Research Paper Presentation

"Artificial Life as a Tool for Biological Inquiry"

Authors: Charles E. Taylor & David Jefferson

Presented By

Sadat Chowdhury

Sep 8, 2005. Graduate Center, CUNY.

Background

- Paper published in Volume 1, Issue 1 - Fall 93/Winter 94 - of "Artificial Life Journal" (~10 years ago)

- Charles E. Taylor (source: UCLA Dept of EEB):
  - Professor @ UCLA's Dept. of Ecology and Evolutionary Biology
  - Research Interests: Population Genetics and Adaptation; population structure of malaria vectors.

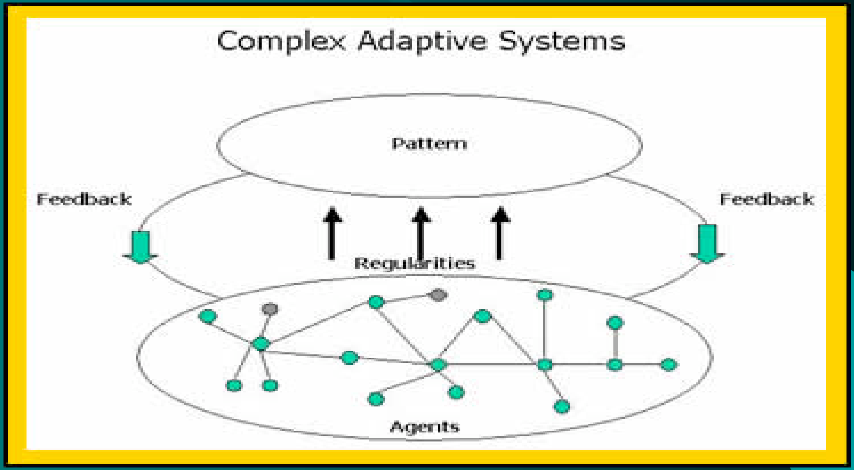
- David R. Jefferson (source: who's who online) :
  - *Formerly*, Professor @UCLA's Dept. of Computer Science
  - *Currently*, @ Digital Equipment Corp (DEC)
  - Research Interests: Artificial Life & Robotics (among others)

Intro & Goals of the Paper

1. Advocates the use of AL as a research tool for investigating many open issues in Biology:
   - Reason 1. AL models capture the essential complexity characteristics of natural life.
   - Reason 2. AL models are more easily controllable and repeatable.
2. Characterizes AL based on four fundamental levels of structure found in natural life-forms.
3. Classifies AL based on medium of experimentation or simulation.
4. Discusses seven open problems in Biology that are good candidates to be addressed by AL.

Characterization of Artificial Life

- Based on four fundamental levels of structure found in natural life-forms:
  - Molecular
  - Cellular
  - Organism
  - Population



- An entity at any of these levels is a *complex adaptive system* exhibiting behavior that *emerges* from the interaction of a large number of elements from the lower levels.

1. Molecular Level

Self-replicating molecules that are fundamental in living processes. Viruses are made up exclusively of RNA. They are mostly involved in the production of Proteins and regulating growth and biochemical processes

- Medium: Wetware
- Mostly bio-chemical lab experiments devised to evolve RNA molecules with specific properties: e.g. RNA's that produce specific proteins.
- May provide experimental proof of the "RNA world" hypothesis - that life on Earth evolved from an exclusive population of RNA molecules that later on evolved into more complex life-forms.

… RNA > DNA > ***protozoan*** > ***metazoan*** …

Higher order than RNA. Encodes genetic information and guides formation of RNA

Single celled life: e,g, bacteria

Multi-celled life: e.g. mosquito, human

2. Cellular Level

> Endosymbiosis: association of distinct cell types within an outer layer of "membrane cells" (skin)

- Medium: Software Systems
- Most AL research directed at this level are computer simulations of CE or OE using Cellular Automaton models.
- **Chemical Evolution**: evolution from self-replicating molecules to protozoic life.
  - (theoretically took 1 billion years)
- **Organic Evolution**: evolution from protozoic life to metazoic life. May have involved ***endosymbiosis*** and association of genetically related cells.
  - (theoretically took 3 billion years)

3. Organism Level

- Medium: Hardware Systems (Robotics)
- Modeling higher-level organisms e.g. insects, dogs (AIBO), humans (ASIMO).
- Computational complexity for total computer simulations exceeds current and near-future capacities.
- Actual physical/hardware medium is used instead: electro-mechanical sensors (input) and actuators (output), mechanical chassis (body), and a computer controlled central processor (brain).
- Current models already display emergent intelligent properties (e.g. simulations shown of crawling/walking models)

4. Population Level

- Medium: Equational Models (past), AL (present).
- Equational models result in computationally complex (differential) equations and cannot easily deal with non-linearity that is inherent in population behavior.
- Instead, population models are more easily built using programs that represent individuals (and their behavior) and a simulated medium that model the environment.
- Instead of solving equations to answer questions of mass behavior - simulations are run and results are easily observed/measured.

4. Population Level (Continued)

- Population Level AL models are good tools to study and/or demonstrate:
  - Evolution: we can have entities programmed to reproduce in an environment and working under selective pressure to meet certain fitness. Controllable mutation rate produces variation.
  - Behavior: the emergent behavior of entities can be observed on an individual or collective level
  - Ecology: the total interaction of entities and environment. Macroscopic effects in population and environment.
  - Developmental Biology: modeling multi-cellular development using simple single cell rules of cell division and differentiation. (e.g. modeling the formation of big branching trees from small plants using L-systems)
  - Academics & Teaching: A large portion of the population doesn't believe in Darwinian evolution. AL offers the possibility of watching evolution in action.

Open Problem 1: Origin of Life & Self-Organization

- AL simulations of conditions on Earth (e.g. physical, chemical, geological, etc) may answer what specific conditions lead to the emergence of life on Earth.
- AL simulations of conditions in other planets may answer what prevents or possibly constrains life in those planets.
- AL simulations may give a more abstracted generalized answer to what leads to the emergence of life or self-organized life-like entities.

Open Problem 2: Cultural Evolution

Richard Dawkins' "Selfish Gene"

- Certain parts of human culture - ideas, fads, fashions, etc seem to have life-like properties: origination, mutation, reproduction, spread, death - resulting in "cultural evolution"
  - Note: these "atomic cultural units" are also known as ***memes***
- AL may aid in identifying what evolves (i.e. the memes), how they maintain their identity and how they interact with one another.

Open Problem 3: Origin and Maintenance of Sex

- Evolution of sex is puzzling. Asexual reproduction passes twice as many genes to the offspring as does sexual reproduction. Yet, sexual reproduction is quite abundant in nature - even more in metazoic life-forms.
- Many theories, but most are not testable.
- AL simulations may be used to study the issues and test theories.
- Author mentions AL experiments that show that sexual systems are better at getting rid of maladaptive mutations. The AL experiments involved population of bit-strings that evolve by genetic algorithms.

Open Problem 4: Shifting Balance Paradigm

- How do populations traverse the adaptive landscapes - gradual fine-tuning via natural selection OR fits and starts and “jumping” adaptive valleys?

- Traditional method of studying populations via complex (differential) equations are not good for exploring this due to the presence of various nonlinear interactions between entities and its environment.

Control of a phenotype by more than one gene

Inverse of Epistasis: multiple genes controlling a single phenotype

- ***Epistasis*** and ***Pleiotropy*** of evolving populations are difficult to model.

A specific encoding of DNA for a specific phenotype

Outward physical expression or trait (hair color)

- AL is ideally suited to model such properties and behaviors in populations of interacting programs modeling creatures with ***genotypes*** & ***phenotypes***

Open Problem 5: Fitness and Adaptedness

- What is the relation between fitness and adaptedness?
- Natural selection doesn't necessarily maximize adaptedness although it might maximize fitness (local maxima?)
- AL might shed some light on this issue.
- AL experiments by Miglino, Nolfi, and Parsi show that variety of genotypes coded for identical phenotypes (neural nets), variety of neural nets coded same behavior, variety of behavior achieved the same fitness - yet each solution had different effects on the future evolution (adaptedness) of the entities.

Open Problem 6: Structure of Ecosystems

- Natural ecosystems exhibit a number of emergent patterns:
  - Ratio of top predators, intermediate species and basal species is roughly constant
  - Linkage density is roughly constant
  - Modal number of ***trophic*** levels is three to four.

Level occupied by an entity in a food-chain

- The reasons behind these regularities are not clearly understood - artificial ecosystems with AL exhibiting similar properties will shed valuable insights into these emergent properties.

Open Problem 7: Mind in Nature

- Scientific Grand Challenge of all time: understanding mind and consciousness.
- Possibility of evolving robots/AL that have sensations and consciousness.
- Does (Artificial) Darwinian evolution eventually produce mind and consciousness.
- Are artificially produced minds and consciousness radically different from that of natural ones? Or, are minds and consciousness, by any means, all the same.
- Authors believe AL will ultimately help solve this "Scientific Grand Challenge of All Time"

Summary

- Authors viewed AL as a Swiss-army knife for tackling issues in Theoretical Biology.
- The essential points can be kept in mind as we study future research works (e.g. is it answering any of the open questions OR what level of AL is it).
- It's been ~10 years since the publication of this paper. Where are we now with AL and the 7 open issues? Has the Biologist's view of AL changed?
- Like any technology, AL will open doors to other vistas not anticipated - genetic engineering, medical nanotechnology, cybernetic implants are a few examples of the merging of AL or AL principles with NL.

References:

- Artificial Life, An Overview, Edited by Langton, C. (textbook)
- Wikipedia (www.wikipedia.com)
- “Selfish Gene” Richard Dawkins
- “Extended Phenotype” Richard Dawkins
- NetLogo Simulations
- Google

The End