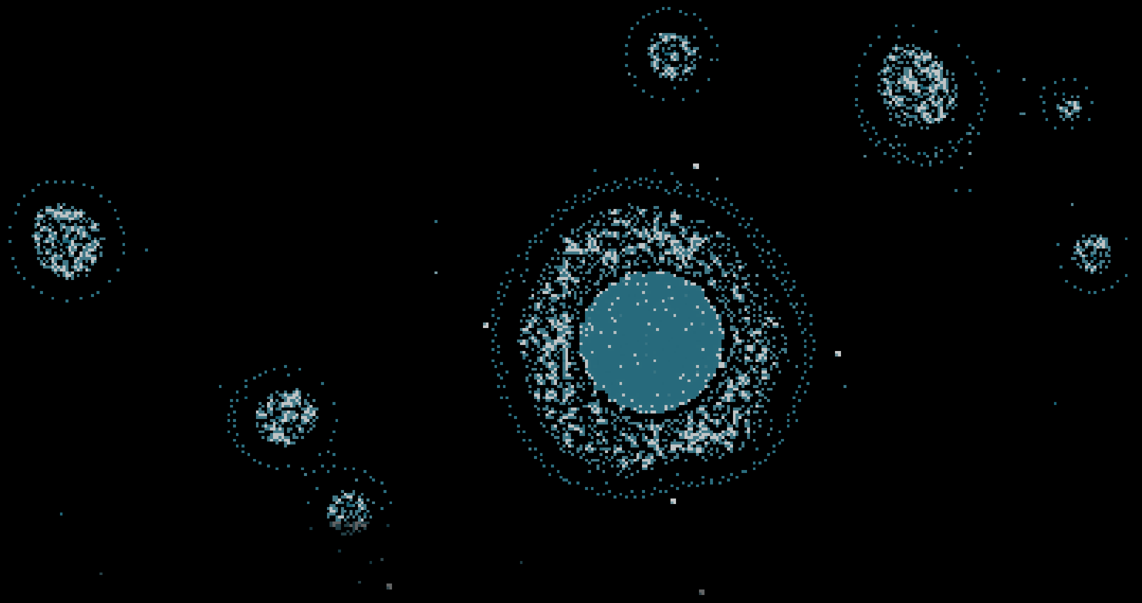

Swarm Chemistry

Guiding Designs of Self-Organizing Swarms

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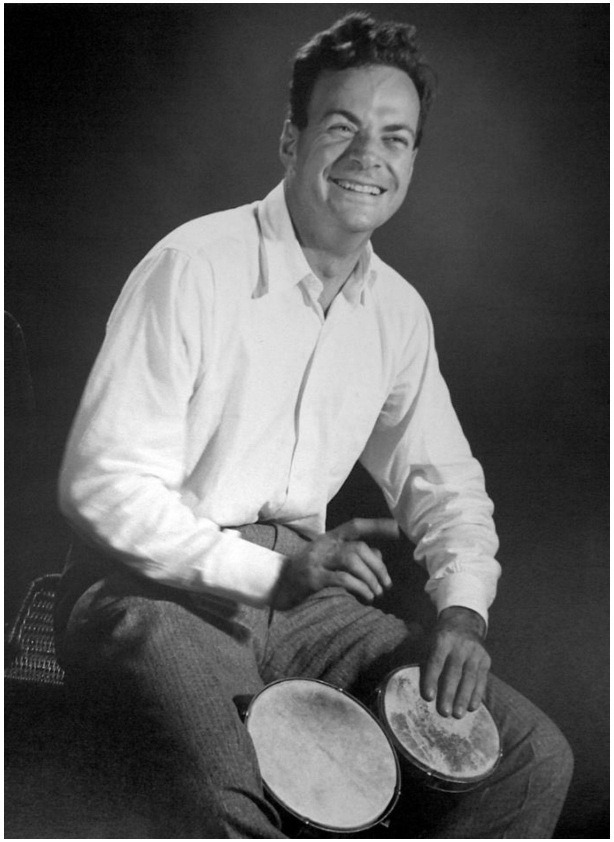
arxiv.org/abs/1308.3400

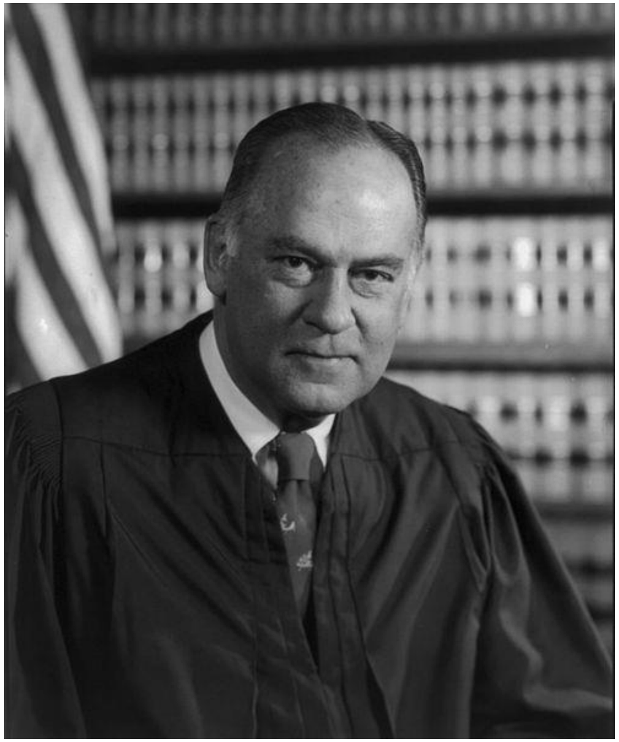
What I cannot create, I do not understand.

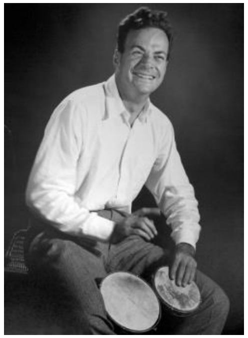
-- Richard Feynman



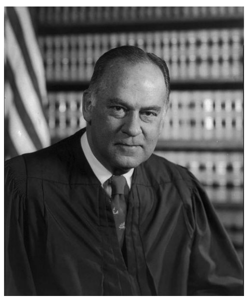
Perhaps I could never succeed in intelligibly doing so. But I know it when I see it.

-- Potter Stewart

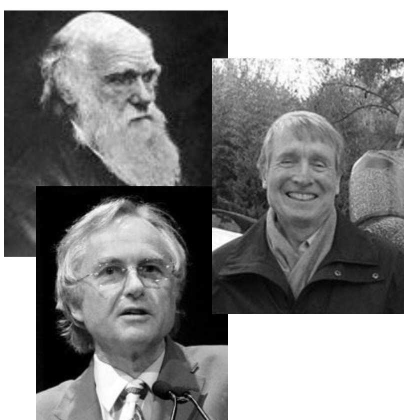




$$\neg C \rightarrow \neg U$$



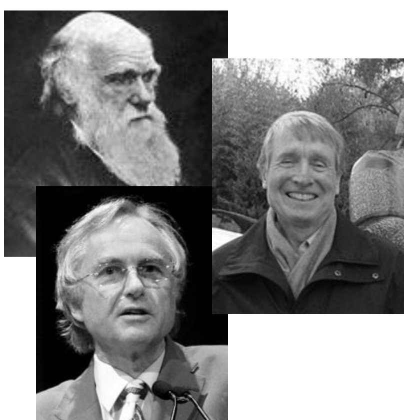
$$\neg U \cap D$$



$$D \rightarrow C$$

$$\neg C \rightarrow \neg U$$

$$\neg U \cap C$$



Evolution enables "creation without understanding"

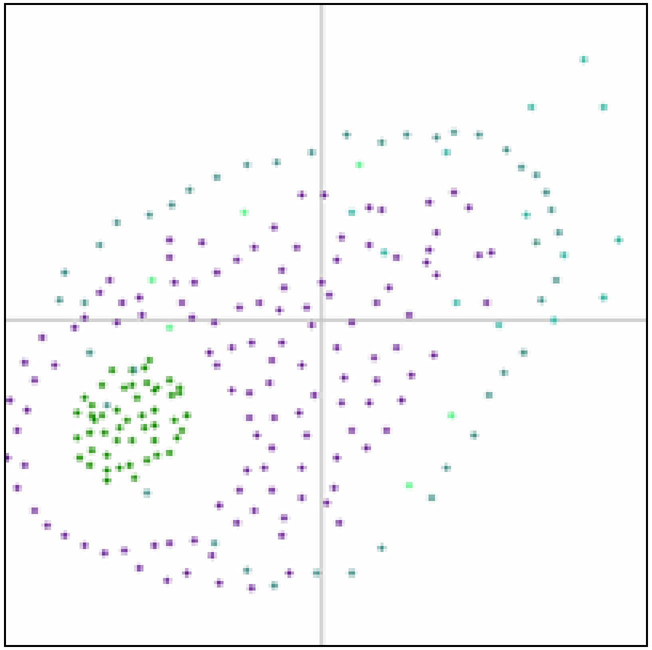
How to Design Complex Systems Without Understanding?

- **Interactive Approach**
  - Hyper-interactive evolutionary computation (HIEC)
- **Automated Approach**
  - Spontaneous evolution
    + quantification of macroscopic properties

Swarm Chemistry

Swarm Chemistry

- An artificial chemistry project where artificial swarm populations are used as chemical reactants

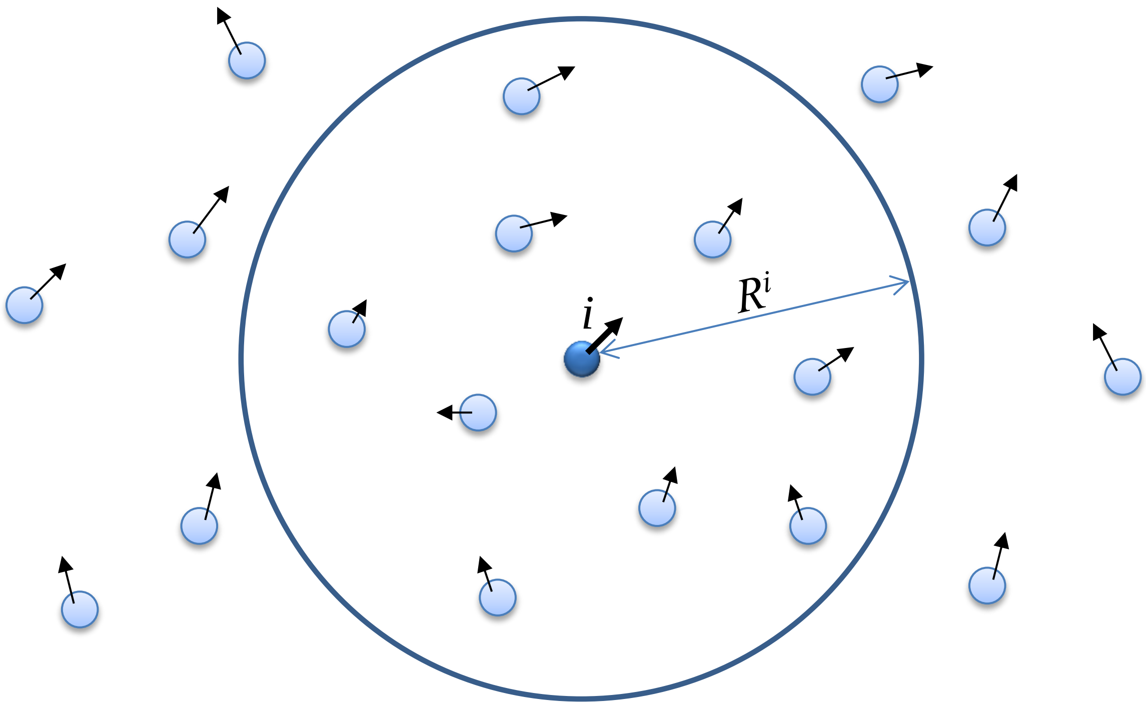


http://bingweb.binghamton.edu/~sayama/SwarmChemistry/

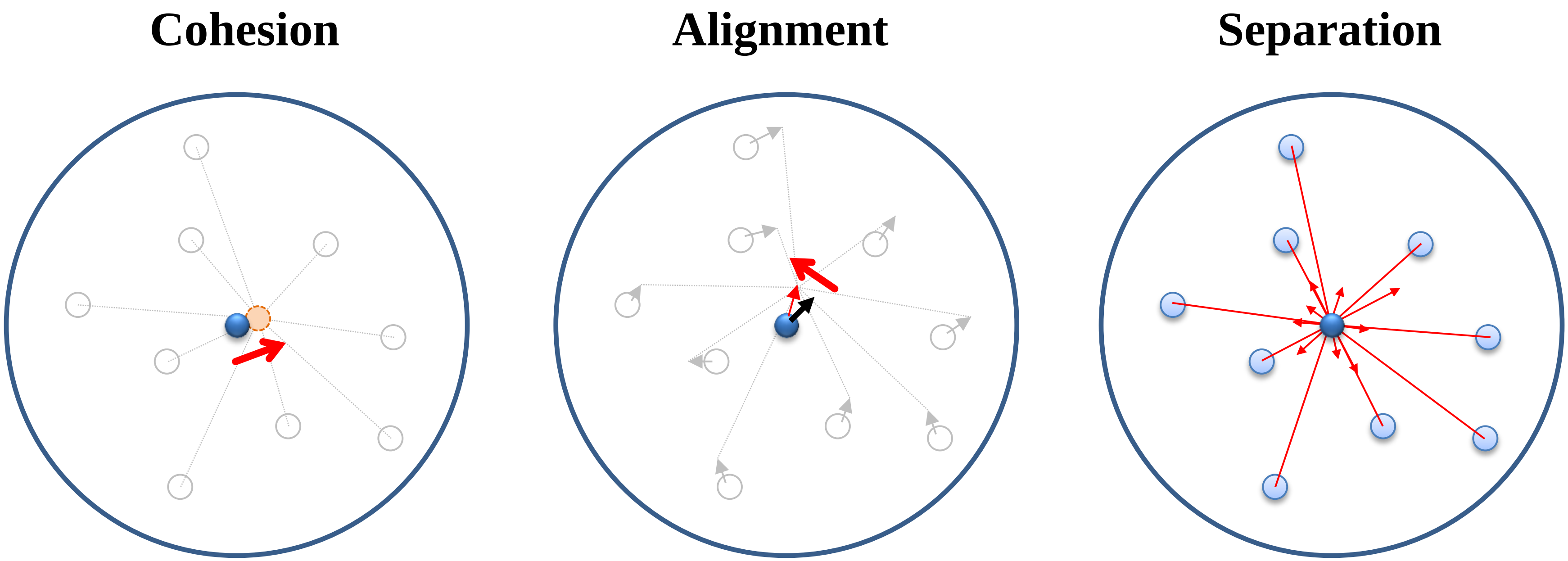
Sayama (2009) *Artificial Life* 15:105-114.

Model Assumptions

- Particles in a continuous open 2-D space
  - Kinetic interactions with local neighbors
  - No capability to distinguish different types



Behavioral Rules



Behavioral Rules

- If no particles are found within local perception range, steer randomly (Straying)
- Otherwise:
  - Steer to move toward the average position of local neighbors (Cohesion)
  - Steer towards the average velocity of local neighbors (Alignment)
  - Steer to avoid collision with neighbors (Separation)
  - Steer randomly with a given probability (Randomness)
- Approximate its speed to its normal speed (Self-propulsion)

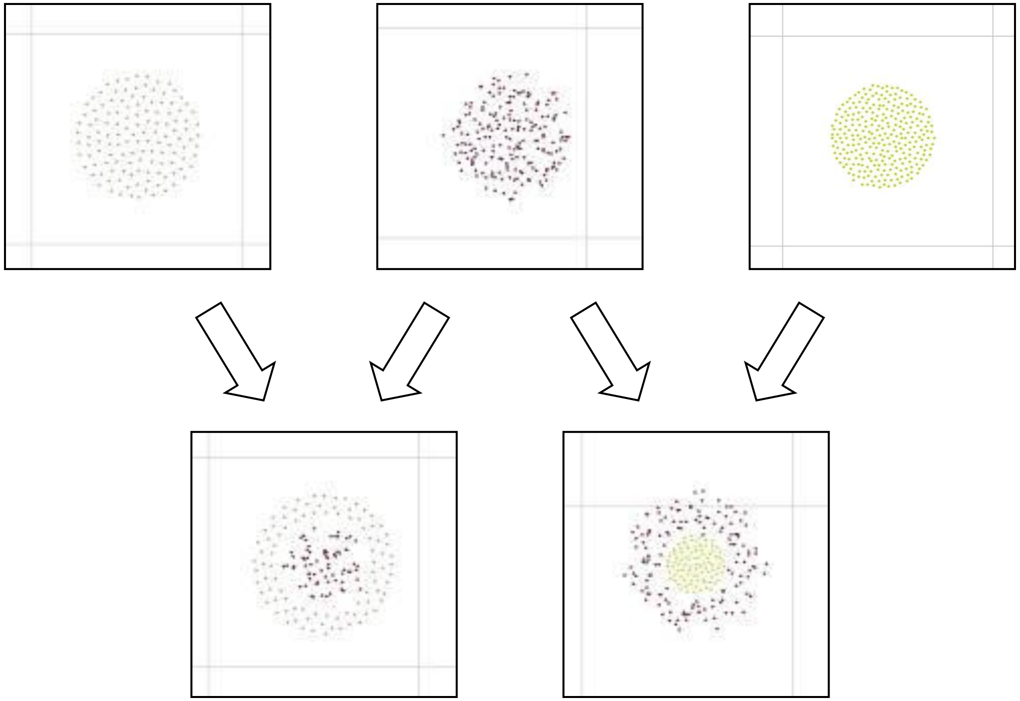
Kinetic Parameters

(Assigned to each particle individually)

Name	Min	Max	Meaning	Unit
R^i	0	300	Radius of local perception range	pixel
V_n^i	0	20	Normal speed	pixel step^{-1}
V_m^i	0	40	Maximum speed	pixel step^{-1}
c_1^i	0	1	Strength of cohesive force	step^{-2}
c_2^i	0	1	Strength of aligning force	step^{-1}
c_3^i	0	100	Strength of separating force	pixel^2 step^{-2}
c_4^i	0	0.5	Probability of random steering	—
c_5^i	0	1	Tendency of pace keeping	—

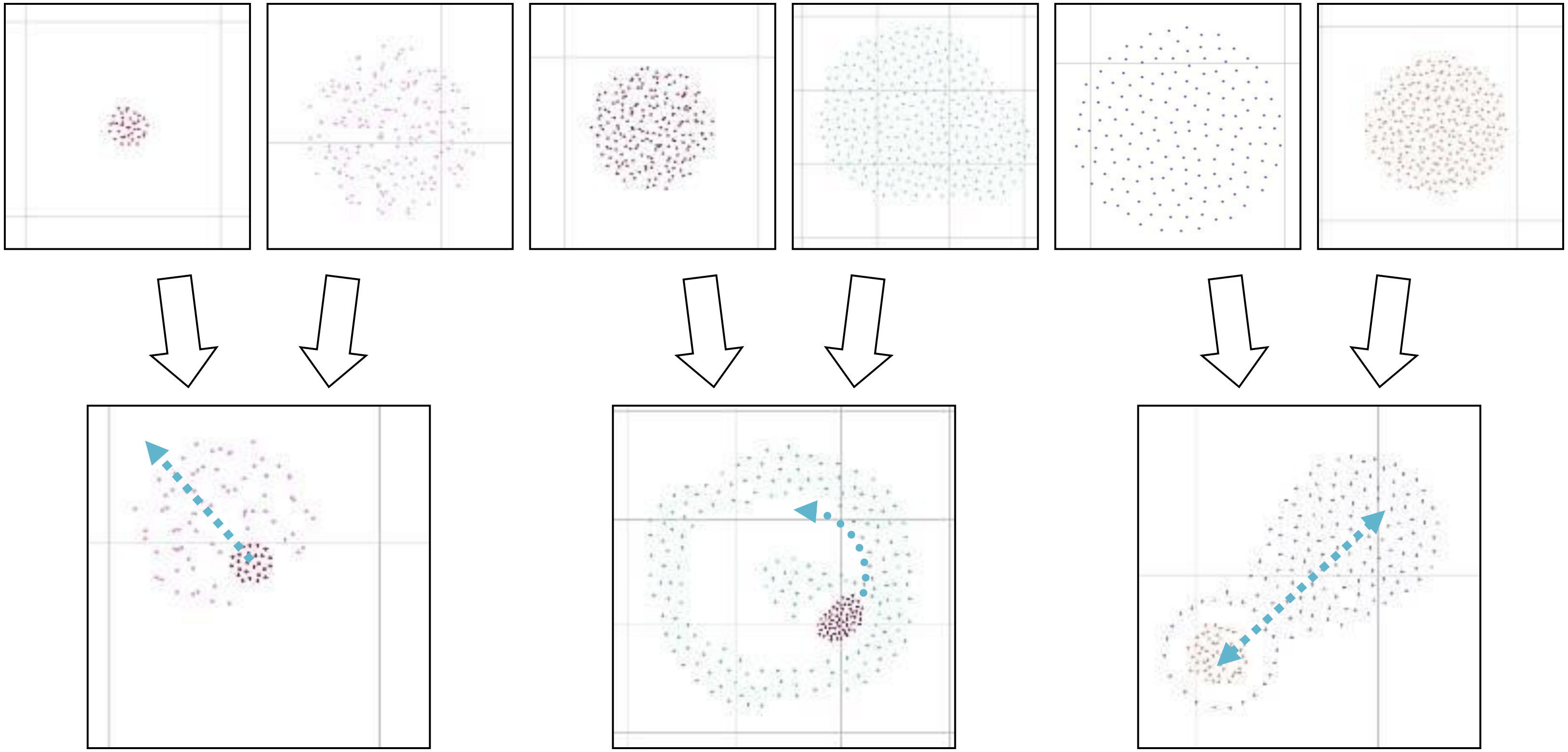
Spontaneous Segregation

- Commonly seen in heterogeneous swarms
- Often creates multilayer structures



Emergent Motion

- Mixing two types may generate new behavior that was not seen in either of them



Linear motion | Rotation | Oscillation

Self-Organization with >2 Types?

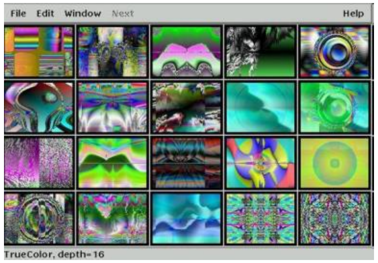
- Possibility space explodes with # of types
  - Exhaustive parameter sweep not feasible
  - Monte Carlo may not give enough resolution

- It is no longer clear what to measure in order to characterize resulting patterns
  - No one knew what to expect

Interactive Approach

Interactive Evolutionary Computation (IEC)

- An alternative, more *exploratory* approach



"SBART" © Tastuo Unemi

- Heterogeneous swarms represented by lists of multiple parameter sets (recipes), evolved over many iterations

"Hunch Engine™" © Icosystem

- A human participates in evolutionary processes by subjectively selecting and varying their recipes

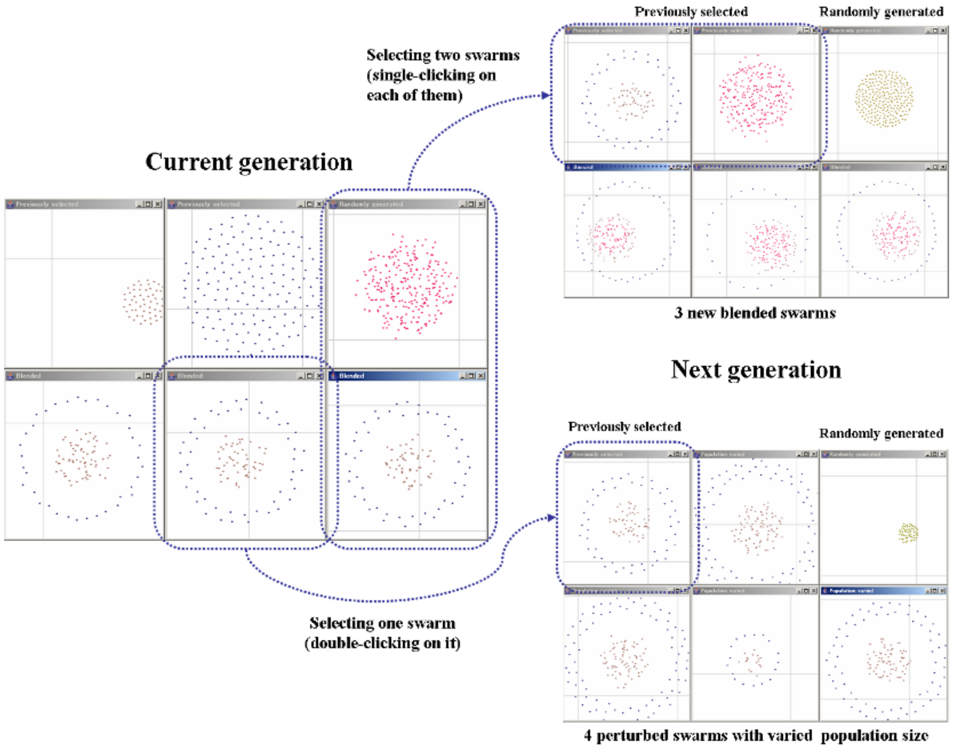
Recipe

- A list of kinetic parameter sets of different types within a swarm
  - Format: # of particles * (R, V_n, V_m, c_1, c_2, c_3, c_4, c_5)
  - Each row represents one type

97 * (226.76, 3.11, 9.61, 0.15, 0.88, 43.35, 0.44, 1.0)
38 * (57.47, 9.99, 35.18, 0.15, 0.37, 30.96, 0.05, 0.31)
56 * (15.25, 13.58, 3.82, 0.3, 0.8, 39.51, 0.43, 0.65)
31 * (113.21, 18.25, 38.21, 0.62, 0.46, 15.78, 0.49, 0.61)

First Version: Swarm Chemistry 1.0/1.1

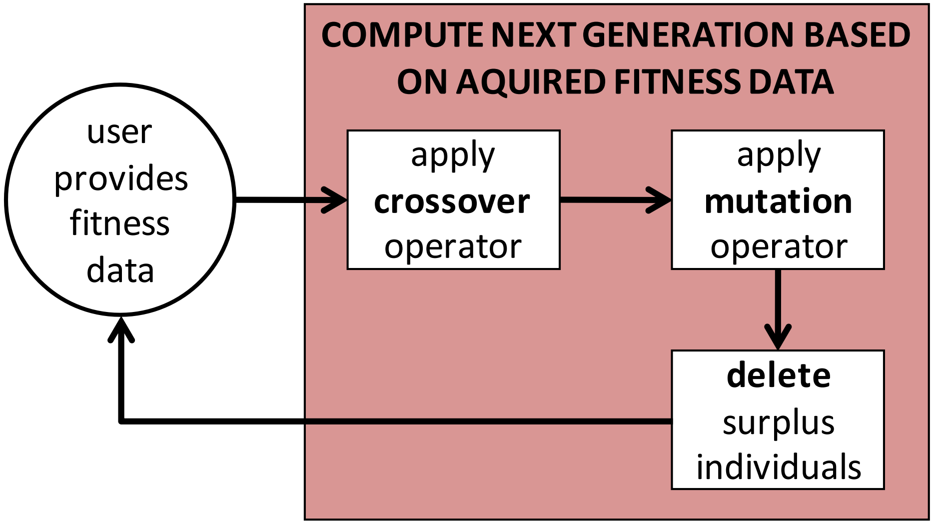
- *Simulated breeding* with fixed number of solutions & discrete generation changes



[demo]

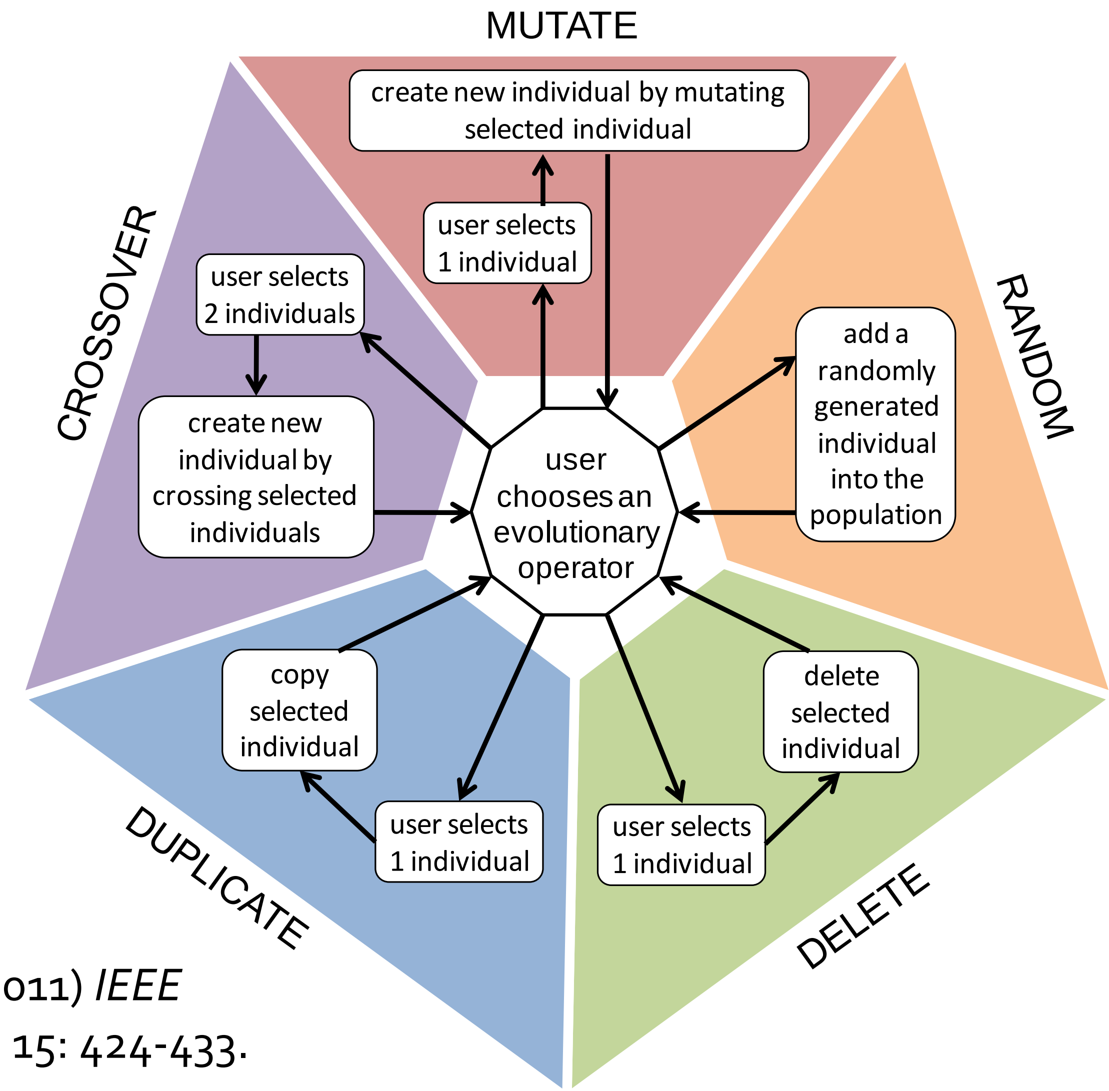
Limitations

- Population size was fixed
- User participates only as a fitness evaluator



- May not fully exploit the creative/exploratory nature of human decision making

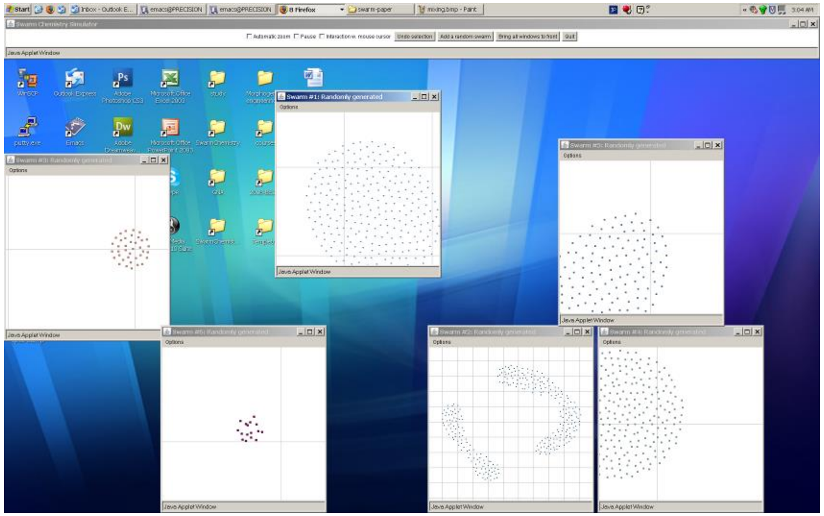
Hyper-Interactive Evolutionary Computation (HIEC)



Bush & Sayama (2011) *IEEE Trans. Evol. Comp.* 15: 424-433.

Improved Version: Swarm Chemistry 1.2

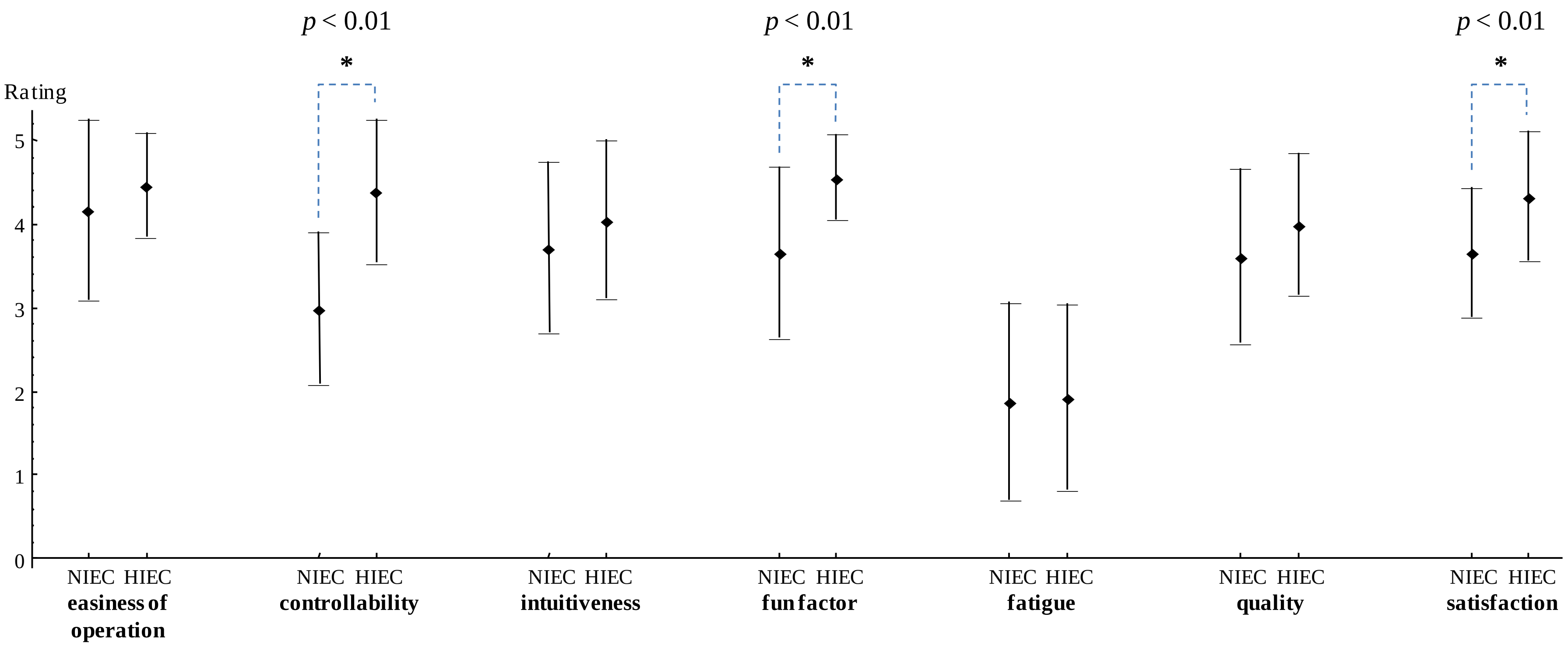
- Based on HIEC
- Evolutionary operators act on each swarm locally and visually



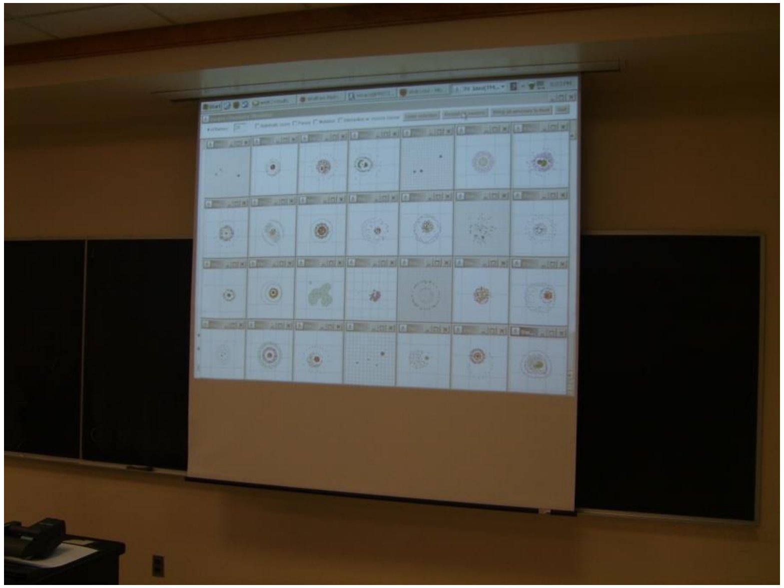
- Continuous generation changes
  - Number of swarms on a screen dynamically changes with no predetermined bound

[demo]

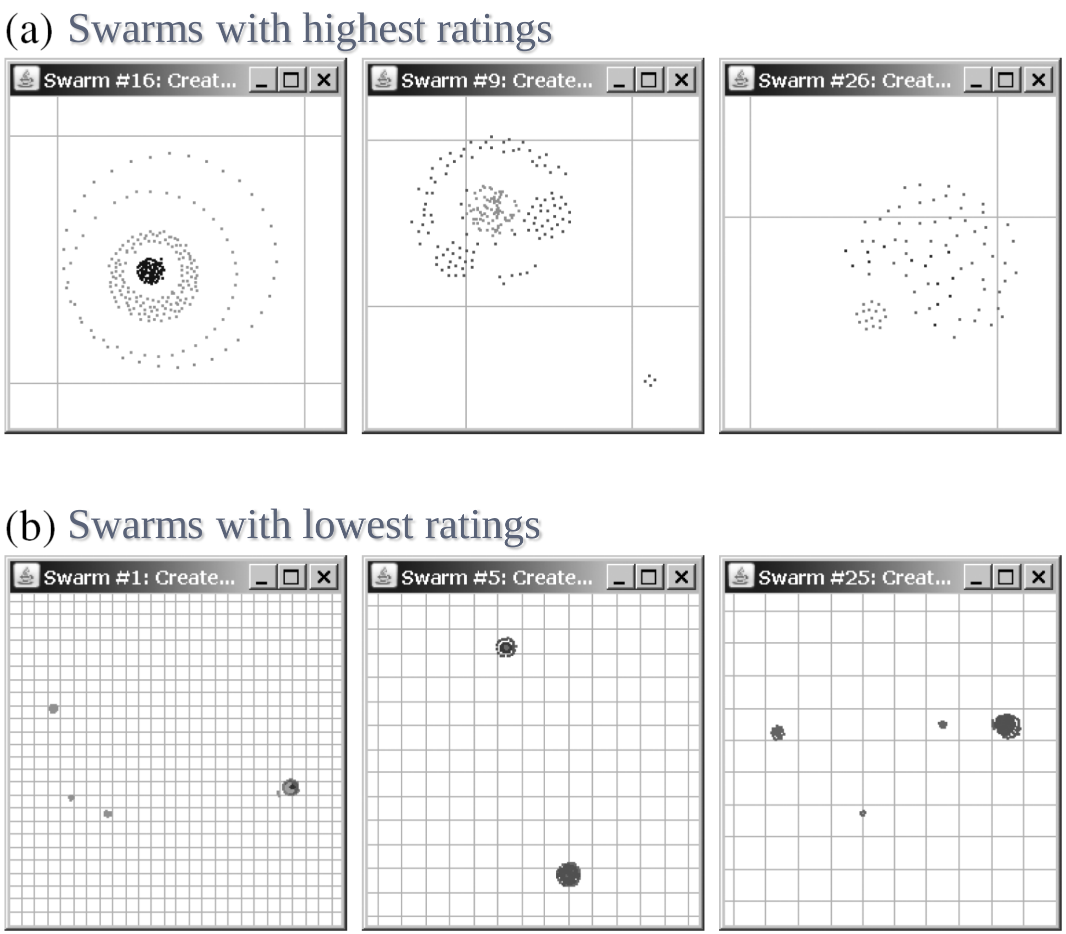
HIEC: More Controllable, More Fun, and More Satisfactory



Peer Evaluation of Product Quality

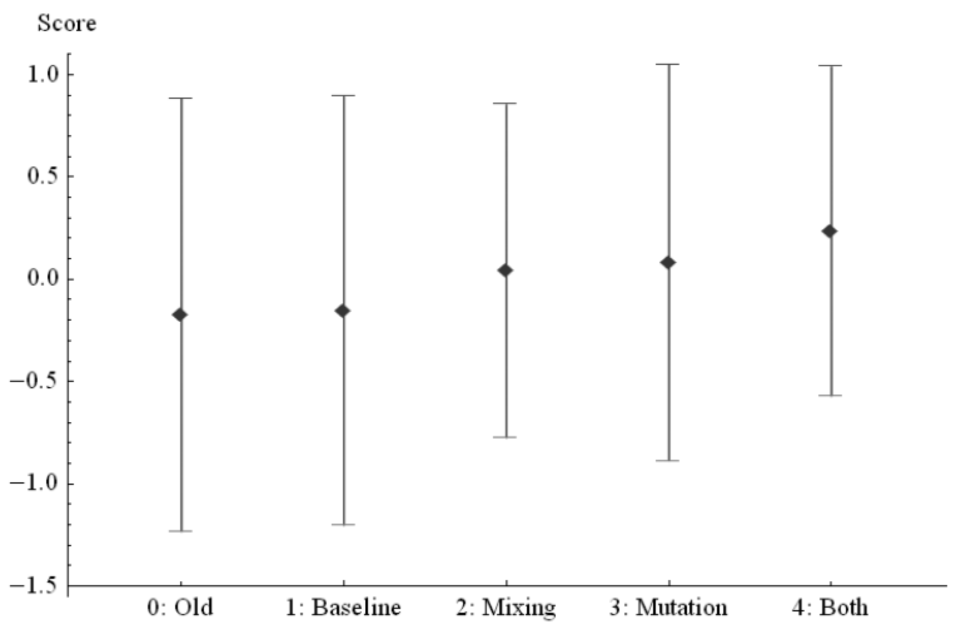


Final Products Created and Selected for/against by Students



[demo]

Conditions and Peer-Evaluation Results

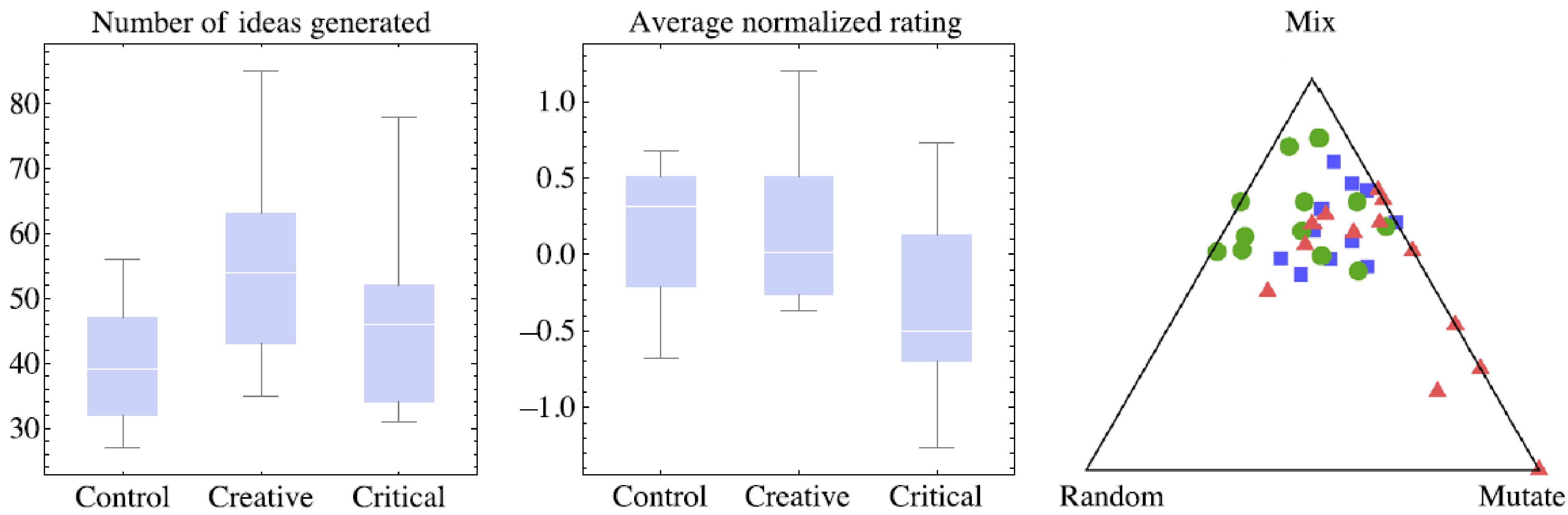


Source of variation	Degrees of freedom	Sum of Squares	Mean Square	*F*	*F*-test *p*-value
Between Groups	4	14.799	3.700	4.11	**0.003***
Within Groups	583	525.201	0.901		
Total	587	540			

Perturbing Human Attitudes

- **Creative:** *"Promote and maintain creative attitude throughout the design process. Crazy inspiration and idiosyncratic thinking is the key to breaking the barrier of stereotyped designs. Incremental improvement of existing designs will never work out."*
- **Critical:** *"Promote and maintain critical attitude throughout the design process. Incremental improvement of existing designs is the key to making a reliable solution. Completely new designs will never be better than well-tested ones."*
- **Control:** (no additional instruction given)

Behavioral Changes



Sayama & Dionne (2015) *Artificial Life* 21:379-393.

Automated Approach

Do We Really Need Human Users?

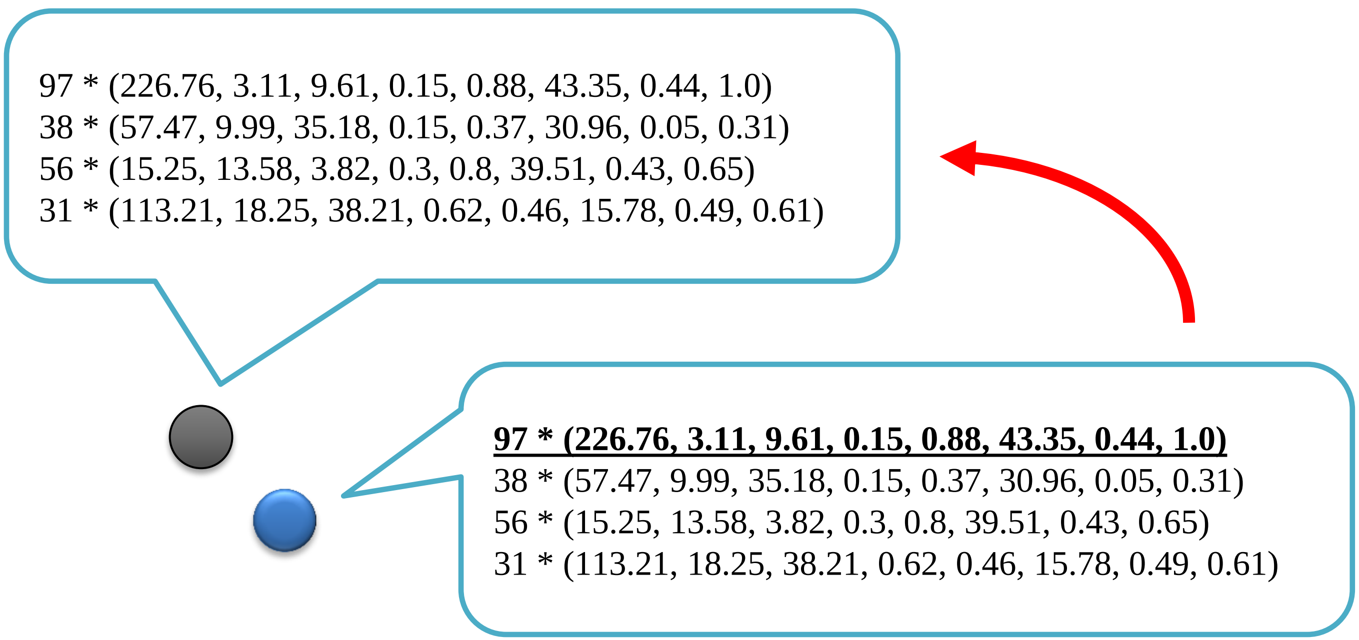
- No we don't, if:
  - The system can spontaneously evolve new potentially innovative designs

  and if

  - We know what kind of quantitative properties human users are looking for

Making It Evolvable (1,2)

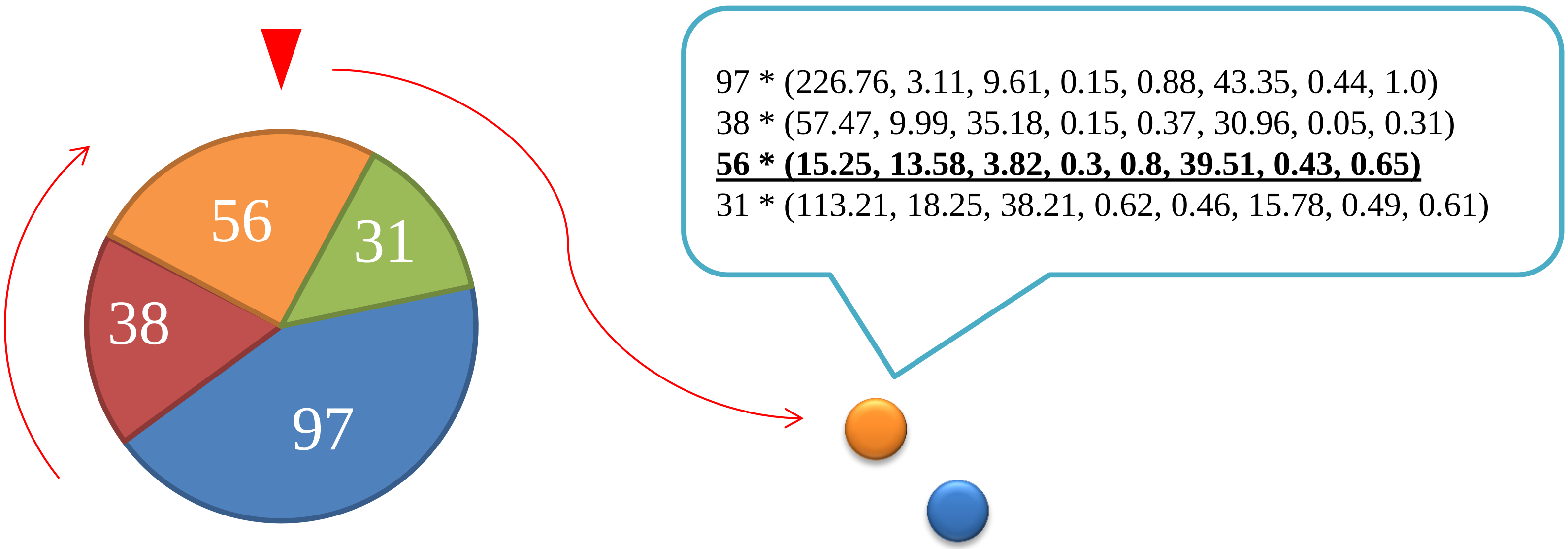
1. Two categories of particles (active/passive)
2. Recipe transmission from active to passive



Sayama (2011) *IEEE ALIFE 2011*, pp. 186-193.

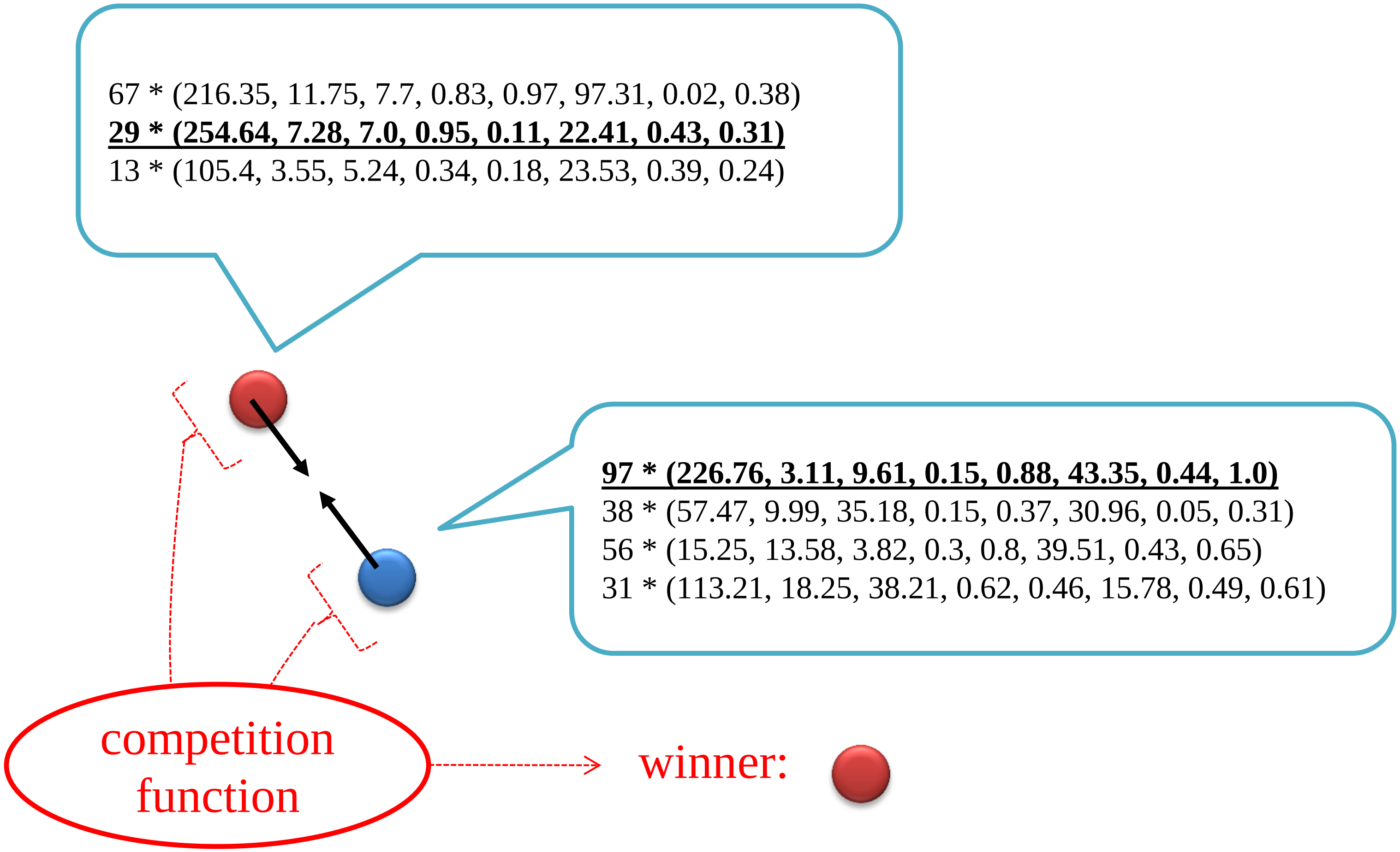
Making It Evolvable (3,4)

3. Random differentiation at the transmission
4. Random continuous re-differentiation



Making It Evolvable (5)

5. Recipe transmission between **active** particles



Making It Evolvable (6)

6. Recipe mutation

67 * (216.35, 11.75, 7.7, 0.83, 0.97, 97.31, 0.02, 0.38)
29 * (254.64, 7.28, 7.0, 0.95, 0.11, 22.41, 0.43, 0.31)
13 * (105.4, 3.55, 5.24, 0.34, 0.18, 23.53, 0.39, 0.24)

75 * (216.35, 11.75, 7.7, 0.83, 0.97, 97.31, 0.02, 0.38)
29 * (254.64, 7.28, 7.0, 0.95, 0.11, **28.56**, 0.43, 0.31)
13 * (105.4, 3.55, 5.24, 0.34, 0.18, 23.53, 0.39, 0.24)

Introducing Exogenous Perturbations

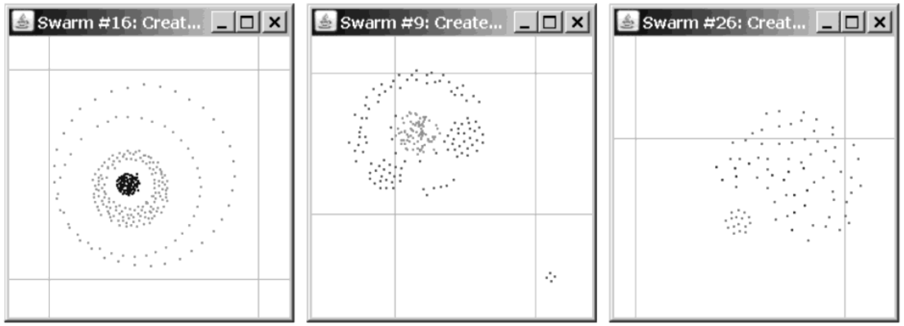
- Perturbation I:
  Competition function switched from "majority-relative" to either "faster" or "slower" for 50 time steps in every *5000* time steps

- Perturbation II:
  Competition function switched from "majority-relative" to either "faster" or "slower" for 50 time steps in every *2000* time steps *only in either left or right half of the space*

Automatic Identification of "Interestingness"

- Can "*interesting results*" be identified automatically without human interventions?

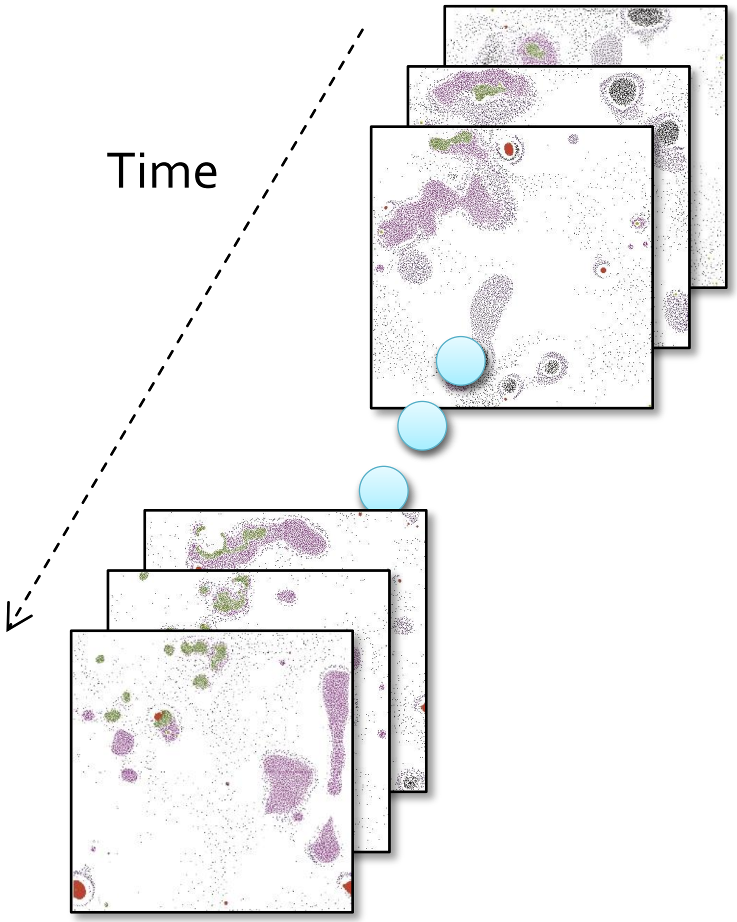
Swarms with highest ratings



- Hypothesis -- People are looking for:
  - Clear structures
  - Continuous changes

Quantifying Macroscopic Properties

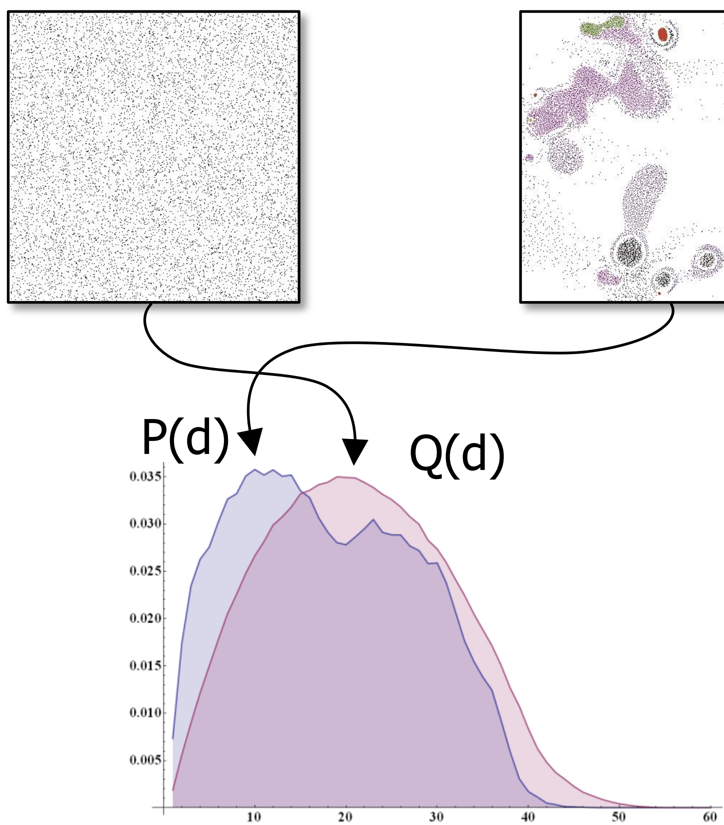
- Developed simple methods to quantify macroscopic properties of swarms *directly from snapshots of past simulation runs*



Sayama & Wong (2011) *ECAL 2011*, pp.729-730.

Measurement 1: Macroscopic Structuredness

Random distribution Actual snapshot

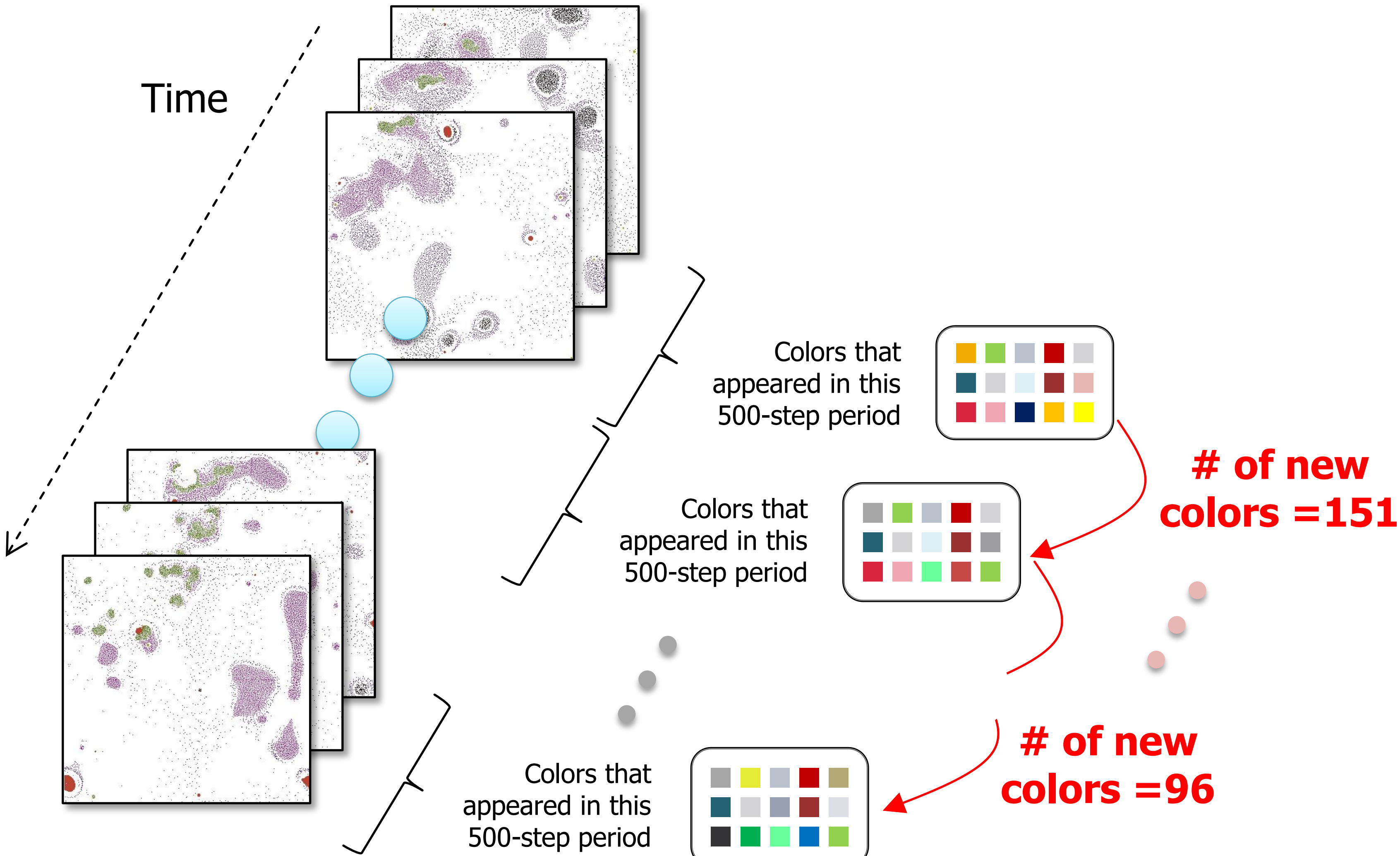


Pairwise distance distribution

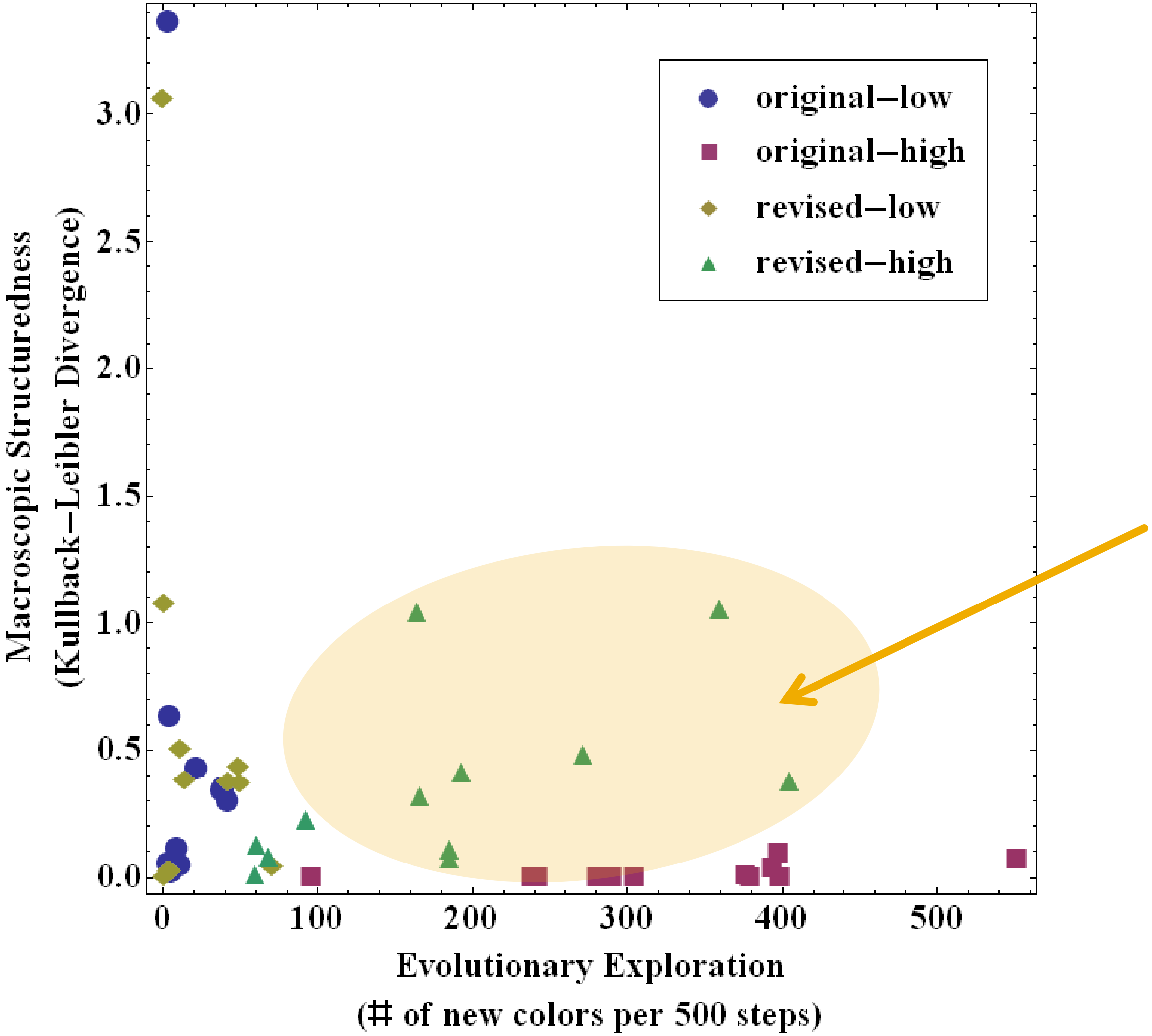
Kullback-Leibler Divergence

$$\sum_d P(d)\log\frac{P(d)}{Q(d)} = \mathbf{0.1184}$$

Measurement 2: Evolutionary Exploration

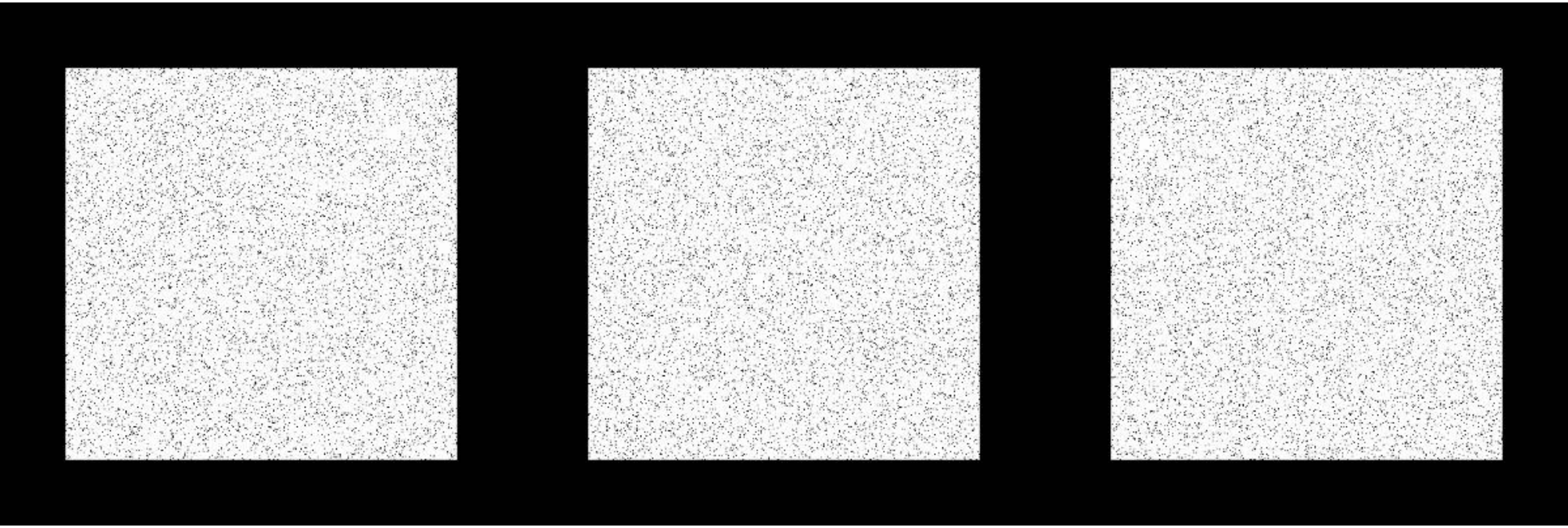


Results



One condition successfully maintained large values for both measurements

Automatically Identified Best Runs



- http://YouTube.com/ComplexSystem/

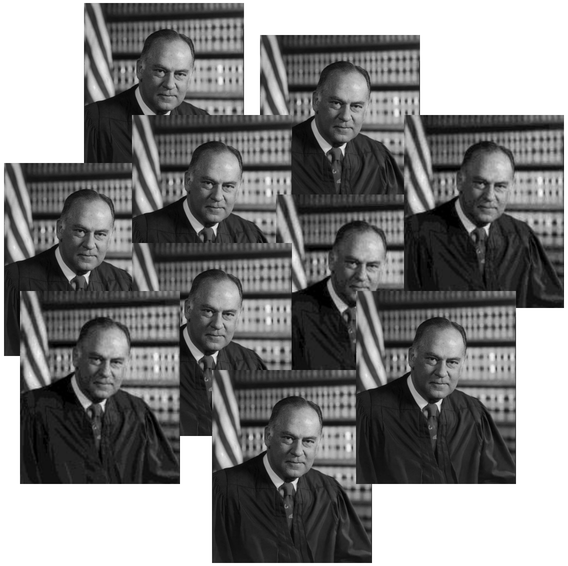
Conclusions

Summary

- Self-organizing complex systems can be designed using evolutionary principles
  - Significant improvement of user experience and design quality by new HIEC architecture
  - More evolutionary operators, better explorations
- Spontaneous evolutionary design possible
  - Recipe transmission with errors, (re-)differentiation, environmental perturbation
  - “Interesting” results automatically identified

Take-Home Message

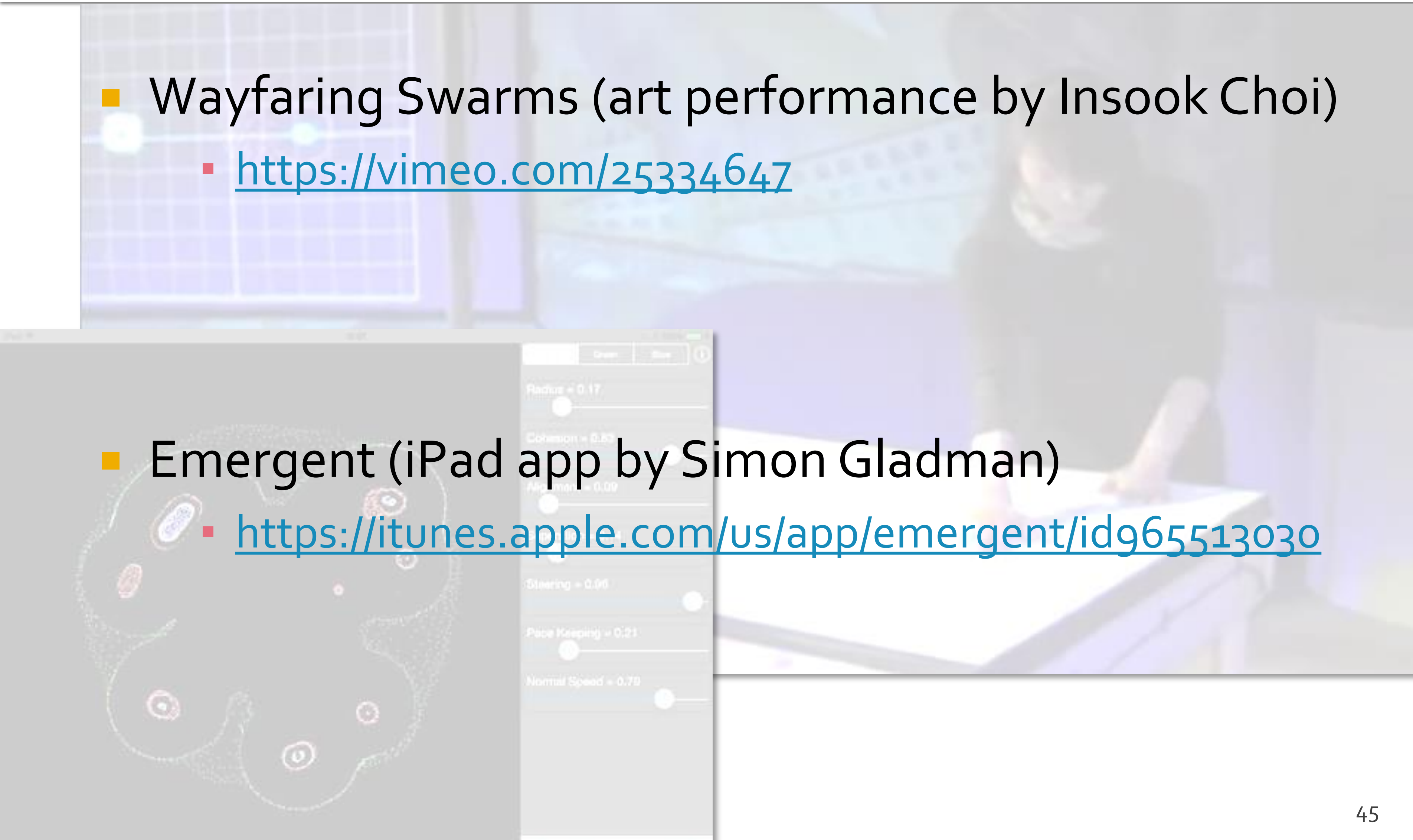
- Evolutionary approaches help guide self-organization without understanding
  - Interactive, spontaneous



What I do not understand,
I can still create. *-- unknown*

Final Notes: Broader Outreach

- Wayfaring Swarms (art performance by Insook Choi)
  - https://vimeo.com/25334647



- Emergent (iPad app by Simon Gladman)
  - https://itunes.apple.com/us/app/emergent/id965513030

For More Info

- Hiroki Sayama (2012) Swarm-based morphogenetic artificial life, in *Morphogenetic Engineering: Toward Programmable Complex Systems*, Springer, pp.191-208.
- Hiroki Sayama (2014) Guiding designs of self-organizing swarms: Interactive and automated approaches, in *Guided Self-Organization: Inception*, Springer, pp.365-387.

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  - Insook Choi
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