BUGS: A Test Bed For Catastrophe Based Collective Behavior

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BUGS: A Test Bed for Catastrophe Based Collective Behavior

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BUGS: A Test Bed for Catastrophe Based Collective Behavior

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INTRODUCTION

IST researchers have constructed a model environment to rapidly generate and test ideas about force-field driven, catastrophe switched behavior. While the ultimate goal of this project is to help produce a dismounted infantry semi-automated force (SAFOR) for the simulator networking (SIMNET) environment, the SIMNET environment is inherently very complex. The simulated environment facilitates the testing of ideas for behavioral modeling.

The program, Bugs, was used to test the ideas reported on in the paper "Human Behavioral Modeling Using Catastrophe Theory" presented at the 2nd IST Behavioral Representation Symposium. (Appendix I contains this paper.)

Bugs was implemented on a NeXT Workstation equipped with a Motorola 68040 processor. The language used was Absoft Objective Fortran. Fortran was chosen because of its ability to include complex numbers and its good match to numeric processing. The Absoft version was used because it included objective extensions that allowed easy implementation of graphics routines. See Appendix I for more detailed information.

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DISCUSSION

The following discussion explains the contents of the source code files needed to compile a working version of the Bugs program for the NeXT workstation. This code works with version 2.0 of the NeXTStep operating system. It is not known whether it will work with version 1.0. Listings of these files are included as Appendices.

Makefile

UNIX style file controlling program compilation and linkage. The variable $FFILES contains the names of dependent code files.

Bugs.inc

Block of code that declares variable in common to all the Bugs programs. All the variables – except the parameter variables $nx, nxi, ncomb – are commoned in the block $GLOBALS. This use of common forces within objective Fortran makes these variables static.

The variable names are meant to be suggestive of their function, but a brief explanation will be helpful.

$nx ($nxi) - size of playing grid (minus 1, need for array sizing)
$meanx, $meany - fossils, defined but not used
$npoten - controls display of potential function
$ngen - number of generations or time steps run
$nodisp - toggle variable to turn off display
$liveb($livef) - number of buddy (foe) agents left alive
stopped - toggle variable to pause simulation
ncomb - maximum number of agents (array dimension)
>xmax,ymax,x0,y0 - maximum and minimum coordinates
dx,dy - grid spacing in screen units
eax - floating point nxm
budr,budi (foer,foei) - real and imaginary parts of buddy (foe) potentials
wbudr,wbudi (wfoer,wfoei) - real and imaginary parts of buddy (foe) weights

Imaginary parts are used to calculate cross-potentials, e.g. foe to bud

xb,yb (xf,yf) - x and y coordinates of buddy (foe) agents
stateb(statef) - state of buddy (foe) agents
budbud(budfoe) - pairwise potential between buddy and buddy (foe)
foebudfoefoe - pairwise potential between foe and foe(buddy)

These are not now used but would be needed in SIMNET.

Bugs.f

Main program - sets up NeXT window objects and main timing loop. This program is a modification of an example provided with the Absoft compiler and some of the peculiarities of syntax reflect this genesis.

For those unfamiliar with objective Fortran syntax, the statements beginning with @ are objective syntax and follow closely the analogous statement in objective C.

The @INTERFACE Bugs : View line specifies the messages to which the object Bugs (which is of class View) responds. Bugs responds to messages @-suspend, @-gofast, @-step, @-density, @-drawSelf as specified by the subsequent lines of code. The @-mouseDown message was not implemented. It would have been desirable to allow mouse driven editing of the agents within the Bugs View, but time precluded implementing this method.

The @IMPLEMENTATION statement begins a section which specifies how Bugs responds to each method. The @+newView section contains initialization code which places the window on the screen (NXeraseRect) specifies the max range of x and y, calls the initialize subroutine (see Bugs_subs.f) and calls the display subroutine (see Bugs_disp).

The strange bracketed code indicates a message being sent. For example, [self newFrame:&r] means self (this object) is being recursively commanded to respond to a newFrame message. Similarly, the [Timer newTimer: ...] message implements the basis timing loop of the program by sending the Timer a message (see Timer.f). The commented message ... setFlip ... is left over from the Absoft prototype. It causes the coordinate system to be flipped vertically which is undesirable when using some fonts on the screen.

The sections beginning @-step, ..., @-drawSelf contain the code that implements the various methods. Most of these methods just change the state of a switch variable in response to a mouse click on a menu item. The method drawSelf does the work. The subroutine neighbor is called to calculate the potential function; then rule is called twice to update the states of the agents: once for friends and once for foes.

The code beginning with PROGRAM main is standard NeXT code for starting a program. A new application NXApp is established by messaging Application; setUp code is called; the application is given a run message and then a free message after completion.
The subroutine `setUp` sets up a needed `rect` window data structure and creates a window view with a message to `Window`. `myWindow` is modified and enhanced by sending it various messages. The `myPanel` window for the menu items is set up by a message to `Panel`, and is subsequently modified. The final section defines the actions in response to various mouse clicks by sending `myMenu` various `addItem` messages.

Briefly these actions are:

- **Info** - the usual NeXT program information message
- **Pause** - stop program execution but retain display, second click toggles
- **GoFast** - continue simulation but turn off display for speed, toggles
- **Single Step** - execute one time step of the simulation
- **Show Density** - display friend-friend potential function as shades of gray, subsequent clicks cycle through friend-foe, foe-foe, foe-friend and off
- **Print** - invokes the standard NeXT printpanel
- **Hide** - miniaturizes the display window, program continues to run
- **Quit** - stop program

**Bugs_disp.f**

This file contains two display subroutines. Both display routines make use of calls to NeXT display Postscript screen commands. These calls are identified by the prefix `PS` and have the effects suggest by their names. One peculiarity is the the use of the `VALO` function which is needed since the native NeXT C-PS functions use call by value whereas Fortran uses addresses. The other thing to note is that the basic unit of Postscript drawing is the path, hence the calls to `PSnewpath` and `PSclosepath`.

The first subroutine `Box` draws a nice box around the playing field of the size specified by its arguments.

The `display` subroutine displays the generation number, the number of agents left alive, and optionally, the positions of agents and the potential functions. Control is basically by nested if statements.

The non-Fortran programmer will be mystified by the sections that first "do i=1,100;living(i)=0;end do" then `encode` according to some `format` and then call a `PS-fucntion`. Fortran is very bad with strings. What is happening is that the array `living` is having string data entered and then the `PS-function` is being called with that string data.

An English version of the program flow is as follows:

A call to `Box` clears the display.

If display is not off or hasn't been displayed for ten generations then display.

Display consists of:

- Two calls to `Box` to make a nice nested appearance.
- If potential display is on, then
  - loop to find max and min of desired potential
  - loop to display potential scaled to `[0,1]`
    - Note - display is via Postscript line drawing function with line width
      set to grid size, `dx`, so that the Postscript machinery automatically
      provides the gray scale display
  - An encode sequence sets a font, another encode then results in display of
the type of potential function.

After setting live\textsubscript{b} and live\textsubscript{f} counters to zero, two loops display the locations of the agents using \textit{PSarc} circle drawing commands. State of agent is indicated by shade of circle.

An encode sequence sets the font and three more encode sequences display the numbers of each type of agents remaining and the generation number. Obviously in go-fast mode the number of agents is updated only every 10th generation, although this could be modified.

\textbf{Bugs\textunderscore subs.f}

This file includes three subroutines that implement the computations underlying the Bugs simulation: neighbor, initialize, and rule. The first, \textit{neighbor}, calculates the pairwise potentials using an FFT calculation of the convolution. The second, \textit{initialize}, sets up the simulation, and the third, \textit{rule}, updates the states of the agents. The discussion begins with \textit{initialize}.

The first section of \textit{initialize} deals with setting up the weight arrays used in calculating the convolution from which the potential is derived. Three Gaussian distributions with standard deviation \(\sigma(1,2,3)\) are used. The Gaussian normalization factors \(a(n1,2,3)\) are calculated once and for all, as are the exponential argument weights \(e(n1,2,3)\). The \(ij\) loop then loads the arrays. As noted above, the real parts of the array are used to hold the like weights (bud\textbullet bud, foe\textbullet foe), and the imaginary parts the unlike weights (foe\textbullet bud, and bud\textbullet foe); this saves a whole set of FFTs. \textit{FFT2DREV} is used to transform the weights to the Fourier domain once and for all.

Finally, a modular pseudo-random function is used to populate the playing grid with agents (Absoft FORTRAN had no convenient random-number generator). The debris of commented statements shows some of the history of experimentation. All agents start in the timid state (0.5).

The subroutine \textit{neighbor} calculates potential functions using multiplication in the Fourier domain. The potential arrays are first zeroed. They are then incremented by the indicator value 1 wherever an agent is located. The transform \textit{FFT2DREV} is then used to pass to the Fourier domain. The transformed locator function is then multiplied by the conjugate of the transformed weights to get the transformed potential function. The potential is brought back to spatial domain via \textit{REVFFT2D}.

Subroutine \textit{rule} begins by setting the parameters, \textit{swfact}, and \textit{dead} for a two dimensional linear-hysteresis approximation to the cusp catastrophe. As mentioned in the paper, a linear approximation was used rather than a cubic cusp switch surface. This was based on the intuition that what matters is the topological pattern of hysteresis not the exact details of the hysteresis.

The like-like (\textit{foe0}) and like-unlike (\textit{bud0}) potentials are looked up. If \(like\text{-}unlike>dead*like\text{-}like\) the agent is killed. If not killed, the state of the agent is calculated. In the linear-hysteresis approximation to the cusp, if \(swfact\text{<}bud0\text{<}foe0\text{<}1\text{<}swfact\), the state is unchanged. If in a overwhelmingly unlike region, \(bud0\text{<}foe0\text{<}swfact\), the agent becomes timid (0.5). If in a largely like region, \(foe0\text{>}bud0\text{<}swfact\), the agent becomes bold (2.0).

For a true cusp the code would be little changed. In this case \textit{swfact} becomes a function of the distance from the origin, so that inserting the statements

\[
\text{sum}=bud0+foe0;\text{diff}=bud0-foe0;\text{hyst}=\text{swfact}(bud0+foe0)**3,
\]
and modifying the ifs to read

\[
\begin{align*}
\text{if } (\text{diff lt.}(-\text{hyst})) \text{ statef(i)} &= 0.5 \\
\text{if } (\text{diff gt.} \text{hyst}) \text{ statef(i)} &= 2.0
\end{align*}
\]

would implement a true cusp; the value of \textit{swfact} will have to be changed correspondingly. The validity of these expressions follows from shifting to sum and difference coordinates in the (bud,foe) plane. This modification has not been tested, but intuitively the behavior should be similar to the linear version and the amount of extra computation required is minimal.

Finally the motion increments \(v1\) and \(v2\) are set according to the agent’s state. The potential gradients are calculated and the agent moves according to \(v1\) and \(v2\) and the sign of the gradients.

\textbf{2D\_FFT.f}

This file contains two dimensional FFT routines. As with one dimensional routines, these routines are provided in pairs so that overhead of bit reversal and transposition is avoided. The extra switch variable \textit{isw} is included to control this function.

For two dimensional, Fourier transforms, one dimensional transforms are first performed along one axis, then one dimensional transforms are performed along the other axis. Since Fortran (most compilers) store multi-dimensional array data first-index fastest, the address of the first element of each column can be passed to a one dimensional transform to avoid the overhead of two dimensional index calculation. If the array is then transposed, the same technique calculates the other transform direction without the overhead.

When the transforms are used for convolution, the arrays do not need to be retransposed, nor so the final transforms need to be bitreversed. This saves additional overhead. The paired routines in this file \textit{FFT2DREV} and \textit{FFTR2DREV} can be used in this fashion. Note that the bit reversal of the first set of transforms cannot be avoided when using standard one dimensional transforms, since skipping it would lead to a very strange data order on input to the second set of transforms.

\textbf{Sub-FFT.f}

This file contains one dimensional FFT routines. The code is rather unremarkable textbook code except that bit reversal is not performed. Two versions are provided \textit{FFTREV} gives bit reversed output, whereas \textit{REVFFT} takes bit reversed input. The argument \textit{is} determines the direction of the transform \(is=+1\) for reverse, \(is=-1\) for forward (blame the sine function for reversal).

These paired routines are useful for convolution. Convolution only requires multiplication of corresponding values in the frequency domain, so that bit reversal is not needed provided appropriately paired transforms are used. This little trick saves the overhead of bit-reversing the time series.

The routines would have been more elegant if Fortran’s complex number data type had been used. Ultimate translation to C would have been more difficult, however.
bitrev.f

This textbook routine reorders time series bit reversed by FFT algorithms. Also in this file is a little integer $\log_2$ function, $\log_2$.

Timer.f

Supplied by Absoft to implement repetitive programs.

RECOMMENDATIONS

The ultimate goal of this project is to apply the ideas reported on in the attached paper, "Human Behavioral Modeling Using Catastrophe Theory", to the dismounted infantry SAFOR applications in the SIMNET environment. The following features must be incorporated in any SIMNET SAFOR code derived from Bugs.

1) Display - Display of agent motion is current via the routines in Bugs Disp.f. This would be replaced by calls to appropriate SIMNET routines (C-functions, whatever) that generate the necessary protocol data units (PDUs) to make agents appear at appropriate locations within the SIMNET world.

2) Force Fields - The force fields play two roles in Bugs. They determine the direction of agent motion by via a gradient ascent algorithm, and they determine agent behavior via the catastrophe-based behavior model. In a SIMNET SAFOR, the force field concept could be used as in Bugs with the addition of "infinite" potentials to implement static features like terrain obstacles (see the paper by Hung Le at the IST BR Symposium). The computational requirements would be relatively high, however, even with FFT techniques, for higher resolution grids than the 32 by 32 used in Bugs.

Slow updates may not be a problem, since a relatively sluggish force-field response (seconds) may be acceptable in SIMNET — agent behavior would of course occur at a faster time scale than the force-field update. Imagine neighbor running slower and asynchronously from rule. To implement this neighbor would have to be modified to takes its inputs from appropriate SIMNET routines.

Perhaps a better approach would be to use the spirit rather than the letter of Bugs. The primary purpose of the force field is to provide a simple test environment for behavioral ideas. These ideas could be implemented directly into code that obtains environmental information from SIMNET routines, evaluates the agent's status using catastrophe theoretic ideas, and then displays the agent's behavior using other SIMNET routines. In this approach, all that remains of Bugs would be modified versions of initialize and rule. The modified rule would determine the density of enemies versus friends directly from calls to SIMNET routines and update state accordingly. Information from SIMNET routines would be used to determine behavior based on the state, and the behavior displayed by invoking other SIMNET routines.
Appendix 1

Human Behavioral Modeling
Using Catastrophe Theory
ABSTRACT

A simple model of human behavior applicable to force simulation and based on catastrophe theory is developed. The large number of agents that must be modeled for a dismounted infantry automated force mandates that the algorithms used be as simple as possible. Simple models in which behavior is determined by local variables are investigated. Models based on cellular automata are found not to be useful. Physically motivated models based on catastrophe theory are promising, however. This is not surprising since the seven fundamental catastrophic transitions have been used successfully to model behavior in a variety of circumstances.

For dismounted infantry, the cusp catastrophe is used to model the transition from bold behavior when surrounded by friends, to timid behavior when surrounded by enemies. In a simulated battlefield environment, infantry agents are modeled as point particles moving under rules determined by the bold or timid state. The infantry in this simple battlefield exhibit interesting, non-trivial behavior. It is thus likely that catastrophe-based behavior will be useful as the basis for more complex simulations.

INTRODUCTION

Current approaches to modeling battlefield behavior are often based on conventional symbolic Artificial Intelligence (AI). If this symbolic AI approach were to be used in our research, then a rule-driven behavior model would be implemented for each of the many agents needed for a dismounted infantry, semi-automated force. However, this symbolic AI approach requires an unmanageable and impractical amount of computing power. As an alternative then, we have chosen to consider non-symbolic models.

Perhaps the simplest such non-symbolic models are based on cellular automata such as John H. Conway’s game of Life (Poundstone, 1985). In a cellular automata, space is divided into discrete squares, each of which is characterized by a state. For behavioral applications these states would represent the absence or presence, and the condition of a simulated agent. In Conway’s Life, each cell is either empty (0) or full (1). Time progresses forward in discrete steps, and the state of a cell at the next time step is determined by its present state and the state of its eight neighbors. Conway’s rules are simple: (1) if a cell is empty now and precisely three neighbors are full, then
the cell becomes full in the next time step; (2) if a cell is full and two or three neighbors are full, then the cell remains full in the next time step; (3) otherwise the cell becomes empty. These rules balance the problems of runaway population growth with the problems of extinction; indeed, Poundstone (1985) shows that Conway's Life automata is sufficiently rich to emulate a universal Turing machine.

Our first attempt at designing a behavior model was based on Conway's Game of Life. Life — as it is called for brevity — contains within it the concept of birth and death of agents in a large matrix of cells. The birth aspect can be thought of as an analogy to the increase in strength of an agent receiving reinforcements and becoming more aggressive. The death aspect is analogous to an agent being overwhelmed by an enemy and becoming timid and retreating.

Life, however, had some serious shortcomings in its unmodified condition. For example, there were only two cell states on the playing board: the 'on' states, which could be considered as an agent; and the 'off' states, which were simply the background environment. To introduce enemy agents, another cell state was added to the game. This cell state is conveniently represented as a third color or else a shade of gray.

There was still another drawback to unmodified Life: the rules of the game only considered the 'on' and 'off' state of cells that were directly adjacent to one another. This is a drawback because on the battlefield, the presence of all units at various distances from your own must be considered important. Life doesn't model this situation. To remedy the problem, a two dimensional Gaussian distribution of weights was introduced into the sum of neighbor states used to determine the next cell state. The neighbor sum thus includes a contribution from non-adjacent cells which models the importance of the presence of units at various distances and remote positions.

Figure 1 shows a snapshot of the results of running a generalization of Conway's Life in which each cell is in one of three possible states: +1 (friendly, white), 0 (empty, gray), or -1 (enemy, black). The state of a cell is determined by the sum of the states of its neighbors. For white, the rules are Conway's; for black, the rules are Conway's with the sign reversed. There are of course many more possibilities for generalizing the rules, and several were tried. Unfortunately, the behaviors of these two-phase automata did not seem to capture the richness of behavior needed on the battlefield. As Figure 1 suggests, the results are generally a useless debris of blinkers (3 cells in a row that alternate directions from one time step to the next), blocks (stable 2 by 2 cell arrays) and other elements from Conway's bestiary. Somewhat surprisingly, the 2 by 2 block is impregnable to enemy attack. That is, a 2 by 2
black block cannot be destroyed by any combination of white cells coming in contact with it. This leads to the interesting but unrealistic prospect that a picket fence of blocks would form an impenetrable and unassailable barrier.

Additional generalizations, such as introducing the long-range Gaussian interactions, were tried but did not result in more realistic behavior. Finding a good balance between birth, death, and conflict has been difficult. The long range interactions resulted in simulations that either quickly died-out or else quickly and exponentially overpopulated.

**PARTICLE-LIKE MODELS**

The failure of cellular automata patterned after Life led to the consideration of other simple models for behavior. In particular, an approach based on physics-like particles, having a few simple internal states, seemed promising. This type of model retains the idea of long-range interactions with locally determined behavior, but now the paradigm is particles moving in a potential field of force. Figures 2 and 3 show the potential fields used in the current work. The potential in Figure 2 is used to model the interaction between agents of like sign — that is, between friend and friend, and between foe and foe. An agent subject to such a potential moves so as to maximize or minimize the potential — that is, the agent moves up or down the gradient. This potential, with its central well, was chosen to provide a repulsive force at short distances: we don’t want the agents to clump into small-sized units.

Figure 3 shows the potential between unlike agents (friend and foe). Because we want agents to close in for the kill when appropriate, this potential has been designed without a central dip.

More formally, the friendly potential $\Phi$ of an agent at a location $(x, y)$ is the sum of the separate potentials for each friendly agent:
\begin{align*}
\Phi(x, y) &= \Sigma_i \phi(x_i - x, y_i - y); \quad (1) \\
\Psi(x, y) &= \Sigma_i \psi(x_i' - x, y_i' - y). \quad (2)
\end{align*}

Similarly, the enemy potential \( \Psi' \) is
\begin{align*}
\Psi'(x, y) &= \Sigma_i \psi'(x_i' - x, y_i' - y). \quad (2')
\end{align*}

Limiting the motion of agents to a discrete grid:
x = i \Delta x, y = j \Delta y, i = 1, \ldots, N, j = 1, \ldots, M, the sums take the form of convolutions:
\begin{align*}
\Phi_{ij} &= \Sigma_{k,i} \phi_{i+k,j+k} f_{ij}, \quad (3) \\
\Psi_{ij} &= \Sigma_{k,i} \psi_{i+k,j+k} e_{ij}, \quad (4)
\end{align*}

Here, \( \phi_{ij} = \phi(i \Delta x, j \Delta y) \) and \( \psi_{ij} = \psi(i \Delta x, j \Delta y) \) are the discrete potentials; the occupancy function \( f_{ij} \) (enemy) is also a discrete function if a friendly (enemy) agent is located at \((i \Delta x, j \Delta y)\), or zero.

The convolution suggests an efficient way to compute \( \Phi \) and \( \Psi \) via the fast Fourier Transform (FFT) algorithm. Fourier transforming \( \phi, \psi, e, \) and \( f \), the convolutions become multiplications (Rabiner and Gold, 1975):
\begin{align*}
\Phi &= T^{-1} [T(\phi) T(f)], \quad (5) \\
\Psi &= T^{-1} [T(\psi) T(e)], \quad (6)
\end{align*}

where \( T \) and \( T^{-1} \) denote the forward and inverse Fourier transforms respectively.

Using the FFT to evaluate \( T \) on an \( N \times M \) grid reduces the calculation time from order \( N^2 M^2 \), to order \( N M (\log_2 N)(\log_2 M) \). For \( N = M = 1024 \), this is a saving of a factor of more than 10,000 in time.

Note that this speedup is achieved for an arbitrary number of agents because the computation time is independent of the number of agents. Of course, if the number of agents is less than \( (\log_2 N)(\log_2 M) \), then evaluating the sums in equations (1) and (2) directly will likely be faster.

Even for a relatively large 1024 by 1024 grid, the advantage is lost if the number of agents exceeds the modest level of 100.

\section*{Catastrophe Theory}

Catastrophe theory is a branch of topology that is concerned with classifying the forms that singularities of functions may take. A remarkable result proved by Rene Thom (Gilmore, 1981) shows that these singularities can only take on a limited number of forms. More precisely, an arbitrary singularity can be transformed via change of variables so that it is closely approximated by one of several basic models; no matter how weird a given catastrophe may seem, it turns out to be close to one of the basis forms. For singularities described by four or fewer parameters, there are seven basic catastrophe models. The canonical equations of these models are exhibited in Table I.

\begin{table}[h]
\centering
\caption{Singularity Equations for Basic Catastrophe Models}
\begin{tabular}{|c|c|}
\hline
Catastrophe & Equation  \\
\hline
Fold & \( \frac{1}{3} x^3 - ax \)  \\
\hline
Cusp & \( \frac{1}{4} x^4 - ax - \frac{1}{2} bx^2 \)  \\
\hline
Swallowtail & \( \frac{1}{5} x^5 - ax - \frac{1}{2} bx^2 \cdot \frac{1}{3} cx^3 \)  \\
\hline
Butterfly & \( \frac{1}{6} x^6 - ax - \frac{1}{2} bx^2 \cdot \frac{1}{3} cx^3 \cdot \frac{1}{4} dx^4 \)  \\
\hline
Hyperbolic & \( x^3 + y^3 + ax + by + cx \)  \\
\hline
Elliptic & \( x^3 - xy^2 + ax + by + c (x^2 + y^2) \)  \\
\hline
Parabolic & \\
\hline
\end{tabular}
\end{table}
In the table, \(a, b, c, d\) are the parameters, and \(x, y\) are the variables which exhibit the singularity. The thing to note is that the equations of these canonical models are simple polynomials.

Some of simpler ones have been successfully used to describe human and animal behavior in various situations (Zeeman, 1976). Of the seven catastrophes, one of the simplest to describe and understand is the cusp catastrophe. It is a geometrical object in the usual three dimension Euclidean space and looks like a folded sheet or blanket. The other catastrophes also have intuitively appealing geometric interpretations as their names suggest.

This cusp catastrophe, which we are using to model a dismounted infantry agent’s response to various battlefield situations, is shown in Figure 4. The vertical axis, \(x\), represents the agent’s behavior on an aggressive to timid scale. The control parameters, \(a\) and \(b\), are the density of friendly agents and the density of enemy agents respectively. When the agent is surrounded by friendly forces, it exhibits bold and aggressive behavior; alternatively, when the agent is surrounded by enemy agents, it shows timid and retreating behavior.

So far this behavior model may seem fairly trivial, but where catastrophe theory shines is in the transition region between the two types of behavior. The arrows in Figure 4 illustrate two possible paths of transition between aggression and timidity. The upper arrow shows how an agent may pass smoothly between aggression and timidity provided the stimuli (friendly and enemy densities) are not too strong. A good commander probably takes his troops into battle along such a path so that their responses remain predictable.

![Figure 4. Cusp catastrophe as applied to modeling agent behavior.](image)

The lower arrows lie in regions where the stimuli are stronger and as a result cross the fold region of the cusp catastrophe. The agent’s behavior now becomes discontinuous. Starting out aggressively, surrounded by friends, the agent keeps up his courage in the face of increasing enemy opposition until suddenly his nerve breaks and he turns timid. Conversely, a timid agent retreating from enemy territory remains timid until he suddenly is heartened by the presence of many friends. The catastrophe model thus introduces a degree of hysteresis into the transition between aggression and timidity.

Aggressive and timid behavior have been considered by some researchers to be influenced by two conflicting emotions: fear and rage. In the dismounted infantry simulation, these emotions are modeled by the response of the agents to various threat conditions posed by enemy troops in the
battlefield. Sometimes the battlefield conditions promote the two emotions of fear and rage simultaneously and to approximately the same degree of intensity. When this happens, the behavior of a military unit will depend on its behavior during the immediately previous time period. If, during this time period, the troops have been aggressive and the battle turns against them, they will still tend to be aggressive for a while. Likewise, if, during this time period, the troops have been retreating in fear, and they start to receive significant reinforcements, some time will be needed before they become courageous enough to attack.

The particle agents exhibit two different potential climbing modes depending on their bold/timid state. When bold, particles are attracted to friends, but are more strongly attracted to enemies; they are on the attack, but try to maintain contact with their unit. When timid, particles are attracted to friends, but are repelled by enemies; they are thus attempting to regroup while avoiding contact with the enemy. Many other variations of behavior are possible, but as shown below these produce interesting results.

RESULTS

A particle model of agents using a cusp catastrophe switch between behaviors as outlined above was coded on a NeXT 25 MHz 68040-based workstation in Absoft Objective FORTRAN (yes, FORTRAN; it is still the only language with a native complex number data type). The grid used was 32 by 32 ($N=M=32$) so that several cycles of time were calculated per second and experimentation could go rapidly. The cusp catastrophe in Figure 4 was actually approximated by two overlapping planes and an additional third behavior was added. When an agent found itself in a thin strip along the enemy axis, it died and was removed from the simulation. The simulation run shown in Figures 5-8 involving three black and three white agents plays out an interesting scenario. The agents were placed at random on the grid in a timid state. Timidity is indicated in the displays by an off-color (off-white or off-black). Aggression is shown when the agent is fully black or white. Figure 5 is several time steps into the simulation and the agents are moving around trying to make contact with friends and to generally get organized. Note that for simplicity in dealing with boundaries, the simulation grid has the topology of a torus. It has no boundaries; the top of the grid is connected to the bottom and the left side is connected to the right side.
Figure 6. The agents soon organize into tight clusters and become aggressive. The upward chase is on.

After several more time steps, the agents have formed tight little clusters and begin an upward trending chase. These clusters persist for two circuits of the grid.

Perhaps tiring of the chase, one black agent reverses field and, crossing the bottom "border", attacks the white group from above. The agent has no such motive, of course; its motion is merely the result of the randomly chosen initial conditions. Still, the nice anthropomorphic interpretation that can be given to its behavior suggests the possibilities of behavior modeling based on catastrophe theory.

The attacking black agent then succeeds in luring a white agent away from its group. The white agent then finds itself in the killing strip of the enemy/friendly plane where it dies and is removed from play. Already in Figure 8, this white agent has turned timid, but it is too late! The white agent cannot get back to its group before it is killed.

This simulation ultimately results in a win by black, albeit black does lose one entity. Again, while the simulation presented here is based on very simple local dynamics, it succeeds in capturing the essence of battle.

CONCLUSIONS

The behavior model presented here shows much promise as the basis for modeling the large number of agents that would be required in a simulated dismounted infantry force. Despite the simple, local basis of the behavior, it captures many features of battle.

The computational resources needed to calculate the potential functions used to guide the particle-like entities are fairly large, but the use of fast Fourier transform techniques enables a single potential computation to serve for all agents.
Figure 8. The maneuver is successful. A white agent is lured away, and becomes timid just before vanishing.

Further investigation is needed to determine how realistic this behavioral model really is and how best to incorporate the model into realistic environments like SIMNET. The model contains much scope for generalization, the potentials could be multi-valued (e.g. vector or tensor values) to produce more complicated motions and to include the possibility of modeling the effects of terrain and other environmental influences.

BIBLIOGRAPHY


Appendix 2
Source Code
Makefile - Unix makefile

# Application makefile.
#
#
# Name of the application.
# NAME = Bugs

#
# Source files for this application.
# MF ILES =
# HFILES =
# FFILES = Bugs.f Bugs_subs.f Bugs_disp.f bitrev.f
# CFILES =
# NIBFILES =
# TIFFFILES =
# PSWF ILES =
# SNDFILES =

# Libraries used by this application.
# LIBS = -lNeXT_s -lsys_s

# Flags to pass on to the compiler and linker.
# CFLAGS =
# FFLAGS = -object -K
# LDFLAGS= -segcreate __ICON __header emptyfile -segcreate __ICON __tiff emptyfile
#
# Rules.
#
SRCFILES = $(MF ILES) $(HFILES) $(CFILES) $(FFILES) $(NIBFILES) $(TIFFFILES) $(PSWF ILES)
OBJFILES = $(MF ILES:.m=.o) $(CFILES:.c=.o) $(FFILES:.f=.o) $(PSWF ILES:.psw=.o)
DERIVED = $(PSWF ILES:.psw=.c)
GARBAGE = $(DERIVED) core errs emptyfile

$(NAME): $(OBJFILES)
touch emptyfile
$(FC) -o $@ $(FLAGS) $(OBJFILES) $(LIBS) $(LDFLAGS)

clean:
   -rm -f *.o $(NAME) $(DERIVED) $(GARBAGE)

goals:
   @echo 'make $(NAME) - to make the application'
   @echo 'make clean - to remove all files but the source'
Bugs.inc – Variable Declarations

integer nx,nxm,meanx,meany,npoten,ngen,nodisp,liveb,livef
logical stopped
real xmax,ymax,x0,y0,dx,dy
parameter (nx=32,nxm=nx-1)
parameter (ncomb=200)
real budr(0:nxm,0:nxm),budi(0:nxm,0:nxm)
real foer(0:nxm,0:nxm),foei(0:nxm,0:nxm)
real wbudr(0:nxm,0:nxm),wbudi(0:nxm,0:nxm)
real wfoer(0:nxm,0:nxm),wfoei(0:nxm,0:nxm)
real xb(ncomb),yb(ncomb)
+ ,stateb(ncomb),budbud(ncomb),budfoe(ncomb)
real xf(ncomb),yf(ncomb)
+ ,statef(ncomb),foebud(ncomb),foefoe(ncomb)
common /GLOBALS/xmax,ymax,x0,y0,dx,dy,meanx,meany,
+ stopped,emax,nbud,nfoe,npoten,ngen,nodisp,liveb,livef,
+ budr,budi,foer,foei,wbudr,wbudi,wfoer,wfoei,
+ xb,yb,stateb,budbud,budfoe,
+ xf,yf,statef,foebud,foefoe
Bugs.f – Main Program

Bipolar Bugs program written in FORTRAN and compiled on NeXT with Object-Oriented FORTRAN from Absoft

The coordinate system of the plot is flipped so that coordinate (0,0) is in the upper-left corner of the view.

INCLUDE "appkit.inc"          ! Kit constants
INCLUDE "Timer.inc"

@INTERFACE Bugs : View

INCLUDE "Bugs.inc"

@+ newView:REAL*4 r(4)
@- suspend
@- gofast
@- step
@- density

@- mouseDown:(NXEvent *)event
@- drawSelf:REAL*4 rect(4) :INTEGER dummy
@END

@IMPLEMENTATION Bugs : View

@+ newView:REAL*4 r(4)          ! Create a new view in window

stopped=.false.
npoten=0
nodisp=1
CALL NXEraseRect(rect)
CALL PSsetgray(val(0.0))
x0=10.
y0=10.
xmax=720;dx=aint((xmax-x0)/nxm)
ymax=720;dy=aint((ymax-y0)/nxm)
xmax=2+nxm*dx;ymax=2+nxm*dy
idy=(700-xmax)/2;idy=(700-xmax)/2
x0=x0+idx;y0=y0+idy
print *,"dx= ",dx," dy= ",dy
\[ x_0 = x_0 + 1; y_0 = y_0 + 1 \]
\[ \text{mean}_x = (nxm)/2; \text{mean}_y = (nxm)/2 \]

print *, "Initializing"
call initialize
print *, "Displaying"
call display

self = [self newFrame: &r]

[Timer newTimer: @0.02D0
 + target: self
 + action: Selector("display")]

c [self setFlip: YES]
newView_ = self
@END

@- step
stopped = .false.
! Suspend evolution and do a single step
[self display]
stopped = .true.
! Temporarily turn off suspension
step = self
! Display new grid
@end

@- suspend
stopped = .not. stopped
suspended = self
! Suspend evolution of grid
@end

@- gosf
nodisp = 1-nodisp
gosf = self
! Toggle suspension state
@end

@- density
npotet = npotet + 1
if (npotet.gt.4) npotet = 0
density = self
! Suspend display of cells
@end

@- mouseDown
mouseDown = self
@END
PROGRAM main
IMPLICIT NONE
INTEGER NXApp
INCLUDE "object.inc"
NXApp = [Application new]
CALL setUp()
[NXApp run]
[NXApp free]
END
SUBROUTINE setUp
IMPLICIT NONE
INTEGER myWindow, myPanel, myMenu, panelText, myView
INTEGER content
REAL*4 rect(4), viewRect(4)

@end
! Draw window view

! Calculate and draw graph

if(stopped) return
repeat
continue

print *,"Summing neighbors"
call neighbor

print *,"Applying rules"
call rule(xb,yb,emax,
+ stateb,budoe,budbud,foei,budr,nxm,nbud)
call rule(xf,yf,emax,
+ statef,foebud,foeoe,budi,foer,nxm,nfoe)

print *,"Displaying"
call display
until keypressed;
go to 10

drawSelf = self

@END

! End of implementation

@end

PROGRAM main
IMPLICIT NONE
INTEGER NXApp
INCLUDE "object.inc"
NXApp = [Application new]
CALL setUp()
[NXApp run]
[NXApp free]
END
SUBROUTINE setUp
IMPLICIT NONE
INTEGER myWindow, myPanel, myMenu, panelText, myView
INTEGER content
REAL*4 rect(4), viewRect(4)
INCLUDE "object.inc" ! Object-Oriented FORTRAN definitions

include "appobject.inc" ! Application kit constant definitions

! Set up a Window
CALL NXSetRect(rect,val(100.0),val(100.0),val(800.0),val(800.0))
myWindow = [Window newContent: &rect
+             style:         NX_TITLEDSTYLE
+             backing:      NX_BUFFERED
+             buttonMask:   NX_MINIATURIZEBUTTONMASK
+             defer:        NO]
[myWindow setTitle:"Battle Bugs"]
[[myWindow contentView] getBounds:&viewRect]
myView = [Bugs newView:&viewRect]
    content = [myWindow contentView]
[[myWindow contentView] addSubview:myView]

! Set up an information Panel
CALL NXSetRect(rect,val(400.0),val(800.0),val(255.0),val(60.0))
myPanel = [Panel newContent: &rect
+               style:         NX_TITLEDSTYLE
+               backing:      NX_BUFFERED
+               buttonMask:   NX_CLOSEBUTTONMASK
+               defer:        YES]
[myPanel setTitle:"About Bugs"]
[[myPanel removeFromEventMask:(NX_KEYDOWNMASK .or. NX_KEYUPMASK)]]

CALL NXSetRect(rect,val(0.0),val(0.0),val(255.0),val(55.0))
panelText = [Text newFrame: &rect
+             text:         "Battle Bugs is written in
+FORTTRAN using Object-Oriented FORTTRAN (TM) from
+Absoft Corporation.  T. L. Clarke"
+             alignment:     NX_CENTERED]
[panelText setSelectable:NO]
[[myPanel contentView] addSubview:panelText]

! Set up a Menu
myMenu = [Menu newTitle:"Bugs"]
[[myMenu adddItem:         "Info...
+             action:       Selector("orderFront:")
+             keyEquivalent: NULL] setTarget:myPanel]
[[myMenu adddItem:         "Pause"
+             action:       Selector("suspend")
+             keyEquivalent: ichar('p')] setTarget:myView]
[[myMenu adddItem:         "GoFast"
+             action:       Selector("gofast")

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+ keyEquivalent: ichar('f') setTarget:myView
[[myMenu addItem: "Single Step" action: Selector("step")
  keyEquivalent: ichar('s') setTarget:myView
[[myMenu addItem: "Show Density" action: Selector("density")
  keyEquivalent: ichar('q') setTarget:myView
[[myMenu addItem: "Print..." action: Selector("smartPrintPSCode")
  keyEquivalent: ichar('D') setTarget:myWindow
[myMenu addItem: "Hide" action: Selector("hide")
  keyEquivalent: ichar('h')
[myMenu addItem: "Quit" action: Selector("terminate")
  keyEquivalent: ichar('q')
[myMenu sizeToFit]
[GetNXApp() setMainMenu:myMenu]

! Display all three windows and PostScript text in view
[myPanel display]
[myMenu display]
[myWindow display] ! Calculate and display graph

! Move myWindow on-screen
[myWindow orderFront:]]
END

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Subroutine Box(xlow,xtop,ylow,ytop, grey)

call PSnewpath()
call PSmoveto(VAL(xlow),VAL(ylow))
call PSlineto(VAL(xtop),VAL(ylow))
call PSlineto(VAL(xtop),VAL(ytop))
call PSlineto(VAL(xlow),VAL(ytop))
call PSclosepath()
call PSsetgray(val(grey))
call PSfill()
call PStroke()
call PSmoveto(VAL(xlow),VAL(ylow))
call PSlineto(VAL(xtop),VAL(ylow))
call PSlineto(VAL(xtop),VAL(ytop))
call PSlineto(VAL(xlow),VAL(ytop))
call PSsetgray(val(0.0))
call PSstroke()
call PScopypage()
return
END

subroutine display
INCLUDE "Bugs.inc"
integer i,nil,living(100)
real xx0,r
r=dx/2
xx0=x0+dx/2
ngen=ngen+1
nit=max0(nbud,nfoe)
call Box(0.0,800.,ymax+2*dy+9,800.,0.666667)
if ((nodisp.ne.0) .or. (mod(ngen,10).eq.0) ) then

call Box(x0-10,xmax+2*dx+8,y0-10,ymax+2*dy+8,0.333333)
call Box(x0-2,xmax+2*dx,y0-2,ymax+2*dy,0.5)
c print *,"nbud, nfoe ",nbud,nfoe

c code displays potential function
if (npoten.ne.0) then
c print *,"# potential displayed ",npoten

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pmax=0.0;pmin=1.0e6
if (npoten.eq.1) then
do i=0,nxm;do j=0,nxm
   pmax=max(pmax,(budr(i,j)))
   pmin=min(pmin,(budr(i,j)))
end do; end do
end if
if (npoten.eq.2) then
do i=0,nxm;do j=0,nxm
   pmin=min(pmin,(budi(i,j)))
   pmax=max(pmax,(budi(i,j)))
end do; end do
end if
if (npoten.eq.3) then
do i=0,nxm;do j=0,nxm
   pmin=min(pmin,(foer(i,j)))
   pmax=max(pmax,(foer(i,j)))
end do; end do
end if
if (npoten.eq.4) then
do i=0,nxm;do j=0,nxm
   pmin=min(pmin,(foei(i,j)))
   pmax=max(pmax,(foei(i,j)))
end do; end do
end if

c  print *,"max/min potential ",pmax,pmin
ascale=1.0/(pmax-pmin)
do i=0,nxm
   x=x0+dx*i
   y=y0+dy*i
   print *,"x= ",x," y= ",y
   do j=0,nxm
      call PSsetlinewidth(val(dx))
      if (npoten.eq.1) dens=budr(i,j)
      if (npoten.eq.2) dens=budi(i,j)
      if (npoten.eq.3) dens=foer(i,j)
      if (npoten.eq.4) dens=foei(i,j)
      CALL PSsetgray(val((dens-pmin)*ascale))
      call PSnewpath()
   CALL PSmoveto(val(x),val(y))
      call PSlineto(val(x),val(y+dy))
      call PSstroke
   end do;
end do;
call PSsetlinewidth(val(1.0))
call PSsetgray(val(0.0))
do i=1,100;living(i)=0;end do
encode(9,301,living)
call PSselectfont(living,VAL(16.0))
call PSnewpath()
call PSmoveto(VAL(x0),VAL(ymax+dy))
doi=1,100;living(i)=0;end do
if (npoten.eq.1) encode(13,201,living)
201 format("Friend-Friend")
if (npoten.eq.2) encode(13,202,living)
202 format("Friend-Foe")
if (npoten.eq.3) encode(13,203,living)
203 format("Foe-Foe")
if (npoten.eq.4) encode(13,204,living)
204 format("Foe-Friend")
call PSshow(living)
call PSsetgray(val(0.0))
call PSstroke()
call PScopypage()
c

liveb=0
livef=0
do i=1,nit
if (i.le.nbud) then
if (stateb(i).gt.0.0) then
liveb=liveb+1
x=dx*(xb(i)+1)y=dy*(yb(i)+1)
c
print *,"x=","y=","grey=0.9
c
if (stateb(i).gt.1.0) grey=1.0
CALL PSsetgray(val(grey))
call PSnewpath()
CALL PSmoveto(val(x),val(y))
call PSarc(val(x),val(y),val(r),val(0.),val(360.,))
call PSfill()
call PSstroke()
end if
end if
grey=0.0
if (i.le.nfoe) then
if (statef(i).gt.0.0) then

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livef = livef + 1
x = dx * (xf(i) + 1); y = dy * (yf(i) + 1)
c
print "," x = "," x; y = "," y
grey = 0.1
if (stateb(i) .gt. 1.0) grey = 0.0
CALL PSsetgray(val(grey))
call PSnewpath()
CALL PSmoveto(val(x), val(y))
call PSarc(val(x), val(y), val(r), val(0.), val(360.))
call PSfill()
call PStroke
end if
call PSarc(val(x), val(y), val(r), val(0.), val(360.))
call PSfill()
call PSstroke
end if
cend do
cend if
CALL PSsetgray(val(0.0))
do i = 1, 100; living(i) = 0; end do
encode(9, 301, living)
301 format("Helvetica")
call PSselectfont(living, VAL(16.0))
call PSmoveto(VAL(x0), VAL(ymax + 3 * dy))
do i = 1, 100; living(i) = 0; end do
encode(20, 101, living) liveb
101 format("Surviving white: ", i3)
call PSshow(living)
call PSmoveto(VAL(3.0 * (x0 + xmax) / 4.0), VAL(ymax + 3 * dy))
do i = 1, 100; living(i) = 0; end do
encode(20, 103, living) livef
103 format("Surviving black: ", i3)
call PSshow(living)
call PSmoveto(VAL(2.0 * (x0 + xmax) / 4.0), VAL(ymax + 4 * dy))
do i = 1, 100; living(i) = 0; end do
encode(22, 105, living) ngen
105 format("Elapsed Cycles: ", i6)
call PSshow(living)
c
call PStroke()
c
call PScopypage()
c
call PSsetlinewidth(val(1.0))
return
END
subroutine neighbor
INCLUD "Bugs.inc"

c wr, wi is transformed weight array
c far, fai is used to for calculations

c a is active grid, b gets neighbor count

c
integer i,j,nxmm,nxmp

if (nbud.gt.0) return

nxmp=nxm+1
nxmm=nxm-1
do i=0,nxm;do j=0,nxm
budr(i,j)=0.0;budi(i,j)=0.0
foer(i,j)=0.0;foei(i,j)=0.0
end do;
end do

doi=1,nbud
ix=mod(nx+nxint(xb(i)),nx)
iy=mod(nx+nxint(yb(i)),nx)
budr(ix,iy)=budr(ix,iy)+1.0
end do

doi=1,nfoe
ix=mod(nx+nxint(xf(i)),nx)
iy=mod(nx+nxint(yf(i)),nx)
foer(ix,iy)=foer(ix,iy)+1.0
end do

call FFT2DREV(budr,budi,nxmp,-1,0)
call FFT2DREV(foer,foei,nxmp,-1,0)
c
print *, "returned form FFT2DREV"
c multiply by complex conjugate

fmax=-1.0e20; bmax=-1.0e20
fmin=fmax; bmin=bmax
do i=0,nxm;do j=0,nxm
tr=budr(i,j)*wbudr(i,j)-budr(i,j)*wbudi(i,j)
ti=budr(i,j)*wbudr(i,j)+budr(i,j)*wbudi(i,j)
budr(i,j)=tr;budi(i,j)=ti
end do;end do

do i=0,nxm;do j=0,nxm
tr=foer(i,j)*wfoer(i,j)-foei(i,j)*wfoei(i,j)
end do;end do
ti=foel(i,j)*wfoer(i,j)+foer(i,j)*wfoei(i,j)
foer(i,j)=tr;foei(i,j)=ti
end do;end do
c print **"calling REVFFT2D"
call REVFFT2D(budr,budi, nxmp,+1,0)
call REVFFT2D(foer,foei, nxmp,+1,0)
c do i=0, nxm; do j=0, nxm
c fmax=max1(fmax,foer(i,j))
c bmax=max1(fmax,budr(i,j))
c fmin=min1(fmin,foer(i,j))
c bmin=min1(fmin,budr(i,j))
c end do; end do
c print **"budmax, budmin, foe max, foemin ",
c + bmax,bmin,fmax,fmin
return
END

subroutine initialize
INCLUDE "Bugs.inc"
integer i,j,nxmp
real weight1,weight2
ngen=0
nxmp=nxm+1
c initialize weight array and transform
smax=(nxm+1);xfold=smax/2
emax=nxm
sig1=smax/4.0
as1=1/sig1**2/2.0;an1=1/(6.2832*sig1)/smax**2
sig2=amin1(smax/8.0,1.0)
as2=1/sig2**2/2.0;an2=1/(6.2832*sig2)/smax**2
sig3=smax/4.0
as3=1/sig3**2/2.0;an3=1/(6.2832*sig3)/smax**2
print **"sig1, sig2, sig3 ",sig1,sig2,sig3
ca=3.0
hywt=1./smax**2
do i=0, nxm; do j=0, nxm
ddx=i;if (ddx.gt.xfold) ddx=ddx-smax
ddy=j;if (ddy.gt.xfold) ddy=ddy-smax
arg=ddx**2+ddy**2
weight1=an3*exp(-arg*as3)-an2*exp(-arg*as2)
weight2=an1*exp(-arg*as1)
c weight=hywt/amax1(1.0, arg)-an2*exp(-arg*as2)
c weight=hywt/amax1(1.0, arg)
c note use of real part for frienc (bud) and imaginary part for foe
wbudr(i,j)=weight1

wbud(i,j)=weight2
wfoer(i,j)=weight1
wfoei(i,j)=weight2
end do;end do

c don't count yourself?
c wbudr(0,0)=0.0;wbudi(0,0)=0
c wfoer(0,0)=0.0;wfoei(0,0)=0
call FFT2DREV(wbudr,wbudi,nxmp,-1,0)
call FFT2DREV(wfoer,wfoei,nxmp,-1,0)

c psuedo random function y=(991*y mod 1024) + 31
iseed = 59
do i=1,ncomb
  iseed=mod(iseed*157,1024)+31
  xb(i)=smax*iseed/3240.+xfold
  iseed=mod(iseed*97,1024)+31
  yb(i)=smax*iseed/3240.+xfold
  stateb(i)=0.5
endo do

nbud=ncomb/2
nbud=3
do i=1,ncomb
  iseed=mod(iseed*157,1024)+31
  xf(i)=smax*iseed/3240.0
  iseed=mod(iseed*97,1024)+31
  yf(i)=smax*iseed/3240.0
  statef(i)=0.5
endo do

nfoe=ncomb/2
nfoe=3

c need to call neighbor to initialize the (bud,foe)(bud,foe) arrays

c when full behaviour is implemented
return
END

subroutine rule

c code is written from viewpoint of foe
+ (xf,yf,emax,statef,foebud,foefoe,bud,foe,nxm,nfoe)
real bud(0:nxm,0:nxm),foe(0:nxm,0:nxm)
real xf(nfoe),yf(nfoe)
+ ,statef(nfoe),foebud(nfoe),foefoe(nfoe)
integer i,nx
nx=nxm+1
ip=1; im=-1
foeequ=5.0
swfact=3.0
dead=20.0
dead=8.1175
do i=1,nfoe
    ix=mod(nx+nint(xf(i)),nxm)
    iy=mod(nx+nint(yf(i)),nxm)
c mode switching hysteresis - catastrophe approx -
c with switching along lines foe=2*bud and bud=2*foe
    bud0=abs(bud(ix,iy))
    foe0=abs(foe(ix,iy))
c if overwhelmed kill it
    if (bud0.gt.(dead*foe0)) statef(i)=0.0
    c check if alive
        if (statef(i).gt.0.0) then
            if (bud0.gt.(swfact*foe0)) statef(i)=0.5
            if (foe0.gt.(swfact*bud0)) statef(i)=2.0
        c set motion increments
            if (statef(i).gt.1.0) then
                v1=0.25;v2=1.0
            else
                v1=0.5;v2=-0.10
            endif
            gradbx=bud(mod(ix+ip,nx),iy)-bud(mod(nx+ix+i,nx),iy)
            gradby=bud(ix,mod(iy+ip,nx))-bud(ix,mod(nx+iy+i,nx))
            gradfx=foe(mod(ix+ip,nx),iy)-foe(mod(nx+ix+i,nx),iy)
            gradfy=foe(ix,mod(iy+ip,nx))-foe(ix,mod(nx+iy+i,nx))
            c
                if (gradfx.gt.0.0) then
                    xf(i)=xf(i)+v1
                else
                    xf(i)=xf(i)-v1
                endif
                if (gradbx.gt.0.0) then
                    xf(i)=xf(i)+v2
                else
                    xf(i)=xf(i)-v2
                endif
                if (xf(i).gt.emax) xf(i)=xf(i)-emax
            c
                if (gradfy.gt.0.0) then
                    yf(i)=yf(i)+v1
                else
                    yf(i)=yf(i)-v1
                endif
                if (gradby.gt.0.0) then
                    yf(i)=yf(i)-v2
            end
else
    yf(i)=yf(i)+v2
end if
if (yf(i).gt.emax) yf(i)=yf(i)-emax
if (yf(i).lt.0.0) yf(i)=yf(i)+emax
end if
! end of kill check
end do

return
END
2D_FFT.f – Two Dimensional FFT

c transform square nxn (power or 2) matrix of values
c if isw=0 leave result untransposed and don’t perform bitreversals
c in order to speed correlation calculations
  subroutine FFT2DREV(ar,ai,n,is,isw)
    dimension ar(n,n),ai(n,n)
c transform rows
    do i=1,n
      call FFTREV(ar(1,i),ai(1,i),n,is)
      if (isw.ne.0) call BITREV(ar(1,i),ai(1,i),n)
    end do
c transpose
c call transpose(ar,ai,n)
c transform columns
    do i=1,n
      call FFTREV(ar(1,i),ai(1,i),n,is)
      if (isw.ne.0) call BITREV(ar(1,i),ai(1,i),n)
    end do
c transpose back if desired
      if (isw.ne.0) call transpose(ar,ai,n)
      return
c

c transform square nxn (power or 2) matrix of values
c if isw=0 assume input untransposed and un-bitreversed
nc in order to speed correlation calculations
  subroutine c(ar,ai,n,is,isw)
    dimension ar(n,n),ai(n,n)
c transform rows
    do i=1,n
c transpose if needed
      if (isw.ne.0) call transpose(ar,ai,n)
c bit reverse if needed
      if (isw.ne.0) call BITREV(ar(1,i),ai(1,i),n)
call REVFPTT(ar(1,i),ai(1,i),n,is)
    end do
nc transpose
  call transpose(ar,ai,n)
c transform columns
    do i=1,n
c bit reverse if needed
      if (isw.ne.0) call BITREV(ar(1,i),ai(1,i),n)
call REVFPTT(ar(1,i),ai(1,i),n,is)
c

c transpose nxn square matrices

subroutine transpose(A,B,N)
real A(N,N),B(N,N)
do i=1,(N-1)
do j=(i+1),N
    T=A(i,j);A(i,j)=A(j,i);A(j,i)=T
    T=B(i,j);B(i,j)=B(j,i);B(j,i)=T
end do
end do
return
end
Sub-FFT.f – One dimensional FFT

c algorithm for FFT with bit reversed output
c
SUBROUTINE FFTREV(XREAL,XIMAG,nn,is)
DIMENSION XREAL(1:nn), XIMAG(1:nn)
INTEGER N,NU,N2,dk,dN,dk2
real dwr,dwi,dthet,wr,wi
N=nn
NU=log2(N)
N2 = N/2
K = 0

C C loop over log2N sub FFTs C
DO L = 1,NU
c input increment to SubFFT
dN=2**(L-1)
c length of SubFFT-1
dk=2**(NU-L)
dk2=dk*2
dthet=6.283185307*float(dN)/float(N)
dwr=cos(dthet); dwi=sin(dthet)
k=1
c print *,"L,dN,dk ",L,dN,dk
C loop over
wr=1.0;wi=0.0
DO i = 1,dk
do m=1,N,dk2
k=i+m-1
c print *,"l,m,k,k+dk",l,m,k,k+dk
x1r=XREAL(k);x1i=XIMAG(k)
x2r=XREAL(k+dk);x2i=XIMAG(k+dk)

dr=x1r-x2r;di=x1i-x2i
XREAL(k)=x1r+x2r;XIMAG(k)=x1i+x2i
XREAL(k+dk)=dr*wr-di*wi
XIMAG(k+dk)=dr*wi+di*wr
end do
if (dk.ne.1) then
tr=wr*dwr-wi*dwi
wi=dwr*wi+dwi*wr
SUBROUTINE REVFFT(XREAL, XIMAG, nn, is)
DIMENSION XREAL(1), XIMAG(1)
INTEGER N, NU, N2, dk, dN, dk2
real dwr, dwi, dthet, wr, wi
N = nn
NU = ilog2(N)
N2 = N/2
K = 0

DO L = NU, 1, -1

input increment to SubFFT
dN = 2**(L-1)
dthet = 6.283185307*float(dN*is)/float(N)
dwr = cos(dthet); dwi = sin(dthet)

dk = 2**(NU-L)
dk2 = dk**2
k = 1

print *, "L, dN, dk", L, dN, dk

loop over
wr = 1.0; wi = 0.0
DO l = 1, dk
do m = 1, N, dk2
    k = l + m - 1
    print *, "l, m, k, k+dk", l, m, k, k+dk
    x1r = XREAL(k); x1i = XIMAG(k)
    x2r = XREAL(k+dk); x2i = XIMAG(k+dk)
    dr = x2r * wr - x2i * wi; di = x2i * wr + x2r * wi
    XREAL(k) = x1r + dr; XIMAG(k) = x1i + di
    XREAL(k + dk) = x1r - dr
    XIMAG(k + dk) = x1i - di
end do
if (dk.ne.1) then
  tr=wr*dwr-wi*dw
  wi=dwr*wi+dw*wr
  wr=tr
end if
end do

C
C
RETURN
END
bitrev.f – Reorders Time Series

C Bit Reversal subroutine for complex data from FFT

SUBROUTINE BITREV(XREAL,XIMAG,n)
DIMENSION XREAL(0:n), XIMAG(0:n)
integer K,NU,m
m=n
NU=ilog2(m)

DO 103 K = 1,m
   I = IBITR(K ,NU)
   IF (I .LE. K) GO TO 103
   TREAL = XREAL(K)
   TIMAG = XIMAG(K)
   XREAL(K) = XREAL(I)
   XIMAG(K) = XIMAG(I)
   XREAL(I) = TREAL
   XIMAG(I) = TIMAG

103 CONTINUE

RETURN
END

FUNCTION IBITR(J,NU)
INTEGER J1,I,J2,JBITR
J1 = J
JBITR = 0

DO 200 I = 1, NU
   J2 = J1/2
   JBITR = JBITR * 2 + (J1 - 2 * J2)
200 J1 = J2

IBITR=JBITR
RETURN
END

function ilog2(n)
ilog2=int(1.442695041*log(float(n))+.01)
print *,"n, log2n ",n,ilog2
return
Timer.f – Supplied by Absoft

! Timer class for real-time control
!
! Start timer with newTimer:target:action: method
! Stop timer with freeTimer: method
!
INClude "Object.inc"
INClude "Timer.inc"

! TimerFunc is the FORTRAN function invoked at each time interval

SUBROUTINE TimerFunc(dum1, dum2, dum3)
    INTEGER*4 theTarget
    INTEGER*4 theAction
    COMMON /TIMER_GLOBALS/ theTarget, theAction
    INCLUDE "object.inc"

    [theTarget perform:theAction]
END

@end

@implementation Timer : Object

! newTimer:target:action: method starts a timer that causes the 'action' method
! to be invoked in the 'target' at each 'interval'.
! Returns the ID of the timer entry.

@end newTimer: REAL*8 interval target:target action:action
EXTERNAL TimerFunc
INClude "ApplicationPARAM.inc"

    theTarget = target
    theAction = action
    self = DPSAddTimedEntry(@interval, VAL(LOC(TimerFunc), VAL(self),
                        +VAL(NX_MODALRESPTHRESHOLD+5))
@end

! freeTimer: removes the timed entry for the specified timer ID

@end freeTimer:integer entry
CALL DPSRemoveTimedEntry(VAL(entry))
freeTimer = self
@end
@end