Theory of Self-Reproducing Automata
John Von Neumann

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Joshua Ridens and David Shubsda

Natural Automata vs. Artificial Automata

Specifically Von Neumann looked at the nervous system and a vacuum tube computer

- Scale: Number of Neurons vs Number of Vacuum Tubes
- Throughput: Speed of Neuron Actuation vs Speed of Vacuum Tube Actuation
- Energy Dissipation: Dissipation of Neuron vs Dissipation of Vacuum Tube
- Memory: Nervous System Memory vs Computer Memory
- System Reliability: Differences between natural and artificial behaviors

Additionally we will look at some current computers in terms of transistors against his comparisons.

Scale

- Estimated number of neurons in nervous system is 10^{10}
- ENIAC has about $2*10^4$ vacuum tubes
- SPARC M7: 10^{10} transistors (Wikipedia)
- Core i7 Haswell: $2.6*10^9$ transistors (Wikipedia)
- Titan Cray XK7 (3rd fastest computer according to top500.org)
  - 299,008 cores, or about 10^12 transistors
  - 50,233,344 CUDA cores, or about 10^17 transistors

Von Neumann noted the differences in scale between natural and artificial automata as a way to measure the differences in complexity.

Throughput

- Human nerve ‘next potential response time’ (according to Von Neumann): 200Hz (once per 5 milliseconds).
- Vacuum tube (at the time): about 5000 times faster, 1 million per second (1MHz)
  - Wikipedia says the ENIAC operates at about 100kHz (ENIAC)
- CPU’s today are capping out around 4GHz, but we also add more cores...

Von Neumann noted that while, at the time, the scale of nerves was huge in comparison to vacuum tubes that the artificial automata is still favored. Because “an n-fold increase in size bring much more than an n-fold increase in what can be done.”

Energy Dissipation

Von Neumann measure this in relation to the the energy dissipation of the transmittal of 1 unit of information.

- Thermodynamic Minimum: $3*10^{-14}$ ergs
- Nerve: $3*10^{-3}$ ergs
- Vacuum Tube: about $3*10^{2}$ ergs
- Transistor Estimate (i7 Haswell): 84W for the chip, at 3.5GHz, and 1.4 billion transistors gives about $1.7*10^{-10}$ ergs

Von Neumann noted that the interesting measurement here was the difference between the energy dissipation of a nerve, and the thermodynamic minimum.

“Though the observation that information is entropy tells an important part of the story, it by no means tells the whole story.”

Memory

Von Neumann points out that the devices used in nature are not actually binary or digital, instead they are analog.

“The thing which remembers is nowhere in particular”

“There’s therefore no reason to believe that the memory of the central nervous system is in the switching organs (the neurons).”

- Estimated human memory: Between 10^{10} (1.5 GB) and 10^{15} (125 TB)

The environment that the automata operates in is very important to the overall behavior of the automata.

Question...

These comparisons between artificial and natural automata result in one question: "Our artificial automata are much smaller than natural automata in what they do and in the number of components they have, and they're phenomenally more expensive in terms of space and energy. Why is this so?"

Von Neumann also says that producing the answer to this is hopeless, but that there are a few discrepancies we can observe:

- Materials
- System Reliability

System Reliability

Errors are unavoidable, and the larger the automata the larger the probability for error.

- Natural System
  - Tend to behave in spite of errors
  - Errors do not in general indicate a degenerative tendency
  - System is flexible (one might say adaptable)
  - Can repair errors, or block off entire portions of its systems
- Artificial System
  - Tend to halt because of errors
  - System is rigid
  - Error repair is difficult

This takes a very considerable autonomy of parts to make possible.

We've made a lot of progress in artificial systems to behave more like natural systems, but the original attitudes were very different.

Input and Output

Turing machine modifies an infinite tape

Neurons receive and produce pulses

Both are qualitatively completely different from the automaton

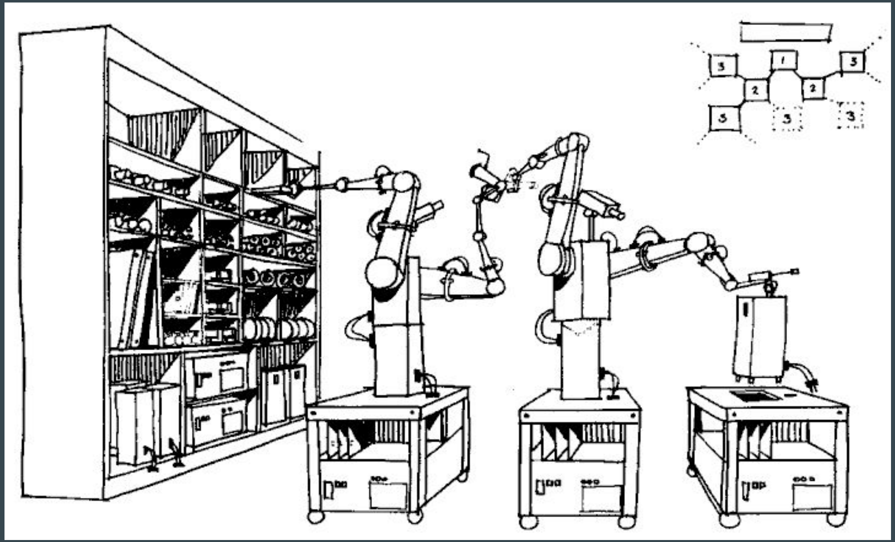
But what about automata which can have outputs similar to themselves?

Replication

Modification of objects similar to themselves

Affect synthesis

- Picking up parts
- Putting parts together
- Take synthesized entities apart



https://upload.wikimedia.org/wikipedia/commons/5/5d/Advanced_Automation_for_Space_Missions_figure_5-29.gif

Elementary Parts

"… it is very difficult to give rigorous rules as to how one should choose the elementary parts."

Too large - define the problem away

Too small - get stuck on questions of the wrong scale

Common sense criteria

Example System

- Neurons
- Muscles
- Energy sources
- Connective Tissues
- Disconnecting Tissues
- 10-15 elementary parts

Potential Problems:

- Simplified system missing important parts
- Avoid explaining these parts' composition
- Size in selection - may vary by multiple orders of magnitude

Questions

“What principles are involved in organizing these elementary parts into functioning organisms?”

“What are the traits of such organisms?”

“What are the essential quantitative characteristics of such organisms?”

Complication

No clear definition

“...an object is of the highest degree of complexity if it can do very difficult and involved things.”

Crudest standard - number of elementary parts

“Miracle of the First Magnitude”

Organisms produce other like organisms

For this reason they are abundant in this world

They are complicated collections of elementary parts

Improbable by any reasonable probability of thermodynamics

Natural Evolution

One degree better than self-reproduction

Description of complex organism encoded in a simpler ancestor?

Genes as a partial description in the milieu

Artificial Automata

Degenerative reproduction

Simpler automata produced by more complex automata

Clear opposite of Natural automata in this detail

Early Model of Self-Reproducing Automaton

Stimulus organ - receives and transmits stimuli realizing or function

Coincidence organ - realizes and function

Inhibitory organ - realizes “p and not-q”

Stimuli producer - source of stimuli

Rigid member - insulated girder

Fusing organ - welds two parts together

Cutting organ - unwelds two parts

Muscle - contracts to create motion