# Studying Adaptation With Echo

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## Abstract

In this paper, we discuss our work aiming at experimenting adaptation via mechanisms of selection in artificial worlds (artificial darwinism). We use J. Holland's Echo as the experimental platform. These experimentations have been performed along two ways. First, an initial cell having been injected in the world, we basically let the system evolves by itself to observe and analyze what the system produces. Cells having different behaviors emerge leading to a complex ecology. Second, we try to simulate situations observed in nature, namely food chains, parasitism, and batesian mimicry. Such simulations are difficult to obtain. We think that the first approach is much more natural in that it leads us to study the dynamics of an evolutionary system. In this regard, the emergence of an ecology of different behaviors in unstable equilibrium is very interesting: an ecology has evolved from a trivial world initially inhabited by a single agent.

## 1  Introduction

The existence and the ubiquity in nature of complex systems is well acknowledge nowadays. This has opened new horizons for the use of computers as tools to investigate complexity. This investigation can go along with the study of natural processes in collaboration with biologists, psychologists, ... (see *e.g.* [TJ94], [BM96]). Computers are also of great usefulness to study artificial worlds which are already much too complex for any useful analytical approach despite their simplicity. In this paper, we address this second approach and we are interested in the study of the adaptation in artificial worlds based on the Echo platform.

Echo was introduced by John Holland and described as a class of models designed to study adaptation to overcome the limitations of genetic algorithms (GAs)

the regards to the study of adaptation [HOL92, HOL94, HOL95]. As a tool of study of adaptation, GAs have been able to confirm that certain well-known mechanisms in genetics of natural living organisms such as epistasis, genetic drift, and hitch-hikers are straitghforward consequences of selection, recombination, and mutation. Furthermore, simulations of the immune system based on GA's have also shown similarities between the natural immune system and what is evolved artificially [FJSP93].

Basically, Echo aims at capturing the very essential characters of the natural selection after Darwin's and successors theory. Terry Jones at the Santa Fe Institute developped the first version of an implementation of Echo [JON93], followed by Simon Fraser. All the developments discussed by John Holland in [HOL95] are far from being implemented today. However, the basic model is implemented and is already worth being studied. Its study is already far from trivial.

The basic idea of Echo is to have a set of agents, situated in an environment which provides them with food. The behavior of the agents is controlled by their genome. Agents can interact in different ways, either aggressively by fighting, peacefully by trading food, or sexually by mating and reproducing by combining their genomes. Asexual reproduction is also occuring. An other major difference with regards to GA's concerns the fitness. The fitness of agents is defined implicitly as their ability to survive. Naturally, Echo implicitly favors the agents that are fit enough to survive. (As in nature, the paradox of the definition of fitness is raised because the fitness of an organism can not be predicted *a priori*; rather we say that an organism is fit if it does survive — see for example [MB93].)

The use of Echo is far from being easy even if Terry Jones designed a nice graphical interface to help us use it. The user is rapidly submerged by an overwhelming number of parameters which role and tuning is far from being easy to master. Consequently, the amount of work published to date is rather small. We consider this small amount more related to the fact that Echo is difficult to study rather than due to the fact that Echo is useless.

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To the opposite, we think that Echo deserves much work as a very nice environment to study adaptation.

Noteworthy are the studies of the dynamics of population in Echo compared to Preston's clustering analysis in [FOR94, FHJ96].

In the rest of this paper, we will first give a short presentation of Echo, the agents and how they interact. Then, we will describe two types of simulations. We consider Echo as a system to study. To achieve this goal, we study the evolution of the system when a single agent is initially put into the environment where it can find food. In this regard, Echo is a dynamical system to study, where the dynamics is driven by a selective process. Second, we try to simulate different situations which happen in nature; we discuss how Echo has to be parameterized to achieve this goal and draw some general conclusions about this kind of simulations. We argue that the first use of Echo is much more interesting than the second one. The central point is that in the former case, we observe what the "natural" evolution of a system, while in the latter case, we enforce it to evolve along some predefined way. Being enforced, the evolution of the world is then a special case of what the system can produce. Furthermore, these evolutions are quite hard to obtain which strongly question the relevancy of these evolutions as being atypical evolutions of the system. Still worse, successful simulations were obtained by getting rid of the genetic evolution mechanism. We think that this irrelevancy is due to a problem of scale: the agents in Echo are very simple, closer (though far yet due to their triviality) to what is supposed to have been the very first living organisms on earth, for sure, much more trivial than the simplest organism living on earth today.

## 2 A short introduction to Echo

In this section, we present Echo as it is currently implemented and, thus, as we have experimented it[1].

In the world of Echo, time is discrete. The world is a toric 2D grid of sites. Each site has 0, 4, or 8 neighboring sites. It is inhabited by agents. Agents are located on sites and are able to move from one site to any neighboring one at each time slot. Agents may interact when they are located close to each other on the same site. Agents exhibit behavioral traits which are the expression of some specific genes of their genome called *condition*. The "external aspects" of agents is defined by their *tags* which are also the expression of specific genes of their

genome. Asexual and sexual reproductions occur allowing the evolution of genotypes, thus of the behavior and the "aspect" of agents.

Each site produces a certain amount of resources at each time slot. This amount is defined by a parameter for each site. It may be null. Resources come in four varieties labelled a, b, c, and d. Agents feed on these resources in order to survive. These resources may be considered as the basic (and only existing) molecules of the Echo world. The genome of agents is made of these four molecules. Up to now, no chemistry exists in Echo: molecules do not react with each others: they are only able to form long chains. Genetics is rather simple in Echo; organisms are haploid; no direct (chemical) interaction exists inside the genome between genes.

### 2.1 Agents

Agents are defined by two elements (see fig. 1):

1. a chromosome which codes the behavior and the external traits of the agent. It is composed of genes. Each gene is a string of resources (or *nucleotide*),

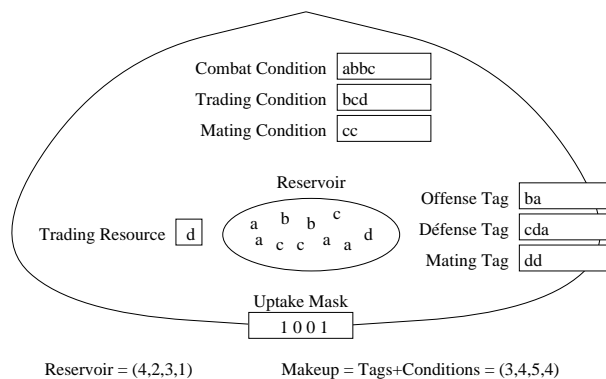2. a reservoir which contains resources stored inside the agent.



Figure 1: The structure of an agent.

### 2.1.1 The chromosome of agents

The chromosome is divided into 8 genes: 3 for tags, 3 for conditions, and 2 controlling the exchange of resources. The amount of each type of resources present in the tags and conditions of an agent is called its *Make-Up*. It is thus a 4-uplet.

Interactions of an agent are controlled by its tags and conditions. Tags define the external traits of agents, that

[1]version 1.2, available via anonymous access at ftp.santafe.edu

is how agents are perceived by the others. There are three genes for tags:

- *Offense Tag*: ability to combat or trade,

- *Defense Tag*: ability to defend itself against aggression from other agents,

- *Mating Tag*: ability to mate.

The conditions define how an agent behaves during an interaction. It regulates thus its behavior. There are three genes for conditions:

- *Combat condition*: behavior when involved in a combat,

- *Trading condition*: behavior when involved in a trade,

- *Mating condition*: behavior when involved in a reproduction.

Exchanges of resources occur either between an agent and the environment, or between two agents during a trade. They are regulated by two genes:

- *Trading resource*: indicates the type of resource (a letter) an agent gives to an other agent during a trade,

- *Uptake mask*: indicates the resources which may be gathered from the environment. It is a bit mask, one bit per type of resource. A resource can be acquired if its associated bit is set.

It should be pointed out that the exchanges of resources (as defined here) are not the only possible way for resources to flow in ECHO. Resources may be acquired during a combat, or by an offspring resulting from cloning or sexual reproduction (see fig. 2).

When it is necessary to describe miscalleneous details with regards to the ECHO genetics, we will use the term chromosome as representing the concatenation of the 8 genes, in the following order: Offense Tag, Defense Tag, Mating Tag, Combat condition, Trading Condition, Mating Condition, Trading Resource, Uptake Mask.

### 2.1.2  Self-reproduction

When an agent has enough resources in its reservoir it can self-reproduce, then producing a clone of itself. The offspring receives a certain amount of resources from the reservoir of its genitor. The chromosome of this clone is then mutated to obtain the actual chromosome of the offspring.
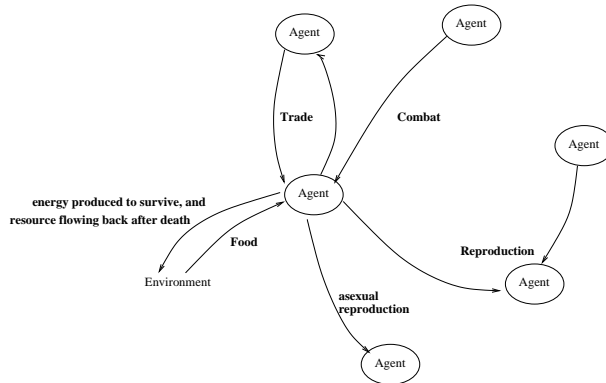


Figure 2: Flows of resources in ECHO. Arrows indicate the flows of resources and their direction. Arrows are labelled with the type of interaction or the reason of the flow.

### 2.1.3  Mutation

In ECHO, mutations act on genes. On tags and conditions, mutations may be of three types:

**deletion** : the last nucleotide of the gene is deleted

**insertion** : a nucleotide is added at the end of the gene

**point mutation** : a nucleotide is modified

The point mutation is the only mutation which is possible on the trading resource. In the case of the uptake mask, mutation acts by flipping a bit.

### 2.2  Interaction between agents

When two agents get close to each other on a site, different events may occur:

**indifference** : no interaction,

**combat** : an agent attacks an other one in order to kill it and obtain its resources,

**trade** : the agents exchange resources between them (not necessarily in equal terms)

**mate** : the agents recombine their chromosomes and produce two new agents.

The number of interactions that occur at each generation is controlled by a parameter of the world. Interactions are driven by a prefix mechanism. Each condition is associated to a tag and an interaction can occur if the condition is a prefix of the tag (see fig. 3).
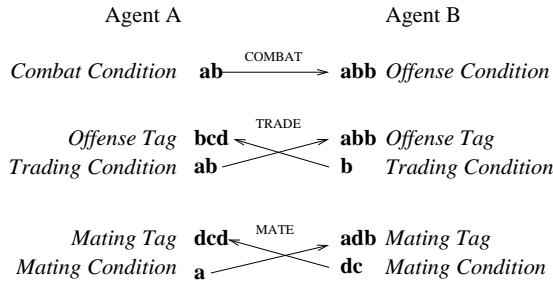
3

|  | Agent A | | Agent B |  |
|---|---|---|---|---|
| Combat Condition | **ab** | $\xrightarrow{\text{COMBAT}}$ | **abb** | Offense Condition |
| Offense Tag | **bcd** | | **abb** | Offense Tag |
| Trading Condition | **ab** | $\xrightarrow{\text{TRADE}}$ | **b** | Trading Condition |
| Mating Tag | **dcd** | | **adb** | Mating Tag |
| Mating Condition | **a** | $\xrightarrow{\text{MATE}}$ | **dc** | Mating Condition |

Figure 3: Interactions between agents. The agent A is able to attack the agent B if its combat condition is prefix of the B's offense tag. Two agents are able to trade if the trading condition of each other is a prefix of the offense tag of the other. Two agents are able to mate if the mate condition of each other is a prefix of the mating tag of the other.

## 2.2.1 Combat

There is a certain probabilty that the agent being attacked escapes. If a combat occurs between two agents, they can no longer interact in an other manner during the same time slot.

When the combat happens, each offense tag is compared to the defense tag of the other agent nucleotide by nucleotide in order to compute a score for each agent. The probability to win for one of the interacting agents is the ratio of its score by the sum of both scores. The winner gets all the resources (the resources of its reservoir and the resources that constitute its genome) of the loser. The loser is removed from the world.

## 2.2.2 Trade

When trading, each agent gives a part of the resources it has in excess in its reservoir, that is the amount the amount of ressources it doesn't need to self-reproduce.

## 2.2.3 Mate

The agents recombine their chromosomes via a two-points crossover-like operation (à la genetic algorithm). The two offsprings replace their parents in the population which thus remains of constant size.

The two crossing-points are chosen as follows. For each crossing-point, a gene is chosen (the same in the two chromosomes undergoing recombination) and a crossing-point is taken in this gene (not necessarely the same for both agents). The number of nucleotides in the genes where the crossing occur is then generally different in the

offspring from that in the parents. This is very important and provides vast possibilities for evolution to agents in ECHO since the length of their genes is no longer fixed at the beginning of the simulation. The length of the genes *trading resource* and *uptake mask* are constants.
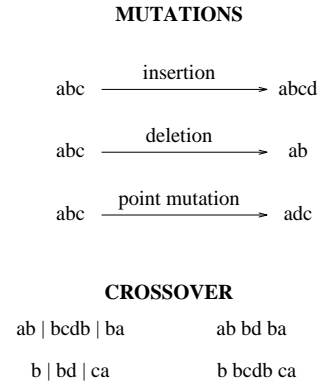
**MUTATIONS**

| abc | $\xrightarrow{\text{insertion}}$ | abcd |
|---|---|---|
| abc | $\xrightarrow{\text{deletion}}$ | ab |
| abc | $\xrightarrow{\text{point mutation}}$ | adc |

**CROSSOVER**

| ab \| bcdb \| ba | ab bd ba |
|---|---|
| b \| bd \| ca | b bcdb ca |

Figure 4: Mutation and crossover operations. The insertion operation adds a nucleotid "d" at the end of the gene "abc". The deletion operation deletes the last nucleotid "c" of the gene "abc". The point mutation operation mutates the nucleotid "b" in the nucleotid "d" in the gene "abc". The crossover exchanges the sequences "bcdb" and "bd".

## 2.3 The ECHO cycle

To complete this brief presentation of ECHO, let us give the layout of the basic cycle of life:

**Interaction** On each site, some agents are selected to combat, trade, or mate. The number of interactions which are performed at each site depends on the number of agents situated on it and on a parameter of the world,

**Feeding** Agents feed on the resources of the sites. The available resources are, as possible, equally distributed among the agents. Left resources are given to agents at random,

**Consumption of energy** Some agents restitute some resources to the environment. For each agent, this is controlled by two parameters of the world,

**Death** Some agents die accidentally according to a parameter of the world,

**Production of resources** New resources are produced on each site. Each site is parameterized with regards

to this production. We may then define sites ranging from sterile providing no food to very fecund, where food is abundant,

**Movement of agents** Some agents migrate to a neighboring site. An agent migrates if it does not find any resource during a cycle (neither during a combat, nor a trade, nor during the resource distribution),

**Cloning** Agents with enough resources produce a clone of themselves.

# 3 Playing with Echo

We aim at assessing whether the dynamics of a population is relevant with regards to what is known in biology to happen in nature. By thus acting, we want to figure out whether Echo is purely artificial or if it captures at least some aspects of what is going on in the real world. Despite its simplicity, Echo is already so complex that a pure analytical approach is out of reach. Thus, we have followed an experimental approach, designing Echo worlds simply to see what happens.

First, we want to know what happens in an Echo world where an initially lonesome agent, with no pre-designed behavior is injected in the environment and the laws of the Echo world act on it. We have then the ability to "replay the band" many times and figure out whether the evolution is strongly deterministic or if different classes of scenarios happen over many runs, or if the evolution is basically unpredictible.

Then, we will try to pre-design agents (that is, their genome) to simulate the well-known processes based on co-evolution and co-adaptation of species as observed in nature.

## 3.1 The origin of life

To achieve our first objective, different issues are important:

- to have a viable population. Thus, the environment has to produce resources in amounts which are compatible with the size of the expected population. Agents have to be able to exploit these resources,

- to have a production of resources in the world in equal proportion for the 4 types of resources,

- to have agents with an initial chromosome with no predefined behavior. The behaviors present in the population evolve spontaneously along time,

- to allow the (genetic) diversity to appear in order that the selection acts and produces its effect.

Basically, the initial population contains only one agent. This agent can gather resources in the environment and its genotype prevents it from interacting with agents having the same genotype. Then, the following bootstrap scenario is expected:

1. the initial agent feeds on the environment and accumulates resources in its reservoir,

2. after a while, it is able to self-reproduce (and does it),

3. due to mutation, the new agent is slightly different from the initial one, thus leading to genotypic diversity, thus to diversity in behaviors present in the population,

4. this diversity makes interactions possible between agents.

### 3.1.1 Experimental observations

Over many runs, the evolution of the population has been rather robust. Population increases at an exponential rate as long as there are enough resources to feed all agents, according to the well-known Malthus' law in population dynamics. Then, the population reaches a threshold because of the limitation of available resources present in the environment in accord with Verhulst's law. In the same time, due to mutations, some agents become able to interact each other. Three types of phasis appear:

**instability period** characterized by combat interactions. There is no well adapted genotype for a long period of cycles,

**stability period** mainly characterized by trading and mating interactions. There is a well adapted genotype for a long period of cycles,

**non interacting period** where no interaction happens at all.

A very important fact with regards to the evolution is that, starting out from one agent, different types of agents appear. These agents evolve different types of behaviors. These types of agents co-adapt along time eventually yielding a state of equilibrium which is not an obvious equilibrium where all the agents are the same, but where different types of agents have auto-organized

their evolution and their activities. Thus, a differentiation between agents have evolved, eventually leading the original simple type of agent to speciate and create different species thus creating an ecology of agents. We want to emphasize here that the use of the word "species" is misleading. If the term is quite well defined when high order organisms are considered (two organisms belong to the same species if they can produce viable offsprings together), it becomes far less clear when more primitive organisms are considered. At this level, organisms which are normally unable to reproduce together might produce viable offsprings in some situations. We will not develop further this issue here and we will use the term "species" with a very loose meaning, as a synonym of type. As already said, agents in ECHO are very simple, much closer to very primitive organisms (for which the "species" are not well defined) than from high order organisms.

Five types of behavior have appeared during the simulations:

**inconditional predation** where an agent attacks all the agents it meets. Inconditional predators are not viable for a long period of time because they finally kill each others. Their population increases and, after a while, interact between themselves and disappear,

**conditional predation** where agents have all types of interaction (combat, trade, and mate). They may kill each others but they are more viable than inconditional predators because they are less aggressive,

**dupery** where an agent lets the other agents attack it but, very often wins the combat interaction. So, an agent having a behavior of dupery appear as an easy prey but is finally very hard to beat by other agents,

**prey** where an agent gets killed in a combat interaction,

**peaceful** where an agent has no hability to fight but has a large capacity to trade or to mate.

It should be emphasized that we speak of "types of behavior" rather than "types of agents" because a given agent is generally able to show one behavior in a situation, and an other one in an other context. That is, the behavior of an agent depends on the agent it interacts with.

The great majority of simulations have shown the emergence of a symbiosis between predators and peaceful agents. During an instability period, the fittest predator develops its genotype along its lineage and eats all the preys. In the same time, peaceful agents appear and reproduce themselves rapidly because their genotypes are

shorter than the genotype of the predators. As there are less and less preys, the population of predators decreases. However, some of them are able to trade with peaceful agents and survive.

### 3.1.2 Discussion

In most of our experiments, after a transient phasis, a state of equilibrium is reached where different types of agents live in symbiosis. The state of equilibrium eventually yield an unstable phasis which ends-up with an other stable phasis. Thus, cycles of stable/unstable phasis are observed. Stable phasis are characterized by the existence of fit agents as opposed to unstable phasis.

During instable phasis the offense tag and the defense tag (mainly responsible for the behavior in a situation of combat) are getting longer and longer, creating a situation of "biological arms race". Stable phasis are characterized by short chromosomes. Short chromosomes have the ability to self-reproduce easier than the long chromosomes of the unstable phasis.

It is striking that this alternance of stable/unstable phasis is commonly observed in dynamical systems. Stable phasis corresponds to moments when the system is in an attractor. After a while, perturbations have accumulated to a point such that the system leaves the attractor leading to an unstable phasis during which the system wanders before falling into an other basin of attraction and reaching an other attractor at which point a new stable phasis begins.

## 4 The simulation of natural situations of co-adaptation

ECHO naturally yield lots of images related to phenomena that are encountered in nature. So, it is very appealing to try to evolve behaviors that more or less simulate natural situations of co-adaptation. In this section, we first experiment the simulation of food chains which are a generalization of prey/predator relationship. Then, we study the simulation of parasitism. We finally tackle situations of batesian mimicry.

### 4.1 Food chains

Food chains appear among species (or sets of species) where there is a partial order based on the relation "eaten by". Some species are preys, others are predators, most are both, depending on the point of view. A simple example is the one of plants, herbivores, and carnivores.

We define three species of agents (see fig. 5):

**plants** which feed exclusively on the resources provided by the environment. All the bits of their uptake mask are set,

**herbivores** feed exclusively on plants. All the bits of their uptake mask are reset thus preventing them from feeding from resources produced by sites directly. Their combat condition is prefix of the plant offense tag so that they can "eat" plants: when a herbivore comes close to a plant, a combat occurs from which the herbivore is always the winner,

**carnivores** feed exclusively on herbivores. All the bits of their uptake mask are reset. Their combat condition is prefix of the herbivore offense tag so that when a carnivore interacts with a herbivore, it always kills it and acquires its resources.
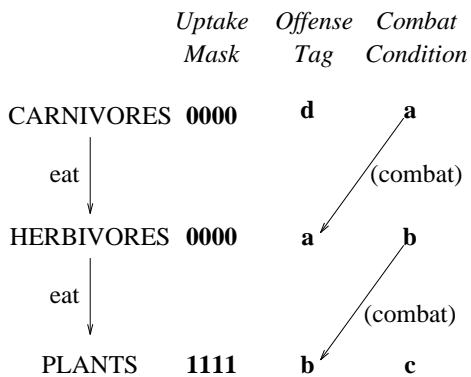


Figure 5: Food modelling chain.

In the real world, preys are more numerous than predators because to produce an offspring a predator must eat many preys.

Simulations have been performed in a world composed of sites producing 100 resources of each type per cycle. For 2 link chains, initial populations are made of 500 preys, and 50 predators. For 3 link chains, the population of plants is initially set to 1000, herbivores to 100 and carnivores to 50. The probability of interaction when two agents get close to each other is set to 0.1.

The mutation and the sexual reproduction between agents have been forbidden in order to maintain the different species of agents. Otherwise, the different types are mixing, ending with a simulation which has nothing to do with food chains.

During simulations, the population of the different species increases to reach a state of equilibrium (see fig.

6). When stability is reached, the size of the population is related to the production of resources by the environment. Food chains with 2 links have been much easier to obtain than chains with 3 links.
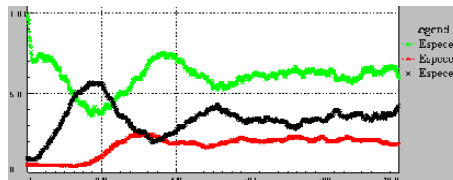


Figure 6: Food chain simulation. The populations of the 3 species are plotted. The upper-most curve is the population of plants. The plot in the middle is the population of herbivores. The lower-most plot is the population of carnivores. After a transient phasis, the 3 populations remain stable.

## 4.2   Parasitism

Parasitism is a kind of prey/predator relationship. The most important difference lies in the fact that in the situation of parasitism, a parasite takes advantage of a host, without trying to kill it. The parasite might kill its host if this provides it some advantage, for example, when the host is no longer useful, or when this helps in spreading the parasite in the environment.

Simulations have been done by defining two species of agents. Parasitism is simulated using the trading interaction (see fig. 7). The hosts and parasites are defined along the following lines:

**host** feeds on the resources found in the environment. The bits of their uptake mask are all set. Their trading condition is prefix of the parasite offense tag. This way, hosts can feed the parasites.

**parasite** feeds exclusively on hosts. The bits of their uptake mask that correspond to the host trading resource and their own bits of trading resource are reset. Thus, parasites have to get their resources from hosts and parasites can not feed the hosts. To allow the trading with hosts, their trading condition is prefix of hosts offense tag.

Simulations have been done with initial populations of 100 parasites and 50 hosts. Miscalleneous adjustments with regards to the production of resources have been done in order that parasites can be fed by their hosts. It is more difficult to obtain a successful simulation of

parasitism than food chains. Experiments have not been successful before a certain amount of tuning was done (see fig. 8).

Again, mutation and sexual reproduction between agents have been forbidden in order to maintain the different species of agents.
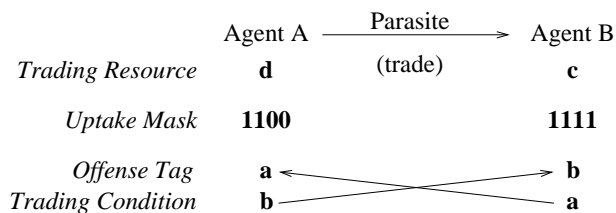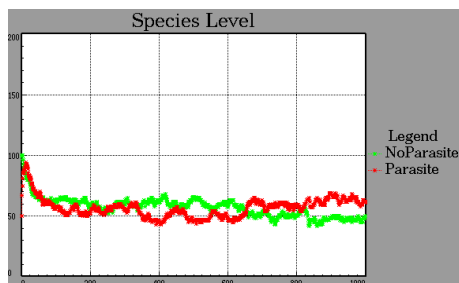
|  | Agent A | Parasite (trade) | Agent B |
|---|---|---|---|
| Trading Resource | d | → | c |
| Uptake Mask | 1100 | | 1111 |
| Offense Tag | a | | b |
| Trading Condition | b | | a |

Figure 7: Parasitism modelling.



Figure 8: A simulation of parasitism. The 2 curves show the population of parasites and hosts are plotted. After a while, a state of equilibrium is reached.
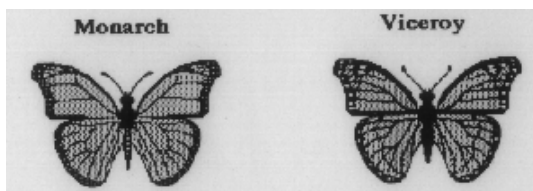
## 4.3  Batesian mimicry



Figure 9: An example of batesian mimicry.

The situation of Batesian mimicry involves three agents: a model, a mime, and a dupe. The mime is normally exploited by the dupe while the model is not; however, mimicing the model, the mime gets a selective advantage as long as the dupe is duped. The mime mimics the model with regards to its phenotype. For example, in the case of the well-known viceroy/monarch butterflies mimicry, monarchs show the same pattern on their wings as viceroys (see fig. 9). Monarchs are repulsive for birds which, once taught, do not eat monarchs because of their taste. Thus, viceroys which have the same wing pattern have a selective advantage since birds do not eat them because they misregard them as being monarchs. Furthermore, the fact that viceroys look like monarchs is an advantage as long as the number of viceroys is relatively low with regards to the number of monarchs. Otherwise, the probability for a bird to accidentally eat a viceroy increases and it will eat viceroys and monarchs (by error) which will make the population of viceroys (and of monarchs) decrease. At this moment, monarchs which are different from the basic monarch get a selective advantage because the birds learn to avoid them. At this stage, the viceroys are no longer protected by their mimicry to the previous form of monarchs. Thus, viceroys which look like this new form are favored by the selection. This whole process leads to some form of regression, the mime looking like the model being first selected, their growing number leading to a disadvantage after some times, the model changing its aspect, the mime looking like this new model being advantaged again.

### 4.3.1  Experimental setup

Explicit learning is not possible in ECHO: an agent can not learn something. The fact that a bird learns to avoid viceroys had to be simulated by the removal of both the agents bird and monarch from the simulation[2]. Thus, birds which have the genotype to avoid interacting with viceroys are advantaged.

To differentiate 3 species, we associate a unique resource to each species of which the chromosome is composed in its whole. Thus, birds chromosome is made of 'a', viceroys of 'b', and monarches of 'c'. The only exception to this rule aims at allowing prey/predator relationship between birds and butterflies (otherwise, agents would not be able to interact at all between them). For that, only the first nucleotide of the offense tag can be different; this defines different types of each species. By convention, we simulate mimicry by the fact that two agents have the same offense tag. So, viceroys which mimics monarches have their first nucleotide of their offsense tag identical. There are also viceroys which first nucleotide of the offense tag is different: these ones do not mimic monarches (see fig. 10). This way, birds can recognize butterflies.

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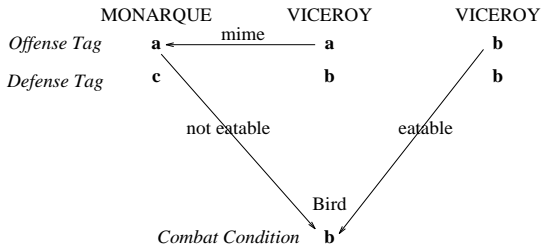[2]ECHO had to be modified in order to act like that.

8

Figure 10: Modelling mimicry.

To keep the distinction clear during the simulation between the 3 species, crossover is disabled (thus, no mate interaction happens) and mutation is restricted to the first nucleotide of offense tags.

In our simulation, birds have to feed on viceroys. So, the bits of their uptake mask are reset and their combat condition is matching the viceroy offense tag.

Simulations where performed in a world of $10 \times 10$ sites. The initial population is made of 3297 viceroys equally distributed in the three types 'a', 'b', and 'c', 120 birds and 128 monarches which discriminating letter is 'd'. Mutation probability was set to 0.2 and the probabilty of interaction when two agents meet is set to 0.1.

### 4.3.2 Results

A successful simulation has been difficult to obtain: many runs where performed, very few leading to a satisfying evolution however restricted to only a short period of time. However, we were able to observe the following facts:

- viceroys which mimic the monarchs are favored by selection (see fig. 11(a)),

- when the population of mimes gets too numerous with regards to the population of monarchs, mimicry does not provide a selective advantage any longer. The model itself suffer from this excess of mimes (see fig. 11(b)).

The problem encountered here is to have an evolution that fits what we want to simulate, mimicry. We have already put several limitations to the possible evolutions of the agents. Clearly, this was not enough yet.

## 5 Conclusion and discussion

In this paper, we have presented experimentations we have performed with the Echo software which imple-
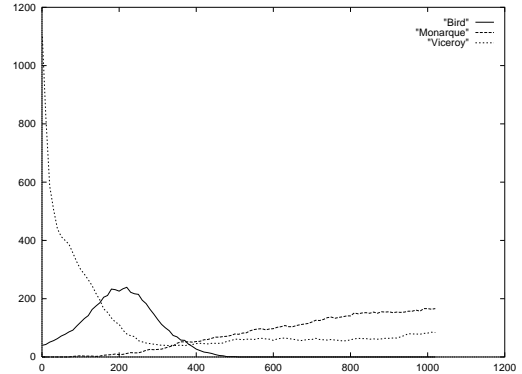


(a) Viceroys considered here are not mime. Thus, their population decreases very fast being eaten by birds.
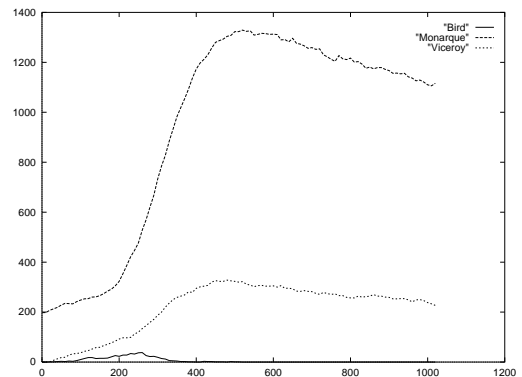


(b) Viceroys considered here are mimicing monarches. Thus, their number is increasing though always remaining much smaller than the population of monarches.

Figure 11: Populations of birds, viceroys, and monarches along the time.

ments some of the ideas of John Holland. We have followed two paths: first, we want to figure out the intrinsic dynamics of ECHO; second, we want to simulate situations of co-adaptation that appear in nature. Along the first line, we obtain a rather robust dynamics where five types of behavior appear and cycles of stable/unstable phasis are observed. Along the second line, the simulation of food chains, parasitism and mimicry have been studied. The probability to simulate a certain situation is getting lower and lower as the complexity of the situation increases. Food chains with 3 links is more difficult to obtain than 2 links chains; mimicry is obtained only during a short number of generations.

This approach has to be criticized in several respects.

First, successful simulations are difficult to obtain because the way a certain set of agents can evolve in ECHO is broad and the evolution that is sought is not the one being the most probable in ECHO.

Second, the agents we deal with in ECHO are simulations of very primitive organisms (far more primitive than the most primitive organism living today which genome counts a few thousands – interacting – genes). With these agents, we wish to simulate the behavior of living organisms which complexity has nothing in common.

Third, in all 3 simulations of natural mechanisms, we have been compelled to forbid, either totally or in a large proportion, the evolution of genomes in order to have stable species over time. Again, this has to do with the simplicity of the ECHO model with regards to the natural situation we want to simulate. In nature, there is no risk that a bird and a butterfly mate, or even that a monarch and a viceroy mate.

Fourth, being so far away from the original situation drawn from nature, we have to question the relevancy of what has been simulated with regards to the process we want to simulate.

However, this approach can be defended as a way to demonstrate that adaptation via selection can produce certain mechanisms observed in nature (such as those we have simulated here). This is of particular importance for certain scientists, such as behavioral psychologists who want to show, among other things, that the capacities of the human brain are the natural consequences of the laws of Darwinian evolution [S77]. So, in this regard, the fact that natural selection can produce at least once out of a whole many times a certain mechanism is worthwhile.

To the opposite, we think that the approach consisting in putting as less as possible pre-defined material at the beginning of the simulations, let the laws defining the simulator act, then observe and analyze what is produced is much more interesting. According to the experiments we have reported here, we know that selection mechanisms already yield a complex evolution of the system in this very simple context. This approach is then much more suited to the study of adaptation than the other tasks we discussed here if we want to make a general study of adaptation by selection.

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