John von Neumann and the Evolutionary Growth of Complexity: Looking Backward, Looking Forward. . .

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Burks' Problem:
Machine Self-Reproduction

- Kinematic Framework
- Cellular Framework (Ulam)
  - Discrete 2D Space/Discrete Time
  - Cells are 29 State FSM's
  - Automata are functional patterns of states over cells, embedded in the space.

Trivial Self Reproduction?

- Burks (1970):

  … This result is obviously substantial, but to express its real force we must formulate it in such a way that it cannot be trivialized …

Trivial Self Reproduction?

- Burks (1970):

  ... Consider, for example, a two-state cellular system whose transition function takes a cell into state one when any of its neighbors is in state one. Define an automaton to be any area, even a single cell. A cell in state one then reproduces itself trivially in its neighboring cells...

Trivial Self Reproduction?

- Burks (1970):

  ... Clearly what is needed is a requirement that the self-reproducing automaton have some minimal complexity...

Burks' Criterion:

- Burks (1970):

  ... This requirement can be formulated in a number of ways. *We will do it by requiring that the self-reproducing automaton also be a [universal?] Turing machine.*

But...
Herman's Counter Example

- Herman (1973):
  - 2D Cellular Framework
  - Cells combine trivial, crystaline, reproduction with universal turing machine head
  - Cells still simpler than in von Neumann model!

But...
Herman's Counter Example

- Herman (1973):

  ...What the result does show is that the existence of a self-reproducing universal computer-constructor in itself is not relevant to the problem of biological and machine self-reproduction...

But...
Herman's Counter Example

- Herman (1973):

  ... Hence, there is a need for new mathematical conditions to insure non-trivial self-reproduction.

Langton's Critique

- Langton (1984):
  Computational criterion too strong rather than too weak?

Langton's Criterion

- Langton (1984):
  - Non-trivial self reproduction characterised by separate processes of copying and decoding of a machine description.
  - Satisfied by von Neumann's design.

But...
Langton's Counter Example!

- Langton (1984):
  Langton's Loop automaton also satisfies this criterion - yet is clearly (?) trivial!

von Neumann's Criterion?

- von Neumann (1949) [Illinois Lectures]:

  … One of the difficulties in defining what one means by self-reproduction is that certain organizations, such as growing crystals, are self-reproductive by any naive definition of self-reproduction, yet nobody is willing to award them the distinction of being self-reproductive…

von Neumann's Criterion?

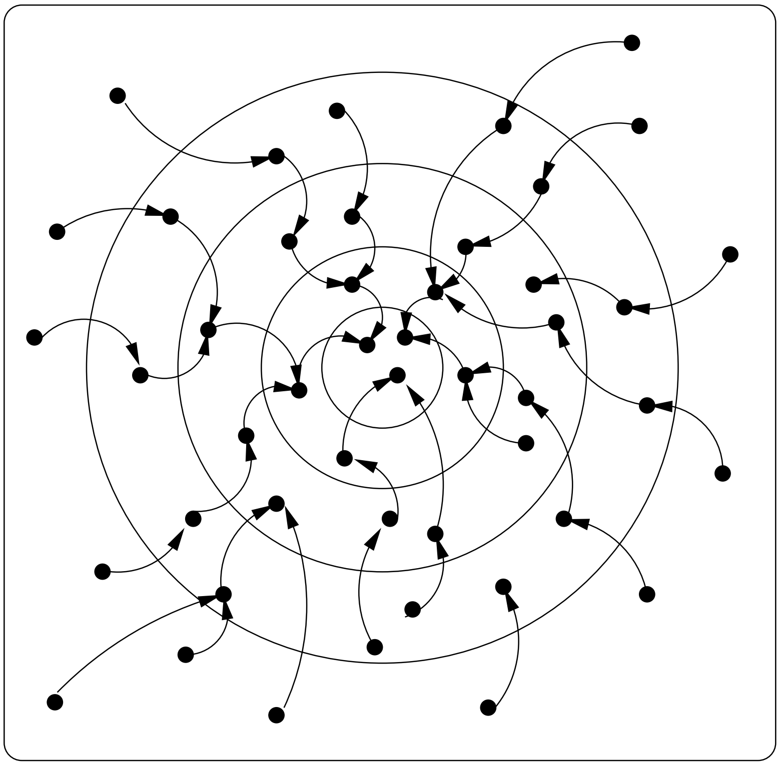
- von Neumann (1949) [Illinois Lectures]:

  ... A way around this difficulty is to say that self-reproduction includes the ability to undergo inheritable mutations as well as the ability to make another organism like the original...

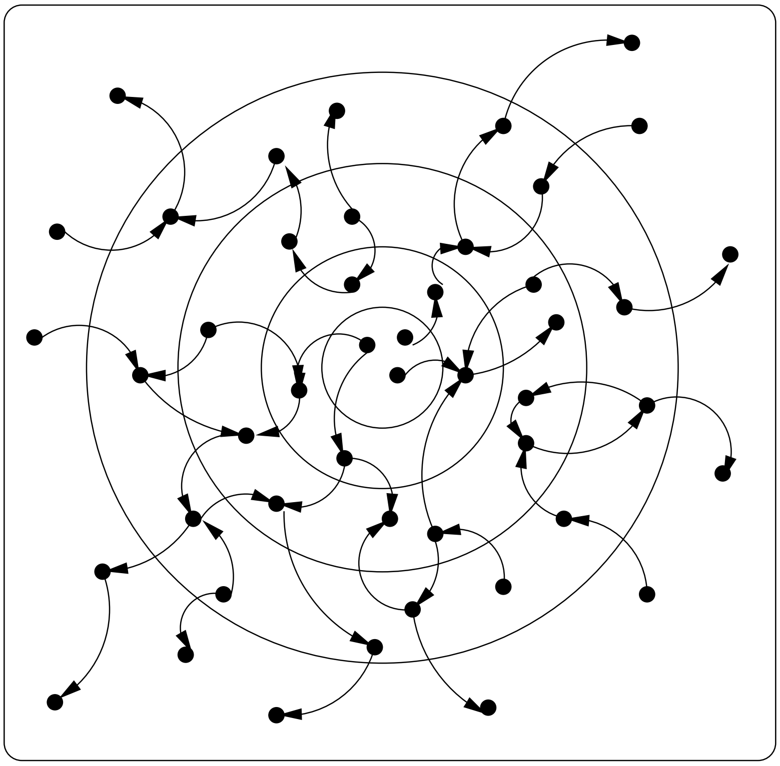
von Neumann's Problem:

- How can machines manage to construct other machines more "complex" that themselves, in a general and open-ended way—i.e., with the potential for unbounded evolutionary growth of complexity.

Degeneration of Complexity (Engineering)



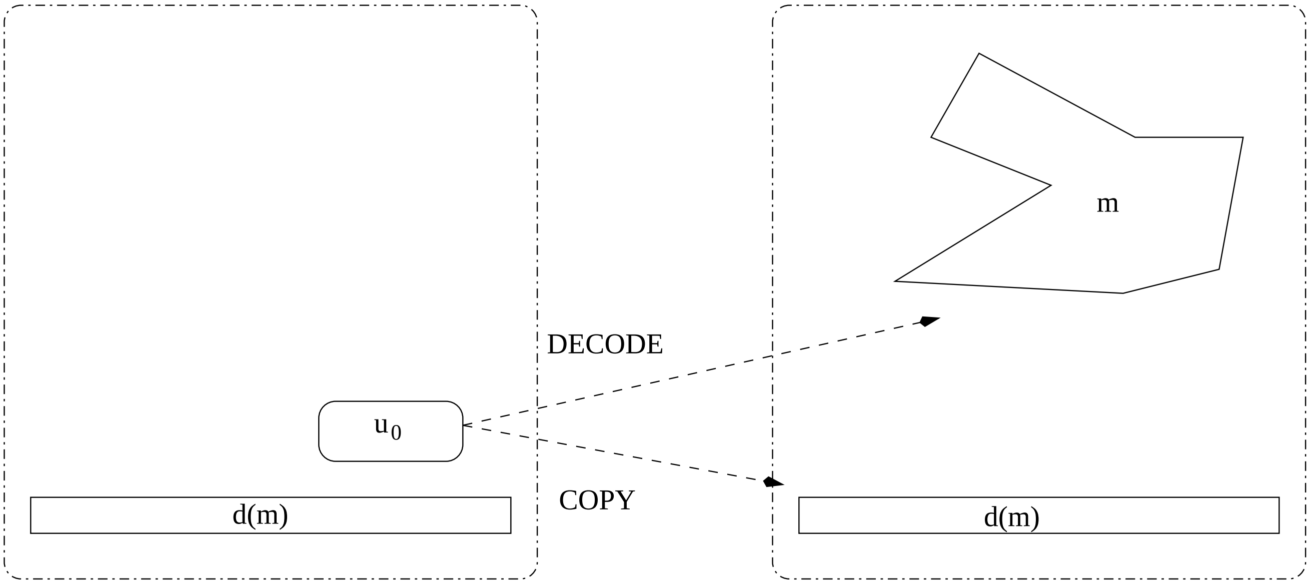
Growth of Complexity
(Biology)



von Neumann's Problem:

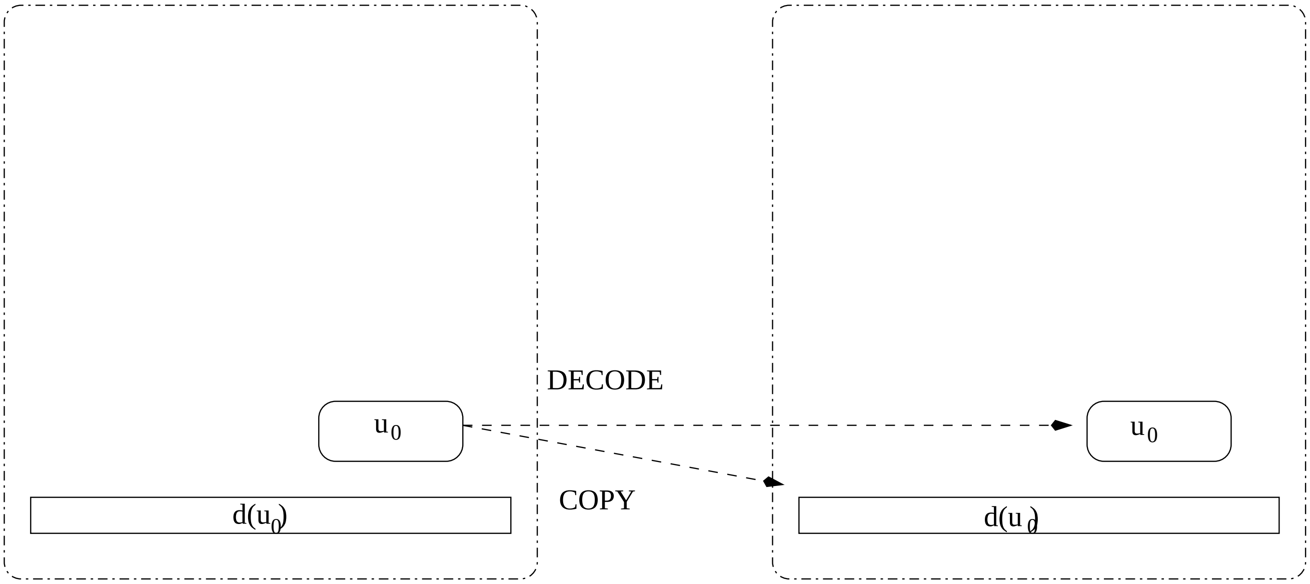
- Exhibit a class of constructing machines, spanning a wide range of complexities, such that the whole class is connected by the relative construction (mutation) network.
- For good measure, require that every machine in the class also be SR (every machine has a self construction loop). This is necessary (not sufficient) for Darwinian selection...

The General Constructive Automaton



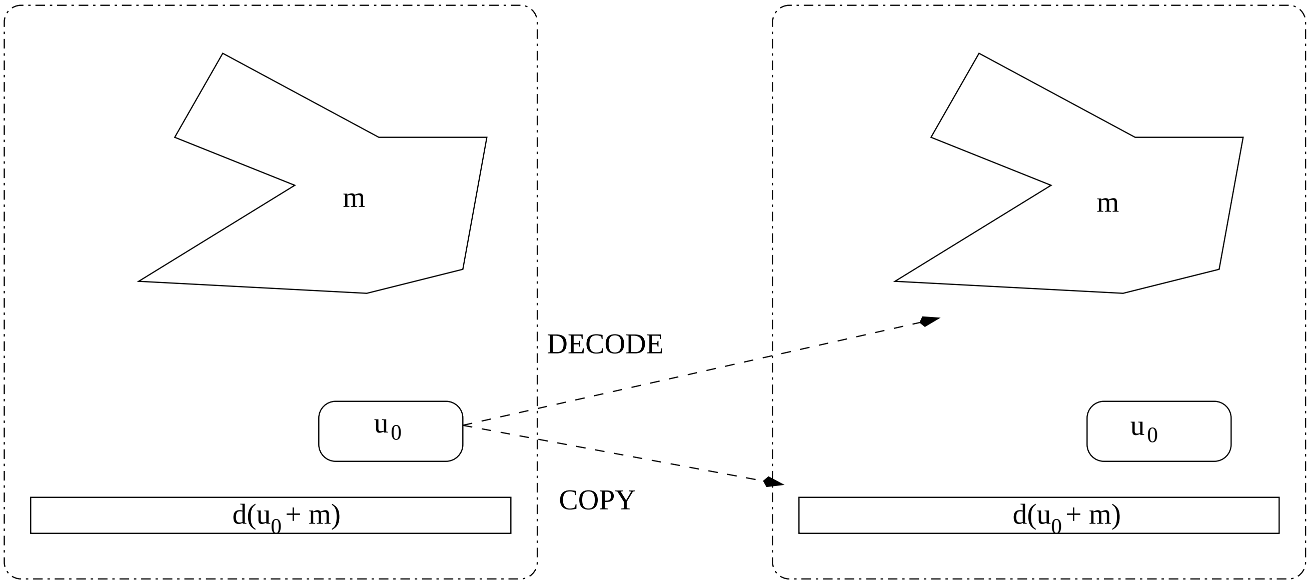
$$(u_0 \oplus d(m)) \rightsquigarrow (m \oplus d(m))$$

Von Neumann SR: Minimal Case



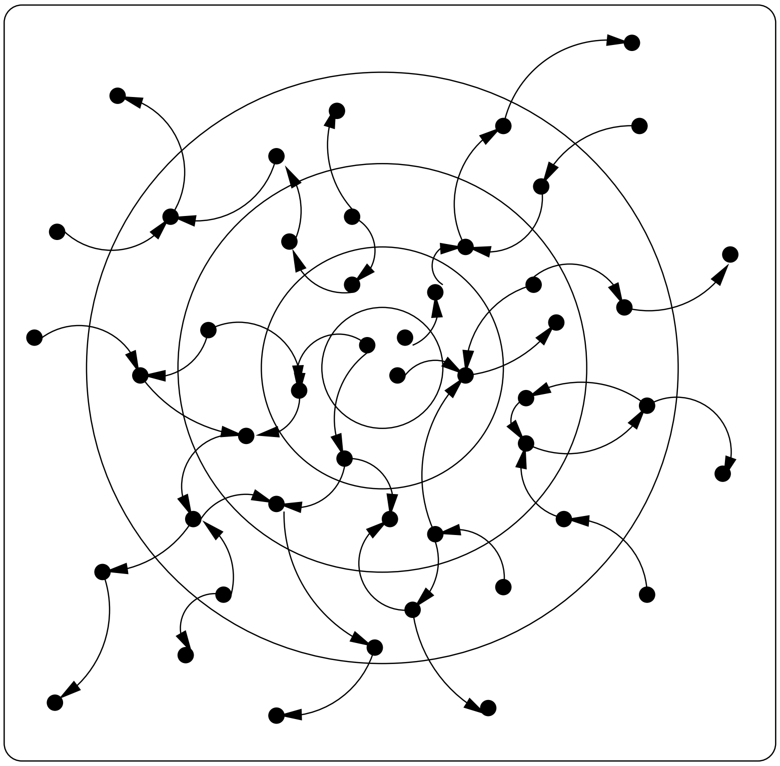
$$(u_0 \oplus d(u_0)) \rightsquigarrow (u_0 \oplus d(u_0))$$

Von Neumann SR: Generic Case



$$((u_0 \oplus m) \oplus d(u_0 \oplus m)) \rightsquigarrow ((u_0 \oplus m) \oplus d(u_0 \oplus m))$$

Growth of Complexity
(von Neumann)



Looking Backward

- Is this the *first* solution?
- Is it the *only* solution?
- Is it the *simplest* solution?

Looking Forward

- Complexity?
- Individuality?
- Origins?
- Evolutionary growth of complexity?

Coda...

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(the *other* SFI...)

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. . . multidisciplinary proposals in Biotechnology/ICT will be welcomed.

Bibliography

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