CONCEPTUAL FRAMEWORK FOR ECOBOTS

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WHAT IS THIS DOCUMENT ABOUT?

This document is aimed at helping anyone who wants to develop this mod further. You might also find this interesting if you just want to understand how this mod works.

Here I will discuss the core principles and processes that make this mod function. Anyone who wishes to expand this mod will need to understand this conceptual framework.

I will not bore you with line by line code, because, to be honest, you can probably figure out better ways of coding this than I have. Instead these are the key challenges your code must solve.

WHAT IS THE AIM OF THIS MOD?

All the mods in the Self Organizing Systems modpack aim to do two things:

1) explore the principles of self organization that underlie so many natural phenomena.
2) Do this exploration in a fun way.

If you want to expand this mod then let those be your goal too - be scientific, and have fun. This is my ideal: these mods should be a fun way to spend some time, and be an engaging way to learn about some otherwise very abstract concepts.

Ecobots itself is about complex adaptive systems - in particular, ecosystems.

These types of system are more than complex. They do more than just create spontaneous order. They are also adaptive. They can change themselves in response to their environment. They can evolve and learn.

Life is a complex adaptive system in many ways. Ecobots tries to capture the ways in which ecosystems are complex adaptive systems. It also includes some examples of group intelligence... mainly because I could, but also because real ecosystems are occupied by intelligent organisms.

SOME BACKGROUND ABOUT SELF ORGANIZATION

What is self organization?

Order from chaos. Spontaneous. No guiding hands. No designers. Just interacting components coming together by themselves by following simple rules. All bottom-up. Ant colonies, enzymes, ecosystems, economies, your own brain. All have arisen through self organization. It is why nature works.

People have been using computers to understand self organization for a while.

The inspiration behind all the Self Organizing Systems mods was cellular automaton. These computer programs consist of grids of cells, where each cell can exist in a set number of states. These states change based on what states the other cells are in. The result is highly complex behavior arising out of very simple rules. Some people have even argued that the entire universe is a cellular automaton.

At this point you might be realizing that Minetest also consists of a grid of cells... and that these cells can be programmed to change state based on the state of the cells around them... and therefore...

All of Minetest, it's entire near infinite world, it's huge range of possible blocks, can be turned into a giant cellular automaton. This is an incredible opportunity to explore complex self-organizing behavior in a fun and very hands on way.

That, in essence, is what the Self Organizing Systems mods aim to do.

Where does Ecobots fit? The highest form of self organization is the complex adaptive system. You are a complex adaptive system. Life is the most brilliant and beautiful example of self organization that we encounter every day. And ecosystems are a central fact of life. Ecosystems are everywhere, from the jungles of the Amazon, to the bio-films on your teeth.

THE KEY CONCEPTS IN ECOBOTS

Life in Ecobots must be managed at three different scales:

- individual organisms
- communities and ecosystems
- landscapes

The trick with organisms is to get them to behave naturally, and not explode into exponential grey goo. The trick with communities is to get all the species balanced, interacting in a functional way. The trick with ecosystems, is to bring the real world of matter and energy flows into a virtual world which doesn't include them and often can't simulate them properly. The trick with landscapes is to get all the different types of ecosystems balanced so that the entire biosphere forms a functional whole.

INDIVIDUAL ORGANISMS

We can split organisms into two types: sessile, and mobile. Those that sit around like plants, and those that run around like animals. Different methods are needed to simulate the two.

SESSILE ORGANISMS

Our key questions here are:

- Growth types: how does it reproduce?
- Growth forms: what does it look like?
- Growth requirements: what does it need to grow?
- Tolerances: what will kill it?
- Lifespans: how long does it live?

Growth Types

We have two forms of growth:

- Clonal: the structure spreads out from its current location.
- Seed-like: new bots are spawned some distance away from the original, like seeds.

Clonal growth makes use of local population limits. See the beginning of “The Theory Behind Ecobots” for an explanation ($p = mr-d$ and all that).

Clonal growth is useful for building individual organisms... well.... actually, it’s useful for giving the appearance of individual organisms. While Ecobots can give trees the appearance of being multi-cellular, the reality is that they are single-celled clones that happen to be growing next to each other. Trees in Ecobots have more in common with stromatolites built by cyanobacteria than with actual trees. However, this is close enough to reality that it works.

Clonal growth can also be used for small scale spreading, to ensure that spreading doesn’t become excessively dense. For example the ground growing plants tend to use this, rather than relying only on seed-like growth. This mimics the way many plants grow asexually, by forming clumps, and with spreading roots.

Seed-like growth is exactly that. It mimics the way organism launch their offspring off into the unknown. Because these “seeds” end up at great distance from the parent they can’t be controlled by the local population limits of clonal growth. Instead we jump up a scale and have to manage it at the community level.

Currently seed-like growth is done very simply - it simply spawns a new bot. But this could be made much more complex. Flowers, pollination, actual seeds.

Currently most Ecobots plants use both growth types. But they could be limited to one or the other. However it is not possible to create trees without using clonal growth - they are stromatolites remember, not real individuals.

Growth Forms

At least four broad types of shape can be made:

- Tree-like: grows supporting structures (e.g. wood) and a clonal canopy. e.g. trees.
- Bush-like: has no supporting structure, but can grow on top of itself. e.g coral reefs.
- Palm-like: grows supporting structure, but does not grow a clonal canopy. e.g. palm trees.
- Herb-like: has no supporting structure, and cannot grow on top of itself. e.g. grass.

Each ends up looking much as like the name suggests. These can be used both for mere aesthetics, and to create organisms adapted to specific conditions. Each growth form lends itself to particular niches. Herb-like for forest floors, palm-like for rapidly bean-poling up through a canopy to reach the light....

Tree like growth is the most complicated. In order to create the illusion of an individual tree it makes use of multiple growth forms.

- Upward: grows bots only on top of other bots. Mainly used to create a supporting trunk in addition to the new bots.
- Branching: grows supporting structures outwards, rather than just up.
- Leafy: grows a canopy without any supporting structure (i.e. it is Bush-like growth suspended up a pole grown by the other two forms)
- Root: grows supporting structures and/or new bots into a substrate. This is partly aesthetic, and partly to allow ground level spreading.

The resulting appearance of the tree is controlled by these factors:

- the balance between the growth forms.
- attachment rules.
- adjacency rules.

The more you have of one form of growth the less you'll get of the other. They compete for space within their local clonal population limit. e.g. fast growing leafy growth will outcompete upward growth and keep the tree short. The opposite can turn the tree into a narrow tower.

Trees (and palms-like) can be further controlled by setting population limits on how much supporting structure they can grow. This will limit how woody they get, and for small plants can limit be used to stop their growth entirely.

To make the tree look like an individual, bots must always be attached to older bots or the supporting structure. Attaching new bots to the sides will create spreading canopies. Up or down creates pillars. Randomly allowing them to go anywhere creates blobs.

Controlling what is allowed to be above, below, or the side of the new bot will further control the shape. e.g. if air must be under new bots then they will always form a canopy. If not then they will spread along the ground.

Growth Requirements

When is a bot allowed to replicate? This will have a huge impact on what it does.

Having growth requirements means that the bots will not simply grow randomly. They will grow in response to their environment. They will spontaneously evolve certain structures as a result.

The most common growth factor in Ecobots is light, but any number of things could be set. Soil types, elevation, the blood of virgins...

Tolerances

This is the opposite of growth requirements. What will it die without? What will it die if it encounters? e.g. the coral reefs die if they have insufficient water, and die if they are exposed to air. As a result the core of the growing reef ends up filled with dead coral, and when you go in and dig around disturbing the reef causing air pockets it results in massive die offs.

Tolerances not only create realism, they prevent super-species capable of taking over the planet. This is important when we jump up to the next scale.

Life-spans

Nothing lives forever. Again this adds realism, but more importantly it allows every structure to be a complex adaptive system. Without death there is no change. Without change there is no adaptation. See "The Theory Behind Ecobots" for more.

For trees, because they are actually clonal colonies, entire trees seldom die. Instead death simulates leaf fall, sending matter from the canopy down to the forest floor. This is why plants have been done with falling nodes - to help simulate the nutrient cycling the occurs upon death.

MOBILE ORGANISMS

Our key issues here are:

- Feeding

- Breeding

- Movement

- Tolerances

- Life-spans

- Intelligence

Feeding

Animals must eat. This is easily simulated by making them remove food blocks when they are beside them. The only question is - what does it eat? This becomes important at the next scale up.

Breeding

We could allow bots to just randomly spawn, but to make it more interesting some conditions should be applied.

- local population limits: the same as for clonal growth in plants, this will help keep population densities down.

- growth requirements: do they need to be on the ground? Near flowers? In a group?

- growth inhibitors: does anything just kill the mood. Cold snow? Bright lights? Bad music?

Note, everything in Ecobots is asexual. You could create the illusion of sex... um... let's not visualize that... but because nothing has genetics it would all just be... empty... meaningless... sex. For aesthetic purposes... I guess.

Reproduction can be done very simply - spawn a new bot next to the parent - or in a very complicated way. e.g. the Eusocial Bot creates nests which must be fed until they are capable of producing a queen who then goes off and starts a new nest.

All manner of complicated life-cycles could be added to Ecobots: eggs, parasitic wasps, larval stages, cocoons....

Movement

When will it move?

How will it move?

When will it stop?

This can be important for allowing them to find food (if they move until they are on top of food they will all quickly disperse and locate food supplies). It is important for balancing predators and prey (a predator who can't catch up with dinner is not going to live long). Movement also becomes essential when we consider intelligent behavior.

Currently most movement is done by random hops. But this could be made more sophisticated. For example, insect movement consists of two things: move in straight lines, and randomly turn. By increasing the rate of turning when in good conditions they ensure they stay put (they go around in circles). By favoring straight lines when conditions are bad they rapidly escape. Copying these kind of simple rules is what it will take to lift Ecobots to an even greater level of self organizing awesomeness.

Tolerances and Life-spans

Same deal as for the sessile organisms

Intelligence

We could make sessile creatures intelligent too, but we'll leave talking trees for now... and stick to talking animals.

Ecobots only includes group intelligence. No individual actually possesses any intelligence. I imagine some kind of AI could be programmed for individuals, but that doesn't really demonstrate the powers of self organization.

Currently Ecobots includes Ant-like, and network intelligence. Many other forms could be added. Here's the basic set up if you want to create more intelligent species.

Ant-like Intelligence

This consists of two essential living components, each of which can be in one of two states:

- Nests: fed, and unfed. Fed nests use their food to create new workers, and internal structures. If left unfed too long they die.

- Workers: searching, and returning. Without giving these two different behaviors their intelligence is greatly diminished.

Both nests and workers are treated like living things with life-spans, tolerances etc as for any other animal.

In addition we have non-living trails. These temporary markers are placed under workers, and are the key to their intelligent behavior. See "The Theory Behind Ecobots."

To get the hive working well, care must be taken with trail formation rates, the balance between trail following and random movement, and the rate at which workers are born. Unbalanced hives can easily starve, or consume entire landscapes.

The Ant-like species also have additional blocks and behaviors which have proved useful.

- Storage Chambers: these act as substitute nests. Whenever too many returning workers are around they create stores, and go back to searching. Nests can also surround themselves with stores to increase the chances of a worker feeding them, and so that the nest can accumulate food reserves.

- Internal food movement: By randomly cycling food from storage and fed nests to those that are unfed the nest becomes much more efficient. Food placed in an easily accessed nest will be redirected allowing incoming workers to continually feed the nest. Otherwise gridlock occurs and nests starve.

- Hive building: Both workers and the nest can be made to create and destroy blocks. If this activity is limited to occur only around the nest then a complex hive will be built. This helps with traffic flow, by preventing the workers from forming a grid-locked mass, and instead funneling them in and out through multiple channels:

- walls growth: workers raise up a block.
- digging: workers dig down around the nest, clearing a central chamber.
- tunnels: these pierce the walls allowing access.
- bridges: these build out from the walls over air gaps, creating tunnels and enclosing the structure.

- Defense: because nests produce huge numbers of workers predators become a problem. They could eat all the workers, but more problematically they block access. This is solved by allowing the workers to kill predators who get too close, if the workers outnumber them.

Network Intelligence

This is explained in the "The Theory Behind Ecobots." The key is the small-world network. The essential elements are:

- a means of communicating

- something to talk about

- something to use that information for

- links to neighbors

- rare links to distant individuals.

These could be done many different ways. For the firefly-like Herbivore communicating is done by light flashes, they only communicate if they have food, and they use it to congregate in a group.

Swarming, Schooling, Flocking

Nothing in Ecobots currently does this, but the herbivore gets close. It is an obvious thing to try. This kind of behavior occurs in bird flocks, fish schools, locust swarms etc. It allows the swarm to act like a single individual. It is based on these minimum rules:

- follow your neighbor

- don't crowd your neighbor

In addition some sort of random or goal directed movement should be added so that the swarm actually does something useful other than just sitting there.

COMMUNITIES AND ECOSYSTEMS

Our big challenge here is to turn our organisms into a working ecosystem. Whenever you create multiple interacting species they will form some kind of system. But there is no guarantee that it will be balanced. It could explode into a monoculture, descend into chaos, or end in mass extinction. Here we need to truly mimic nature. Planet Earth has been cracking away at this problem for some time now.

FOOD WEBS

Assuming you've got animals, then you've got a food web.

This at its most basic is what you should have:

Primary Producers > Primary Consumers > Secondary Consumers >....

and because things die we also have

Dead stuff>Decomposers>.....

When you add a species the first thing you need to figure out is where it fits in this chain. The life history strategy it will need to adapt will differ a lot depending on where it fits.

Of course this isn't a chain, but a web. Real food webs look like spaghetti. Don't be afraid to make food webs complicated. If anything it should make the system more stable. However, the higher up the chain the more likely the species will go extinct. Life's tough at the top. They depend on the success of everything beneath them. Therefore it makes more sense to add an abundance of herbivores, rather than an abundance of predators.

NICHES

Your species needs a strategy. It can't (or rather shouldn't) do everything. Ecobots already contains a range of broad niches (snow tolerance, sand tolerance, aquatic, fast growing etc).

Remember, because this is a virtual world you must make an effort to add tradeoffs. Otherwise you will create super-pests. For example, being able to grow in the fiery pits of hell should be coupled with, say, an intolerance for cold showers.

If you get these tradeoffs and niches right you should be able to create a system in which many species can coexist. They will divide up the space between them. Competing species will have different advantages in different places, therefore neither will drive the other extinct.

MATTER AND ENERGY FLOWS

Minetest allows you to create matter out of nothing. Reality does not. If you ignore energy flows you will get odd unrealistic behavior.

Real ecosystems gain their matter and energy by one of two means:

- Photosynthesis: turning light and air into usable matter
- Chemosynthesis: turning inorganic chemicals into usable matter.

Currently Ecobots only includes photosynthesis (although the aquatic creatures are forced to just assume the water is doing it - we can't create small enough blocks for microscopic phytoplankton!).

Chemosynthesis would be a good way to fill out the underground realms. Think of deep sea volcanic vents. Black smokers. They support entire ecosystems.

Real ecosystems also exist in a state of balance (over the very long run).

Matter in is balanced by matter out. Death and decomposition completes the cycle. If you don't allow for this you'll end up massive accumulations. Occasionally this does happen in the real world - soil building, peat bogs, coal from ancients swamps, limestone from shellfish. But mostly things are in balance.

It doesn't always makes sense to simply let something decompose. Other means may be needed to clear out the dead. e.g. the coral reefs create persistent dead skeletons. These are a core part of a reef so we can't just get rid of them. But if we don't the reef will clog up and eventually they whole thing will die of old age. As a solution a very small number of the skeletons gets removed, and there is a chance for some of the dead to come back to life.

Energy flows must be considered when making food webs. Very little energy makes it up food chains. It's about 10% with each step up. Therefore, to create realism animals must eat ten units of matter and energy for every one unit of growth. For simplicity we can make one block = 1 unit of matter and energy. This could be made more complicated - giving different blocks different energy densities, etc.

A final consideration is the difference between ecosystems that make their own food, and those that import it. Caves, some rivers, and the deep oceans are typically food importers. That means they have no primary producers. They eat whatever falls in.

LANDSCAPES

We need balance. Organisms are able to change their environment. Plants are very good at covering hostile terrain in organic matter and making it suitable for life.

Therefore, if we don't want the oceans to fill in, or the deserts to be covered over, we need to find balance. Every creation must be matched by destruction. The advance of forests must face up to the advance of sand dunes.

We could get away with ignoring this... but it is important for making the whole biosphere stable in the long run.

This can be achieved at least two ways:

- "Terraformers": species which spread their biome type. e.g. sand dune building grasses.

- Different rules in special biomes: e.g. in deserts the accumulation of dead matter could be switched off to stop soil formation.

Perhaps you can think of more.

CONCLUSION

If you want to add a species to Ecobots consider these questions:

- What ecosystem type does it belong to?
- Where does it fit in that ecosystem's food web?
- if it's a consumer then what does it eat?
- if it's a producer what is its energy and matter source?
- What is its niche, it's strategy for survival?
- Is it sessile or mobile?
- if it's sessile: is it Tree-like, Bush-like, Palm-like, or Herb-like. Does it grow clonally or by seeds?
- if it's mobile: how does it move? How does it breed? Is it intelligent?
- What does it need to grow?
- What can't it live without?
- What will kill it?
- How long does it live?

Once you have answered these questions most of the effort consists of fine-tuning, achieving balance. All these systems are incredibly non-linear. Even the smallest changes can have dramatic effects. Take your time.