Evolution, the First Programmer

Kyle Harrington
DEMO Lab, Computer Science
Brandeis University

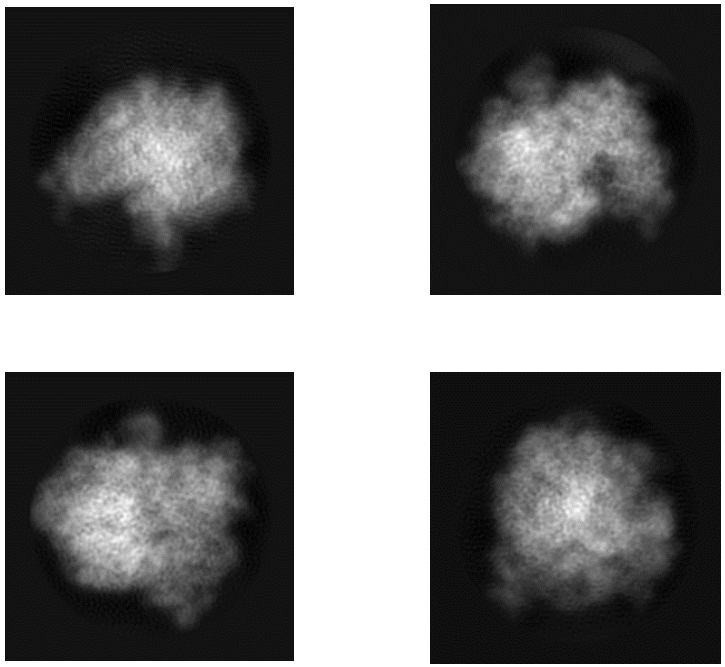
Primate Programmers

- The Infinite Monkey Theorem:
  - In the limit of infinite time, monkeys can write Shakespeare.

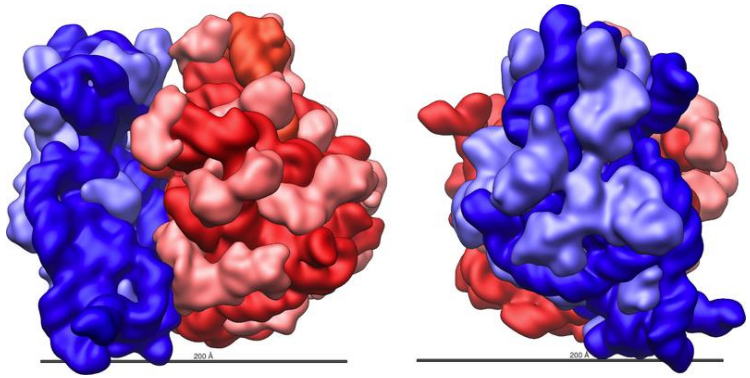
6 monkeys, a computer, and 1 month later
5 pages of mostly the letters S, A, J, L and M.
(From U Plymouth, reported in Wired)

Images: Wired
Brooks, J. L., et al. (1989). The Simpsons. Twentieth Century Fox.

Micrographs to 3D structures



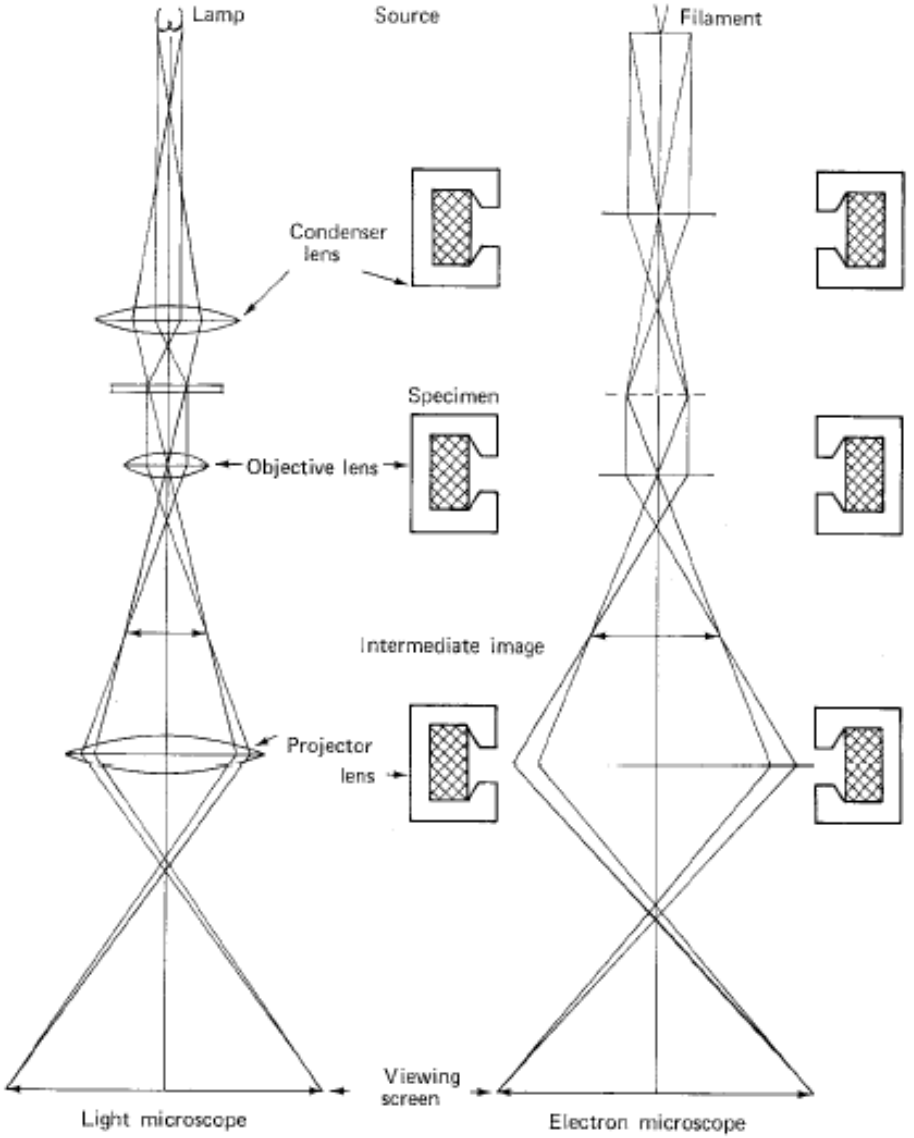
Rendering of experimentally-derived ribosome structure

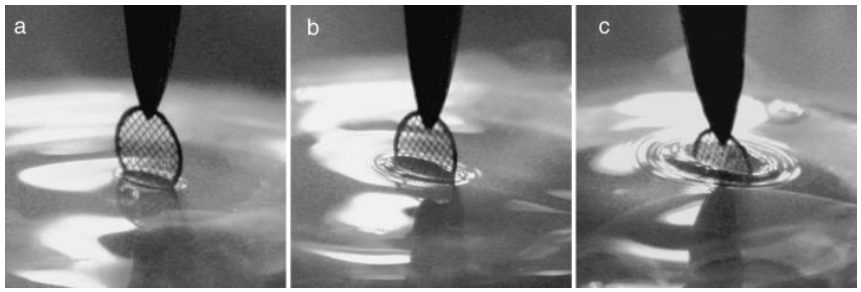


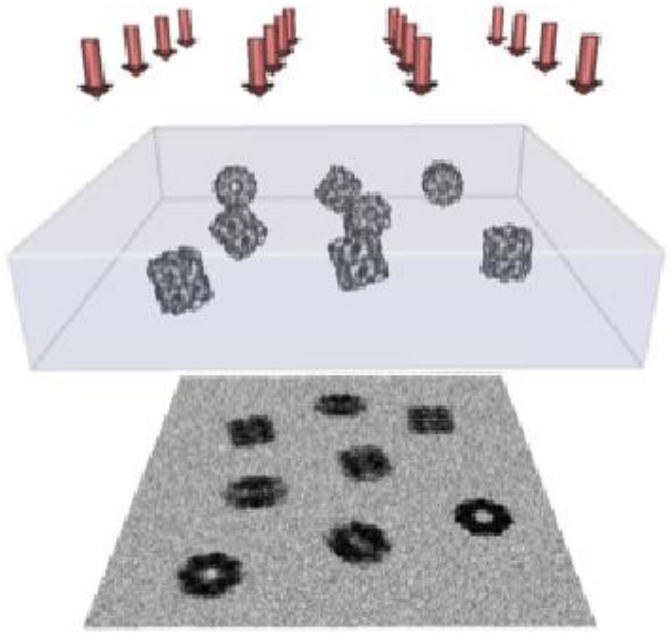
3D reconstruction

Images courtesy of Axel Brilot
Wikimedia

Recap: Axel's Fancy Tools

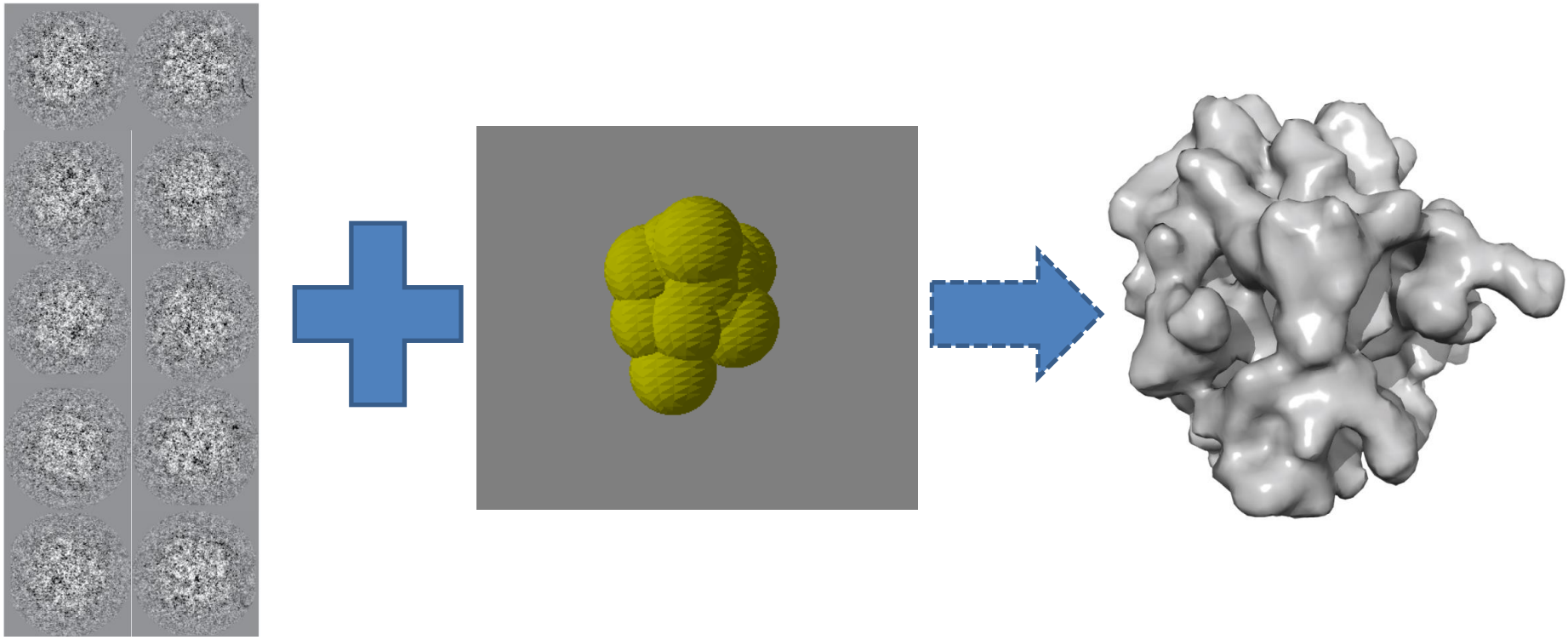




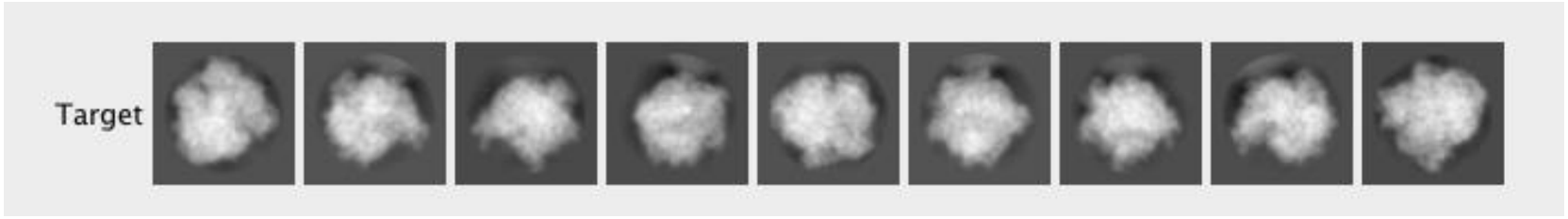


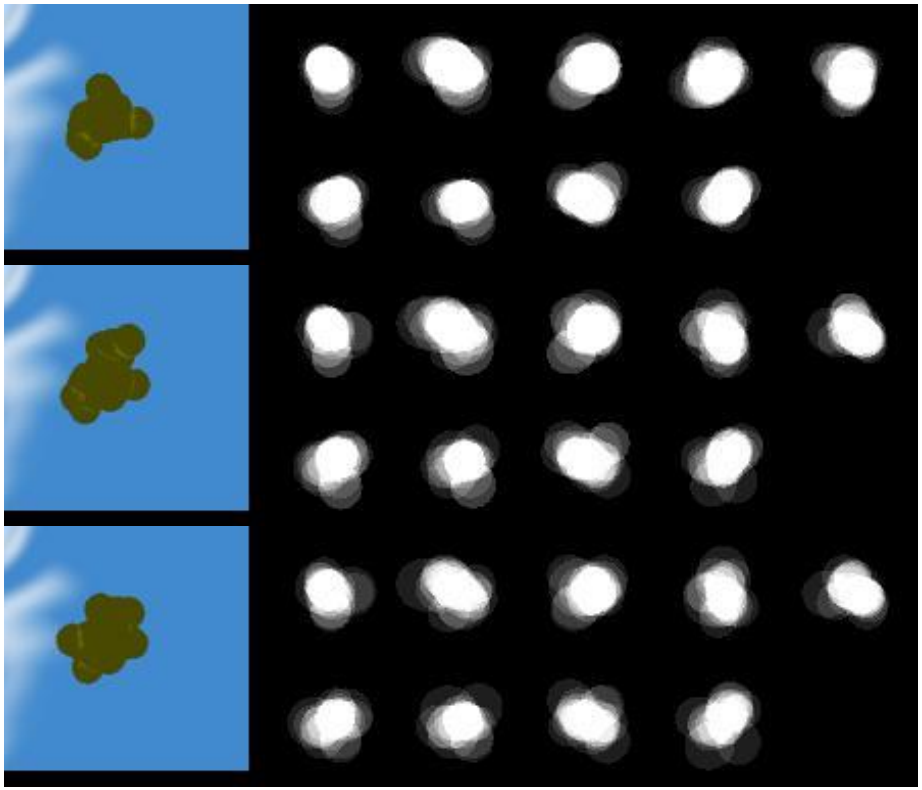
(see references in Axel's slides)

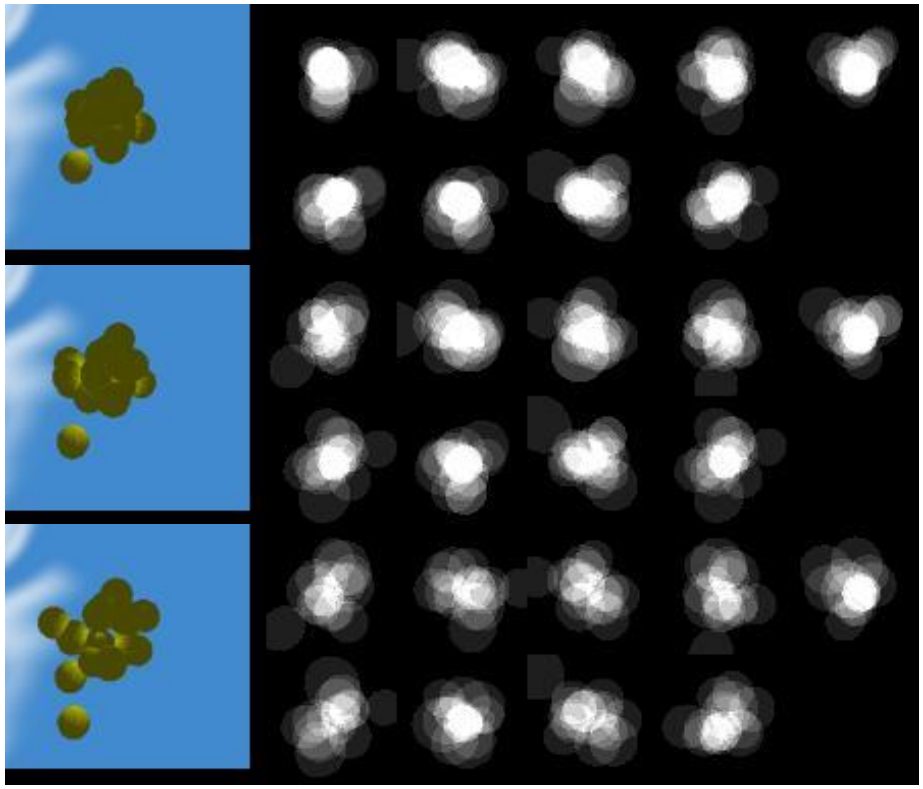
BEADS Evolutionary Automated Discovery of Structures



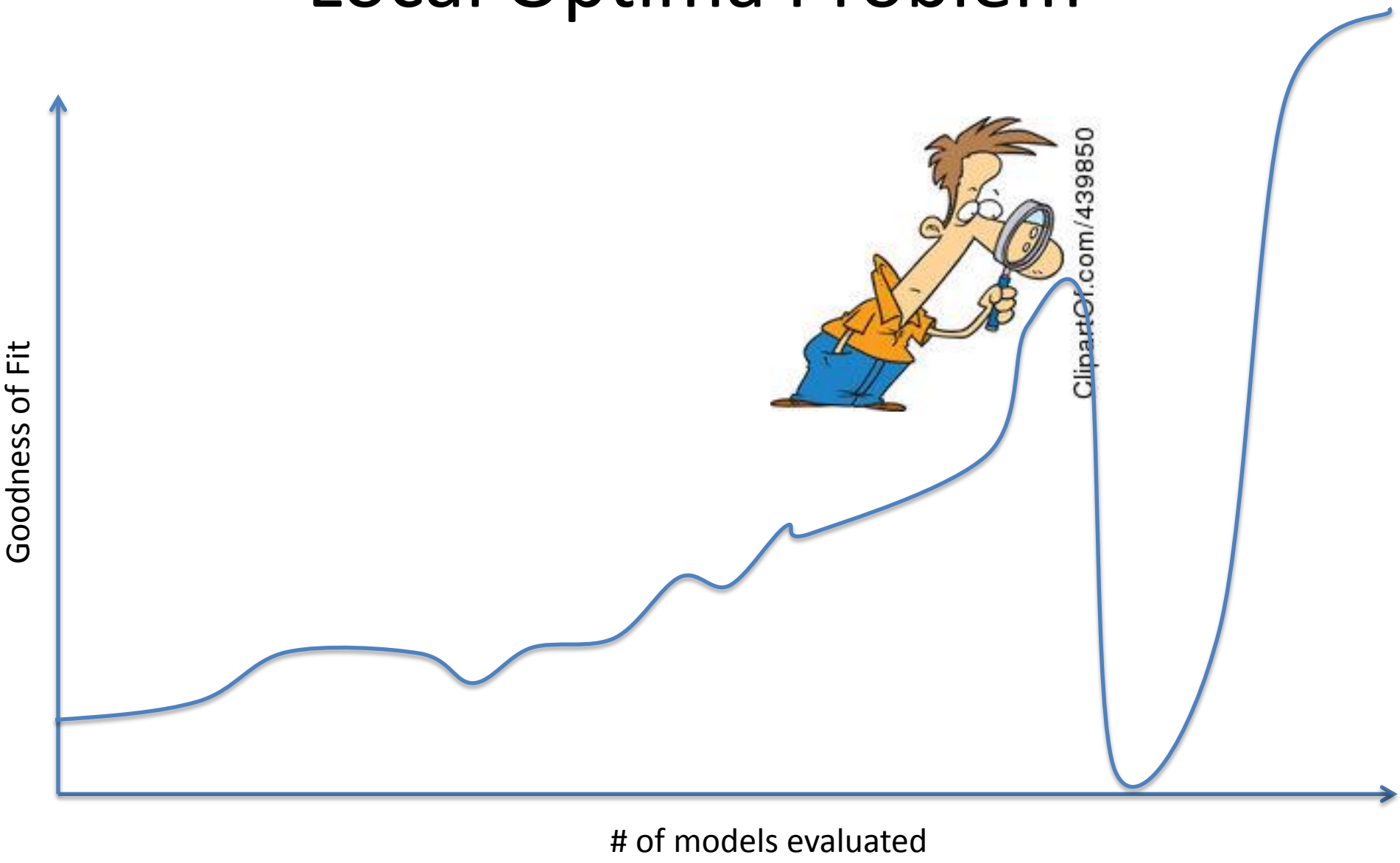
Example: Structure Search





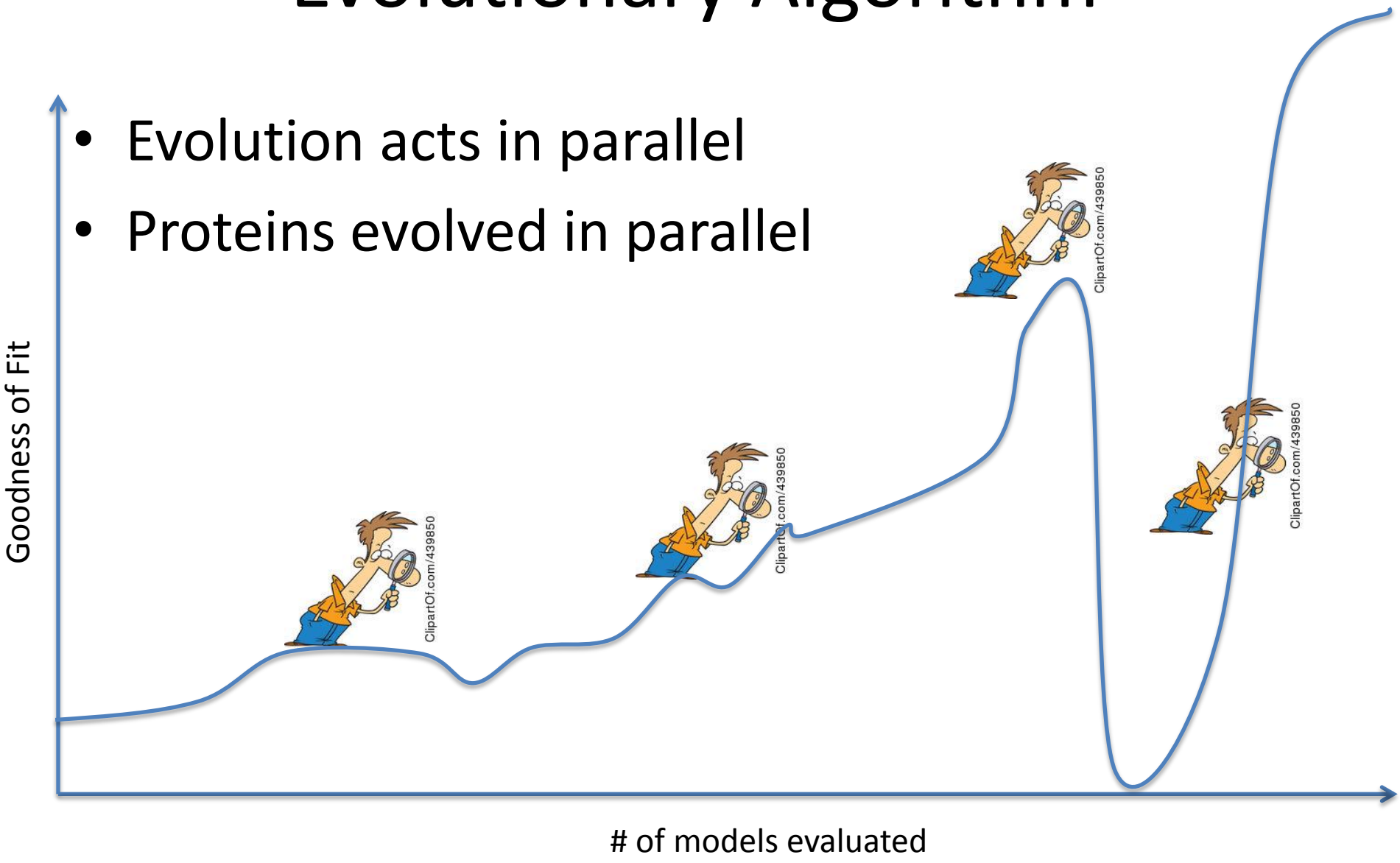


Local Optima Problem



Evolutionary Algorithm

- Evolution acts in parallel
- Proteins evolved in parallel



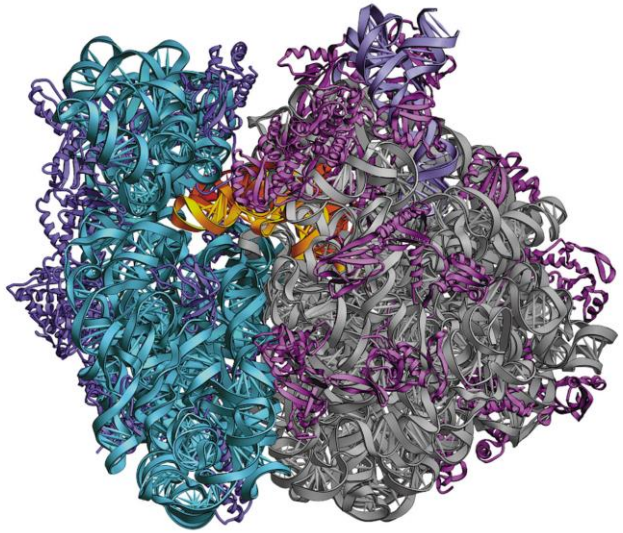
Representation

- How does one represent a candidate model?

- Computational evolution uses bit strings

1	0	0	1	1	0	0	0	1	0

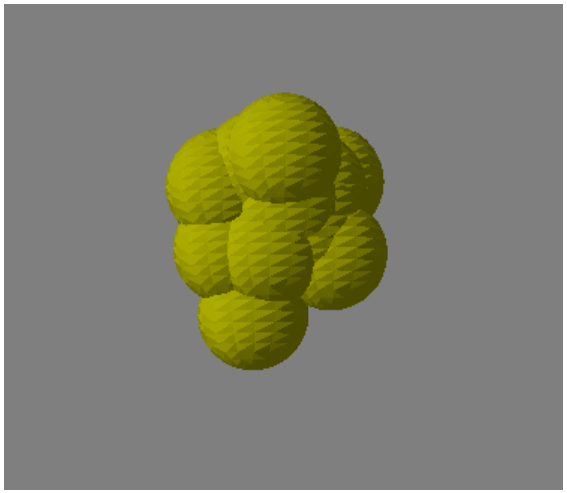
- What about representing this?

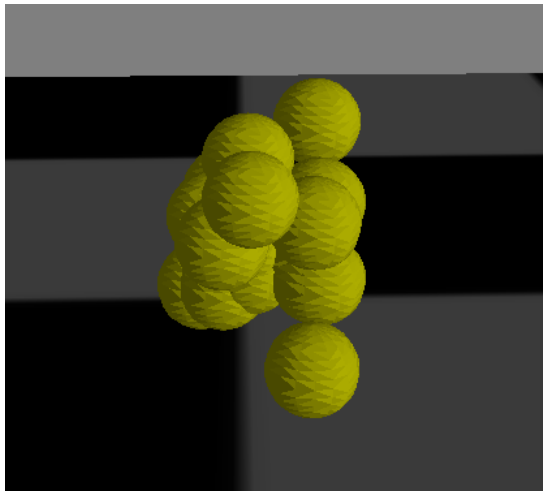


Images courtesy of UCSC, RNA Center

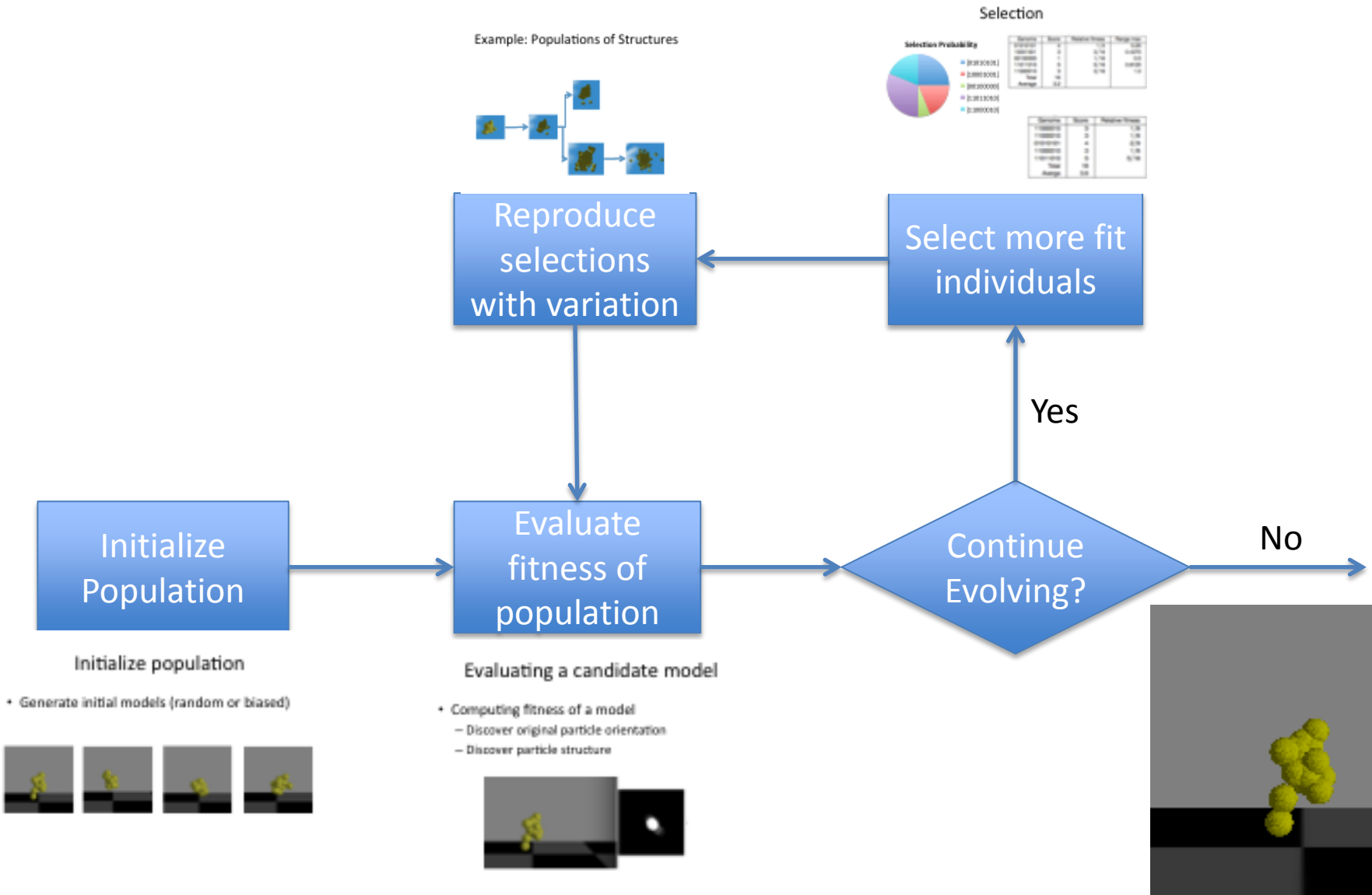
Our Representation

- Volumes of density as spheres
  - Variable number of spheres
  - Variable radius





Evolving Structural Models

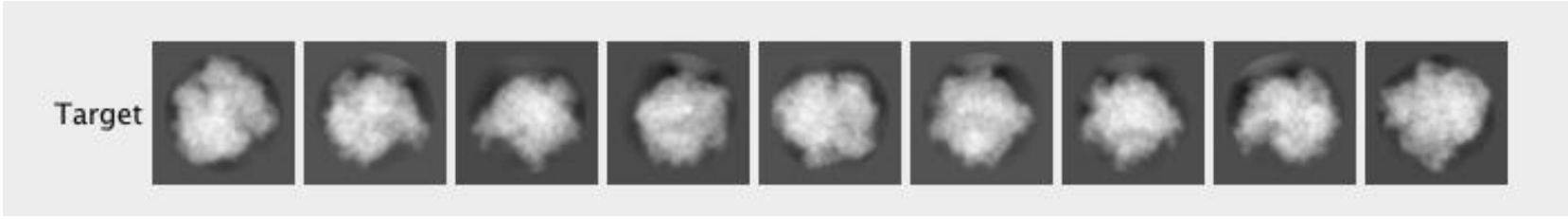


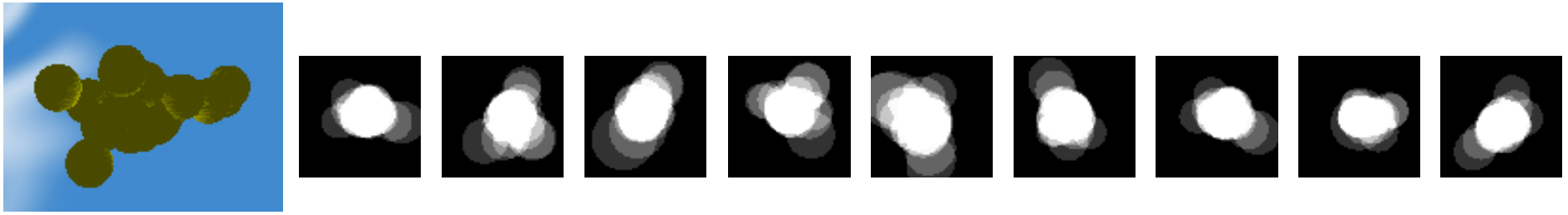
Initialize Population

- Generate initial models (random or biased)

Evaluating a Candidate Model

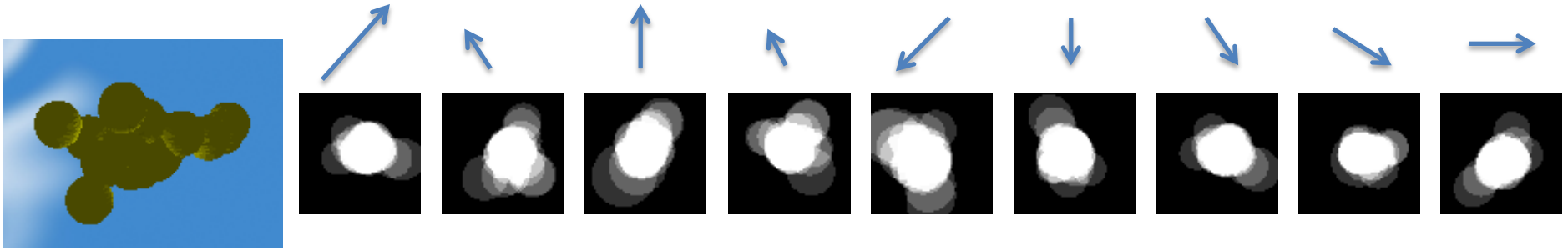
- Computing fitness of a model
  - Simulate microscope imaging
  - Ray-trace from imaging plane

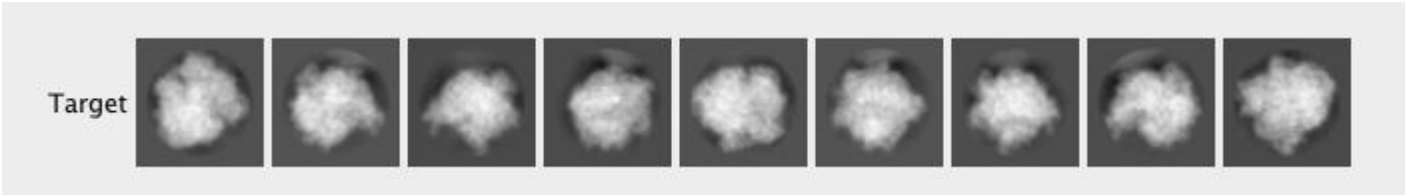


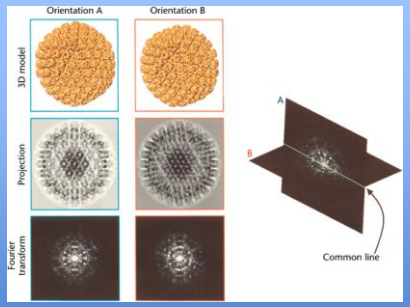


Particle Orientation

- Coevolve orientation and structural model

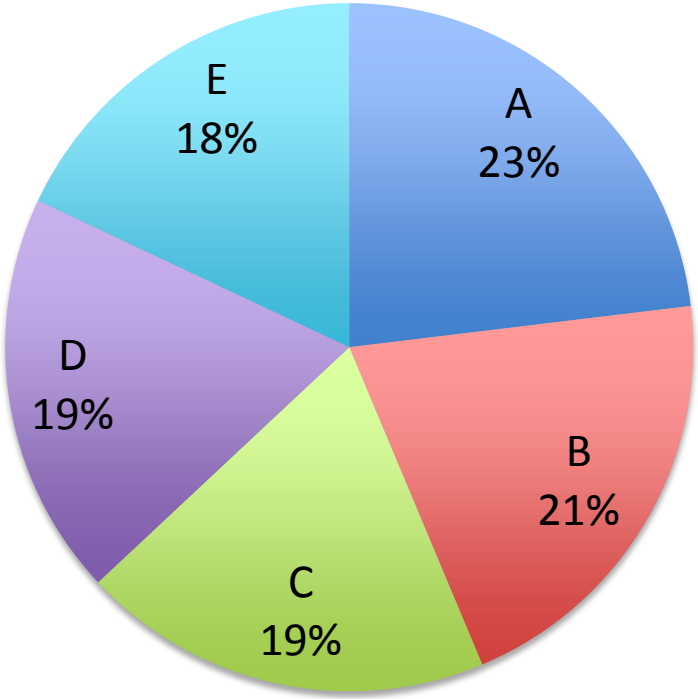




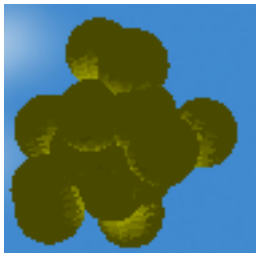


Common lines approach
(see Axel's slides)

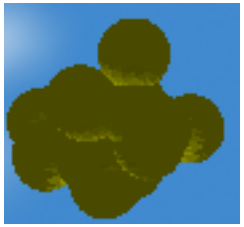
Selection



A

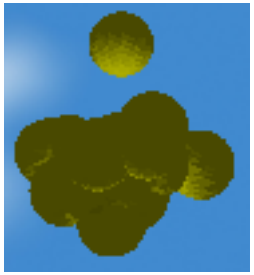


B



C

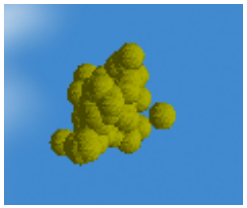
D

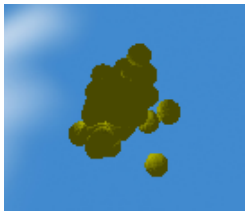


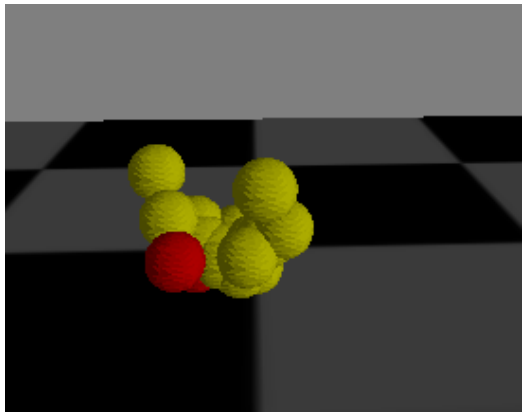
E

Mutation

- Mutation randomly perturbs candidate model

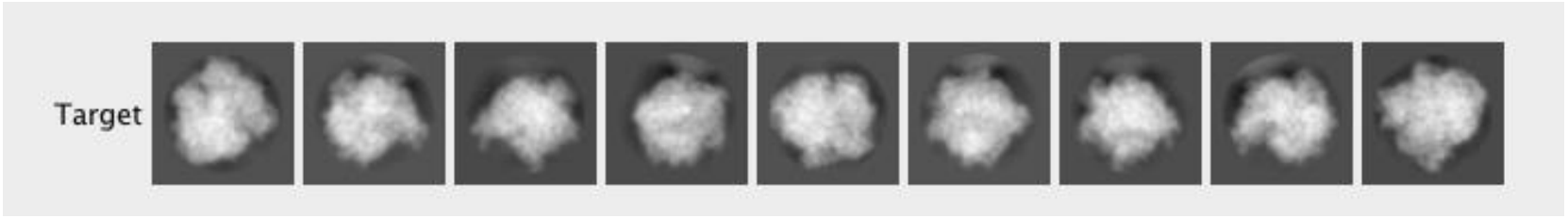


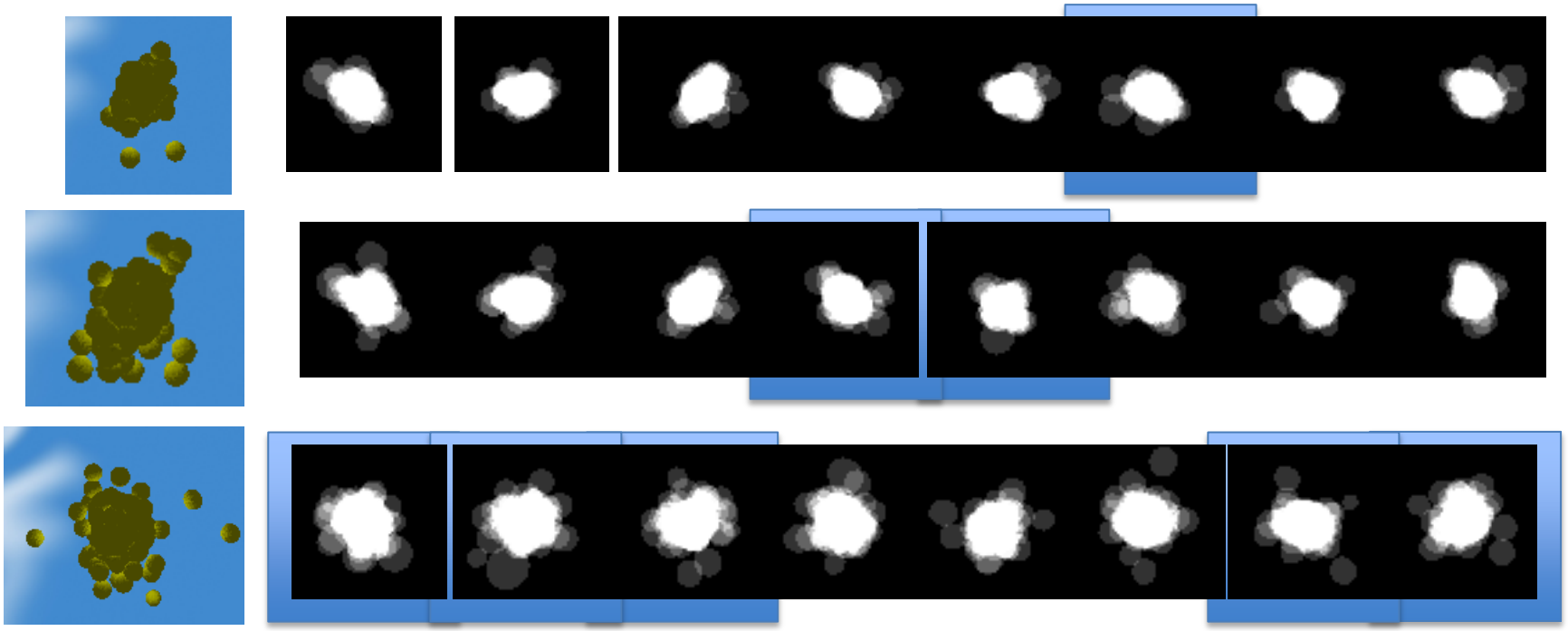




Populations of Models

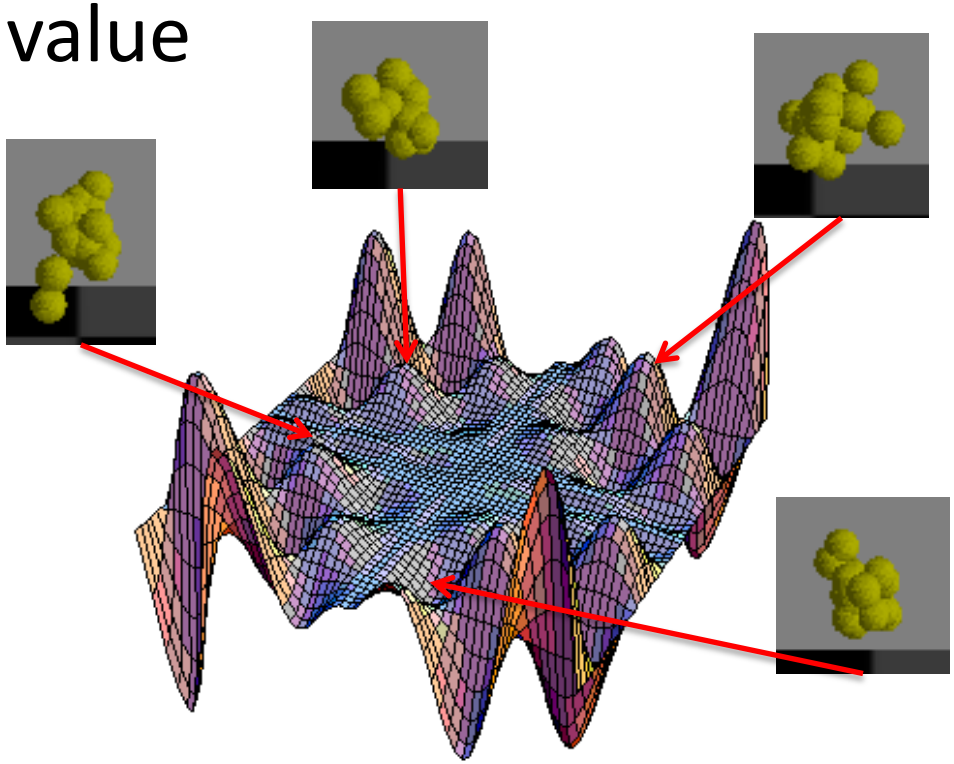
- Individual models may favor different features





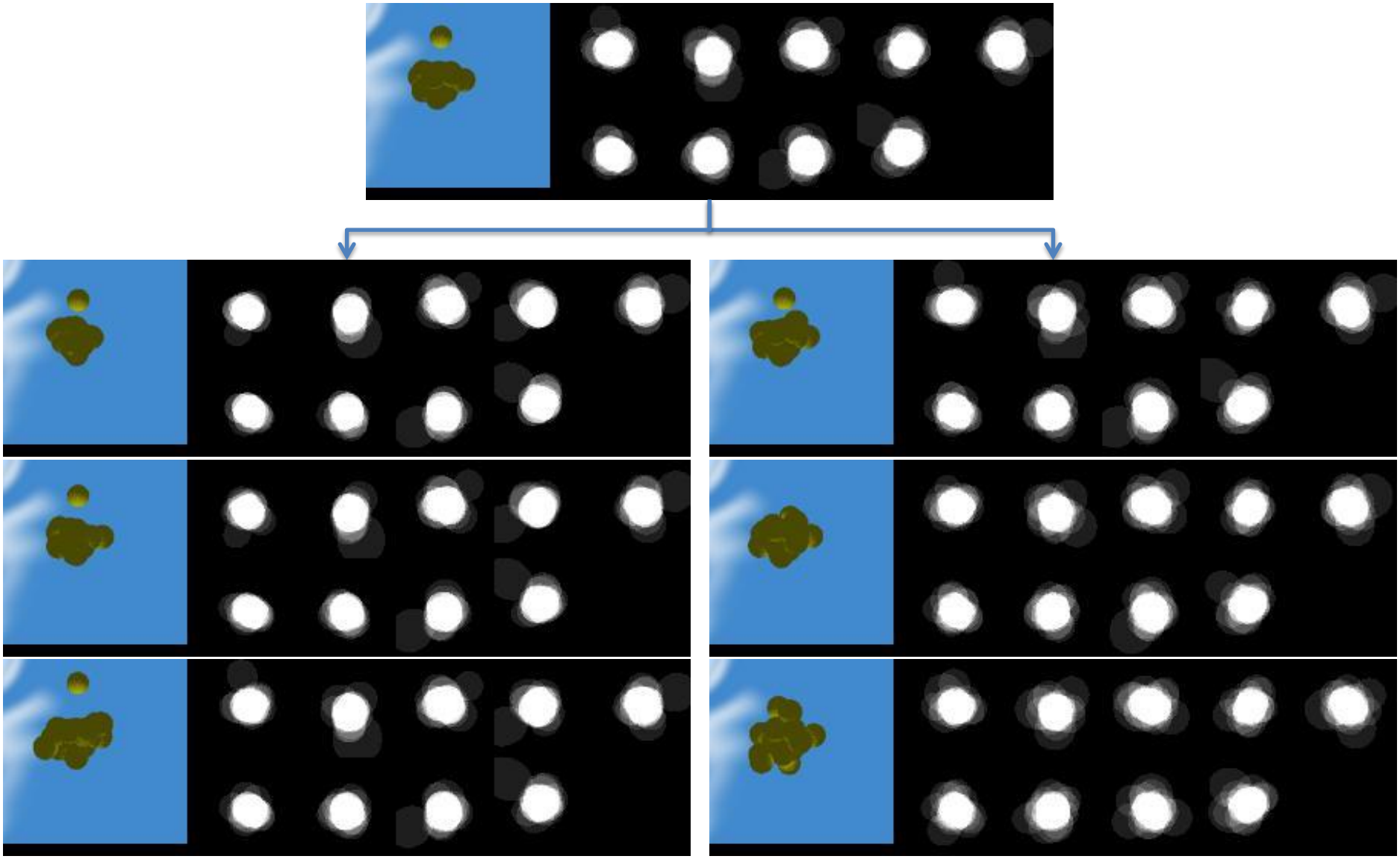
Fitness Landscapes

- Fitness landscape describes the distribution of phenotypes by fitness value
- Local optima
- Multiple peaks
- Deceptive optima



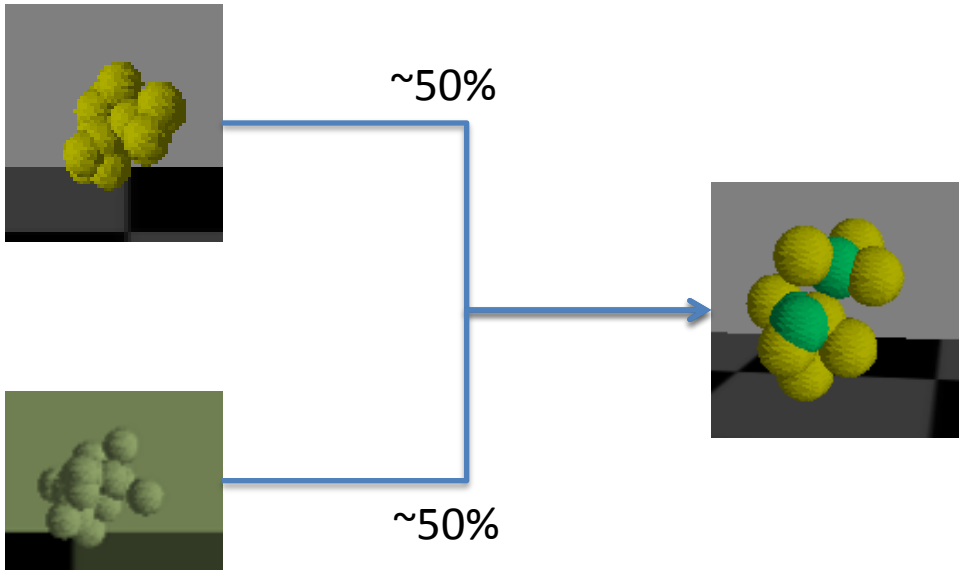
Images courtesy of M. Frame

Example: Evolutionary Branching



Recombination Optimizes Mixability

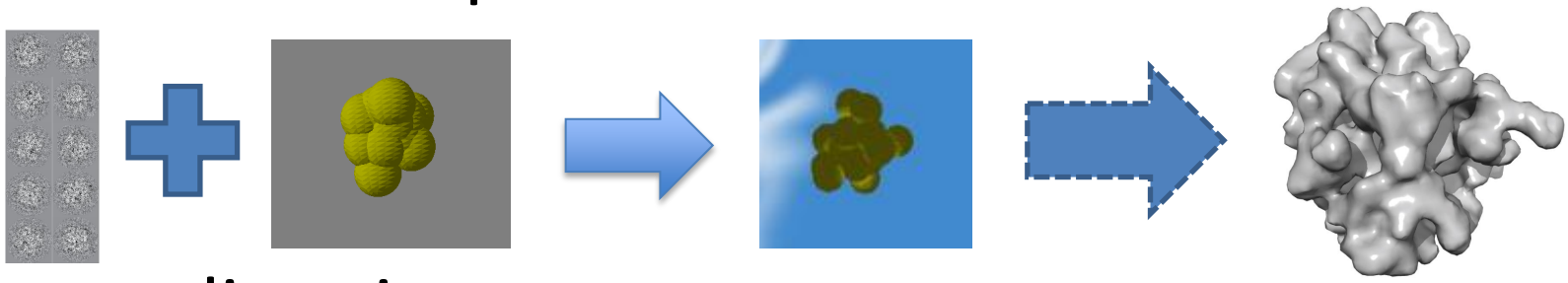
- Selection acts on the mixes of individuals (children)



Livnat, Adi, et al. *PNAS* 105.50 (2008)

Concluding Particle Reconstruction

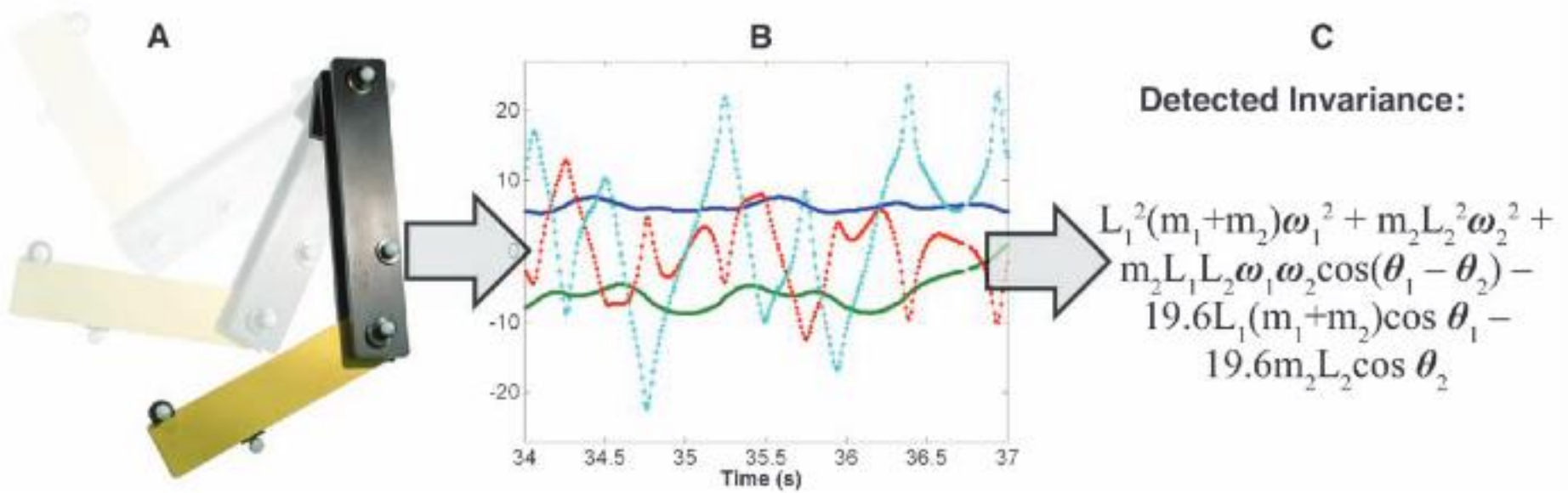
- Evolutionary particle reconstruction is a natural next step for the field



- Future directions:
  - Unifying existing algorithms with evolutionary algorithms
  - Recombination and environmental variation

Evolving Mathematical Models

- Goal: discover best model from experimental data with minimal human effort.

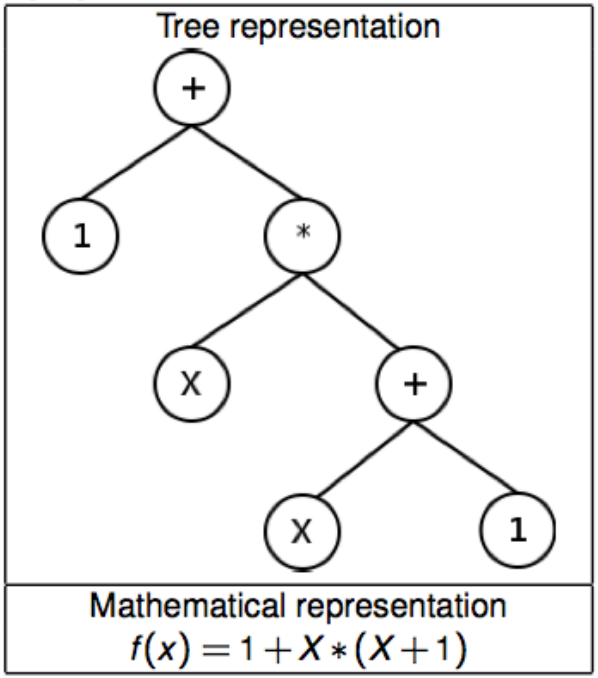


Schmidt, M. and Lipson H. (2009) Science

Evolving Mathematical Models

Target expression: $g(x) = X^2 + 2X + 1$

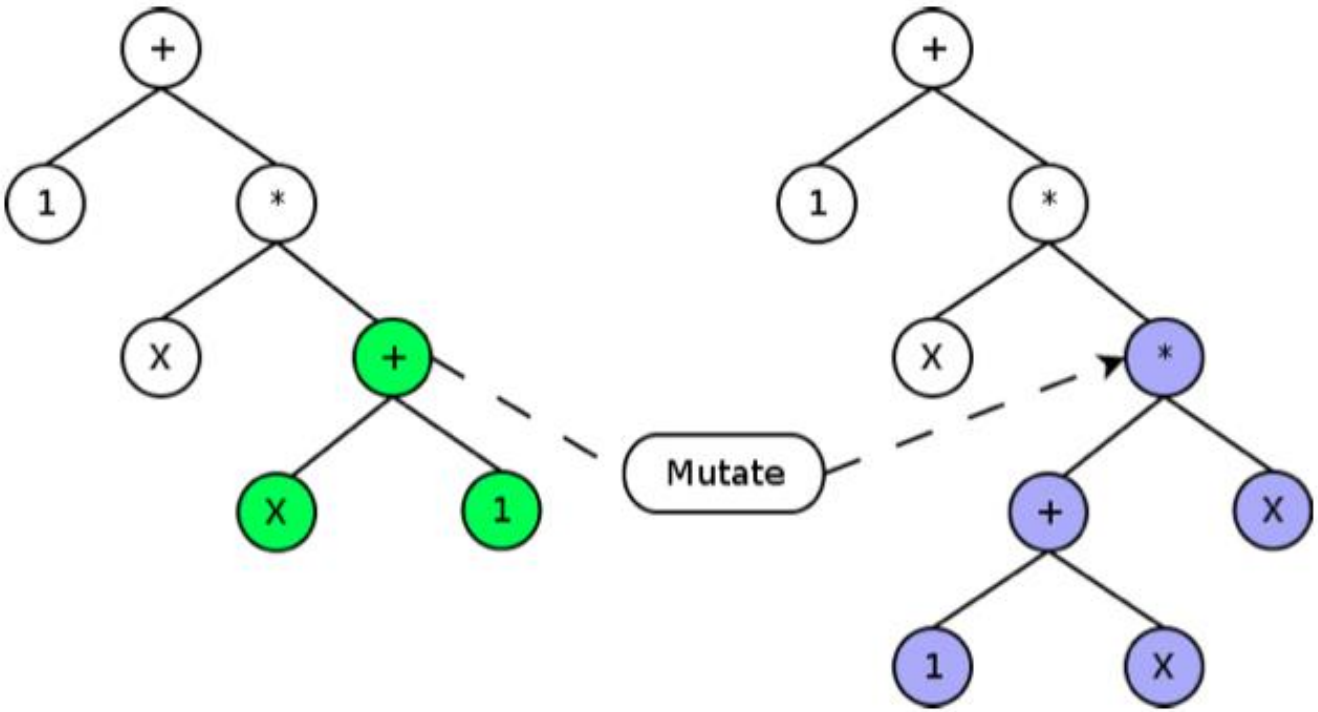
Example individual:



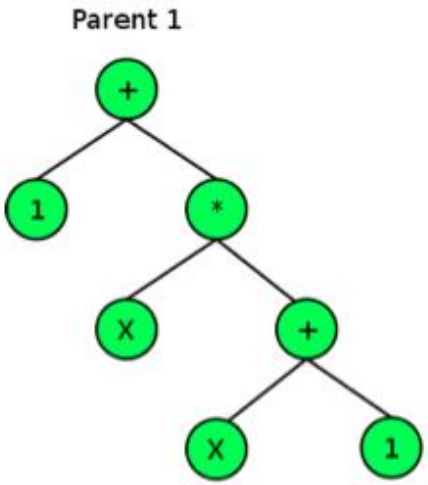
- $X = 0, f(X) = 1, g(X) = 1$
- $X = 1, f(X) = 3, g(X) = 4$
- $X = 2, f(X) = 7, g(X) = 9$

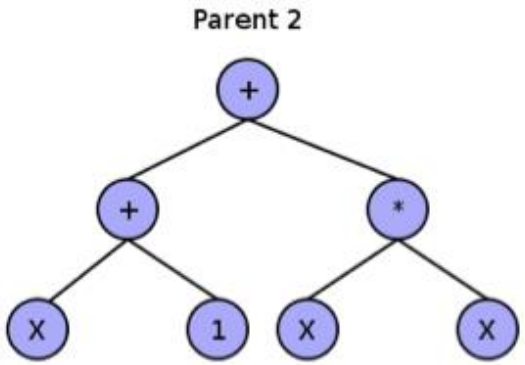
Individual's error: 3

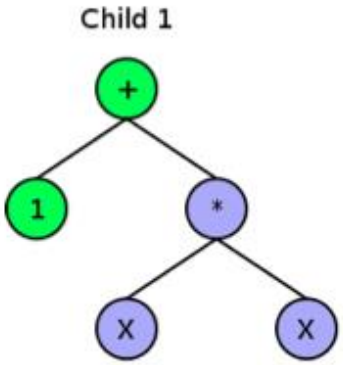
Mutating Expressions

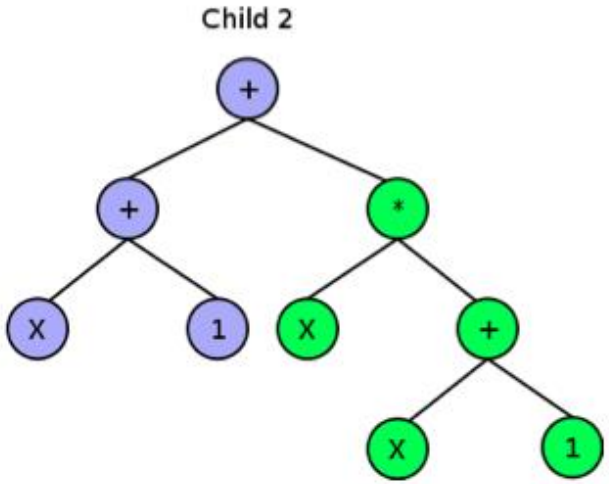


Crossing Over Expressions



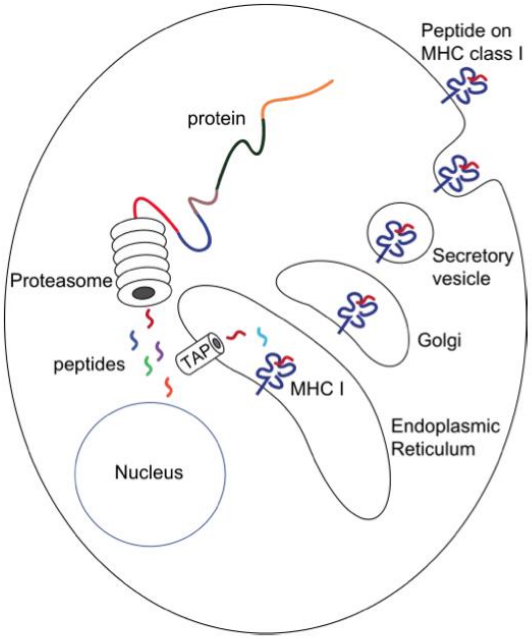


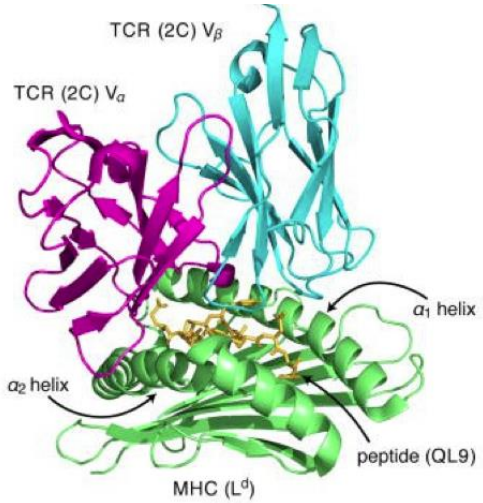




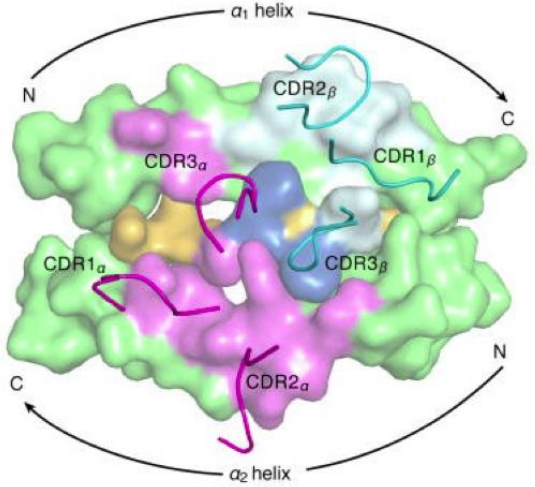
Predicting Epitope Binding

- Evolving mathematical models of molecular docking





Crystal structure of TCR bound to peptide+MHC

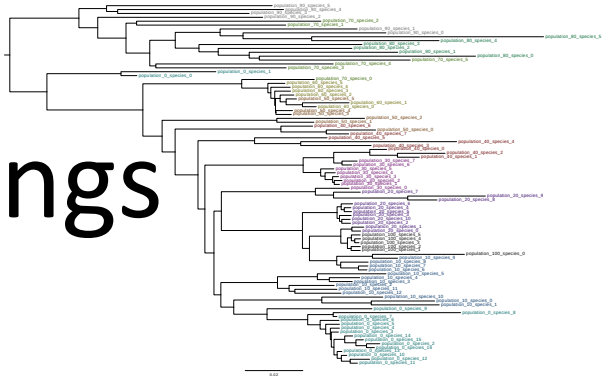


Surface structure of TCR footprint

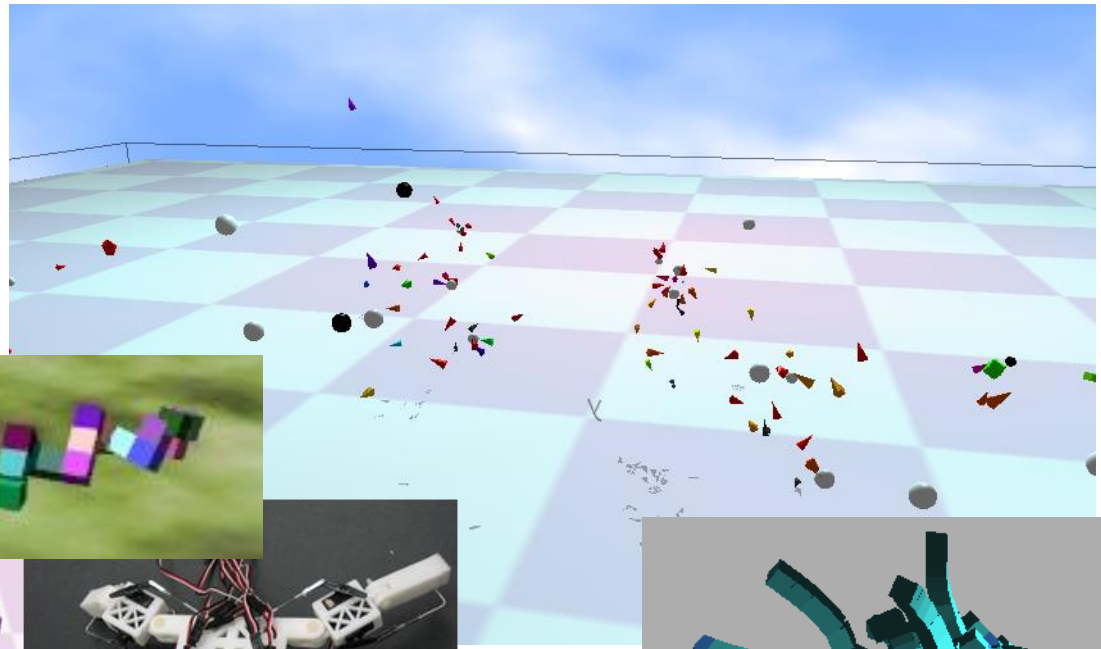
Images: Wikimedia

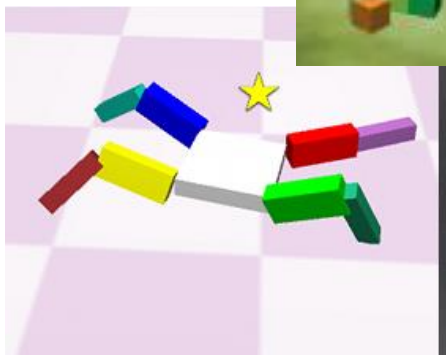
Wolfson et al., (2011) J Phys Chem

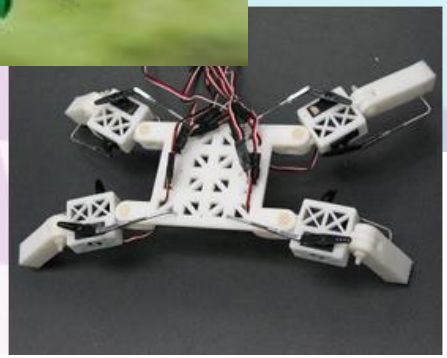
Evolving Other Things

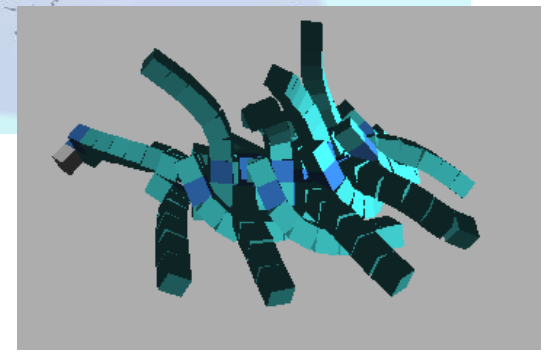


- Swarm ecosystems
- Animats
- Robots



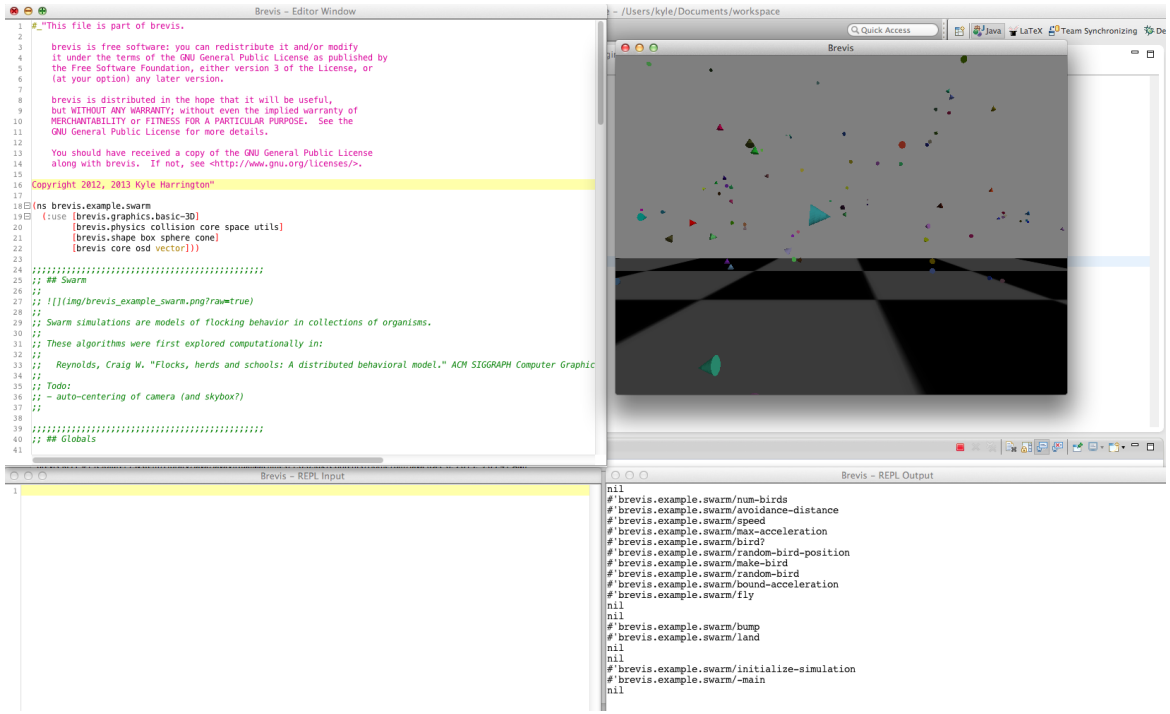






Brevis

- http://brevis.golemics.org
- Open-source, interfaces with existing science software, and stable release coming-soon



Thank you

- Jordan Pollack
- James Chin
- Jessica Lowell
- Jeff Gelles and Jane Kondev
- QB program
- Audience