

**An Evolutionary Approach to Synthetic Biology:  
Zen and the Art of Creating Life.**

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# Author Bio

- Harvard trained Evolutionary Biologist.
- Professor @ University of Oklahoma. Dept. of Zoology.
- Creator of “Tierra” – quite well known in the ALIFE community.
- Currently Researching in Human Information Science Laboratories in Japan.



# Intro

- Author is proposing a totally new approach to ALIFE.
- Author is assuming and even explicitly stating that (the Theory of) Evolution is all you need to create Life in a sufficiently complex medium that supports units that can self-replicate.
- New approach involves adhering and respecting what is more natural to the artificial medium.

# Main Sections

|                             |                         |                                |                     |
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# 1. Synthetic Biology

- Two approaches to ALIFE:
  - (1) *Simulating Organic Life by creating mimics. Simulating Real Physics, Chemistry and Biology [Simulation].*
  - (2) *Simulating entirely **New Instances of Life**. New physics-chemistry-biology that is suited to the medium is engineered [Synthetic Biology].*
- Creating New Instance of Life requires:
  - (1) Understanding and respecting the natural form of the artificial medium.
  - (2) Letting evolution find life-forms that are more “naturally” adapted to the medium and exploits the medium.
- Paper describes some guidelines on what the rules might be for *such an instance of synthetic biology* suited to the medium of computers and software.

## 2. Recognizing Life

- Lots of ideas and disagreements on the essential properties of Life.
- Author's private list consists of only two properties that living systems exhibit: (1) *self-replication* and (2) *open-ended evolution*.
- Author proposes to dismiss our preconceived notions about Organic Life – other instances of life might have extremely different properties.  
(Pluralistic approach)

# 3. What Natural Evolution Does

- Evolution is a *search* process that explores the possible space of self-replicating entities and moves towards natural attractors inherent in that medium (bacteria, virus, insects, birds, plants)
- Evolution is a universal process: works on any medium that supports *self-replication* and *variation in copies*.
- Notes that, Non-Organic Evolution may produce entities that are vastly different and difficult to recognize.
- Notes that, Non-Organic Intelligence may even be more difficult to categorize and test: Turing Test may not be viable.

# 4. The Approach

- Involves...Implementation of Evolution in Computational Medium of Computers, Software, Networks, etc.
- Involves...Not Simulating Real Physics, Real Chemistry and Real Biology. None of this is natural in the context of Computational Medium (CM).
- Instead...Try to come up with a synthetic physics, synthetic chemistry and synthetic biology more suited to CM.
  - Ex 1. There is no 3D Euclidean Space within Computer Memory Space.
  - Ex 2. Inter cellular communication is chemical in nature. In CM, communication is passing of bit patterns.

# 5. The Computational Medium

- CM (Computational)
- Universe of Information and Logic.
- Flat Space (memory).
- CPU+Instructions = Dynamic Activities.
- Operating System oversees resource allocation and rule application.
- RM (Real)
- Universe of molecules, atoms, quarks.
- 3D Euclidean Physical Space.
- Matter + Energy = Dynamic Activities
- “**Nature**” oversees resource allocation and Physics application.

## 6. The Genetic Language

- In CM, machine language instruction set of the CPU is “naturally” suited to be the genetic language.
- Digital Life (DL) are programs written in this language and executes in the CPU.
- **Problem:** Machine Language is brittle and leads to degeneracy. Causes large number of non-viable offsprings.
- Research suggests, these can be handled by proper machine language and fault-tolerant CPU design.

# 7. Genetic Operators

- **Errors:**
  - Evolution needs variations caused by copying errors.
- **Point Mutation:**
  - Introduced by bit-flip errors during copying.
- **Flaws:**
  - Environmental Errors. Probabilistic CPU instructions.
- **Cross-Over:**
  - Sexual Reproduction: wider variety in off-springs.
- **Transposon implementation:**
  - Parasitic self-replicating genetic expressions theorized to have caused Eukaryotic explosion during the Cambrian Period.  
Implementation may cause similar explosion in CM.

## 8. Artificial Death

- Death is a natural phenomena in Evolution. It replaces/recycles valuable resources.
- Death is not natural in CM. It needs to be introduced.
- Artificial Death can be implemented via
  - Reaper Functions that clean up older organisms as newer ones are introduced
  - Flaw rate could increase for older organisms
  - Suicide instructions
  - Death by Crowding
  - N number of reproductions before death.

## 9. Operating System

- Nature or Reality enforces the Laws of Physics and resources are allocated and reallocated according to the Laws of Physics.
- In CM, the counterpart to this Rule Executor and Resource Allocating Agent is the Operating System.
- Operating System can enforce any arbitrary set of rules based on Informational Logic: thus any Synthetic Information Based Physics can be enforced.

# 10. Spatial Topology

- The memory based space in CM is composed of RAM, disks, networks, etc.
- It is falsely identified as one dimensional space.
- It is non-Euclidean.
- It has a complex structure based on differing access times (e.g. between 64K boundaries, disks, networks, etc).
- It is not necessary to enforce 2D or 3D Euclidean structure in CM. Rather, memory already has a sufficiently complex structure. Complex DL can evolve in such a space.

# 11. Ecological Context

- Studies indicate Ecology has the following universal properties:
  - Evolving entities themselves modify the environment. Thus, the environment is ever changing.
  - Certain behaviors and phenomena are only exhibited when entities are co-evolving (e.g. parasitism).
  - Species variety increase with available Space. Rate of Extinction is inversely proportional to Space.
  - There are natural ecological attractors (plants, animals, mammals, birds, insects, etc).
- ALIFE creatures, traditionally, in contrast, evolve against a static fitness function and in limited space.
- If CM is to evolve truly new instances of DL, evolution must be allowed to be open-ended (not against a fitness function) and in bigger space.

## 12. Cellularity

- Cells are the building blocks in Organic Life. A cell represents an individual Organism. A cell membrane defines the boundary and restricts material coming in and passing through.
- The concept of self-contained atomic building block is inherent in Nature: atoms, molecules, complex-molecules, cells, tissue, etc.
- Such a basic DL building block in CM could be an allocated block of memory holding the machine language program.

# 13. Multi-Cellularity

- Multi-celled creatures are higher level and more interesting.
- Multi-celled DL translates to parallel processes.
- Evolution has been greatly successful in creating ever complex multi-celled life – hence evolution has a proven record of being able to produce complex massively parallel software.
- Multi-cellular entities are guided by initial mother cells that direct the growth and eventually delegate specific tasks to specialized daughter cells.
- This abstracted concept of multi-cellularity can be implemented in almost the same way in DL in CM.

# 14. Digital Husbandry

- Humans have been controlling evolution of plants and animals for thousands of years (agriculture, breeding/domestication, etc). Such plants and animals perform useful tasks.
- Evolution in CM is especially well-suited to evolve DL that perform useful tasks: more optimized code, “grown algorithms/modules”, robotics, nano-bots, etc.

# 15. Living Together

- It is important to realize both the benefits and dangers of living side-by-side with any different life-forms: DL in CM is no exception.
- If properly planned, we can have a symbiotic relationship with DL and have a harmonious future.

# 16. Challenges

- Respecting the medium: not easy to get over our preconceived notions about Physics, Chemistry and Biology
- Understanding Evolvability: not easy to understand what makes certain things more evolvable.
- Creating Organized Sexuality: Many theories, but still not known why nature prefers sexual reproduction. Evolution of DL should open them to both possibilities (sexual and asexual).
- Creating Multi-Cellularity
- Controlling Evolution
- Living Together

# Presenter's Summary

- Evolving machine language programs in virtual machines is indeed natural ALIFE practice in CM.
- Paper presented a strong argument against the use of static fitness functions and favored open-ended evolution – assuming the goal is to evolve DL.
- Computers don't exist in vacuum. They themselves are bound by the Laws of Physics. Thus, the meta-physics of CM are ultimately bound by Real Physics. Proof: non-Euclidean memory space is limited by physically real resources.
- THE END.