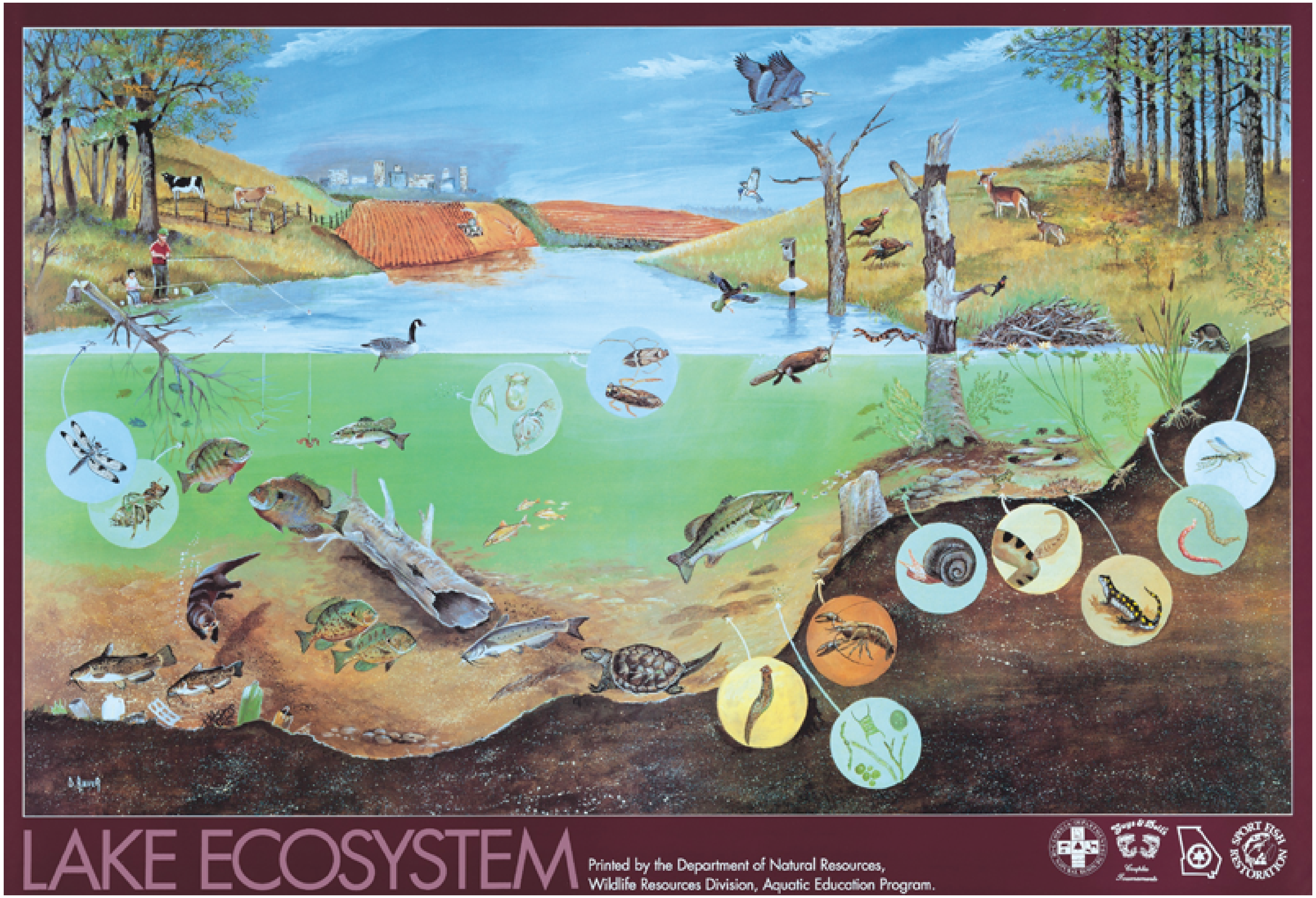


http://gastateparks.org/content/Georgia/parks/education/LakeEcosystem_Poster.jpg

# *Virtual Ecosystems*

**FIT3094** AI, A-Life and Virtual Environments

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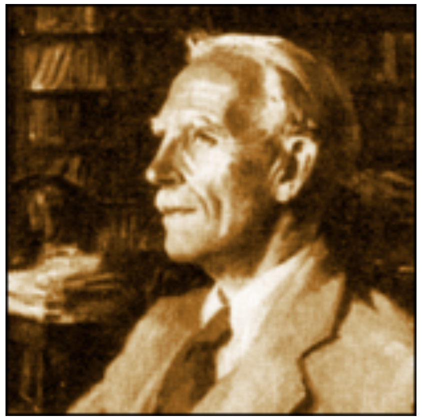
## Learning Objectives

To understand the basic interactions that constitute real ecosystems.

To understand the simulation of evolutionary processes and energy exchange that allow evolutionary simulation of ecosystem dynamics.

To know how to employ virtual ecosystems to generate complex, dynamic game worlds.

## What *is* an ecosystem?



An *ecosystem* is a set of interacting organisms and their abiotic* environment — Tansley 1935

American ecologists, E.P. & H.T. Odum teach a university course and write a text book (1st edition, 1953)

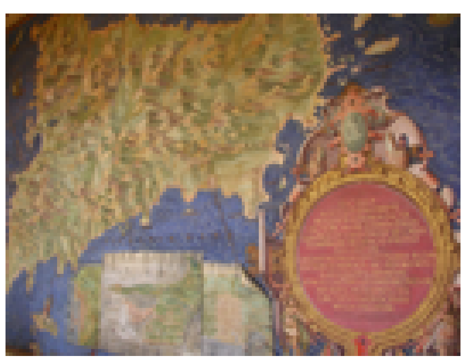
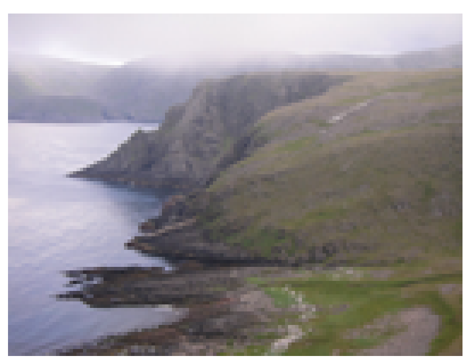
Any unit that includes all of the organisms... in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure**, biotic diversity, and material cycles (i.e. exchange of materials between living and non-living parts) within the system is an ecological system or ecosystem — E.P. Odum 1971

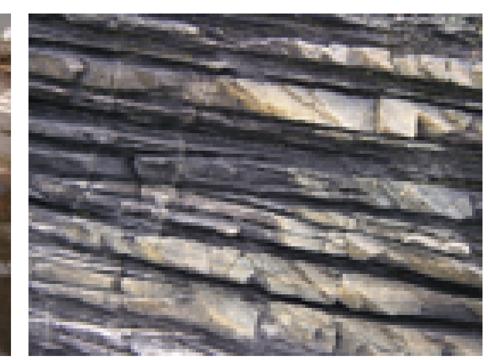
* *abiotic*, not biological (e.g. rock, air, water, light, heat...)

** *trophic structure*, levels of who eats what? (e.g. carnivores eat herbivores eat primary producers (such as plants), and decomposers eat everybody when they die)

## Ecosystem size

Real ecosystems range in size and type from planetary to that of a damp crack in a rock wall.

## Ecosystem dynamics

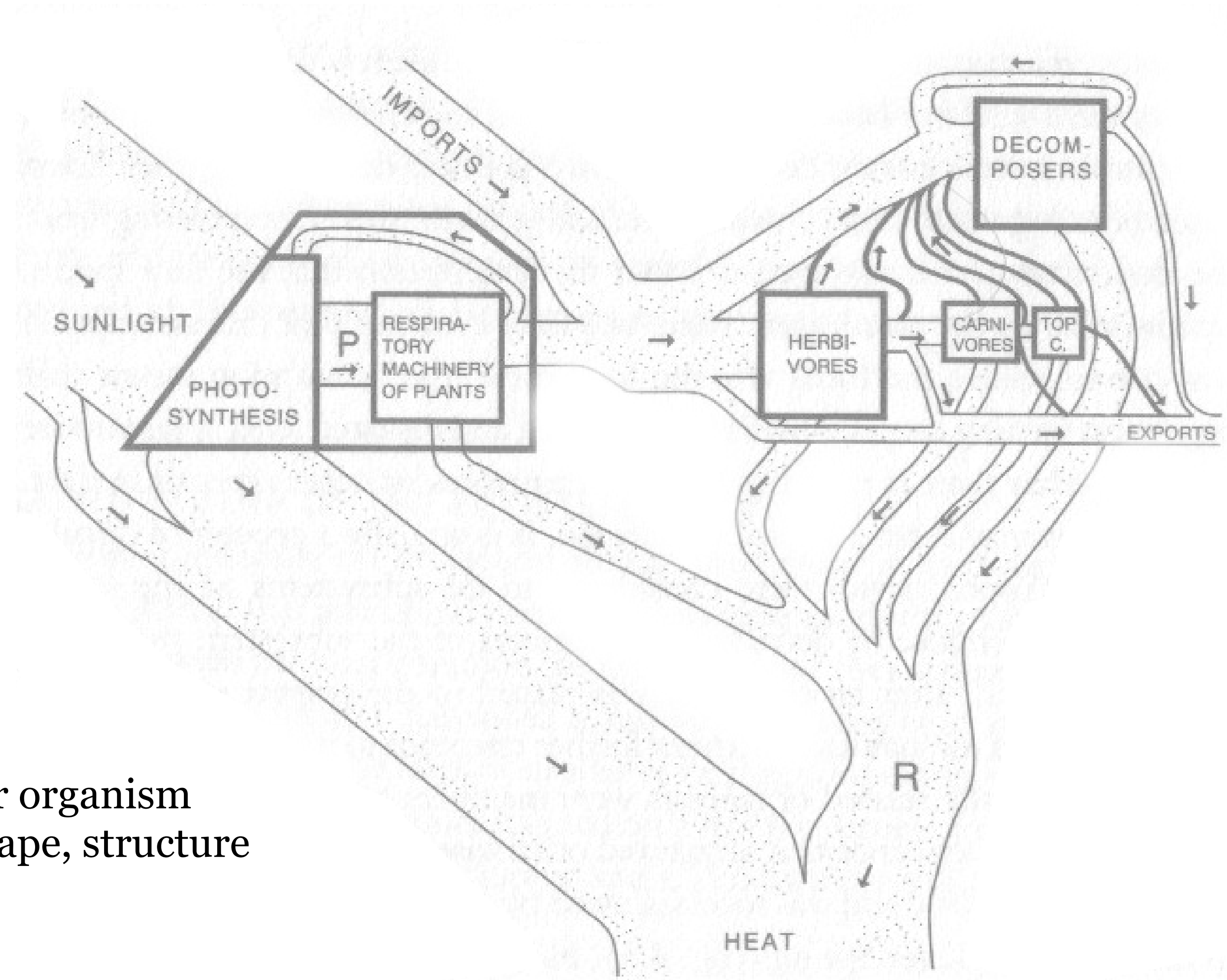
Ecosystems are dynamic. These changes are caused by exchanges of

1. Energy
2. Matter

...and changes over generations caused by:

3. Evolution

# 1. Energy




Energy flows give rise to:

- trophic levels
- food chains and webs
- productivities and efficiencies

Processes for energy flow are one determining factor for organism evolutionary adaptation (e.g., metabolism, organism shape, structure and locomotion).

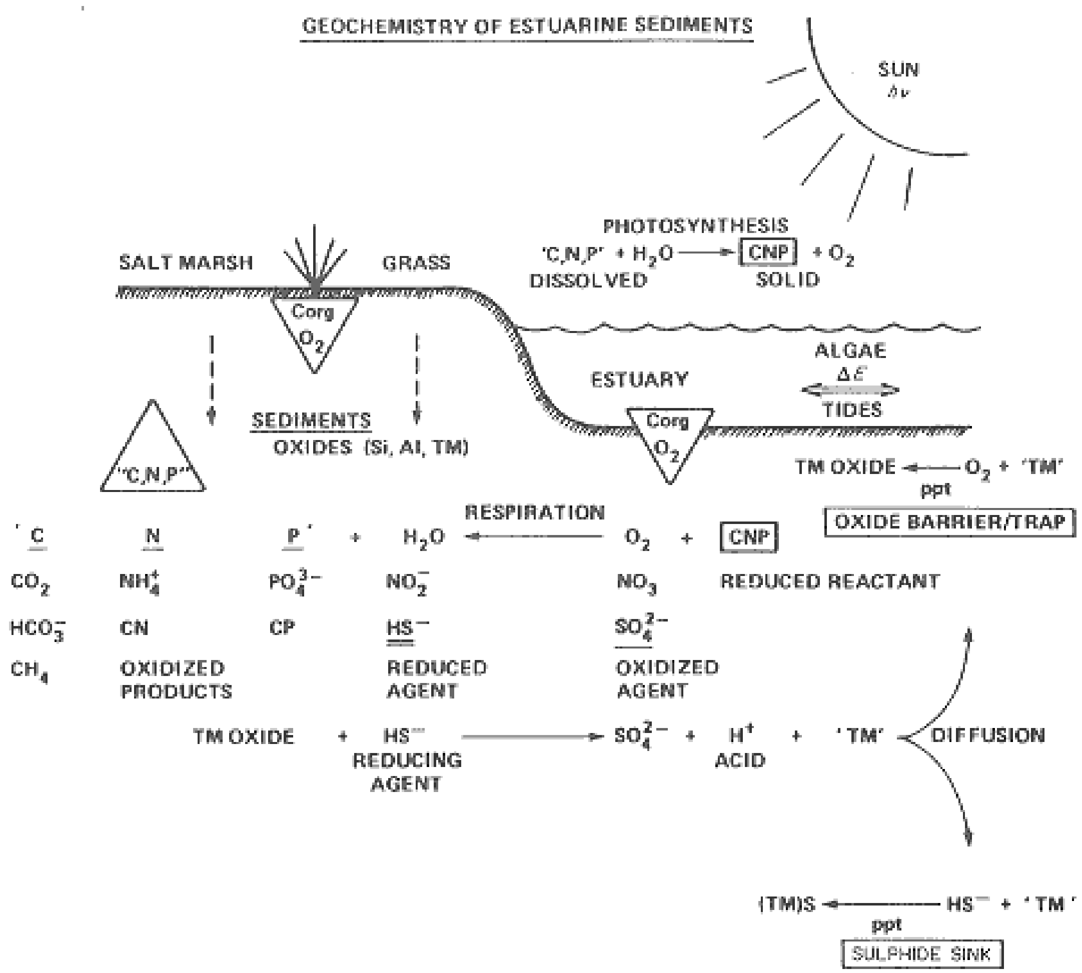
Energy enters the system from the Sun or geothermal sources.
Organisms require energy to maintain themselves or act.
Energy exists in many forms (chemical, kinetic, potential etc.) and can be inter-converted.

Organisms must evolve behaviours *and* structures *and* metabolic processes to acquire and utilise energy.

Energy is not “free”.

Image taken from Odum

# 2. Matter

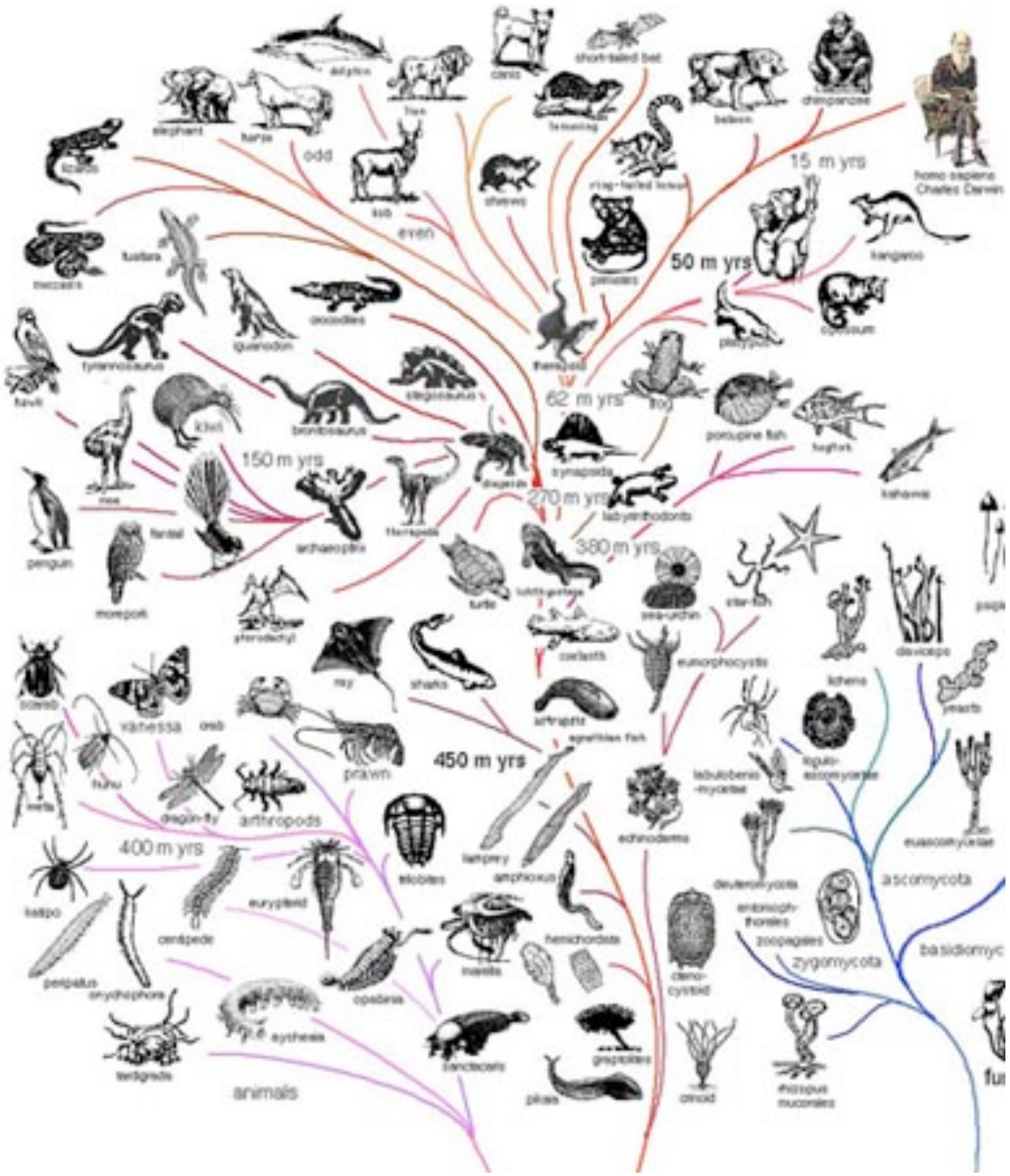



http://www.icsu-scope.org/downloadpubs/scope48/images/fig6.2.gif

An organism's ability to extract elements from complex materials to construct biomass is an important aspect of the way it functions and its physical structure.

Organisms excrete waste and accumulate matter in their bodies, impacting on the relative amounts of materials in the environment and its suitability as habitat for other organisms and itself.

# 3. Evolution




As we have seen in an earlier lecture, evolution is the driving force behind the earth's life forms over billions of years.

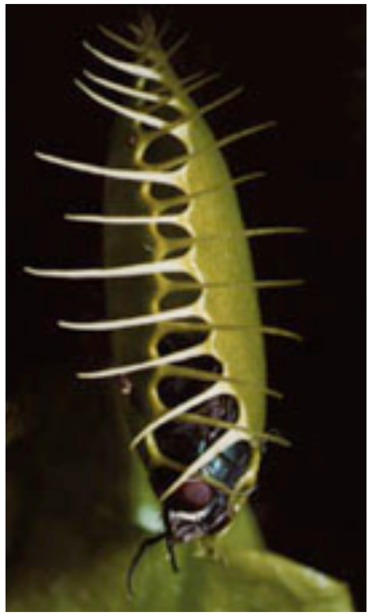
It is the process that shapes organisms and the behaviours that determine the way in which energy and matter can be utilised and exchanged by and between them.

## What kind of behaviours are observed in ecosystems?

Ant lion

### Predation

Pack hunting (lions, wolves)
Chasing (leopards)
Trapping (spider's web, Venus Fly Trap)
Ambushing (jumping spiders, ant lions)



Carnivorous plants

### Aggregate and social behaviours

Pack hunting (lions, wolves)
Flocking (sheep, birds)
Schooling (fish)
Removing lice (monkeys)
Nest construction (termites, ants, bees, wasps)

Ant colony

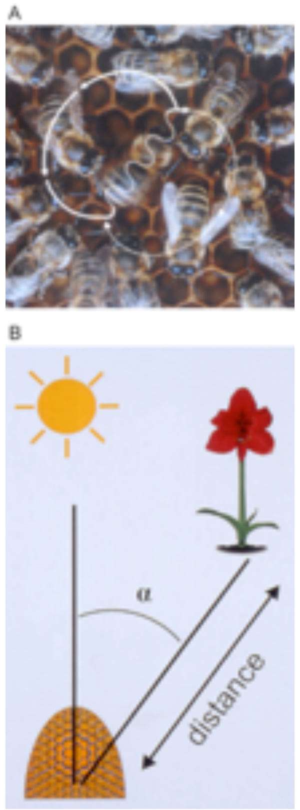
Inter-species **competition** & **co-operation** etc. etc.

# What kind of behaviours are observed in ecosystems?

## Communication

Warnings (cries, colouration)
Mating (calls, diplays)
Food signals (bee's dance)
Territory markers (pheromones)

Warning colouration




Bee’s dance


## Mimicry

Camouflage
Batesian mimicry

Flounder

Leaf insect

Moth

Orchid

Syrphid fly

# Building a Virtual Ecosystem

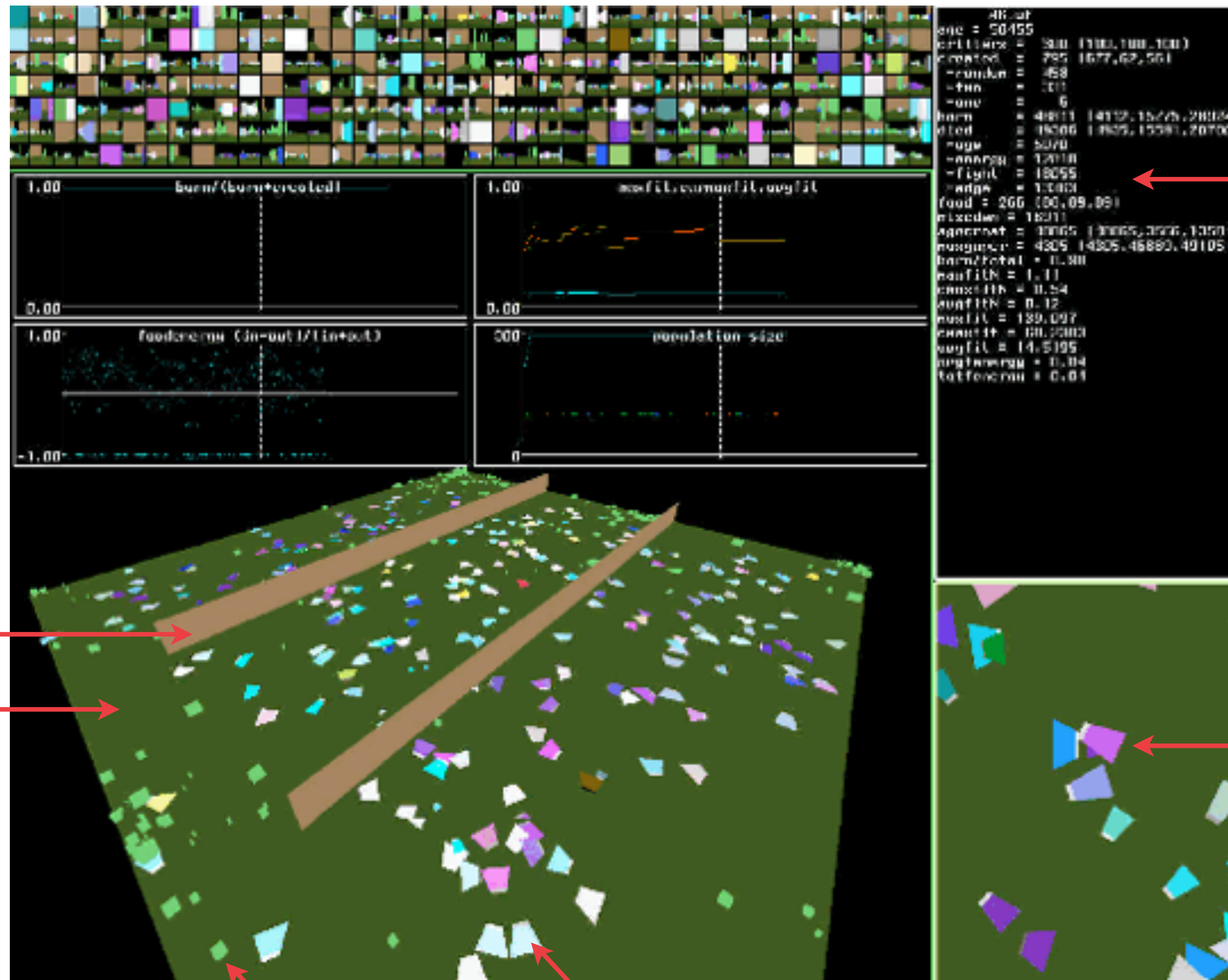
We can set up a virtual space with basic rules of matter and energy exchange and use.

We scatter this space with some agents that can interact with one another and with the energy and matter in different ways.

We can then use artificial evolution to optimise agent behaviour to create a complete virtual world.

# *Polyworld*, by Larry Yaeger

We shall discuss this well-known example in a little detail.




Yaeger, L. (1992). Computational Genetics, Physiology, Metabolism, Neural Systems, Learning, Vision and Behavior or Polyworld: Life in a New Context. *Artificial Life III*. C. Langton, Addison-Wesley: 263-298.

# Agent behaviour in Polyworld

- **Eat.** Replenish energy resources.
  Condition: agent's location overlaps food *and* its eat behaviour is triggered.

- **Control field of view**. Control the horizontal cone of vision.

- **Change colour brightness**. Control the brightness of polygons on the front of the agent.

- **Mate**. Visually represented as blue colouration. Reproduce.
  Condition: agent's location overlaps another's and *both* organisms' mating behaviours are triggered.

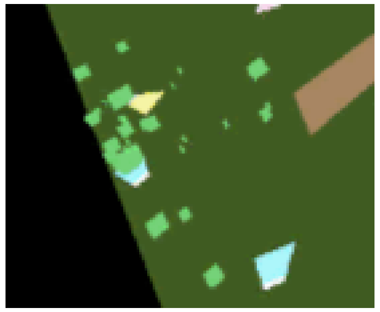
- **Move**. Step forward some amount.

- **Turn.** Turn some amount.

- **Fight.** Visually represented as red colouration. Attack another organism.
  Condition: agents overlap and *one* agent’s fighting behaviour is activated.

# Polyworld energy and matter exchange

Agents expend energy on all activity (including brain activity).
Energy is acquired by an agent by executing the *eat* behaviour near food.



Freely growing food (green polygons)

Growth rate and energy value may be controlled.
Location is stochastically determined.

Dead organisms

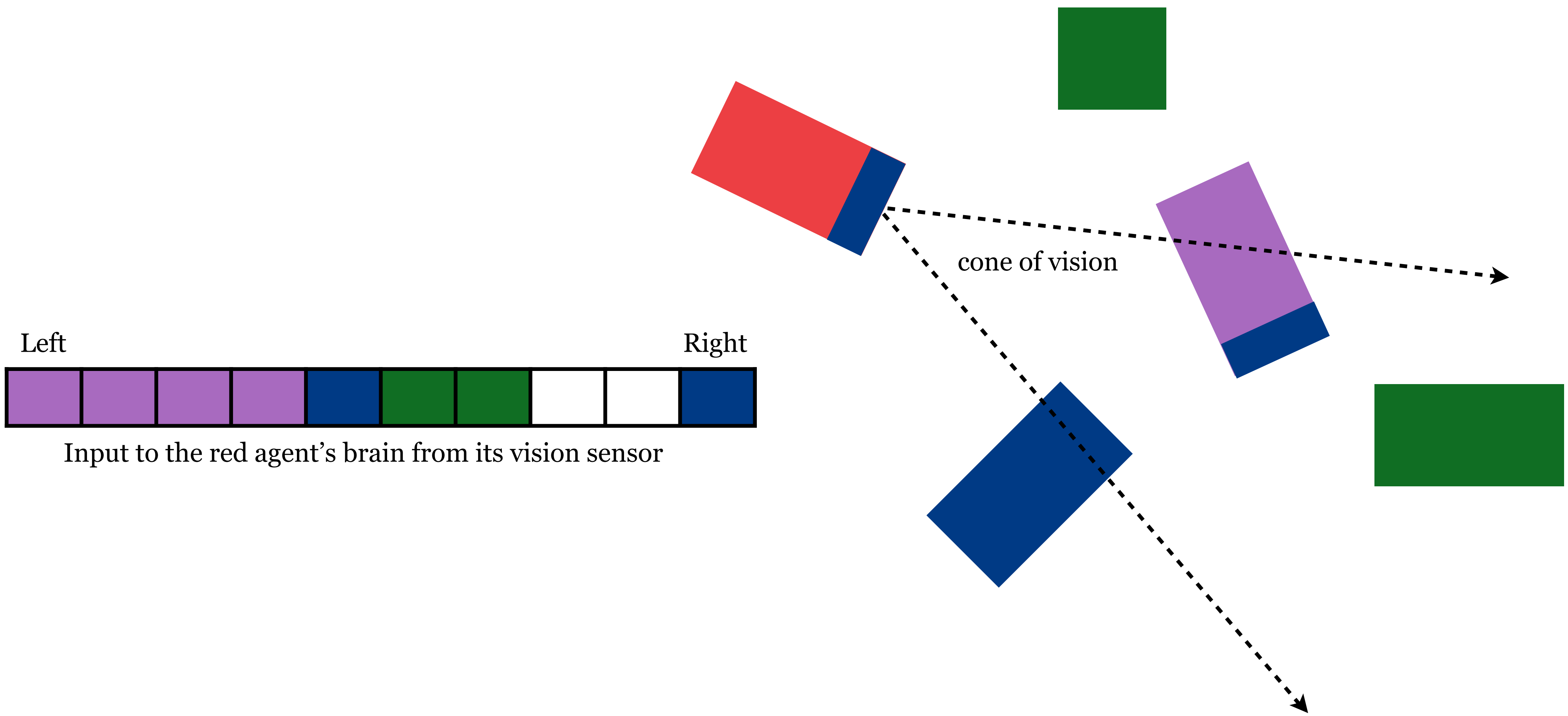
An organism dies when its *health* energy is zero.
A dead organism may have non-zero *food* energy value.

Agents do not exchange mass (although they have size). Is this a problem? Why or why not?

# Polyworld vision

Agents and other objects are represented visually (for us) as coloured polygonal objects.

Agent vision is implemented by rendering a one-dimensional relative view of the world and using this as input to the agent's brain.



# Polyworld brains

Agents have Artificial Neural Network brains employing *Hebbian* learning methods.
An agent's brain determines its behaviour.
Agent neural states are updated synchronously.

Each of the output neurons corresponds to one of the agent’s basic behaviours.

In some cases if an output neuron fires, the agent attempts to execute the behaviour it corresponds to (e.g. eating, mating).

In some cases, the strength of the output firing indicates the degree to which the behaviour is executed (e.g. the distance moved or turned)

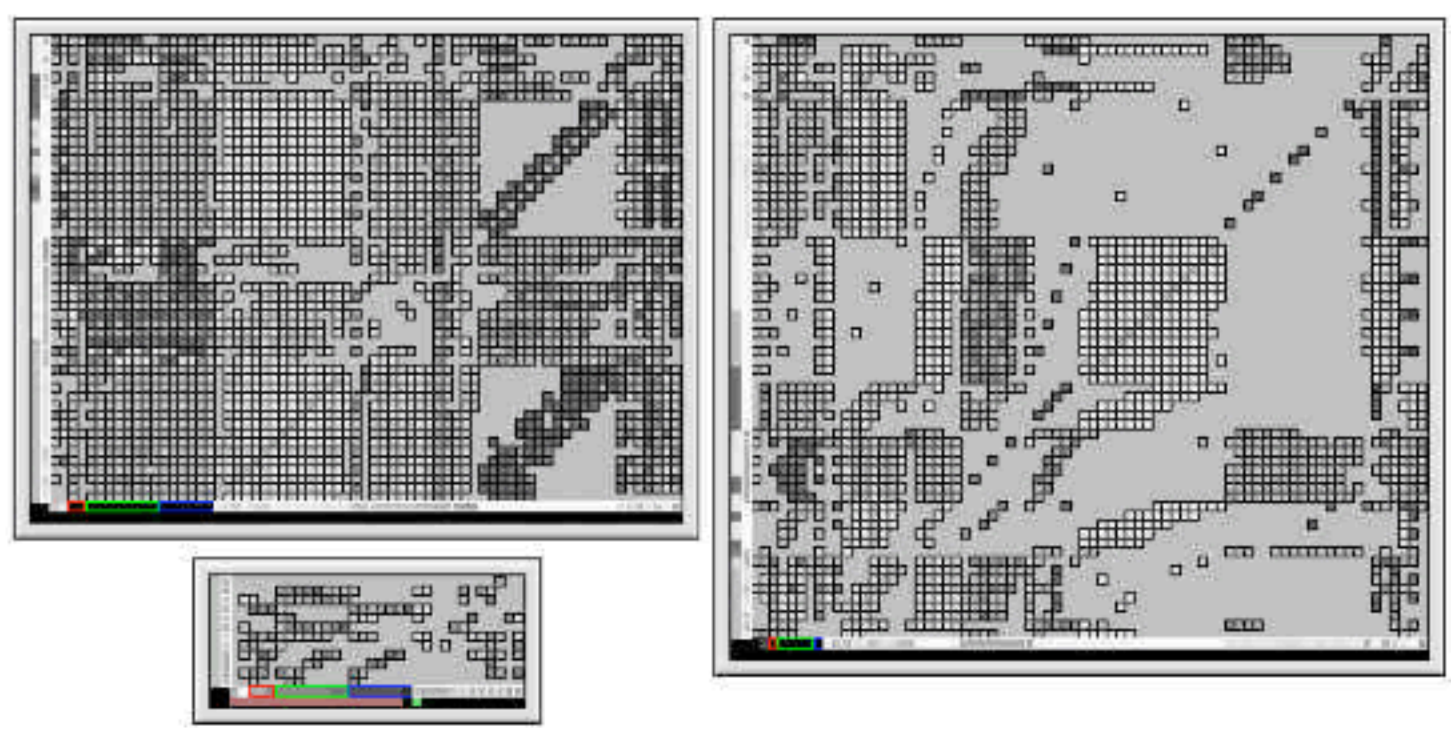
**Neural input clusters:**

- Red, Green, Blue
- Agent health
- Random value

**Neural output clusters:**

- Eat, Mate, Fight
- Move, Turn
- Focus, Lighten

Representations of Polyworld agent neural structures.



# Polyworld sex

**Genetic algorithm mode** - to get the ecosystem kick-started

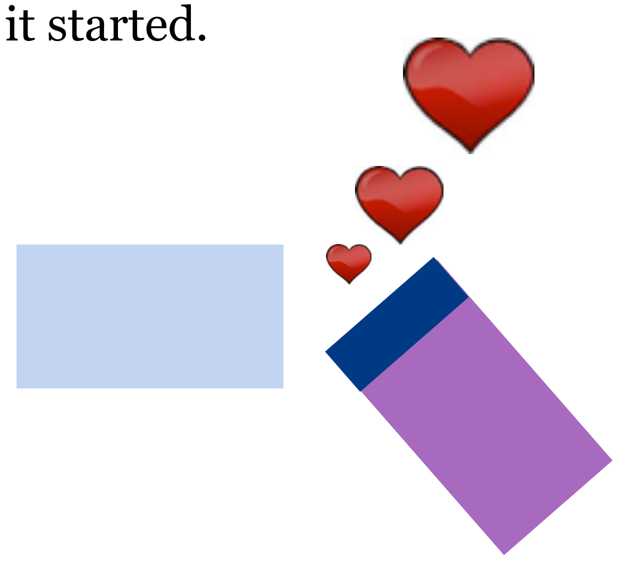
Inhabitant fitness is measured at predetermined times according to a pre-determined function.
The fittest organisms are mated by the system using a standard evolutionary algorithm.

In this mode it doesn't matter if the parents are next to one another in space, nor if they "want" to mate.

**Free-running mode** - once agents have evolved enough to look after themselves

The organisms select mates and reproduce under their own control.
Reproduction utilises an evolutionary algorithm.

Agents must be adjacent to mate and both must "want" to.
Agents provide some fraction of their energy to their offspring to get it started.

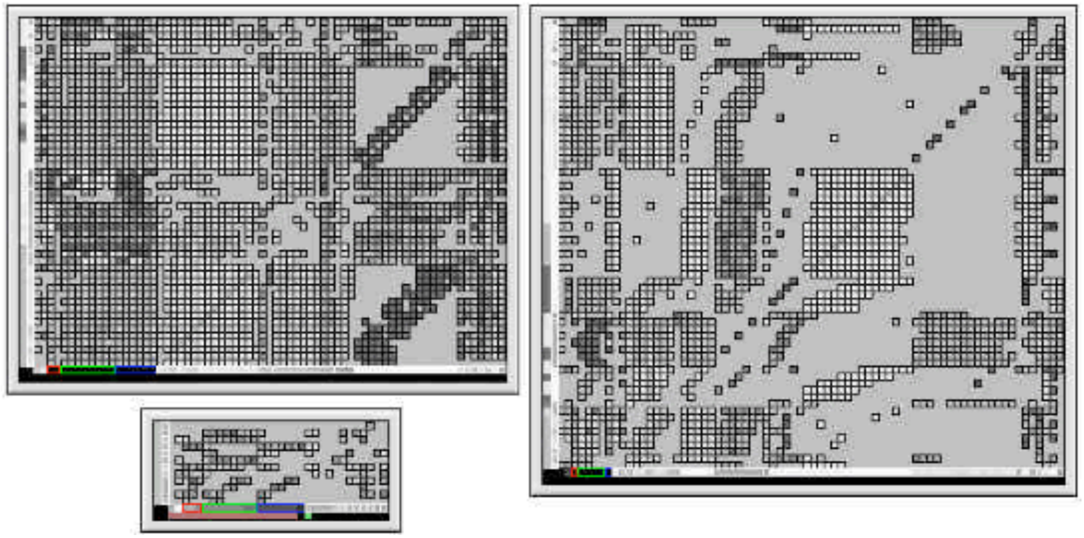


# Polyworld Agents and their Levis 501's (Genes)

**Physiological Genes**

- Size effects metabolic rate, fights, max. energy storage
- Strength effects metabolic rate, fight outcomes
- Maximum speed effects distance covered and metabolic rate
- ID: represented visually as green component of agent’s colour
- Mutation rate for reproduction
- Number of crossover points for reproduction
- Life span
- Energy fraction donated to offspring

**ANN-Specific Genes**



- Number of neurons devoted to red vision component
- Number of neurons devoted to blue vision component
- Number of neurons devoted to green vision component
- Number of internal neural groups

- Number of excitory neurons in each internal group
- Number of inhibitory neurons in each internal group

- Initial bias of neurons in each non-input neural group
- Bias learning rate for each non-input neural group
- Connection density between pairs of neural groups & neuron types
- Topological distortion between pairs of neural groups & neuron types
- Learning rate between all pairs of neural groups & neuron types.

# Polyworld outcomes

A few species Yaeger reported on:

The *frenetic joggers* run straight ahead at full speed, always wanting to mate, always wanting to eat.

The *indolent cannibals* congregate and do not move. They kill, mate with and eat each other all on the spot.

The *edge runners* dash around the edge of a bounded world, eating or mating with all who pass.

Other interesting behaviours that emerged:

- Respond to visual stimuli by speeding up
- Respond to attack by running away (speeding up)
- Respond to attack by fighting back
- Grazing, respond to food by slowing down
- Seeking out and circling food
- Following other agents

So are you thinking…

“Is that *all?* I could write FSMs to do the same thing!”

# Why bother with all this?

## Why bother with virtual ecosystems?

They have the potential to completely change the way games are designed, and played.

They may add unimagined complexity to the virtual space that is completely infeasible under the direct control of human hands.

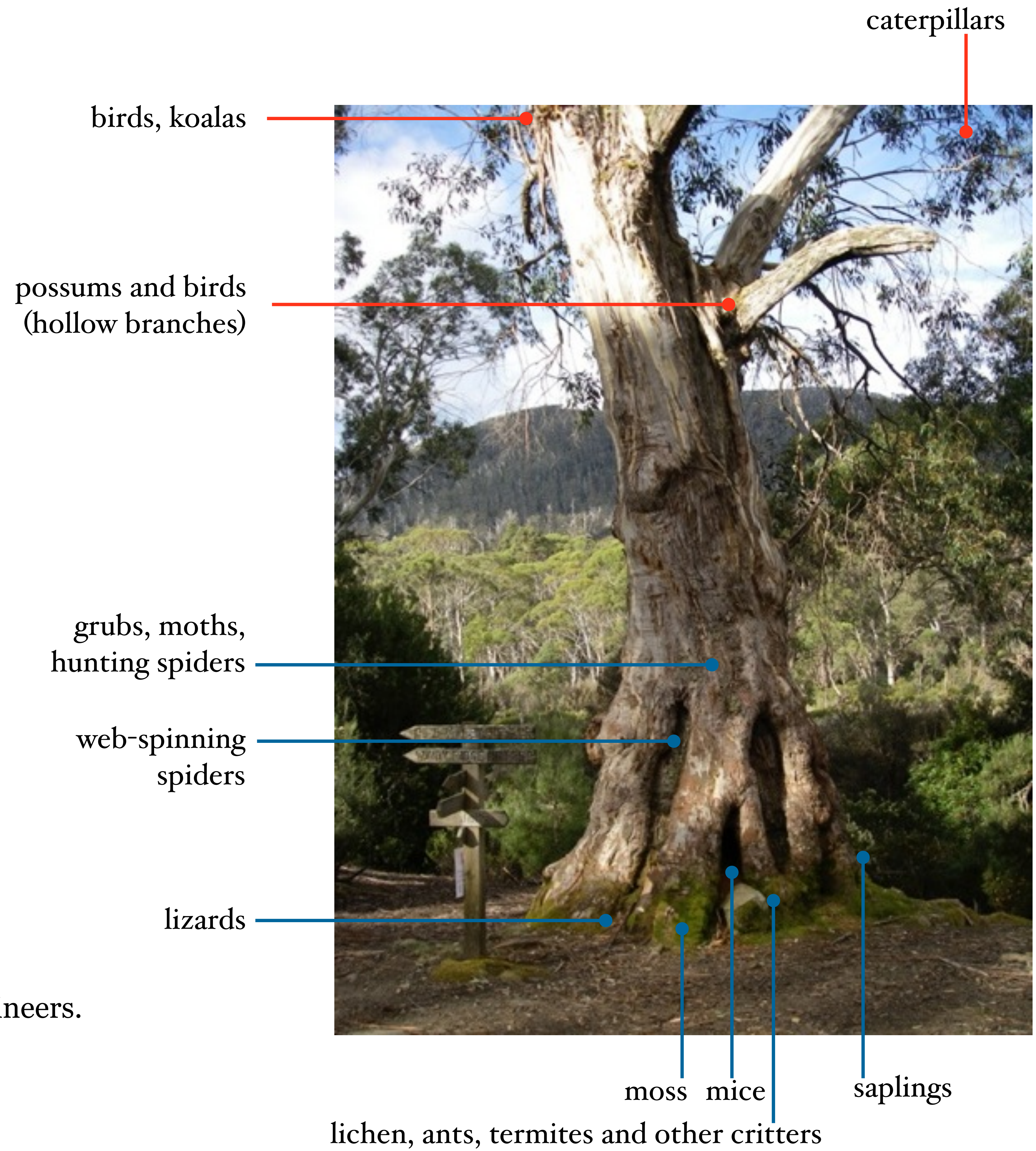
We aren't there yet, but games like *Creatures* and *Spore,* even complex real-time strategy games, are looking in this direction.

*Spore* (Maxis, 2008)

# What’s missing? *Ecosystem engineers*…

Ecosystem engineers are species that provide habitat by changing the availability of resources or forces acting on other organisms.

These are not often modelled in virtual ecosystems — a serious oversight!




Gum Tree, Lake St. Clair, Tasmania 2007

E.g. trees are *significant* ecosystem engineers.

**Have you met the learning objectives?**

What is a virtual ecosystem?
What are its basic elements?

Design a virtual ecosystem of your own.

Use agents whose visual structure is represented by some simple genes and whose behaviour is governed by an FSM.

The FSM’s states and transitions must also be specified by the genotype.

What can the agents do? How can they sense their environment? What are they made of and what do they need to survive?

What other questions need to be answered to make the system work?