Modelling Complex Systems

Genetic Algorithms

This lecture includes adapted slides of David Sumpter and Yu Liu, and work of Charitini Stavropoulou and Katarzyna Kowalczyk

Evolution

- Evolution solves "problems"
- But there is no specific problem needed to be solved, only one general problem: increasing fitness
- We have specific problems

Evolution

- e.g., **eye**

- Large solution space
- Open-ended
- Natural selection (adaptation):
  1. reproduction
  2. mutation
  3. competition (e.g., limited resources)

Genetic Algorithm (GA)

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- Large solution space, hard to check every possibility
- Not open-ended (should stop)
- Natural selection in computer:
  1. reproduction?
  2. mutation?
  3. competition?

Genetic Algorithm (GA)

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- John Henry Holland, 1970s
- Computer programs that evolve over generations to find (some of) the “fittest” out of a very large number

Basic GA Recipe

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- 1. Define a format (a string) to represent different strategies. We call one strategy as one chromosome.
- 2. Give a population of some random chromosomes
- 3. Calculate each chromosome's fitness
- 4. Evolution: cross-over and mutate
- 6. Repeat from step 3 for enough generations

Basic GA Recipe

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GA Evolving Robot

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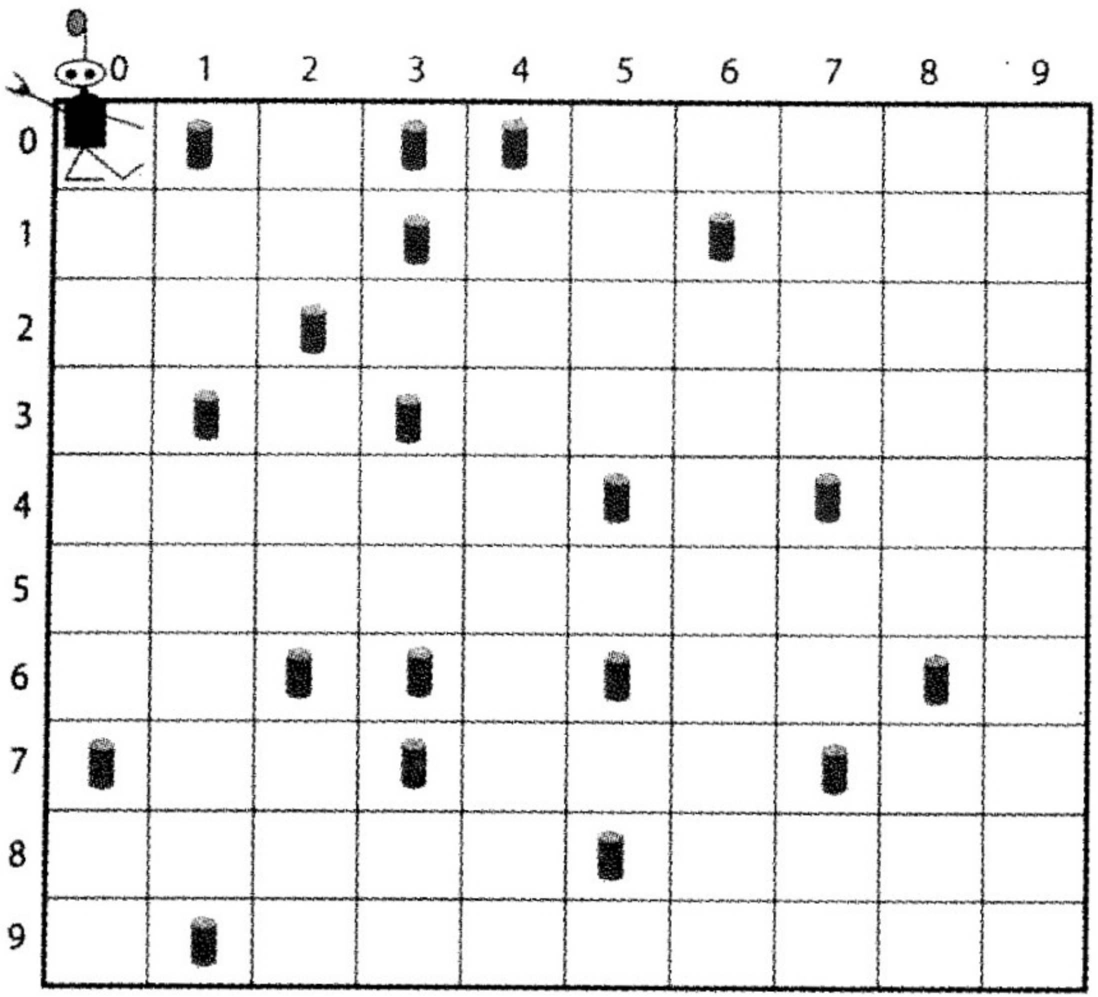

GA Evolving Robot: Strategy Format

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Situations					Action
North	East	South	West	Here	
-	-	-	-	-	Move north
-	-	-	-	can	Move east
-	-	-	-	wall	Pick up can
-	-	-	can	-	Move
……					
wall	-	can	wall	-	Stay still
……					
wall	wall	wall	wall	wall	Move east

GA Evolving Robot: Strategy Format

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Situations					Action
North	East	South	West	Here	
-	-	-	-	-	0
-	-	-	-	can	1
-	-	-	-	wall	6
-	-	-	can	-	4
......					
wall	-	can	wall	-	5
......					
wall	wall	wall	wall	wall	1

GA Evolving Robot: Strategy Format

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- 3^5 = 243 situations

- Move north
  Move east
  Move south
  Move west
  Move randomly
  Stay still
  Pick up can

GA Evolving Robot: Strategy Format

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- $3^5 = 243$ situations

- Move north
  Move east
  Move south
  Move west
  Move randomly
  Stay still
  Pick up can

- Each chromosome is a string of 243 digits, each of which is between 0 and 6.

- There are $6^{243} = 1.23e189$ possible chromosomes.

2330032342163034353054600610256251511141622260435654334066511514
15650220640642051006643216161521652022364433363346013326503000
40622050243165006111305146664232401245633345524126143441361020
150630642551654043264463156164510543665346310551646005164

GA Evolving Robot: Measure Fitness

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- Given a finite time, the number of cans it picks up.
- The minimum time to pick all cans up.
- **Pick up can correctly +10;**
  Try to pick up but no can -1;
  Crash to the wall -5;
  Otherwise 0.

The fitness should be an average measured in many cases (e.g., 100 cases)

23300323421630343530546006102562515114162260435654334066511514
15650220640642051006643216161521652022364433363346013326503000
40622050243165006111305146664232401245633345524126143441361020
150630642551654043264463156164510543665346310551646005164

GA Evolving Robot: Cross-Over

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16411343121025360340361241431201104235462525304202044516433665
61035322153105131440622120614631432154610256523644422025340345
30502005620634026331002453416430151631210012214400664012665246
351650154123113132453304433212634555005314213064423311000

23300323421630343530546006102562515114162260435654334066511514
15650220640642051006643216161521652022364433363346013326503000
40622050243165006111305146664232401245633345524126143441361020
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GA Evolving Robot

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- 1. Define a format (a string) to represent different strategies. We call one strategy as one chromosome.
- 2. Give a population of some random chromosomes
- 3. Calculate each chromosome's fitness
- 4. Evolution: cross-over and mutate
- 6. Repeat from step 3 for enough generations

GA Evolving Robot

- 1. Define a format (a string) to represent different strategies. We call one strategy as one chromosome.
- 2. Give a population of some random chromosomes (200)
- 3. Calculate each chromosome's fitness (100 random cases)
- **4. Evolution: cross-over and mutate**
- 6. Repeat from step 3 for 1000 generations

GA Evolving Robot

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- **4. Evolution: cross-over and mutate**

- 4.1 Randomly select chromosome A and B based on their fitness
- 4.2 Randomly select a position and cross-over
- 4.3 By small probability (e.g., p = 0.05), mutate one gene
- 4.4 Repeat from 4.1 until you get 200 chromosomes

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- What parameters do we have in this case?

- 1. fixed population of chromosomes (200)
- 2. number of repeats to calculate average fitness (100)
- 3. mutation rate per chromosome (0.05)
- 4. number of generations (1000)

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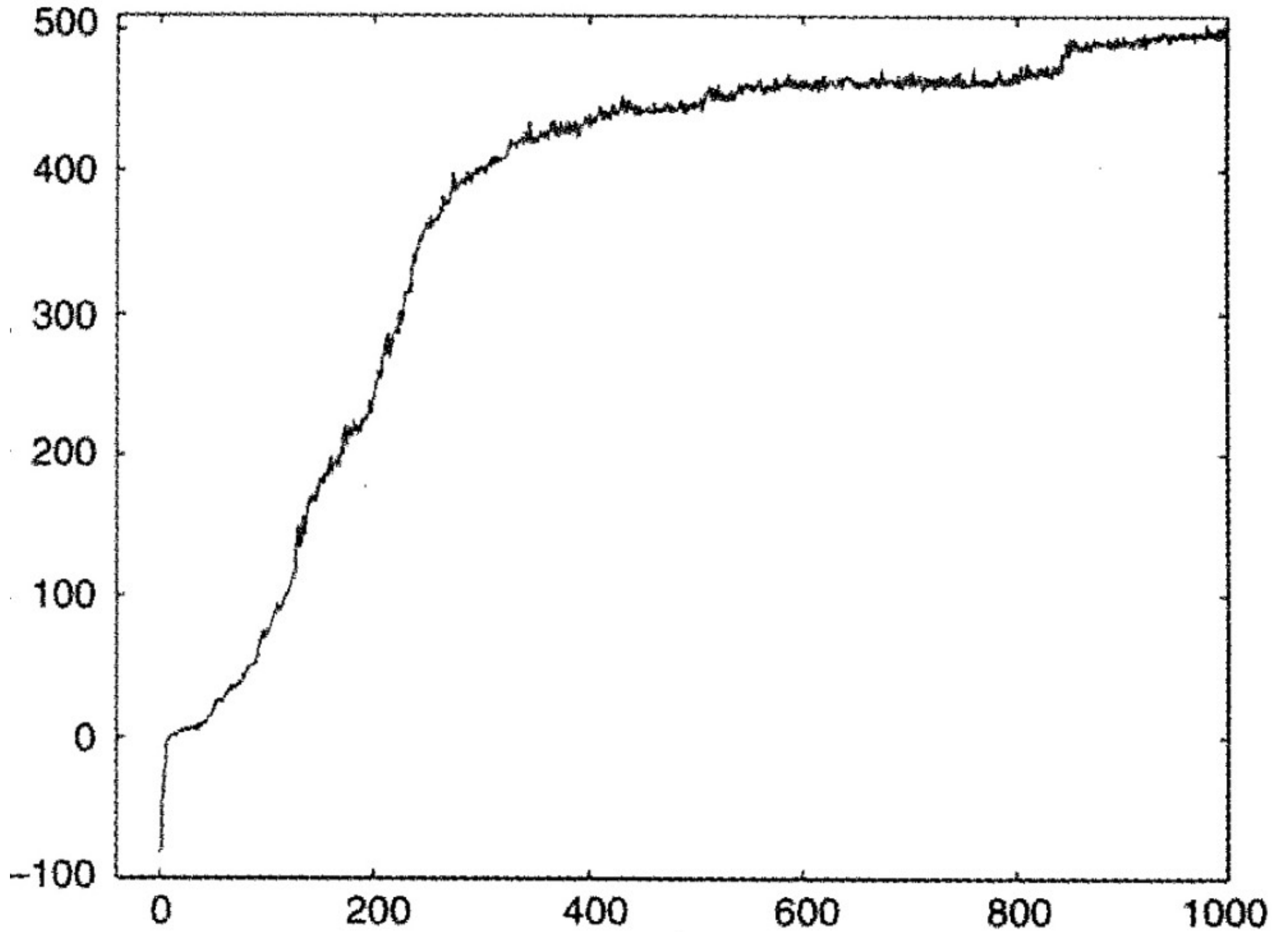

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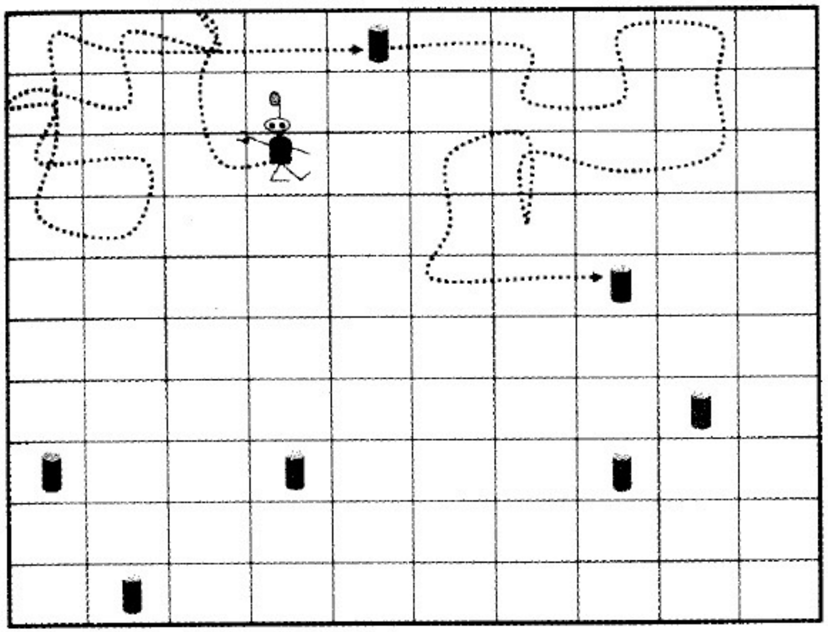

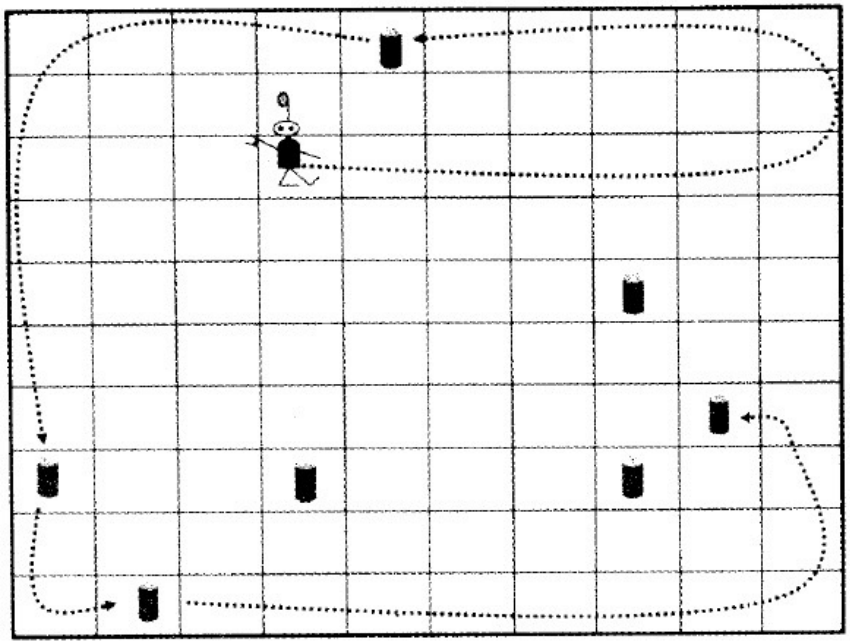

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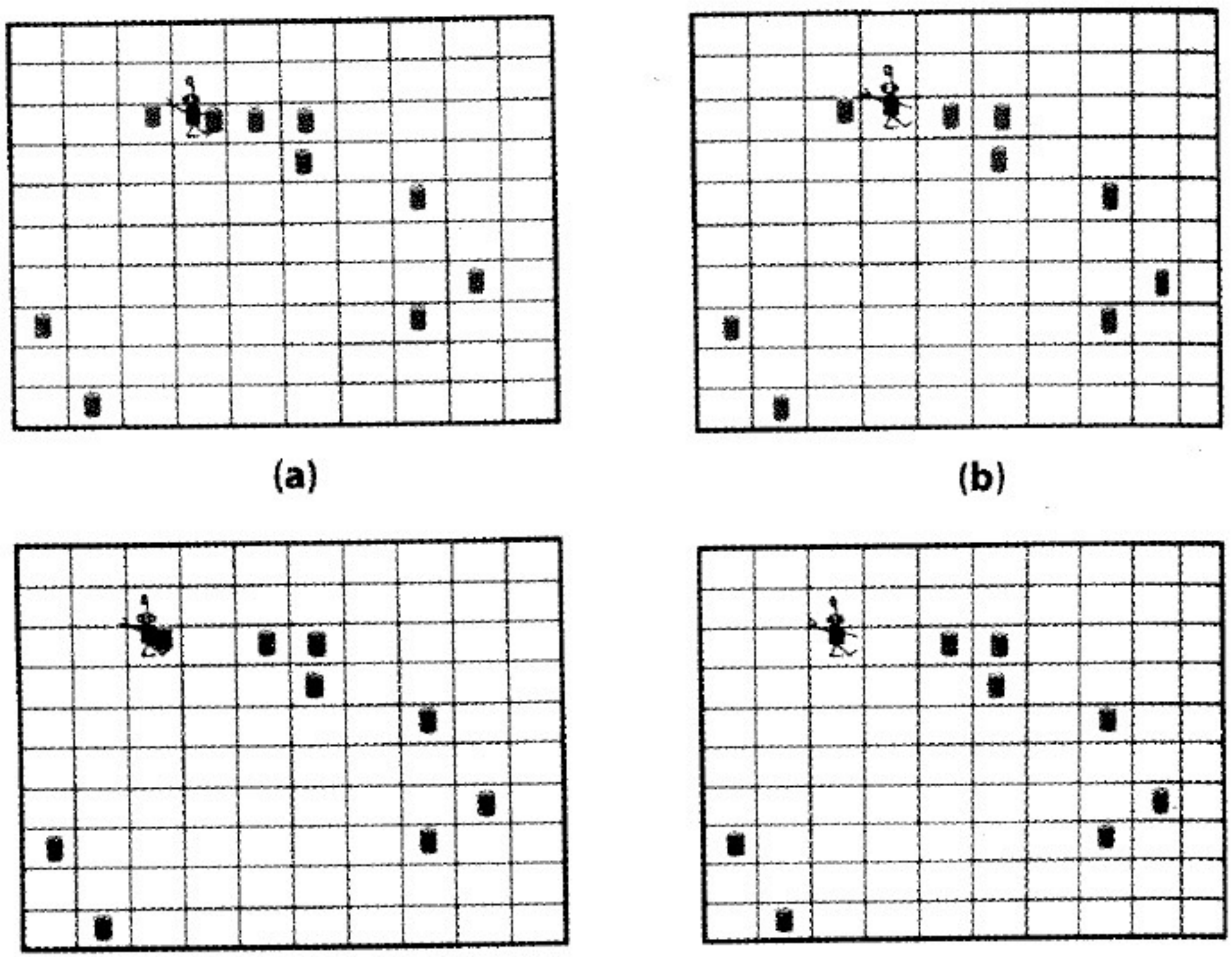
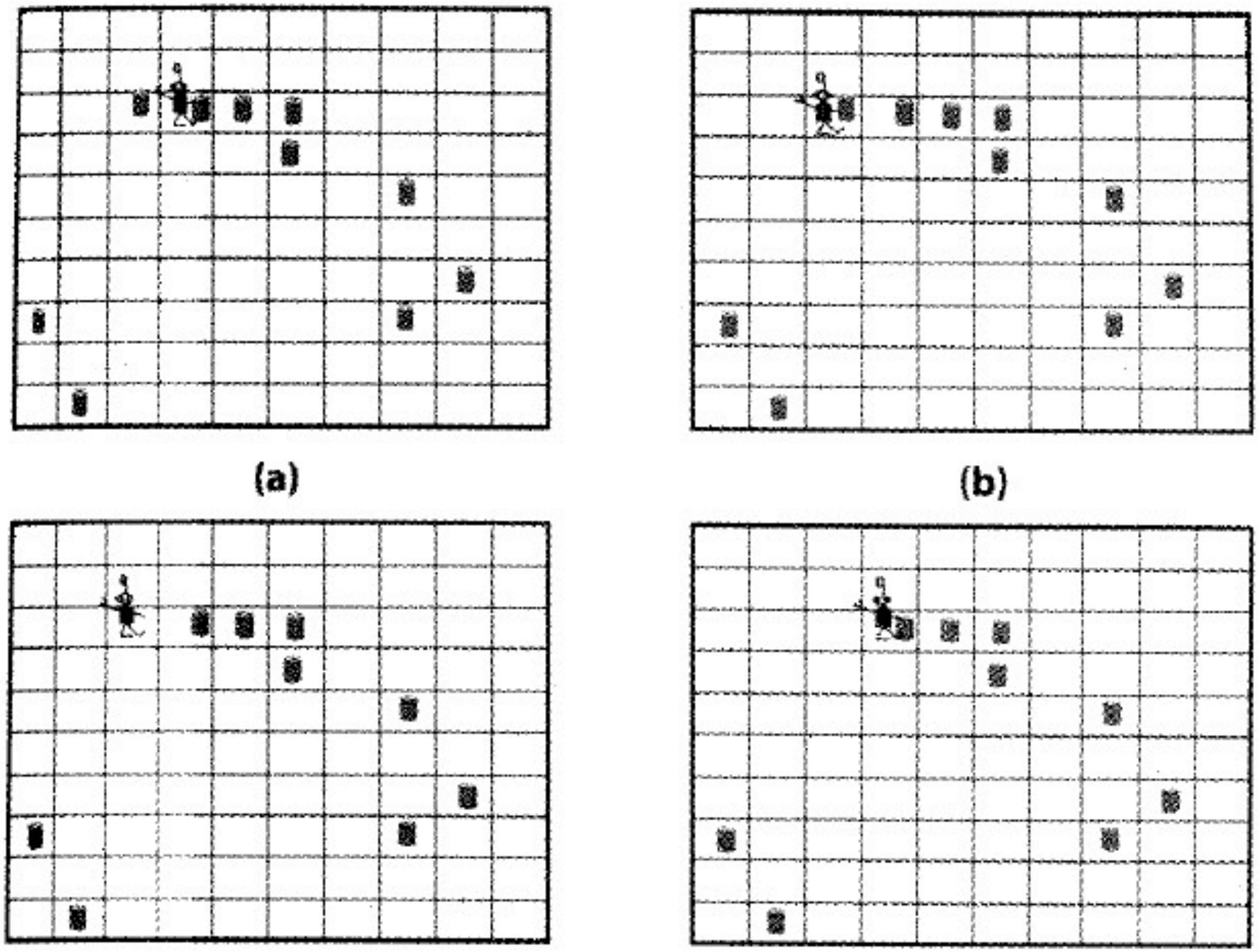


(a) (b) (c) (d)

GA Evolving Robot



GA Evolving Robot

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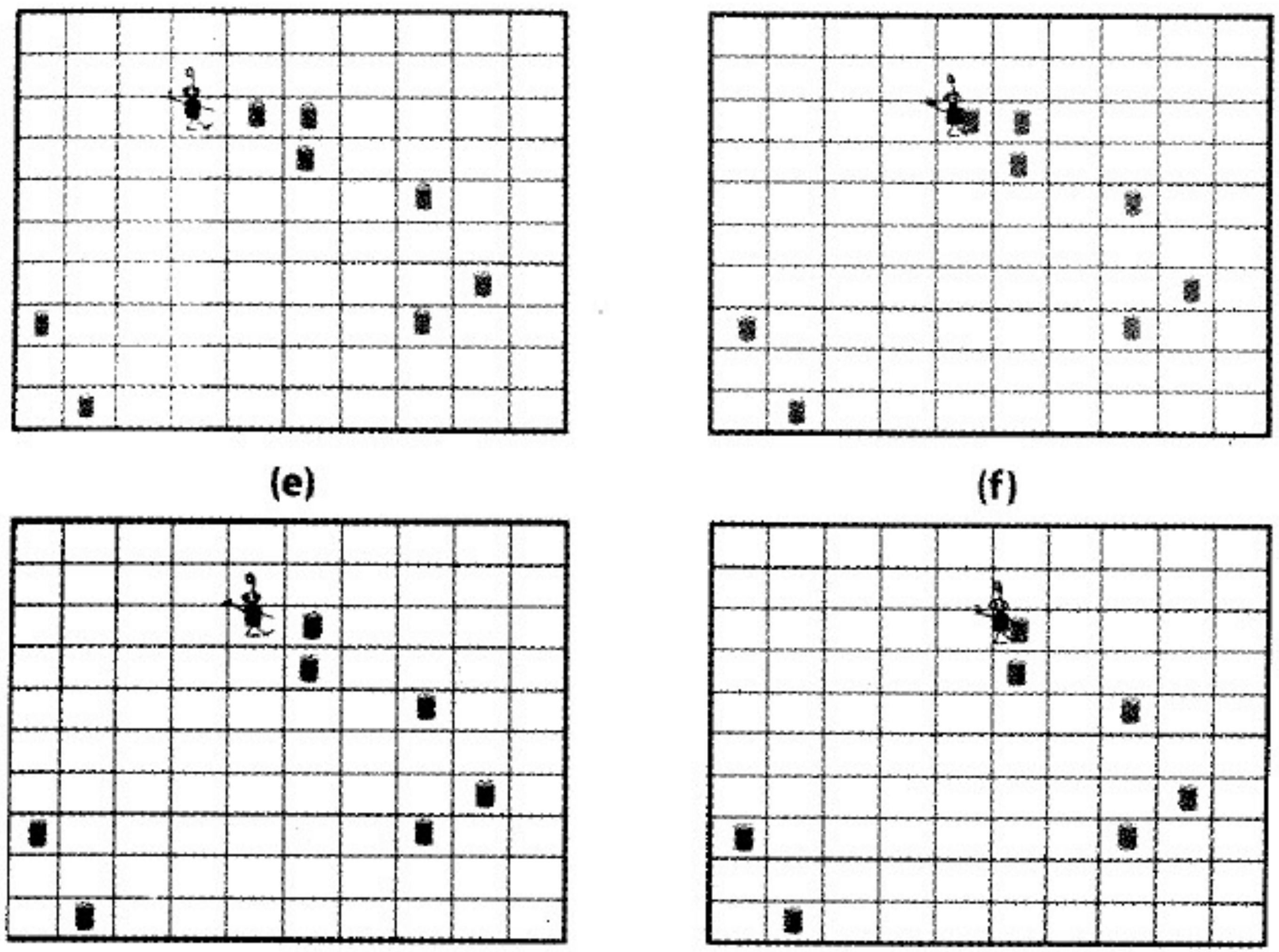

GA Evolving Robot

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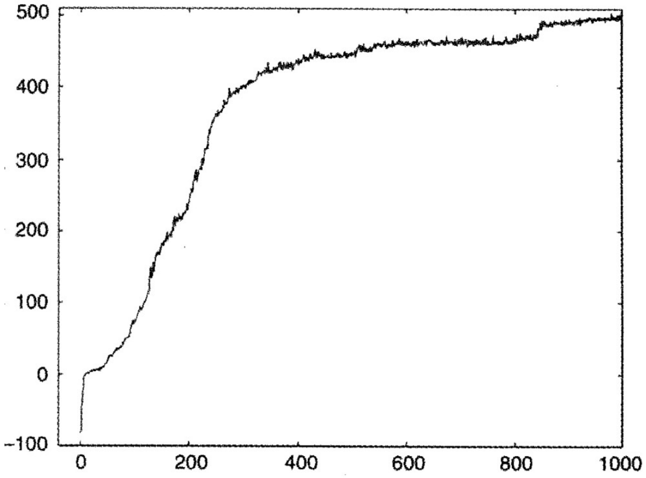

- Independent good genes are easy to appear.
- Cooperative genes are difficult to appear but also very important.

GA Evolving Robot

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- Why does GA work?
- A balance between selection, mutation and cross-over.
- 1. Low mutation rate make sure that 1) genes are not easy to be wiped out (both good and bad genes), and 2) there is chance of good innovations.
- 2. Good strategies can always be made of groups of good gene modulars. The cross-over can assemble modulars.
- 3. Selection picks the good genes and good gene modulars.

GA Cellular Automata Computer

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- Tell whether there are more black grids or not, based on local information.

GA Cellular Automata Computer

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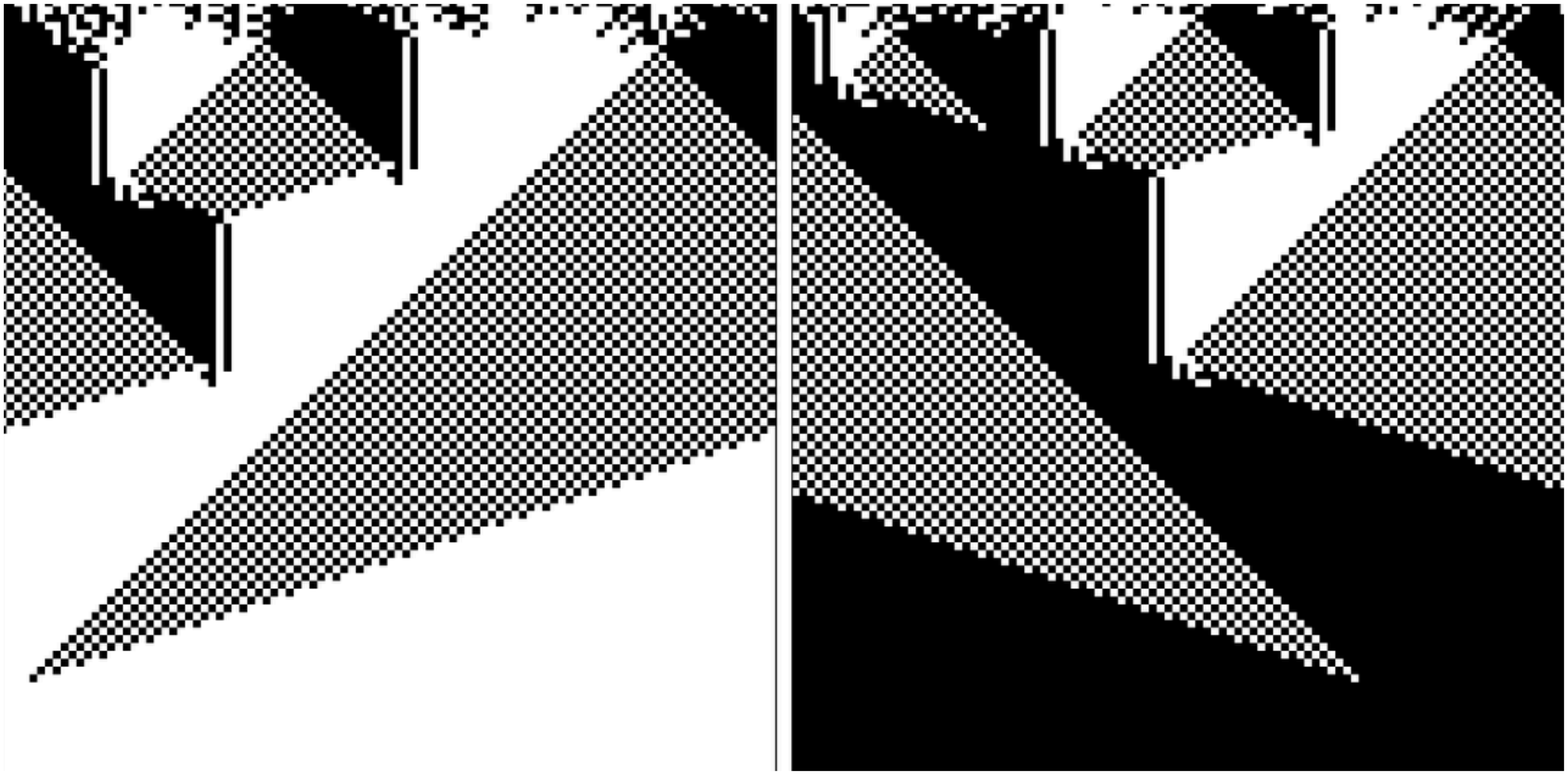
- Given a string of 0 and 1, tell whether there are more 1s or not, based on local information.

- $2^5 = 32$ situations;
  Each situation has 2 possible actions, so there are
  $2^{32} = 4.295e9$ strategies.

GA Cellular Automata Computer

- Given a string of 0 and 1, tell whether there are more 1s or not, based on local information.



Example: GA K-Means

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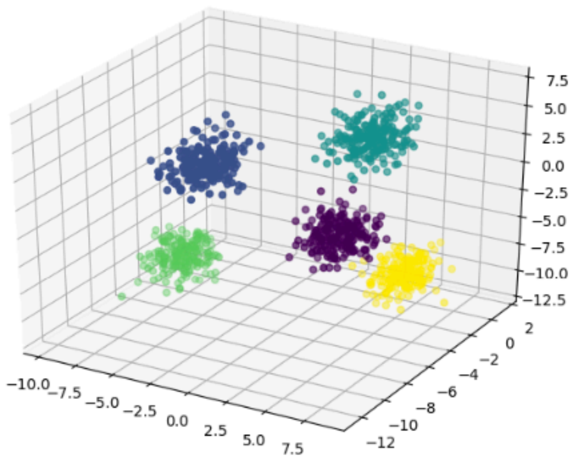
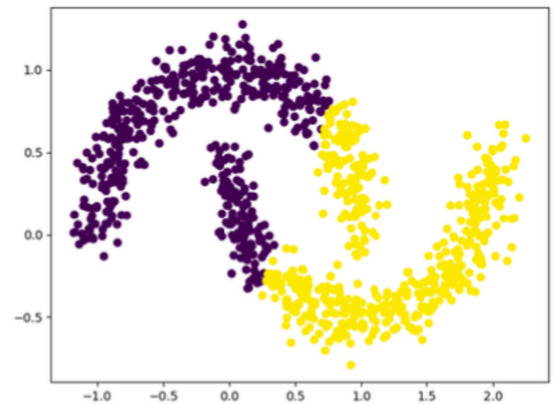
- K-means - way to cluster pts in n-dimensions into k clusters





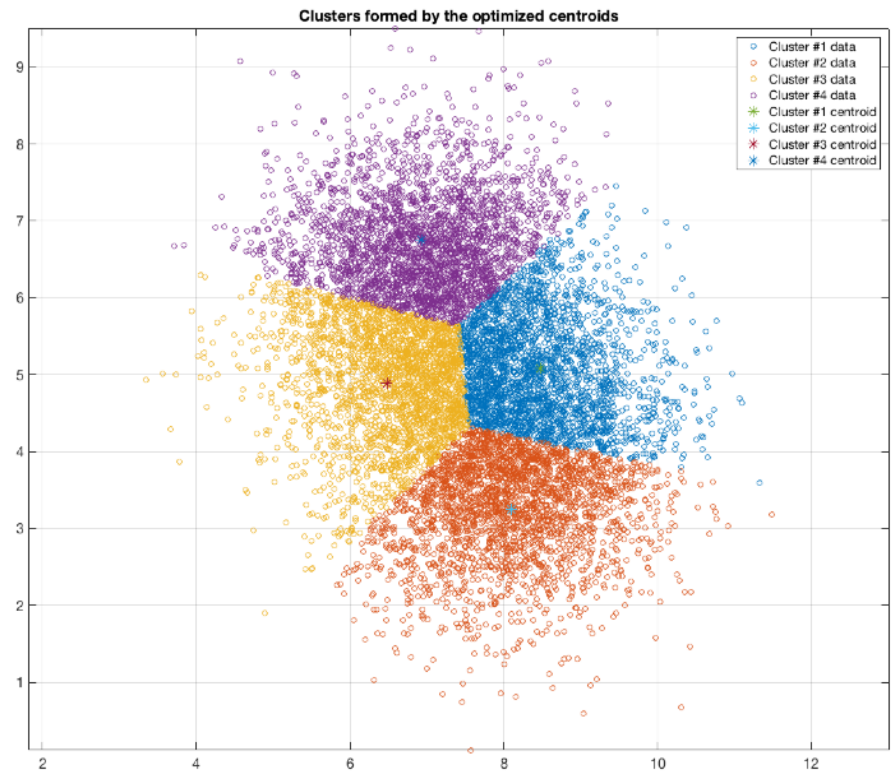
$$\mathscr{M}(C_1, \ldots, C_K) = \sum_{i=1}^{K} \sum_{\boldsymbol{x}_j \in C_i} ||\boldsymbol{x}_j - \boldsymbol{c}_i||$$

Charitini Stavropoulou

Katarzyna Kowalczyk

Example: G A K-Means

- K-means - way to cluster pts in n-dimensions into k clusters



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Dataset To Cluster -

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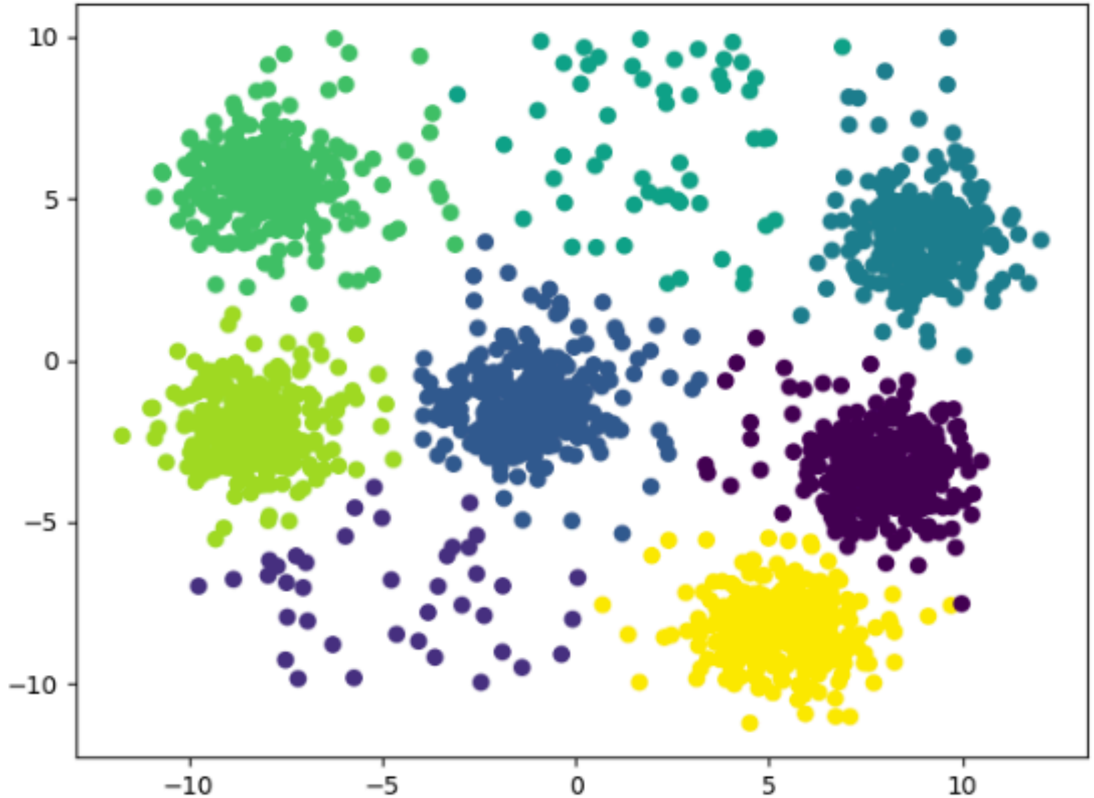

Figure 2: Data set used in the experiments.

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Selecting Which Chromosomes Breed…

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- Tournament - pick groups of s individuals and return individual with highest fitness.

e.g. if $s = 2$ and chromosomes i, j chosen then return $\arg\max\{f_i, f_j\}$

- Roulette wheel - each chromosome i chosen with probability proportional to fitness f_i.

$$\text{Probability of choosing } i = \frac{f_i}{\sum_j f_j}$$

- Fitness - calculated to be $\sim 1/\mathscr{M}$

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Selection Matters

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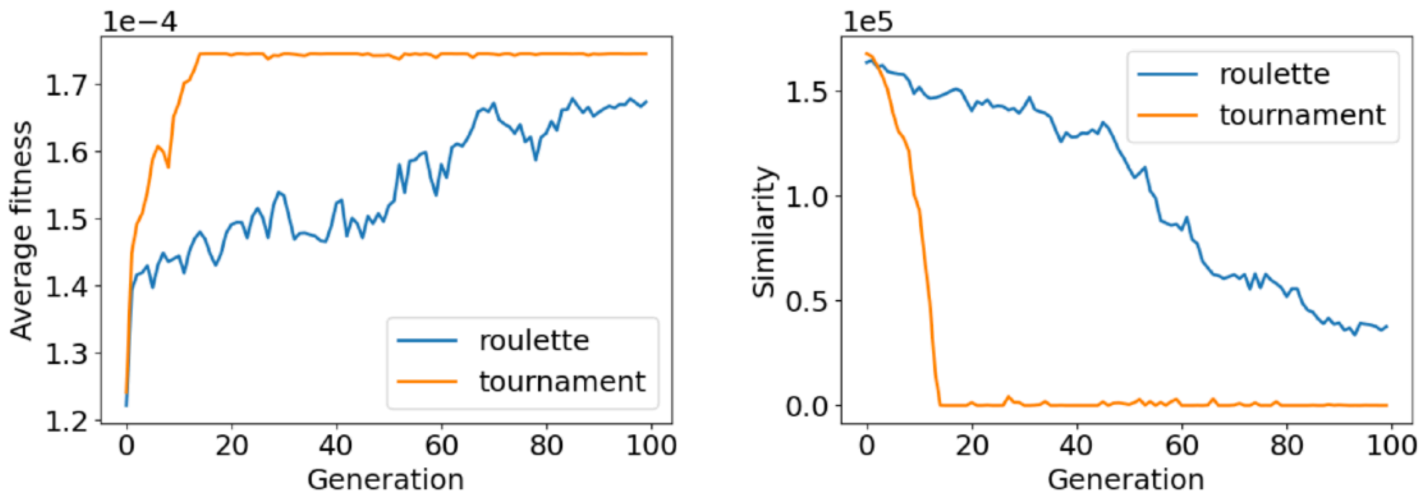

(a) Average fitness (b) Generation similarity

Figure 6: Comparison of two selection strategies for the same data set and GA parameters: 100 generations, population of 100, $\mu_c = 0.8$, $\mu_m = 0.01$.

- Generational similarity. Treat each chromosome as a point in $\mathbb{R}^{kn}$ and define to be sum of pairwise distances of chromosomes in generation.

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Comments On GA

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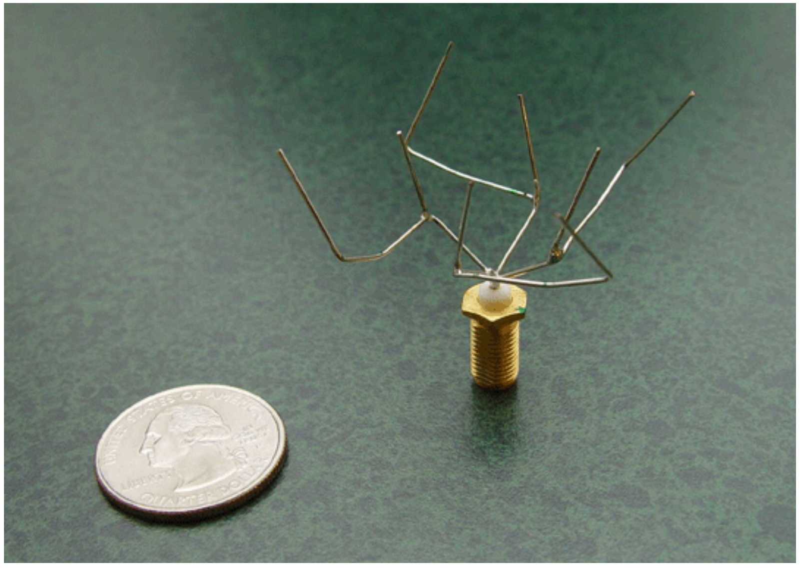
- Automated design (e.g., Shape of the plane, antenna)
- Analyse satellite images
- Animations in film (e.g., horses in The Lord of the Rings III)
- Develop new drugs
- Protein folding
- ……



https://en.wikipedia.org/wiki/List_of_genetic_algorithm_applications

Comments On GA

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- GA always cannot get the best solution (there may be not a best solution), but can be good enough.
- Biological evolution is open-ended, while we define an end for GA.
- For biological evolution, the whole solution space is not fixed; while for GA generally, the whole solution space is actually fixed.

G A Vs Machine Learning

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- The common part is the ability to learn or 'fit' to data for predictions.
- Both have a fitness function - to determine how well the algorithm is performing
- GA is an example of reinforcement learning
- GA group of algorithms, rather than a single algorithm.
- Update rules from group of algorithms to group of algorithms in GA, very different to how one updates algorithms in other machine learning contexts.
- Nice example of reinforcement learning, (but not a GA!) is: arxiv:1707.02286

-see videos here - https://www.youtube.com/watch?v=hx_bgoTF7bs