Artificial Life by C. Langton

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I585: Biologically Inspired Computing
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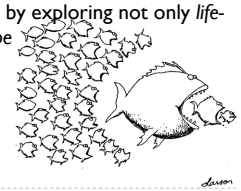
Agenda

- Overview of Key Concepts
- The Biology of Possible Life
- Biological Automata
- Recursively Generated Objects
- Evolution & Genetic Algorithms
- The Role of Computers in Life Generation
- Linear vs. Nonlinear systems
- Conclusion

Overview of Key Concepts

- AL is the study of man-made systems that exhibit behaviors characteristic of natural living systems.
- Biology attempts to *analyze* (top-down) living organisms while AL attempt to *synthesize* (bottom-up approach) life-like behaviors within computers and other artificial media.
- AL can contribute with biology by exploring not only *life-as-we-know-it* but *life-as-it-could-be*

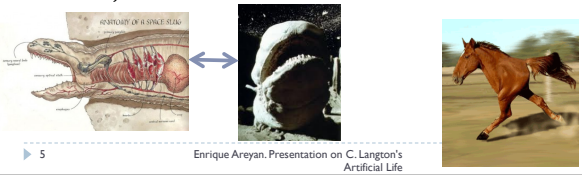


The Biology of Possible Life

- life-as-we-know-it vs. life-as-it-could-be
  - Biology: study of *life-as-we-know-it*, based on carbon-chain chemistry, the only kind of life available for study.
  - Is it possible to derive general theories from single examples?
  - Life, as a dynamic physical process, could "haunt" other physical material. What matters is the organization of such material.

The Biology of Possible Life

- According to Langton, life, as a process and regardless of its material bases, must share certain universal features
- What are these universal features? The answer will allow us to recognize life by its dynamic form alone, without reference to its matter
- We could try to synthesize alternative life forms, *life-as-it-could-be*, to search for universal features of life



Artificial Life

- A field that uses a synthetic approach to the study of *life-as-it-could-be*. Life as a **property** of the organization of the matter, rather than a property of the matter itself.
- Biology deals with the material basis (using an analytical, top-down approach) whereas AL deals with the formal basis (using a synthetic, bottom-up, distributed, local determination of behavior approach).
- Construct large aggregates of simple, rule-governed objects, which interact with one another in a nonlinearly fashion.
- **Key Idea: Emergent behavior**

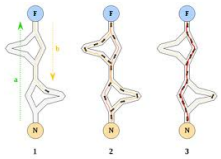
Artificiality

- Connotes perceptual similarity but essential difference, resemblance from without rather than within.
- The artificial object imitates the real by turning the same face to the outer system.

- AL seeks to capture the behavioral essence of the components of a system – if organized correctly they should exhibit the same behavior as the natural system

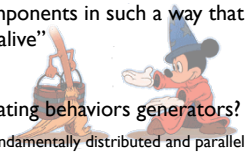
Artificiality

- Force the basic components (behavioral primitives) of a system to obey basic rules of interaction among them, organized them as in the real system and let the behavior of interest **emerge**.
- The computer is the right tool for this computing-intensive approach.
- Illustrative idea: **colony of ants**.



The Animation of Machines

- There is no need to "bring" life to a machine, we only need to organize its components in such a way that their interactive dynamics is "alive"
  - Reject vitalism
- How we go about creating behaviors generators?
  - Consider that nature is fundamentally distributed and parallel
- AL main focus is to create behaviors generators, i.e. identify the mechanisms by which behavior is generated and controlled in natural systems, and recreate these in artificial systems.



Biological Automata

- AL searches for abstractions of the logical form of organisms from its material configuration
- Behavior generation in nature is primarily bottom-up, exceedingly parallel and distributed
- Genotypes and Phenotypes are key from the biological behavior generation point of view
  - Genotypes: set of genetic instructions encoded in the linear sequence of nucleotide bases that constitutes the DNA
  - Phenotypes: is the physical organism itself, the structure that emerge in space and time as the result of the interpretation of the genotype in the context of a particular environment
  - Morphogenesis is the process from genotypes to phenotypes

Biological Automata

- Generalized genotypes (GTYPE) and phenotypes (PTYPE) The idea is to abstract the way nature generates behavior to approach other, non-biological situations
- GTYPE = largely unordered set of low-level rules
- PTYPE = behaviors/structures that emerge out of the interactions among GTYPE in some specific environment
- Think of GTYPE as an abstract specification for a set of "machines" and PTYES as the result of this interaction.
  - Nowhere is the behavior as a whole specified. The global behavior of the aggregate is a consequence of many interactions.
  - Local, nonlinear interaction produces PTYPE.

Unpredictability of PTYPE from GTYPE

- The set of all possible PTYPE is huge (factorial order) on the set of possible GTYPES. Many possible behaviors.
- Trade-off between behavioral richness and predictability.
- We cannot know (through a formal procedure) which specific alterations must be made to a GTYPE to effect a desired change in PTYPE!
- They may be a way to change a GTYPE to alter an specific portion of PTYPE but it is not feasible to compute (exhaustive search)
- Nature addresses this issue through a process of trial and error grounded on natural selection, *arguably* the only efficient procedure

Recursively Generated Objects (RGO)

- From recursive rules (GTYPE) that apply to local structures ***emerges*** complex structures or behavior (PTYPE) of the global system.
- This is a much simpler approach to the generation of complex behavior than its alternative, top-down, analytical approach (counter example: expert system).
- RGO is a general approach to construct GTYPE/PTYPE systems
  - GTYPE = the recursive description of the object
  - PTYPE = the developing structure or the recursively-generated object or behavior obtained trough a process of morphogenesis.
  - The system starts with a single part to which the rules are applied recursively over and over again.

Examples of RGO:

- Growth and development of structural PTYPE
  - Lindenmayer systems: Simple Linear Growth/Branching Growth
- Development of a behavioral PTYPE
  - Simulation of flocking behavior

The rules: (the "recursive description" or GTYPE):

```
1)  A -> CB
2)  B -> A
3)  C -> DA
4)  D -> C
```

When applied to the initial seed structure "A," the following structural histor develops (each successive line is a successive time step):

```
time    structure       rules applied (L to R)
0         A             initial "seed"
1        C B            rule 1 replaces A with CB
2       D A A           rule 3 replaces C with DA & rule 2 replaces B with A
3     C B C B           rule 4 replaces D with C & rule 1 replaces the two
4    ....(etc).....     A's with CB's

      And so forth.
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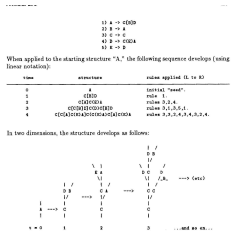


Evolution & Genetic Algorithms

- How do we go about finding GTYPES that will generate lifelike PTYPES?
- Traditional Trial & Error relies on our preconceived notions of what life-like behavior (PTYPES) should be. We are missing on much of the search space.
- A possible solution: nature's **"Intelligent" Trial & Error**, or evolution by the process of natural selection among variants.
- Use natural selection as an algorithm to search the GTYPE space

General schema of a Genetic Algorithm

1. Form populations of PTYPE by interpreting a set of GTYPES within a specific environment. Let the different PTYPES interact with one another and with the environment.
2. Evaluate the relative, application-specific performance (fitness function) of PTYPES and select (with certain probability) the GTYPES of the best performing PTYPES. The best the PTYPE, the higher the chances of selecting its associated GTYPE.
3. Out of these GTYPES select a pair and reproduce them (apply genetic operators, e.g. crossover operator) in such a way that the copies are similar but not identical to the originals.
4. Replace the least successful GTYPES with the offspring recently created. Repeat steps 1-4 ad infinitum.

Genetic Algorithms

- As imposed by the formal limitations on predictability, we have to let each GTYPE interact with the environment and others in order to explicitly evaluated its performance as expressed by its associated PTYPE.
- The GA explores a very large space of possible PTYES in an intelligent manner. In general, the GA selects the GTYPES building blocks most often associated with the most successful PTYPES thus, biasing the sample towards a probable better population of GTYPES.

The Roles of Computers on Life Generation

- Both AI and AL are concerned with generating complex behavior and employ the computer to study complex, natural phenomena. However, they do this very different:
  - AI uses the technology of computation as a model of intelligence. In other words, it attempts to "explain" life as a kind of computer program.
  - AL attempts to develop a new computational paradigm based on natural processes that support living organism. AL uses the computer as a tool to explore the dynamics of interacting information structures or programs.

The Roles of Computers on Life Generation

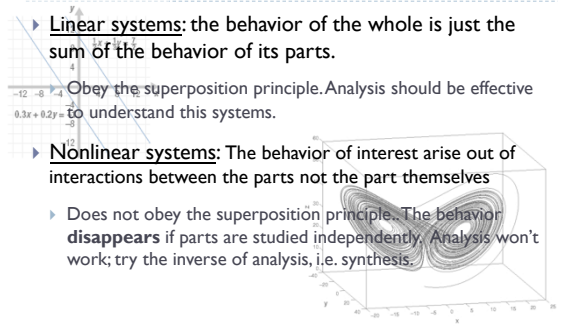
- In the context of AL:
  - Computer should be thought of as an important laboratory that provides an alternative medium within which we can try to synthesize life.
  - If we consider life just as a myriad of information structures interacting with one another, then computer is the primary tool for the manipulation (synthesis) of information.
  - Computer as a workstation for performing scientific experiments within artificial universes. Let the Computer take care of the mundane -but huge amount of- calculations.

The Roles of Computers on Life Generation

- Complex behavior **does not need to have complex roots**.
- If the same is true about what we call life, then we can try the much simpler task of synthesizing complex behavior in the computer rather than creating it from a top-down approach.

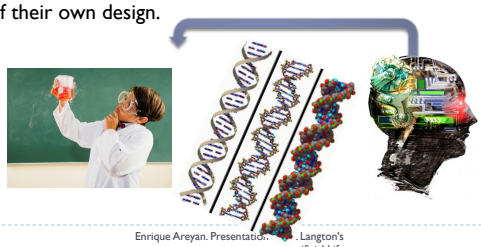
Linear vs. Nonlinear systems

- Linear systems: the behavior of the whole is just the sum of the behavior of its parts.
  - Obey the superposition principle. Analysis should be effective to understand this systems.
- Nonlinear systems: The behavior of interest arise out of interactions between the parts not the part themselves
  - Does not obey the superposition principle. The behavior **disappears** if parts are studied independently. Analysis won't work; try the inverse of analysis, i.e. synthesis.



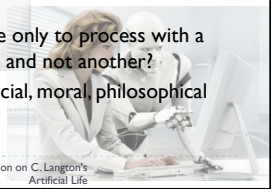
Conclusion

- The process of evolution by natural selection (Blind Watchmaker) has created "seeing watches" capable of understanding what makes them "tick", i.e. humans, which in turn may be able in the future to construct "watches" of their own design.



Conclusion – Topics of Discussion

- How can we justify our manipulations?
- How can we take it upon ourselves to create life, even within the artificial domain of computers, and then snuff it out again by halting the program or pulling the plug?
- What right to existence does a physical process acquire when it is a "living process", regardless of the medium in which it takes place?
- Why should these rights accrue only to process with a particular material constitution and not another?
- AL is a technical as well as a social, moral, philosophical and religious challenge.



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