John McCormack's

Eden

(2000 -2006)

"It may be possible to create artificial organisms that can develop their own autonomous practice." -- J. McCormack

Presented by Aaron Levisohn

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Evolutionary Music and Art

Research Goals

1. **Art Making/Understanding :** Create music that is intended to be appreciated by a human audience.

   This type of research is often very individualized and reflects the values of one researcher or artist.

1. **Artificial Creative Systems:** Research the concept of creativity in general.

   This type of research looks at creativity in ways that are independent of culture or species. It may even attempt to discover new forms of creativity

   Challenge: Would we be able to identify non-human creativity if we encountered it?

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Genetic Algorithms

Terminology

Biological terminology is used to describe the various elements in the genetic algorithm.

Genotype: The underlying representation of “chromosomes”

Phenotype: The representation of the creature, individual or agent based on its genotype.

Creatures evolve by mating with each other using the metaphor of Darwinian and Lamarckian evolution.

Creatures (phenotypes) are evaluated using a specific **Fitness Function.** Those that meet this criteria mate, those that don’t die off.

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Genetic Algorithms

Genetic Representations

A **dog** could be described using the following adjectives:

Hairy
Slobbers
Barks
Loyal

Binary stings are used to model the **genotype**.
Each bit in the string represents a characteristic.
If that characteristic **is** present then the bit is set to **1**
If that characteristic is **not** present the bit is set to **0**.

In this way the **phenotype** of a dog can be represented as a string in the form of:

1111000000000000

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Hypotheses

Organisms will mirror the environment in which they live.

If the environments are more complex, then the organisms will reflect this complexity.

Selection Pressure can be used as an ***Implicit* fitness Function**

Each species will try to increase its reproduction rate to outpace other species.

Successful individuals will emerge in response to challenges set by the environment.

Individuals can cooperate or compete to survive.

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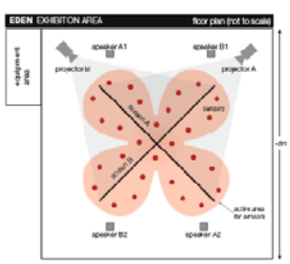
Physical Description

Visual Elements

Eden consists of **2 translucent screens** placed at 90 degrees to each other forming an X Shape in an 8m x 8m space.

The simulation is projected onto the screens using 2 projectors allowing the audience to see through the interface, integrating the physical and virtual worlds.



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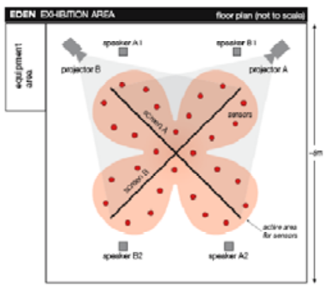
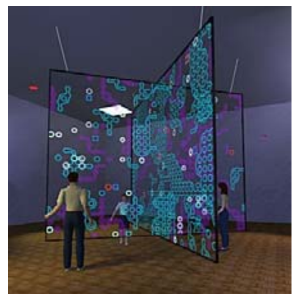
Physical Description

Audio Elements

A multi-channel audio system capable of sound spatialization is used so that sounds seem to emanate from a specific point in virtual space.





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The Virtual World

The Eden environment is a 2D cellular lattice on which agents interact.

Environmental Components:

Rocks: Inert matter that acts as an obstacle to agent movement.

Biomass: Food source for agents. Biomass grows based on a seasonal cycle and requires radiant energy. The availability of radiant energy is dependent on a number of factors including the local absorption rate of energy and seasonal variation.

Sonic Agents: Mobile creatures with evolvable *performance systems.*

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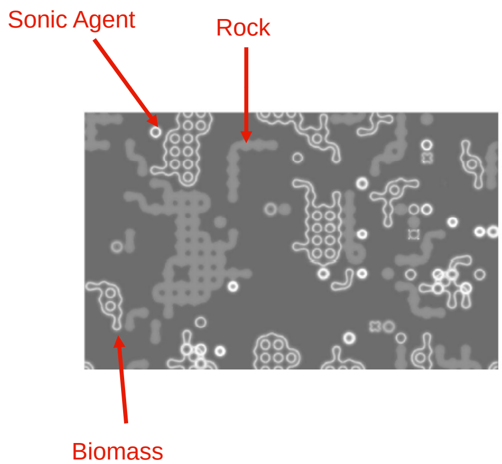
The Virtual World



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The Agents

Agents are comprised of:

Set of (algorithmic) sensors
Provide information about the environment and internal agent status

Rule-based Performance System
Converts sensor messages from the environment into desired actions.

Set of Actuators
Actuators attempt to carry out actions in the world. Note that just because an agent wants to do something, it may not be possible (e.g. Walking through a rock.)

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The Agents

At the start of each world, agents are seeded into the environment. Each is assigned different internal data.

Current Age:

The age of an agent. Agents live up to100 years.
(One Eden year = 10 minutes real-time)
Agents cannot mate in their first year of life.

Health Index:

An indication of the current health of an agent represented as an integer value.

Energy Level

The amount of energy an agent currently has.
Energy is expended whenever an agent takes an action. When an agent's energy reaches 0 it dies.

Mass:

Linearly proportional to its energy level plus an initial birth mass.

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Agent Sensors

Algorithmic Sensors are used by agents to measure environmental variables or their own internal status.

Sensor data is in the form of 32 bit binary strings.

Sensor data are updated during every "time-step". A time step is the smallest unit of action in the Eden world.

Not all sensor data is used by each agent. Agent's will only use data that has proved useful in the past.

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Agent Sensors

Sensor Data

Color Detection:
Agents can "see" colors of objects in facing and neighboring cells. Rocks, Biomass and other agents all have different colors.

Nutrition Sensor:
Determines the nutritional value of elements in the current cell. This includes biomass and dead agents.

Sound Sensor:
Detects (virtual) sound pressure and frequency over 3 bands. Agents are able to detect sound at a greater distance than color.

Pain Sensor:
Negative changes in an agent's health level.

Energy Sensor:
An agent's current energy level.

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Actuators

At each time-step an agent can take the following actions:

Move: Agents can move only in the direction they are facing.

Turn: Agent's can turn left or right.

Hit: Agents can hit whatever else is in the same cell as them. Hitting uses energy and hitting a rock will harm health levels.

Mate: Mate with another agent in the same cell.

Eat: Eat whatever is in the current cell.

Sing: Made an audible sound that is heard by other agents.

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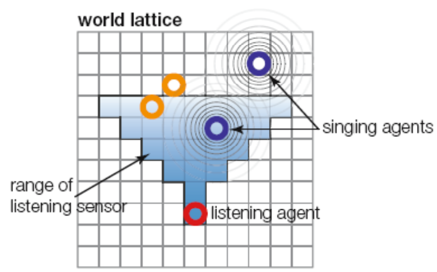
Singing

Singing itself does not improve the health of an agent.

Singing can be used as a survival strategy or be done in response to environmental challenges. (More on this later)

When an agent sings, their sound propagates through the environment based on a simplified physical model of sound pressure. **The audio is also generated for the audience.**

Agents can hear other agents singing only if they are in front of them and within the conical reception areas. Agents are always listening for other agents.



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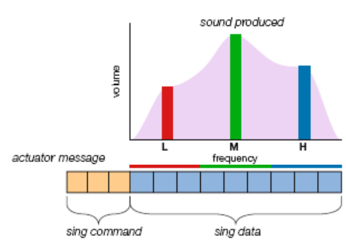
Sound Generation

Agents can produce sound in 3 frequency ranges:

Low: 100-1,000Hz
Mid: 1,000 – 10,000 Hz
High: 10,000 – 20,000 Hz

Sound messages encode volume levels for each frequency range using 3 bits. **This results in 512 distinct sounds**.

Every sound has a pre-recorded sample associated with it.



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Performance System: Agents

The performance system allows each agent to communicate with its actuation system.

Sensor data arrives to each agent as a 32 bit binary message. Messages are placed into the agent's ***Active Message Table.***

At each time step, the message at the top of the message table is compared with each rule in the agent's ***Rule Table*** to look for matches.

Rules that match the incoming message string **bid** for use.

The winning Rule sends an output string back to the Active Message Table.

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Performance System: Rules Table

The rules table has 3 components:

1. **Condition String**
   Condition strings are compared to incoming messages.
   A bit string composed of 0's, 1's and #'s.
   A one must match a one. A 0 must match a 0.
   #'s can match either a 1 or a 0 in the message string.

   Example: 10##1##0

2. **Output Message**
   The message that is output if the rule wins the bid. These are 32 bit messages identical to sensor data messages. They can trigger actions, but do not have to.

3. **Credit**
   A measure of the usefulness of a rule based on past performance.

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Performance System: Rules Table

Rules Table

RULE		
condition string	output message	credit
10010111	00001000	100
10010##1	00000010	100
1######1	01000000	200

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Performance System: Bidding

Bidding:

Any **Condition Strings** that match the incoming **Sensor Message** take part in a bidding process.

The **winning bid** is the condition string with the highest **Strength**.

Strength = Specificity x Credit

The rule that wins the bid sends its **Output Message** to the **Active Message Table**.

MATCHING RULES				
RULE				
condition string	output message	credit	specificity	strength
10010111	00001000	100	1	100
10010##1	00000010	100	0.75	75
1######1	01000000	200	0.25	50

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Performance System: Bidding

Specificity

Specificity is a the number of matching 1's and 0's in condition messages. (Not #'s).

Examples:

######## Has a specificity of **.00** *(but will match any message)*

###1#101 Has a specificity of **.50**

1#00110# Has a specificity of **.75**

MATCHING RULES

RULE				
condition string	output message	credit	specificity	strength
10010111	00001000	100	1	100
10010##1	00000010	100	0.75	75
1######1	01000000	200	0.25	50

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Performance System: Credit

Credit

Rules are assigned credit values based on how useful they have been in the past helping the agent find food or mate.

Determining Credit Values

Step 1:

When a rule wins a bid it pays that bid to the message that it matched. This can either be a **sensor message** or a **rule message** in the rules table. *(Output Rules go back into the Active Message Table for processing)*

The total credits paid to the **Environment** and to the **Rules Table** are summed and stored in a separate table along with all the rules that called them.

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Performance System: Credit

Determining Credit Values

Step 2:

When an agents **health differential** exceeds a particular magnitude (positive or negative) a credit payoff is made.

The payoff is made to all rules that have been applied since the last credit payoff.

If the agents overall health has **increased** the payment will **add** credit to the active rules.

If the agent's health has **decreased** the payment will **subtract** credit from the active rules.

The payments are based on the frequency of use of each rule in proportion to the total bid payoff to the environment.

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Performance System: Credit

Why This Credit System Works

Computing credit values using this system rewards not just the rules that were **directly** involved in improved the health of an agent, but also the rules that were **indirectly** involved.

This lets the system learn to apply patterns of rules in order to obtain goals.

Example:

Rules for turning or moving may not directly improve the agents health, but without them the agent cannot find food.

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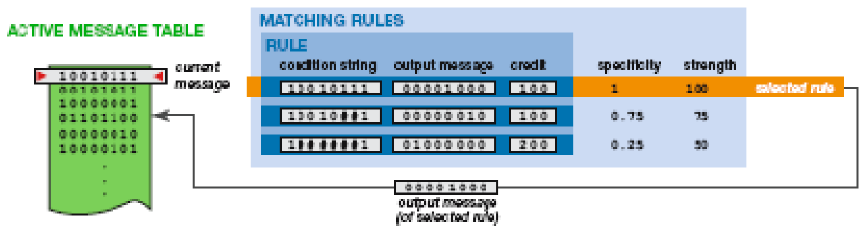
Performance System



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Agent Evolution

When two agents mate they create a new agent that has a new **Rule Table** that is a combination of the parents' tables.

Rules with the highest strength from each parent are selected.

These rules are then evolved using the **Crossover** and **Mutation**.

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Genetic Algorithms
Crossover

Split Point

Two Phenotypes are split at a random point

1010110010101	011100100010
1011001010011	010100101010

Their bits are recombined

1010110010101	010100101010
1011001010011	011100100010

Offspring are generated

1010110010101	010100101010
1011001010011	011100100010

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Genetic Algorithms
Mutation

Mutations are introduced into the system in order to explore creative possibilities that might be overlooked.

Mutations flip random bits in the genotype (1 in every 10,000) introducing variation into the system.

It also prevents the development of a population that is incapable of further evolution.

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Interaction by Audience

Goals:

The system should respond to visitor's behavior without the need for explicit interaction.

The users should direct the system towards subjectively satisfying output even if they are unaware of their doing so.

This means that the installation should be **Reactive** rather than **Interactive**

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Interaction

Visitor's movements through the installation space is tracked.

(In the current implementation this is done using computer vision, but earlier works used infrared range finders.)

Parameters Tracked:

1. Presence of an object
2. Location of the object in relation to the virtual space
3. Movement of the object

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Interaction

Mapping

Physical object presence increases the absorption rate of energy for biomass in the adjacent virtual space.

Effect: There will be a greater abundance of food in areas where people stop which will reinforce the health of the agents in that location.

Physical object movement increases mutation rates for agents in the adjacent virtual space.

Effect: Agents in areas that do not attract an audience will mutate faster causing their output to morph as well.

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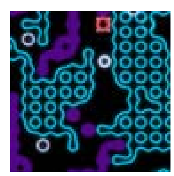
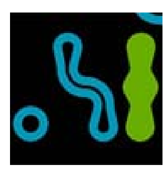
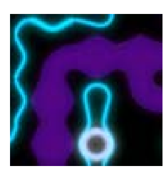
The Experience







Audio 1 Audio 2 Video

http://www.csse.monash.edu.au/%7Ejonmc/projects/eden/

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References

Holland, J. H. (1992). Genetic algorithms computer programs that 'evolve' in ways that resemble natural selection can solve complex problems even their creators do not fully understand, *Scientific American*, 62-72.

McCormack, J. (2007). Artificial Ecosystems for Creative Discovery. Proceedings of the 9th annual conference on Genetic and evolutionary computation, 301-307.

J. McCormack: *New Challenges for Evolutionary Music and Art,* in Lanzi, P. L. (ed), ACM SIGEVOlution Newsletter, Vol. 1(1), April 2006, pp. 5-11, ISSN 1931-8499.

McCormack, J. (2005). *On the Evolution of Sonic Ecosystems* A. Adamatzky & M. Komosinski (Eds.), Artificial Life Models in Software, 211-230. Springer.

McCormack, J. 2003, 'Evolving Sonic Ecosystems', *Kybernetes*, 32(1/2), pp. 184-202.

McCormack, J. 2002, 'Evolving for the Audience', *International Journal of Design Computing*, 4 (Special Issue on Designing Virtual Worlds).

McCormack, J. (2001). Eden: An Evolutionary Sonic Ecosystem. *Proceedings of the 6th European Conference on Advances in Artificial Life*, 133-142.

http://www.csse.monash.edu.au/%7Ejonmc/projects/eden/

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