The Coevolution of Weapons and Aggression

by
Philip G. Feldman

A Graduate Project submitted to the Johns Hopkins University
in conformity with the requirements
for the degree of Master of Science in Interdiscplinary Science Studies

Baltimore, Maryland

Summer, 1995

Sponsor: Dr. Anthony Barbera
Advanced Technology and Research Corporation

Acknowledgments

Gee. A lot of people helped me get this done. Thanks to Sande, teem stoopit, and those members of the Baltimore Bike Club who put up with me talking about this project for the last nine months. Thanks to Vicki, who jumped in and saved me in the historical section. Thanks to Tony, for sponsoring this. And finally, thanks dad. This wouldn't have gotten done without you.

Abstract

I have developed a computer model that simulates the effects of weapons on the evolution of aggression. It simulates a simple animal system of coevolving natural weapons, defenses, feeding and reproductive strategies. To this system, variables are introduced that simulate the effect of technologically derived weapons. The result of this introduction is that the entities in the simulation become extremely aggressive towards other, unrelated entities. This in turn results in changes in the ecological makeup of the simulated environment, such as diminished diversity, lower populations, and rapid transitions between dominant species.

Introduction

There are many forms of aggression. A sea lion may fight to the death for its harem. A drive-by shooting may claim a victim. A single bomb may obliterate a city.

Agression is defined as "*1) A forceful action or procedure, 2) The practice of making attacks or encroachments 3) Hostile, injurious, or destructive behavior or outlook*[1]" In other words, aggression is a targeted act by one individual that directly interferes with the functioning or actions of another individual to the detriment of that individual. To further narrow this definition and to eliminate behaviors such as eating from this definition, the targeting individual must gain no direct energy benefit from the interference with the target individual. Using this definition, we can distinguish between action such as the ones described in the first paragraph and actions such as feeding and symbiotic parasitism. In this context, hunting and killing prey is aggressive only if the prey is not used directly for food.

Human beings are more aggressive than any other animal on the planet. They will engage in aggressive actions under more circumstances, and be more relentless in the execution of those actions to a degree that is simply not seen in the animal kingdom. Genocide is not practiced by animals. Neither is torture.

Why is this? The model seems to indicate that the presence of weapons for the past 1,500,000 years[2] has led to the evolution of humans that are far more aggressive than they would be had weapons never been introduced.

There are several types of weapons used in the animal kingdom. There are those that are grown, such as teeth and claws. There are behavioral systems such as pack hunting by wolves, there are even "artificial" weapons: The archerfish will shoot drops of water at it's prey, and the butcher bird will impale it's prey on thorns. These weapons have evolved over many generations. The weapons that humanity uses are technologically derived weapons, such as stone-tipped spears and cruise missiles. These weapons are developed and used in over a period of days, years or decades - an instant of evolutionary time.

How is it that time makes such a difference?

Even the comparatively rapid change implied by punctuated equilibrium allows time for a defense to evolve to any threat and vice versa. Against the stone-tipped spear, the animal world has still not had the time to evolve a defense.

Weapons have continued to evolve and improve. We are no longer dealing with stone-tipped spears. Technology has brought bows, swords, and directed energy weapons. What effect has that had on the species that uses them?

By definition, an aggressive individual is more likely to use a weapon than an nonagressive individual un an unprovoked situation. If that individual uses the weapon sucessfully, and can dominate his environment with it, then he increases his chances of survival and reproduction. The same applies for groups of individuals.

These individuals may not last. They may be defeated, Their weapons may become obsolete. But others will take their place, and better weapons will show up. As they use their weapons, a selection process is set in motion. Over sufficient lengths of time, the selection process will have results similar to thos of natural selection. The system will steadily select for aggressive individuals, and remove the others.

This is why weapons and aggression have coevolved and why it is still going on.

Background

This project depends heavily on research that has been done over the past 20-30 years in the field of artificial life, or "alife". The examination of life through the generation of artificial "life forms" has been the subject of exploration and analysis since Von Neuman's Cellular Automatons in the late 1950s[3]. The production of complex behaviors or patterns from a small set of simple rules is generally the hallmark of these programs.

The first, and probably best known, of the computer-based alife programs is probably the game of "Life", developed by Horton Conway in 1970. It contains many of the principles used by most subsequent systems: The environment is a simple grid, such as a chessboard, but with no size constraints. Initially, a few grid squares are populated by dots, no more than one per grid square. From the current pattern of dots, a new generation is created using the following rules: 1) a cell is turned on (highlighted) if three of its neighbors are turned on, and 2) a cell remains on if two or three of its neighbors are also on; otherwise it is turned off[4]. All the pieces are moved each time the clock is advanced, and a new pattern is created.

This combination of a simple environment, simple rules, and discrete time made it very easy for life to run as a computer program. The results of running the "Life" program can be remarkably complex. Patterns can emerge, reproduce, move, and interact with one another. Using certain patterns known as gliders, researchers have been able to build structures that behave like switches and gates, in essence creating the components for a virtual computer in the game environment[5]. This implies that systems of infinite complexity may evolve from runs of the game, given a computer of sufficient speed and capacity. The capacity to replicate complex patterns within the game environment has been used as an argument that the executing game is indeed a form of life, silicon based instead of "wet".

Much research in artificial life has followed these two early works. Algorithms based on genetic characteristics have been developed to provide mechanisms by which programs can be bred to meet a certain goal[6]. Computer viruses – believed by many to be the first true artificial life forms – have made their presence widely felt. Alife research has covered a wide variety of topics, from the initial development of life to the evolution of cooperation[78]. In this body of work however, I have been unable to find any study that examines the influence of technologically developed weapons and their influence on the evolution or development of aggression or related behaviors.

Overview

The computer model that I have developed a simulates the effects of weapons on the evolution of aggression. It does this in two stages. In the default state, it simulates a simple animal system of coevolving natural weapons, defenses, feeding and reproductive strategies. The duration of this stage is under user control. The switch to the next stage is done by introducing variables that simulate the effect of technologically derived weapons.

When the model does not include technologically derived weapons, it behaves in what could be considered a representation of the animal world. Over time, one can discern the ebb and flow of a variety of aggressive and defensive strategies against diverse population backgrounds. In this configuration, the model shows that aggression usually does not pay. The most successful strategies in this near-equilibrium state are those that directly affect reproduction and food gathering.

The introduction of technologically derived weapons into this system approximates the development of weapons by early hominids. The results are dramatic. Entities that acquire the weapon and that are aggressive enough to use it rapidly dominate the environment. Any population that does not posses this weapon is rapidly hunted to extinction. The domination of the environment by the weapon-possessing group is absolute. This domination is maintained until an individual with a superior weapon arises and establishes another group that takes over and destroys the previous group. Once established, this pattern is stable and maintains indefinitely.

An additional effect resulting from the introduction of weapons is a dramatic loss of diversity in the population. Basically, once the aggressive entities take over, they attack and destroy any mutation that occurs. This results in what is essentially a monoculture.

The overall population is usually lower. This may reflect the lower diversity in the environment. With fewer niches occupied, the overall population must be lower.

The age of some individuals dramatically increases. The absence of any competition or threat from other different entities, plus the increase in available resources, allow individuals to live to the natural limits of their lives. Since there is no age limit in the simulation, the age increase can become a significant portion of the execution of the program.

While such a simulation is no more than a theory, it has the advantages of providing clear results, of being internally consistent, and spanning a sufficient amount of time.

The Model

There are four basic elements represented in the model. These are 1) the individual entities, 2) weapons, 3) the environment that supports interactions between the entities, and 4) the rules of engagement. The representation of these components has been abstracted to limit the scope of the study to a manageable size. These are discussed in detail below.

1) Entities

Entities are unique individuals that exist at a particular point in time and space. To provide a convenient and manipulatable mechanism for storing the unique configuration of the entity, a character-string based system was chosen. Manipulating the characteristics of the entity then becomes the manipulation of this "genome". The complete list of all possible elements of this genome is listed in Table one, below:

Character	***Name***	***Description***
A	*increase energy ratio*	increases the amount of food that is converted into energy reserves relative to other destinations
B	*decrease energy ratio*	decreases the amount of food that is converted into energy reserves relative to other destinations
C	*increase armor ratio -*	increases the amount of food that is converted into defensive energy reserves relative to other destinations
D	*decrease armor ratio*	decreases the amount of food that is converted into defensive energy reserves relative to other destinations
E	*increase speed ratio*	increases the amount of food that is converted into movement energy reserves relative to other destinations
F	*decrease speed ratio*	decreases the amount of food that is converted into movement energy reserves relative to other destinations
G	*increase teeth ratio*	increases the amount of food that is converted into offensive energy reserves relative to other destinations
H	*decrease teeth ratio*	decreases the amount of food that is converted into offensive energy reserves relative to other destinations
I	*attack none*	if set, the entity will not attack
J	*attack any*	if set, the entity will attack any other entity within its detection range
K	*attack unrelated*	if set, the entity will attack any dissimilar entity within its detection range
L	*attack related*	if set, the entity will attack any similar entity within its detection range

M	*increase attack radius*	increase the range at which an entity will move to and attack another entity.
N	*decrease attack radius*	decrease the range at which an entity will move to and attack another entity.
O	*increase attack delay*	increase the amount of time between detection of a target and the instigation of the attack.
P	*decrease attack delay*	decrease the amount of time between detection of a target and the instigation of the attack.
Q	*increase hunger threshold*	increase the energy threshold that will trigger actions based on hunger
R	*decrease hunger threshold*	decrease the energy threshold that will trigger actions based on hunger
S	*graze*	gather energy from what is directly available from the environment.
T	*increase defend delay*	increase the amount of time between an attack and a counter attack
U	*decrease defend delay*	decrease the amount of time between an attack a counter attack
V	*passive defend*	if set, causes the entity to not respond to an attack
W	*active defend*	if set, causes the entity to respond to an attack (counter attack or retreat)
X	*move random when hungry*	move in a random direction if the energy stored drops below the hunger threshold
Y	*move to best food when hungry*	determine the highest food concentration in the immediate vicinity and move in that direction.
Z	*increase retreat delay*	increase the amount of time between an attack and a retreat response
[	*decrease retreat delay*	decrease the amount of time between an attack and a retreat response
\	*retreat*	if set, retreat in the face of an attack
]	*increase fission energy*	increase the energy threshold that will trigger reproduction
^	*decrease fission energy*	decrease the energy threshold that will trigger reproduction
_	*attack weaker*	if set, attack only entities that are weaker (less energy, armor).

'	*weapon 1*	if set, the entity possesses a weapon of type 1
a	*weapon 2*	if set, the entity possesses a weapon of type 2
b	*weapon 3*	if set, the entity possesses a weapon of type 3
c	*weapon 4*	if set, the entity possesses a weapon of type 4

Table 1: Character String Genome Elements

As can be seen, the elements that comprise this "genome" modify both the physiology of the entity (e.g. "D - decrease armor ratio") and its behavior (e.g. "Z - increase retreat delay"). The string can be any arbitrary length and any combination of characters.

An individual entity's genome will contain some subset of this entire list. In this model, the minimum length was 3(?) and the maximum length was 40(?). The characters can be placed in any order, and can be repeated. Ordering is important in the case of mutually exclusive options. if the character for *attack none* (I) follows the character of *attack any* (J), then the behavior of the resultant entity will be *attack none*.

Each entity begins its creation process in a default state. The genome character string then read from left to right to modify this state as the entity in initialized. Certain states are mutually exclusive: *attack any* cannot coexist with *attack none*. In this case, the last character read that affects this state is the one that sets the final state for the entity.

The default entity is as follows:

fission threshold = 1.0 energy units[9]

hunger threshold = 1.0 energy units

energy reserves = 1.0 energy units

defense reserves = 1.0 energy units

offense reserves = 1.0 energy units

motion reserves = 1.0 energy units

equal food energy distribution among 1) energy reserves, 2) defense 3) offense 4) motion

no attack mode (equivalent to *attack none*)

no *attack weaker*

no attack delay

no retreat delay

no retreat

no defend delay

defend is *passive defend*

no move mode

An entity in this default state will perish rapidly. The cost of continuing existence is 1% of energy stores per cycle, so therefore, the entity will starve within 100 cycles. At a minimum, the entity requires a method of gathering energy. This can be done either by successfully attacking its neighbors or by grazing. Once an entity develops this minimum set of characteristics, it may live long enough to reproduce, pass on its genes, and evolve.

These genome elements affect movement, sensing, feeding, reproduction, and offensive/defensive capability. These compromise a sufficiently limited set of characteristics that can be manipulated independently and examined in detail.

Movement: the minimum set of characteristics that define an entity's motion are its current position, velocity, and heading. Choosing a direction to move could be based on a variety of possibilities. An entity could move randomly, toward the highest food concentration, toward a potential victim, or away from an aggressor. These behaviors would be triggered by the presence of ...X, Y, I, J, K, L, and \ in the character string genome.

Feeding: An entity must be capable to gather and utilize energy for purposes such as motion, reproduction, offense/defense, etc. However, it is not necessary to deal with the detailed metabolism of how this is done. In this study, the feeding process is limited to "grazing" (extracting energy from the surrounding environment), or feeding off of prey. The energy gathered in this fashion is divided among the following: 1) an internal energy store 2) defensive reserves, such as armor, 3) energy for motion, and 4) offensive reserves, such as teeth.

The genome string characters A, B, C, D, E, F, G and H affect the amount of energy that gets diverted to energy stores, offensive and defensive energy, and movement energy. For example, if an entity's string contained AAA, then a greater percentage of incoming energy (either from grazing or successful attacks) would be diverted to energy stores. This would be at the expense of offense, defense, and movement. However, such an entity would be less likely to starve, and would reproduce faster.

Sensing. Entities in this study sense the presence, direction, and relative abundance of food (in a manner that is functionally similar to most single-cell entities). They have a limited sense of time, in that they have the capability to delay an action. They have an awareness of their own internal state - they can tell when they are hungry and when they can reproduce. Finally, they can sense the presence of neighboring individuals, and whether these neighbors differ in makeup from themselves. They do this by examining one anothers genome string. If, for example, an entity with the string KMS (*attack unrelated, increase attack radius, graze*) encountered an entity with the genome SY (*graze, move to best food when hungry*) wandering into its range, it would compare the intruder's string against its own. Since they do not match, the attack behavior would be triggered.

Reproduction. When an entity reaches a certain energy level, it will split into two entities - reproducing by fission. In the reproductive process, the character string genome of the original entity is copied and used to create the second individual. In the process of that duplication, random errors are introduced. These can be deletions of characters, or insertion of new characters. If the new string differs from the original, then the resultant entities will be different - a mutation.

This mutation may reflect different behaviors. For example, the default state of *attack none* may be changed by the addition of the L character to the string so that the behavior is now *attack related*. Such an offspring would attack any subsequent offspring, so long as they had not mutated further.

The mutation may also result in a physical change to the entity. The ratios of energy gathered from grazing or successful attacks may be adjusted between energy stores, and offensive, defensive, and movement capability. This mutation will manifest itself over the lifetime of the entity, as it adds to these stores or capabilities.

2) Weapons

Weapons in the most abstract sense can be considered force amplifiers. Where the application of a few foot-pounds of force applied over a large area would result in nothing worse that an inconvenient shove, that same force applied through a point such as a fang can result in a fatal wound.

A different sort of weapon would be a technologically derived device such as a gun or knife. These are different from weapons that evolve naturally because of the speed that they develop and are introduced. Where as the fangs and speed of the cheetah evolved side by side of with the defensive mechanisms of its prey over thousands of years. In contrast, the development of the gun from blunderbuss to M-16 took less than 400 years. As such, there is no evolutionary mechanism that can directly deal with this new threat[10].

Because the use of a weapon is independent of any direct genetic component, an entity may find itself in the possession of a useful weapon by almost happenstance when considered on an evolutionary time scale. Further, the time that the weapon is effective may also be limited and subject to a variety of external variables. History is full of such examples: the transition from stone to copper to bronze to iron, the introduction of cavalry, body armor, the crossbow, firearms, the blitzkrieg, battleships to aircraft carriers[11]. These technologies have enabled one group or another to gain dominance for a period of time, and have then been superseded by a more effective system. From a genetic viewpoint, it does not matter what the weapon is or how it works. What is important is that a single group possesses it and uses it to gain dominance.

In this study, such technologically derived weapons are portrayed as a variable that an entity may or may not posses (', a, b, or c in the character string genome). Whether or not this variable affects the outcome of an attack or defense depends on whether that particular variable is globally set active. If this is the case, then any entity possessing that particular weapon for that particular cycle will have a significant advantage in a conflict with another entity.

3) Environment

The environment needs to provide the following: 1) sufficient nutrients to allow a reasonable population of entities to grow and reproduce 2) enough space so that the population can settle into subgroups, and 3) a limit to both the space and nutrient levels so that there is an implicit competition resources when the population rises beyond a certain level.

This is achieved by creating an environment that exists as a two-dimensional grid containing "nutrients" at each grid point. The nutrients are in arbitrary energy units that may be acquired by an entity by "grazing". These nutrients are slowly replenished as a function of time, and are evenly distributed across the environment.

The environment is toroidal in that an entity heading off the northern edge of the grid will be placed on the southern edge, and an entity heading off the western edge will be placed on the eastern. This provides infinite motion over a finite area, and avoids the complications that corners and edges might add.

4) The Rules of Engagement

Entities in this study can interact in two of ways. They can essentially ignore each other, or they can interact in an aggressive context. These can be grouped into *attack*, *counterattack*, *retreat*, and *passive defense*. Of these, two are affected by the presence of weapons: *attack* and *counter attack*

Attacks occur when one entity finds itself within the *attack radius* (or territory), of an entity that has the configuration that matches the first entities attack profile. This profile is set at the beginning of the entity's existence by the I, J, K, and L behavioral characteristics. Respectively, these are *attack none* , *attack any* , *attack unrelated* , and *attack related* . Whichever of these letters appear last in the entity's characteristic string, or genome, will be the behavior that entity exhibits.

Attacking behavior can further be modified by 1) increasing or decreasing the attack radius, 2) increasing or decreasing the amount of time that passes between the time that an entity senses prey to the time that entity attacks, and 3) only attacking weaker entities. these behaviors are dictated by the presence of the M, N, O, P, and ' characters in the entities genome.

The success of an attack is determined by comparing the offensive energy reserves the attacker has (teeth) with the defensive energy reserves that the prey has (armor). If the attacker has more teeth than the prey has armor, the attacker wins, and gets one-half of the energy reserves of the prey.

Weapons modify this process by eliminating the armor/teeth comparison. If the attacker possesses an active weapon (a, b, c, or d in the characteristics genome), then the attacker wins, and gets energy from the prey.

Defense against an attack can of three types: 1)*passive* - the target entity does not respond to the attack. If the target entity has superior armor, than this strategy is successful. 2) *active* - if the target entity survives the initial attack, it then counterattacks, using the same rules as *attack*, above, and 3) *retreat* - the target entity flees from the attacking entity at its maximum speed. These characteristics are represented by the characters V, W, and \.

Defense can be modified by increasing or decreasing the time that the prey detects that it is being attacked to the time that it counterattacks, or by increasing or decreasing the time that the prey detects that it is being attacked to the time that it retreats. These characteristics are represented by the characters T, U, Z, and [.

Materials and Methods

The simulation program was developed and implemented in 'C' on a Silicon Graphics 310VGXT UNIX workstation. Output from the program was in the form of binary data files and three-dimensional graphic images. The binary output files were then sorted and formatted by additional programs (also written in 'C' on the Silicon Graphics). The output of these programs were ASCII files that were read into Microsoft Excel 5.0 spreadsheets running on a Power Macintosh 7100/66AV. These listings are included in the appendices.

Results

The simulation program takes the genomes, creates entities from them, and controls the interaction with the environment. Time is not continuous, but iterative. Each entity is moved sequentially by the program, once per complete cycle or iteration. The program itself executes for one million iterations. During the course of a typical simulation, an average entity tends to live 1,000 iterations, which means that runs typically have 1,000 generations of entities.

The program was executed nine times with the same initial conditions, differing by only the random number seed used to determine the random construction of the "genomes" that were used to determine the entity's behavior and appearance. For the first set of nine runs, all software that involved the effect of weapons was turned off. All conflict between entities was resolved by determining the relative amounts of offensive and defensive "hitpoints" that the entities had accumulated over the course of their existence as described in *Entities*, above.

Weapons Off

The results shown below are the results of a simulation begun with a seed value of 4. The run is typical of the majority of runs of the program with the weapons functions turned

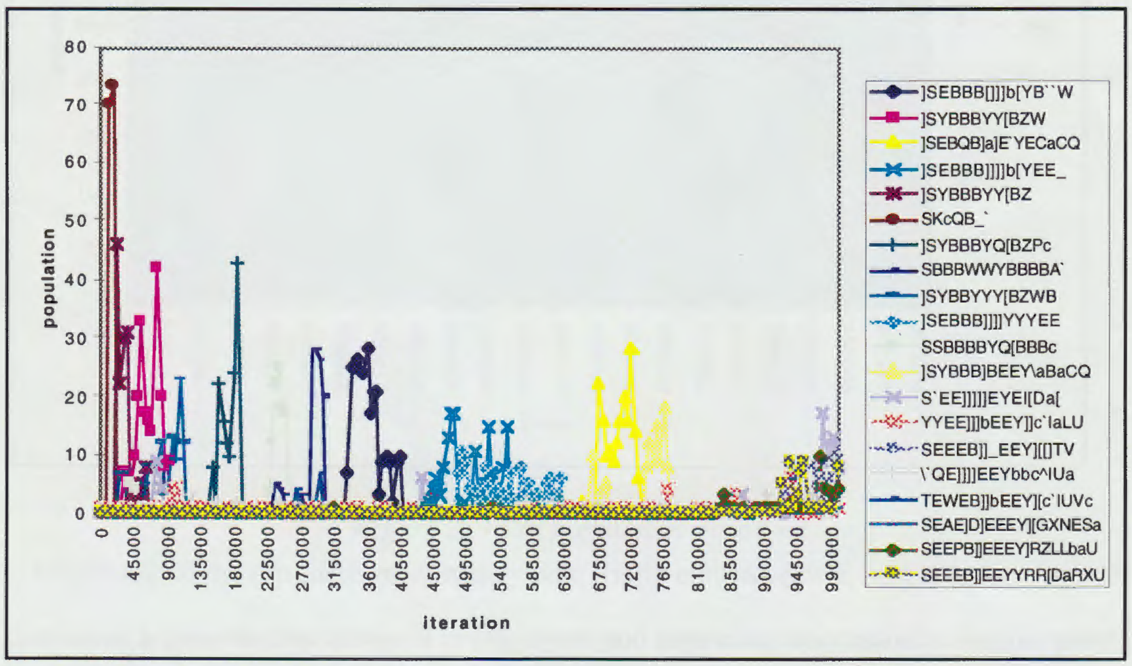

Figure 1: Genome populations over time

off. Figure one shows the fifteen most successful entities (as determined by total population) over the course of a one million iteration run. As can be seen, an initial successful entity quickly rises to comprise the majority of the population. After a few generations, it is replaced by a succession of other populations. None of these subsequent “species” comprise as major a share of the total population as the initial, however. This means that there is a large number of entity groups that have very small populations. Therefore, this pattern is indicative of a total population of high diversity.

Figure two shows the overall population of entities in the environment. At the

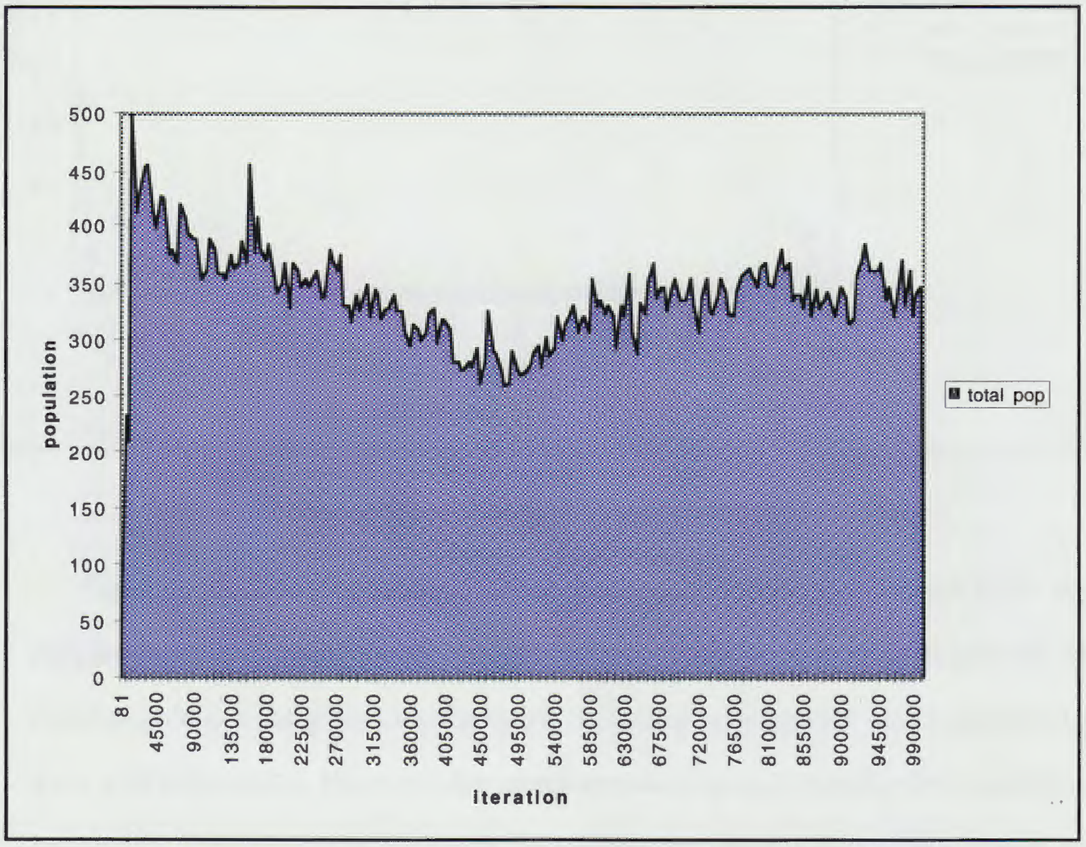

Figure 2: Total population over time

beginning of the run there are virtually zero living entities. Soon, however, one entities evolves a genome that allows it to eat, move and reproduce successfully. At this point, the population rapidly rises as the initial resources of the environment are exploited. Soon, the population is too high for the environment to support, and the population drops irregularly until the population is in equilibrium with the food production capacity of the environment, a population of 250 to 400 individual entities.

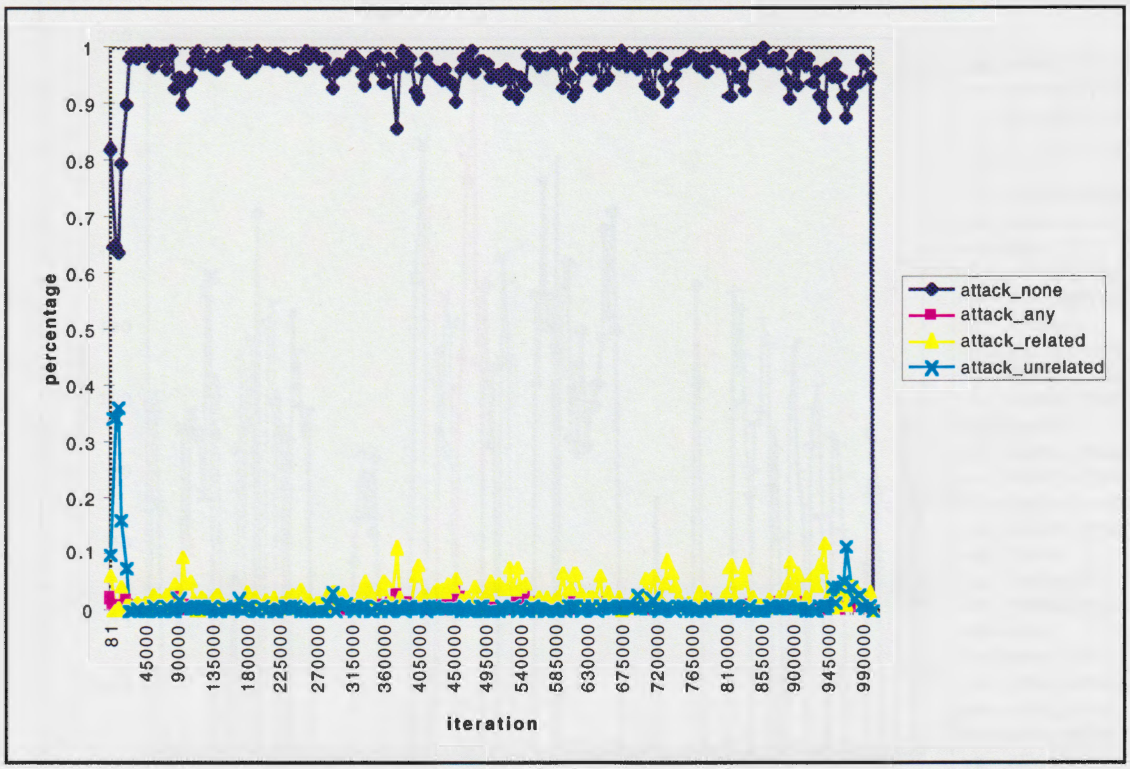

Figure 3: Attack behavior ratios

Figure three shows the relationship of the aggression functions (*attack none*, attack *any*, *attack related*, *attack unrelated*) that the entity may incorporate in its genome. In the initial population, subgroups incorporating the *attack none* and the *attack unrelated* gene were well represented. However, the *attack unrelated* gene is rapidly eliminated from the population. Throughout the course of the program the *attack related* gene appears and reaches a population penetration of approximately 10% before fading back and subsequently rising again. The dominant gene for the duration of the simulation run is *attack none*. After the first few generations, the percentage of the population having this gene is almost always grater than 90 percent.

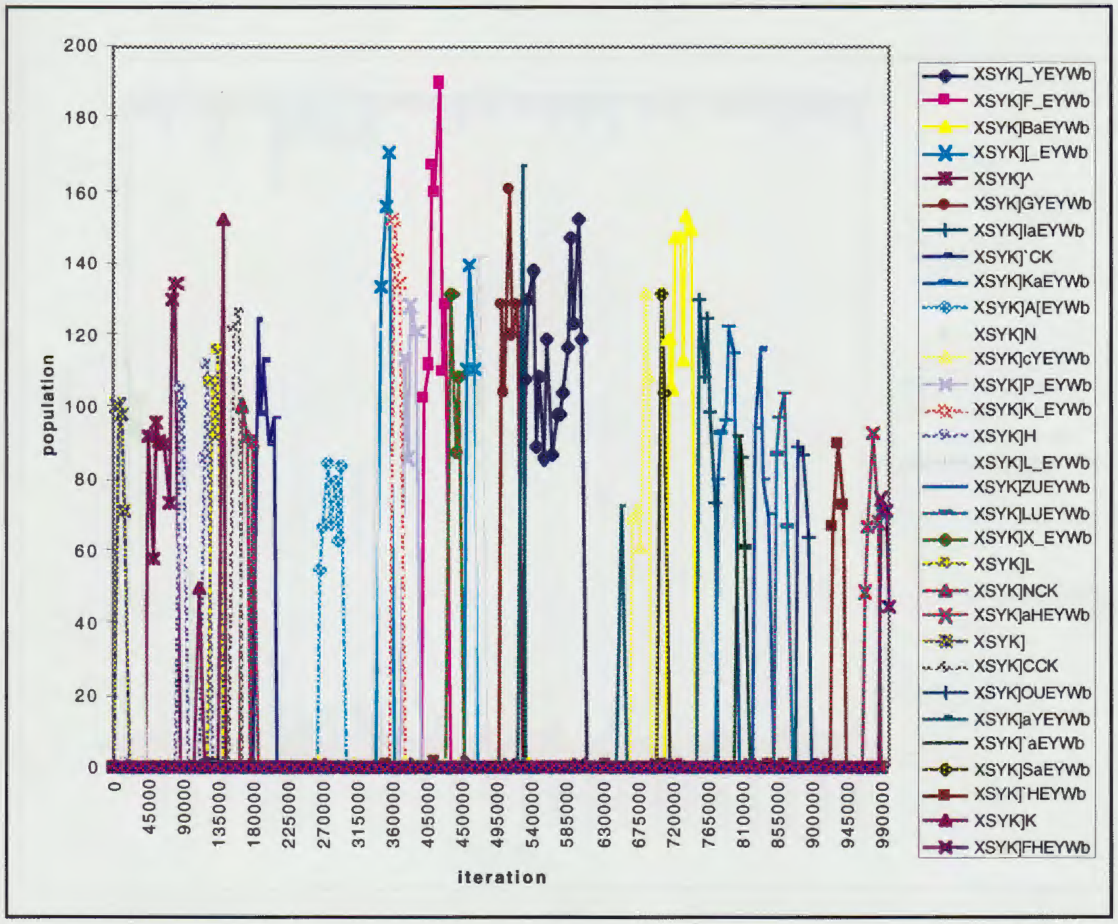

figure 4: Aggressive genomes over time

For most of the seeds, the above description is representative: high diversity, high population, low aggression (*attack none* dominates). For a few of the runs, however, an entirely different scenario occurred. In this outcome, the aggressive behaviors dominate early and do not get replaced. This results in significantly different populations and behaviors. First, as seen in figure four, the genomes of the entities are shorter. Evolution is apparently proceeding more slowly, or the outcomes are considerably more restricted. This fits with a behavior that causes any different entity to be attacked immediately. Second, single species dominate for a few to several tens of generations to the exclusion of all other species. This is markedly different from the previous run, where the diversity is so high that at times no particular species can be considered dominant.

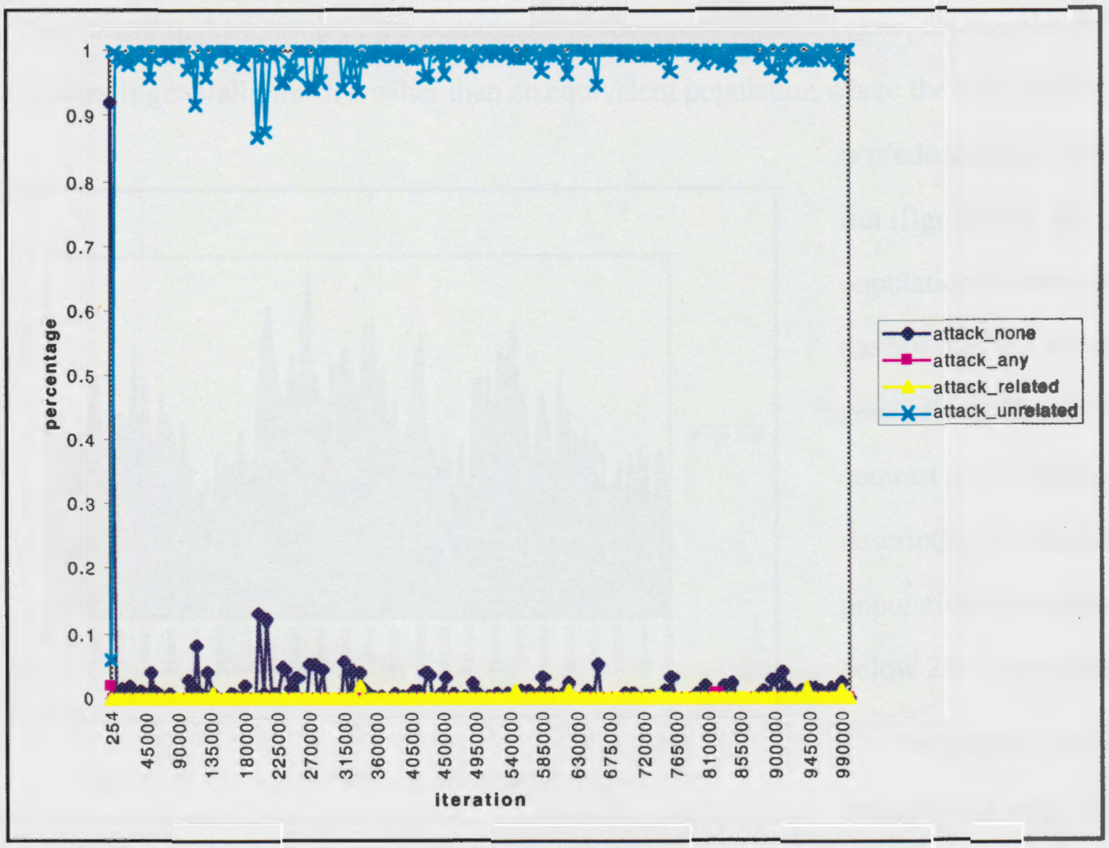

Figure 5: Aggressive behavior representation ratios

In figure five, the relative percentages of the aggression behaviors is shown. The *attack unrelated* gene quickly rises to 100% of the population and seldom drops below that point thereafter. The behavior *attack none* rises to approximately 15 percent of the population toward the beginning of the simulation - between iteration 175,000 and iteration 225,000. There is a corresponding drop in the percentage of entities with the *attack unrelated* gene. This indicates that a population of entities had spread into an area that was not inhabited by the *attack unrelated* species. Once they came into contact with the more aggressive entities they were reduced to very low levels thereafter and were unable to re-emerge throughout the course of the rest of the simulation.

Pursuing and attacking other entities takes energy that could be used for growth and reproduction. As a result of the dominance of the *attack different* gene, the population of entities is generally much smaller than an equivalent population where the *attack none* gene is predominant. On this run (figure six), the population dropped into the 50s and 60s for many generations. This in contrast to the earlier description in which the population never dropped below 250 individuals

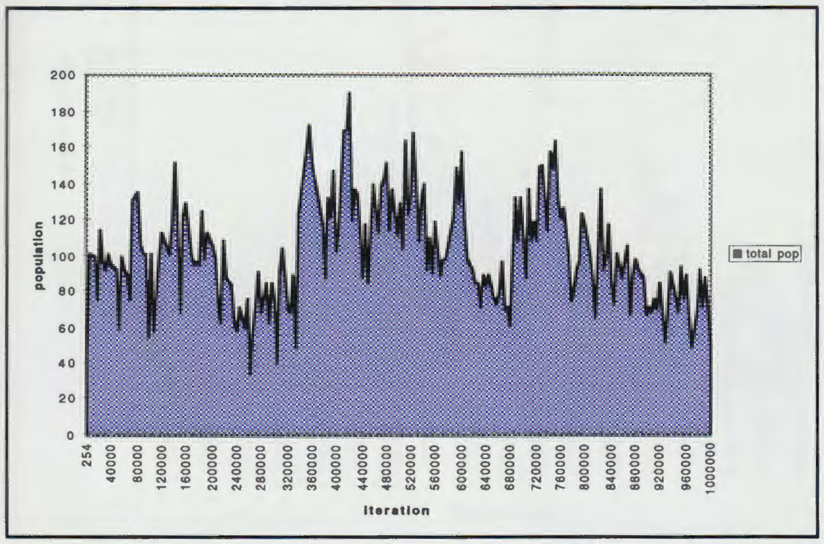

*Figure 6: Dominant **attack unrelated** population*

The preceding are examples of when fully aggressive or fully passive behaviors dominate the population. In several runs, however, the population switched from one behavior to another. In figure seven, a run based on a seed value of six, an initially passive population was overtaken by an *attack unrelated* population, which in turn gave way to an *attack none* population. This population in turn appears to be stable.

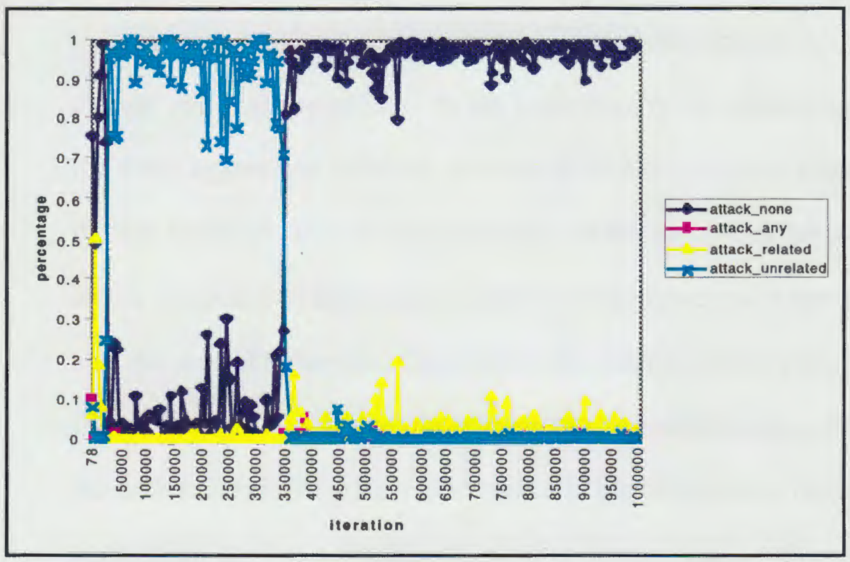

*Figure 7: Transition from **attack unrelated** to **attack none***

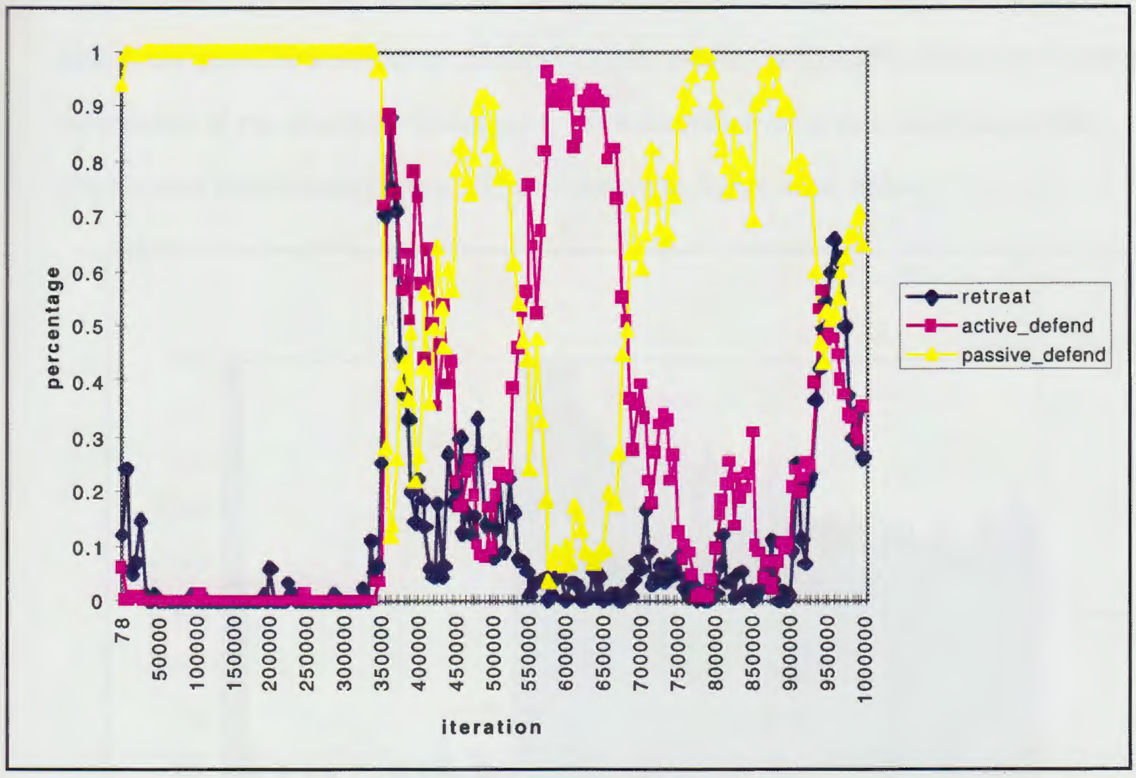

Figure 8: Defense behavior ratios over time

Figure eight shows the presence of three behaviors in the population: *retreat*, *active defend*, and *passive defend*. At the beginning of the simulation (during the dominance of the early aggressive entities), passive defend is completely dominant. Since this is the default behavior, this is not surprising. At the point that the population transitions from attack unrelated to attack none, there is a steep rise in the percentage of the *active defend* and the *retreat* behaviors. This allows the entities to run away counter attack if attacked, but otherwise to spend time gathering energy and reproducing. These behaviors seem to break the *attack unrelated* gene's dominance in the population. Interestingly, once the aggressive population has been eliminated, passive defend reemerges as the dominant behavior, and retreat slides back to a low percentage of the population. Since both of these behaviors consume more energy than a passive strategy, once the threat has been eliminated, there is little selection pressure for them.

As with the other scenarios, the population reflected the dominance of the particular *attack xxx* gene. Populations were considerably smaller and racially more pure during the dominance of the *attack unrelated* gene. With the *attack none* gene dominant, both populations and diversity grew. This is shown in figure nine, below

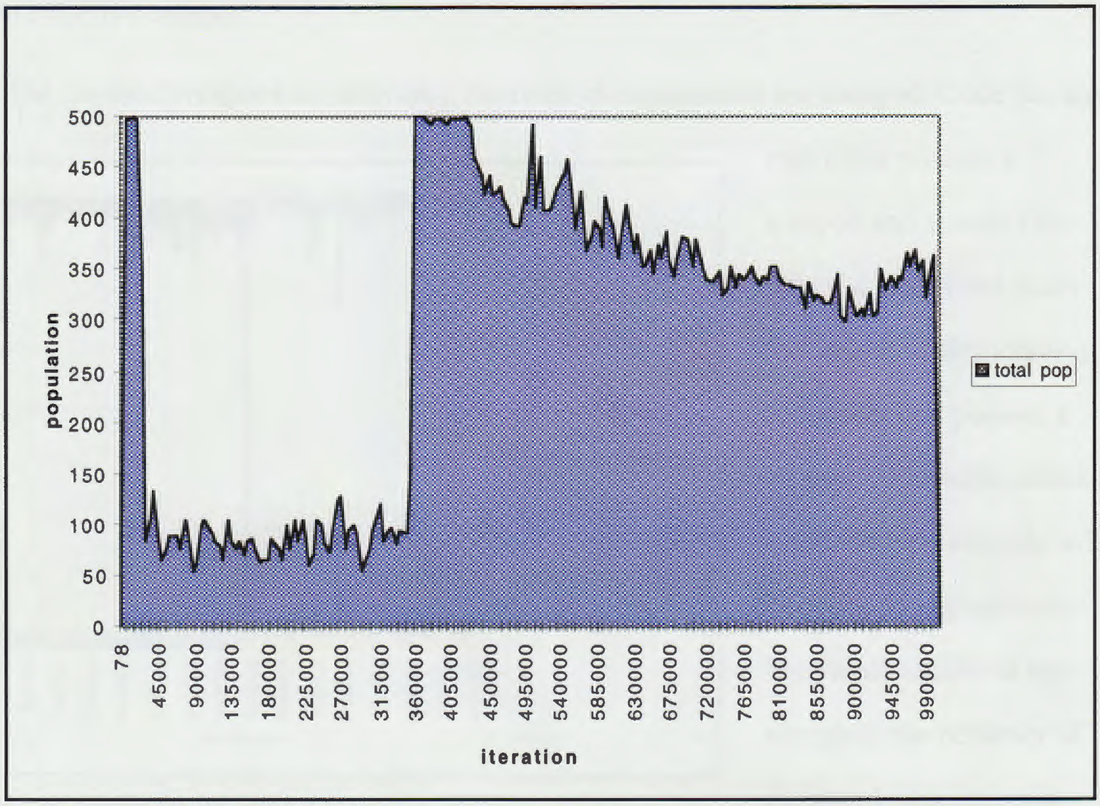

Figure 9: Transition population

Weapons On

The runs described above were executed again with the weapon functions activated halfway through the simulation (at iteration 500,000). Each simulation was started with the seed for the random number generator used to populate the environment and generate the initial genomes. As such, the runs are identical up until weapons activation.

Weapons activation in these simulations means that two additional tests are made per cycle for each entity. First, the program checks the values of a global variable to see which weapon is 'on'. (Weapon 1 is from iteration 500,001 to iteration 625,000, weapon 2 is from 625,001 to 750,000, and so on). Secondly, the genome character string is examined for the presence of the character "'", "a", "b", or "c". If the genome string contains an "a" and the global variable is set to *Weapon 1,* then that entity is determined to be in possession of an effective weapon.

The moment weapons are activated, the rules of engagement are changed. Once set, any entity that possess a weapon and attacks first kills it's victim and gains that energy. Additionally, and entity that possess a weapon and counterattacks a non-weapon attacker will also win its engagement. The ramifications of this change in the behavior of the population are rapid and significant. As important, with minor variations, all the simulation runs converged towards the same result. What is shown in the charts below are the results of a simulation run begun with a seed of 4. This is the same as the first few charts in *Weapons Off*, above.

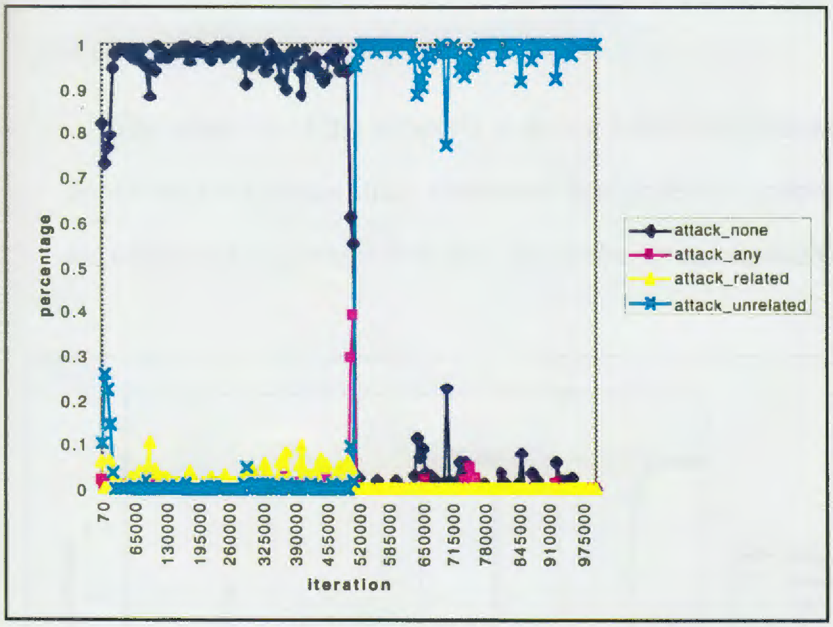

Figure 10: Weapons introduction effects on aggressive behavior

In figure ten, the first weapon is turned on halfway through the simulation, at X index 100. At this threshold, several things are visible. First, *attack none* becomes a non-viable strategy. In its place, two strategies *attack any* and *attack unrelated* rise rapidly. Over the course of 10,000 iterations, *attack unrelated* becomes the dominant behavior. It stays this way until the end of the simulation.

It appears that the introduction of weapons so disrupts the "balance of power" between the entities in the simulation that attack behaviors that were previously selected *against* are now selected *for*. What appears to happen is that a single entity mutates to both possess the active weapon gene and the *attack unrelated* character. This entity is almost unstoppable, since it will attack anything that is not a clone of itself. It will reproduce rapidly, since it is gaining energy not only from grazing, but also from its victims. This fecundity is compounded since this entity is using very little energy in prosecuting its attacks. Rapidly, it takes over the environment.

The adoption of the weapons is shown below in figure eleven In the first 500,000 iterations, the genome string characters that represent weapons are randomly represented by the success of organisms that they are randomly associated with. This changes at the halfway point, when *weapon 1* is "turned on". It rapidly rises to 100 percent, indicating an incorporation of two of the weapon characters. This representation in the population for the duration that the weapon is in effect.

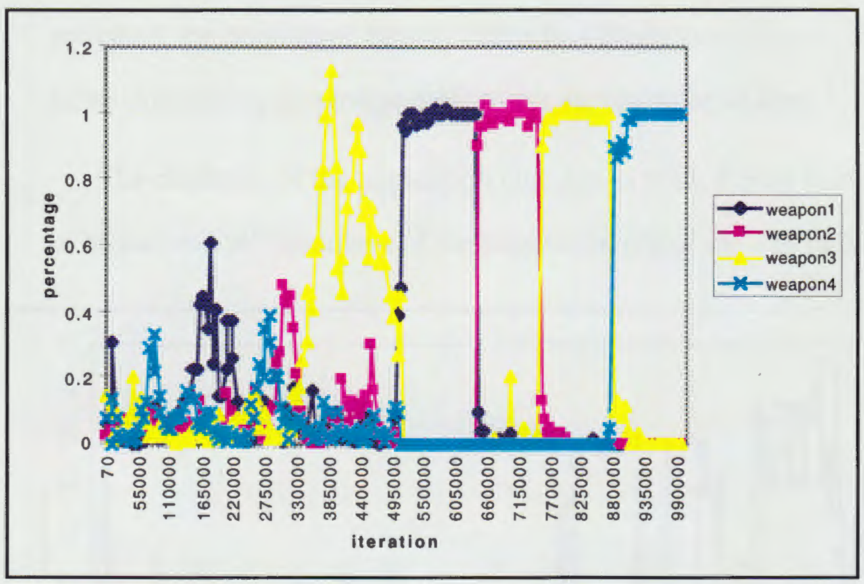

Figure 11: Weapon incorporation

One hundred twenty five thousand iterations later, *weapon 2* is activated. Again, it is rapidly selected for, as is *weapon 3* and *weapon 4*. after they are set. Note that although the weapon genome characters are completely swapped out, the *attack unrelated* genome string is essentially unchanged. Weapons, once introduced into these populations move rapidly through them and stay there as long as they are effective.

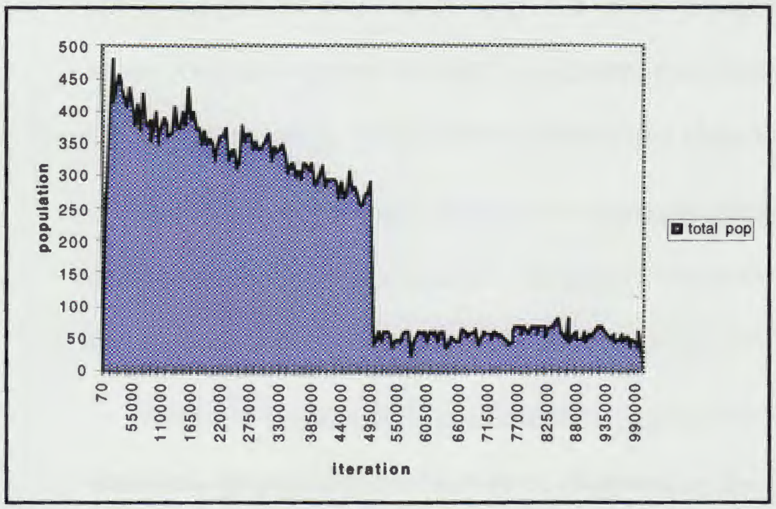

Figure 12: Population transition at weapon introduction

Population is affected in the same manner as non-weapon exposed populations where aggressive behavior is dominant. In figure twelve it can be seen that up until the point that weapons are introduced, the population is relatively high, reflecting a high diversity of non-aggressive entities. Once weapons are activated, the population rapidly drops to a much lower figure. This is the signature of an entity dominating its environment to the exclusion of all else.

The character of the population changes as well. Figure thirteen below shows the 21 most successful[12] members of the population out of the 228 individual entity types that

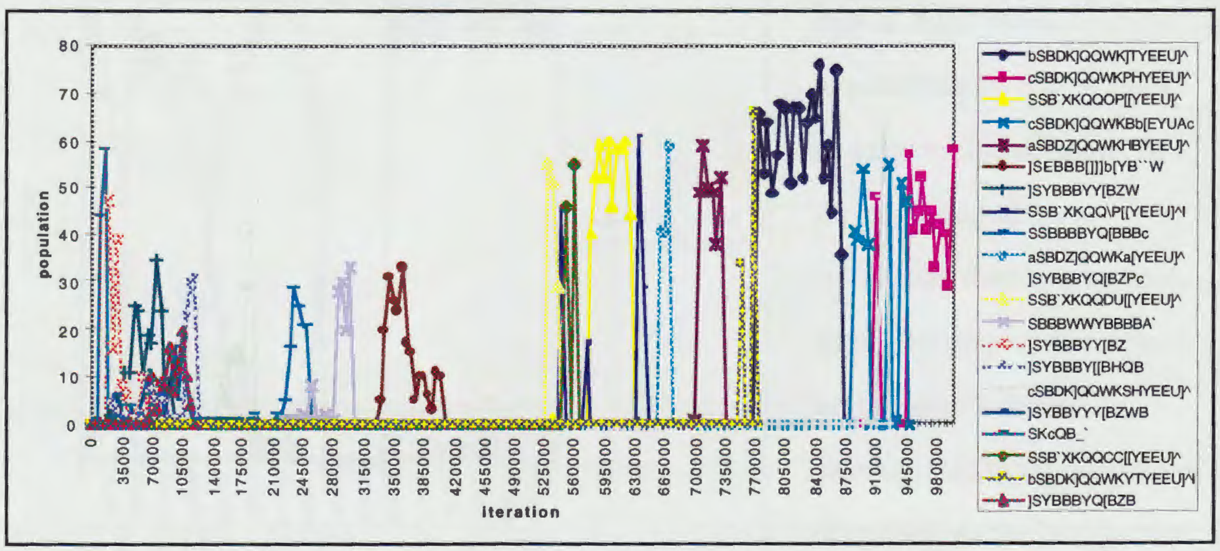

Figure 13: Genome population transition at weapon introduction

appeared throughout the entire run. The early part of the simulation is dominated by an initial aggressive species. After this initial period, it is rare for an individual genome to rise above the general noise level. There are entity populations that are reasonably large, but when compared against the total population, the seldom amount to more than 10% - 20% of the total population. This is shown in the large chart in Appendix I.

Once weapons are introduced, this character changes. Instead of a large number of small populations living together, the pattern becomes one of a single small population taking over, then being replaced by another.

When the population is dominated by aggressive characteristics, the transition between dominant groups does not have to be triggered by the switching of the simulation from one active weapon to another. Although there are twelve dominant group transitions, while there are only four weapon transitions. This exchange reflects different strategies on top of the use of the weapons. Only in one case, does a particular entity, identified as the genome string “bSBDK]QQWK]TYEEU][13]”, last for the duration of the activation of a weapon function (weapon 3)

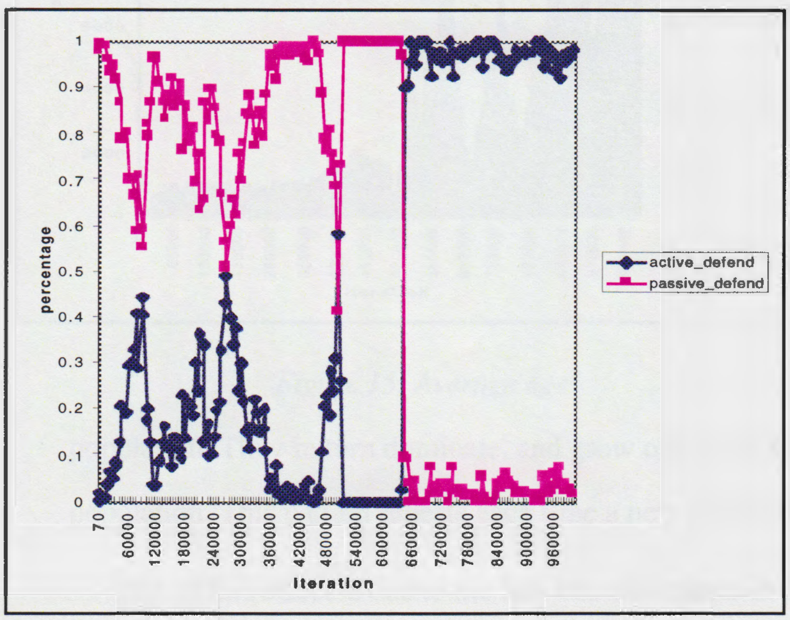

Figure 14: Defense strategies

Other characteristics appear in the transition to the aggressive state that is linked to weapons introduction. In the beginning of the simulation, there is a general, though incomplete dominance of the *passive defend* characteristic in the population of entities. At the introduction of the first weapon, *passive* *defend* rises to 100% of the population. This could be interpreted as the weapon species descending from a population that shared this trait.

Near the introduction of the second weapon, *passive defend* it is almost completely superseded by the *active defend* characteristic. This trait allows an entity to counterattack an attacking entity. Since the counterattack can use weapons, this allows for a much more robust defense against non weapon using entities.

This combination of *attack unrelated* and *active defend* appear to be an evolutionary stable configuration. It bridges between the introduction of subsequent weapons (and the species that accompany these introductions), and maintains to the end of all weapon-incorporating simulation runs.

Figure fifteen shows the average age of the population of entities. Throughout the initial (pre weapon) phase of the program, the age is relatively low and consistent. After the introduction of weapons, the entities in position of the weapons die rarely, and the average age rises dramatically. At each weapons introduction, the dominant population is destroyed by the incoming population. They in turn dominate, and grow old in the same manner as the proceeding population. This pattern repeats each time a new weapon is introduced.

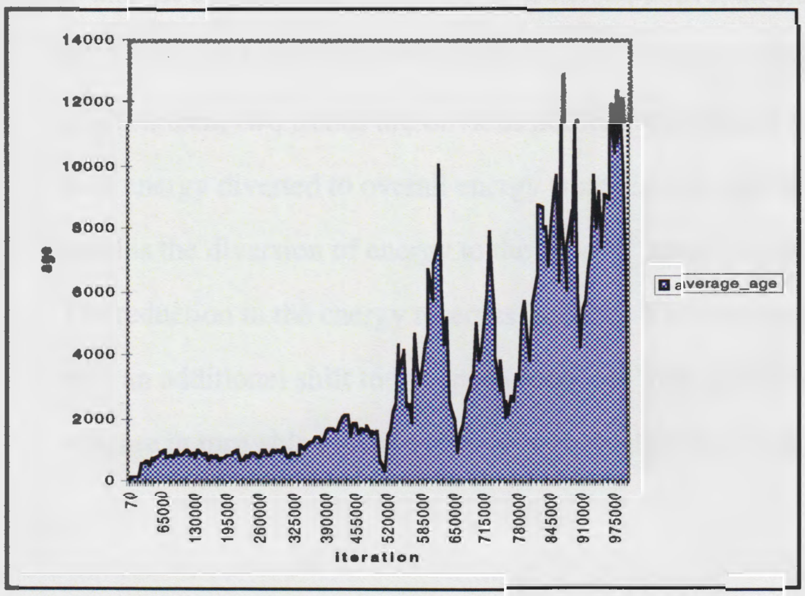

Figure 15: Average age

Part of this effect is due to the fact that the entities in the simulation have no pre-determined lifespan. In this respect, they are similar to single-cell organisms. This allows single entities to become very old. It is possible, therefore for a single entity to live for the entire simulation. An additional factor is the tendency for aggressive populations to be much smaller than the passive ones.

This means that a single, very old individual can have a greater effect on the results more quickly. This effect can be seen in the second half of figure fifteen, where the overall trend is upward, even though this trend is interrupted by several mass extinction's. The small size of the population is also evident in the more "ragged" appearance of the second half of the chart. The death of a single entity in a population of 30 - 60 has a significant effect.

Once weapons are introduced into the simulation, evolution of many characteristics slows or stops. The leveling effect of weapons seems to eliminate any particular advantage to one set of traits over another. As described above, an entity's energy, armor, speed, and teeth stores can be adjusted by including one or more characters in the genome string. In chart sixteen, two trends are obvious before weapons are introduced. First, the amount of food energy diverted to overall energy stores is reduced by approximately 25%. The other trend is the diversion of energy to the "speed" reserves and away from the energy reserves. The reduction in the energy reserves provides a default increase in the other components, with an additional shift to the speed reserves. This allows for faster and faster organisms, who are in turn able to harvest more high-quality food in less time.

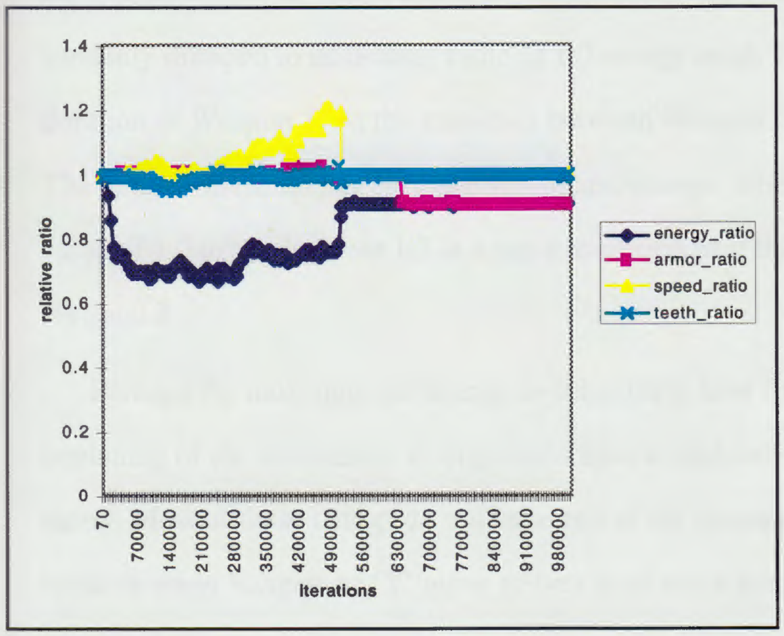

Figure 16: Armor, Speed, Teeth and Energy evolution

Once weapons are introduced, these trends are eliminated. Furthermore, the amount of change visible is far less after weapons introduction than in the first half of the simulation. When weapons are first introduced around index 100, evolution freezes with a default speed ratio and a slightly decreased energy ratio. The next noticeable event happens at the transition between weapons 1 and 2, where the armor ratio drops slightly. From this point on, there is no significant change in the relationship of any of the ratios.

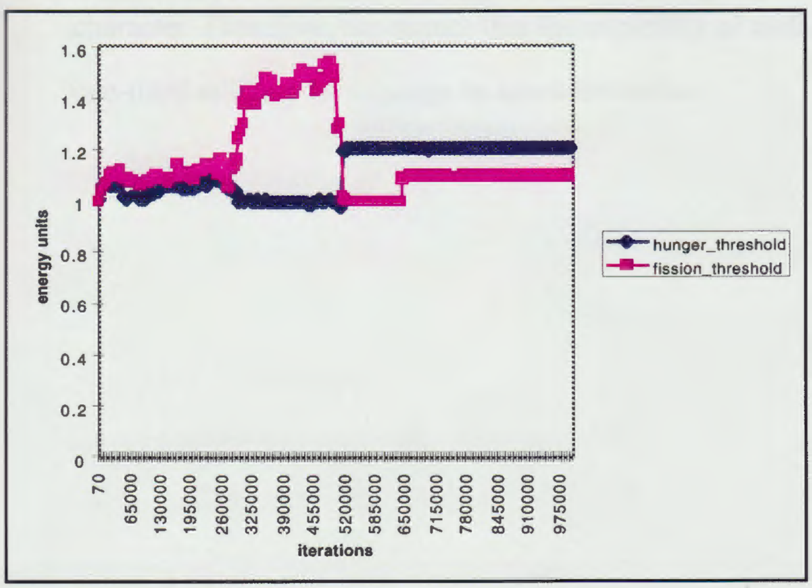

Figure 17: hunger and fission threshold evolution

This change is also manifested in the thresholds that control when an organism is hungry and when it is ready to reproduce. In the pre-weapon population, there is an easily discernible increase in the amount of energy required to reproduce, and there are some random fluctuations in the hunger threshold. As the weapons functions are turned on, the fission threshold, which had been considerably higher than its default setting of one is suddenly dropped to its default value of 1.0 energy units. This change is locked in for the duration of *Weapon 1*. At the transition between *Weapon 1* and *Weapon 2*, it rises slightly. The hunger threshold has only one significant change, where it goes from near its default value of 1.0 to a value near 1.2 in a rapid transition near the change from *Weapon 1* to *Weapon 2*

Perhaps the most unusual change in behavior is how feeding behavior changes. In the beginning of the simulation, all organisms have a randomly determined genome character string. Most of these strings do not have any of the characters for motion ('X' *move random when hungry*, or 'Y' *move to best food when hungry*).

The default state of the entity is *move none*. There is no character for this state. Instead, for an organism to lose the ability to move, it needs to have the particular character deleted from its genome. This can since the mutation operators on the genome string are add, substitute and delete, there is a one in three chance that any one mutation will be a deletion. This is comparison to the *Attack*___ behaviors. In these, there is an explicit *Attack none* character. Therefore, the chance that the capability of motion would be lost by a mutation is one-third as likely as a change in attack behaviors.

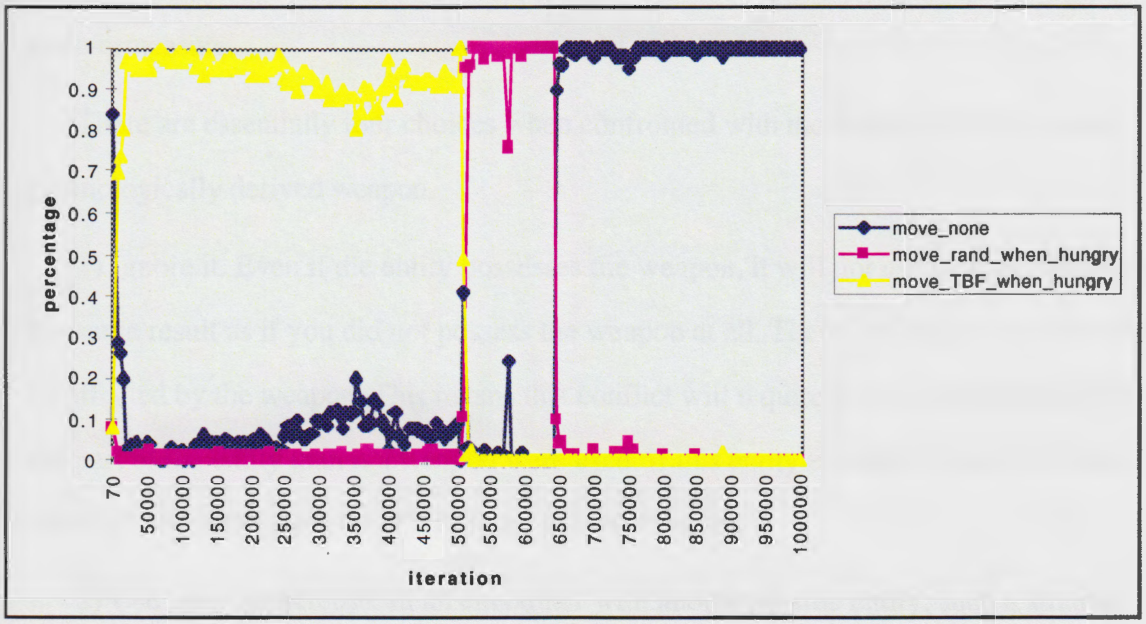

Figure 18: Feeding behaviors

In the chart eighteen, one can see that in the pre-weapon part of the simulation the selection pressure is strong for *move to best food when hungry*. With the introduction of *weapon 1*, the population shifts dramatically and suddenly to the previously unused *move random when hungry*. At the transition between *Weapon* 1 and *Weapon* 2, there is a transition to *move none*. This behavior remains dominant with no significant perturbation until the end of the simulation.

This suggests a population of entities that is rooted to the ground most of the time. The only time that these entities will now move is if a different entity is detected within their detection radius. Since these entities have the *attack unrelated* gene, they will move to and attack any different entity they sense. From a functional viewpoint, these entities have become extremely territorial.

Conclusions

This model shows how a set of defined aggressive behaviors evolve in the presence of weapons. Because technologically derived weapons come into existence virtually instantaneously, there is no way for the mechanisms of evolution to develop a suitable countermeasure.

There are essentially four choices when confronted with the development of a new technologically derived weapon.

1) Ignore it. Even if the entity possesses the weapon, it will not use it. This strategy has the same result as if you did not possess the weapon at all. Therefore, any conflict will not be affected by the weapon. This means that conflict will require more time and energy on the part of the entity than if a weapon were used. If this entity encounters another entity willing to use their weapon, it will loose in that situation.

2) Use only for defense. In an encounter with another hostile entity, such a strategy will help survival only if the other entity does not poses (and use) the weapon.

3) Use only for offense. As long as the entity has sufficient energy to continue to attack and still reproduce, this is a highly effective strategy, since competition for resources will be very low.

4) Use always. In result, this is only slightly different from (3). The survival benefits are high, with a slight added advantage of protection from surprise attacks from unarmed entities.

In addition to the use/nonuse decision is the selectivity of the weapon use. An entity may use the weapon indiscriminately, may attack only those who are related, or those who are unrelated.

In these simulations two conclusions can be easily reached.

• In the absence of technologically derived weapons, the most successful strategy is to focus developmental energy on competing for resources rather than fighting for them. Indeed, even when an aggressive entity emerged early and dominated the environment, the domination was unstable. Sooner or later, the aggressive line is usually out-competed, and dies out. An aggressive line does not appear to emerge from a mature, non-aggressive population. It seems that the dominance of the environment by an aggressive species is essentially a saddle point. Once dislodged, the strategy is never again successful.

• The introduction of technologically derived weapons provides a completely different situation. Aggression now requires only the presence of a usable weapon. In response to this new situation, aggressive entities exploiting weapons rapidly become dominant throughout the environment. Population diversity is eliminated as coexistence is no longer tolerated. Succession is sudden and thorough. Succession may be instigated by a new strategy, or by the introduction of a new weapon. Regardless, the aggressive behavior remains. The best strategy appears to be the aggressive exploitation of a weapon as soon as it comes into existence.

Discussion

This model attempts to explore the relationship between the introduction of weapons and their impact on the evolution of aggressive behaviors in organisms. In the model, this link appears to be strong. Almost as soon as a weapon is introduced, an entity evolves that uses it. This entity quickly spreads to dominate the environment of the simulation. In every simulation run, the result of weapons introduction was the evolution of a highly aggressive population, where the entities would attack anything that was not related that came within their sensory range.

In the real world, the link cannot be as well defined. Understanding even one element of the vast web of interrelationships that makes up behavior - human or otherwise - is far more difficult than simply writing a few programs and analyzing the results. In addition, this model has been intentionally simplified to explore a single relationship - that between technologically derived weapons and aggression. It does not, for example, include what effect the introduction of technologies such as agriculture might have on the need for cooperation between larger populations. Nonetheless, there are some striking similarities between the behavior of the entities in the simulation and the behavior of organisms in the real world. This can be shown in two examples: the presence of higher levels of aggressive behavior in animals that use weapons and the spread of weapons through a population.

Highly Aggressive Behavior

In the model, the "activation" of a particular weapon lead to the rapid adoption of the weapon and the domination of the environment by entities with the *attack unrelated* gene. Generally, this new type of entity replaced a more peaceful population that possessed the *attack none* gene. This was a rapid and significant increase in the level of aggression displayed by the entities in the simulation.

Aggression at this level is quite rare in the animal kingdom. Usually, aggressive behavior among animals is limited to a highly ritualized defense of a given area (territory) and/or hierarchies of precedence within social groups[14]. Such behavior is usually limited to certain times of the year, and in addition, it is seldom lethal.

People, on the other hand, will engage in aggressive actions under more circumstances, and be more relentless in the execution of those actions than any other animal species. This aggressive behavior does not appear particularly ritualized, and is certainly not limited to a particular season. However, are there other species that exhibit high, if not human, levels of aggression?

There are some examples of extremely aggressive behavior in animal species. Generally, such a situation involves an extreme case of territory defense or place in a social hierarchy. For example, elephant seal males will engage in vicious fights with one another for the possession of a harem of females. The justification of this behavior is the payoff - without a harem, a male will not reproduce. Therefore, any male that wishes to reproduce must either be extremely lucky in finding an unattached female, or he must fight another male for the harem. Such a situation must rapidly select for those males that can fight successfully to gain or maintain a harem[15]. Another example is the killing of lion cubs by the new dominant male. Again, the male gains no genetic payoff by allowing these cubs to live. Indeed female lions have adapted to this behavior and go into estrus when this occurs[16].

Chimpanzees also engage in lethal aggressive behavior. However, in this case, the justifications of the behavior are far less clear. One group will attack individual males or females from other groups, sometimes killing them, and then leaving the bodies[17]. These attacks are coordinated. Chimpanzees will wait until an intruder is isolated and then attack. A group of chimpanzees will move into the territory of another group, find members of that group in isolation and attack them using their teeth, hands, and *thrown rocks and thrust branches*[18].

There does not appear to be a direct territorial gain from this behavior. The boundaries of the various group's territories do not always shift in a way that can be attributable to these attacks. Since males and females are attacked, there doesn't appear to be the level of specificity found in the previous examples. Rather, it appears that chimpanzees have developed a social structure and communication skills allow them to attack as a group, and a sophisticated enough understanding of their surroundings to use objects as weapons.

These behaviors appear to be unique to chimps among the great apes. Gorillas, for example, have a close social structure, but aggression is limited to vocalizations and posturing. This is more in line with the behavior of the majority of the animal kingdom, and not like chimpanzees and humans. Something about the chimpanzee changed the cost/benefit relationships that governs behavior of the chimps so that they have become far more aggressive than their cousins.

Weapons Spread

The spread of weapons in the model is represented by the speed that the new "active" weapon genome character is incorporated into the population. This happens very rapidly as the newly dominant entities take over the environment that was held by the previous group. Basically, the population using the successful weapon spreads as fast as the organisms can attack, restricted only by the need to feed.

In Human history the question is more complex - it is not always clear what weapon brought success. Weapons can be used poorly or effectively. Therefore, in human conflict, weapons and their strategies must be examined together. A great weapon may compensate for poor strategy and tactics, and vice versa. However, in either case, the result is the same. Groups that develop or find successful weapons/strategies and exploit them almost inevitably spread quickly outside their current boundaries. Listed below are several examples.

The Roman Legion

The Roman legion - particularly under Caesar - was a combination of weapons, strategy, and tactics. The pilum spear and gladius short sword provided the hardware, the formation the tactics, and the use of massive numbers of highly trained soldiers the overall strategy[19]. This was a very complex combination that was difficult to oppose and was not duplicated for many centuries[20]. Using this force, the Romans built and maintained one of the first great empires in history, covering most of Europe and the Middle East.

The Stirrup

The stirrup was initially developed in the far east somewhere between 200 - 500 AD. By 800 AD, it had reached eastern Europe. The stirrup provides a rider of a horse with greater control and far more leverage when manipulating a weapon, particularly lances. Where before the stirrup, a rider stood a good chance of sliding off the back of the horse with the transmitted shock of a delivered blow, with a stirrup the rider could brace against the blow and deliver tremendous force to the target. Charles Martell was the first to discover this potential and developed a new style of shock combat based around these principals[21]. This sort of warfare depended on heavy cavalry quickly riding around or storming through a defense, while the infantry follows in and cleaned up what was left of the confused, demoralized enemy. Using these means, Charles Martell consolidated the Frankish Empire, which expanded to cover all of Europe, reaching its zenith under his grandson Charlemagne[22].

The "Needle Gun"

The first successful breech loading firearm was developed by Nikolaus von Dreyse in 1838. This was a great advance over the previous muzzle loading rifles, since the soldier could reload prone, carry a greater load of ammunition, and maintain a higher rate of fire. The needle gun was adopted by the Prussian Army in 1840. In 1864 the Prussians attacked and defeated Denmark. In 1866, they attacked and defeated Austria. In both cases the needle gun was used to devastating effect against armies equipped with muzzle loading weapons. The breech loading rifle was determined to be so effective that during the next thirty years, all armies introduced variants on this weapon[23].

Although these examples do not validate the model in themselves, they do point out that similar behaviors exist both in the model and in the real world. The model makes additional predictions as well, although these are more difficult to examine. For example, the model predicts that the introduction and adoption of technologically derived weapons leads to a significant reduction in the diversity of entities in the simulation. Basically, the entities in the simulation attack anything that is different. In humans, there is a strong element of racist and xenophobic behavior. Additionally, the human race is remarkably homogeneous. We do not share the planet with Neanderthals or other offshoots of Homo Erectus. This may be the result of the Cro-Magnon population radiating out of Africa 40,000 years ago and attacking all other hominids[24]. However, there is no archeological evidence of whether the Neanderthal population was annihilated, out-competed, or just vanished. Another prediction the model makes is that evolution slows dramatically in weapon using species. Again, there is insufficient evidence to determine that this may be the case.

The similarities between the behavior of the entities in the model and the behavior of technologically derived weapons in the real world do not prove the causality of the relationship between weapons and aggression. For this to be definitively proved would require the monitoring of similar populations over many generations, some with weapons, some without, and watching what happens. At present, such a study is well beyond even science fiction. For the foreseeable future such studies will be limited to computer simulations and therefore fundamentally impossible to truly validate.

Even so, the similarity to the model and the behavior of humans (and chimpanzees to a lesser extent) should not be overlooked. There may or may not be a causal connection between the presence of technologically derived weapons and the expression of high levels of aggression. But the results of this study certainly indicate that more research into this area may well be warranted.

References

[1] Webster's Ninth New Collegiate Dictionary 1983 Mirriam Webster Inc. p 64

[2] Lewin, R. *The Origin of Modern Humans* 1993 Scientific American Library pp. 31-33

[3] Levy, S. *Artificial Life* 1993 Vintage Books p.30

[4] Emmeche, C. *The Garden in the Machine*. 1991 Princeton University Press p. 6

[5] *Ibid*., pp. 63-70

[6] Davis, L. *Handbook of Genetic Algorithms* 1991 Van Nostrand Reinhold

[7] Waldrop, M. *Complexity* 1992 Simon & Schuster pp. 122-125

[8] Axelrod, R. *The Evolution of Cooperation* 1984 Basic Books Inc.

[9] energy units are arbitrary. They are relevent in that a certain amount of energy is required to exist, to move, to reproduce, to attack and defend, and so on.

[10] Baer D., and McEachron *A Review of Selected Sociobiological Principals:Application to Hominiod Evolution I. The Development of Group Social Structure.* Journal ofSocial and Biological Structures vol. 5. pp 69-90

[11] Bronowski, J. *The Ascent of Man* 1973 Little, Brown and Company pp.80-89

[12] As measured by total population at the end of the simulation run

[13] translates to:

b	weapon 3
S	graze
B	decrease energy ratio
D	decrease armor ratio
K	attack unrelated
]	increase fission energy
Q	increase hunger threshold
Q	increase hunger threshold
W	active defend
K	attack unrelated
P	decrease attack delay
H	decrease teeth ratio
Y	move to best food when hungry
E	increase speed ratio
E	increase speed ratio
U	decrease defend delay
]	increase fission energy
^	decrease fission energy

[14] N. Collias *Aggressive Behavior Among Vertibrate Animals* Physiological Zoology, January 1944, V XVII N I, p. 83

[15] Gould, J and Gould, C. G. *Sexual Selection* 1989 Scientific American Library pp. 143 - 146

[16] Ibid pp152 - 156

[17] Goodall, Jane , *The Chimpanzees of Gombe*, 1986, The Belknap Press of Harvard University Press, pp. 489-519

[18] Ibid pp. 549-556

[19] Lynn Montross, *War Through the Ages* 1960, Harper & Brothers Publishers, p. 46

[20]ibid, pp. 49-51

[21] White, Lynn *Medieval Technology and Social Change*, 1962, Oxford University Press, p.28

[22] Ian McNeil ed, *An Encyclopedia of the History of Technology* , 1990, Routlage, London p.972

[23]IIbid, p.984

[24] Lewin, R. *The Origin of Modern Humans* 1993 Scientific American Library pp. 66-67