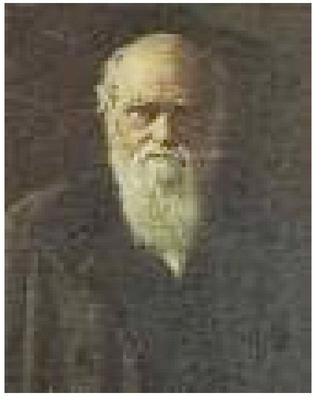
Genetic Algorithms

Seong Ki Lee
MAS 0607 CAAD
Swiss Federal Institute of Technology

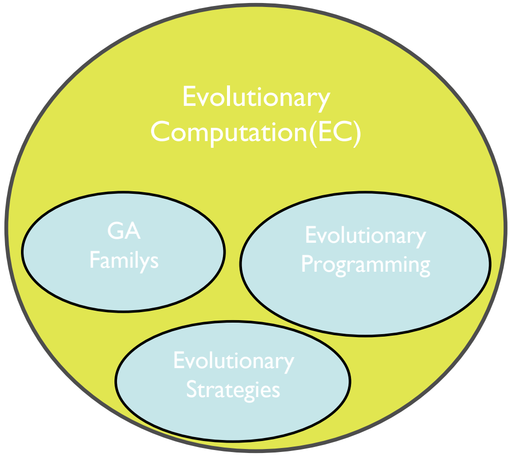
Introduction



Generic algorithms are a part of evolutionary computing

C. Darwin's theory about evolution

Solving a problem by genetic algorithm



Short history

Rechenberg “Evolution strategies” (1960s)

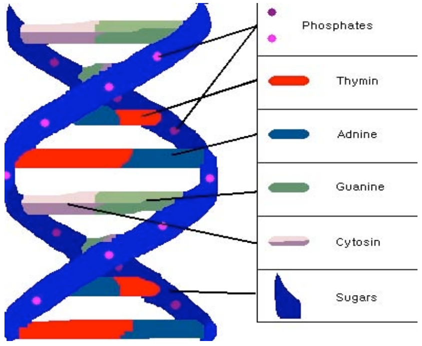
Fogel, Owens, Walsh “Evolutionary Programming”

J. Holland “Genetic Algorithms”

- “Adaptations in Natural and Artificial Systems” (1975)

J. Koza “Genetic Programming (GP)” (1992)

Chromosome



http://www.chromosome.com/images/biology/87.jpg

All living organisms consist of cells.

In each cell there is the same set of **chromosomes**.

Chromosomes are strings of DNA and serves as a model for the whole organism.

A chromosome consist of **genes**, blocks of DNA. Each gene encodes a particular protein. Basically can be said, that each gene encodes a **trait**, for example color of eyes.

Possible settings for a trait (e.g. blue, brown) are called **alleles**. Each gene has its own position in the chromosome. This position is called **locus**.

Complete set of genetic material (all chromosomes) is called **genome**. Particular set of genes in genome is called **genotype**. The genotype is with later development after birth base for the organism's **phenotype**, its physical and mental characteristics, such as eye color, intelligence

Reproduction

Recombination (crossover) - Genes from parents form the whole new chromosome.

Mutation - Elements of DNA are a bit changed (caused by errors in copying genes from parents)

The fitness of an organism is measured by success of the organism in its life.

Outline of the Basic GA

[Start] Generate random population of *n* chromosomes (suitable solutions for the problem)

[Fitness] Evaluate the fitness *f(x)* of each chromosome *x* in the population

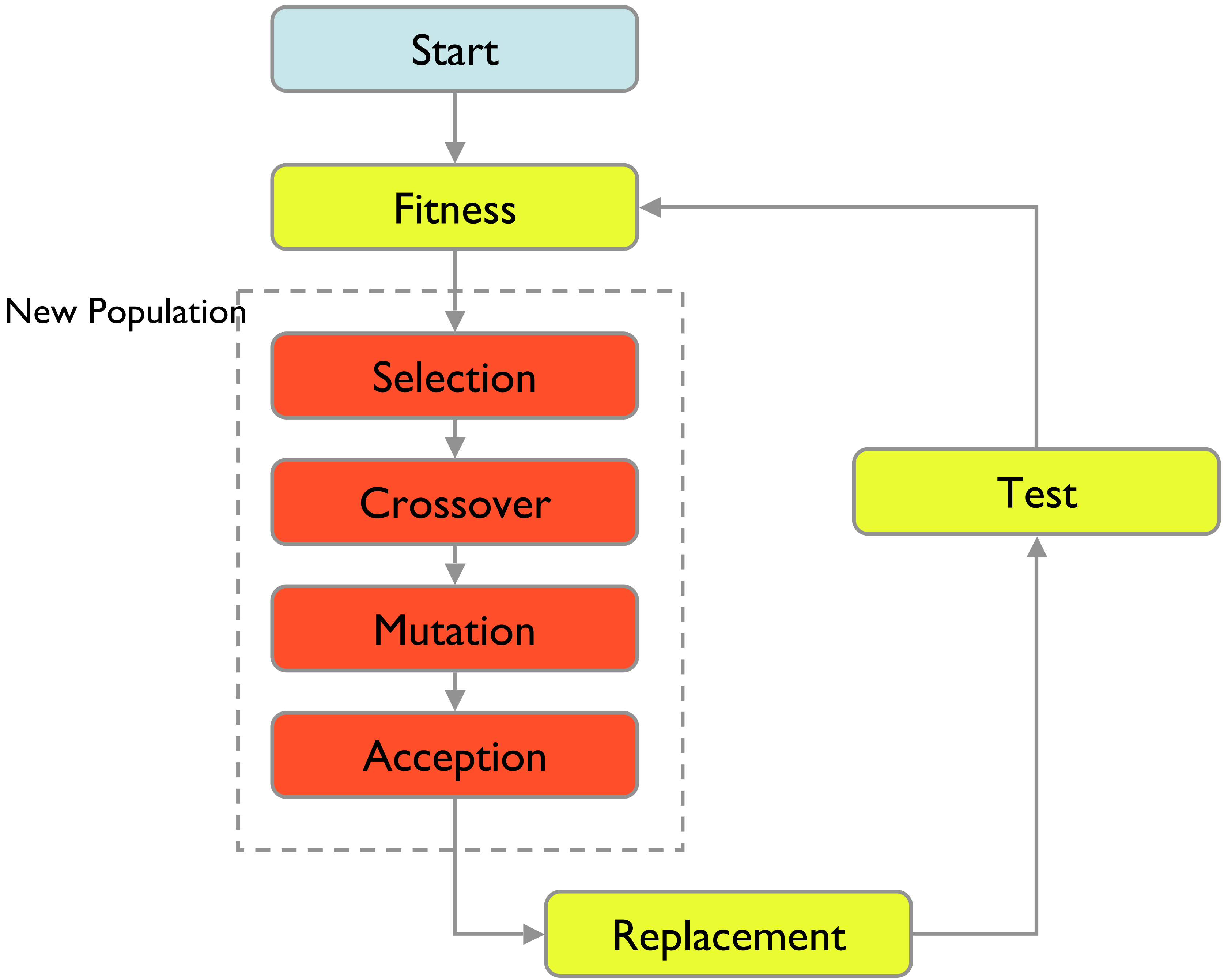
[New population] Create a new population by repeating following steps until the new population is complete

- [Selection] Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected)
- [Crossover] With a crossover probability cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents.
- [Mutation] With a mutation probability mutate new offspring at each locus (position in chromosome).
- [Accepting] Place new offspring in a new population

[Replace] Use new generated population for a further run of algorithm

[Test] If the end condition is satisfied, **stop**, and return the best solution in current population

[Loop] Go to step **2**


Start
Fitness
New Population
Selection
Crossover
Mutation
Acception
Test
Replacement

Operators of GA

Crossover

Mutation

Encoding of a Chromosome

The chromosome should contain information about solution

The most used way of encoding is a binary string

Each chromosome has one binary string

Each bit in this string can represent some characteristic of the solution or the whole string can represent a number

Chromosome1 = “10101011111100010101001”
Chromosome2 = “101010100010100000101110”

Crossover

Crossover selects genes from parent chromosomes and creates a new offspring

The simplest way to do this is to choose randomly some crossover point and to copy everything before crossover point from a first parent and then copy everything after a crossover point from the second parent.

More crossover points

Chromosome1 = “10101011111100010101001”
Chromosome2 = “10111010001010000101110”
Offspring1 = “10101011111110000101110”
Offspring2 = “10111010001000010101001”

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Mutation

After crossover is performed, mutation take place.

Mutation change randomly the new offspring

For binary encoding, we can switch a few randomly chosen bits from 1 to 0 or from 0 to 1.

Chromosome1 = "10101011111100010101001"
Chromosome2 = "10111010001010000101110"

Offspring1 = "10101011111110000101110"
Offspring2 = "10111010001000010101001"

Mutated Offspring1 = "10101011011110000101110"
Mutated Offspring2 = "10111010001100010101000"

Encoding

Encoding of chromosomes is one of the problem, when you are starting to solve problem with GA. Encoding mainly depends on the problem.

Very important

Binary encoding

Binary encoding is the most common, mainly because first works about GA used this sort of encoding

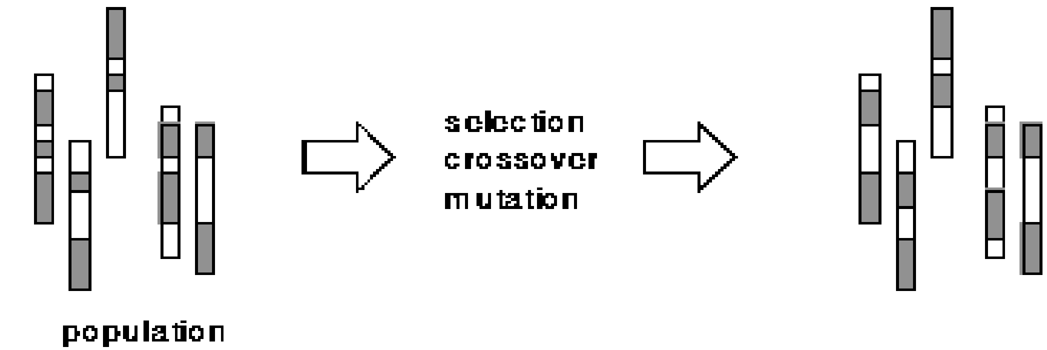
In binary encoding, every chromosome is a string of bits, 0 or 1.

Binary encoding gives many possible chromosomes even with a small number of alleles.

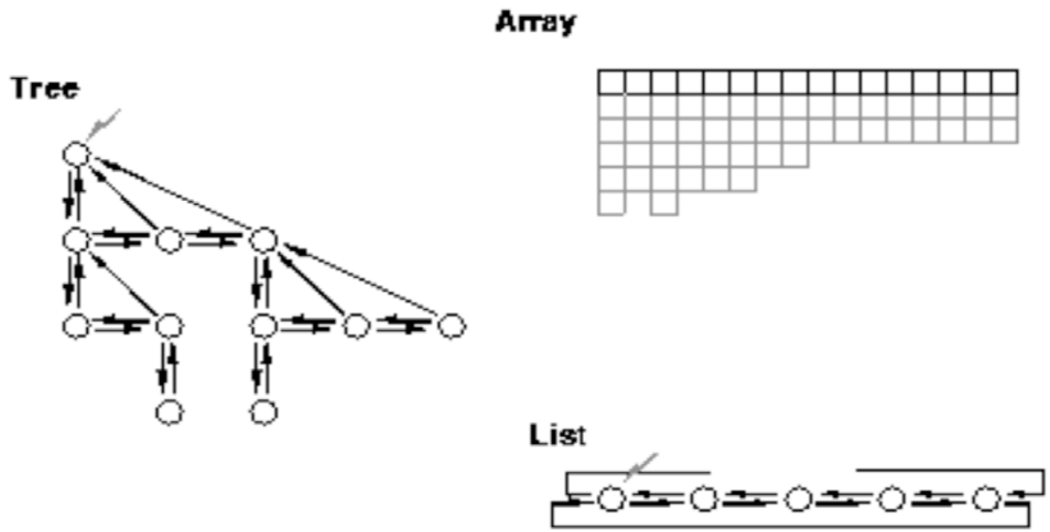
On the other hand, this encoding is often not natural for many problems and sometimes corrections must be made after crossover and/or mutation.

ChromosomeA = “101010111111000101010 01”
ChromosomeB = “101010100010100001011 10”

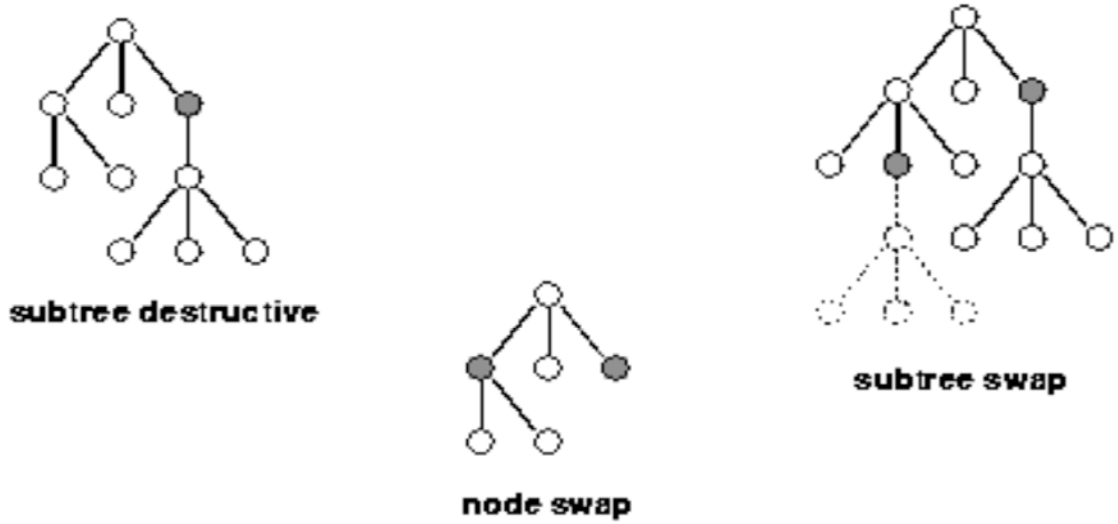
The GA lingo


chromosome
gene
1 0 1 1
allele
selection
crossover
mutation
population

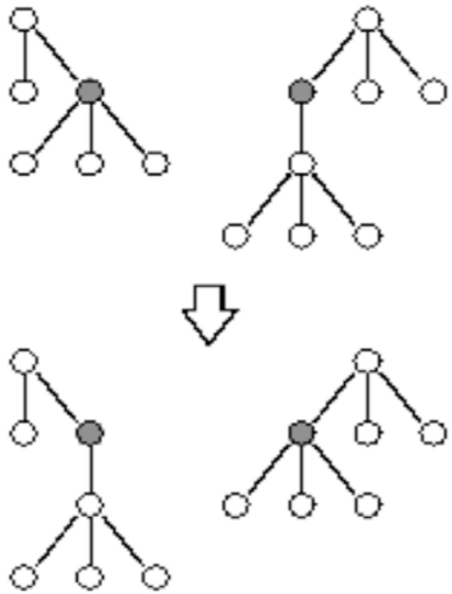
Other representations



Tree mutation operations

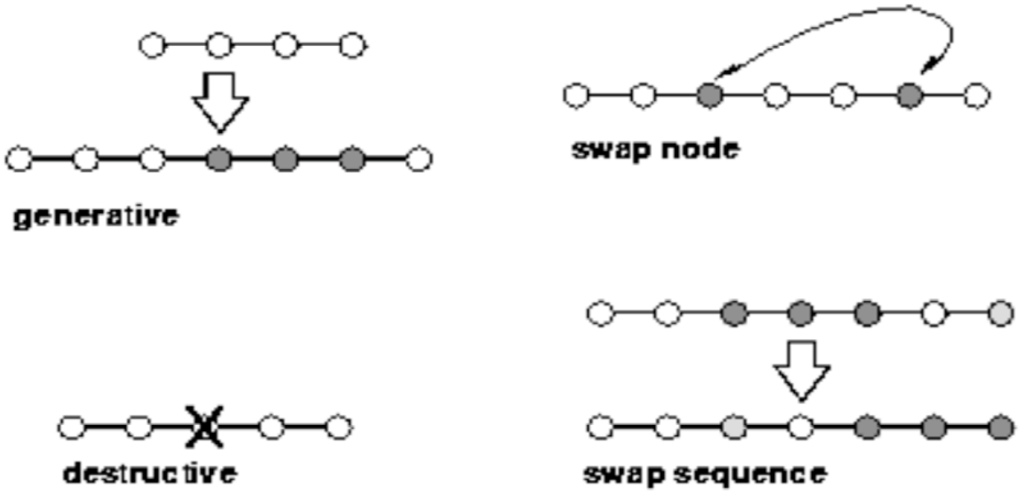


Tree crossover operators

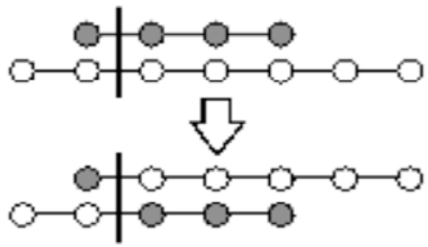


single point subtree

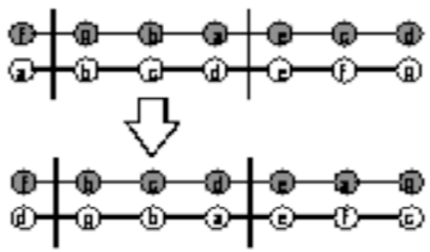
List mutation operators



List crossover operators

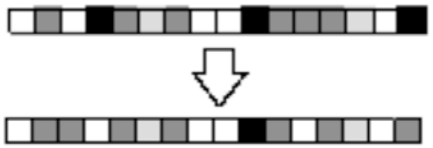


single point

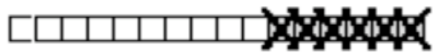


order-based

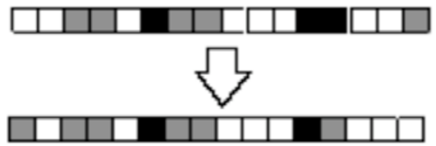
Array mutation operators



element flip

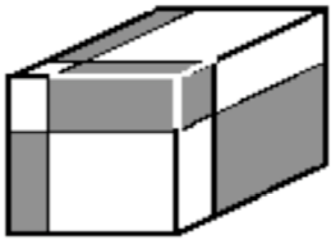


destructive

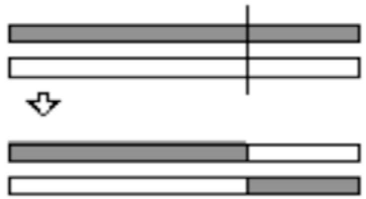


element swap

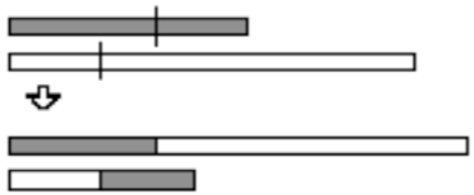
Array crossover operators



3D single point crossover



1D single point crossover



1D variable length crossover

Usage of GA

Optimization : numerical optimization, combinatorial optimization(circuit design, job shop scheduling)

Automatic programming : cellular automata, sorting networks

Machine and robot learning : prediction of dynamical systems, weather prediction, prediction of protein structure, designing neutral networks, evolving rules for learning classifier systems, symbolic production systems, designing and controlling robots

Economic models : modelling processes of innovation, development of bidding strategies, and the emergence of economic markets

Immune system models : somatic mutation during an indivisual's lifetime, the discovery of multi-gene families during evolutionary time

Ecological models : biological arms races, host-parasite co-evolution, symbiosis, resource flow in ecologies

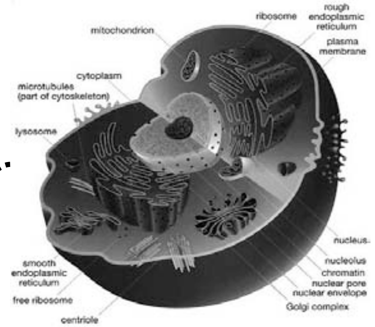
Population genetics models

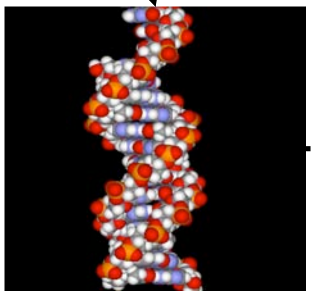
Interactions between evolution and learning

Models of social systems : evolution of cooperation, communication, trail-following behavior in ants

Usage of GA in Architecture

Usage of GA in Architecture





Simplified model of a genome

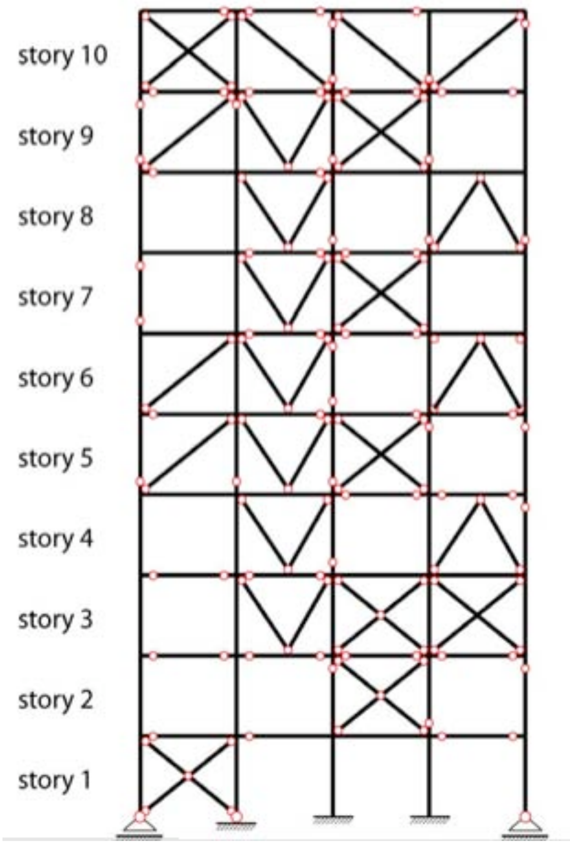
Simplified DNA_1 = “0101000100010…”

DNA_1 = “AGGCTTCGGAAA…”

Usage of GA in Architecture

Source from : Tomasz Arciszewski, Rafal Kicinger, "Structural Design Inspired by Nature", AICC 2005, August, Rome

Evolutionary Design



Topological optimum design problem

Planar transverse designs of steel skeleton structures in tall buildings

7 types of wind bracings

2 types of beams

2 types of supports

Usage of GA in Architecture

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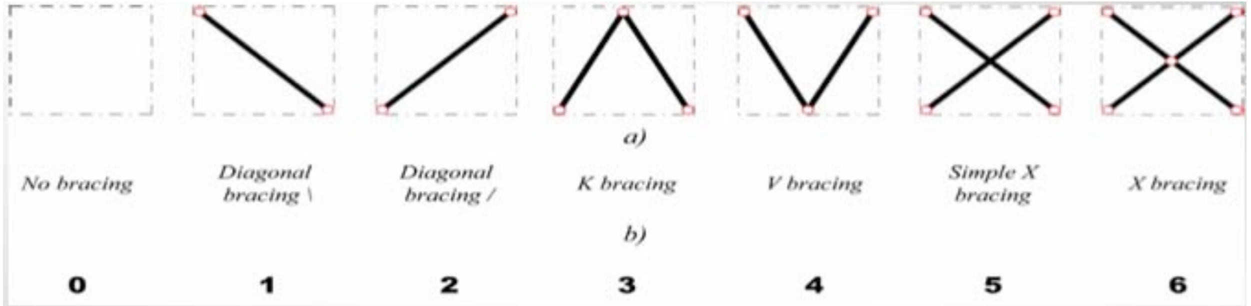
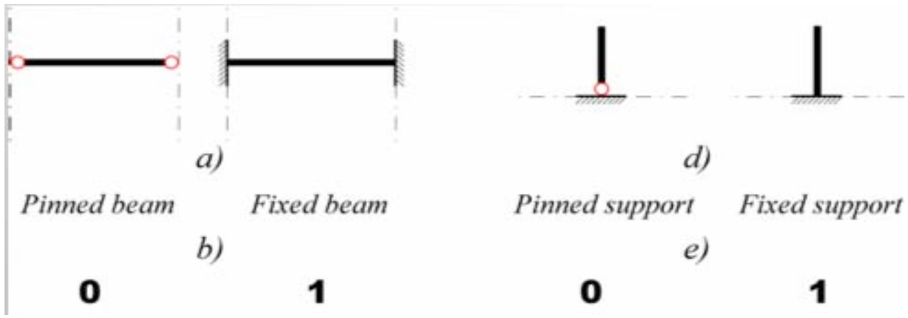
Wind bracings

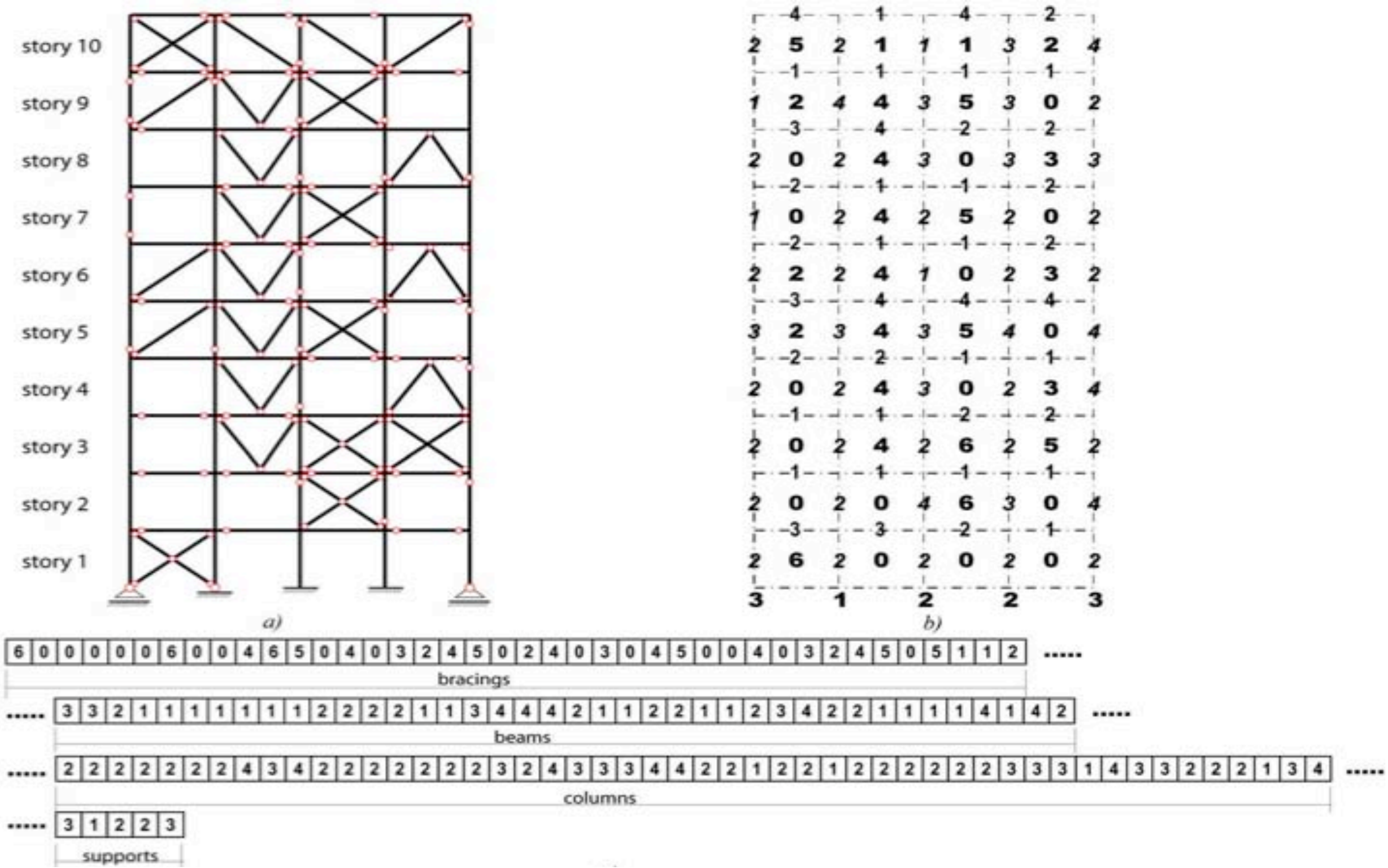


Beams and Supports



Structure Design

Source from : Tomasz Arciszewski, Rafal Kicinger, “Structural Design Inspired by Nature”, AICC 2005, August, Rome



Structure Design

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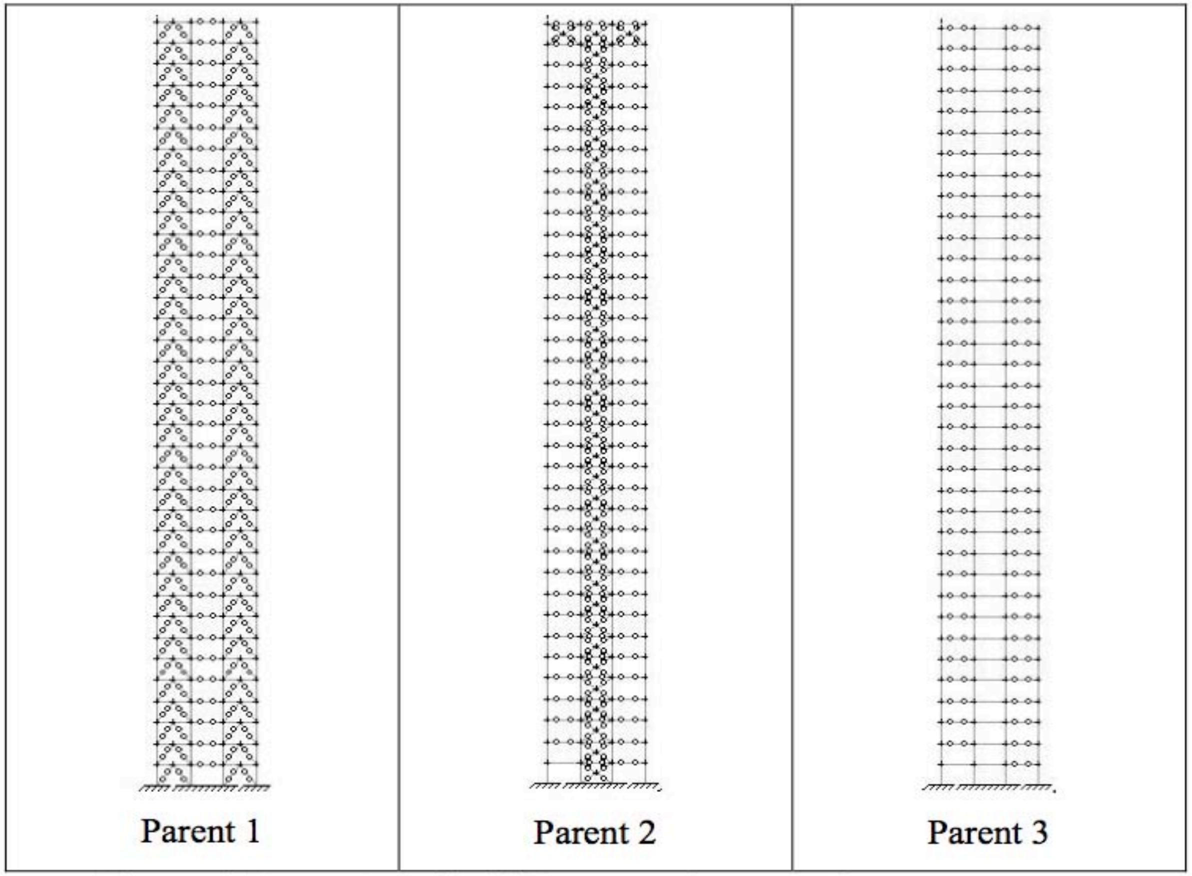

Figure 4. Examples of initial parents for evolutionary processes

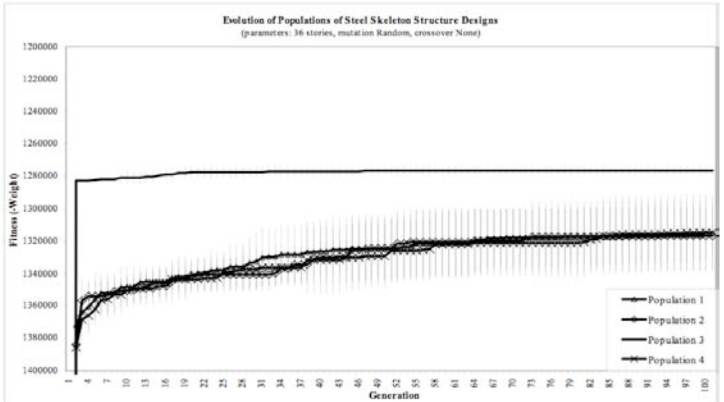

Figure 5. Examples of initial parents for evolutionary processes

Structure Design

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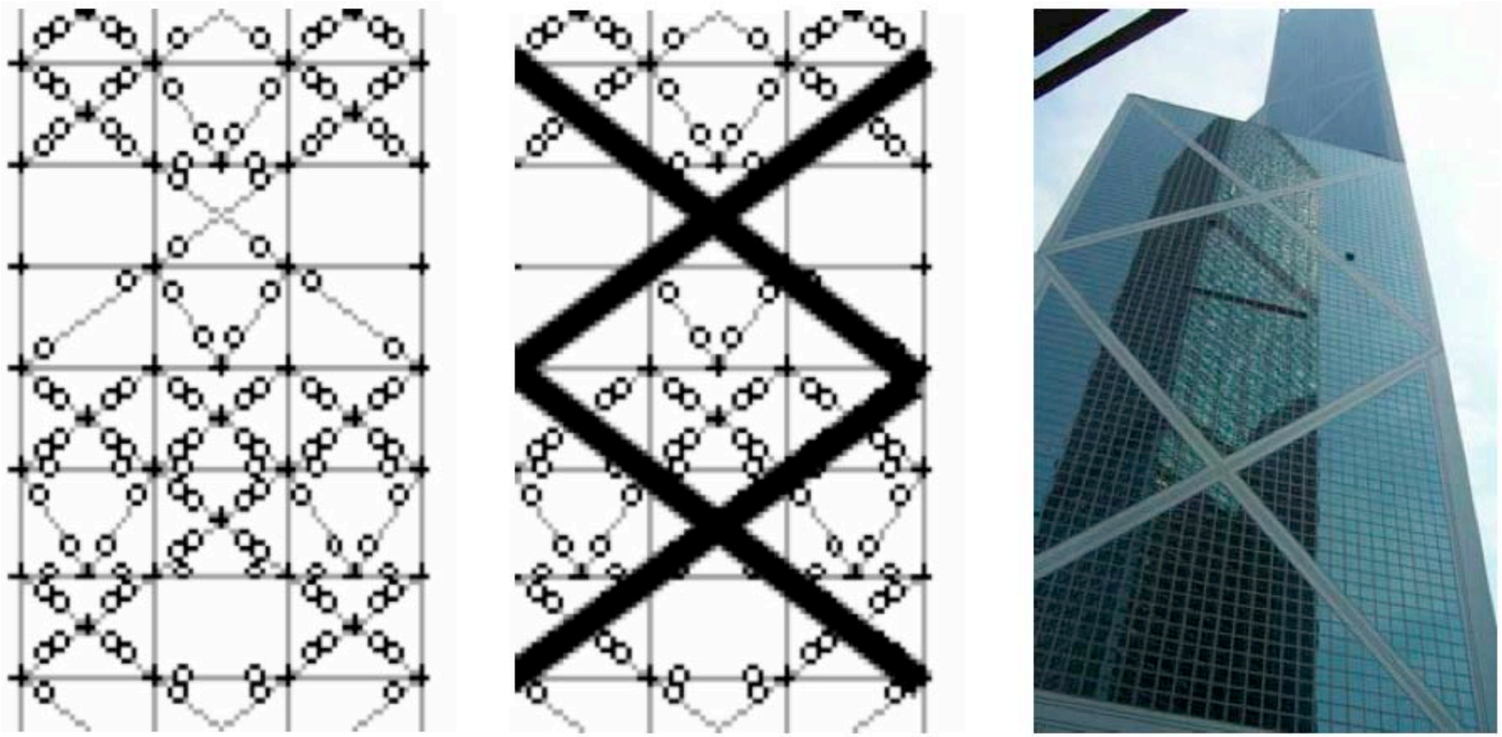


Figure 6. Emerging substructures in evolving designs compared to the state-of-the-art

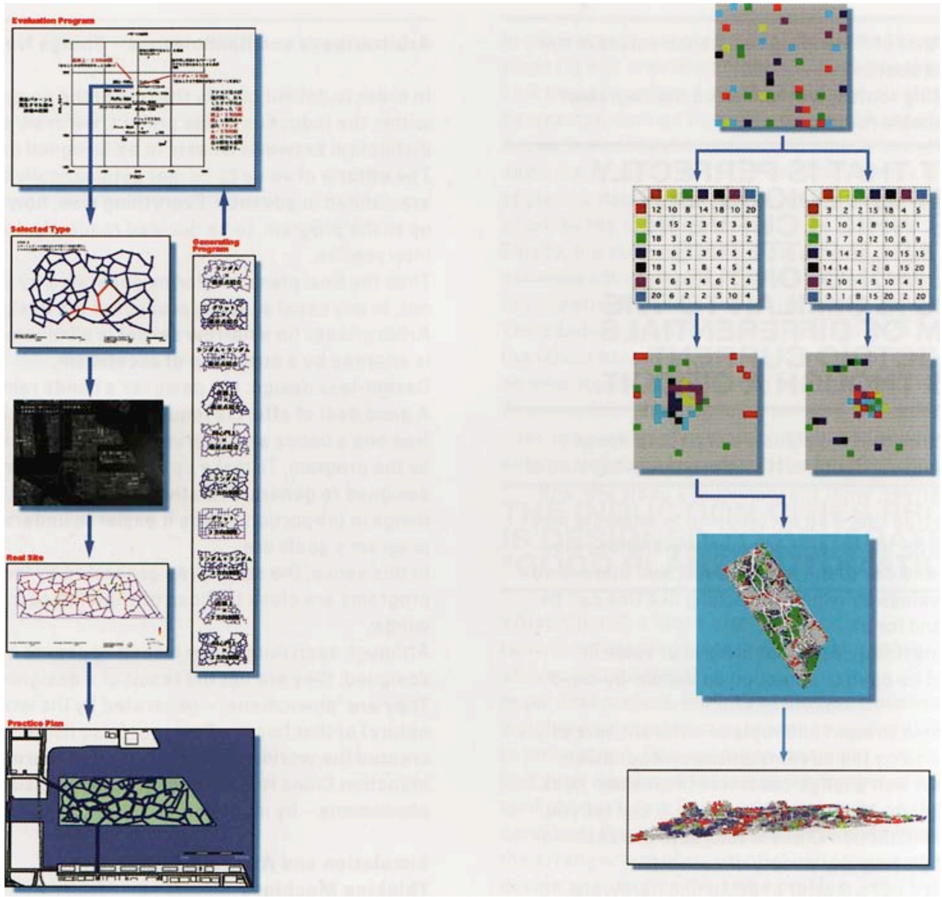
Building design

Source from : Makoto Sei Watanabe, “Induction Design / Induction Cities 1990 2005” in Towards an Interactive and Integrative Design Process, M. Shamiyeh and DOM Research Lab. (eds.), DOM Pub., 2006, pp.81 -109

“Good street”

leading quickly to the destination
(the number of intersections and the number of intersecting streets.)

Pleasant route to follow
(maximize the degree of diversity in available routes)



Building design

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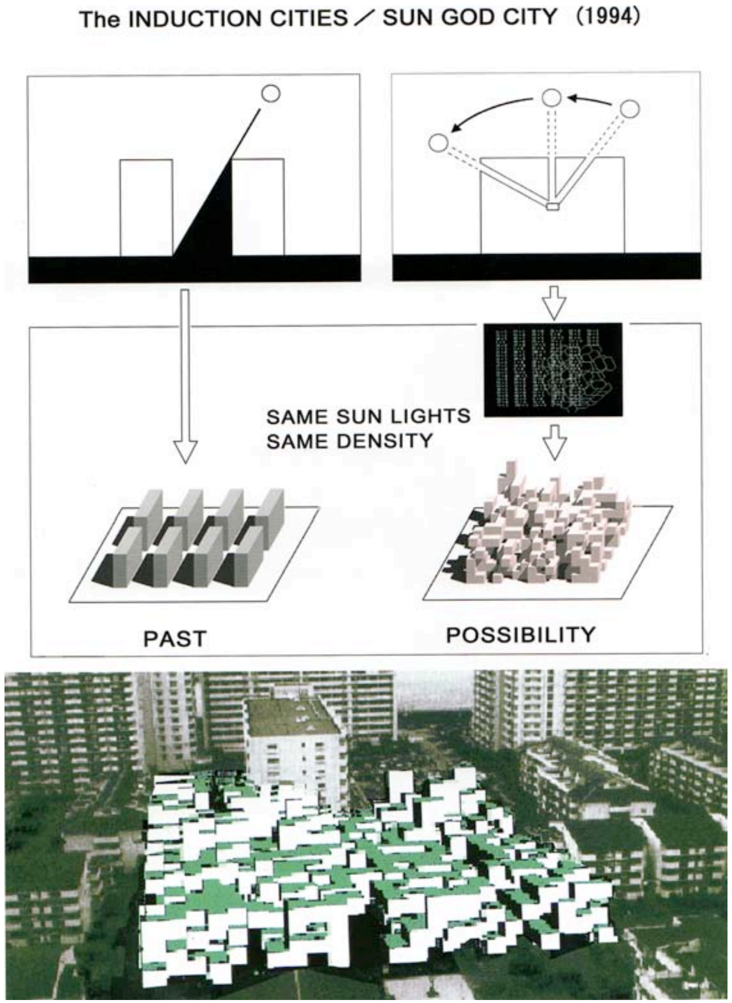
Basic Structures of Induction Cities

1. Criteria of value
2. Evaluation programs
3. Generating programs
4. Connection
5. Generation of the final program
6. Feedback



Maximum exposure to sunlight : each residential unit must receive at least a given number of hours of sunlight each day.

Building design

Source from : Makoto Sei Watanabe, “Induction Design / Induction Cities 1990 2005” in Towards an Interactive and Integrative Design Process, M. Shamiyeh and DOM Research Lab. (eds.), DOM Pub., 2006, pp.81 -109

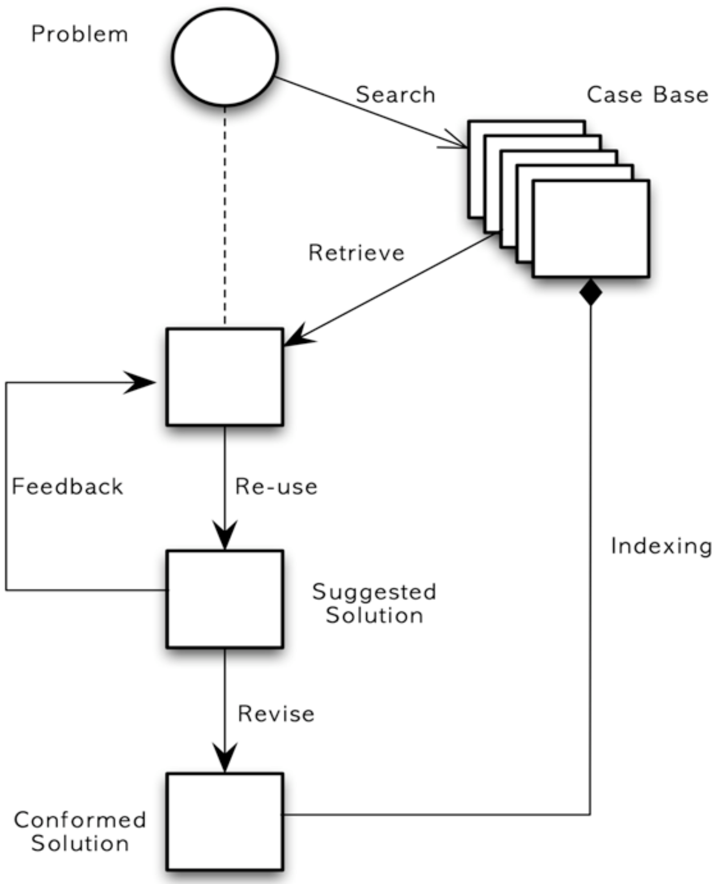
The theoretical ideal is never reached, but a solution that is close enough can be obtained.

SUN-GOD CITY (1994) “X hours of sunshine for each unit”

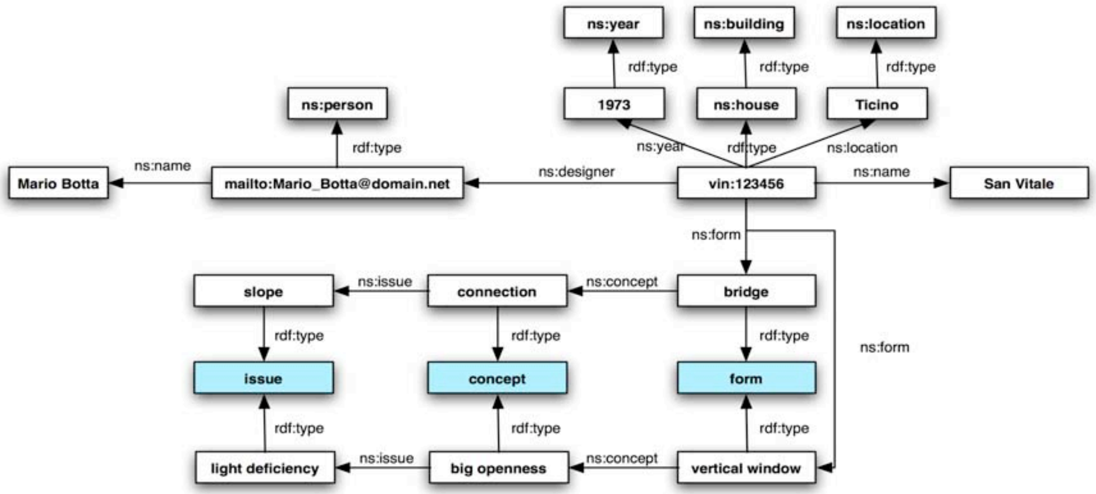
GENERATED CITY BLOCKS (1995) “Streets are major and houses are minor” “What makes a street nice?”

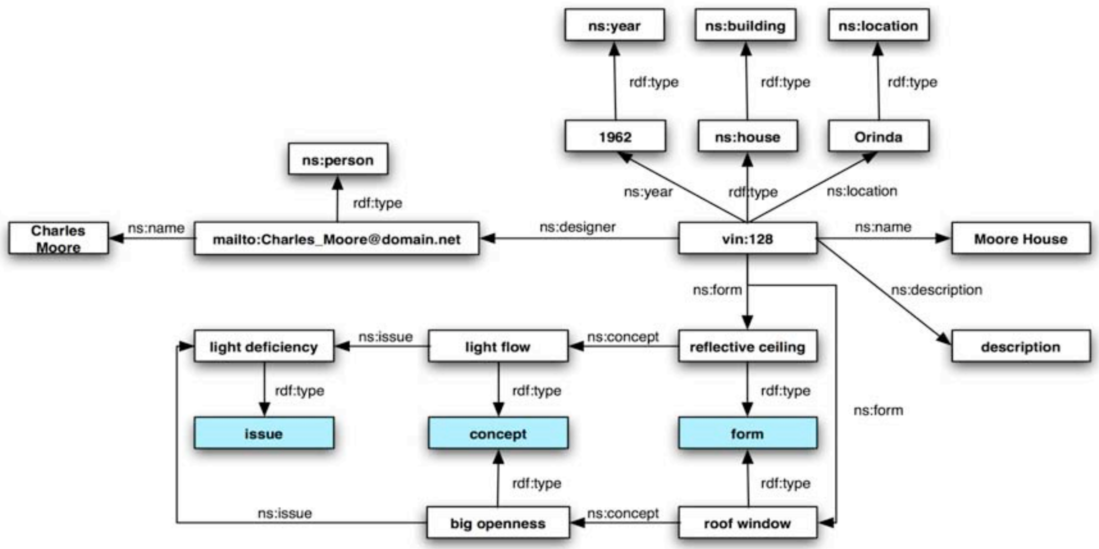
Case Based Design

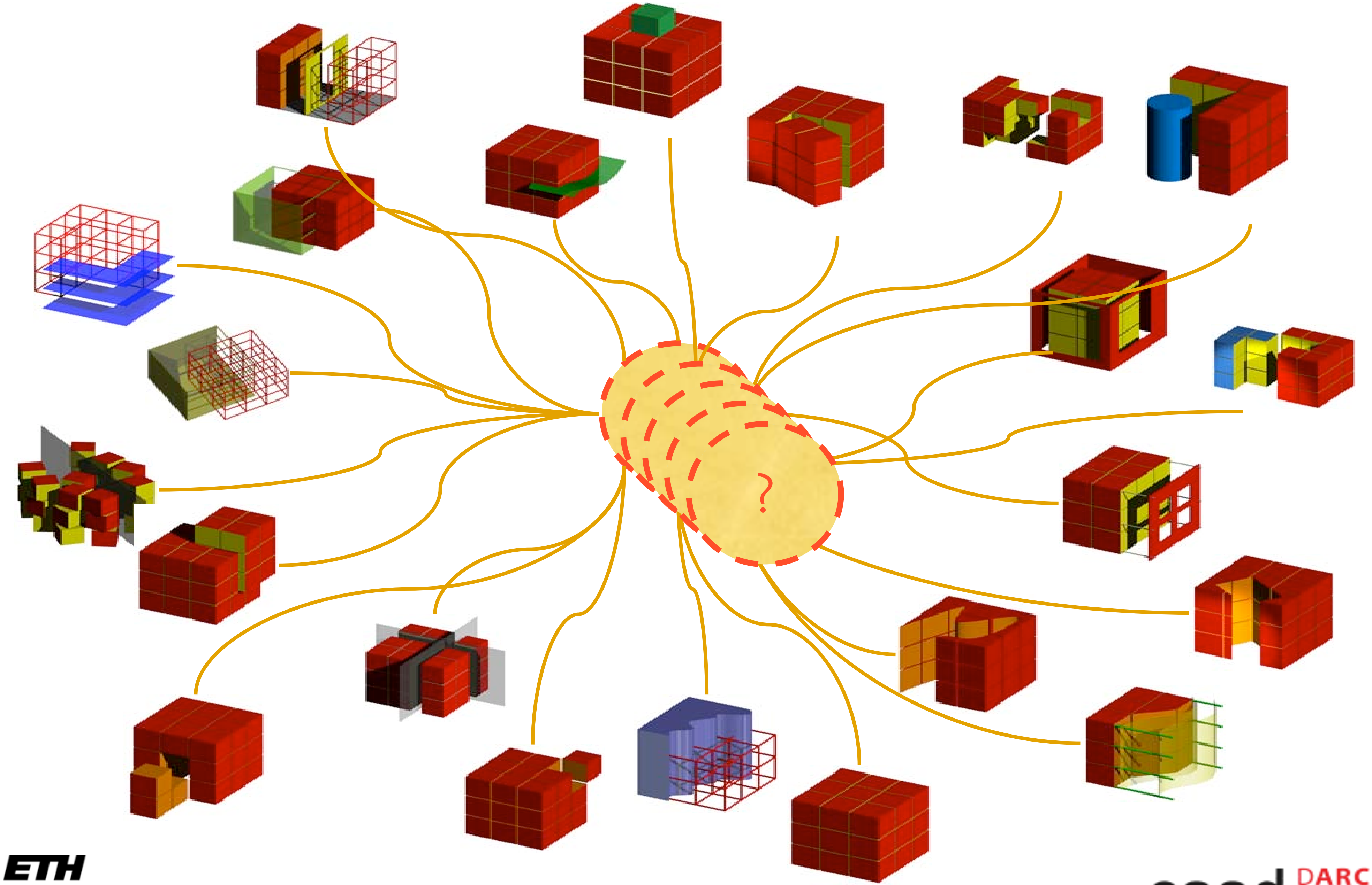
We can think that there exists a similarity between Case-Based Design and GA in design domain in that…



Case Based Design







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Conclusion

Discusion

If we think that design process is to find design solution, how can define the design solution to the design problem?

What sorts of methodology can be used for?

Among design topics, which can be solved adapting GA?