John von Neumann and the Evolutionary Growth of Complexity

“Vague, unscientific, and imperfect . . . ”

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Complexity: Theoretical Foundations & Practical Implications
Altonaer Stiftung für Philosophische Grundlagenforschung
(Beamer Presentation)

Burks' Problem: Machine Self-Reproduction

Various Frameworks considered:

- Kinematic Framework
  - Tinker toys (Lego Technic)?
  - Not tractable (at least, not in 1940s/1950s; today maybe simulate in an off the shelf physics engine; see also this 16-bit ALU in minecraft!)
- Cellular ("Tesselation") Framework (Ulam/von Neumann)

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(Non-)Trivial Self Reproduction? Burks' Criterion

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 . . .*

> *. . . 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 . . .*

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

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Herman (1973):

- 2D Cellular Framework
- Cells combine trivial, crystaline, reproduction with universal turing machine head
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...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...

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Langton (1984):

- Critique: Computational criterion too strong rather than too weak?
- Alternative: Non-trivial self reproduction characterised by separate processes of copying and decoding of a machine description.
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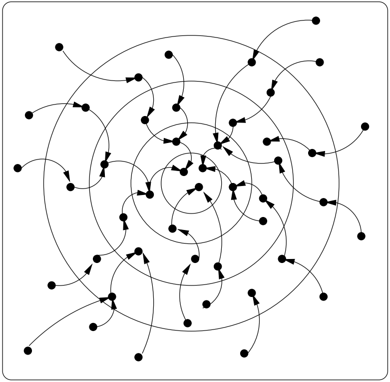
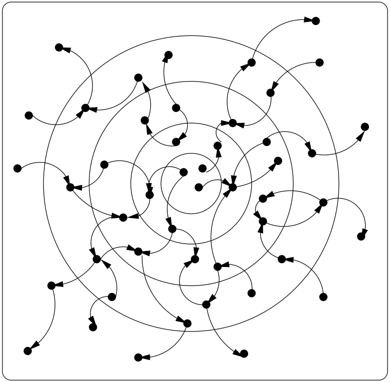
Degeneration of Complexity (Engineering)



Growth of Complexity (Biology)



von Neumann's (*real*) 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.
- What might count as a "solution"?
    - 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...

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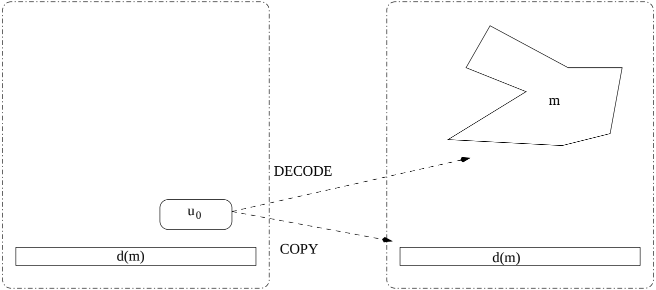
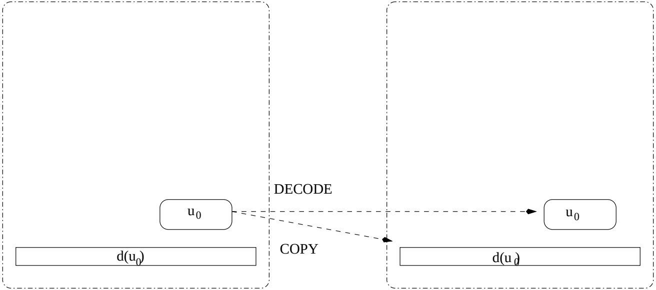
The General Constructive Automaton



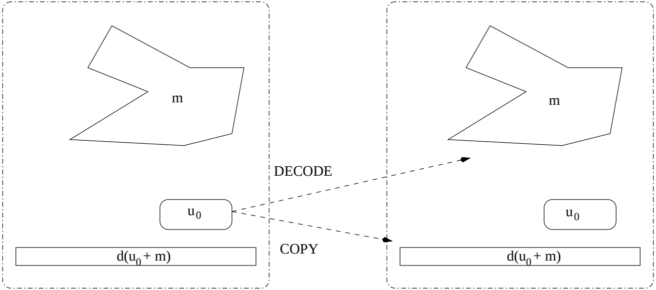
$$(u_0 \oplus d(m)) \rightsquigarrow (m \oplus d(m))$$

Von Neumann SR: Minimal Case



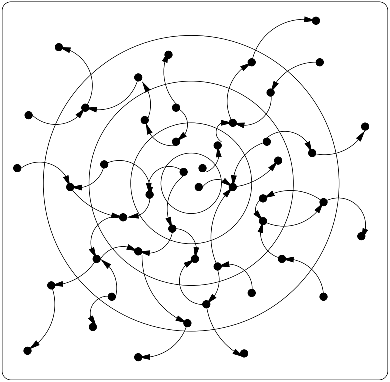
$$(u_0 \oplus d(u_0)) \rightsquigarrow (u_0 \oplus d(u_0))$$

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)



Conclusions: Looking Backward

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

Conclusions: Looking Forward

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

References

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Related Online Resources

- Source files for presentation (LaTeX+beamer):
  - http://alife.rince.ie/talks/altona-2011/altona-2011-src.zip
- Full Paper (Artificial Life, Vol. 6, Issue 4, Fall 2000, pp. 347–361):
  - http://alife.rince.ie/bmcm-2000-01/
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