Hash Chemistry: An Open-Ended Evolutionary System with Cardinality Leap and Universal Fitness Evaluation

Hiroki Sayama

sayama@binghamton.edu

Paper Coming Up

- Sayama, H. (2019) Cardinality leap for open-ended evolution: Theoretical consideration and demonstration by "Hash Chemistry", *Artificial Life* 25:2, in press.
- Preprint available: https://arxiv.org/abs/1806.06628

Artificial Life (1987-)

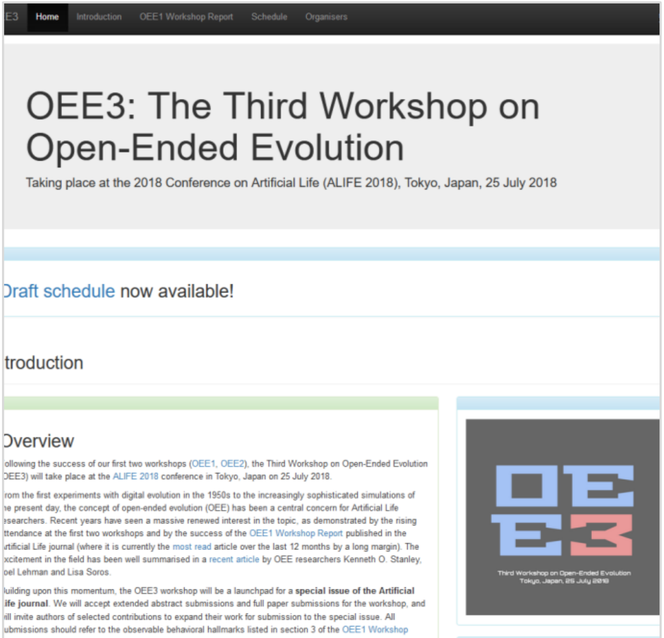
- Interdisciplinary field founded by Christopher Langton

- International Society for Artificial Life (ISAL; 2001-) http://alife.org
- Artificial Life journal (MIT Press)
- ALIFE/ECAL conferences
- IEEE ALIFE, AROB conferences

“Artificial Life”

- “... is a field of study devoted to understanding life by attempting to abstract the fundamental dynamical principles underlying biological phenomena, and recreating these dynamics in other physical media — such as computers — making them accessible to new kinds of experimental manipulation and testing.”
- “... In addition to providing new ways to study the biological phenomena associated with life here on Earth, *life-as-we-know-it*, Artificial Life allows us to extend our studies to the larger domain of "bio-logic" of possible life, *life-as-it-could-be*.”

  - *C. G. Langton, "Preface", In C. G. Langton, C. Taylor, J. D. Farmer, and S. Rasmussen, eds., Artificial Life II, vol. X of SFI Studies in the Sciences of Complexity, pp. xiii-xviii, Addison-Wesley, 1992.*



E3 | Home | Introduction | OEE1 Workshop Report | Schedule | Organisers

OEE3: The Third Workshop on Open-Ended Evolution

Taking place at the 2018 Conference on Artificial Life (ALIFE 2018), Tokyo, Japan, 25 July 2018

)raft schedule now available!

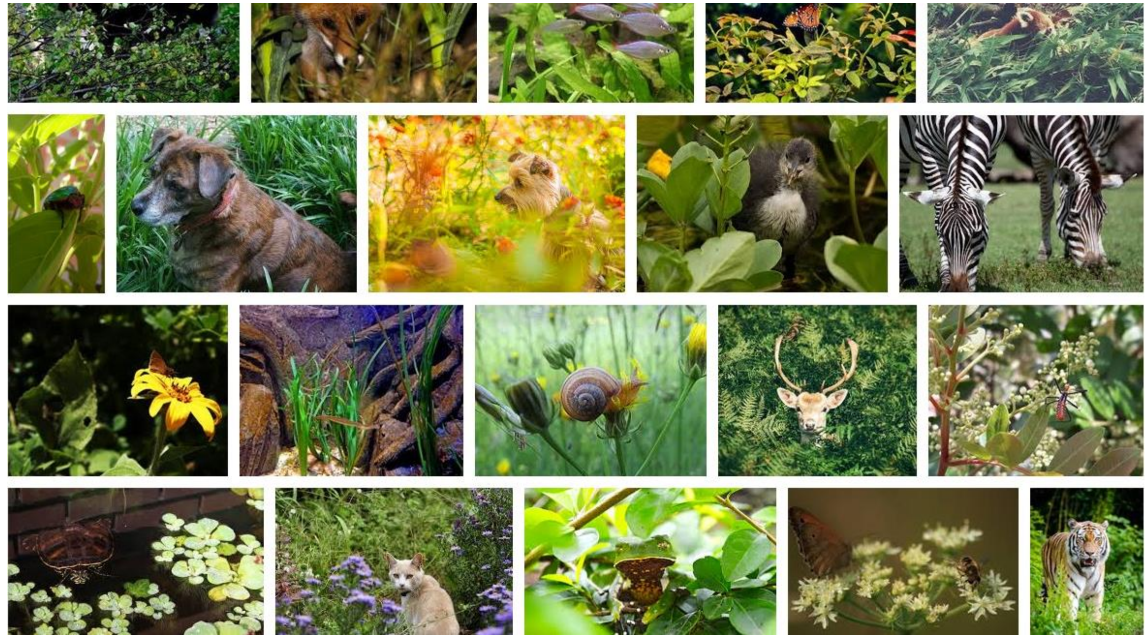
troduction

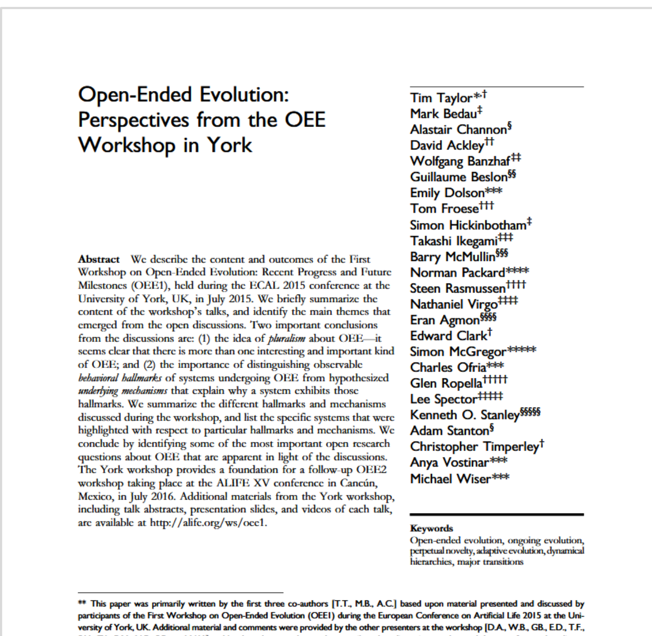
)verview

ollowing the success of our first two workshops (OEE1, OEE2), the Third Workshop on Open-Ended Evolution)EE3) will take place at the ALIFE 2018 conference in Tokyo, Japan on 25 July 2018.

rom the first experiments with digital evolution in the 1950s to the increasingly sophisticated simulations of ne present day, the concept of open-ended evolution (OEE) has been a central concern for Artificial Life esearchers. Recent years have seen a massive renewed interest in the topic, as demonstrated by the rising ttendance at the first two workshops and by the success of the OEE1 Workshop Report published in the rtificial Life journal (where it is currently the most read article over the last 12 months by a long margin). The xcitement in the field has been well summarised in a recent article by OEE researchers Kenneth O. Stanley, oel Lehman and Lisa Soros.

uilding upon this momentum, the OEE3 workshop will be a launchpad for a **special issue of the Artificial ife journal**. We will accept extended abstract submissions and full paper submissions for the workshop, and ill invite authors of selected contributions to expand their work for submission to the special issue. All ubmissions should refer to the observable behavioral hallmarks listed in section 3 of the OEE1 Workshop





Open-Ended Evolution: Perspectives from the OEE Workshop in York

Tim Taylor[*,†]
Mark Bedau[‡]
Alastair Channon[§]
David Ackley[††]
Wolfgang Banzhaf[‡‡]
Guillaume Beslon[§§]
Emily Dolson[***]
Tom Froese[†††]
Simon Hickinbotham[†]
Takashi Ikegami[‡‡‡]
Barry McMullin[§§§]
Norman Packard[****]
Steen Rasmussen[††††]
Nathaniel Virgo[‡‡‡‡]
Eran Agmon[§§§§]
Edward Clark[†]
Simon McGregor[*****]
Charles Ofria[***]
Glen Ropella[†††††]
Lee Spector[‡‡‡‡‡]
Kenneth O. Stanley[§§§§§]
Adam Stanton[§]
Christopher Timperley[†]
Anya Vostinar[***]
Michael Wiser[***]

Abstract We describe the content and outcomes of the First Workshop on Open-Ended Evolution: Recent Progress and Future Milestones (OEE1), held during the ECAL 2015 conference at the University of York, UK, in July 2015. We briefly summarize the content of the workshop's talks, and identify the main themes that emerged from the open discussions. Two important conclusions from the discussions are: (1) the idea of *pluralism* about OEE—it seems clear that there is more than one interesting and important kind of OEE; and (2) the importance of distinguishing observable *behavioral hallmarks* of systems undergoing OEE from hypothesized *underlying mechanisms* that explain why a system exhibits those hallmarks. We summarize the different hallmarks and mechanisms discussed during the workshop, and list the specific systems that were highlighted with respect to particular hallmarks and mechanisms. We conclude by identifying some of the most important open research questions about OEE that are apparent in light of the discussions. The York workshop provides a foundation for a follow-up OEE2 workshop taking place at the ALIFE XV conference in Cancún, Mexico, in July 2016. Additional materials from the York workshop, including talk abstracts, presentation slides, and videos of each talk, are available at http://alife.org/ws/oee1.

Keywords
Open-ended evolution, ongoing evolution, perpetual novelty, adaptive evolution, dynamical hierarchies, major transitions

** This paper was primarily written by the first three co-authors [T.T., M.B., A.C.] based upon material presented and discussed by participants of the First Workshop on Open-Ended Evolution (OEE1) during the European Conference on Artificial Life 2015 at the University of York, UK. Additional material and comments were provided by the other presenters at the workshop [D.A., W.B., GB., E.D., T.F., S.H., T.I., B.M., N.P., S.R., and N.V.] and by the other coauthors, who contributed to discussions at the workshop or afterwards online.

Open-Ended Evolution

Evolution that keeps producing novel forms and adaptations with no apparent limit https://www.oreilly.com/ideas/open-endedness-the-last-grand-challenge-youve-never-heard-of

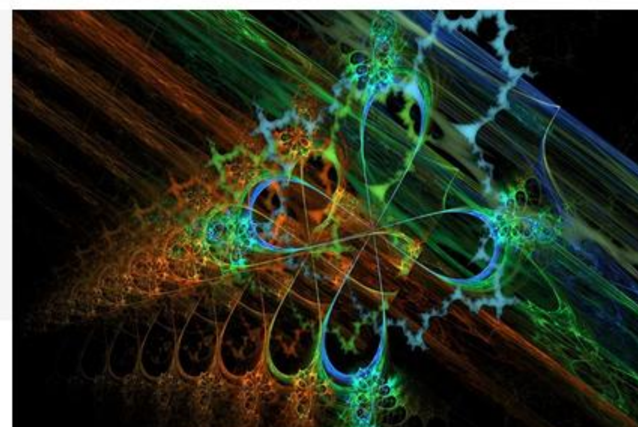
AI

Open-endedness: The last grand challenge you've never heard of

While open-endedness could be a force for discovering intelligence, it could also be a component of AI itself.

By Kenneth O. Stanley, Joel Lehman, and Lisa Soros. December 19, 2017





Fractal (source: Pixabay)

Artificial intelligence (AI) is a grand challenge for computer science. Lifetimes of effort and billions of dollars have powered its pursuit. Yet, today its most

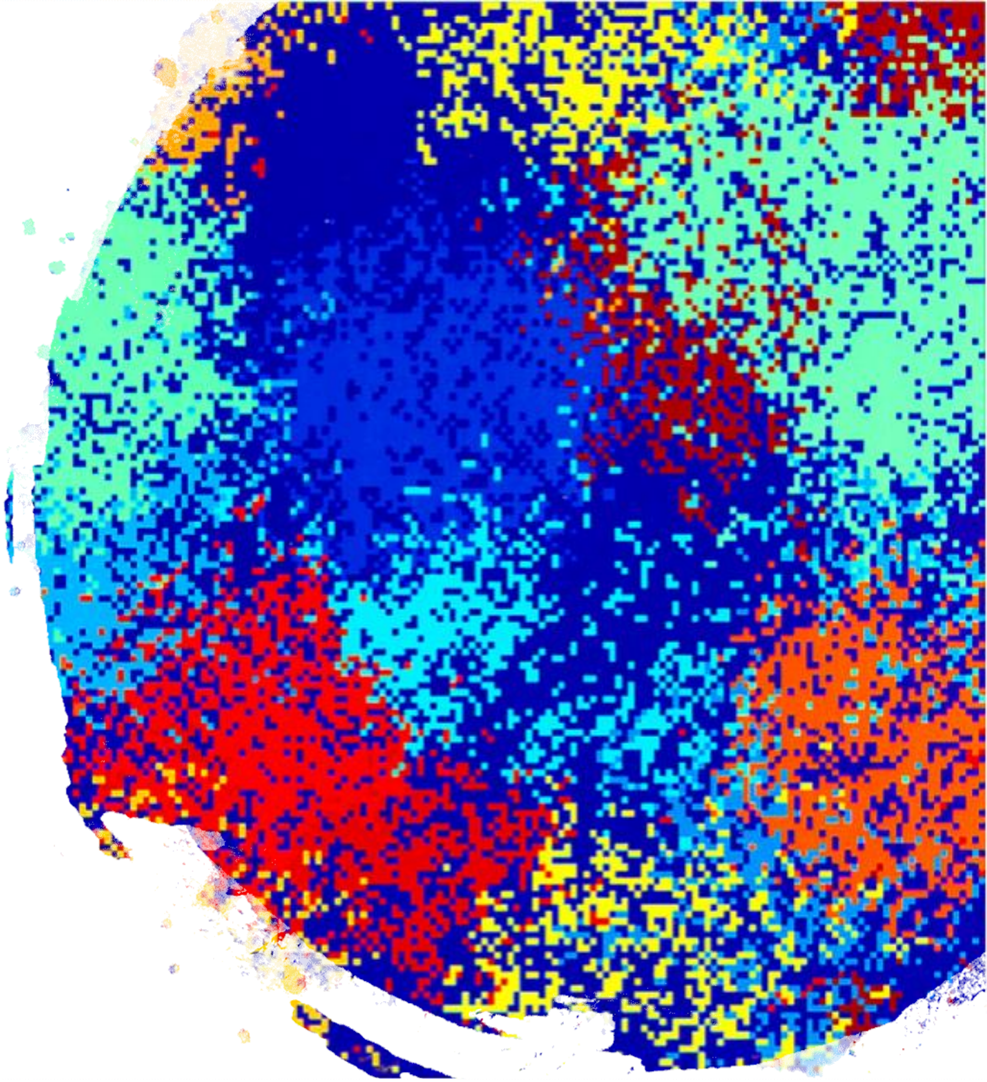
Toward Open-Ended Evolution in ALife

Examples:

- Avida (Adami et al., 1993-)
- Geb (Channon 2001-)
- Stringmol (Hickinbotham 2010-)
- Evolutionary Swarm Chemistry (Sayama 2011-) etc.

Challenges:

- Definition & characterization
- Candidate mechanisms
- Specific implementations



An Issue

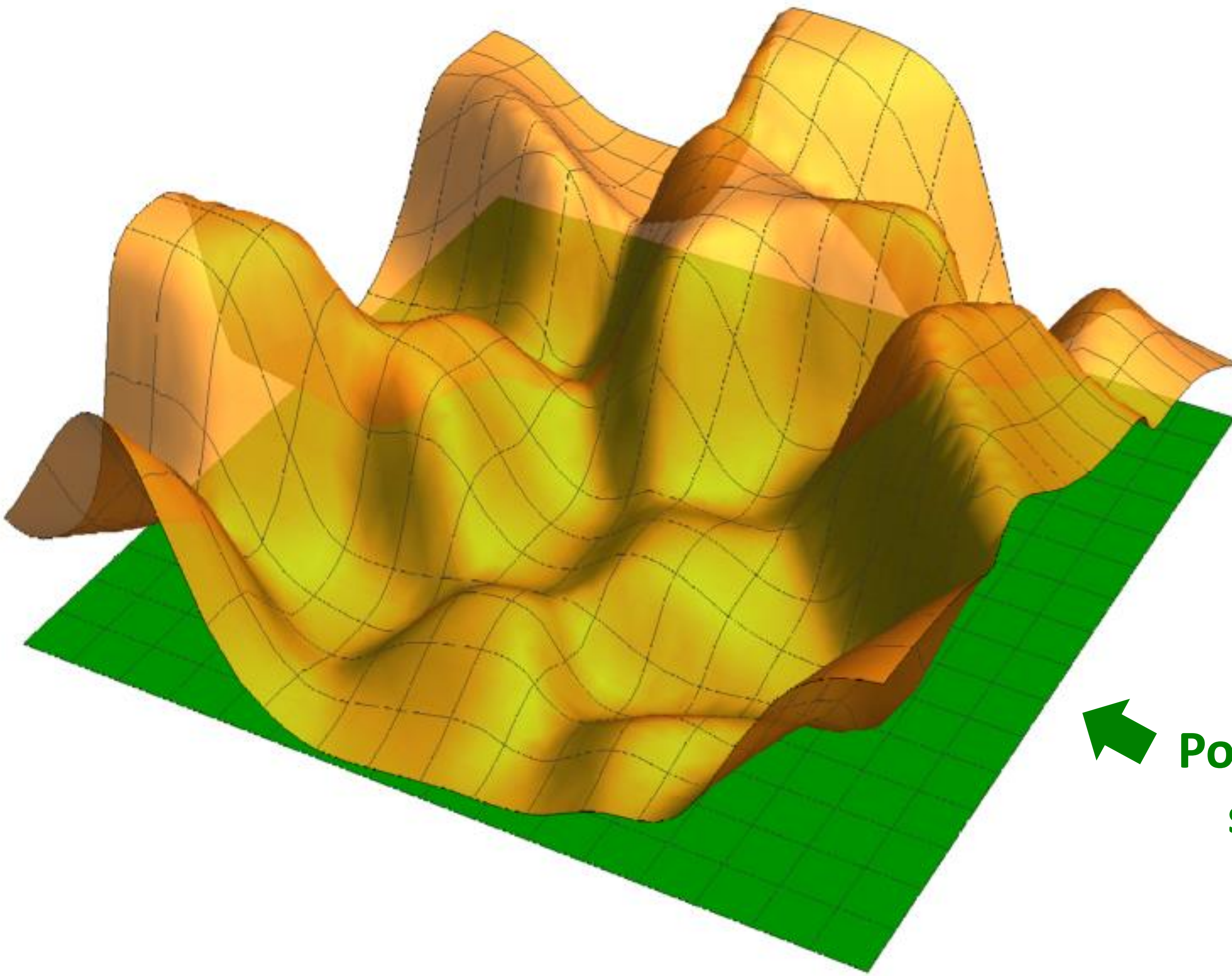
Evolution on a well-defined, finite fitness landscape *cannot be open-ended*, by definition

How can we effectively achieve an infinite possibility space in an artificial evolutionary model?

Bottom-up evolution by interactions of lower-level entities	Formation of unbounded higher-level organizations

Theoretical Consideration

Evolution in a Typical “Landscape” View



Possibility space *S*

Cardinality of Possibility Set S

$S = \{ A, B, C \}$ $\Rightarrow$ $|S| = 3$ Countably finite

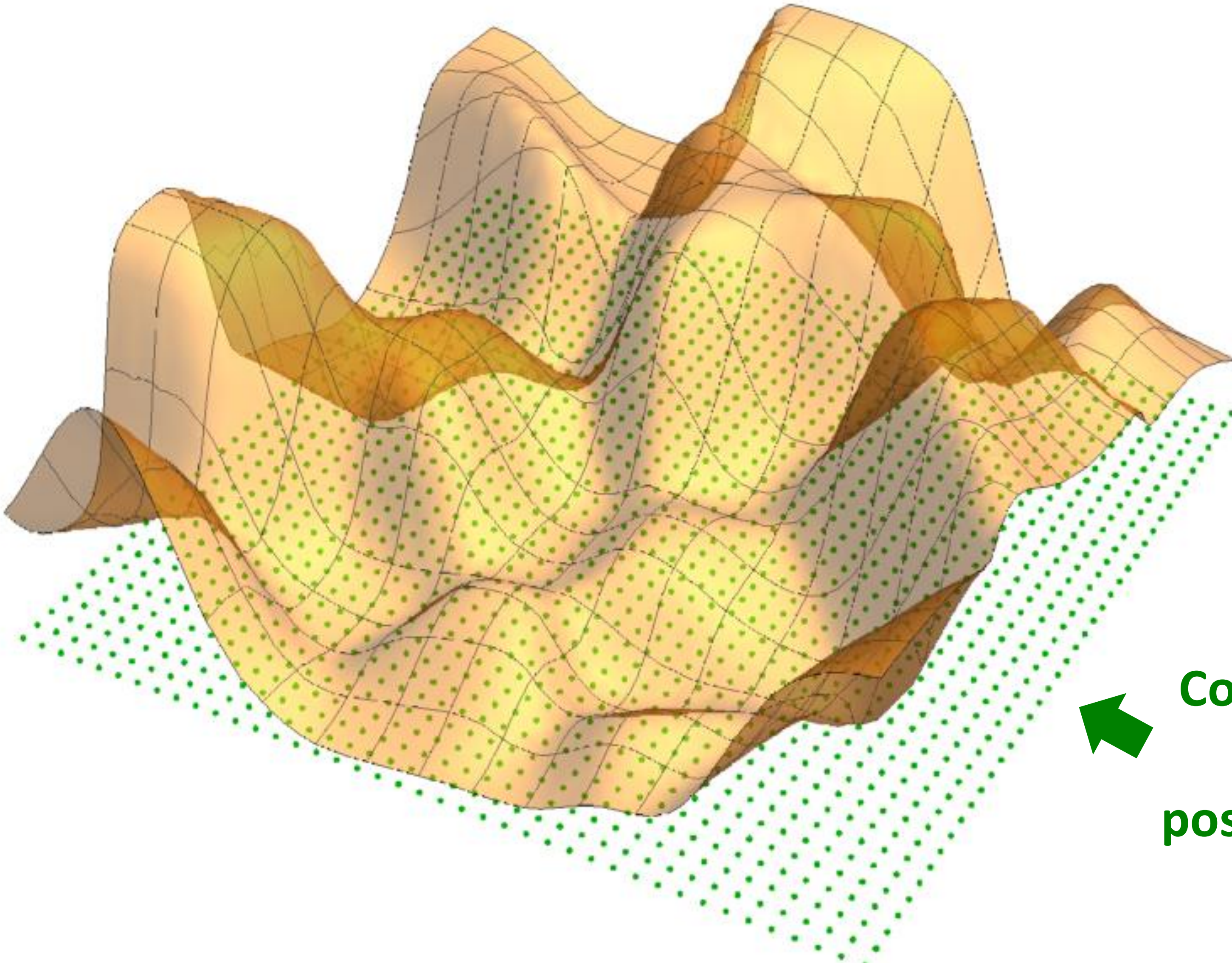
$\wedge$

$S = \{ 1, 2, 3, 4, 5 \dots \}$ $\Rightarrow$ $|S| = \infty$ **Countably infinite**

$\wedge$

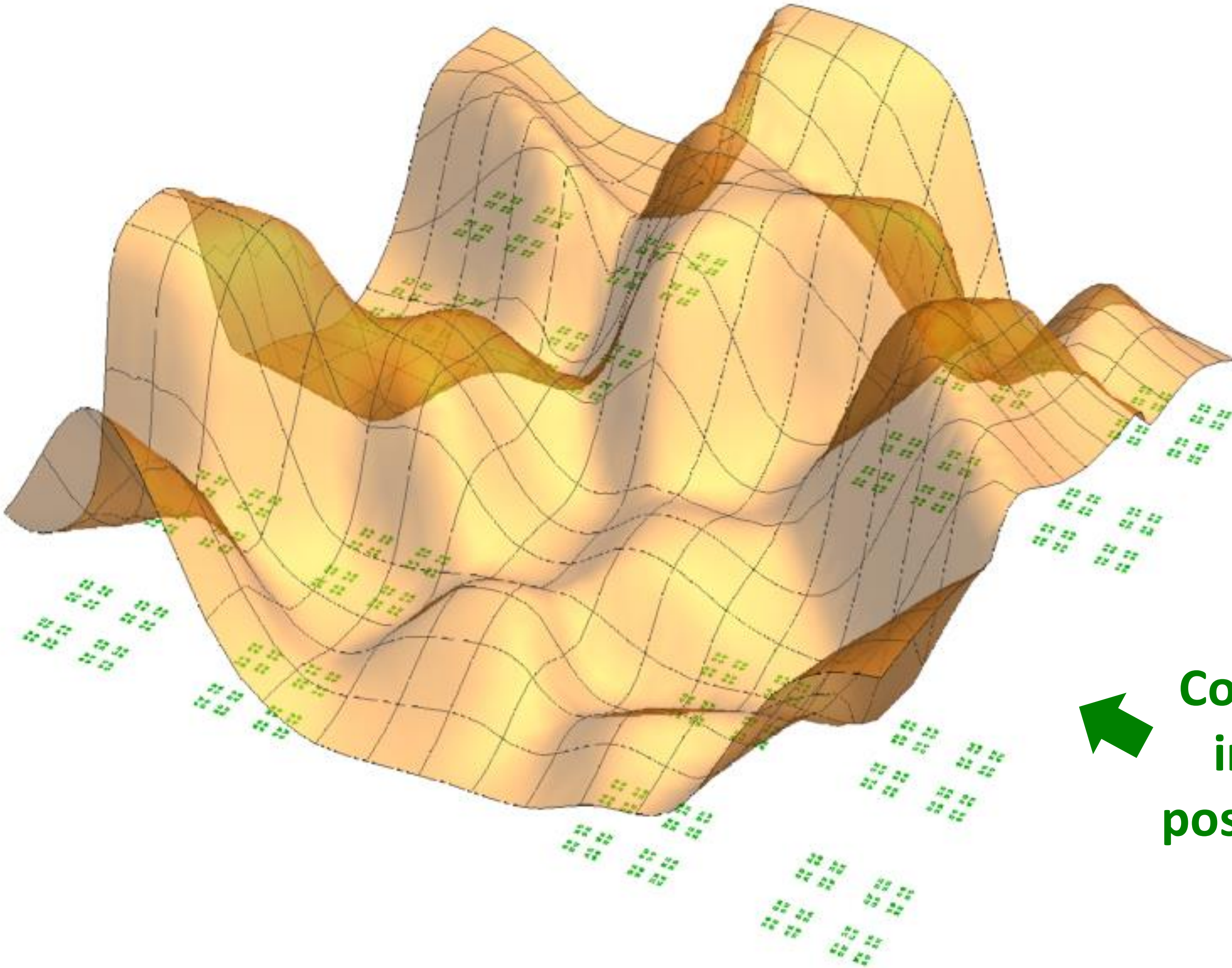
$S = \{$ (any real number) $\}$ $\Rightarrow$ $|S| = \infty$ **Uncountably infinite**

Countably Finite Possibilities



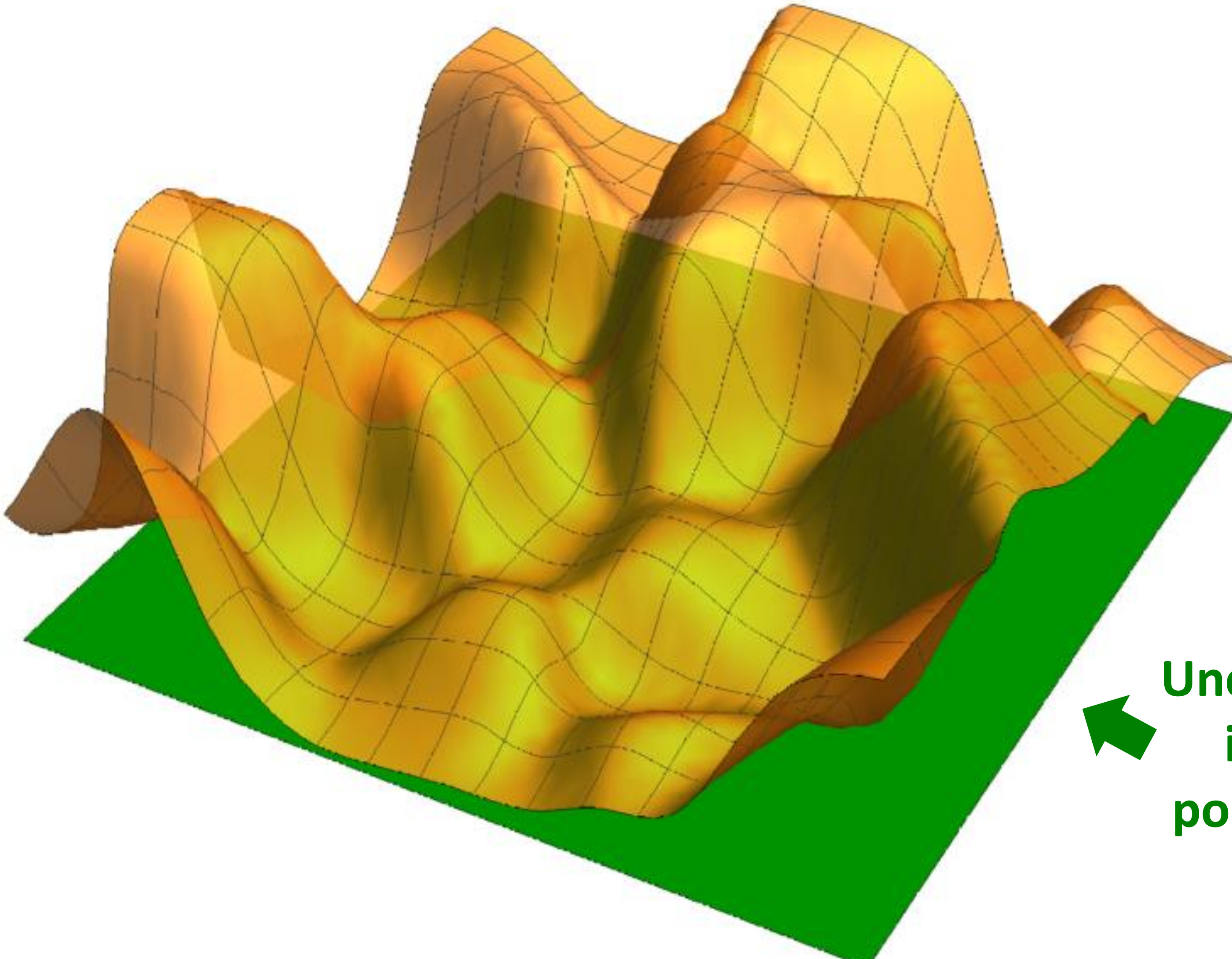
Countably finite possibilities

Countably Infinite Possibilities

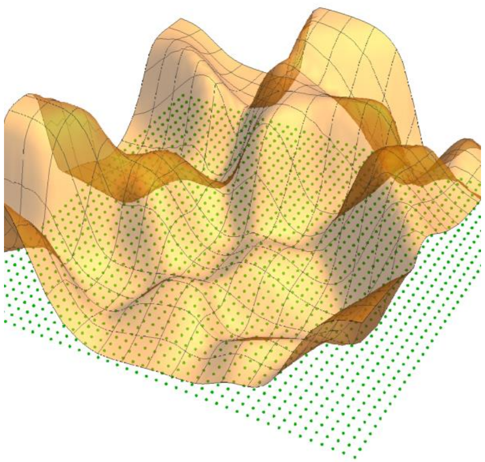
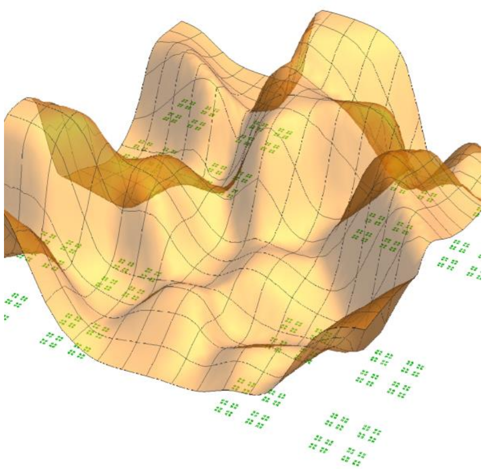


Countably infinite possibilities

Uncountably Infinite Possibilities



Uncountably infinite possibilities

Cardinality of Possibility Set *S* and the Fate of Evolution

Open-ended evolution is a parallel search process that must keep testing *novel possibilities*

If *S* is finite, OEE will eventually reach the optimal type in a finite amount of time (which ironically makes the evolution NOT open-ended!)

(If *S* is countably infinite, OEE is possible, though a bit unnatural)

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Now What?

- **"Finite but very large *S* is sufficient"**

  => Sure, fair enough

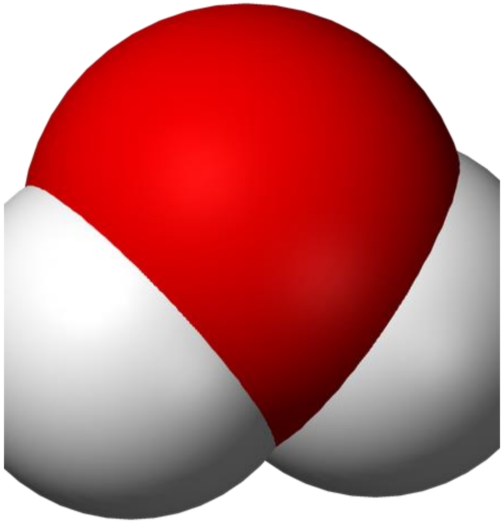
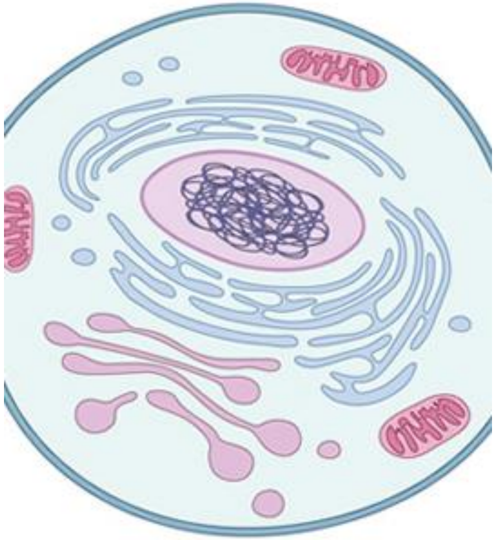
- **"Continous *S* solves the problem"**

  => Real biological entities use discrete, symbolic codes

  => With this, simple chaos would also be considered OEE

- **"Formation of higher-order entities in *S* solves the problem"**

  => Hell yes, we should do it

Cardinality Leap

Allowing entities in *S* to form higher-order entities (i.e. multisets)

Cardinality Leap: Examples

$S = \{ A, B, C \}$ ⇨ $S^* = \{ \{\}, \{A\}, \{B\}, \{C\},$
$\{A,A\}, \{A,B\}, \ldots,$
$\{A,A,A\}, \{A,A,B\}, \ldots \}$

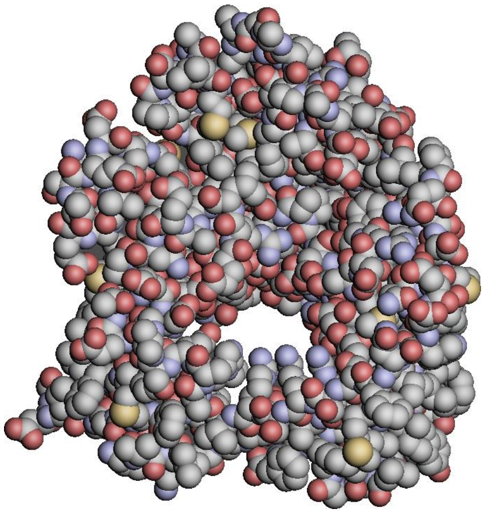
$S = \{ 1, 2, 3, 4, 5 \ldots \}$ ⇨ $S^* = \{$ (all possible frequency distributions defined on all positive integers) $\}$

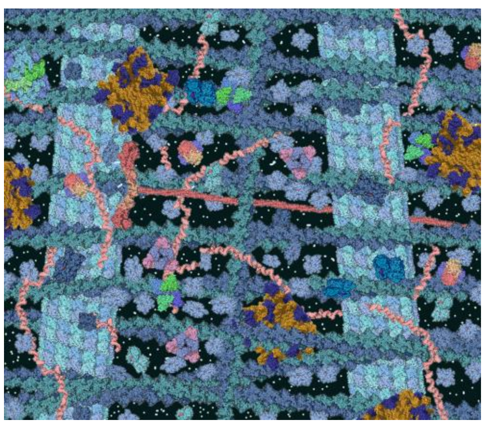
Higher-Order Entities and Cardinality Leap

- **Cardinality of the set of higher-order entities jumps up**
  - Finite -> Countably infinite
  - Countably infinite -> Uncountably infinite

- This approach has been used in several different forms
  - Multisets in Artificial Chemistry models
  - Unbounded code trees in Genetic Programming

    etc…





Examples

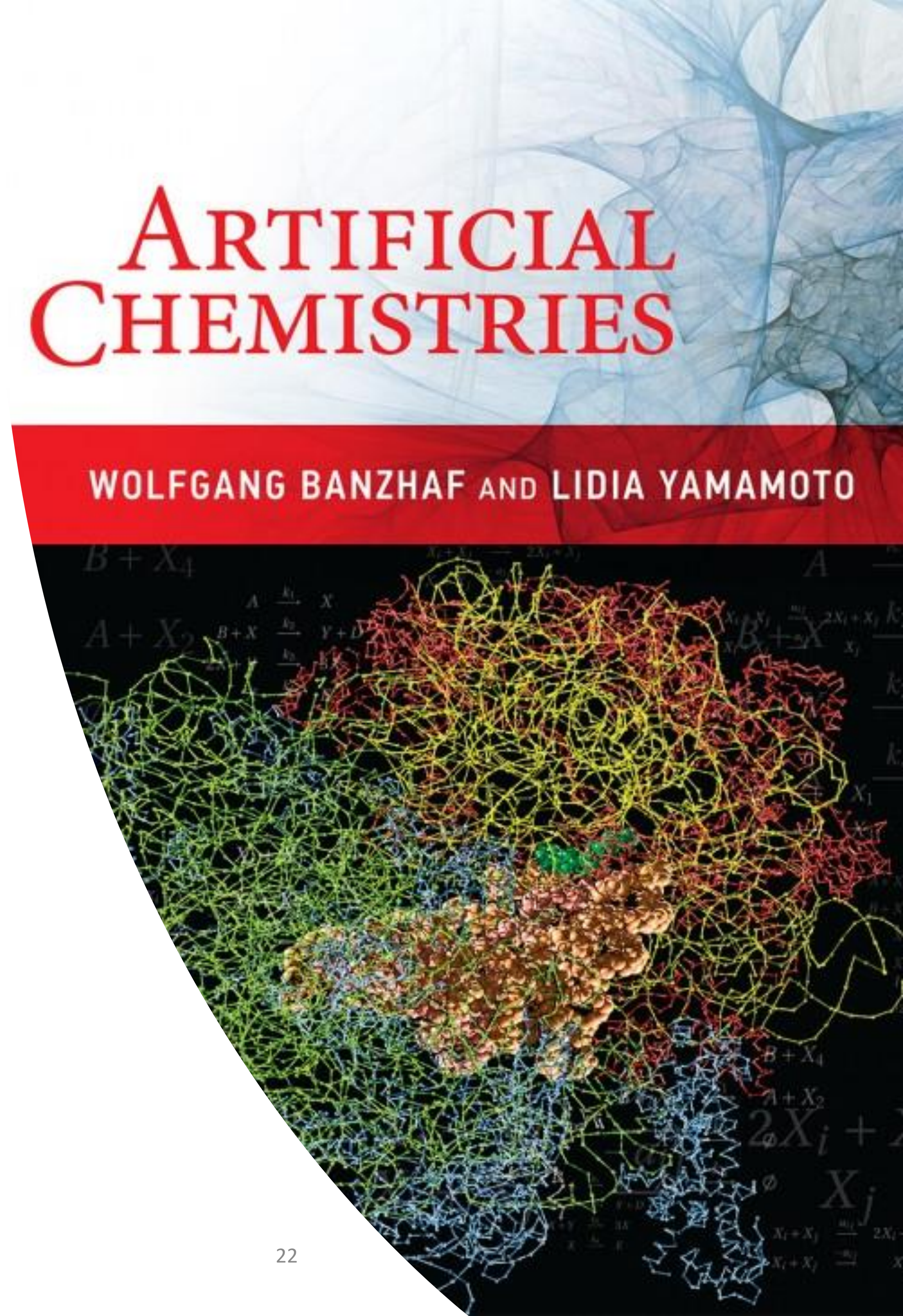
- From finite to countably infinite
  - Individual entities: *Chemical elements*
  - Higher-order entities: *Multisets of elements (i.e., molecules)*

- From countably infinite to uncountably infinite
  - Individual entities: *Molecules*
  - Higher-order entities: *Multisets of molecules (e.g., cells)*

An Illustrative Toy Model: “Hash Chemistry”

Artificial Chemistry

- A sub-field of Artificial Life where models of artificial chemical reactions are used to study the emergence and evolution of life from non-living elements



A Challenge

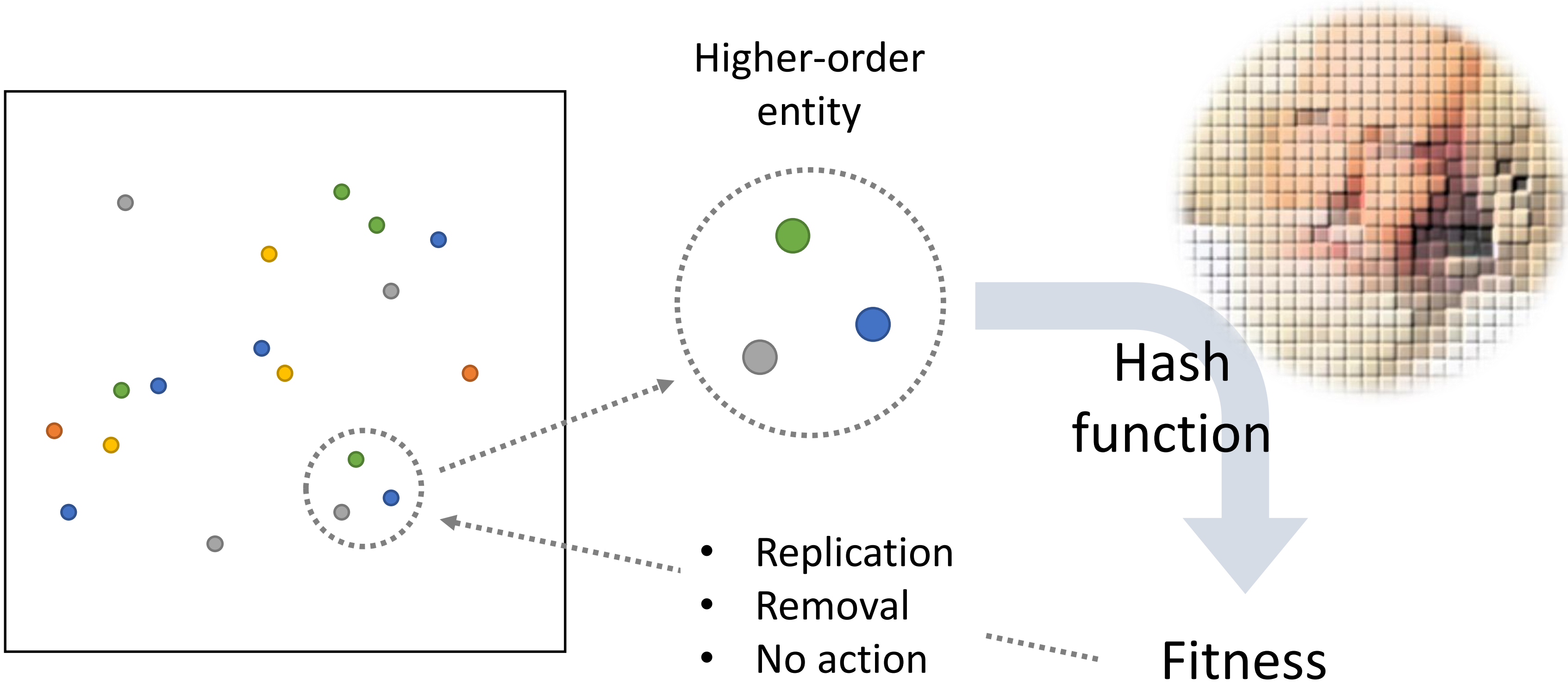
How can one design a mechanistic, ***universal*** means for evaluating the level of success of entities of any arbitrary size or order?

A Lazy Solution: Hash Function

Hash Function: Examples

```
Hash["Hiroki"]

2 114 612 129 374 295 693

Hash[{1, 1, 2, 3}]

5 349 994 258 566 133 103

Hash[{1, -3, {0, 1 - 10 i, {3, 21, "abc"}}, {{}, {{}}}}]

731 100 058 976 559 080
```

Hash Chemistry: Outline

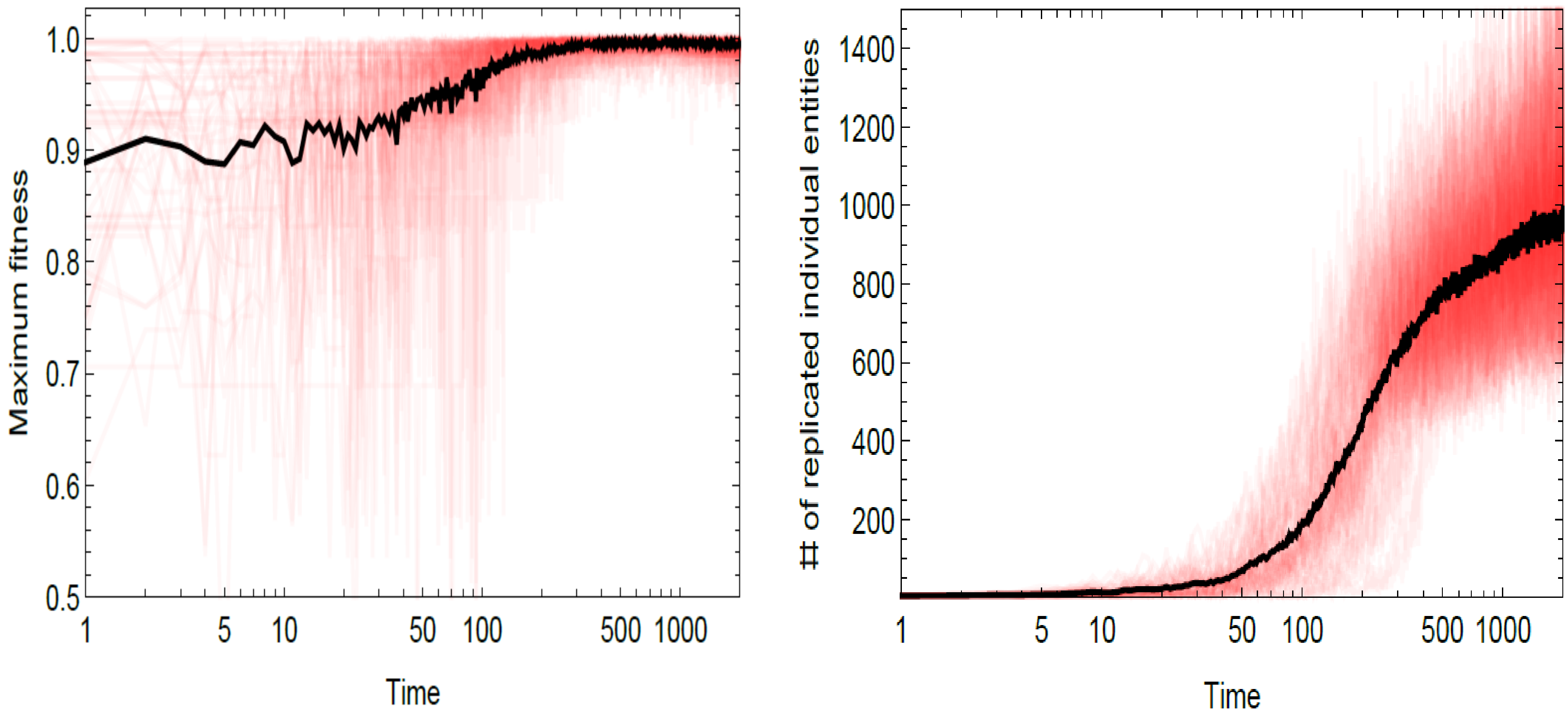


Hash Chemistry: Details

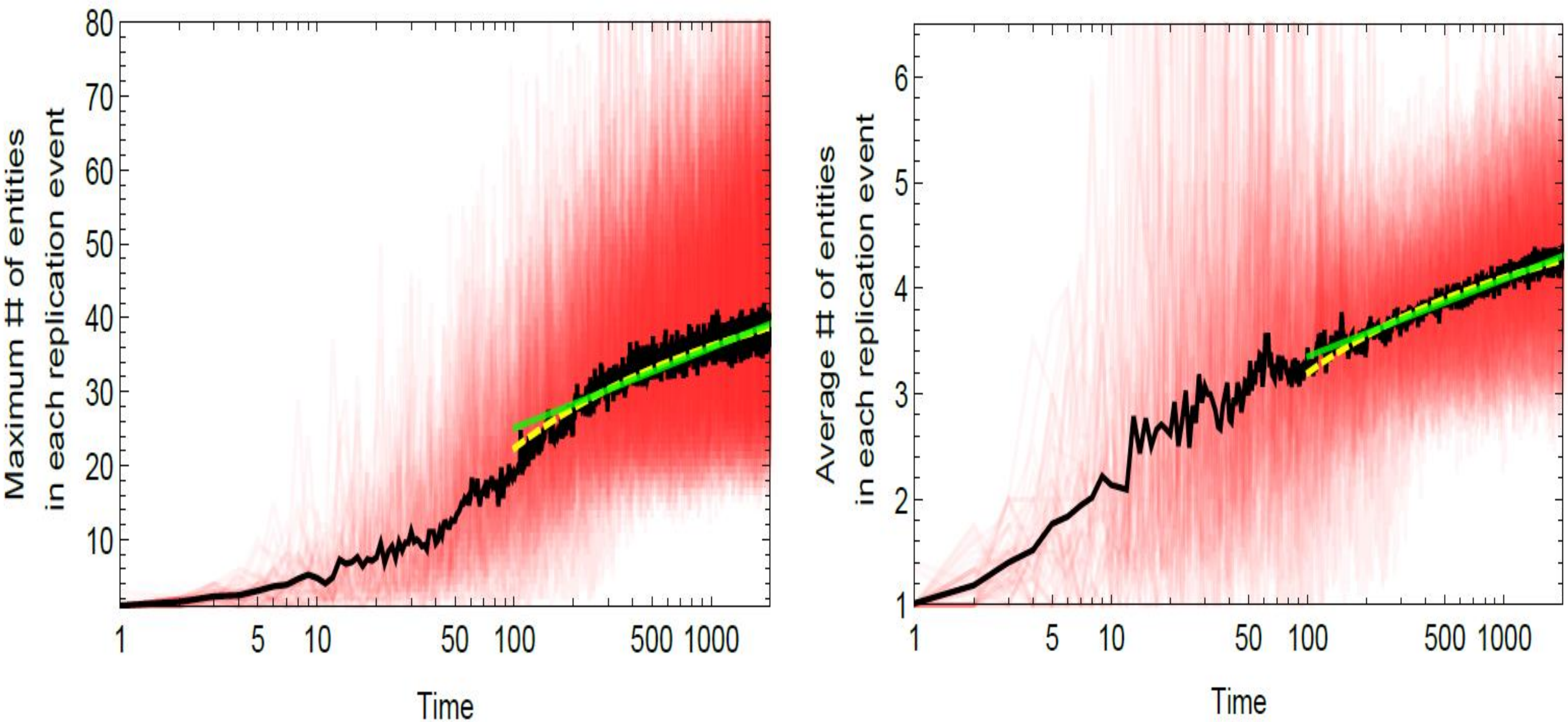
1. Move particles randomly
2. For each particle's position:
   a) Select a random subset (s) of particles in vicinity (N)
   b) With probability $1/|s|$:
      i. Sort the content of s
      ii. Calculate fitness f of s using a hash function
      iii. With probability $1 - f$, remove s from space
      iv. With probability $f\,(1 - |N|/d_{\mathrm{max}})$, add a copy of s to space
3. Mutate particle types probabilistically
4. Randomize the order of particles

https://youtu.be/fVwUJ7pdPWY

Fitness Increases (Obviously)

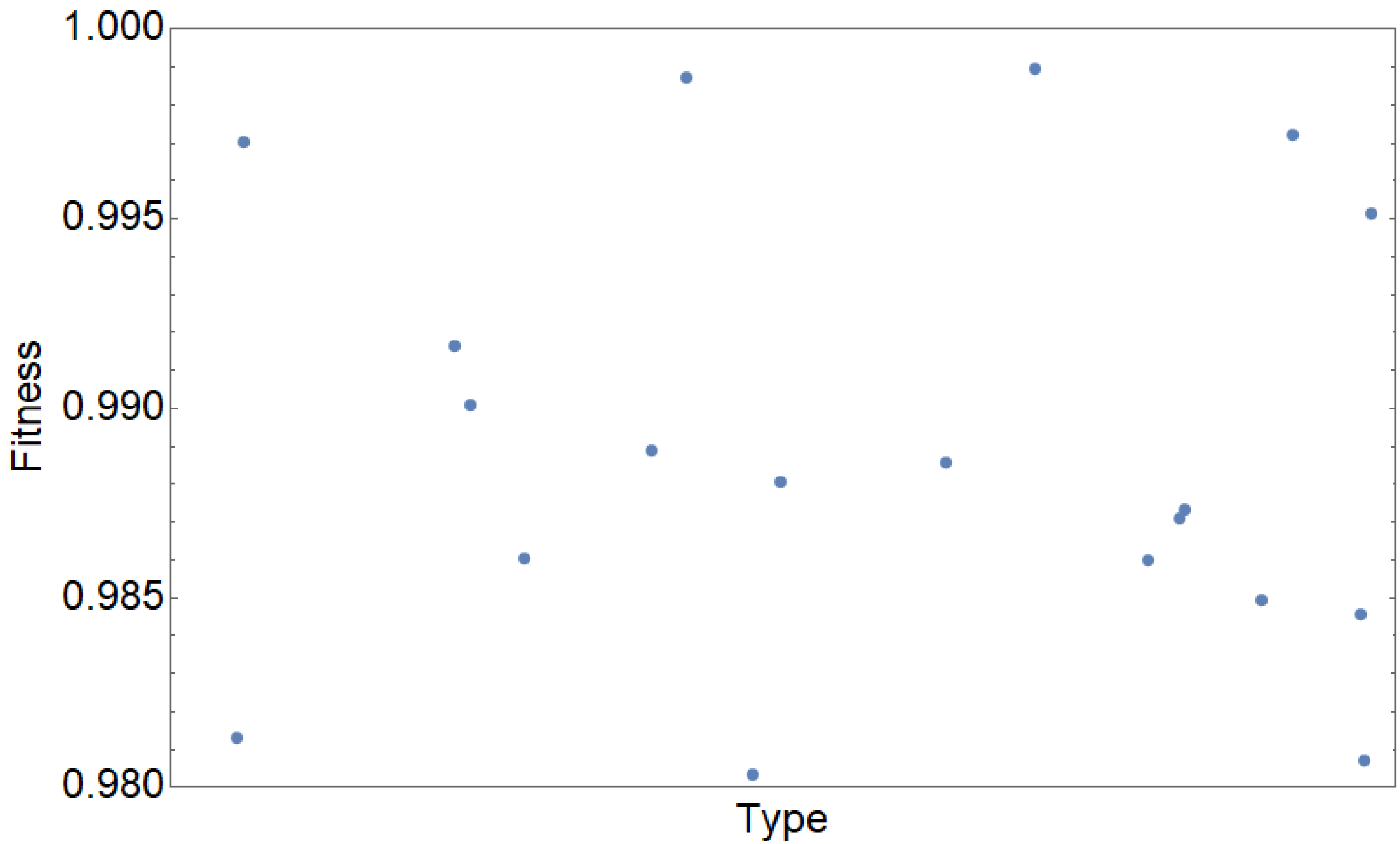


Units of Self-Replication Becomes Larger



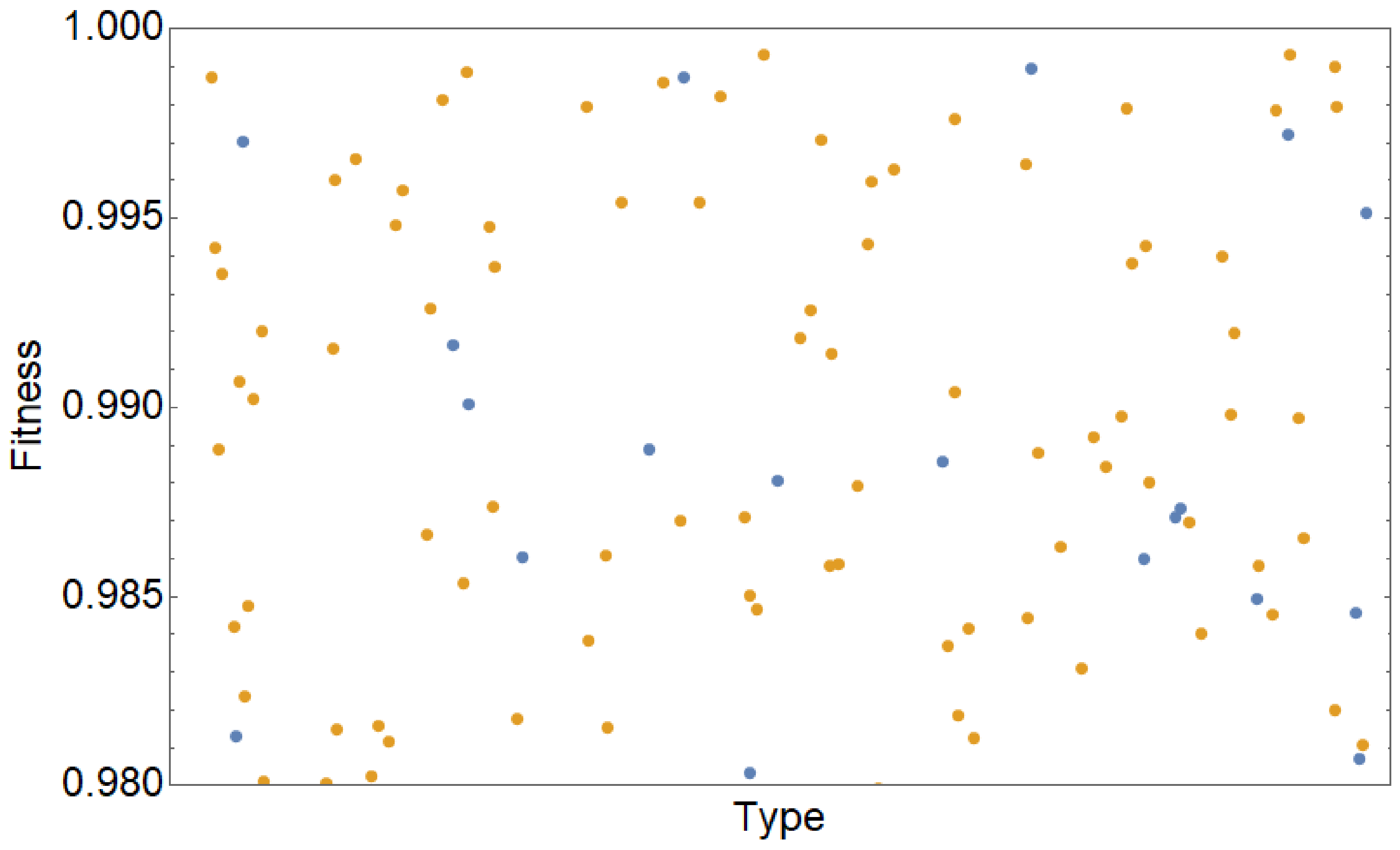
What Is Happening?

Single individual entities only



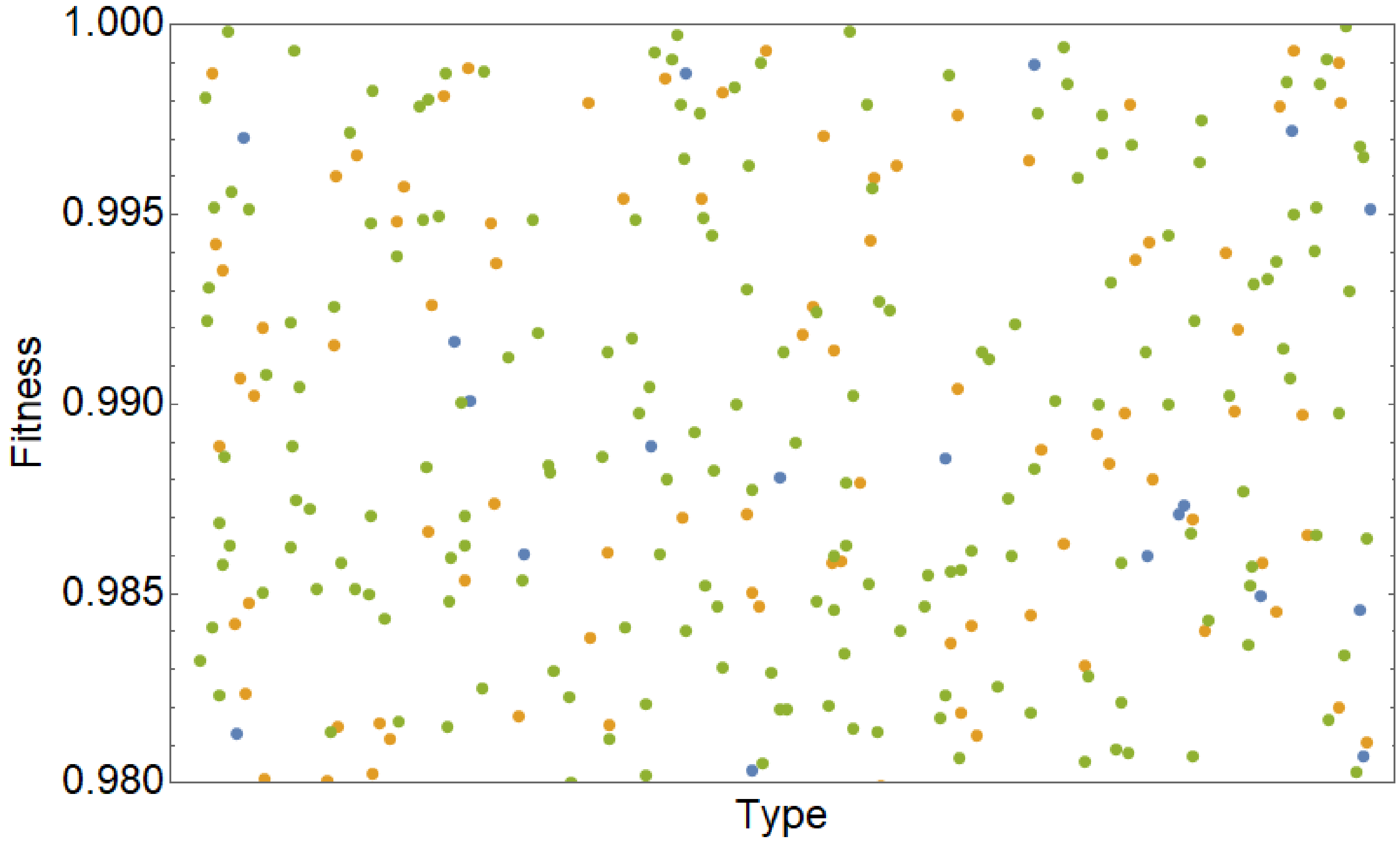
What Is Happening?

Pairs of individual entities included

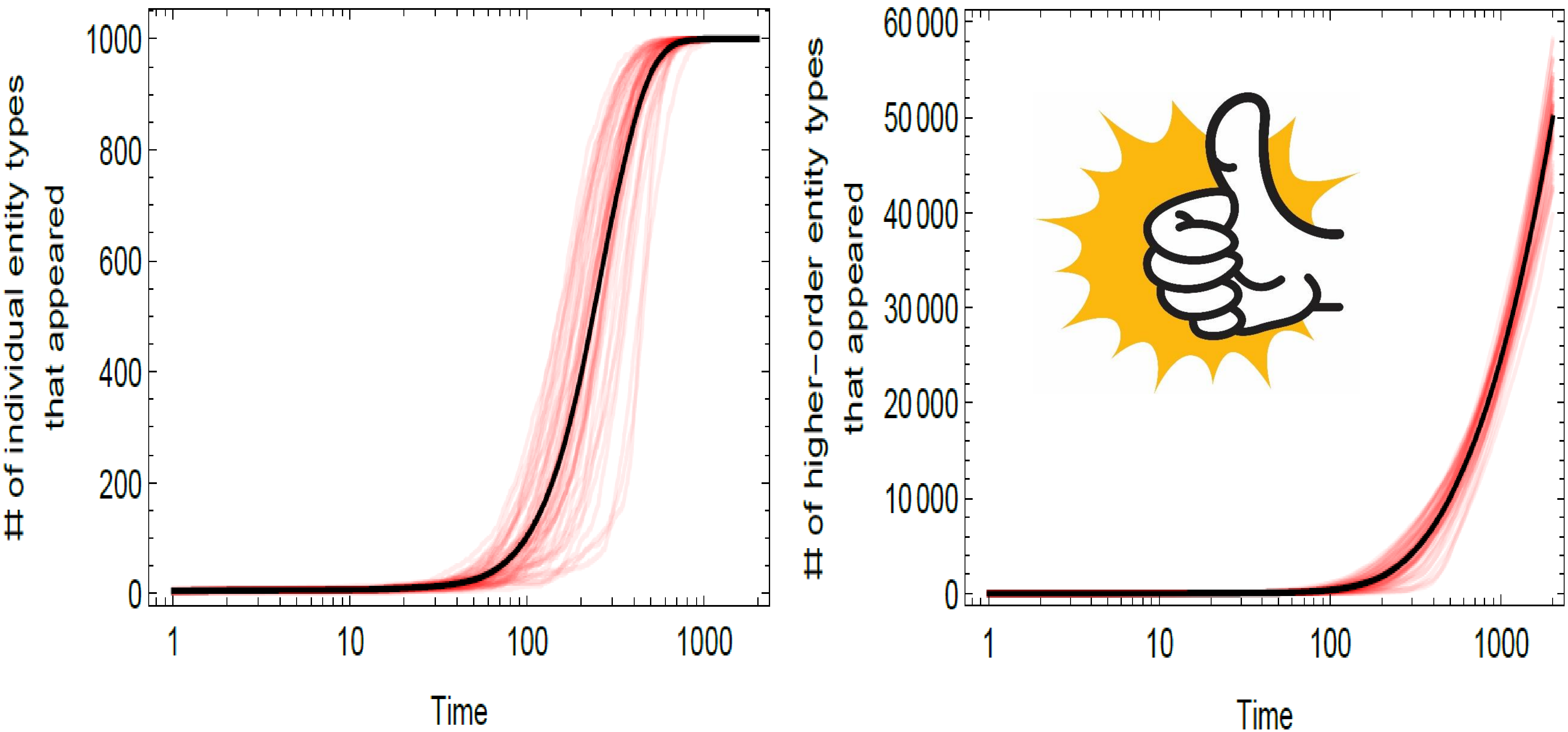


What Is Happening?

Triplets of individual entities included



Unbounded Possibilities by Cardinality Leap



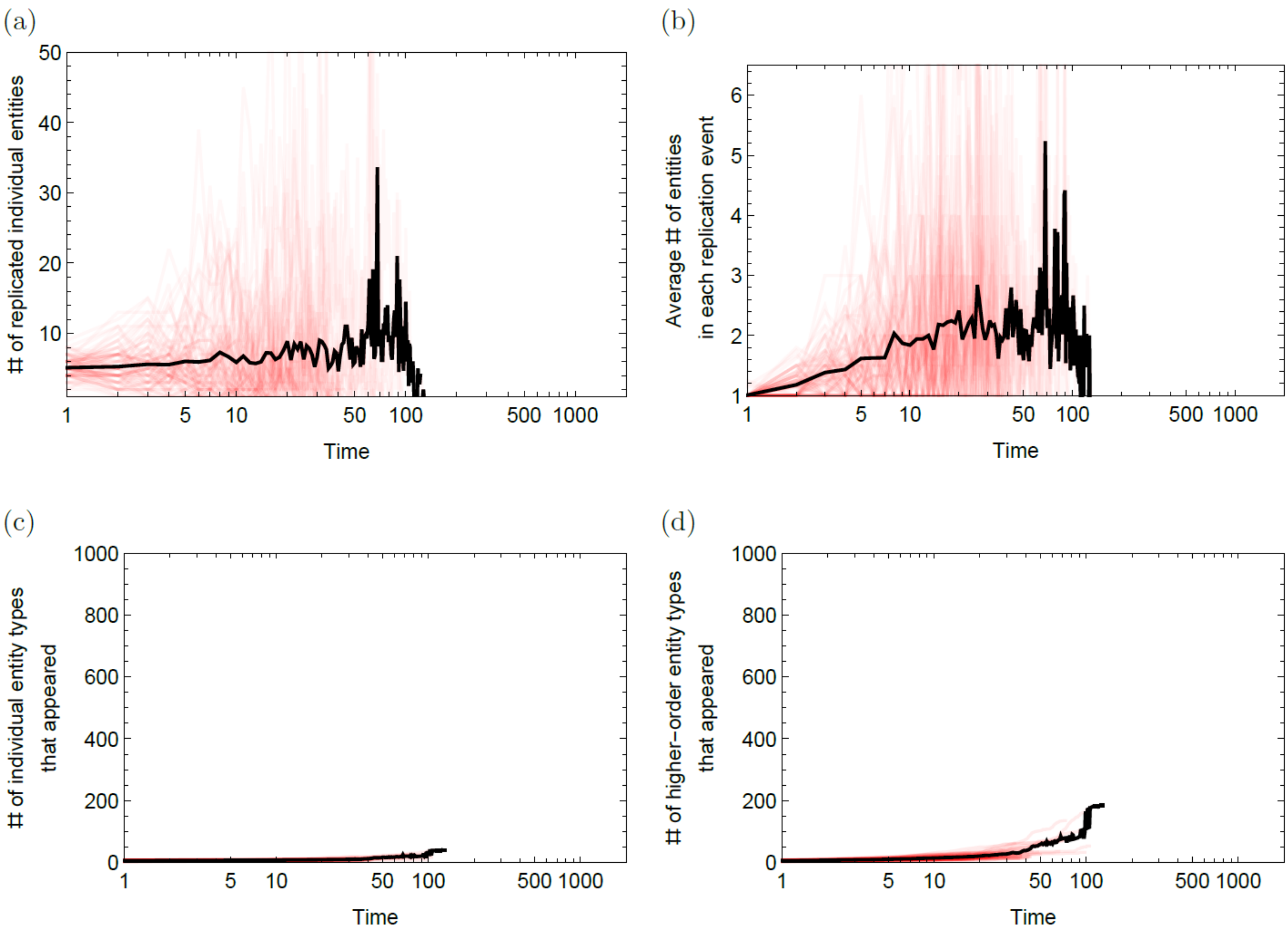
Then, Reviewer #2 Comes In

- **Is this really adaptation?**
- **Any random number generators may be used as fitness to produce similar results.**

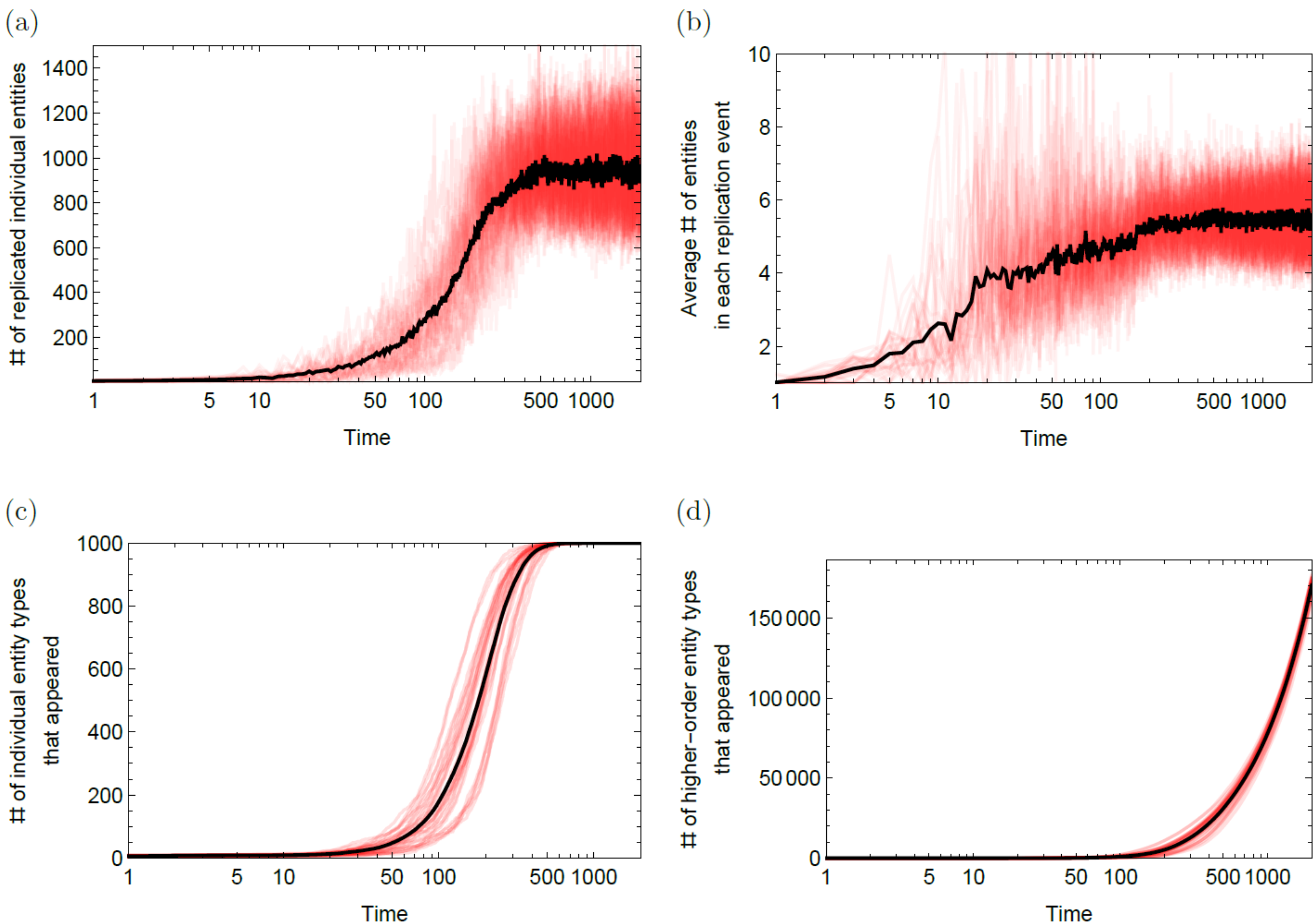
Control Experiments

1. Move particles randomly
2. For each particle's position:
   a) Select a random subset (*s*) of particles in vicinity (*N*)
   b) With probability $1/|s|$:
      i. Sort the content of *s*
      ii. Calculate fitness *f* of *s* using **<u>a random number generator</u>**
      iii. With probability $1 - f$, remove *s* from space
      iv. With probability $f\,(1 - |N|/d_{max})$, add a copy of *s* to space
3. Mutate particle types probabilistically
4. Randomize the order of particles

This Is What Happened



With Positively Biased Random Number Generators



Reviewer #2 Receives a Reply

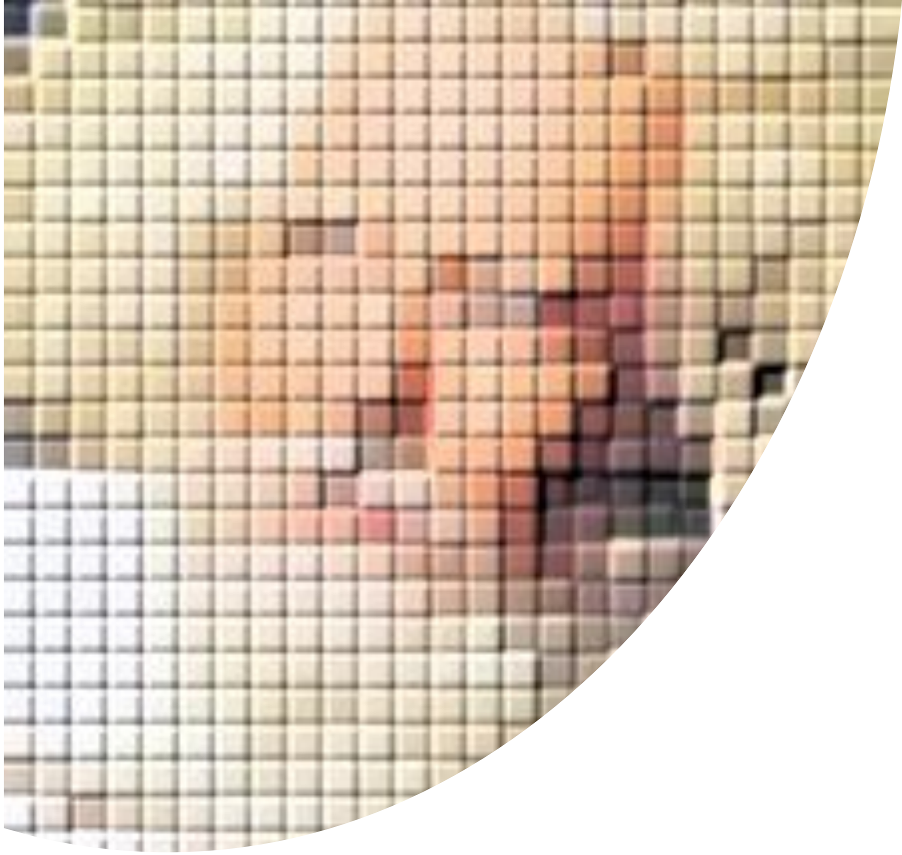
- **Is this really adaptation?** ➡ **Yes**
- **Any random number generators may be used as fitness to produce similar results.** ➡ **No**

Conclusions

- Proposed formation of higher-order entities as an effective way to cause a "cardinality leap"
- Proposed a toy model "Hash Chemistry" using a hash function as the universal fitness evaluator
- Cardinality leap facilitated unbounded increase in the production of novel types
- Control experiments showed the observed dynamics were evolutionary adaptation driven by selection

Acknowledgments

- Howard H. Pattee (Professor Emerius at SSIE Dept.)
- Two anonymous reviewers ☺
- Organizers of the Open-Ended Evolution Workshop 3 at ALIFE 2018 (Tim Taylor, Norman Packard, Mark Bedau, Alastair Channon, Steen Rasmussen, Takashi Iegami)



Thank You