, communication of activation from one unit to a neighbor depletes the activity of the source unit. Like the discharging of a capacitor, this has the effect of sending a powerful pulse followed by an exponentially decaying trickle. 2 illustrates this effect.

Whenever opposing armies occupy the same location on the grid, a battle ensues, wherein each side sustains damage by the other until one side is eliminated. A nonlinear function is used to compute the damage to each party to the conflict, such that forces of equal strength suffer equal damage, while an unequal match greatly favors the superior force. A random factor is combined with the nonlinearity to produce stochastic results. Resupply to the embattled location can replenish the losses suffered in each update cycle and greatly increases the chance of a successful attack. The nonlinear battle function is a simple square law, whereby the damage sustained by each side is proportional to the square of the ratio of enemy strength over friendly strength, multiplied by a constant that can be adjusted at run time, which modulates the steepness of the

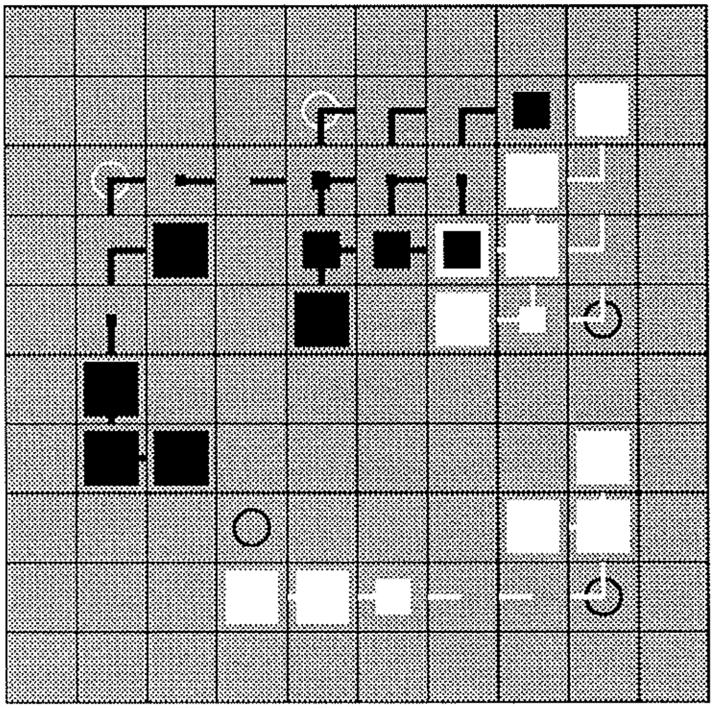

Figure 1: **Sample Simulation display.** The black and white squares represent troops, and the short black and white lines indicate movement between adjacent squares. The circles represent supply bases that supply troops at a steady rate. Battles are indicated by black and white squares in the same grid location. Bases in the north west are supplying black armies along a front with white, which is supplied from the south east. An unclaimed base in the south west is being approached by both sides, and a battle is in progress in the north east where black is mounting a flanking attack from north and west on a white army.

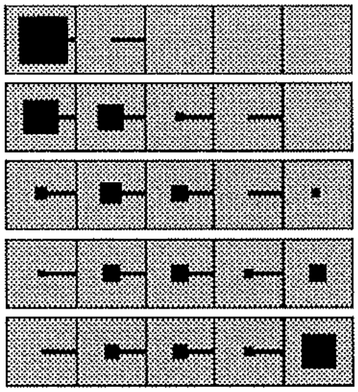

Figure 2: **Troop Movement Dynamics.** The rows show subsequent time steps as the troops advance from the left most to the right most square. The column is seen to disperse along the line or march and reassemble at the destination. When more troops advance in a dense column, regions of congestion develop in periodic patterns, like traffic jams on a busy highway.

function.

In some simulations geographical inequalities and topographical features were represented by variations in the conducting properties of the elements. These were either reversible, representing hills, where the work expended in ascent is returned on descent, or irreversible, representing a generalized hinderance to motion, such as forests, marshes, or bodies of water.

3 Global Behavior of the Model

The simple dynamics defined for the individual elements in the model resulted in remarkably realistic global battle dynamics despite the highly abstract nature of the representation. The capacitative discharge behavior has the effect of stretching a marching column into a stronger van leading a trail of stragglers. The column will continue to disperse as it travels unless it is stopped, when it slowly re-groups at the van as the stragglers re-join the main body. This represents the generalized behavior of many diverse forms of land transportation. When attacking enemy positions, this property has the effect of giving an advantage to the defense, since the attackers tend to arrive in a stream while the defenders remain concentrated. This makes it necessary for the attackers to stop and assemble before an attack, and to attack simultaneously from two or more sides if possible in order to arrive at maximal strength. As in real combat, a large scale law of local superiority emerges naturally from the local laws, so the simulation exhibits a fractal-like self-similarity across scales in tactical and strategic laws of supply and attack. Also, the small scale tactical advantage of the flank attack results in a similar large scale strategic advantage to larger flanking thrusts, which results in a realistic twisting and turning of opposing battle lines in an attempt to isolate bulges and salients in the enemy lines. The capacitative discharge property also produces another dynamic typical of combat, i.e. the vulnerability of a retreat under fire, because the retreating stragglers can be easily overwhelmed by an enemy in close pursuit.

The model also illuminates the pivotal importance of resupply to all military operations. There were two kinds of supply sources used in the simulations, fine grained and coarse grained. The fine grain supply sources were in the form of a uniform input signal to every element in the grid at all times. This represents troops and supplies accumulated from local sources, which are proportional to the land area occupied, an approximation to the large scale strategy of national conflicts.

The decay of each node is such that the small input signal cannot accumulate to any significant quantity in a single node, but a dynamic equilibrium is achieved at a very small troop strength, which represents the number of troops that can live off the produce of a local plot of land. When all surplus from a larger area is funneled into a single location however, a sizeable army can accumulate, and the size of the army reaches a dynamic balance with the area of territory supporting it. The basic unit of warfare therefore is not the isolated army, but also the territory supporting it, and the dynamics of warfare are governed by the the struggle to capture enemy territory to increase your own force, or to cut off the enemy from their own supply sources. This dynamic is very well represented in the xbattle simulation. Separating an army from its source of supply is much like separating a head from a body, thus the dynamics of outflanking and cutting off of an enemy are reproduced. In the coarse grained simulations more sparsely scattered concentrations of supply were established at fixed geographical locations. This simulates localized strategic resources, such as towns or factories, and the type of combat that emerged from this kind of simulation was more dynamic and unpredictable, as is characteristic of smaller scale battles and skirmishes, where large swings of fortune are precipitated by surprise attacks on key supply points. Intermediate grain and mixed grain simulations were found to have intermediate properties.

4 Results

More conventional battle simulations generally strive to reproduce a specific technology and can thereby be evaluated by comparing their performance to that of actual military hardware. The intention of this simulation however is to capture the general principles behind many technologies, and to reproduce those dynamics which are common to them, using a simple set of very general dynamic mechanisms. The two metrics by which this model is to be evaluated therefore are first, whether the dynamic laws of this system are indeed simple, and second, whether a simple adjustment of basic parameters can recreate a wide range of realistic dynamics seen in different battle scenarios.

To address the issue of simplicity, the model was kept as simple as possible – using simple continuous saturating functions throughout, whose steepness was modulated by simple control arguments to achieve the variety of different behaviors. The Grossberg shunting equation which was used for the activations is a general purpose saturating dynamic system.

There is no simple analytical or numerical method for evaluating the accuracy and generality of the simulation as a model of actual battle dynamics; the only real way to perform such an evaluation is to elicit the opinion of military experts who have studied military strategy or have actual combat experience. Currently, the model is under evaluation by a number of such experts, and although the detailed analysis is not yet available, initial results are promising. Furthermore, an intensive and on going testing of the model by a group of researchers here at Boston University has revealed that the model continues to exhibit new and interesting dynamics after a year of operation on an almost daily basis.

5 Conclusions

As a model of the principles of combat dynamics, xbattle does not pretend to duplicate the exact mechanism of mental imagery used by military commanders, but rather, to illustrate how a simple generic model can be used to represent a wide range of dynamic situations, which shows that the character of a dynamic mechanism can be modeled without necessarily reproducing the exact mathematical functions, but rather by selecting similar but generic functions that saturate in similar ways. It is interesting that the representation of this model bears hardly any resemblance to the physical properties of artillery, armor, infantry, etc. of actual military forces, and yet it captures the highest level or most abstract qualities of the behavior of those forces. As such, xbattle can serve as a training tool to illustrate the principles of strategy and tactics, or as a platform for implementing computer algorithms for automated reasoning about military strategy. Indeed, the xbattle simulation has already begun to serve in that role, hosting a variety of diverse algorithms to automate tactical and strategic reasoning, which will be the subject of future work.

6 Appendix

$$\frac{d}{dt}x_i = -Ax_i + (B - x_i)\left(C\sum_j x_j w_{ji} + I_i\right) - C\sum_j (B - x_j)x_i w_{ij}$$

This equation shows the modified Grossberg shunting equation used in this simulation. The first term is the decay term whereby the activation x_i of the i^{th} node decays in proportion to its current value, governed by the decay constant A. This represents the consumption of resources by the troops. The next term is the shunting input term, where the growth of activation is gated by the difference between the current value and the maximum possible value, B. This establishes B as an upper limit of activation. Input I_i is the external source, and the rest of the input is from orthogonally adjacent neighbors via the weights w_{ji}, which are binary, and can be created or deleted by the operator during the simulation. The actual implementation was an integer approximation to this dynamic equation, and the activations were normalized for movement so that the number of troops that arrive in a square is equal to the number that departed into it from adjacent squares plus the external input to that square. This operation is represented by the final term in the equation.

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