

A Computational Model of Evolution: Haploidy versus Diploidy



P. Isasi A. Sanchis J. Molina A. Berlanga

Departamento de Informática
Grupo de Vida Artificial
Universidad Carlos III de Madrid
Avda. de la Universidad, 30, 28911 Leganés, Madrid.
e-mail: isasi@ia.uc3m.es

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Abstract

In this paper, the study of diploidy is introduced like an important mechanism for memory reinforcement in artificial environments where adaptation is very important. For this study, it has been simulated an ecosystem of birds. The individuals of this ecosystem are able to genetically "learn" the best behaviour for survival. Critical changes, happening in the environmental conditions, require the presence of diploidy to ensure the survival of species. By means of new gene-dominance configurations, a way to shield the individuals from erroneous selection is provided. These two concepts appear like important elements for artificial systems which have to evolve in environments with some degree of instability.

1 Introduction

Life can be described, in some sense, as a selective system for processing and storing information. This system perpetuates itself by reproduction and changes according to variations in the environment. This model has been running for million of years on Earth.

The life on Earth is the result of a large non programmed nor established development, emerged as a result of evolutive changes. Biological evolution is very complex, the basic principles of this evolution have been described by Charles Darwin[Dar59]:

- All individuals are different in several aspects. Some of these differences are transmitted by inheritance.

- Individuals produce offsprings. Some of these new members will not survive even with good environmental conditions.
- Some of the fittest offsprings to the current environmental conditions will be multiplied and they will survive. This selection will be guided by subtle differences.

Advantageous changes will be accumulated through natural selection in groups of members or individuals. This theory resumes the two main principles of biological evolution[Haa86]:

- Occasional changes in genetic material of individuals can produce a vast number of new offsprings.
- The necessity for natural selection produces this variability, through the best adapted individuals.

In 70's J. Holland at Michigan University developed Genetic Algorithms (GA's)[Hol75], a model to abstract and explain the adaptive process of natural systems. They are used to design software for simulating the mechanisms of natural systems: "ability to evolve as a function of the environment" and "ability to solve different problems", in other words, to reflect the robustness of biological systems[BIMS98].

Artificial genetic evolution is based on genetic operators (crossover, inversion, mutation,...) and reproduction (using selection)[Hol75, BK93]. However, there are several ways of improving the robustness of artificial systems, using observed mechanisms in natural genetic systems[TJ94]. One of these ways could be to considerate individuals with diploid or polyploid genotypes. Indirectly, this fact implies the use of dominance and recessive operators.

In Nature, most of the individuals are diploid. Their genotypes have one or more pair of chromosomes (or homologous) reporting on the same phenotype. This redundant information is eliminated by a genetic operator (dominance). At a locus, one allele (the dominant one) dominates the other allele (the recessive one).

Diploidy provides a mechanism for remembering alleles and allele combinations useful in the past. It performs like a long term memory. Dominance provides an operator to protect remembered alleles from erroneous selection in a hostile environment. This is a way of protecting this kind of memory from fast destruction[Gol89].

An important problem in Machine Learning with GA's is the large period of time necessary to perceive the changes[DeJ88]. If environmental conditions suddenly change, even strongly adapted individuals could disappear completely before they could evolve and adapt themselves. For this reason, the most effective individuals are those able to quickly adapt to changing conditions[Gol89]. These organisms (with diploidy) have more chance of survival. The useful lessons learned for previous environmental modifications are codified in their genetic structures.

The work areas of evolutionary computation (EC) and biology have many common fields. Biology has inspired most of the new advances in EC [Sch94, DeJ94, Fog94, Rec94, Kit94]. EC has also proved its capabilities in the research of biology. Computational models have been used for helping and testing biological theories in many works [Bar97, Axe84, Axe89], and also, been used as a useful tool in biological studies [JD96, Fog97]. The simultaneous advances in both, computational and biological areas have resulted in the application of those results in many practical problems [GD96, MNA96, RN97].

Several studies have focused on diploidy as a mechanism of improving the capabilities of GA's. The first works come from early: Hollstien, and Holland [Hol75] introduced the so called tri-allelic scheme of evolving dominance for GA's, in a steady-state model. Since then many works have focused in the development of different models of diploidy and dominance [KMS95, YN94, HE97], based on biological ideas. Some theoretical works have also been done. Smith and Goldberg [SG92] developed a theoretical and experimental analysis about how a diploid codification and a dominance schema can solve more efficiently some complex optimisation problems. Some more recent works have been done showing the effects of diploidy in the genetic search [Gre96], and the development of stochastic models [BOF95a, BOF95b]. In this way some works comparing haploid and diploid codifications have been done [FBPM95]. The results prove the advantage, in number of generations, of diploidy for complex problems. The diploid schema has also been used for the practical solution of specific problems: neural networks development [CGNP97], hardware evolution [HHS97]; or more general problems like: global optimisation [PMO⁺97], multi-objective optimisation [VFM96].

The main goal of this article is to explain the degree of influence of physical factors in the evolution of artificial populations, using a simulated environment. Specially, the role of diploidy and the dominance and recessive genetic operators in those populations, will be shown. Differences between diploidy or non-diploidy in organisms of the population will be analysed in subsequent sections. In the last section, practical examples of these issues will be presented.

2 Artificial Environment Developed

The artificial environment designed is a two dimensional world in a grid, where three types of elements (Objects, Heat source and Birds) can be found:

Objects: Objects appear in the space at randomly generated static places. The number of objects is defined in a file called Environment Description File (EDF).

Heat Source: The heat source (HS) is a circular surface of a defined and static radius. This surface has a straight movement with a defined velocity. Both radius and velocity are defined in the EDF. The utility of the heat source

is to proportionate energy to the birds that are located into its surface. The rules that guide energy interchange (ΔE) are the following:

- Only the birds inside the heat source can increment their energy values.
- The increment of energy is bigger if the bird is closer to the heat source centre.

These rules are implemented using a parameter called Energy Interchange Rate (EIR). When the value of EIR is 0, no energy increment is produced. When EIR has a higher value, the increment of energy is proportional to EIR and inverse to the distance, equation 1.

$$\Delta E(B_i) = EIR(Pos(B_i)) \times d^{-1}(B_i, HS) \quad (1)$$

where B_i is a bird, and $Pos(B_i)$ and $E(B_i)$ are the position and the energy of bird B_i respectively.

Birds: Birds have three physical features: movement, energy and behaviour. The energy is governed by physical rules of the environment. Birds have an initial amount of energy. This energy can decrease or increase following the rules:

- Faster movements require more energy.
- Energy goes down through time.
- To increase its energy the bird ought to be close to the heat source. The amount of energy increased is proportional to the inverse of the distance to the heat source centre as described in equation 1. If birds are farther than a distance value, called heat source radius, no energy is gained by them.

The environmental physical rules are very straightforward. Bird life has four phases: birth, movement, reproduction and death.

- When born, birds initially have some amount of energy that they can keep, lose or increase, following some rules that will be described later.
- The movement is guided by some phenotypic features, allowing birds to be heat sensitive, to have some degree of agility and sociability.
- The reproduction could be done only if birds have reached the sexual maturity. The reproduction is sexual, but there are not two different sexes. When a bird is in the age of reproduction, it is ready to accomplish it. Firstly, it has to find a partner with the same availability and within a matching neighbourhood. This neighbourhood area is a circle defined by a previously specified radius. If the previous conditions occur, matching happens, and then a new offspring is born. Parents have to wait for a

gestation period to be able to reproduce again. If a bird with sexual availability does not find other partner to reproduce, it has to wait the gestation period in the same way as if it had has the offspring.

- Birds can die due to:
 1. **Old age:** The death due to old age happens when a bird reach some full age set when it is born and it is different for each one following the equation 2.

$$Old_age = \mathcal{N}(h, \frac{h}{3}) \quad (2)$$

where h is some constant called “life expectancy” and $\mathcal{N}(m, \sigma)$ it is a normal random distribution with mean m and variance σ .

2. **Collision:** Birds take up some space where there can not be more than one bird, otherwise a collision happens and both birds die. The death also happens if the bird tries to go through an object.
3. **Temperature:** The death happens when the bird has an energy level lower than some threshold called “gelid threshold”, or above some other threshold called “burning threshold”.

Above parameters, that specify the bird’s biological structure, are defined (and can be modified) in the EDF. The movement and behaviour of birds are set by the genetic characteristics of each individual.

3 Bird’s genetical description

The physical bird’s features (phenotype) are specified by a single chromosome in haploid individuals, or by two chromosomes in diploid individuals.

3.1 Haploid individuals genetical description

A chromosome is composed by ten elements. Each one of them could belong to three different types: A, B, C. The chromosome has five genes to set five different physical features of each individual (Figure 1). Each gen is composed of two elements, so, each gen has 3^2 , different alleles.

Table 1 shows each different allele for the genes and their related phenotypic features. The meaning of these parameters are: S is the size of the heat source and ν , δ and α are neighbourhood, agility and speed constants respectively. All of them are also written in the EDF. The particular meaning of each gene is the following:

- **Heat sensitivity.-** It is specified by the value of the first gene, located in locus zero and six in the chromosome. Table 1 shows the possible values for this gene. For instance, the allele AA implies that there is not any

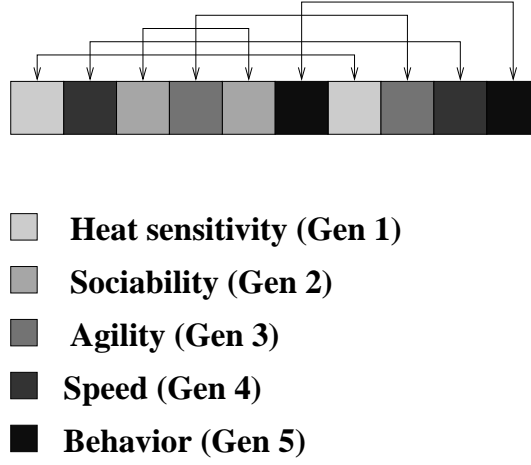


Figure 1: Bird's gen description.

Allele	Heat sensitivity	Sociability	Agility	Speed	Behaviour
AA	No detection	0	0	α	R
AB	$\frac{S}{2}$	ν	$\frac{\delta}{2}$	2α	NH
AC	S	2ν	δ	3α	HS
BA	$\frac{3}{2}S$	3ν	$\frac{3}{2}\delta$	4α	\overline{NH}
BB	2S	4ν	2δ	5α	\overline{HS}
BC	$\frac{5}{2}S$	5ν	$\frac{5}{2}\delta$	6α	NH + HS
CA	3S	6ν	3δ	7α	$\overline{NH} + \overline{HS}$
CB	$\frac{7}{2}S$	7ν	$\frac{7}{2}\delta$	8α	$\overline{NH} + HS$
CC	4S	8ν	4δ	9α	$\overline{NH} + \overline{HS}$

Table 1: Different alleles for the genes and their related phenotype.

sensitivity to heat, all other values endows an individual gradually more sensitive. This information will be translated to a distance value from where the bird detects the direction of the heat source. For the *BC* allele (Table 1) a value of $\frac{5}{2}S$ implies that the individual knows the direction of the heat source only if the distance between the heat source and the individual is less than $\frac{5}{2}S$.

- **Sociability.**- It is specified by the value of the second gene, located in locus one and eight in the chromosome. It represents the degree of individual acceptance in the group. This phenotypic feature allows to know the general behaviour of each individual. This characteristic is determined by the distance to its sociability neighbourhood related with a standard value ν . It allows to determine the position of the centre of gravity of birds

in the neighbourhood that is known by the individual. In other words, for some allele BC , the bird has the property of knowing where is the centre of gravity of birds that are 5ν or less distant from the individual.

- **Agility.**- It is specified by the value of the third gene, located in locus two and four in the chromosome. It explains the bird's ability to avoid other birds or objects near him. It also depends on the speed of the birds. If the bird is more agile, it is more likely to avoid an object even if the bird is moving faster. If a bird doesn't have enough agility to avoid an object or another bird, a collision takes place and the bird dies. This characteristic determines the distance from where a bird starts to avoid an object. This distance is related with a standard value δ . If the bird starts to avoid an object far away but it is moving with very high speed, a collision could happen equally. By the opposite, if it has not a high agility but it is moving slow, it could be able to avoid a collision. The equation (3) describes this behaviour.

$$Collision = \begin{cases} Yes & \text{If Agility} < \text{Distance from object} < \text{Speed} \\ No & \text{Otherwise} \end{cases} \quad (3)$$

- **Speed.**- It is specified by the value of the fourth gene, located in locus three and seven in the chromosome. It is the speed of the bird in relation to a constant α .
- **Behaviour.**- It is specified by the value of the fifth gene, located in locus five and nine in the chromosome. It specifies the next movement of the bird, just giving the direction of movement. Birds have to decide the direction each time they have to move, therefore they can change the direction of movement even if they have always the same behaviour. When birds are born, some "default direction" is acquired. They follow it if they have the allele AA in this gen, otherwise they could get the next possibilities:
 - AB .- They follow the sociability neighbourhood, in other words, when the sociability degree is high, they have the same behaviour as other birds. As the sociability degree decrease less birds are considered to compute the movement direction. With no sociability, the bird will follow their default direction.
 - AC .- They follow the heat source only if they are able to detect it, otherwise they will follow their default direction. Birds with this allele but with low heat sensitivity depends on their position to determine if they will follow the heat source.
 - Other alleles.- With the same dynamic as the previous cases it will follow: neighbourhood opposite direction, heat source opposite direction, the average direction of neighbourhood and heat source direction, the average direction of neighbourhood direction and heat

source opposite direction, the average direction of neighbourhood opposite direction and heat source direction and the average of neighbourhood opposite direction and heat source opposite direction; to the BA , BB , BC , CA , CB and CC alleles, respectively.

Example. Suppose a bird with the following genotype:

ACBBBAACCA

Therefore genes have the following values:

Heat sensitivity	Sociability	Agility	Speed	Behaviour
AA	BB	BC	CC	AA

that describes an individual with the following features:

- No heat sensitivity, not able to detect where the heat source is.
- 4ν for sociability, this means a high degree of knowledge of birds on its surroundings.
- A high agility and the maximum speed. Then, if the bird is somewhere close to an object and it decides to move towards the object, the bird will collide because of the high speed it is moving on, following the equation 3.
- Behaviour: it will move towards the default direction.

If its behavioural allele is changed for AC , he would have to follow the heat source, but because of having the AA allele for heat sensitivity the bird won't be able to detect it, so the bird will have the same behaviour. For this bird the behaviour could only change if the heat sensitivity allele is AB .

3.2 Adding diploidy to birds

The simulator gives the possibility to create birds with diploid morphology, in order to compare the evolution of haploid and diploid populations. To accomplish this task, the genetic material for each individual has been duplicated, generating a new twin chromosome. Then, each phenotypic feature could be specified by two different alleles, the Figure 2 shows this structure.

Now a definition of dominance is needed to know how the phenotypic features will be generated from the couple of genes. Table 2 shows an example of the dominance used. In the system a different dominance mapping for each locus is introduced. Then, no values predominate over others, it depends on the locus they are. For instance, if the locus six of one chromosome has a C value and its twin chromosome has an A value, the dominance is defined in Table 2, row six, column AC where the result is a value of C . This value will be the dominant on this locus for this individual.

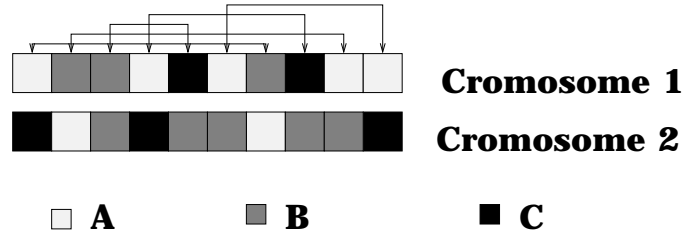


Figure 2: Genetic description for diploid birds.

Locus	AB	AC	BC
0	A	A	C
1	B	A	C
2	A	C	B
3	A	C	B
4	A	C	C
5	B	A	B
6	A	C	C
7	B	A	B
8	B	A	B
9	B	C	B

Table 2: Dominance table for each locus.

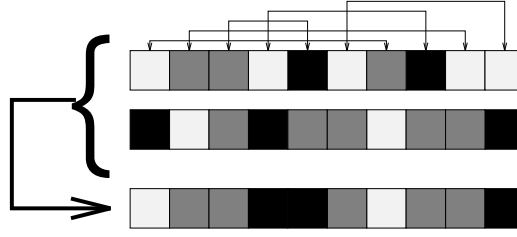


Figure 3: Dominant features for previous table.

Figure 3 shows the result of application of diploidy using Table 2 for a particular individual. This individual will have the following dominant alleles from its chromosomes:

Heat sensitivity	Sociability	Agility	Speed	Behaviour
AA	BB	BC	CB	BC

These values produce an individual with very similar features to the one from the previous example. The only difference between them is the speed.

3.3 Model dynamics

The following parameters guide the dynamics of the model:

- Number of birds.- Initial number of birds in a simulation. Bird's genotype is created randomly.
- Number of objects.- Number of objects in a simulation. The shape and size of the objects is randomly determined.
- Heat source radius.- Heat source is a circle of a size determined for this parameter. The initial position of the source is determined at random, and it is always moving with constant speed. The radius is measured in pixels.
- Heat source speed.- The distance, in pixels, between the heat source in two different steps of the simulation. The direction of movement is kept constant, and it is randomly determined at the beginning of the execution.
- Neighbourhood radius.- Parameter used in the bird's genotype to determine its movement.
- Speed limit.- Maximal velocity a bird could reach.
- Life expectancy.- Number of time steps a bird is expected to live. Used to compute the full age of each bird.
- Maximum energy.- Maximal and initial amount of energy of each bird.

- Mutations rate.- Probability of each gene of being mutated
- Reproduction radius.- Is the maximal distance, in pixels, between two individuals in order to mate.
- Reproduction age.- Age after which a bird is able to mate.
- Crossingover.- Minimum number of genes of each parent that have to be present in the offspring.
- Gestation period.- Number of time steps that a bird has to wait between successive reproductions.

In each period of time all birds and the heat source compute and make their movements. Then, a cycle of death and birth is performed and the age of each bird is incremented in a step. In order to reproduce, a bird has to match the following reproduction conditions:

- The bird has reached the reproduction age.
- The bird is not in the “waiting reproduction” period.
- There is at least a bird in its reproduction radius neighbour, that matches the reproduction conditions. One of these birds is randomly selected as mate.

Once a couple of birds are selected, a new bird is created through uniform crossover, with the only restriction that a minimum number of genes from each parent have to be present in the offspring. In the diploid codification, each chromosome is crossed-over independently.

4 Experiments

The inclusion of diploidy could be seen as an advantage when the conditions of the environment suffer drastic changes. In the artificial environment the drastic change has been implemented as two different states of the Heat Source defined by two different behaviour rules respectively:

- First state (EIR_1).- This state corresponds with values of $EIR = 0$ outside the heat source surface and $EIR = 1$ inside the heat source surface. As birds need energy to survive, and they are outside the HS, no energy is acquired by birds, they ought to evolve behaviours that make birds follow the HS.
- Second state (EIR_2).- This state corresponds with values of $EIR = 1$ outside the heat source surface and $EIR = 2$ inside the heat source surface. As the energy necessities are supplied outside the HS, and inside the HS the energy acquired will surpass the burning threshold, bird could die, so they ought to evolve behaviours that make birds go in the opposite direction to the HS.

In those cases the duplicated genetic material could help to the survival of individuals accurately adapted to old conditions. The experiments described in this section try to test this possibility. The initial environmental setup applied to all simulations are resumed in table 3. The followings are the default parameters.

Number of birds	100
Number of objects	2
Heat source radius	130
Heat source speed	5
Neighbourhood radius	20
Speed limit	200
Life expectancy	100
Maximum energy	50
Mutations rate	0.01
Reproduction radius	10
Reproduction age	25
Crossingover	5
Gestation period	10

Table 3: Environmental initial conditions.

Some of these values have been changed to find equilibrium or no-return states in the population, as those become more stable in EIR_1 . With these parameters, the number of individuals in the population evolves in three steps (Figure 4):

1. Firstly, the number of birds decreases as the worse individuals die.
2. Secondly, the gradual adaptation of better individuals make the number of birds to increase.
3. Finally, as all the individuals become adapted, a stable situation is reached, and the number of birds reaches and keeps the maximum value.

As it could be seen in figure 4, the evolution of the number of birds has two particular points: where the minimum value is reached (from first to second steps), and where the maximum value is reached (from second to third steps). These particular points have been selected as the time instants to produce a critical change. Therefore, two experiments have been defined. In experiment one the transition from EIR_1 to EIR_2 occurs in the first point, and in experiment two the transition occurs in the second point.

Another experiment with different initial conditions has been defined in order to make the environment less aggressive. In this case the HS size has been duplicated. When the HS is bigger, birds have less difficulties in adapting to the environment, and faster and accurate adaptation could occur. When the level of adaptation of birds is high, a critical change in the environment makes more difficult the re-adaptation to the new conditions.

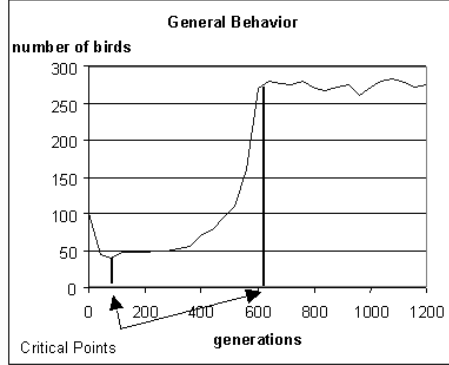


Figure 4: Number of birds evolution for equilibrium parameters in EIR_1

In resume, the experiments have been defined in this way:

1. Critical change in stable situation.
2. Critical change in first steps of adaptation.
3. Critical change in less aggressive environment.

All the results showed in next sections correspond to average values over the 20 more similar simulations from 25. This means that, for each experiment, five outsiders are not considered. All experiments are carried out over the same number of step periods. In some cases where 1200 runs, and in other cases 600 runs.

4.1 Results of experiments with critical change in stable situation

In these experiments, the change occurs when the population has reached a high degree of adaptation. In this situation, two different behaviours appear in both populations of haploid and diploid individuals:

- Simple behaviour: birds that follow HS. This behaviour is achieved by evolving the value AC in the movement gene.
- Complex behaviour: birds that use other birds with simple behaviour to survive. These behaviours are achieved by evolving different alleles in related genes that makes birds to be inside the HS most of the time.

The possibility of survival without a specialised behaviour allows to maintain genetic diversity. In a population with genetic diversity, critical changes

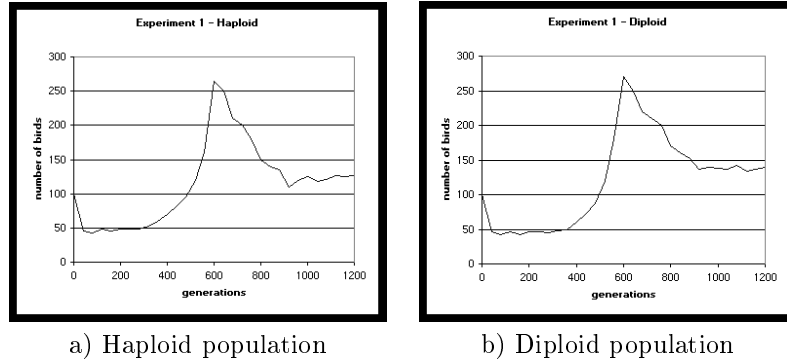


Figure 5: Number of birds evolution when critical change in stable situation

could be overcome. In Figure 5 the evolution of number of birds is showed. In generation 600, when the population is stable, a critical change is introduced. In this moment the population size decreases drastically up to generation 900. Birds with simple behaviour and some with complex behaviour are specialised in following the HS, in a direct or indirect way, and soon disappear in the population. However, some complex behaviour, not specialised in following the HS, are able to re-adapt to the new situation. As these behaviours are adapting to the new situation, new behaviours appear and the number of birds in the population begins to keep constant. Additionally no difference between haploid and diploid populations can be observed, in terms of number of individuals.

4.2 Results of experiments with critical change in first steps of adaptation

In these experiments, the change occurs in first steps of adaptation. In this situation, only one behaviour appears in both populations of haploid and diploid individuals, previously named simple behaviour.

Therefore, the population is a short population, about 20 individuals, totally adapted that directly follow the HS. This situation is very different from previous experiment:

- In the haploid population there are not genetic diversity when the critical change occurs.
- The only adapted individuals show simple behaviour and they are not able to survive in the new environment.
- The haploid population tends towards the extinction (Figure 6a).

By the opposite, the genetic diversity is kept in the diploid population, this is the fundamental advantage of diploid codification.

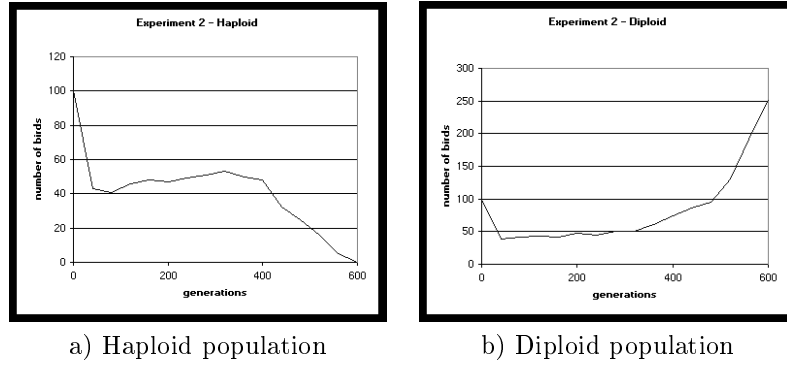


Figure 6: Number of birds evolution when critical change in first steps of adaptation.

The evolution of the number of birds in diploid population is very different (Figure 6b). In this case, the birds begin to decrease in number by the critical change, but some generations later, the intrinsic diversity allows to evolve individuals able to survive in those new conditions, and less birds died. The number of birds keeps constant from generation 100 to generation 500. In this period, the birds are continuously adapting to the new environment, and in generation 500 a complete adaptation has been reached and the number of birds begins to increase exponentially.

This experiment proves the advantage of the diploid codification in terms of the genetic diversity. This diversity could become the only way of re-adaptation when drastic changes occur in the environment, making the populations able to survive, and to re-adapt to critical changes.

In all previous experiments, the change in the environment is very drastic. In the next experiment a less drastic change has been introduced to test the importance of the change strength in re-adaptation and the effect of codification.

4.3 Results of experiments with critical change in less aggressive environment

In order to make the change less drastic, the size of the HS has been duplicated. This increment in the size of the HS has two consequences:

1. There are more surface where birds can get energy, therefore there is no need in evolving as complex behaviours to survive as previous experiment.
2. When the change happens, there are less surface outside the HS. Then, the adaptation to the new situation is more difficult.

The general behaviour of the populations when the HS is duplicated its size is showed in figure 7, when no changes occur in the environment.

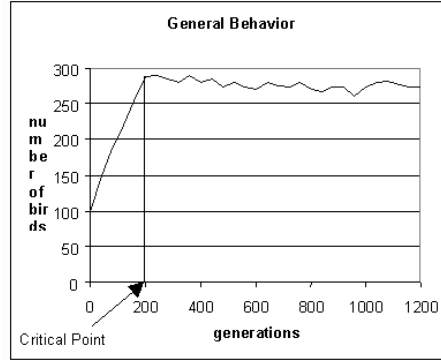


Figure 7: Number of birds evolution for HS size doubled in EIR_1 .

In this case, there is no initial decrement in the number of birds, the number of birds increase from the beginning and in generation 150 reaches the maximum number of birds. This continuous increasing of the number of birds appears because the birds have not to evolve special behaviours to survive. As the HS is moving, HS goes to the same location periodically. Increasing the HS size decreases the period of time in which a location is not gathered by the HS. Therefore, even behaviours that tend to move almost randomly can have some chances of survival. As the birds adapt, the behaviours becomes more sophisticated and the number of birds increases, but there is always a high diversity in the population.

The general evolution of the figure 7 shows only one point of inflexion in the graph. In this case, the experiment consists of introducing the critical change at this point (generation 150).

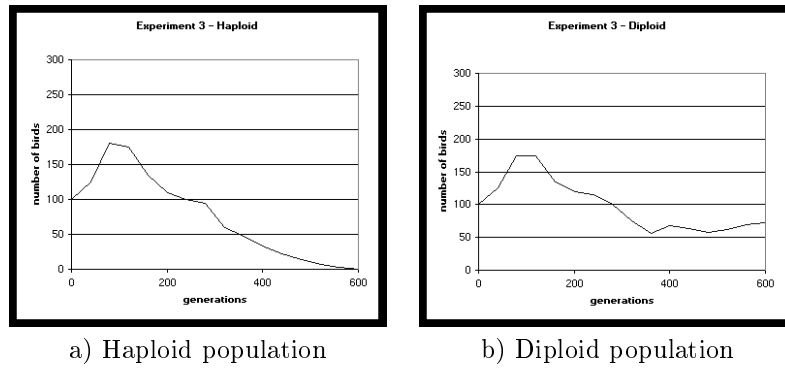


Figure 8: Number of birds evolution when critical change in stable situation.

The evolution of both haploid and diploid populations under the above conditions is showed in figure 8. The haploid populations goes toward the extinction (Figure 8a). The hard conditions of the new environment and the evolved alleles don't allow the generation of new adapted alleles, and the population extincts. The genetically richer diploid population, has in many cases the same behaviour, and also goes toward the extinction. But in some cases sufficient changes occurs in the population that could evolve individuals able to survive. In these cases, the population decreases in number but can keeps the size in 60 individuals, more or less.

5 Conclusions

The addition of diploidy is an advantageous help to deal with environments where sudden changes could happen. This advantage grows when those changes are determinants and periodic. It could be appreciated how physical critical features on haploid populations find a stability point towards the searching of individuals adapted to a stable state.

When a sudden change occurs in environmental conditions, the population of super-adapted individuals is extinguished. Under identical conditions the diploid population is able to adapt keeping a higher degree of genetic diversity. This feature gives them the capability to adapt and survive under the same sudden environmental changes.

If a suitable physical features of the environment is set, the haploid population could not achieve the same level of specialisation as before, emerging different clusters of organisms able to survive. This fact increases the genetic diversity and, therefore, the probability of survivance. In this case, there is no too many differences in relation to diploid population.

Finally, the inclusion of diploidy in the system increases the genetic diversity without loosing the ability of specialisation. This feature is very important for all the genetic searching and in extremely dynamic artificial life systems.

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