Linking the Dynamics of Genetic Algorithms to the Encoding of Information

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Presentation overview

An introduction to genetic algorithms

Algorithms inspired by evolution

Genetic algorithms evolve *data sequences* by using the concepts of *mutation*, *reproduction* and *selection*

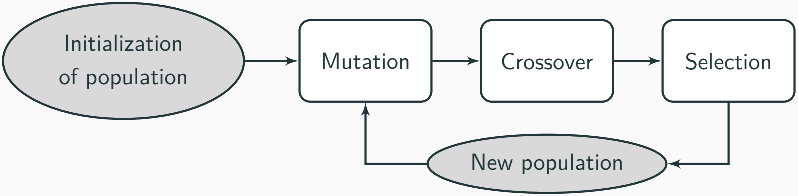
... for optimisation purposes

... for solving hard combinatorial problems

... for studying evolutionary dynamics

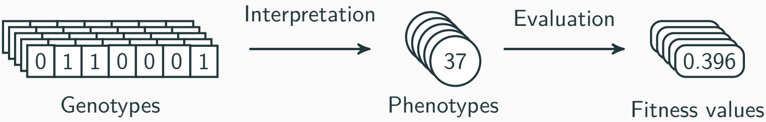
General structure

- Genetic algorithms maintain a pool of *candidate solutions* and modify them using *mutation* and *crossover* (recombination) operators
- A *selection* operator determines which solutions are mutated, recombined or picked for survival



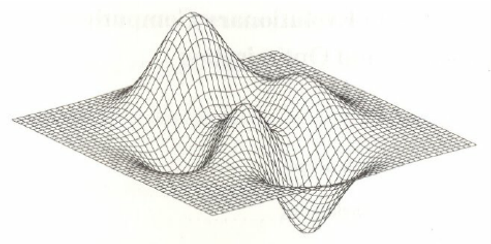
General structure

- Information (*phenotype*) is encoded as a data sequence (*genotype*)
- Phenotypes are evaluated by a *fitness*, *cost* or *objective function*



The search space

- The algorithms traverse a *fitness landscape*, or *search space*



- This is done by mutating and recombining the current data structures to produce new sample points

Genetic operators

- The **mutation** operator changes the genome such that a new candidate solution is produced

  A common choice is the *point mutation* operator

Before mutation	0	1	1	1	1	0	0	0	1
After mutation	0	1	0	1	0	0	0	1	1

- The **selection** operator determines diversity and bias by picking individuals for survival or reproduction

  A common choice is *tournament selection*

The encoding and decoding is problem specific

1	1	0	1	1	0	0	0	1

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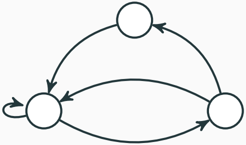
1.1	1.4	0.4	1.9	6.1	5.1	2.2	0.0	1.0

`true`	`false`	`false`	`false`	`false`



Genotypes

Phenotypes

Question: What are the differences between encodings which code for the same phenotype?

Encoding integers

Integers are normally encoded with a **Binary** encoding scheme

Genotype:	0	1	1	0	1	1	0	0	0	1

Phenotype: $1 \times 2^8 + 1 \times 2^7 + 1 \times 2^5 + 1 \times 2^4 + 1 \times 2^0 = 433$

Problem: adjacent phenotypes are not adjacent genotypes (e.g. 0111 [7] and 1000 [8])

Solution: **Gray code** – all adjacent phenotypes are also adjacent genotypes

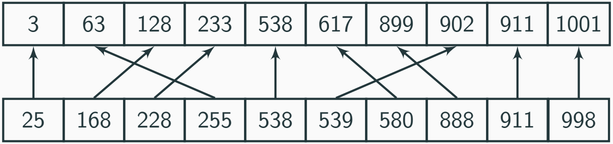
Experiment setup

Algorithm settings

- Population of 40 bitstrings
- All bitstrings are duplicated every generation
- Duplicates undergo point mutation ($p = 1/\text{genome length}$)
- 40 new bitstrings are selected for survival by tournament selection
- No crossover operator

Algorithm objective

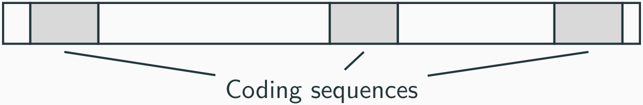
- Find a set of 10 random integers, $I_i \in [0, 1023]$
- The cost is measured as the sum of pairwise differences



- Smallest pairs are prioritised

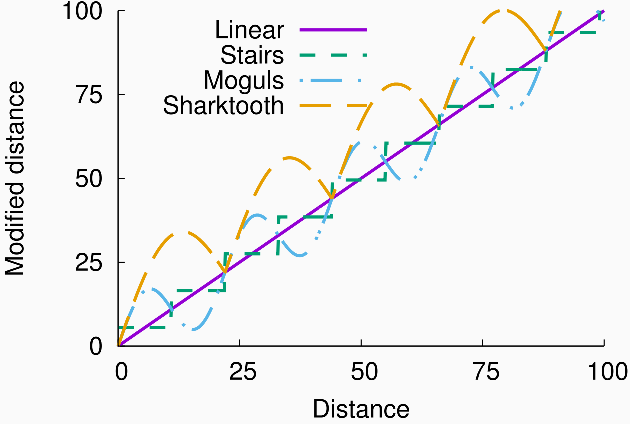
Encodings used

- Binary
- Gray code
- *Consensus encodings*: “Dead code” with coding segments



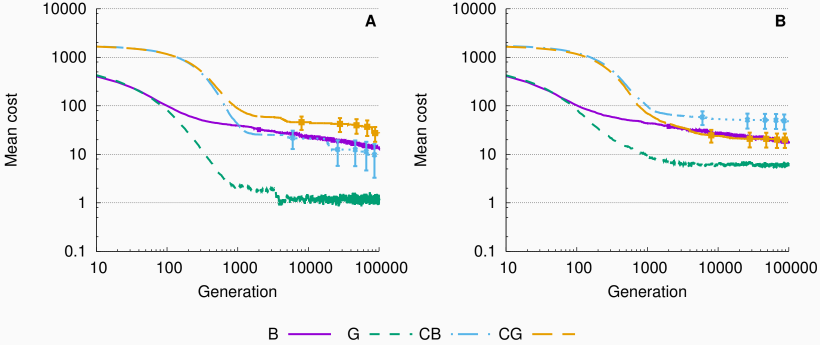
- Coding parts are signified by a start sequence of six bits: `110011`

Search spaces



Results

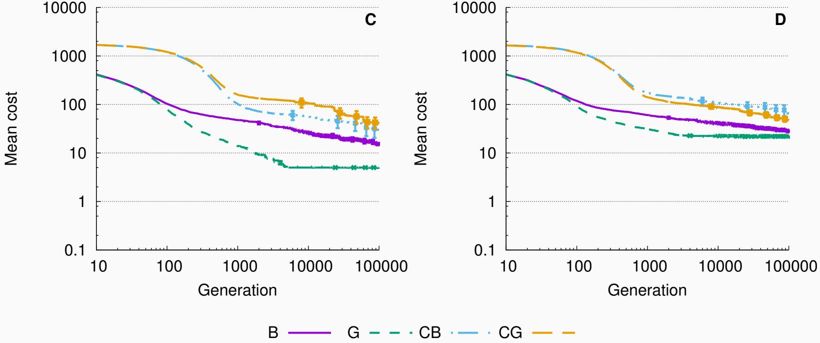
Performance



A: Linear, B: Stairs

- Gray code performs the best. Binary is grouped with consensus encodings.
- Binary performance is unaffected by complexity changes

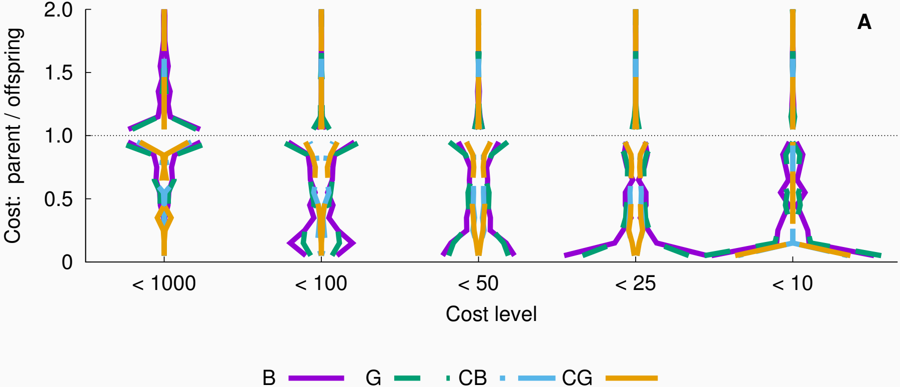
Performance



C: Moguls, D: Sharktooth

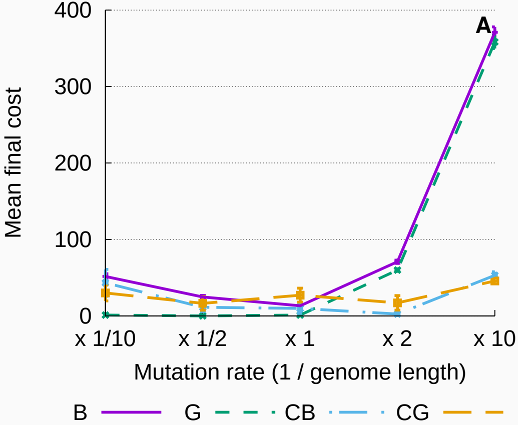
- With high enough complexity, Gray code loses its benefits

Distribution of cost effects – Linear transformation



- Binary and Gray are similar. Consensus encodings are similar.
- Gray code has consistent positive mutations
- Consensus encodings evolve by adding and removing random numbers

Robustness – Linear transformation



- Consensus encodings are more robust, bijective encodings sensitive to high mutation rates
- Gray code evolves mainly by single bit flips, Binary by multiple

Concluding remarks

Implication of the results

- The different modes of evolution give rise to different overall evolutionary dynamics
- Bijectivity is not everything – also directly available states and the connectivity between states matter
- Non-bijectivity make for more flexible genomes

Thank you!

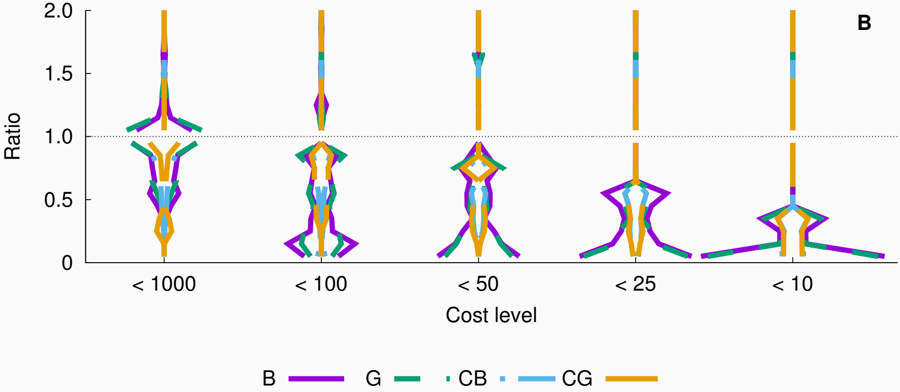
Binary–Gray code table

Integer	Binary	Gray	Gray as integer
0	000	000	0
1	001	001	1
2	010	011	3
3	011	010	2
4	100	110	6
5	101	111	7
6	110	101	5
7	111	100	4

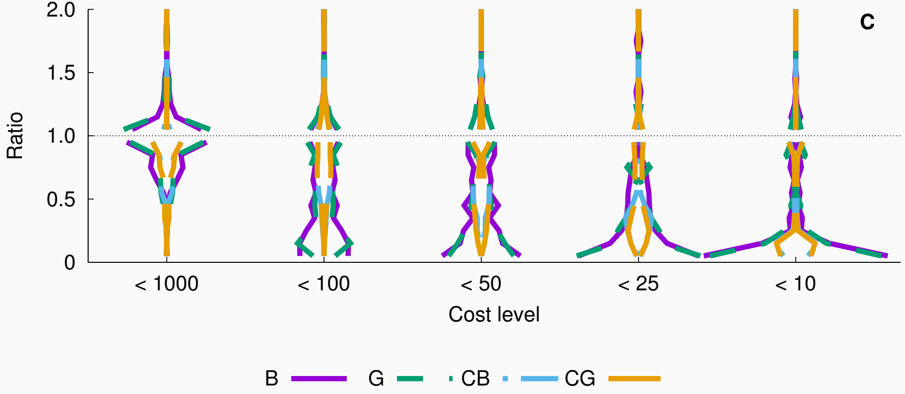
What about the biology?

- Biological genetic strands carry large amounts of ”dead code”
- Natural evolution is a product of itself – what are the alternatives?
- Evolutionary mechanisms are complex and not well understood

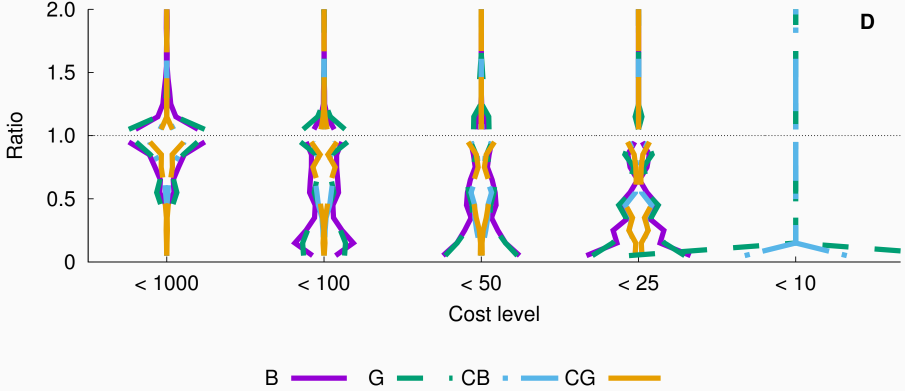
Distribution of cost effects – Stairs transformation



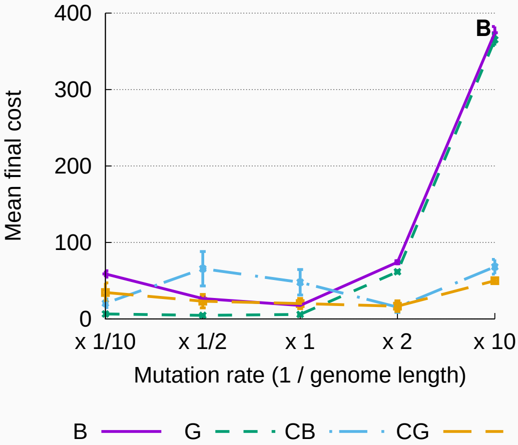
Distribution of cost effects – Moguls transformation



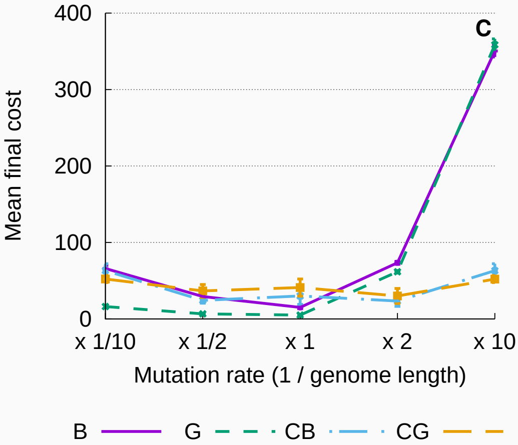
Distribution of cost effects – Sharktooth transformation



Robustness – Stairs transformation



Robustness – Moguls transformation



Robustness – Sharktooth transformation