

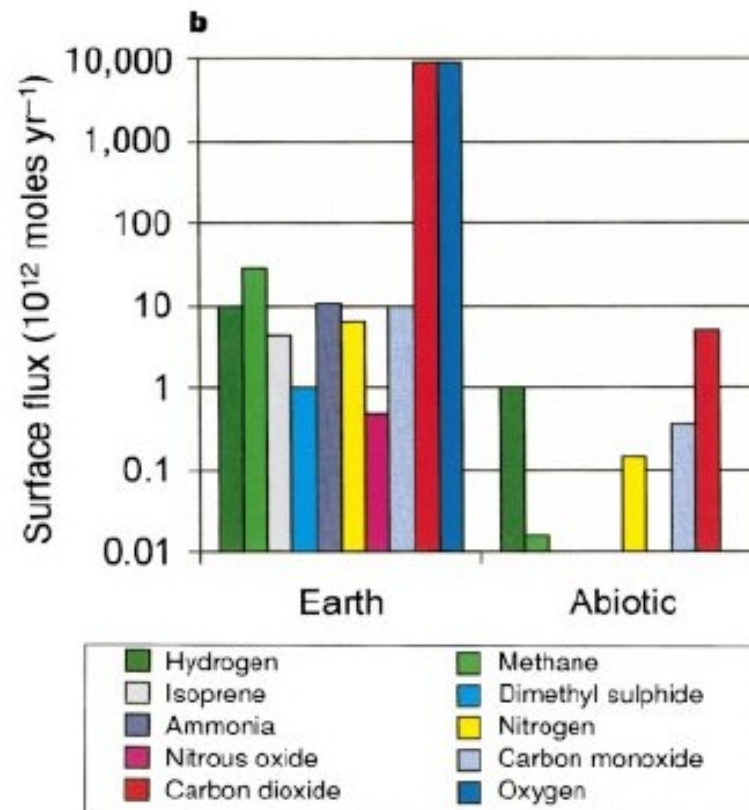
Speciation models & Stability emersion

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In the last century there has been a change in the interpretation of evolutive dynamics:

Before: the environment is stable, the species are adapting to it

Now: the species are adapting to the environment but their activity **alter the environment** homeostatic equilibrium



Now there is well documented empirical evidence of negative feedback system, able to maintain important parameters like temperature, frequency of precipitations, sea salinity and acidity, concentration of gas in the sea and in the atmosphere, etc.

The effect of these feedback is to **maintain in life-permitting ranges the controlled parameters.**

Box 1 Daisyworld: self-regulation without teleology

Daisyworld^{20,21} is an imaginary grey world orbiting, at a similar distance to the Earth, a star, like our Sun, which gets warmer with time. The world is seeded with two types of life, black and white daisies. These share the same optimum temperature for growth, 22.5°C, and limits to growth of 5°C and 40°C.

Initial conditions on the planet are so cold that daisy seeds cannot germinate. As solar forcing increases and the temperature reaches 5°C, the first seeds germinate. The paleness of the white daisies means that they are cooler than their surroundings, hindering their own growth. The

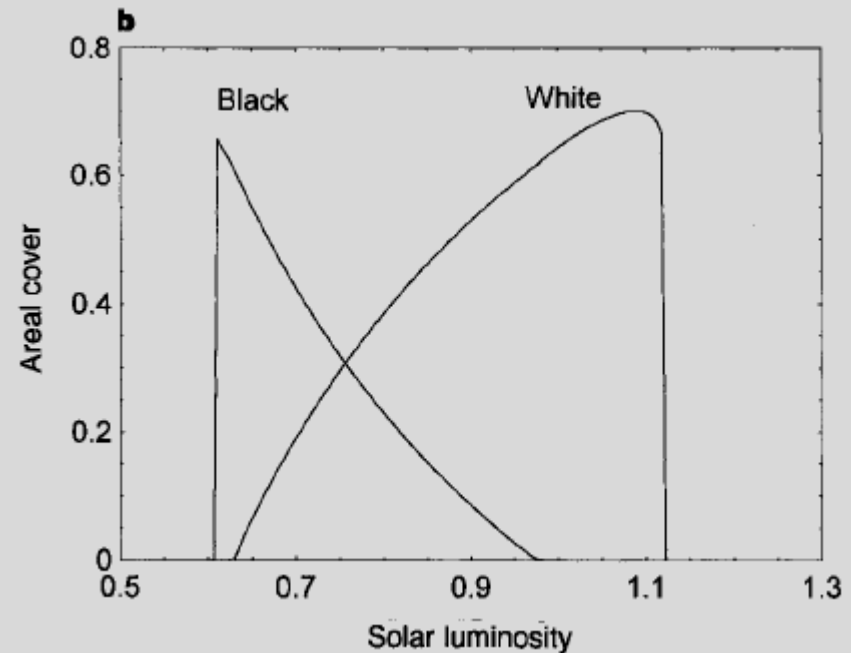
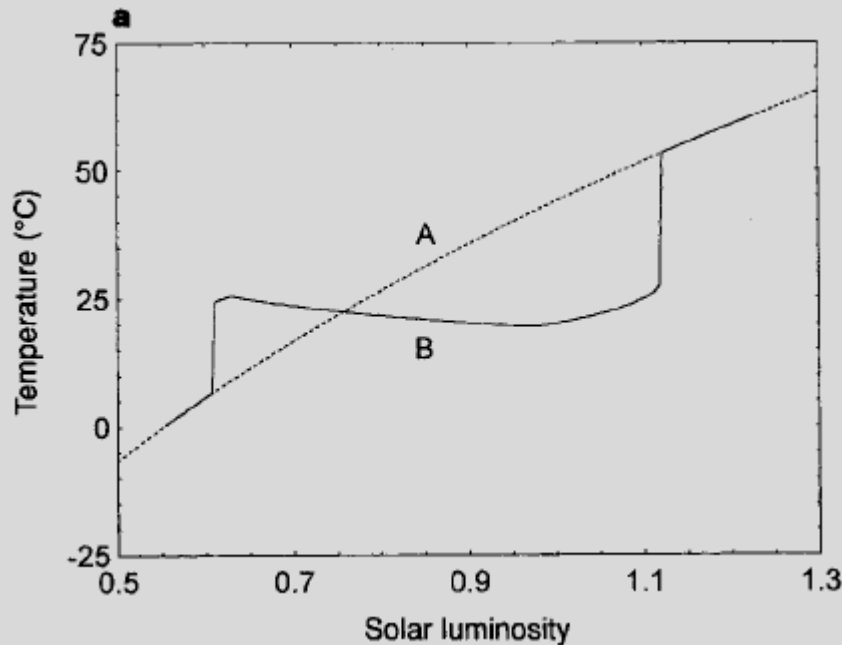
black daisies, in contrast, warm their surroundings, enhancing their growth and reproduction. Hence black daisies come to dominate the initial community (see figure).

As they spread, the black daisies begin to warm the planet. This increases the growth rate of all daisies, an environmental positive feedback that reinforces the spread of life. As the warmer, darker daisies are closer to the optimum temperature than the white daisies, they remain dominant. Soon the limited area of planet surface constrains the explosion of life. When daisies fill the world, the average temperature has risen close to the

optimum for daisy growth.

As the sun warms, the temperature rises to the point at which white daisies begin to appear in the daisy community. As it warms further the white daisies gain the selective advantage over the black daisies and gradually take over. Eventually, only white daisies are left, and when the solar forcing gets too high, self-regulation collapses.

The self-regulation of Daisyworld is impressive: although the solar input changes over a range equivalent to 45°C the surface of the planet is maintained within a few degrees of the optimum temperature for daisy growth.



There are a lot of daisyworld model variation, but a model that show not only that autoregulation is possible, but the dynamics of negative feedback formation, starting from the speciation, is missing.

But what's a species?

"I was much struck how entirely vague and arbitrary is the distinction between species and varieties" Darwin

"No term is more difficult to define than '*species*', and on no point are zoologists more divided than as to what should be understood by this word" Nicholson

We will define species as a population of agents whose genotypes form a **cluster in the** (further defined) **genetic space.**

In order to obtain a model with emersion of feedback, we need to include a **model of speciation**, as the species are the element that form such interactions.

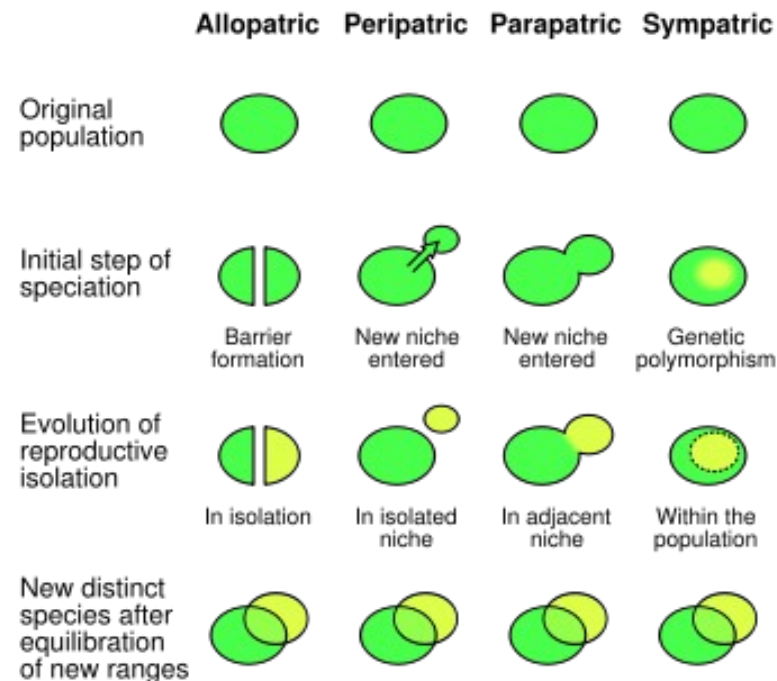
The hypothesis is that there is a selective pressure acting against or in favour of each speciation phenomena, depending on the effect of the new capabilities on the existing system:

-a **local effect** depending on simple competition with the other agents

-and a **non-local effect** from the perturbation of the homeostatic equilibrium and formation of feedbacks

Speciation

Speciation is the evolutionary process by which new biological species arise. There are four modes of natural speciation, based on the extent to which speciating populations are geographically isolated from one another: **allopatric**, **peripatric**, **parapatric**, and **sympatric**.



In order to permit the hypothesized selections of the existing system against or in favour the speciation phenomena we need to implement a **sympatric speciation model**.

There is a lot of debate about the existence of speciation without a geographical isolation (sympatric), but in 1966 Maynard Smith proved the plausibility of such mechanism and now well documented empirical evidence exists

One example of sympatric speciation is the case of *Microtus savii* speciation, a small rodent whose geographical distribution is limited to a large part of Italian peninsula and Sicily, studied in 2003 by Galleni et al.

A chromosome investigation carried out in *M.savii* from central Italy and from Calabria showed different amount of heterochromatin in the sex chromosomes, from crosses hybrids were formed but no offspring at all was obtained from the crosses between hybrids

An artificial life simulation was presented where a mixed population of agent of two species are capable to move in a bidimensional space, they compete for limited resources and when a pair of agents of different sex are near they can produce an offspring, generating a sterile hybrid if the two parents agents aren't of the same species.

The result of simulations is the emersion of **monopopulation areas separated by contact zones populated by hybrids**. The effect of the hybrids is to **stabilize** the presence of the two similar population in the same niche.

This simulation model show that there exists possible mechanisms that permit the coexistence of similar populations in the same niche, a situation needed for the sympatric speciation.

But it's not enough, we need a model that enable **not only the maintainment** of such diversity for the time necessary to form full different species, but that **permit the subpopulation formation**.

We developed a simulation model of speciation based on agent interactions.

A 2-dimensional **geographical space**.

A 2-dimensional **genetic space**.

An **agents** population: each agent is characterized by geographical position, genetic position, **energy** level.

Initially, every agent has the same genetic position and they are randomly placed in the geographical space.

A **fitness function** is defined on the genetic space such that 2 different direction of mutation are fitness increasing in the genetic space from the common starting genetic position

An iteration of the simulation consists of:

1 each agent make a **random direction small movement** on the geographical space.

2 a fixed amount of resources are randomly placed in the geographical space, every near agent can **compete** for it, the competition success is based on the fitness values; the agent that win get a fixed increment of energy level, then the resource is removed.

3 each agent get a fixed **decrement of energy** level; if the level is negative the agent die and is removed.

4 each agent with energy level over a fixed amount is enabled to mate: a couple of near agent enabled can **mate**, decreasing their energy levels a fixed amount and **generate a third agent**; the newborn has genetic and geographical position the mean point of his parents ones and a fixed energy level. The genetic position of the newborn make a **random direction small movement on the genetic space**.

Such a simulation model has a **local selection**: the selection pressure is determined by the nearby agents, there is not affect from the distant agents until they randomly moving gets near.

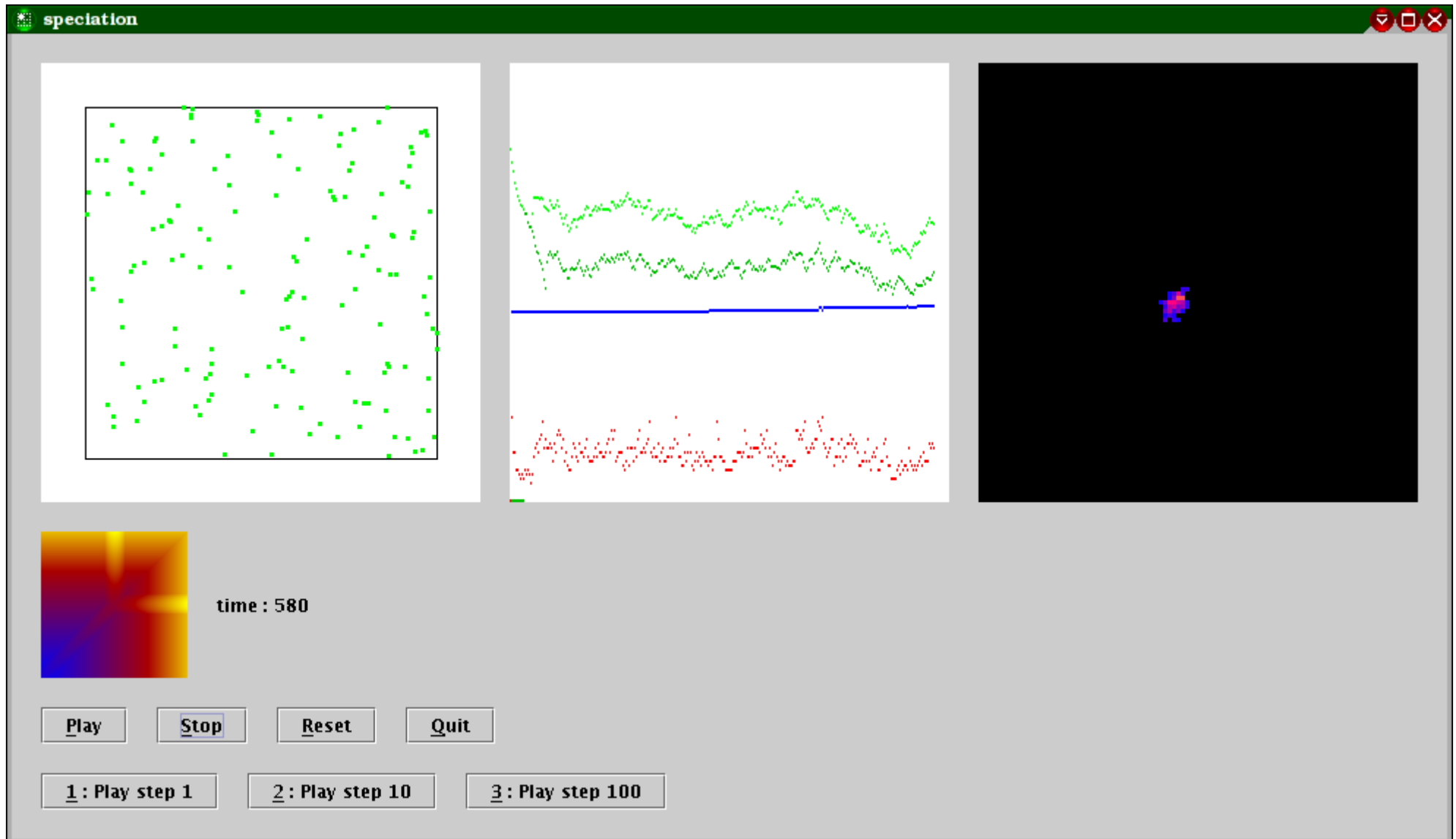
In this simulation the **speciation can occur** on some parameter ranges: if the geographical space is large compared to the movement capability of agents, in different far areas different direction of speciation are possible, but when the genetically different population comes in contact **the situation become unstable and only one population will survive the competition.**

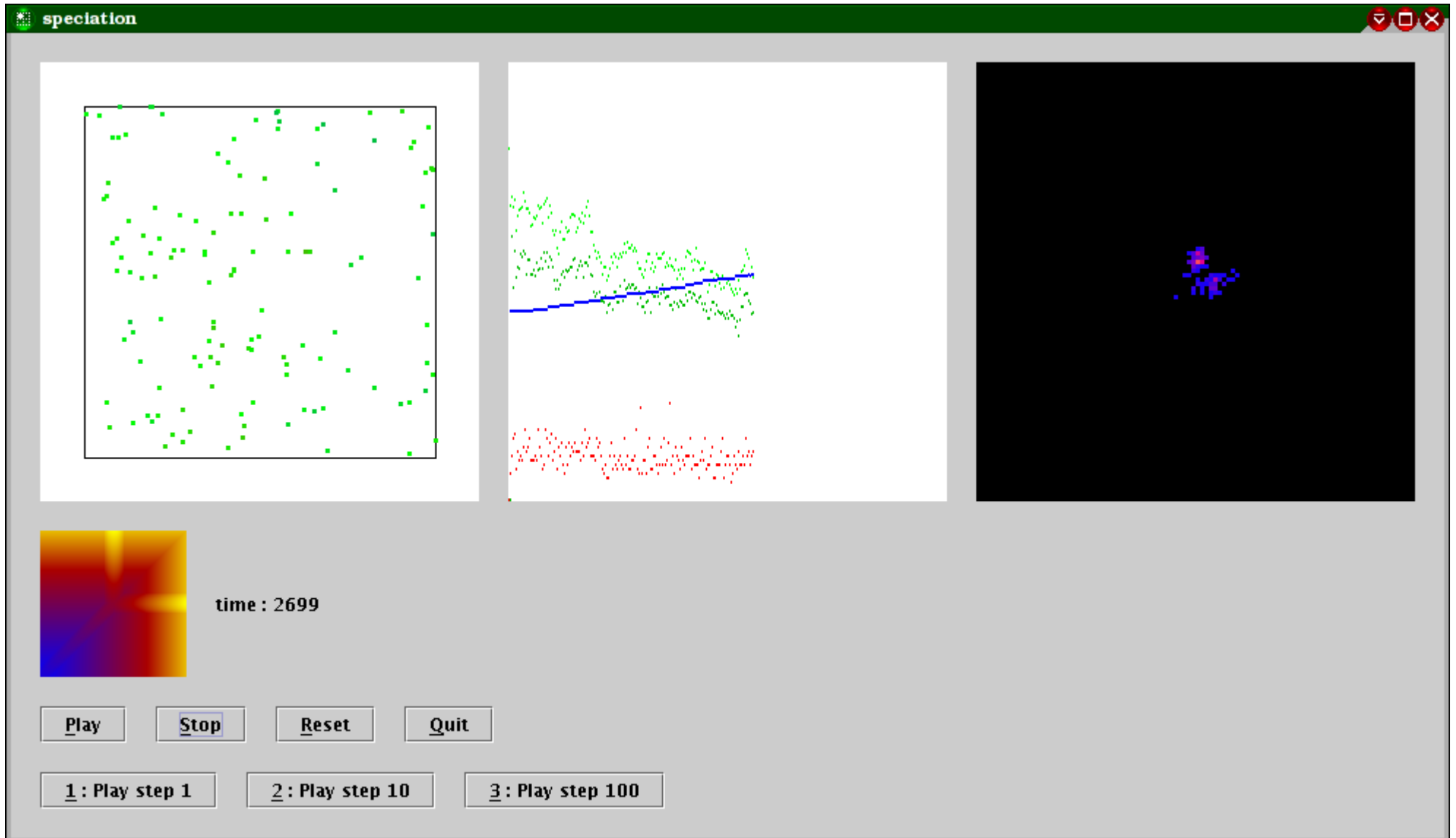
We can add a simple **diversity maintaining element** based on biological observations: a **variable fertility** based on the **genetic distance** between the parents.

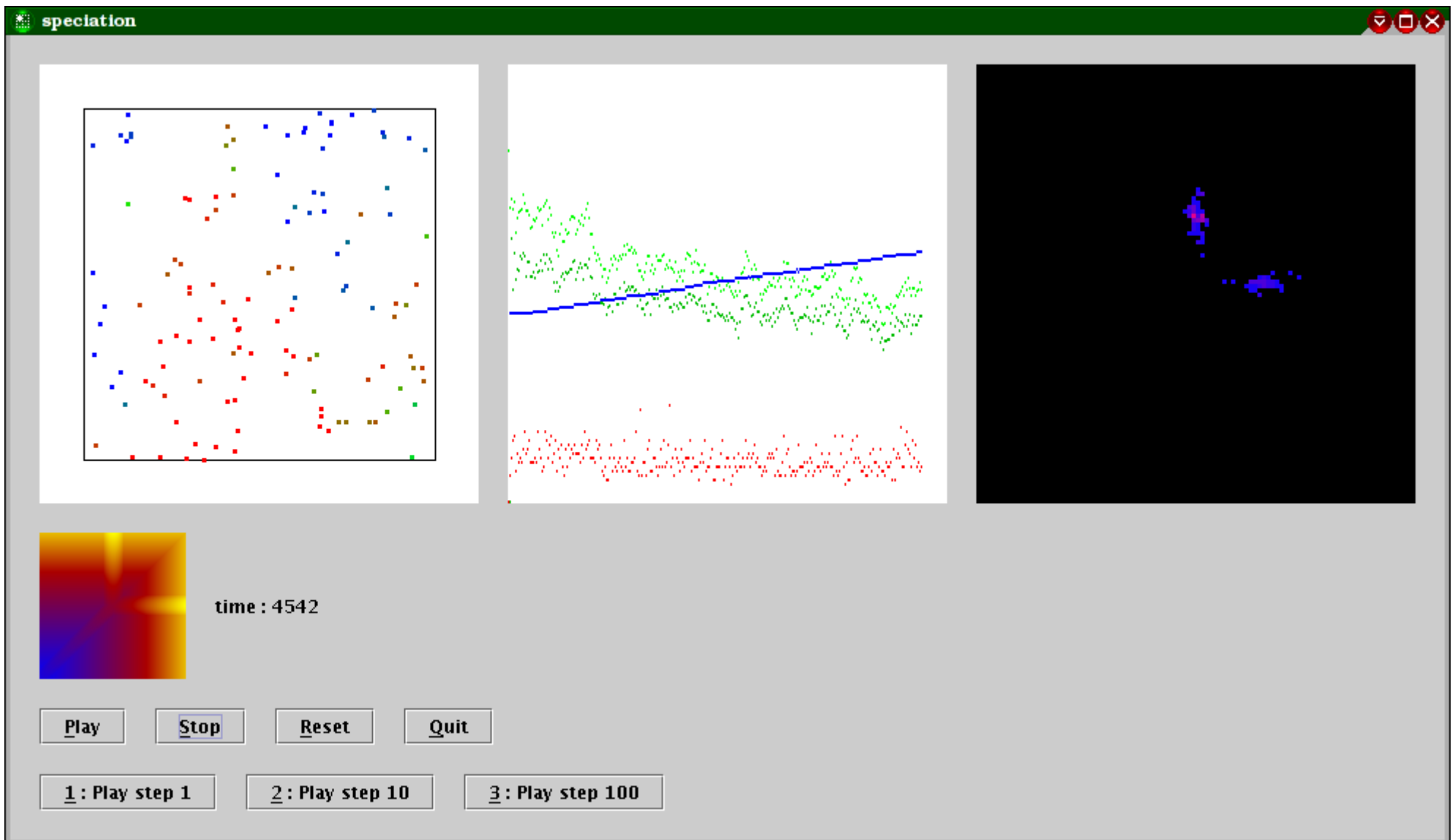
We **abort** the newborn of every mating couple with a probability **proportional to the distance in the genetic space** of the parents.

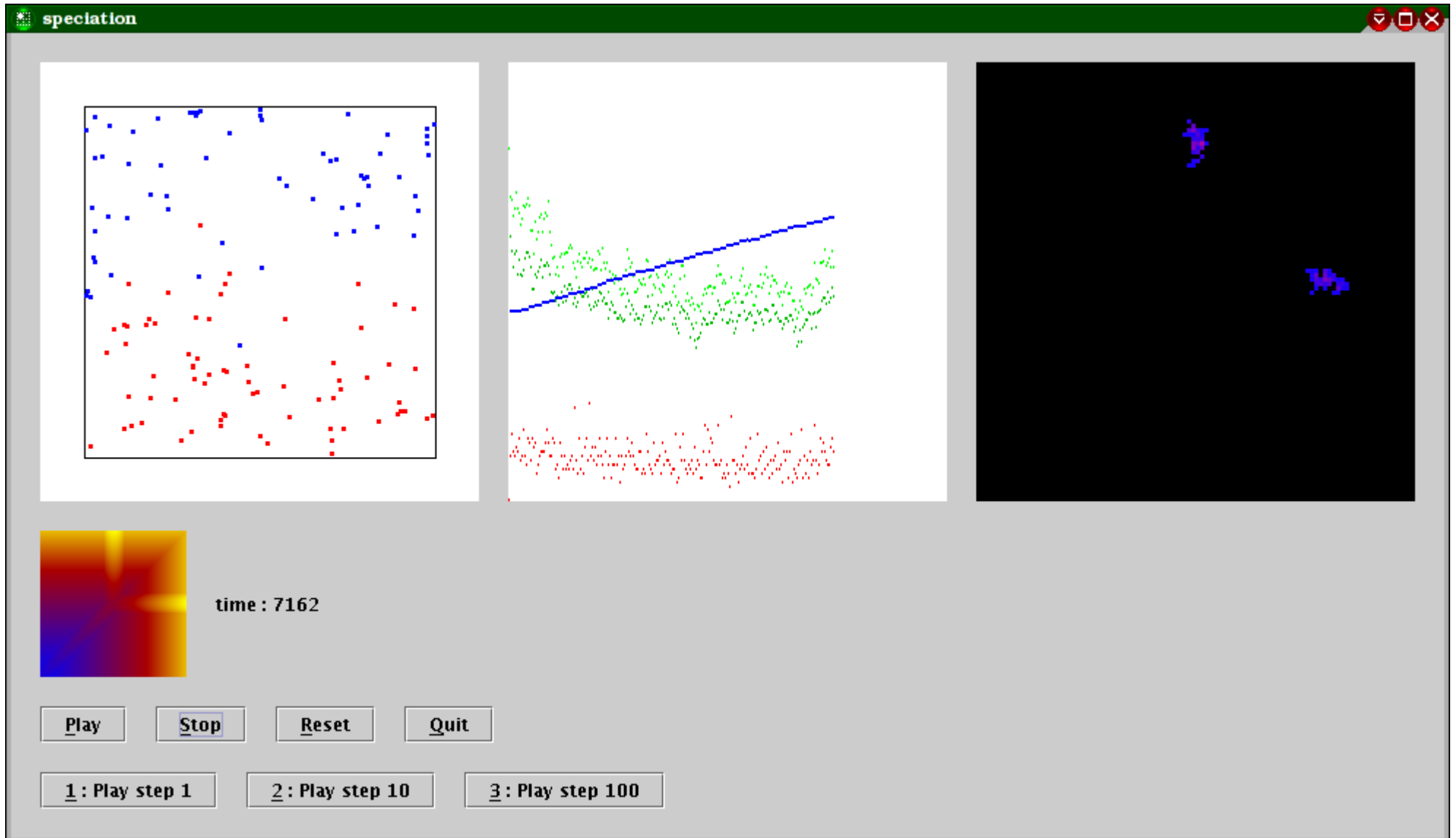
In the simulation now the speciation can occur in a lot wider parameter selection and the agents distribution is based on **monopopulation areas with a good stability** in time.

starting situation









This models only an **initial phase** of a complete speciations, in the final model the agents subpopulation need to be able to **change their capability** and eventually they will no longer compete for the same resources, sharing a common geographical mixed-populated area.

In order to obtain feedback emersion **the agents needs to alter the environment** they live in.
So, first, we need an environment.

We can obtain an environment in **homeostatic equilibrium** in a simple way:

We fix a number of different **resource classes**.

For every class we define an **energy value** $[0, 1]$ and a number of possible **spontaneous transformations** (for example, $A \rightarrow B$, $A \rightarrow D$, $A \rightarrow 2F$, $A \rightarrow \text{null}$) and spontaneous transformation **rates** (quite low), such that every transformation decrease the total energy.

An iteration of the simulation consists of:

1 fixed (integer) increase of one or more resources class.

2 for each single resource of each resource class we stochastically check the transformation rates and eventually **apply the transformation.**

After an amount of iterations determined by the parameters the system, in the absence of '*accumulation*' resource classes without degradation to null, the levels of each resource class reaches an **homeostatic equilibrium.**

Now we have to insert in such a system the **agents**.

An agent now become a **container of resources** with membrane **pumps** and **enzymes**.

A **membrane pump** is **specific for a resource class**, it can pumps **inside or outside** the agent with an **intensity**.

In absence of membrane pumps the resource concentrations inside the agent will be **similar to the outside concentrations**, when there is a pump the fluxs are altered.

An **enzyme** is **specific for a resource transformation**, an enzyme has an **efficiency** and an **intensity**.

In absence of enzymes the resources in an agent are **subjected only to spontaneous transformation** as are the resources outside any agent.

But if an enzyme is active the internal resource are **subjected to the enzymatic transformation** with a **rate** depending on the enzyme intensity.

The enzyme **efficiency** specify **how many energy is wasted**: for every enzymatic transformation executed the energy level of the agent is **incremented** by the difference between the starting resource/s and the producted one/s, minus the efficiency value.

The **genetic space** become now quite complex: it have to define all the agents pumps and anzymes, additionally it needs to be structurated to enable mutations and **recombination**.

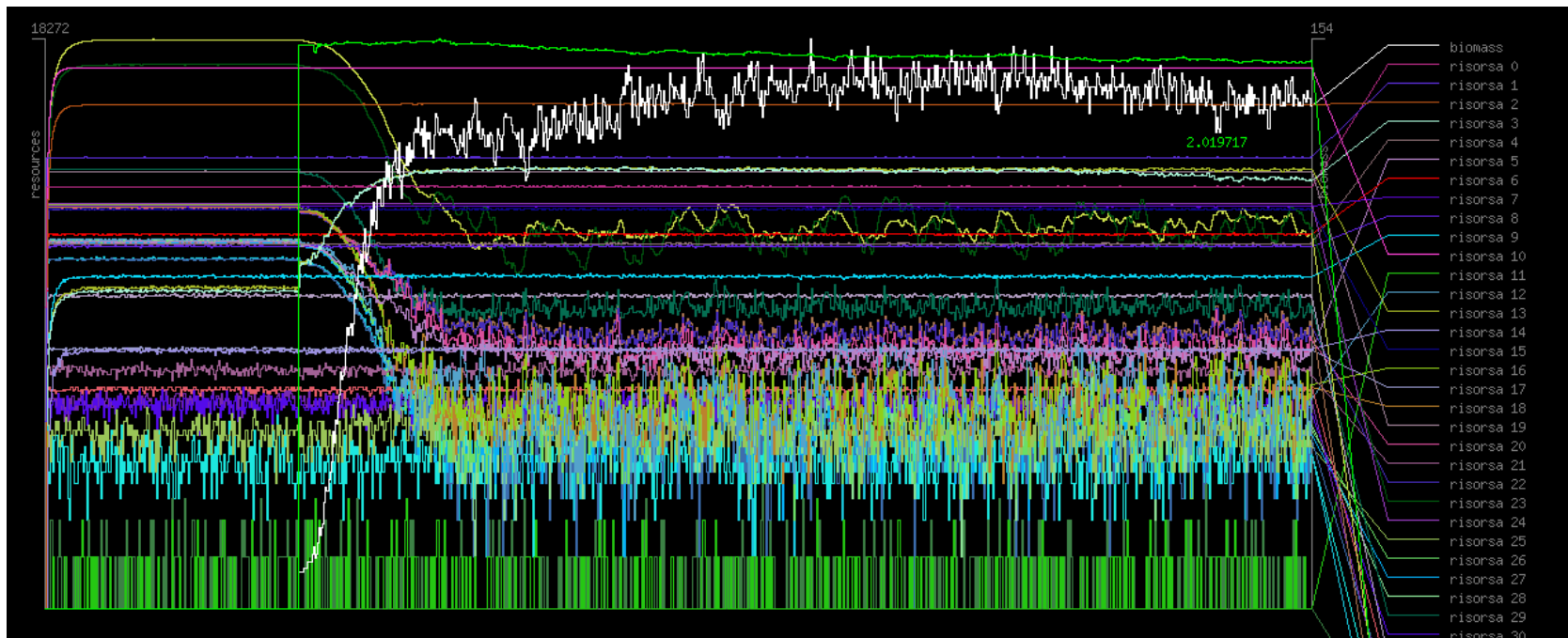
This complexity arise the problem to **define a distance measure for the variable fertility**.

Additionaly, we have to **place resource in the space**. In oreder to reduce computational costs we chose to approximate the single resource position and movement **dividing the space in areas**, with the resource aviabile to every agent inside such an area, and a dynamic of resource diffusion between adjacent areas.

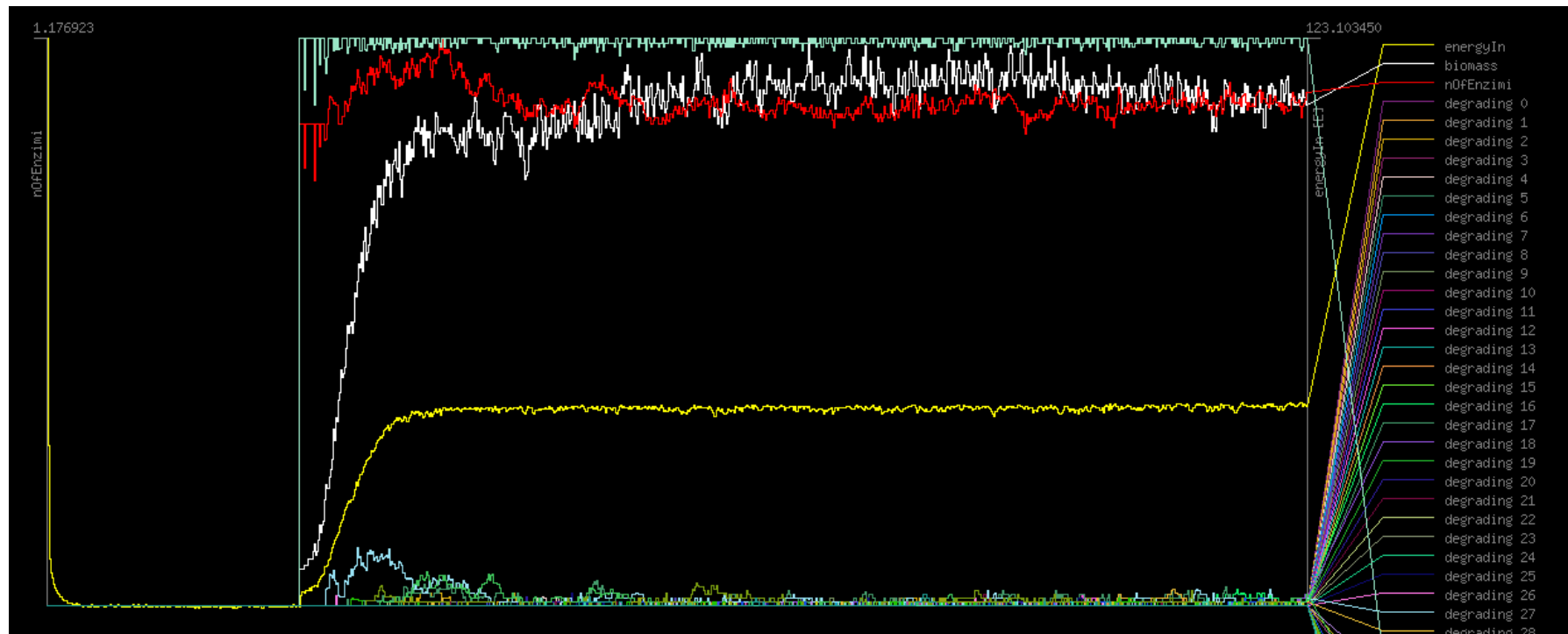
An iteration of the simulation now is:

- 1** each agent make a **random direction small movement** on the geographical space.
- 2** the resource **irradiation, spontaneous transformations and diffusion** is computed for every resource area.
- 3** the resources inside every agent are modified based on his **pumps** and the difference of resource concentration inside and outside the agent.
- 4** the **enzymatic transformations** are computed.
- 5** each agent get a **decrement of energy level** depending on the **number and intensity of his pumps and enzymes**; if the level is negative the agent die and is removed.
- 6** each agent with energy level over a fixed amount is enabled to **mate**: a couple of near agent enabled can mate, decreasing their energy levels a fixed amount and generate a third agent; the newborn has geographical position the mean point of his parents ones, a **genetic point obtained from recombination** of his parents genetic points and a fixed energy level. The **genetic position of the newborn gets a random mutation**. The newborn is **aborted with a probability proportional to the the genetic distance of the parents**.

This simulation need to be agentless for some iteration in order to **reaches an homeostatic equilibrium**, then the dynamic depend on the starting agent population (they need at least one energy-producer enzyme).



The dynamic early show an **alteration of the homeostatic equilibrium**, a **development of pumps** to enhance the needed resources flux and to decrease the poison-effect of too many internal not usefull resources.

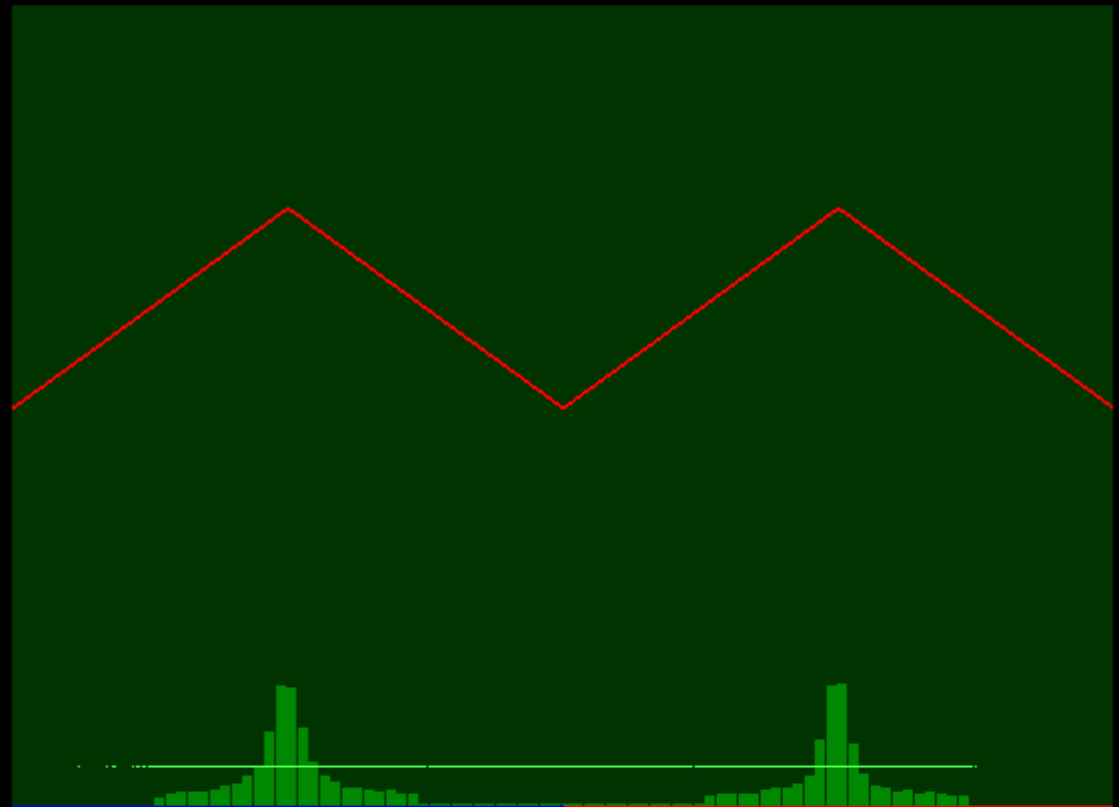
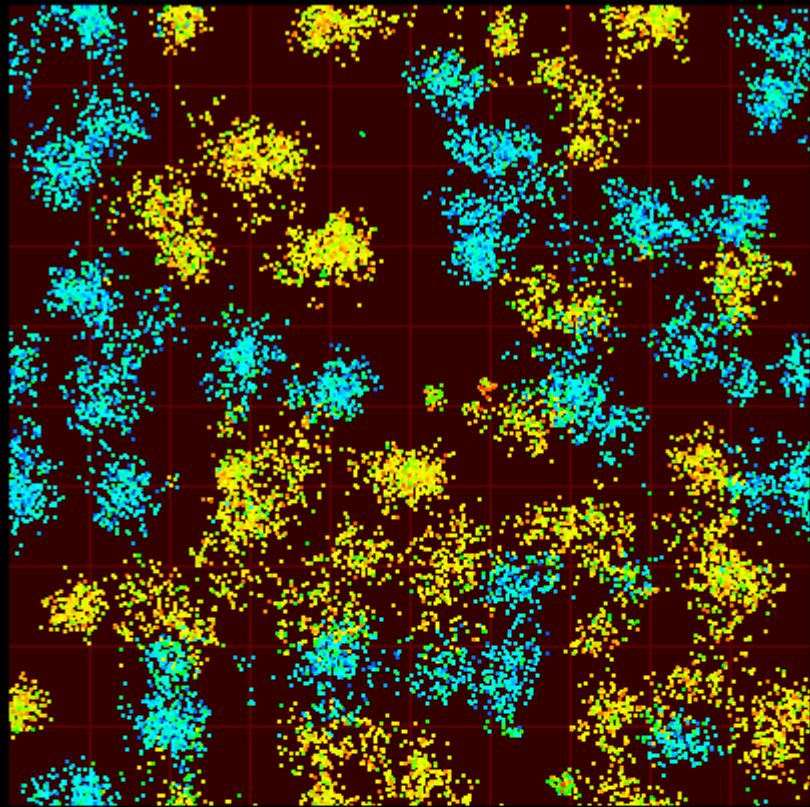


Then **new enzyme creation** events can occur: there will be agents with 2 or more enzymes but then they will find that not only the cost to maintain too much enzyme is high, but that if they have **a lot of different resource classes needed**, then they are **unable to specialize their pumps** to optimize internal concentrations as the agents that need only one or two classes, and **lose in efficiency**.

We are actually developing a system to trace the speciation events and we still need to define a **characterization of resource classes** that will **permit feedback systems emersion**: at the moment feedback is obtained only in particular **crafted situation**, usefull to better understand the mechanisms of formation (and positive feedback inibition), but in the actual state we are unable to export this emergent feature in other contexts.

On the other hand, the sympatric speciation model get its successfull application to the field of **Evolutionary Algorithms**.

diversity



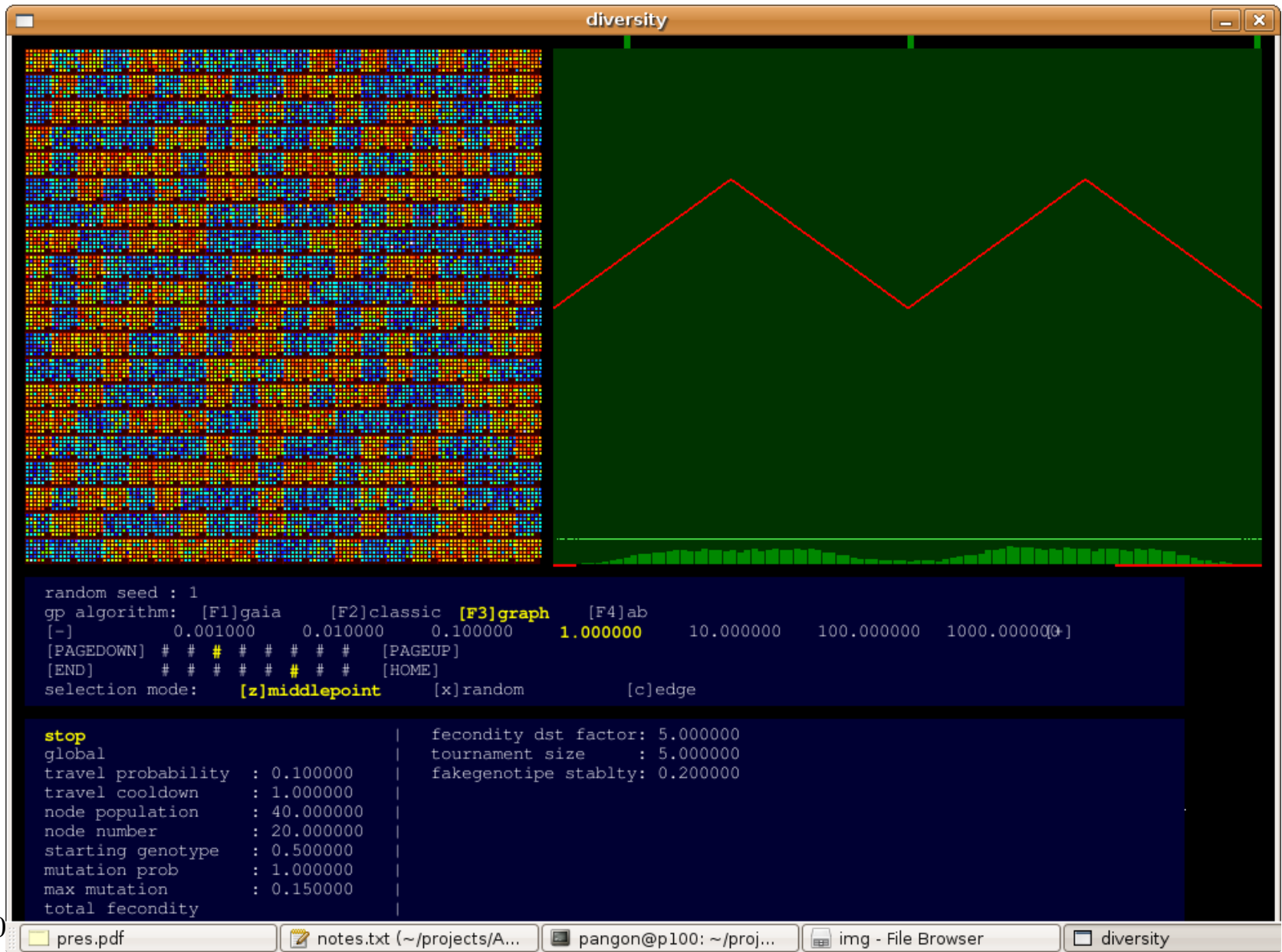
```

random seed : 1
gp algorithm: [F1]gaia      [F2]classic [F3]graph  [F4]ab
[-]          0.001000    0.010000    0.100000    1.000000    10.000000    100.000000    1000.000000
[PAGEDOWN] # # # # # # # # # [PAGEUP]
[END]      # # # # # # # # # [HOME]
selection mode: [z]middlepoint [x]random [c]edge
  
```

```

stop
starting agents      : 100.000000 | max energy          : 100.000000
starting genotype   : 0.500000   | born energy         : 40.000000
environment size    : 100.000000 | sexual act min ener : 70.000000
macroarea number    : 10.000000 | mutation prob       : 1.000000
movement step size : 0.200000   | max mutation        : 0.120000
macroarea res       : 50.000000
res value           : 5.000000
base metabolism     : 1.000000
metabolism increment: 0.005000
  
```

modified island model



lost bifurcation

