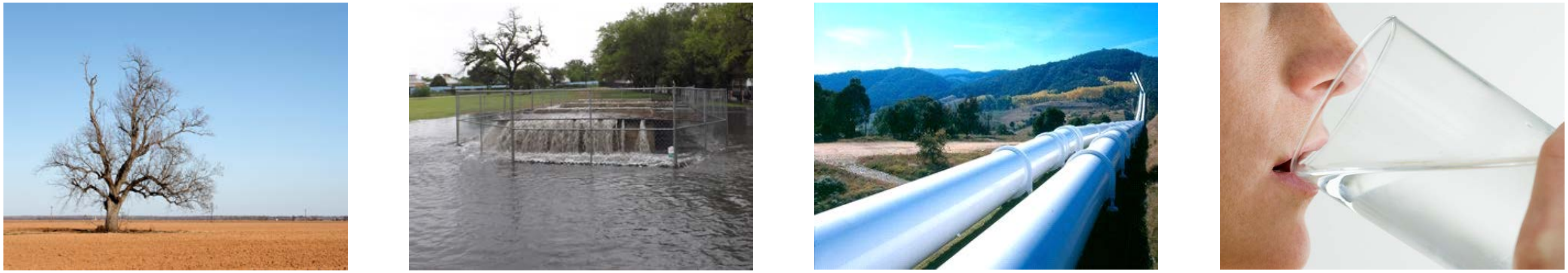


Water Resources Systems Analysis: the Search for Sustainable Solutions

Dr. Marcio Giacomoni

San Antonio, December 17th 2014

Agenda/Topics

10:00 - 10:20 Overview of the WeARE Project
- Lines of Research

10:20 – 10:40 What is Sustainability?
- Definitions of Sustainability
- Reliability, Resilience and Vulnerability of Water Systems

10:40 – 11:20 Introduction to Water Resources Systems Analysis
- Design versus Analysis
- History of Systems Analysis
- System Thinking

11:20 – 11:40 Evolutionary Algorithms
- Genetic Algorithms Operators
- Water Resources Applications

11:40 – 11:50 Q&A and General Discussion

Sustainability

- The term “sustainable development” was defined in 1987 by the World Commission on Environment and Development as:

“development that can meet the needs of the present generation without compromising the ability of future generation to meet their own needs”

Water Resources Sustainability

"Water resources sustainability is the ability to use water in sufficient ***quantities and quality*** *from the local to the global scale to meet the needs of* ***humans and ecosystems*** *for the present and future to sustain life, and to protect humans from the damages brought about by* ***natural and human-caused disasters*** *that affect sustaining life"*

(Mays 2007)

Threats to Water Resources Sustainability

Accute Issues

- Immediate response

Chronicle Issues

- Recurring or prolonged

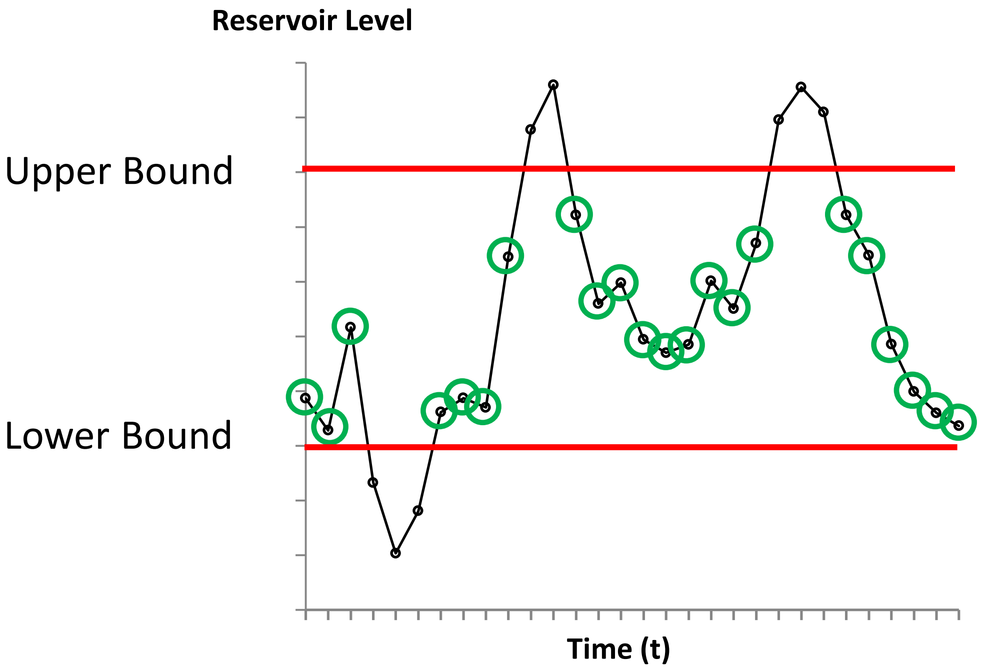
Emerging Issues

- Recurring or prolonged

How can we measure sustainability?

- Sustainability Index defined as the product of the following indexes:
  - Reliability
  - Resilience
  - Vulnerabilities

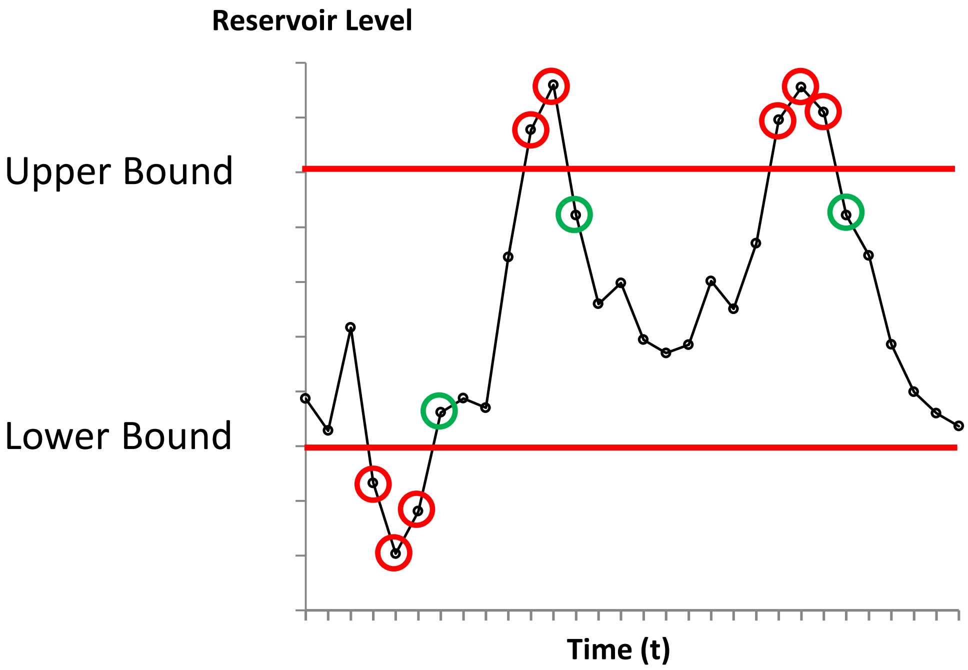
Sustainability Metrics:



Reliability is the probability that a system or component will perform its required functions under specified conditions for a specific period of time

Loucks, D. (1997). "Quantifying trends in system sustainability." *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, 42(4), 513-530.

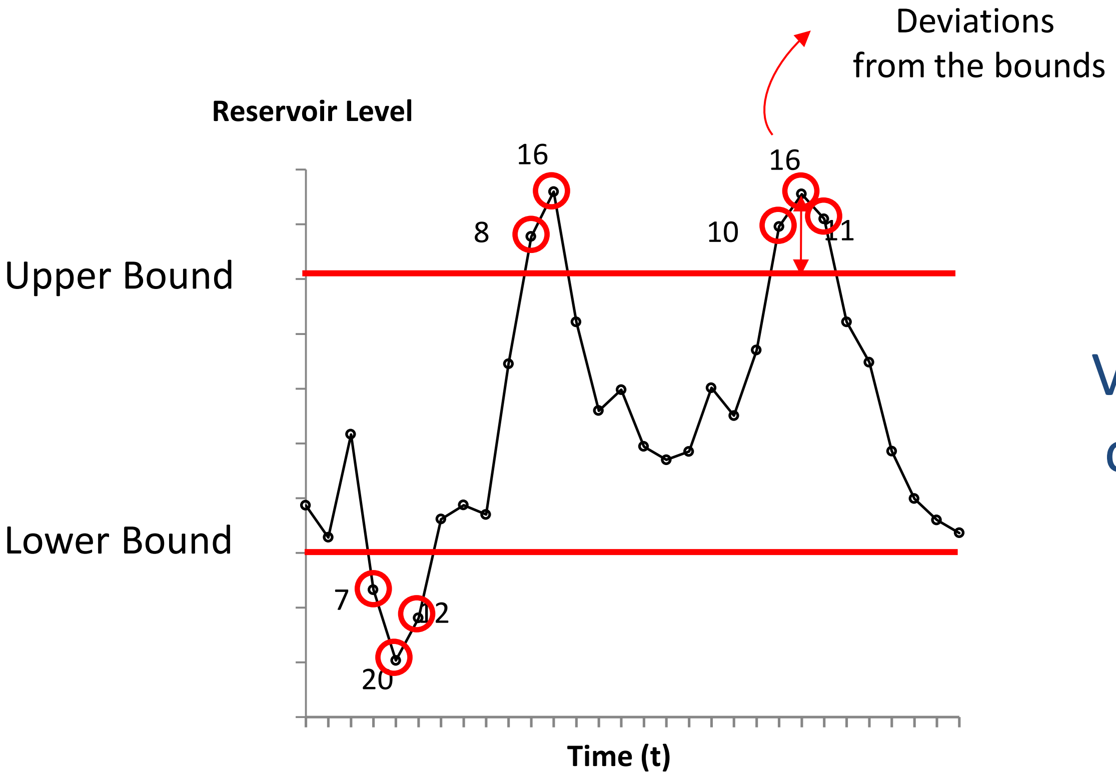
Sustainability Metrics:



Resilience is an indicator of speed of recovery once a failure occurs

Loucks, D. (1997). "Quantifying trends in system sustainability." *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, 42(4), 513-530.

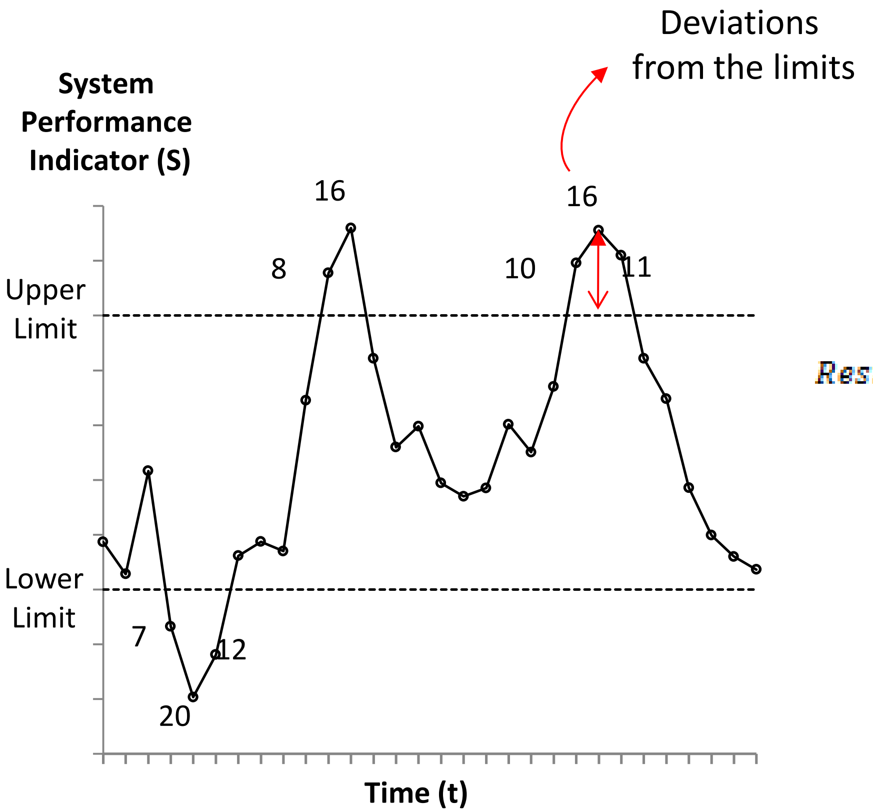
Sustainability Metrics:



Vulnerability is a measure of the extent or duration of failure

Loucks, D. (1997). "Quantifying trends in system sustainability." *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, 42(4), 513-530.

Sustainability Index



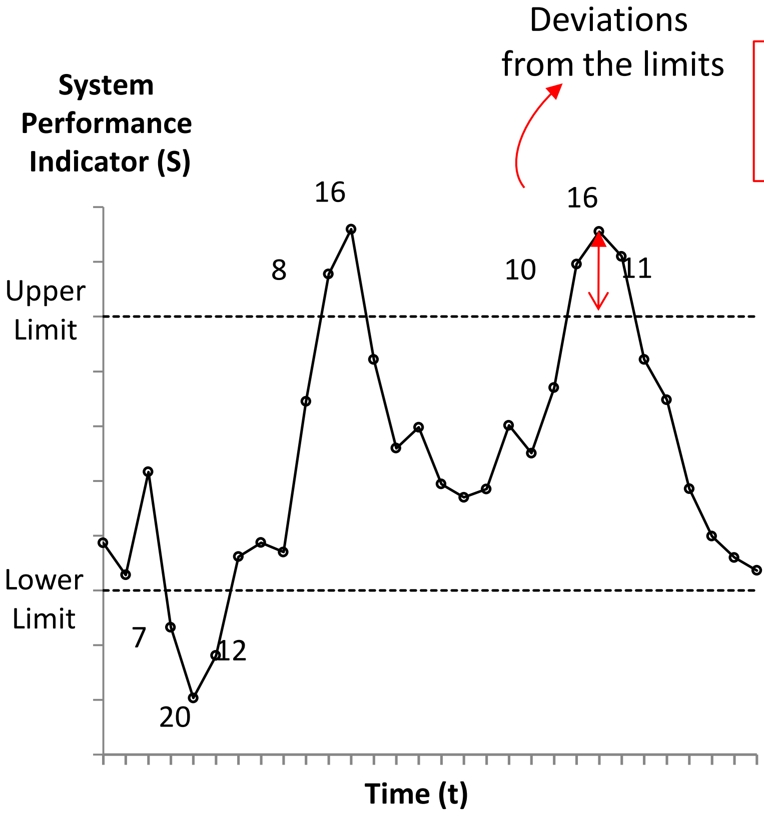
$$Reliability = \frac{\#\ of\ Satisfactory\ Values}{Total\ \#\ of\ Values} = \frac{22}{30} = 0.73$$

$$Resilience = \frac{\#\text{ of Times a Satisfactory Value follows a failure}}{\#\ of\ Unsatisfactory\ Values} = \frac{3}{8} = 0.38$$

$$Extent\ Vulnerability = \frac{\sum Deviation}{\#\ of\ Failures} = \frac{98}{8} = 12.3$$

Loucks, D. (1997). "Quantifying trends in system sustainability." *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, 42(4), 513-530.

Relative Vulnerabilities



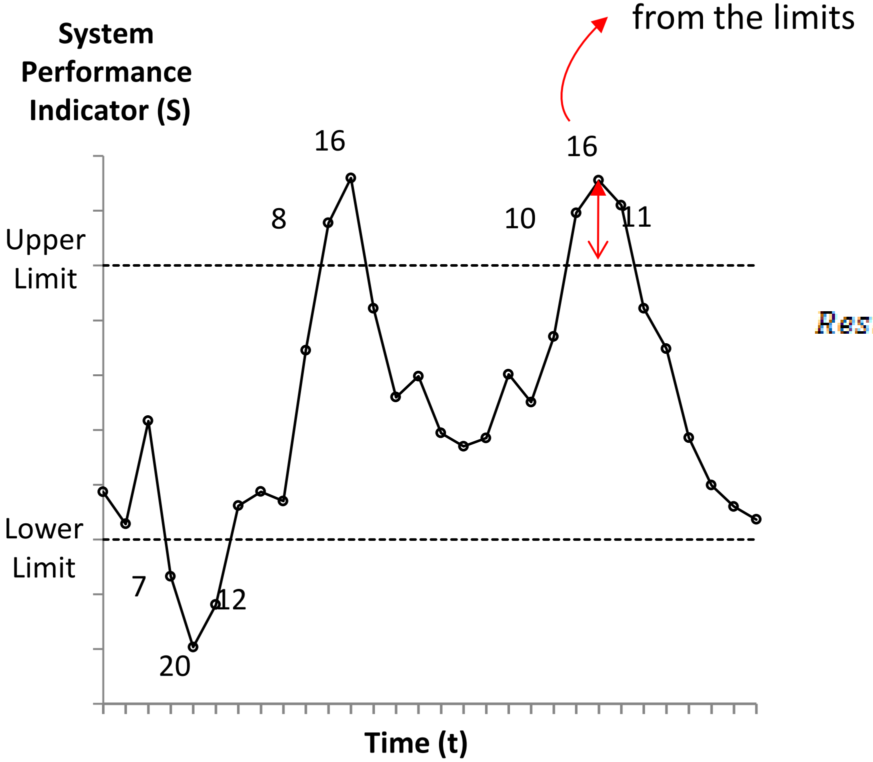
$$Relative\ Vulnerability = \frac{Extent\ Vulnerability}{Maximum\ Vulnerability}$$

$$Maximum\ Extent\ Vulnerability = \frac{\sum Max\ Violation}{Total\ \#\ of\ Violations}$$

$$Maximum\ Extent\ Vulnerability = \frac{20 \times 30}{30} = 20$$

$$Relative\ Extent\ Vulnerability = \frac{12.3}{20} = 0.62$$

Sustainability Index



Deviations
from the limits

$$\mathit{Reliability} = \frac{\#\ \mathit{of\ Satisfactory\ Values}}{\mathit{Total}\ \#\ \mathit{of\ Values}} = \frac{22}{30} = 0.73$$

$$\mathit{Resilience} = \frac{\#\ \text{of Times a Satisfactory Value follows a failure}}{\#\ \mathit{of\ Unsatisfactory\ Values}} = \frac{3}{8} = 0.38$$

$$\mathit{Extent\ Vulnerability} = \frac{\sum \mathit{Deviation}}{\#\ \mathit{of\ Failures}} = \frac{98}{8} = 12.3$$

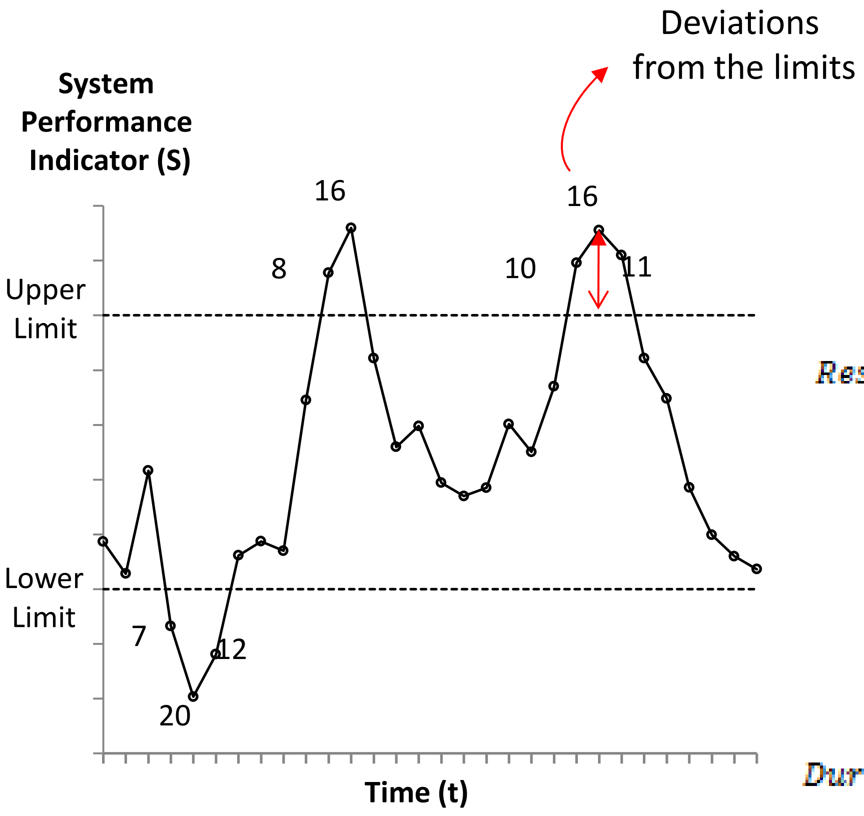
$$\mathit{Relative\ Extent\ Vulnerability} = \frac{12.3}{20} = 0.61$$

$$\mathit{Sustainability\ Index} = \mathit{Reliability} \times \mathit{Resilience} \times (1 - \mathit{Relative\ Extent\ Vulnerability})$$

$$= 0.73 \times 0.38 \times (1 - 0.61) = 0.11$$

Loucks, D. (1997). "Quantifying trends in system sustainability." *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, 42(4), 513-530.

Sustainability Index



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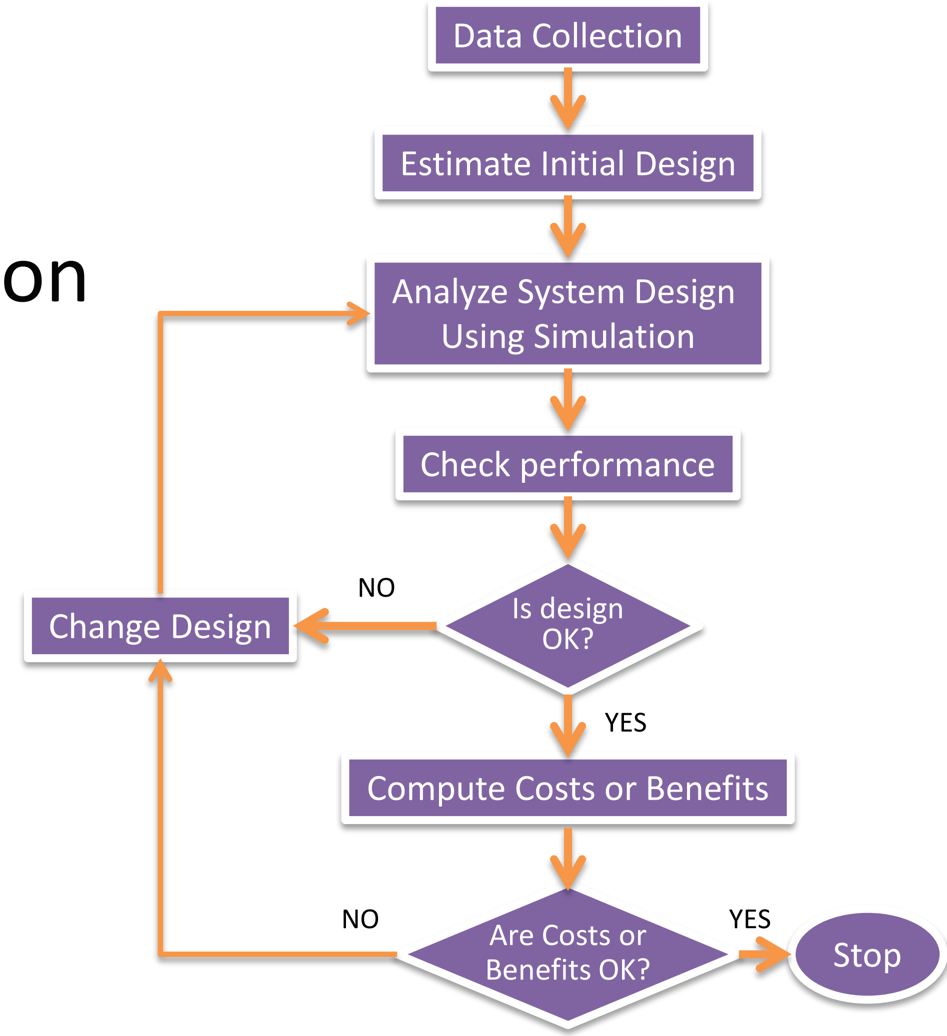
$$Extent\ Vulnerability = \frac{\sum Deviation}{\#\ of\ Failures} = \frac{98}{8} = 12.3$$

$$Duration\ Vulnerability = \frac{\#\ of\ Failures}{\#\ of\ Continuous\ Failure\ Events} = \frac{8}{3} = 2.7$$

Loucks, D. (1997). "Quantifying trends in system sustainability." *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, 42(4), 513-530.

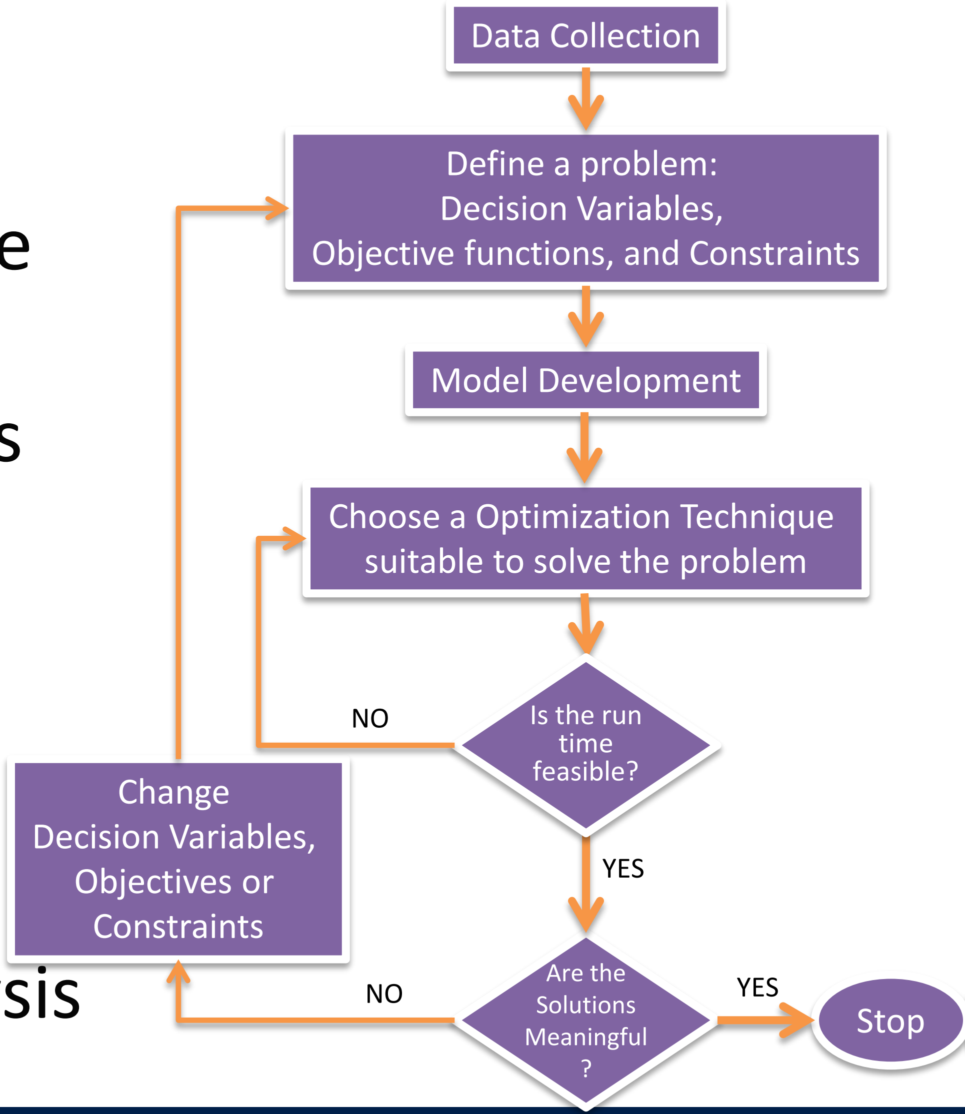
Conventional versus Optimization Procedures

- Trial and Error
- Effectiveness depend upon an engineer's intuition, experience, skill, and knowledge
- It can led to inefficient design and analysis of complex systems



Conventional versus Optimization Procedures

- Eliminates Trial and Error
- Automatically changes the design parameters
- Mathematical expressions that describe the system and its response to the system inputs for various design parameters
- It can led to better efficient design and analysis



What is Systems Analysis?[1]

- Systematic analysis of design or decision alternative to solve a problem.
- To formalize this approach, it is necessary to describe the problem in Mathematical terms :
  - DECISIONS
  - OBJECTIVES
  - CONSTRAINTS

$$\boldsymbol{Minimize/Maximize}$$

$$\boldsymbol{f(X) = f(\vec{X}) = f(x_1, x_2, \ldots, x_n)}$$

subject to constraints:

$$\boldsymbol{g(X) = 0}$$

and bound constraints on the decision variables

$$\boldsymbol{\underline{X} < X < \overline{X}}$$

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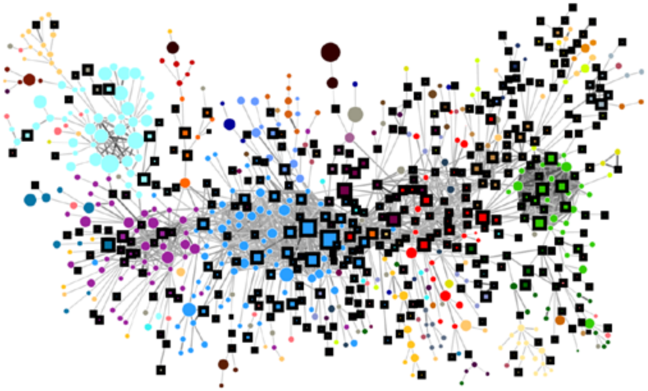
[1] Water Resources Systems Analysis through Case Studies: Data and Models for Decision Making. Edited by David W. Watkins, Jr. sponsored by Task Committee on Environmental and Water Resources Systems Education, Environmental and Water Resources Institute, American Society of Civil Engineers. ISBN 978-0-7844-1287-9 (paper) – ISBN 978-0-7781-6 (ebook).

What is Systems Analysis?[1]



- Often the problems are too complex and the number of alternatives too large
- Automation is then necessary to find the best solution through a mathematical algorithm
- In this case, Systems Analysis is referred as:
  - Optimization or mathematical programming
- Fields specializing in the techniques of optimization/mathematical programming are:
  - Operations Research
  - Management Science
  - Industrial Engineering

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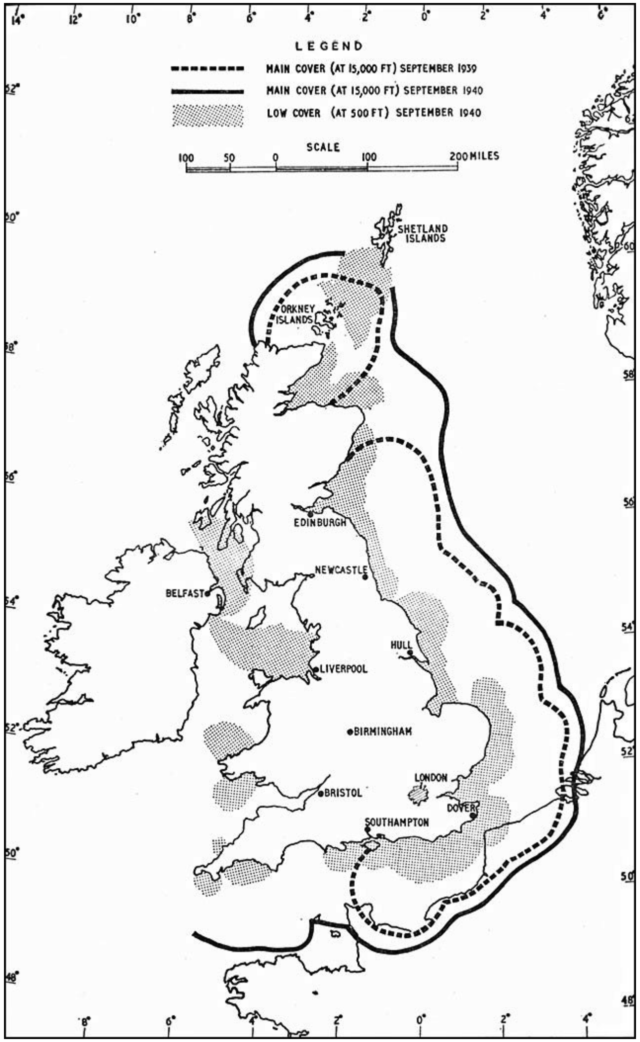
History of Operations Research

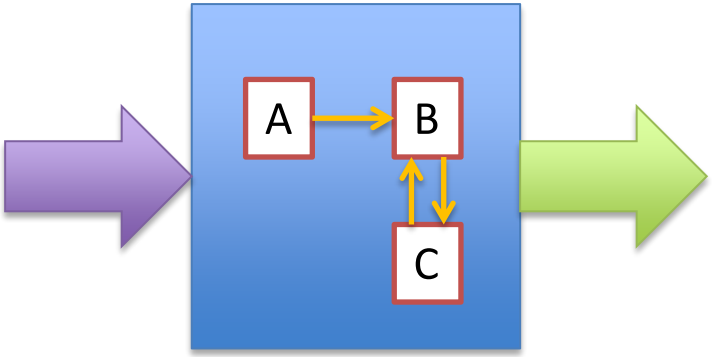
- Development of RADAR for R.A.F during WWII, by Robert Watson-Watt (Radio Department of the National Physical Lab).
  - feasibility of “death rays”
- Rapidly increase of scientists engaged in operations research:
  - 1,000 people in Britain
  - 200 research scientists worked for British Army
- Expansion of OR: equipment, training, logistics, and infrastructure.

RADAR COVER SEP. 1939 and SEP. 1940



What is a System?

- General System Theory by Ludwig von Bertalanffy in 1940
  - Biological Sciences
  - Reaction against “scientific reductionism”
- “A system is composed of interrelated parts or components (structures) that cooperate in processes (behavior).”



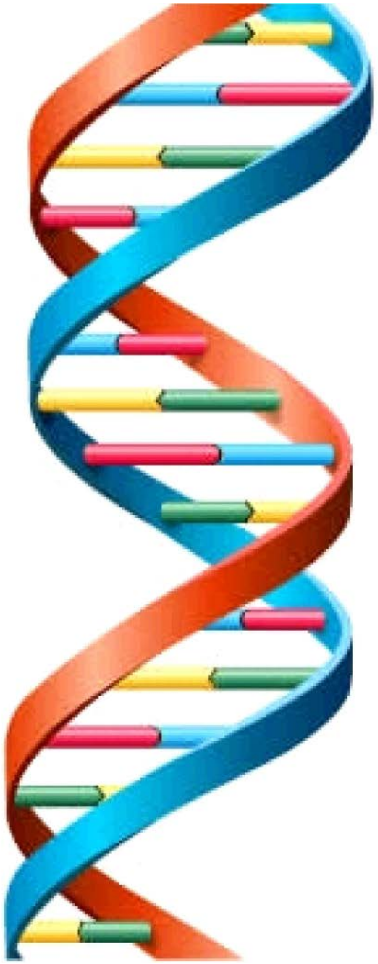
What is a System?

- SYSTEM: *set of interacting elements that perform independent from each other* (Mays & Tung, 2002)
  - System boundary: definition of elements
  - Processes: how the elements interact
  - Inputs: stimulus from external environmental
  - Outputs: behavior and results from the inputs

Systems Thinkers or Systems Modelers

- Are able to perform:
  1. Describe a system and formulate a engineering design/planning/operational problem in terms of decisions, objectives, and constraints;
  2. Simplify (if necessary) and formulate the problem, in mathematical terms;
  3. Select an appropriate mathematical programming tool, or computer software to solve the problem;
  4. Understand the solution procedure;
  5. Interpret the solution and analyze the uncertainties associate with it;
  6. Explain the solution, solution sensitivity, and limitations of the approach to someone unfamiliar with optimization or mathematical programming.

Evolutionary Algorithms

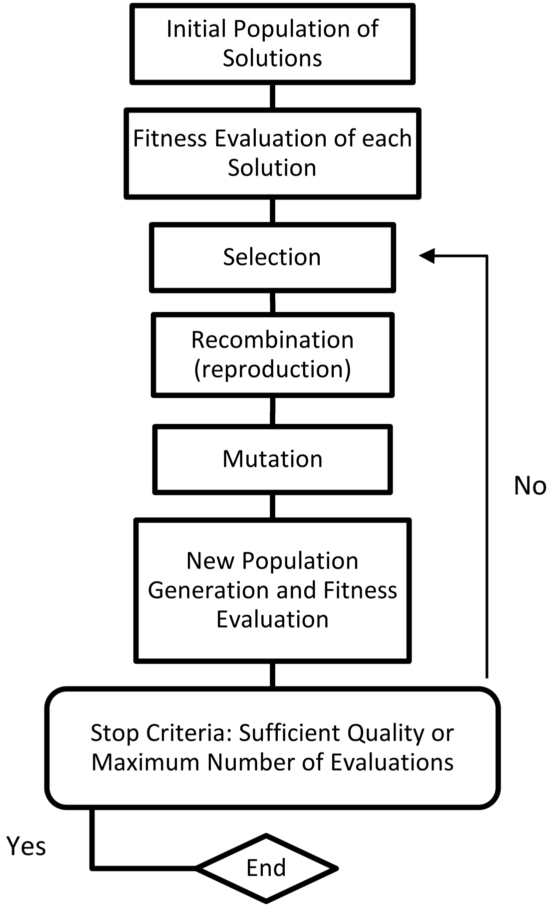


- A subfield of artificial intelligence
- Applies the concept of biological evolution to global optimization algorithms
  - reproduction, mutation, recombination, and selection.
- Example of EA:
  - Genetic Algorithm (GA)
  - Evolution Strategies (ES)
  - Genetic Programming (GO)
  - Particle Swarn Optimization (PSO)
  - Ant Colony Optimization

Genetic Algorithms (GA)

- developed by John Holland, professor of psychology and electrical engineering at University of Michigan
- is a search algorithms that mimics the process of natural selection and natural genetics.
- combine the survival of the fittest among string structures with a structured yet randomized information exchange to a form a search algorithm

General steps of a GA



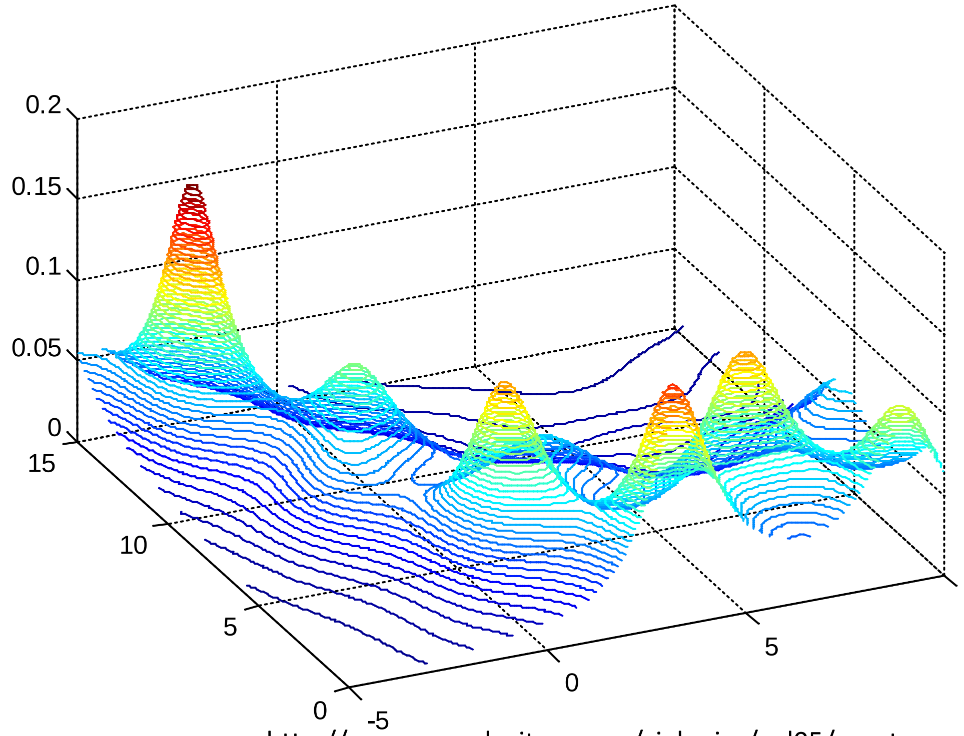
Simple Example: Modified RCOS Test Function

$$Maximize\ z = f(\boldsymbol{x}, \boldsymbol{y})$$

$$= \frac{1}{[a(y - bx^2 + cx - d)^2 + e(1 - f)\cos(x)\cos(y) + \log(x^2 + x^2 + 1) + e]}$$

$$a = 1\,;\mathrm{b} = \frac{5.1}{4\pi^2};c = \frac{5}{\pi};d = 6\,;e = 10\,;f = \frac{1}{8\pi}$$

$$x \times y \in [-5{,}10] \times [0{,}15]$$

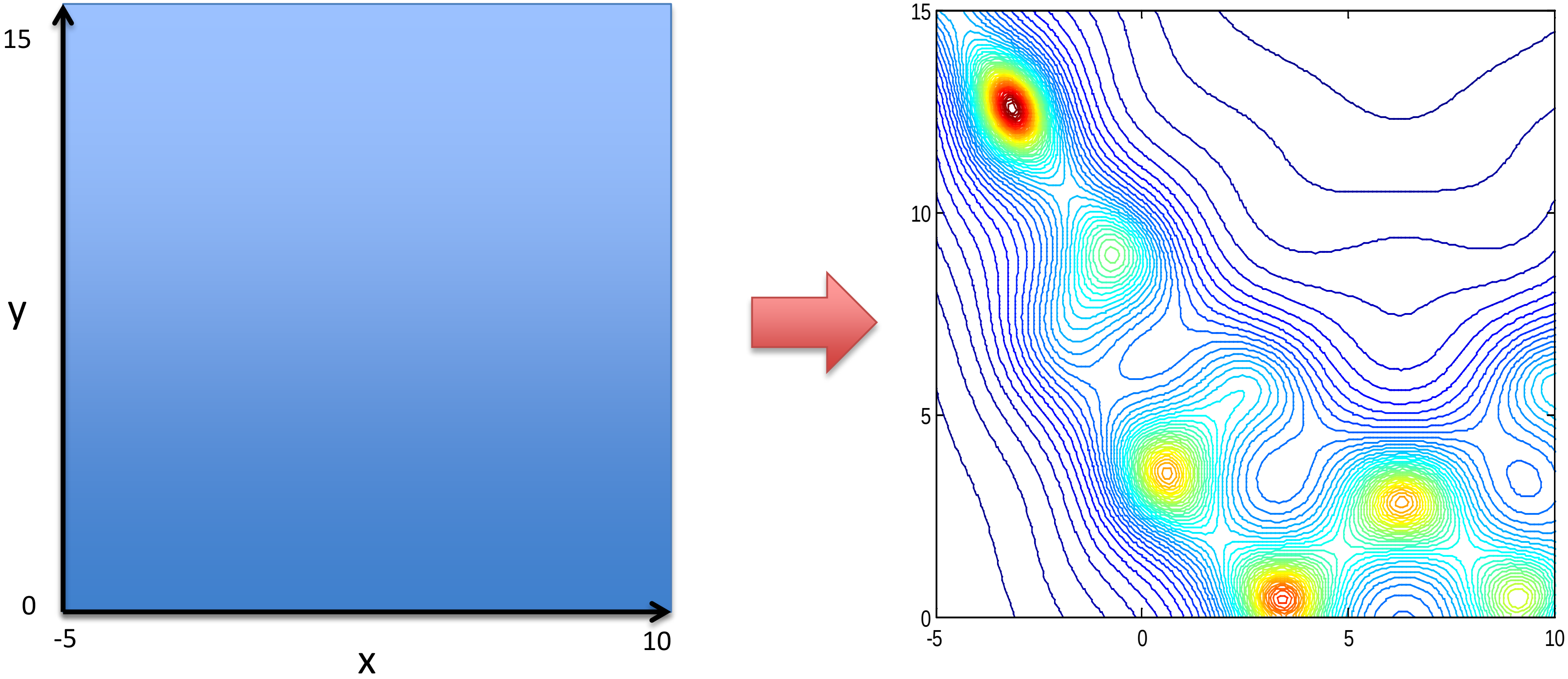


http://www.complexity.org.au/ci_louise/vol05/munteanu/munteanu.html

Decision and Objective Space

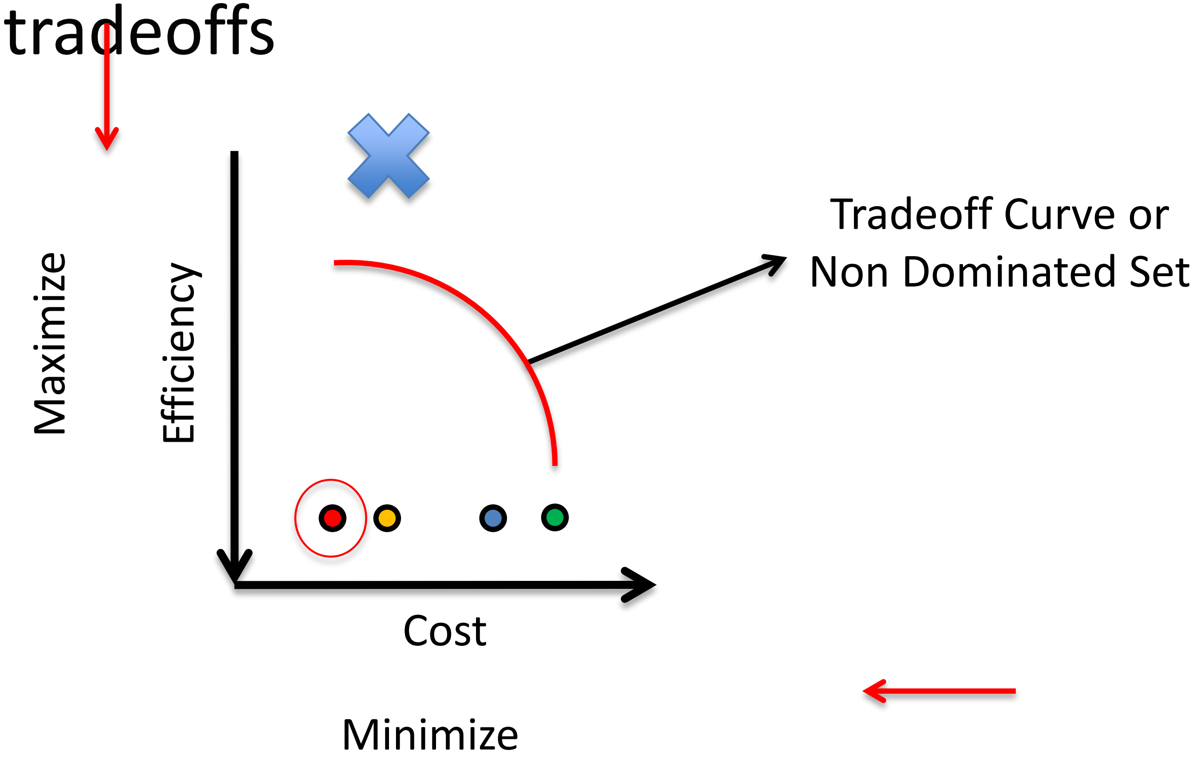
- Decision Space is the set of all possible solutions
- Objective Space is the corresponding objective values

$x \times y \in [-5,10] \times [0,15]$



Multi-Objective Optimization

- Multi-Objective Evolutionary Algorithms:
  - identify the optimal decisions
  - identify tradeoffs



Simple Example:

$$Maximize\ z = f(\boldsymbol{x}, \boldsymbol{y})$$

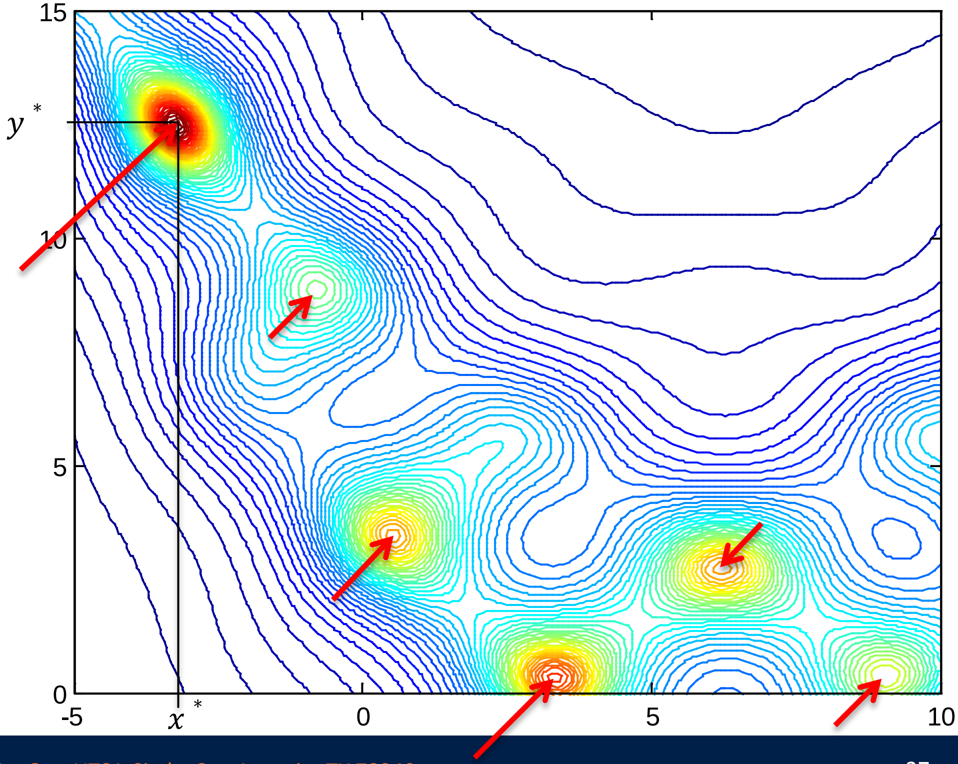
$$= \frac{1}{[a(y - bx^2 + cx - d)^2 + e(1 - f)\cos(x)\cos(y) + \log(x^2 + x^2 + 1) + e]}$$

$$a = 1\,;\mathrm{b} = \frac{5.1}{4\pi^2}; c = \frac{5}{\pi}; d = 6\,; e = 10\,; f = \frac{1}{8\pi}$$

$$x \times y \in [-5{,}10] \times [0{,}15]$$

- 5 local optima points
- 1 global optima point:

$$z(x^*, y^*) = 0.179$$
$$x^* = -3.197, y^* = 12.526$$



Solutions and Individuals

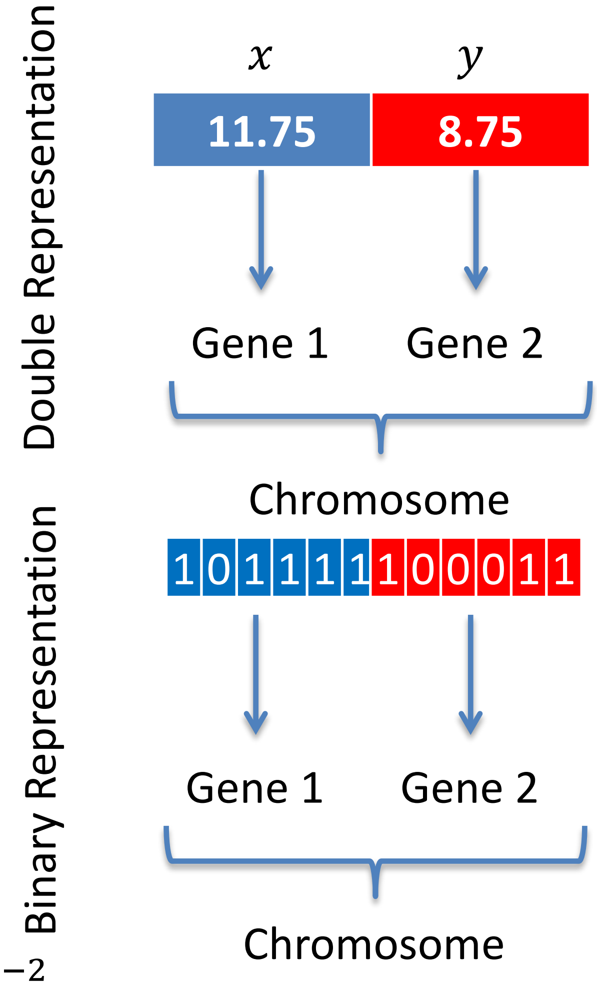
$x \times y \in [-5,10] \times [0,15]$

- Individual is a virtual representation of a solution for a problem that can be mathematically evaluated
- An individual is made of genes or chromosomes that can be translated or encoded to decision variables.

$$x = \sum_{i=3}^{i=-2} b_i \times 2^i =$$

$$= 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 + 1 \times 2^{-1} + 1 \times 2^{-2}$$

$$= 8 + 0 + 2 + 1 + 0.5 + 0.25 = 11.75$$



Fitness Function

- GA don’t handle constraints directly
- FF = Objective Function - Penalty Function

x	y
11.75	8.75

$$z = f(\mathbf{11.75, 8.75}) = \frac{1}{[a(y - bx^2 + cx - d)^2 + e(1 - f)\cos(x)\cos(y) + \log(x^2 + x^2 + 1) + e]} = 0.0429$$

$$x \times y \in [-5,10] \times [0,15]$$

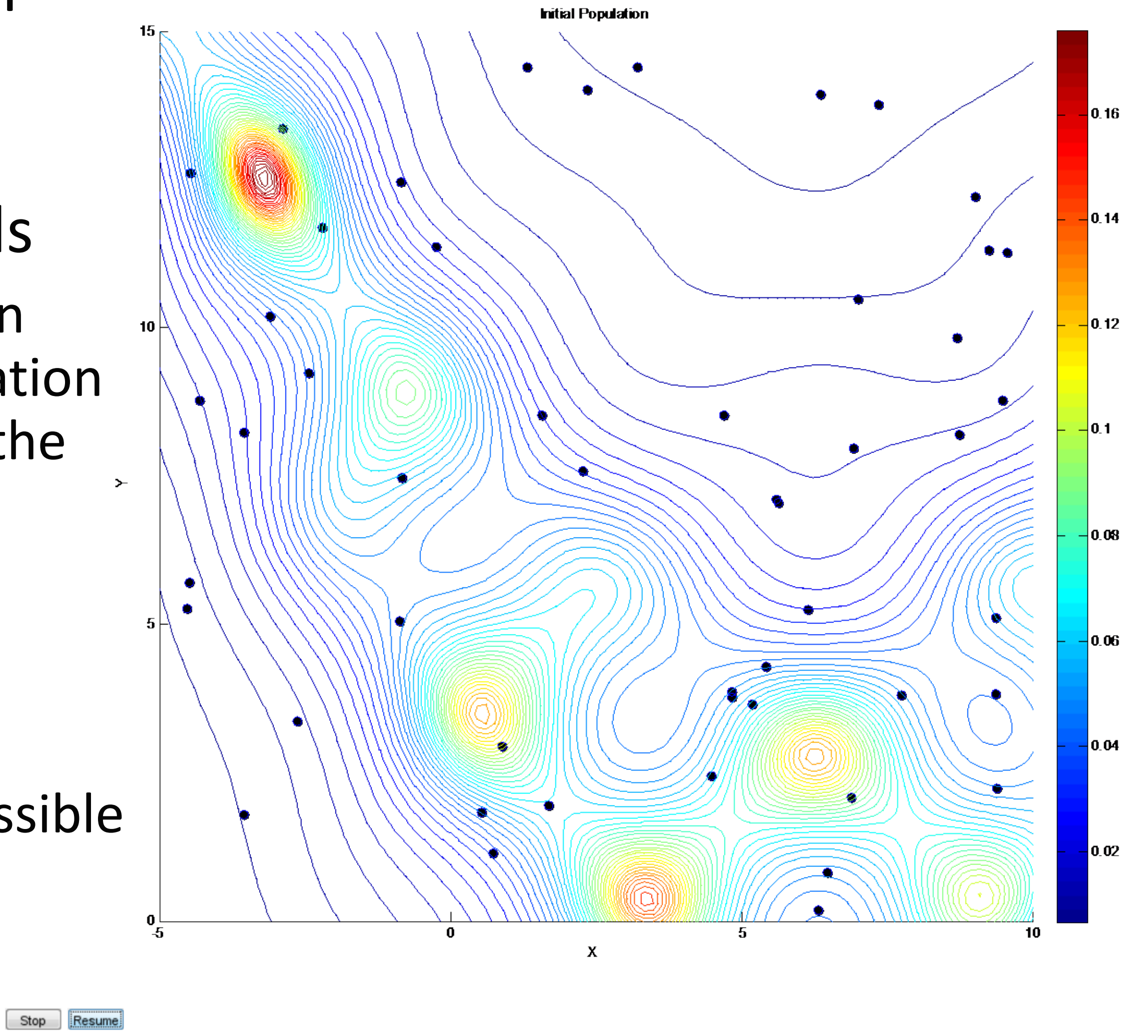
x	y
-11.75	8.75

Infeasible Solution

$$z = f(\mathbf{-11.75, 8.75}) = \frac{1}{[a(y - bx^2 + cx - d)^2 + e(1 - f)\cos(x)\cos(y) + \log(x^2 + x^2 + 1) + e]} = -0.00086 \underbrace{- 100000000}_{\text{Penalty}} = - 1000000000.000086$$

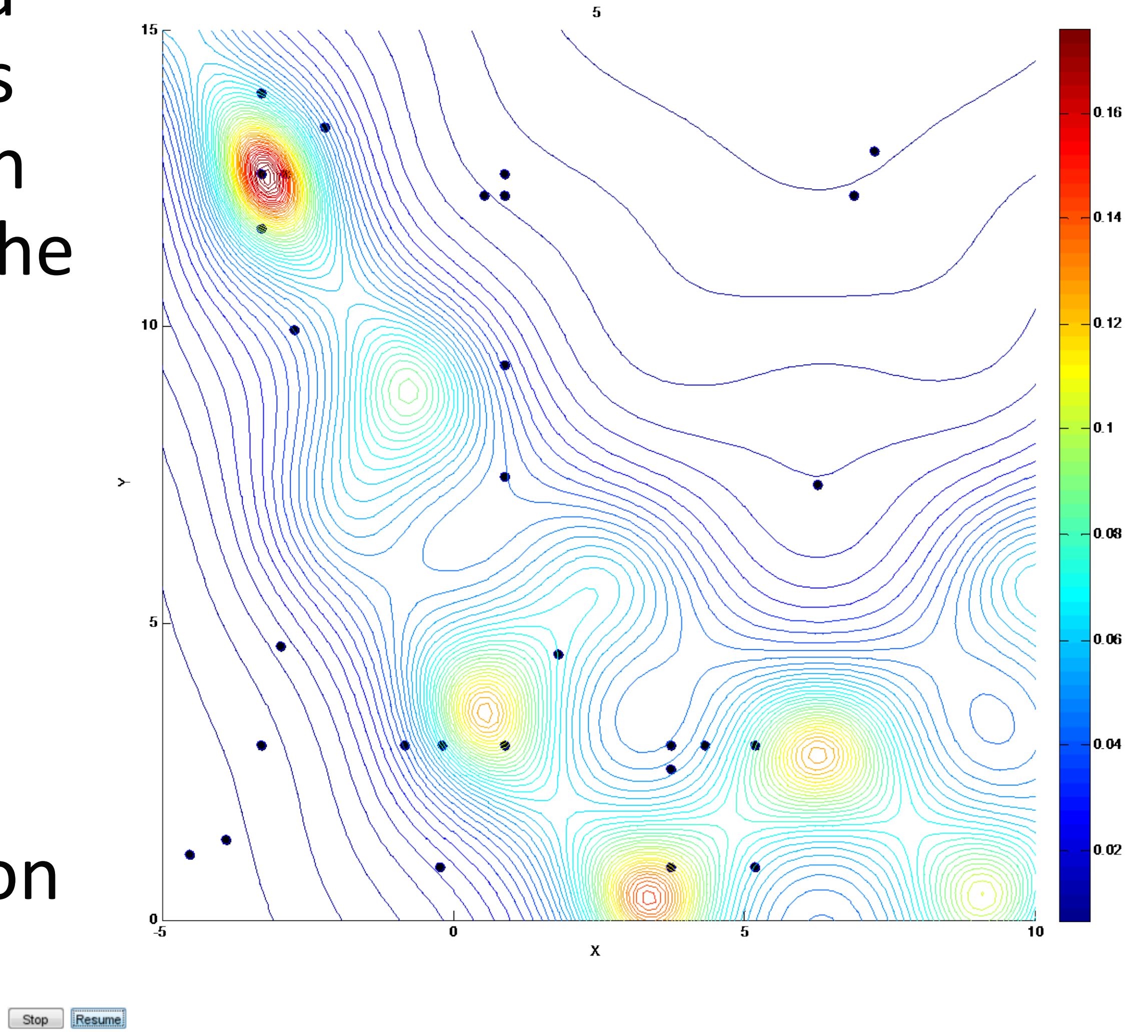
Population

- A set of individuals or solutions
- Normally has a fixed number of individuals
    - some formulation can have dynamic population sizes, that vary over the search.
- Initialization:
    - A set of individuals is randomly generated
    - Cover as much as possible the decision space

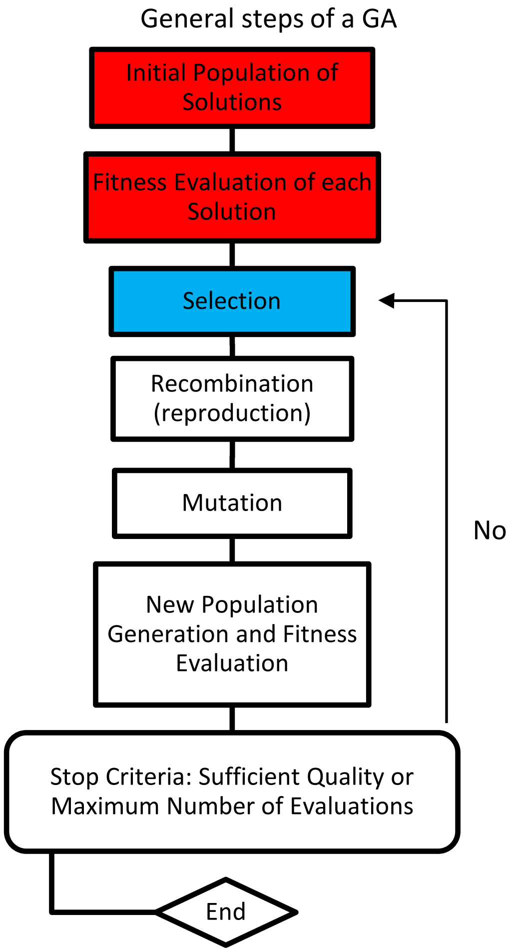


Generation

- Represents new a population that is generated at each iteration during the search
- At each new generation, new individuals are created by the operators Cross-Over and Mutation



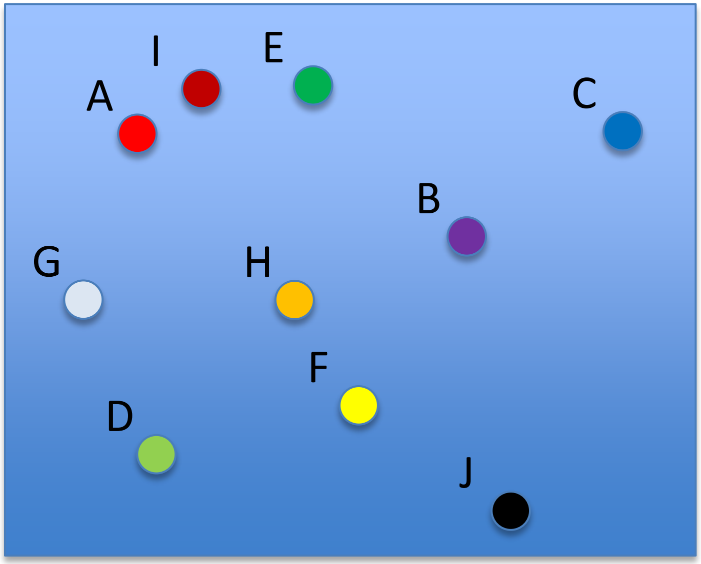
Main Steps of GA: Selection



- Purpose: to identify better solutions from prior populations and eliminate the least fittest
- Many different ways:
  - tournament selection, proportional selection, stochastic universal sampling, fitness scaling, rank-based proportional selection, etc.

Tournament Selection

- Pick 2 or more random solutions
- Select the best between the solutions selected



Generation “n”

x

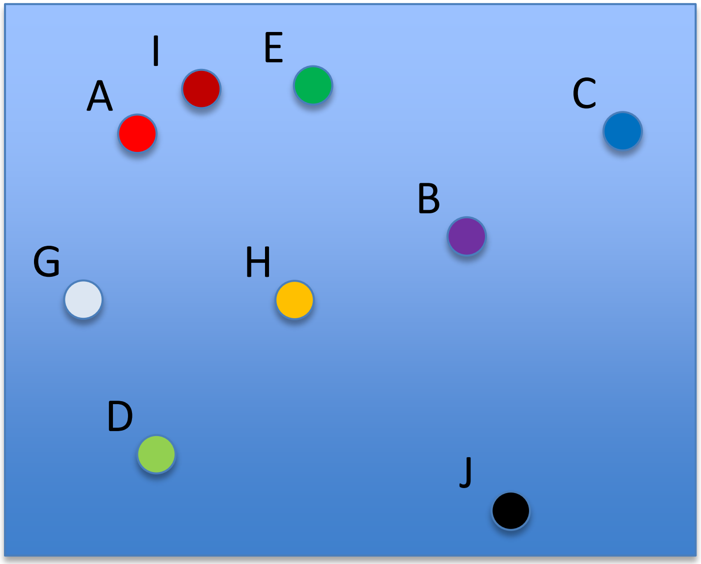
$z^I = 0.0429$

$z^F = 0.24$

Generation “n+1”

Tournament Selection

- Pick 2 or more random solutions
- Select the best between the solutions selected

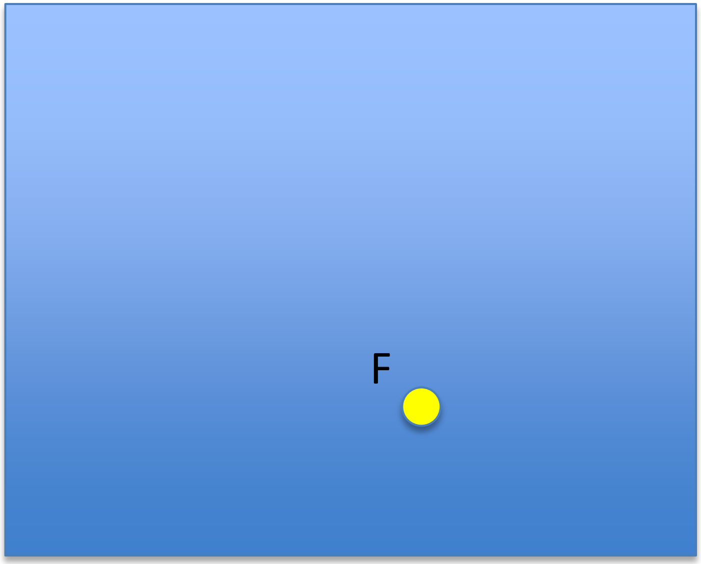


Generation “n”

x

$z^G = 0.2$

$z^J = 0.14$



Generation “n+1”

Tournament Selection

- Pick 2 or more random solutions
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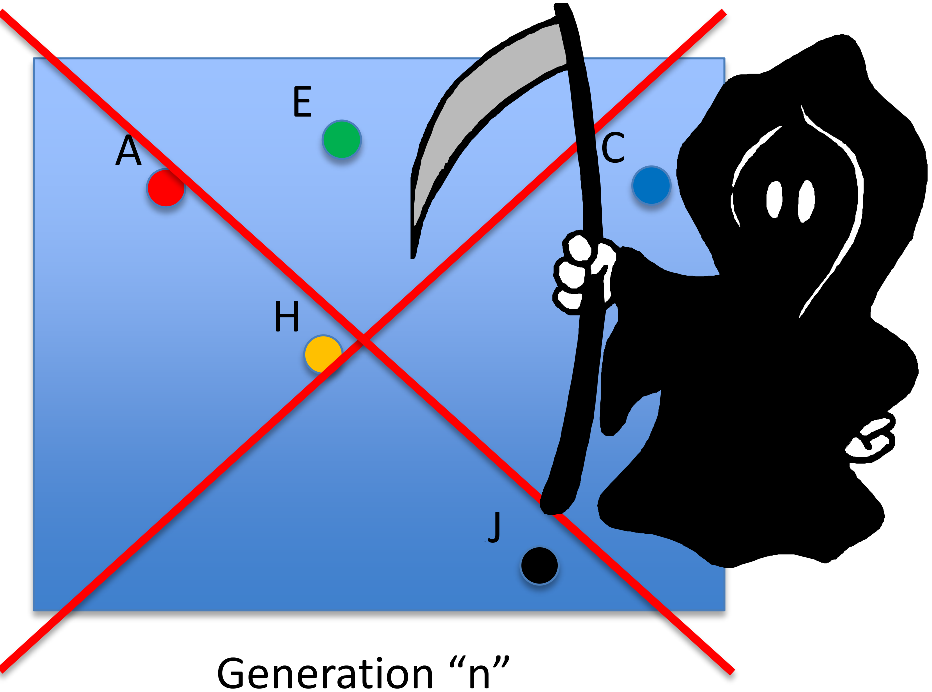
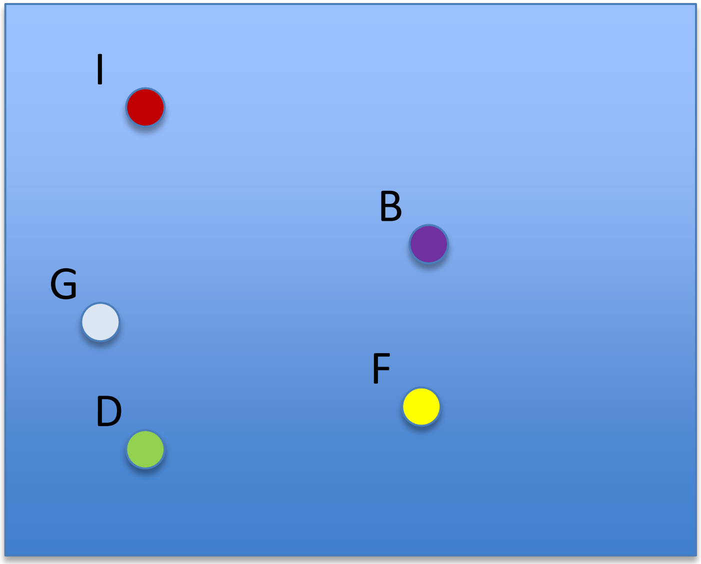
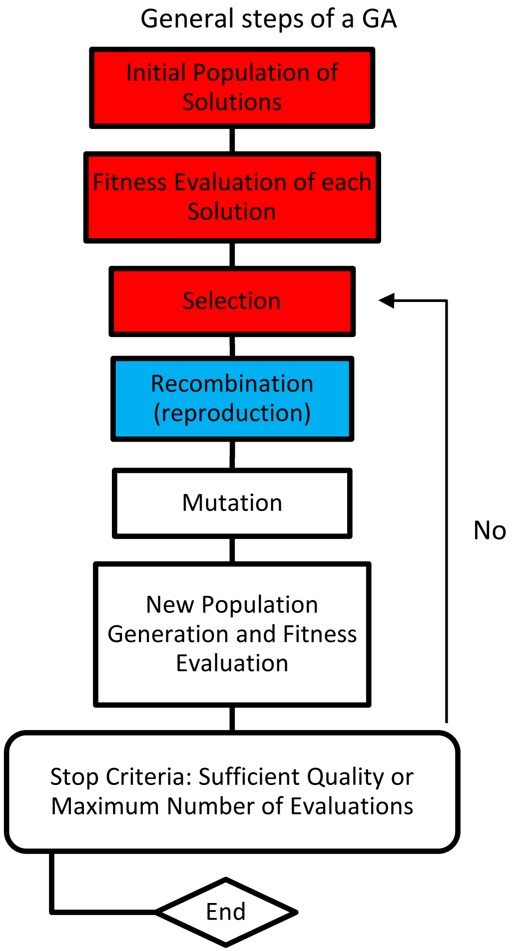


Generation “n”



Generation “n+1”

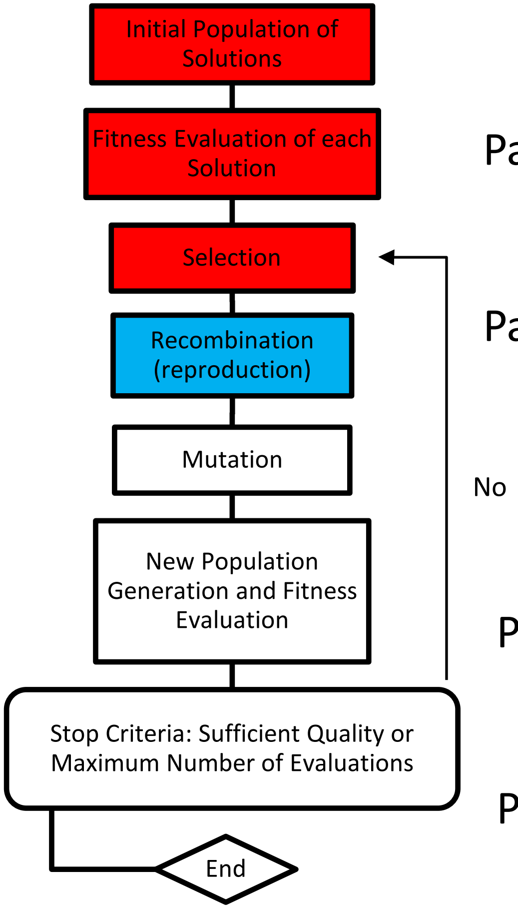
Main Steps of GA: Recombination



- Purpose: generate new solutions (children or offspring) by randomly combining characteristics of parent individuals
- Offspring not necessarily be better than parents, unless the parents transfers “building blocks”
  - Subset of Decision Variables that are related and produce good fitness value

Main Steps of GA: Recombination

General steps of a GA



Initial Population of Solutions

Fitness Evaluation of each Solution

Selection

Recombination (reproduction)

Mutation

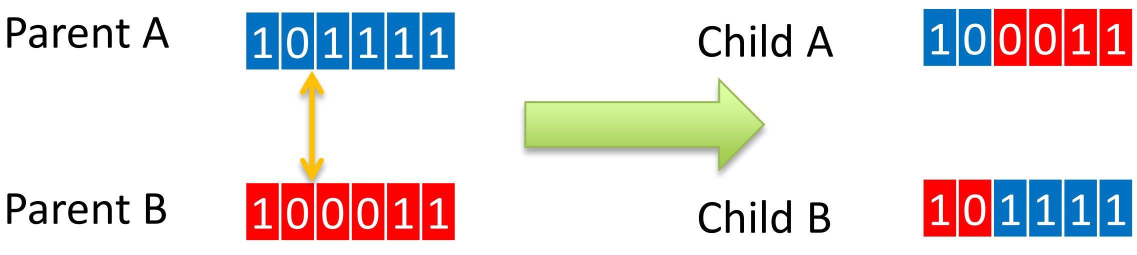
New Population Generation and Fitness Evaluation

Stop Criteria: Sufficient Quality or Maximum Number of Evaluations

No

End

- Single Point:



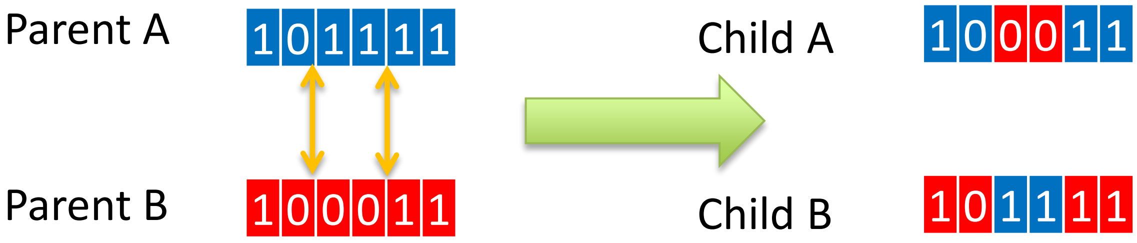
Parent A 1 0 1 1 1 1

Parent B 1 0 0 0 1 1

Child A 1 0 0 0 1 1

Child B 1 0 1 1 1 1

- Multi Point:



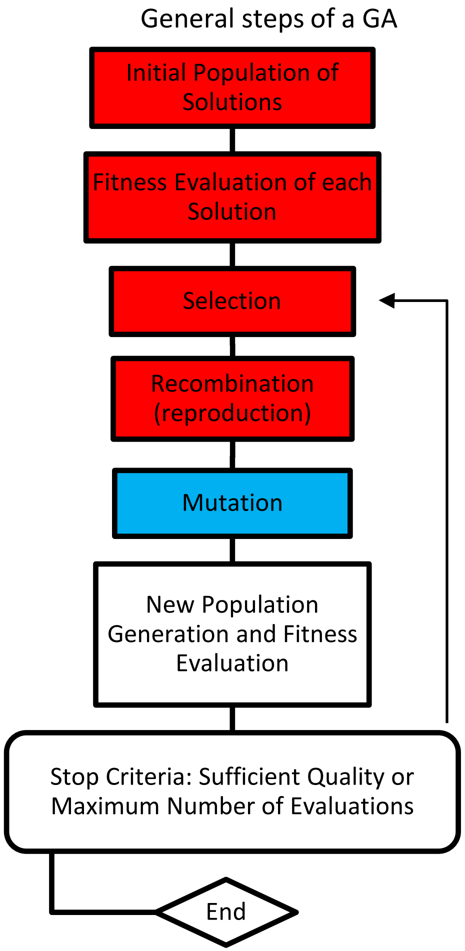
Parent A 1 0 1 1 1 1

Parent B 1 0 0 0 1 1

Child A 1 0 0 0 1 1

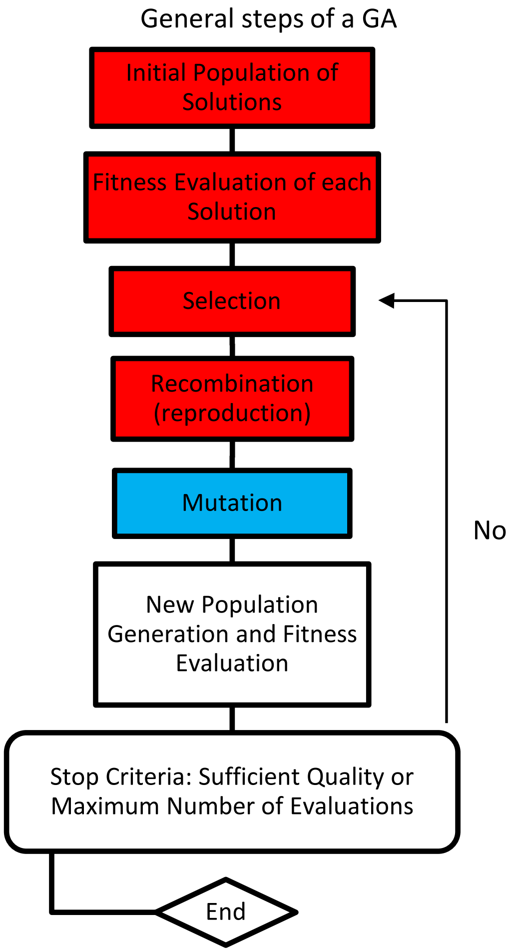
Child B 1 0 1 1 1 1

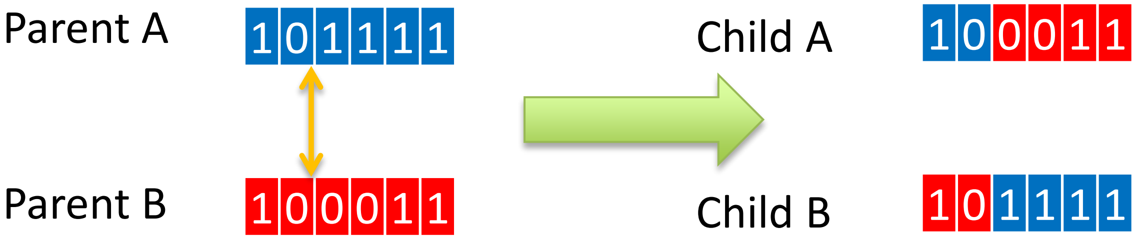
Main Steps of GA: Mutation



- Purpose: generate new solutions around the “good” solutions
- Allow the exploration of the decision space and avoid premature convergence
- Mutation Rate: represents the probability of genetic material being randomly altered

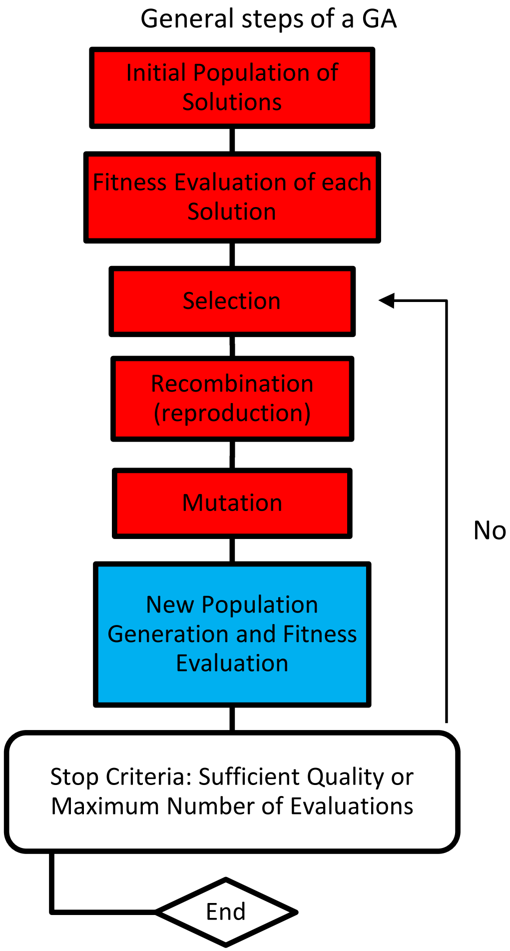
Main Steps of GA: Mutation





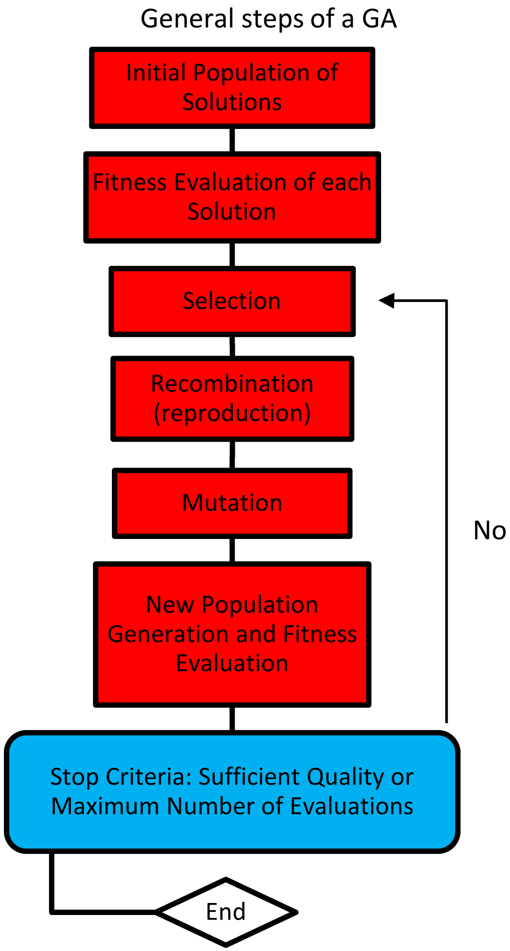
- Assume $P_m = 0.1$
- For each gene, a random number is generated
  - If random > 0.1 -> gene doesn’t change
  - If random <= 0.1 – flip gene

Main Steps of GA: Fitness Evaluation



- New solutions are evaluated

Main Steps of GA: Stop Criteria


General steps of a GA

Initial Population of Solutions

Fitness Evaluation of each Solution

Selection

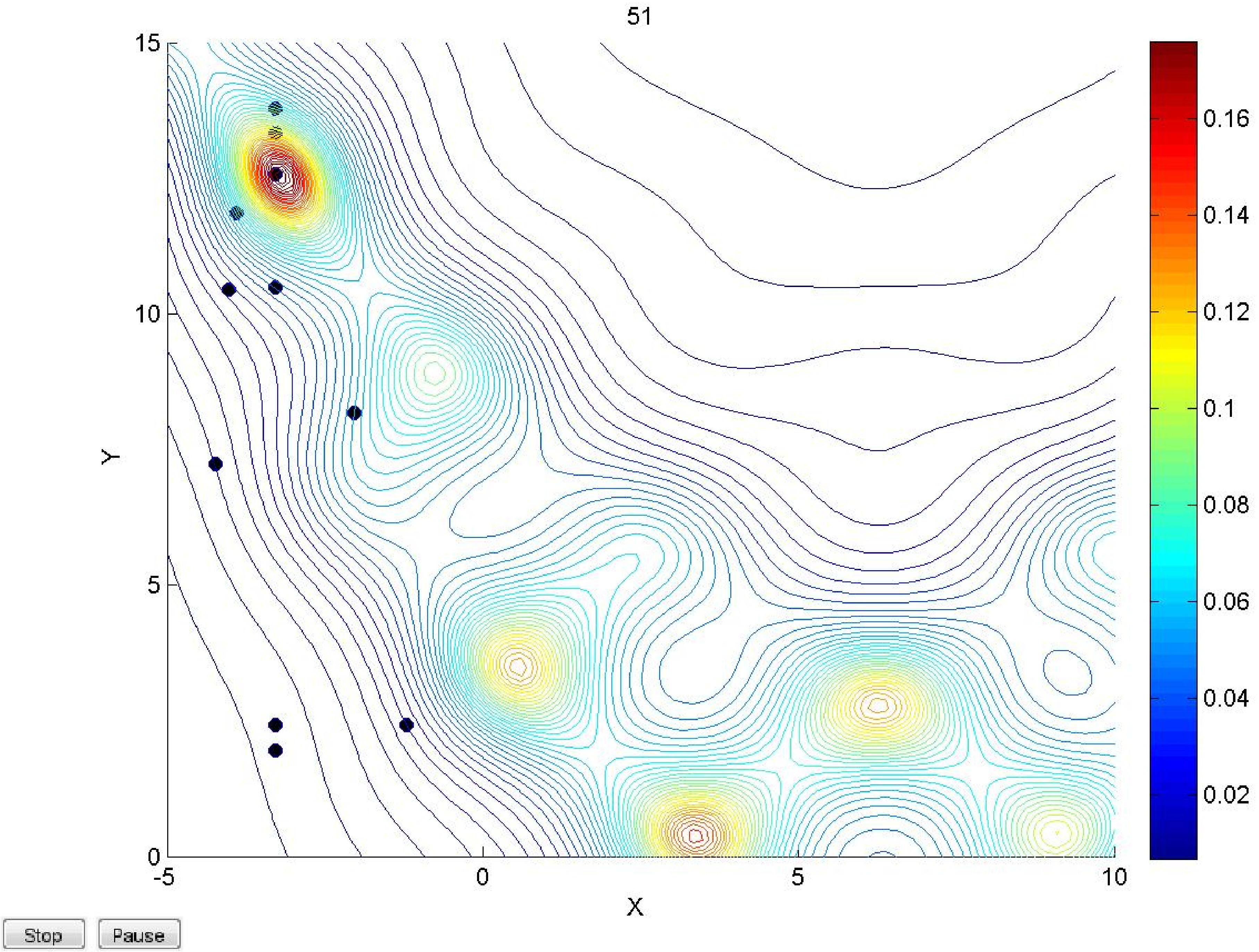
Recombination (reproduction)

Mutation

New Population Generation and Fitness Evaluation

Stop Criteria: Sufficient Quality or Maximum Number of Evaluations

- Check if solutions achieved sufficient quality and stop the search
  - Fitness values of best solutions don’t improve
  - Maximum number of generations is achieved
- It is problem specific:
  - It depends on the fitness evaluation time
  - How good the final solution should be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15
10
5
0
-5
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10
X
Y
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0.12
0.1
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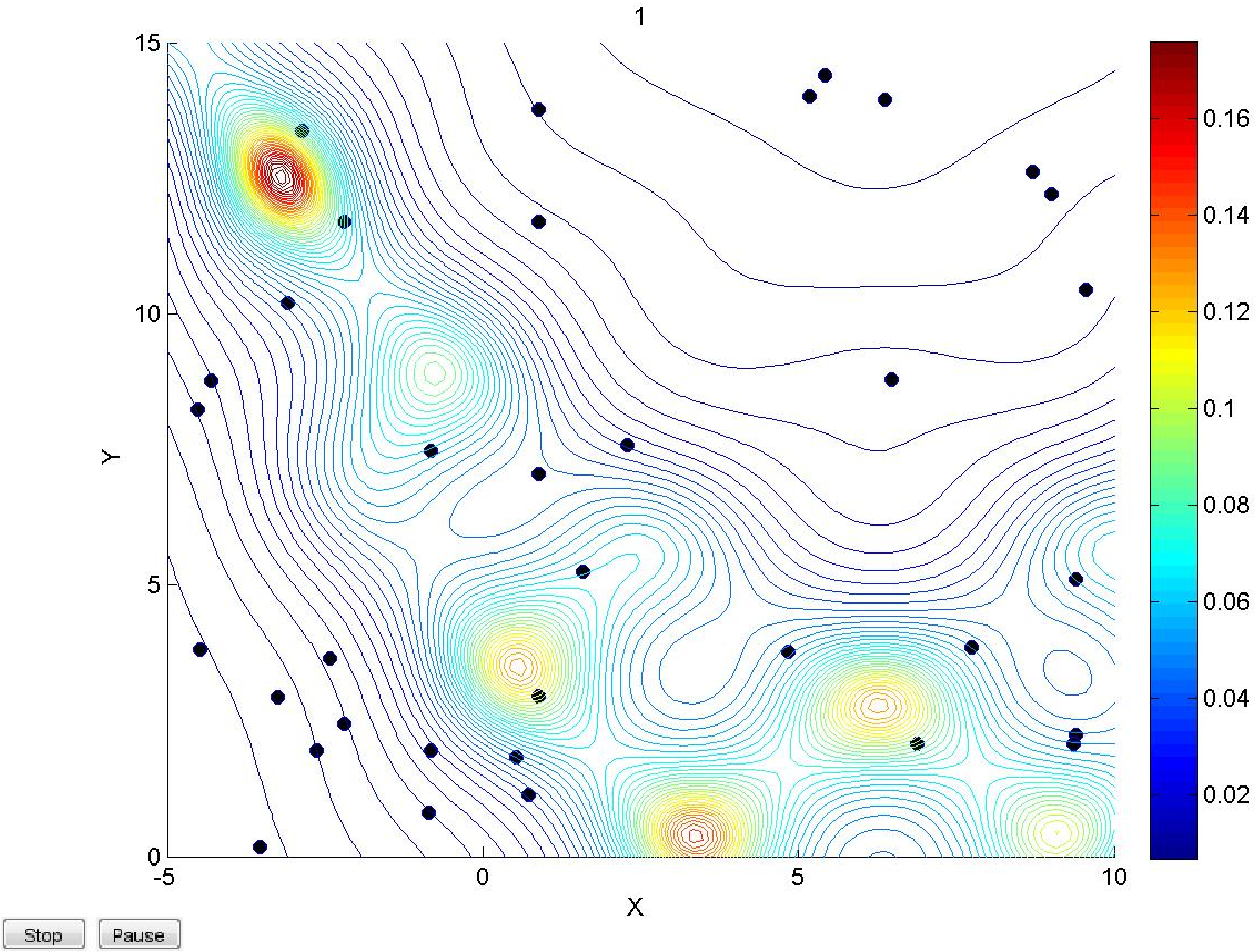
0.06
0.04
0.02
Stop
Pause


1
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Stop
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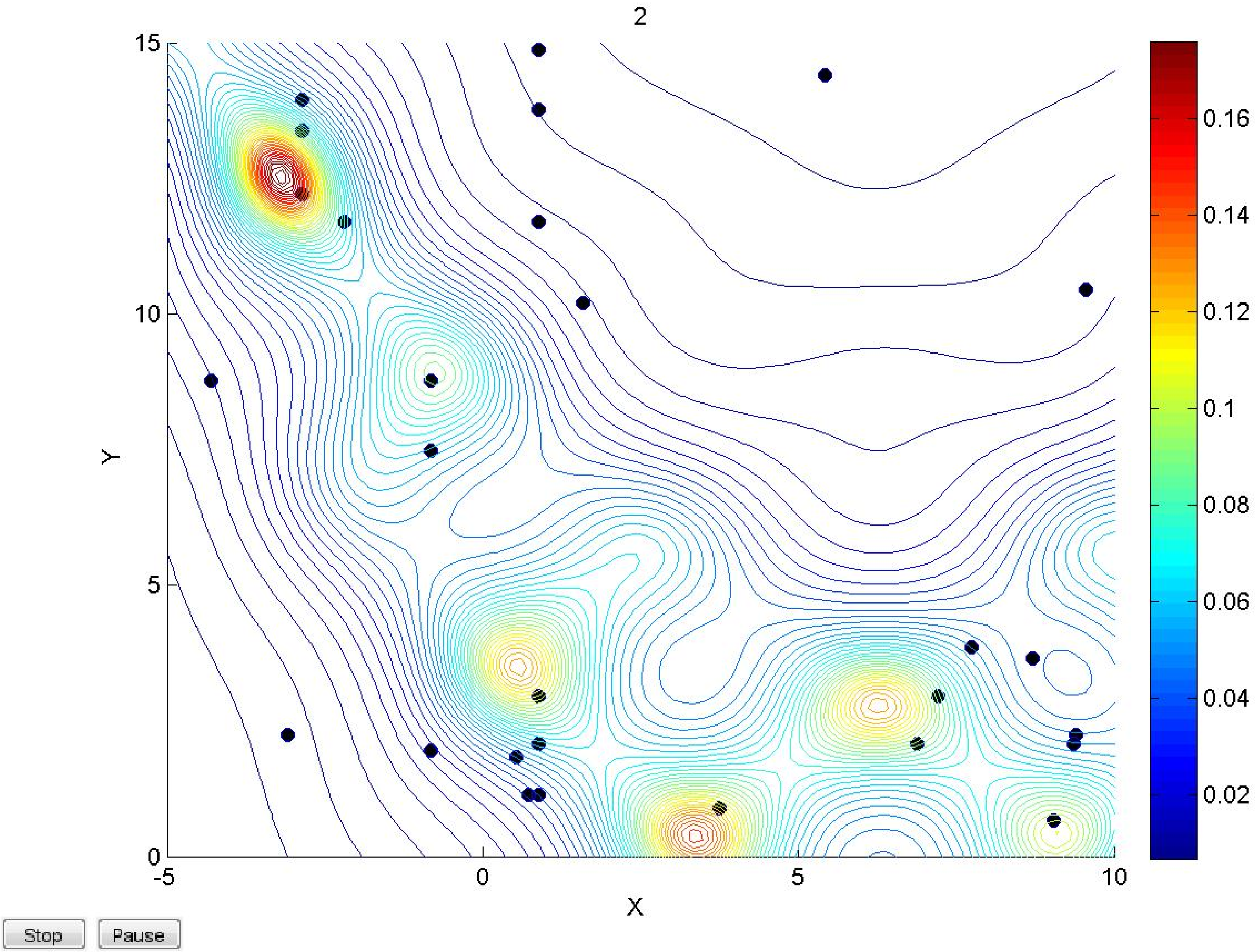
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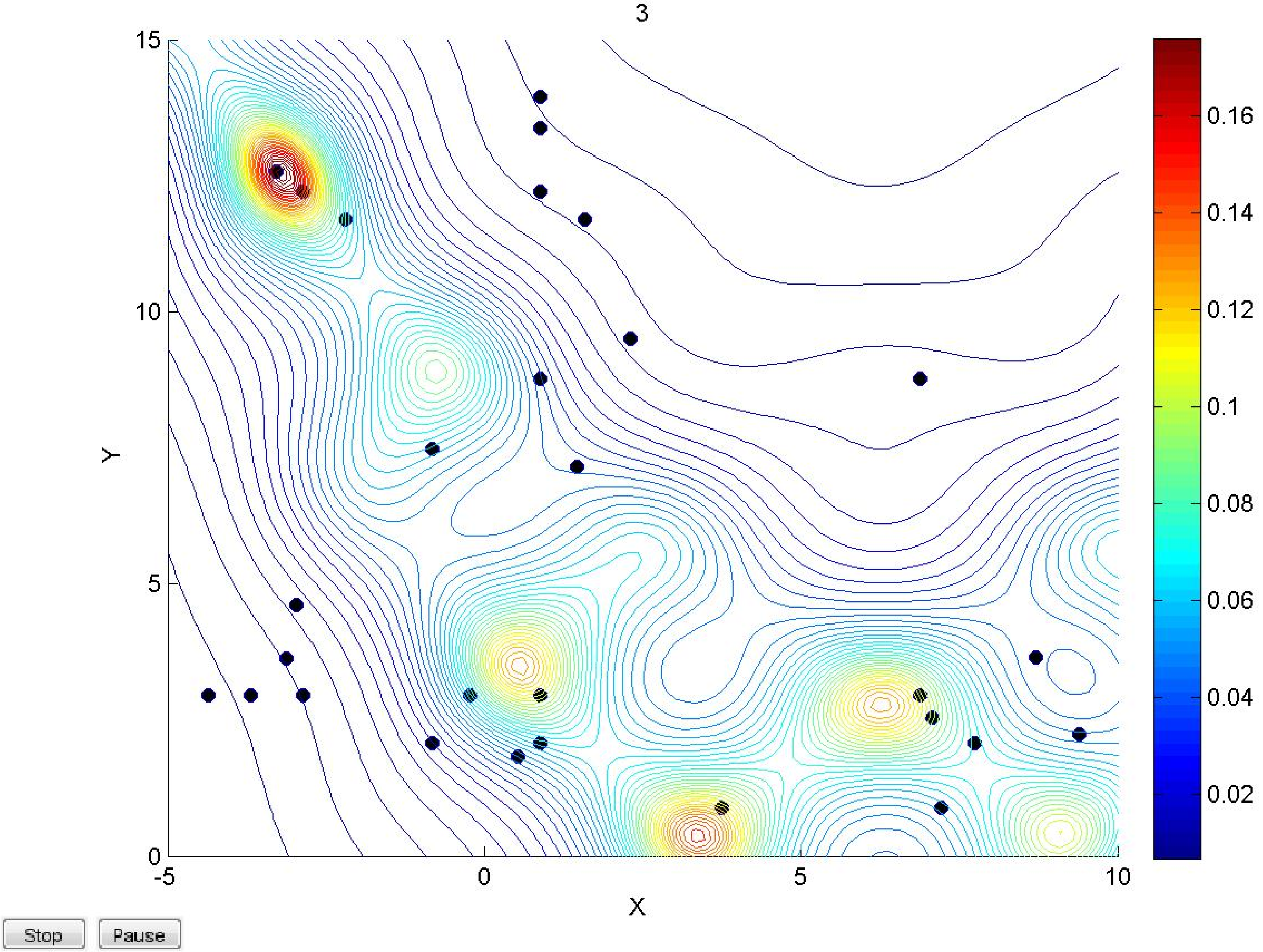
Stop
Pause


3
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10
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0
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10
X
Y
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0.1
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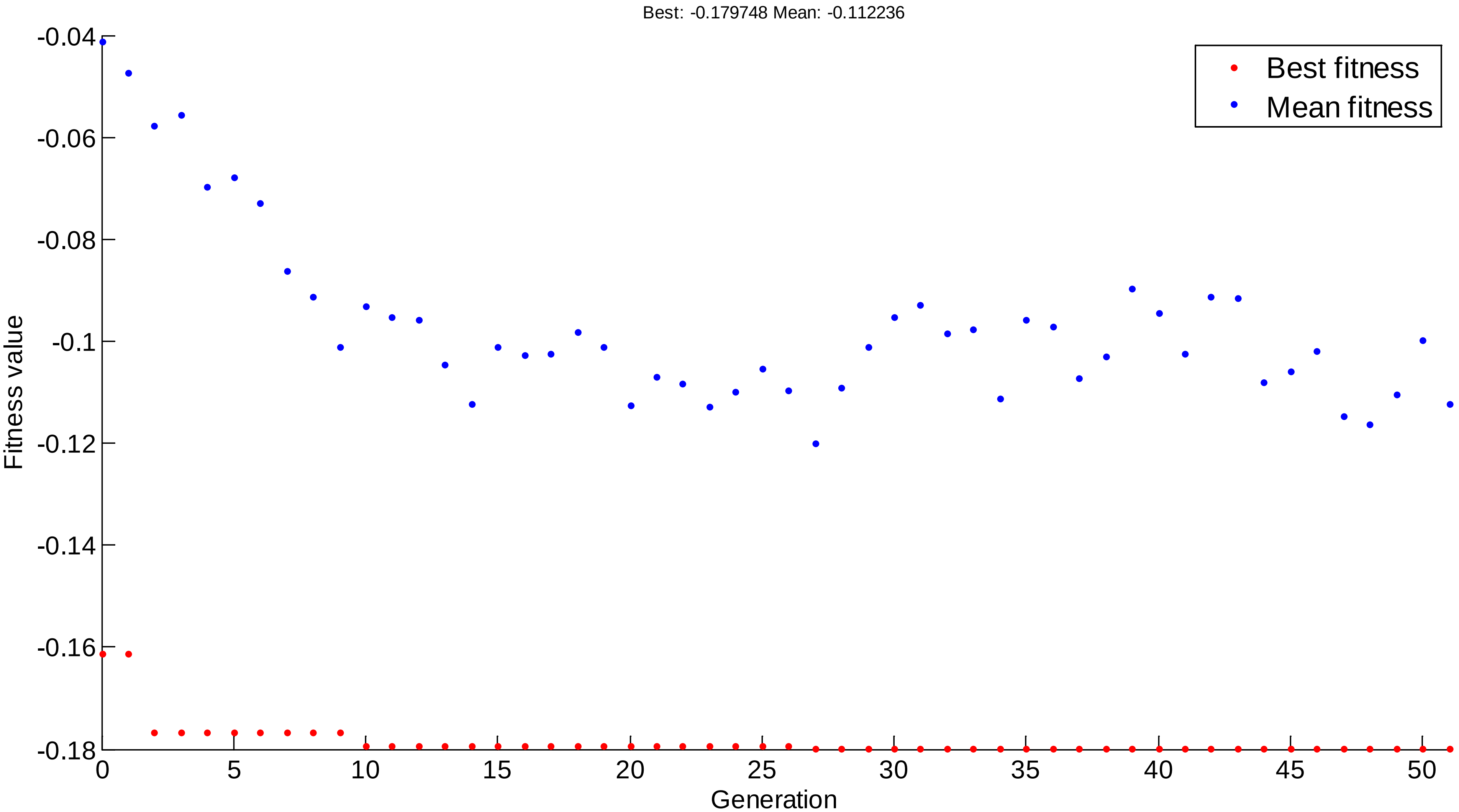
0.06
0.04
0.02
Stop
Pause

Convergence Plot



Exploitation vs Exploration

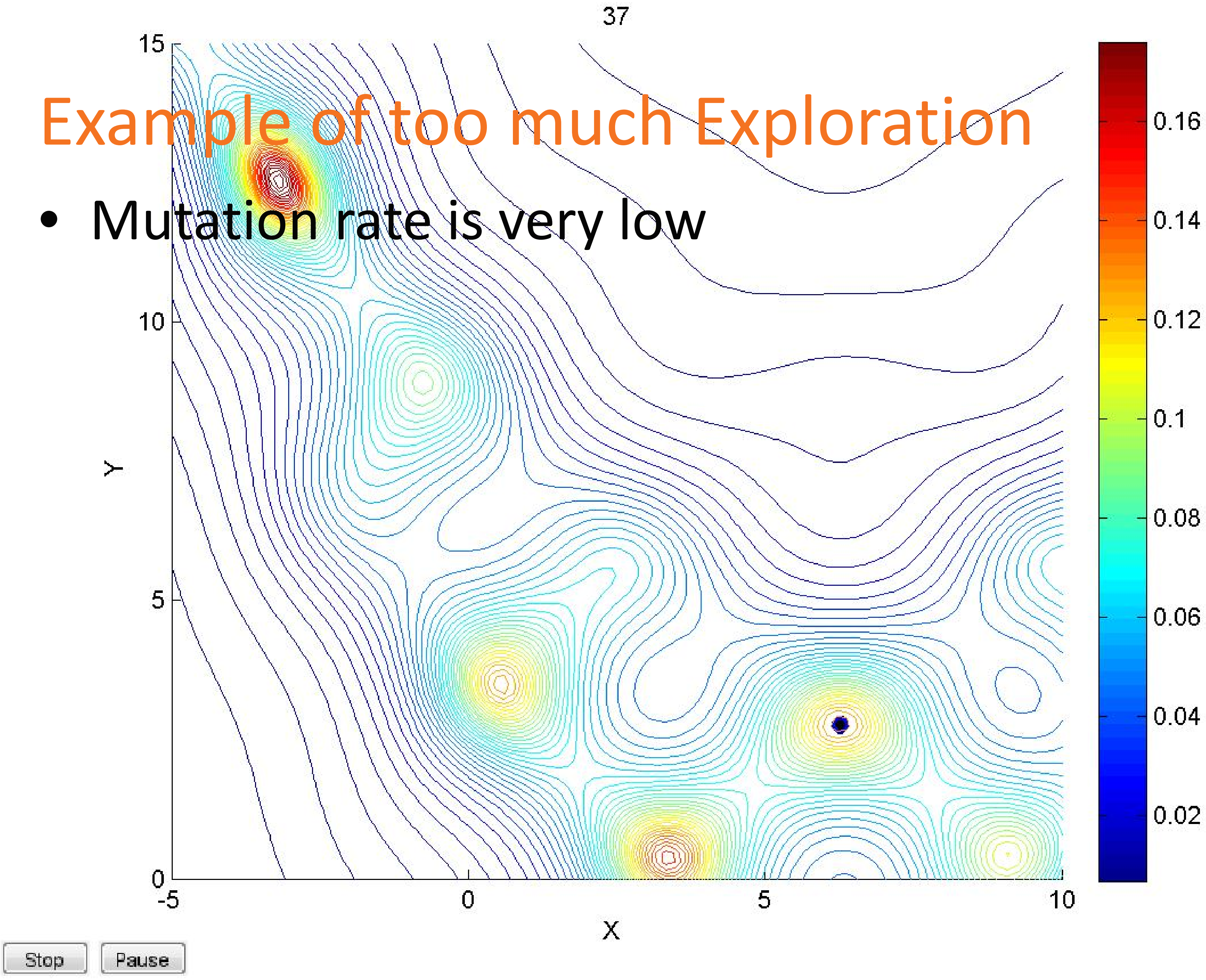
- Local Search
  - Focus in a small region of the decision space

- Random Search
  - Explores the entire decision space

- If there is too much exploitation, it is possible the algorithm gets trapped in a local optima
- If there is too much exploration, the algorithm might not converge

Example of too much Exploration

- Mutation rate is very low

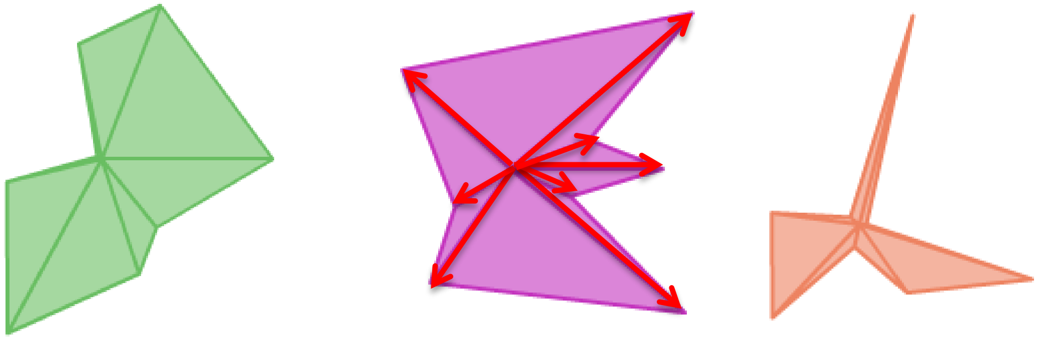


BoxCar 2D (http://boxcar2d.com/index.html or http://rednuht.org/genetic_cars_2/)

- Program learns to build a car using a genetic algorithm.
- It starts with a population of 20 randomly generated shapes with wheels and runs each one to see how far it goes.
- The cars that go the furthest reproduce to produce offspring for the next generation.
- The offspring combine the traits of the parents to hopefully produce better cars.

BoxCar 2D

- Decisions Variables:
  - Each car is a set of 8 randomly chosen vectors: direction and magnitude.
  - All the vectors radiate from a central point (0,0) and are connected with triangles



  - For each wheel it randomly chooses a vertex to put the axle on

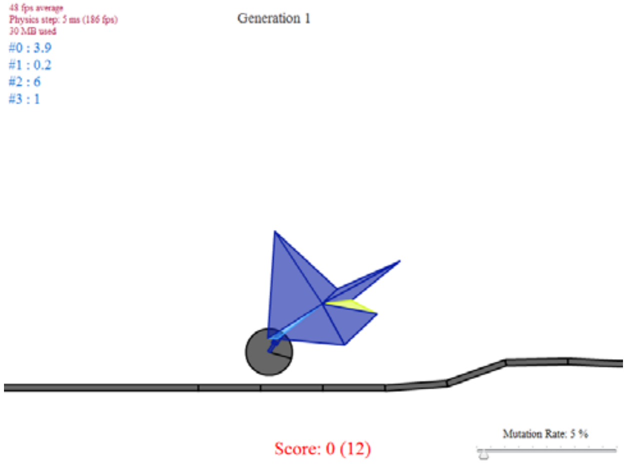
BoxCar 2D - Chromosome: Representing the Solution

- Each chromosome/car has 16 + 3 * 2 = 22 variables, each represented as a real number (or integer) with varying ranges.

Cart Angle$_0$	Cart Mag$_0$	Cart Angle$_1$	Cart Mag$_1$	…	Cart Angle$_7$	Cart Mag$_7$	WheelVertex$_0$	Axle Angle$_0$	Wheel Radius$_0$	Wheel Vertex$_1$	Axle Angle$_1$	Wheel Radius$_1$

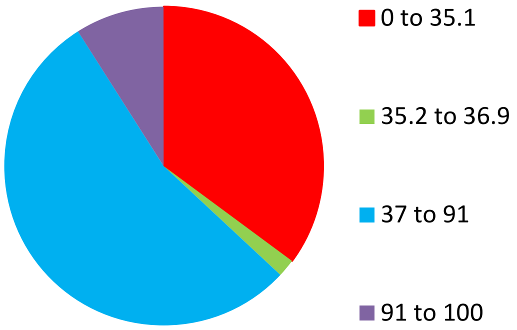
BoxCar 2D - Selection

- At the end of each generation, pairs of parents have to be selected to produce offspring for the next generation.
- Roulette-Wheel Selection
  - it finds the sum of all fitness scores for that generation and divides each score by the sum to get the probability.
  - Summing the probabilities creates a wheel we can select from
  - Picking a random number from 0-100 to pick a car for mating



```
48 fps average
Physics step: 5 ms (186 fps)
30 MB used
#0 : 3.9
#1 : 0.2
#2 : 6
#3 : 1
```

Score	Probability	Roulette wheel piece
3.9	35.1%	0 to 35.1
0.2	1.8%	35.2 to 36.9
6.0	54.1%	37 to 91
1.0	9.0%	91 to 100



BoxCar 2D - Selection

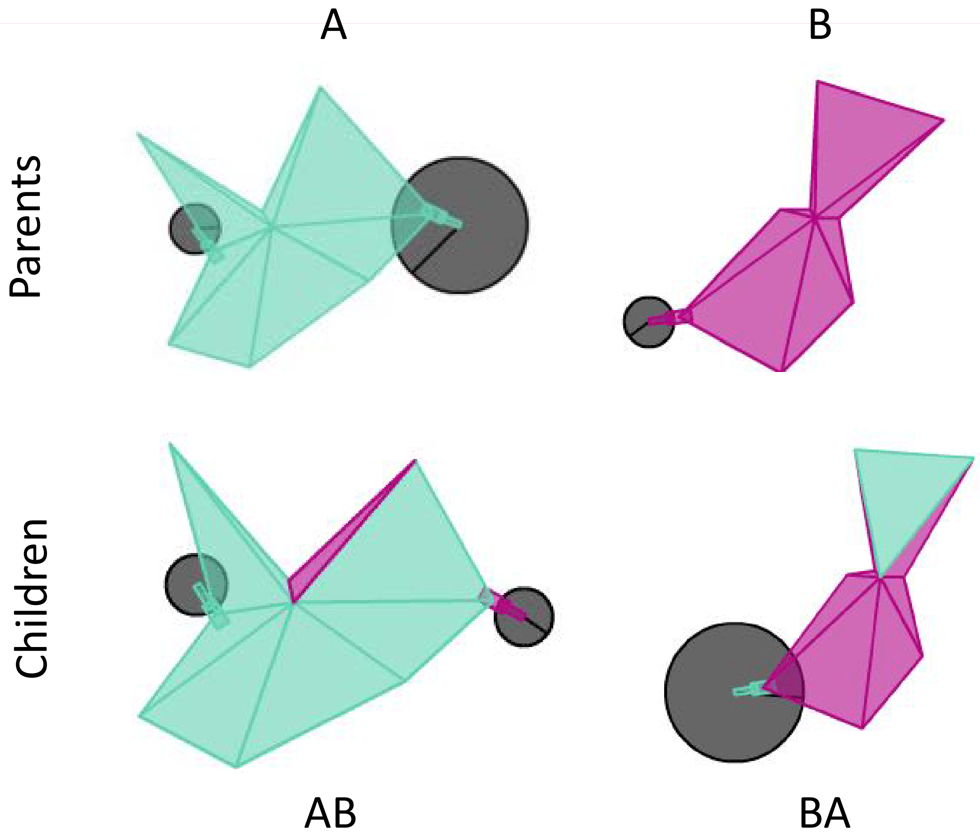
- Tournament Selection
  - *for each car A

```
*for each car A
    *pick a random car B (excluding A)
    *highest score of A and B wins tournament
    *put winner in mating pool
*randomly pick pairs from mating pool for crossover
```

BoxCar 2D - Crossover

Car	Angle0	Mag0	Angle1	Mag1	…	…	…	…	…	…	…	…	…	…	…	…	Wheel Vertex 0	AxleAngle0	Wheel Radius 0	Wheel Vertex 1	AxleAngle1	Wheel Radius 1
A	0.769	2.614	0.584	0.319	0.278	2.883	0.666	1.13	0.305	2.752	0.376	2.507	0.814	1.963	0.392	2.872	3	5.284	0.434	7	2.625	1.191
B	0.535	2.682	0.732	2.256	0.422	0.149	0.676	0.578	0.709	2.774	0.592	2.623	0.519	1.531	0.924	0.404	-1	0.704	0.122	4	0.167	0.409

- two point crossover



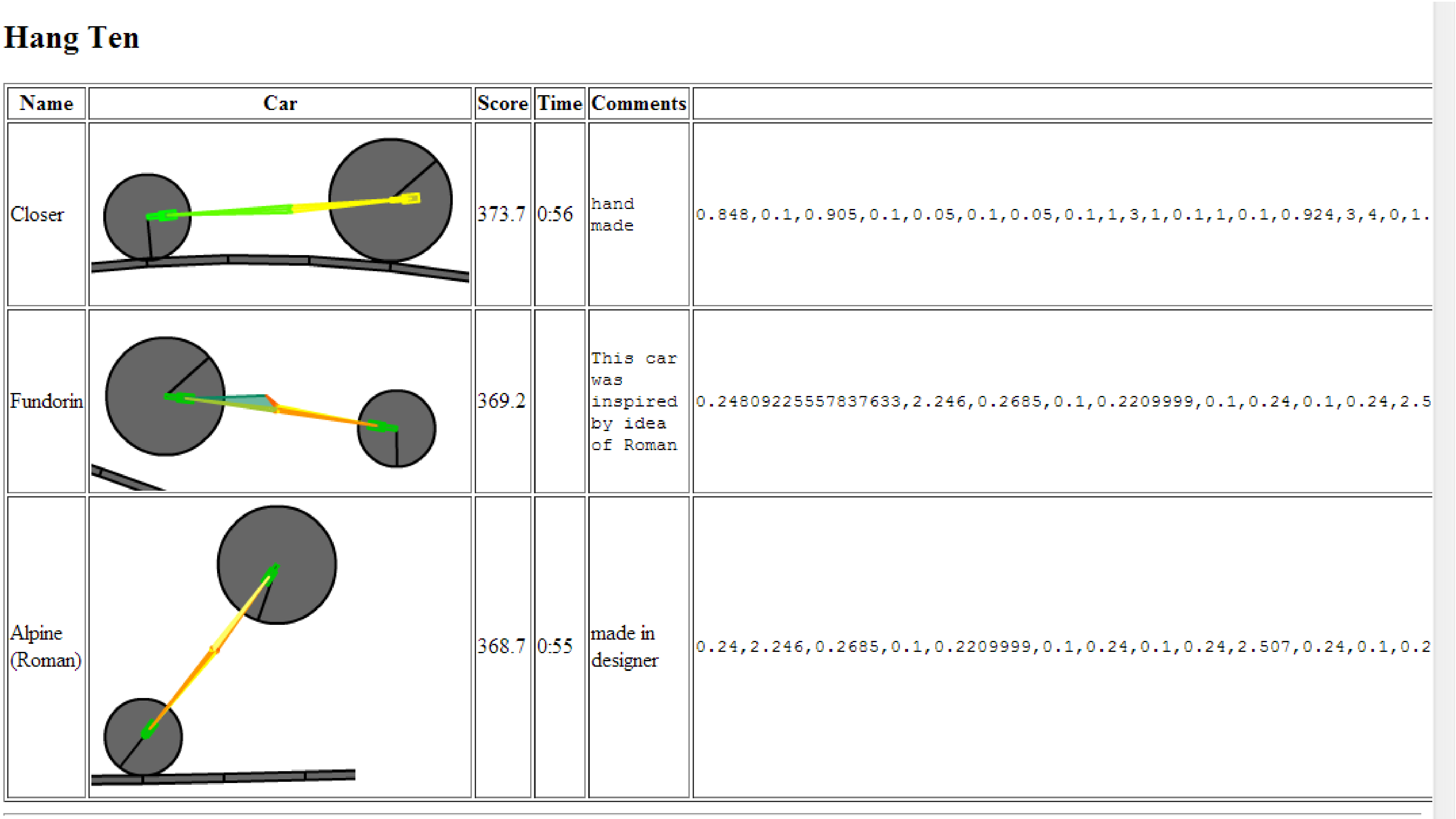
BoxCar 2D - Mutation

- Each generation the chromosomes go through mutation.
- This means there is a probability that each aspect of the car (or variable in the chromosome) will change
- When a variable mutates, a new value is randomly chosen in the desired range.

Car	Angle0	Mag0	…	…	…	…	…	…	…	…	Angle5	Mag5	…	…	…	…	Wheel Vertex 0	AxleAngle0	WheelRadius0	WheelVertex1	AxleAngle1	WheelRadius1
AB	0.535	2.682	0.584	0.319	0.278	2.883	0.666	1.13	0.305	2.752	0.376	2.507	0.814	1.963	0.392	2.872	3	5.284	0.434	7	2.625	0.409
AB$_m$	0.535	2.682	0.584	0.319	0.278	2.883	0.666	1.13	0.305	2.752	0.376	0.940	0.814	1.963	0.392	2.872	4	5.284	0.434	7	2.625	0.409

- By definition at 100% mutation rate, every variable is chosen randomly each generation and no information is retained.

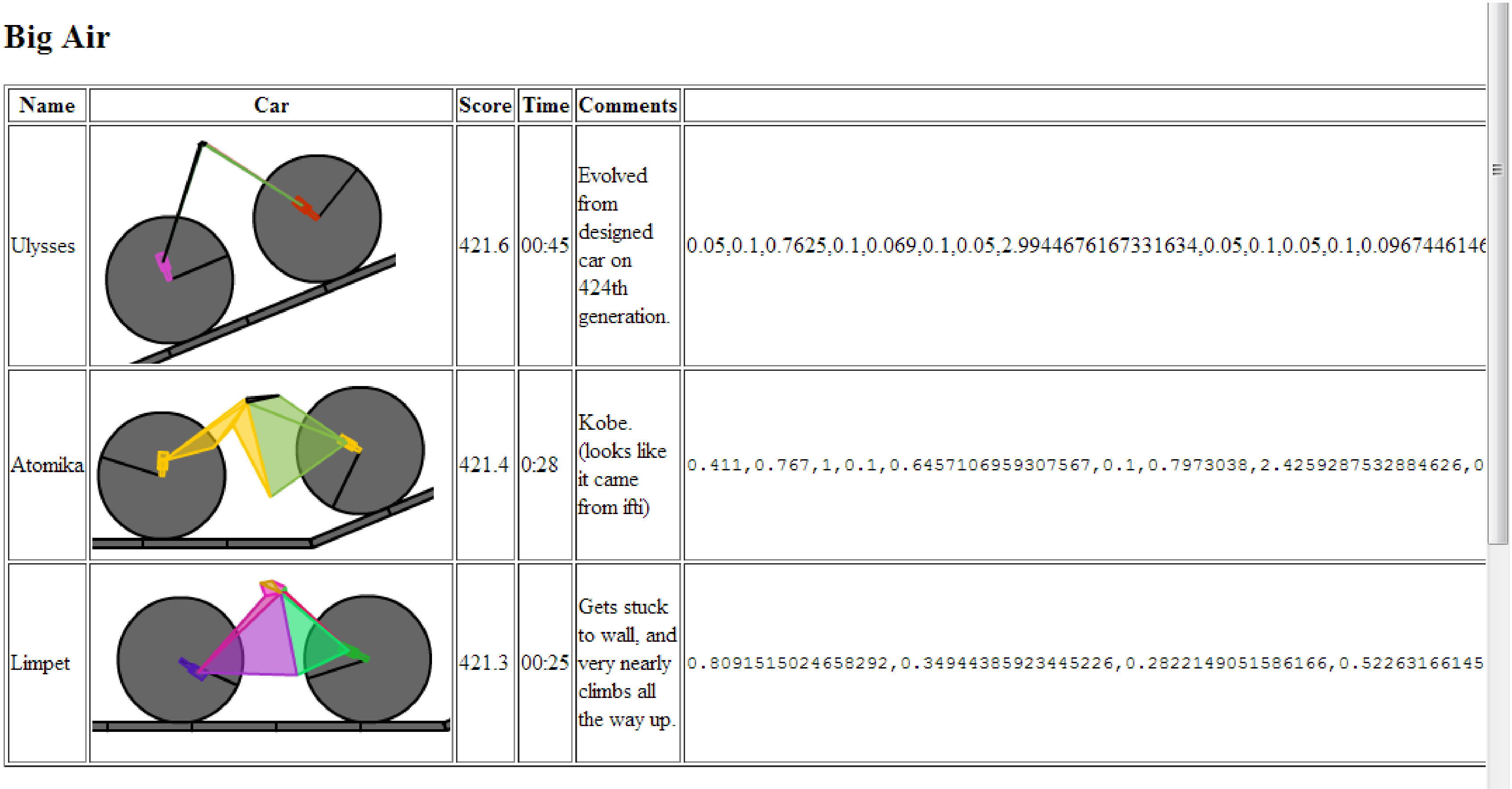
Box 2D Competition



Hang Ten

Name	Car	Score	Time	Comments	
Closer		373.7	0:56	hand made	0.848,0.1,0.905,0.1,0.05,0.1,0.05,0.1,1,3,1,0.1,1,0.1,0.924,3,4,0,1.
Fundorin		369.2		This car was inspired by idea of Roman	0.24809225557837633,2.246,0.2685,0.1,0.2209999,0.1,0.24,0.1,0.24,2.5
Alpine (Roman)		368.7	0:55	made in designer	0.24,2.246,0.2685,0.1,0.2209999,0.1,0.24,0.1,0.24,2.507,0.24,0.1,0.2

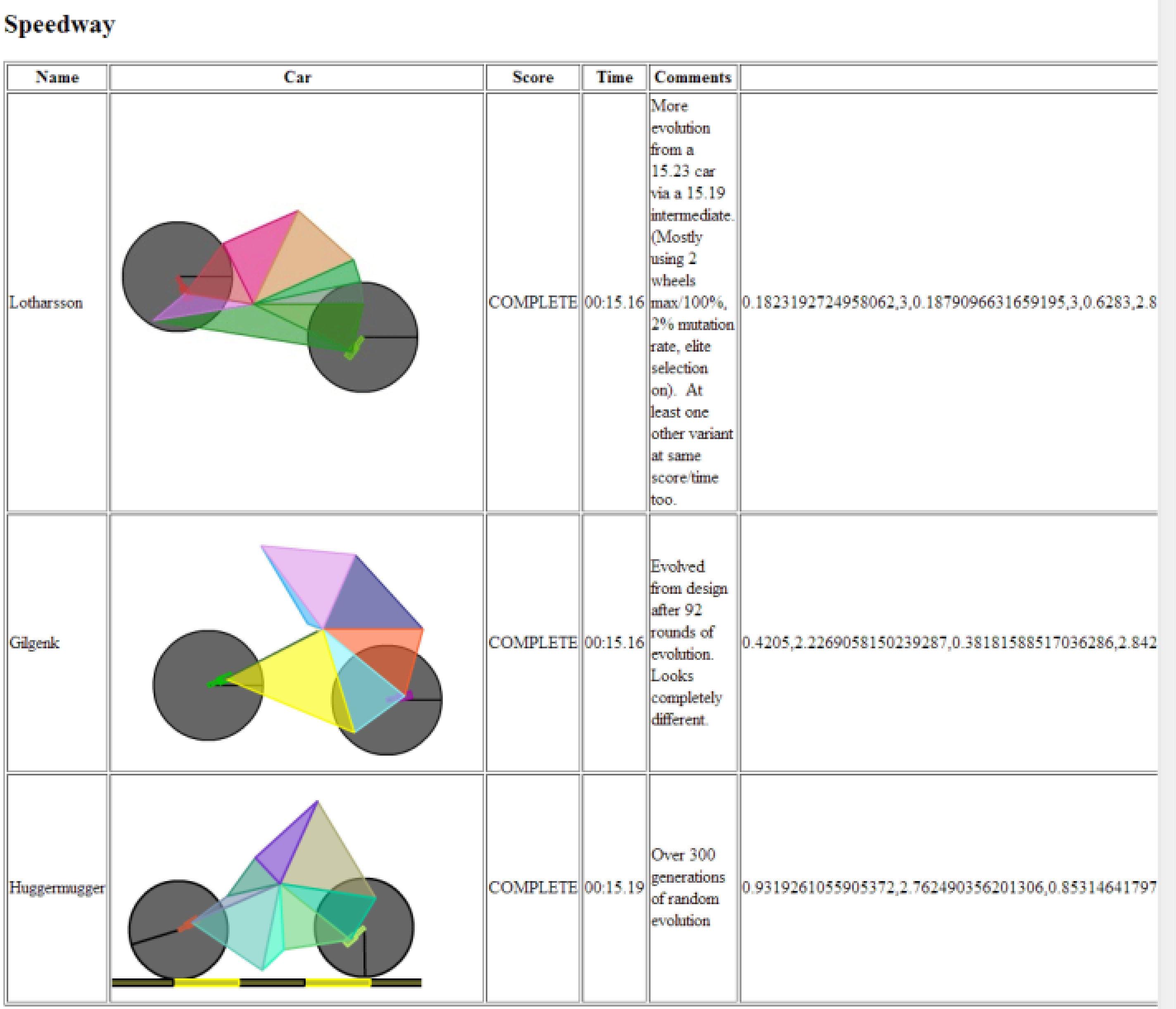
Box 2D Competition



Big Air

Name	Car	Score	Time	Comments	
Ulysses		421.6	00:45	Evolved from designed car on 424th generation.	0.05,0.1,0.7625,0.1,0.069,0.1,0.05,2.9944676167331634,0.05,0.1,0.05,0.1,0.0967446146
Atomika		421.4	0:28	Kobe. (looks like it came from ifti)	0.411,0.767,1,0.1,0.6457106959307567,0.1,0.7973038,2.4259287532884626,0
Limpet		421.3	00:25	Gets stuck to wall, and very nearly climbs all the way up.	0.8091515024658292,0.3494438592344522б,0.2822149051586166,0.52263166145

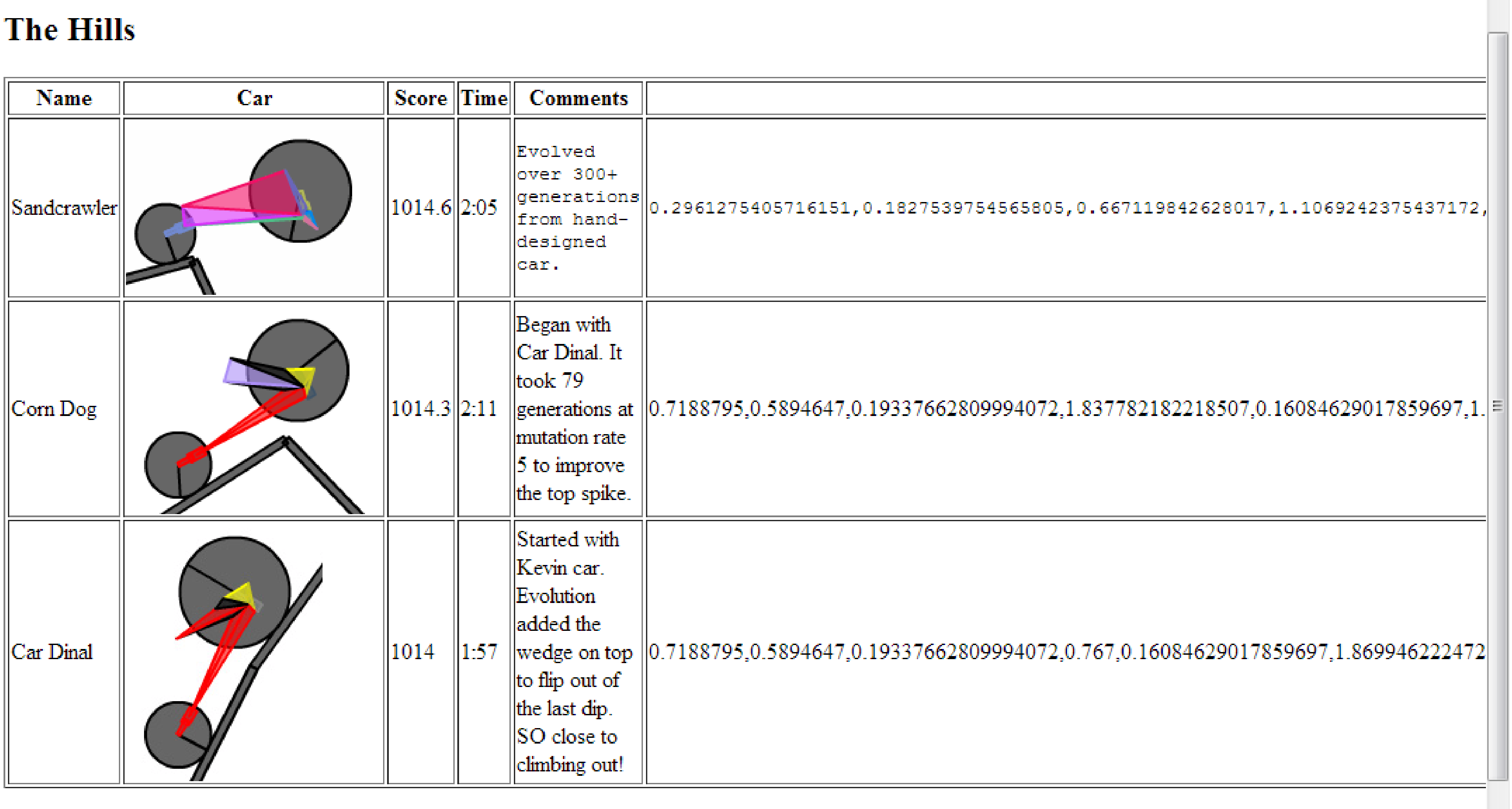
Box 2D Competition



Speedway

Name	Car	Score	Time	Comments	
Lotharsson		COMPLETE	00:15.16	More evolution from a 15.23 car via a 15.19 intermediate. (Mostly using 2 wheels max/100%, 2% mutation rate, elite selection on). At least one other variant at same score/time too.	0.1823192724958062,3,0.1879096631659195,3,0.6283,2.8
Gilgenk		COMPLETE	00:15.16	Evolved from design after 92 rounds of evolution. Looks completely different.	0.4205,2.2269058150239287,0.38181588517036286,2.842
Huggermugger		COMPLETE	00:15.19	Over 300 generations of random evolution	0.9319261055905372,2.762490356201306,0.85314641797

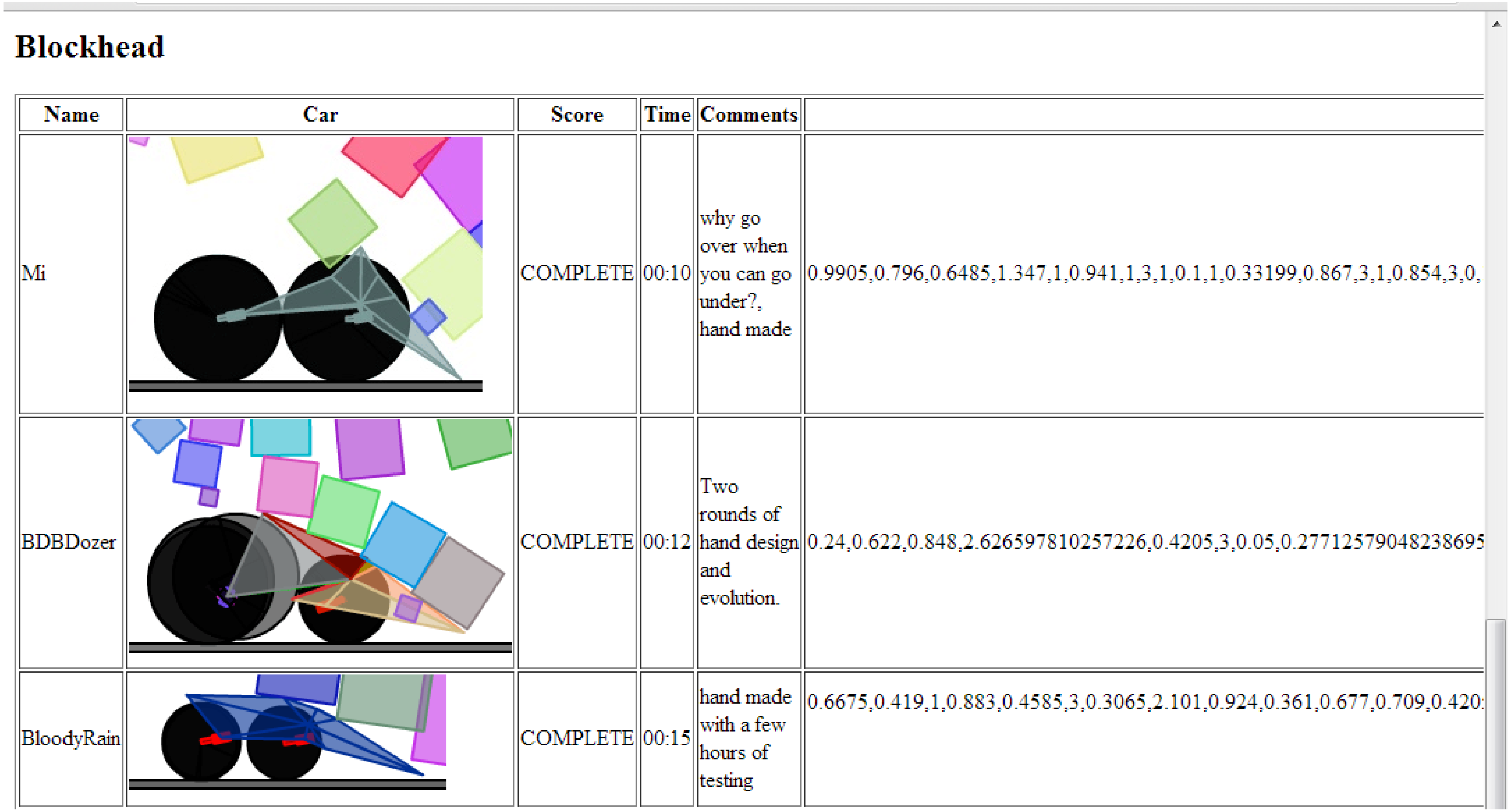
Box 2D Competition



The Hills

Name	Car	Score	Time	Comments	
Sandcrawler		1014.6	2:05	Evolved over 300+ generations from hand-designed car.	0.2961275405716151,0.1827539754565805,0.667119842628017,1.1069242375437172,
Corn Dog		1014.3	2:11	Began with Car Dinal. It took 79 generations at mutation rate 5 to improve the top spike.	0.7188795,0.5894647,0.19337662809994072,1.837782182218507,0.1608462901785969 7,1.
Car Dinal		1014	1:57	Started with Kevin car. Evolution added the wedge on top to flip out of the last dip. SO close to climbing out!	0.7188795,0.5894647,0.19337662809994072,0.767,0.16084629017859697,1.869946222472

Box 2D Competition



Blockhead

Name	Car	Score	Time	Comments	
Mi		COMPLETE	00:10	why go over when you can go under?, hand made	0.9905,0.796,0.6485,1.347,1,0.941,1,3,1,0.1,1,0.33199,0.867,3,1,0.854,3,0,
BDBDozer		COMPLETE	00:12	Two rounds of hand design and evolution.	0.24,0.622,0.848,2.626597810257226,0.4205,3,0.05,0.2771257904823869
BloodyRain		COMPLETE	00:15	hand made with a few hours of testing	0.6675,0.419,1,0.883,0.4585,3,0.3065,2.101,0.924,0.361,0.677,0.709,0.420

Box 2D Competition

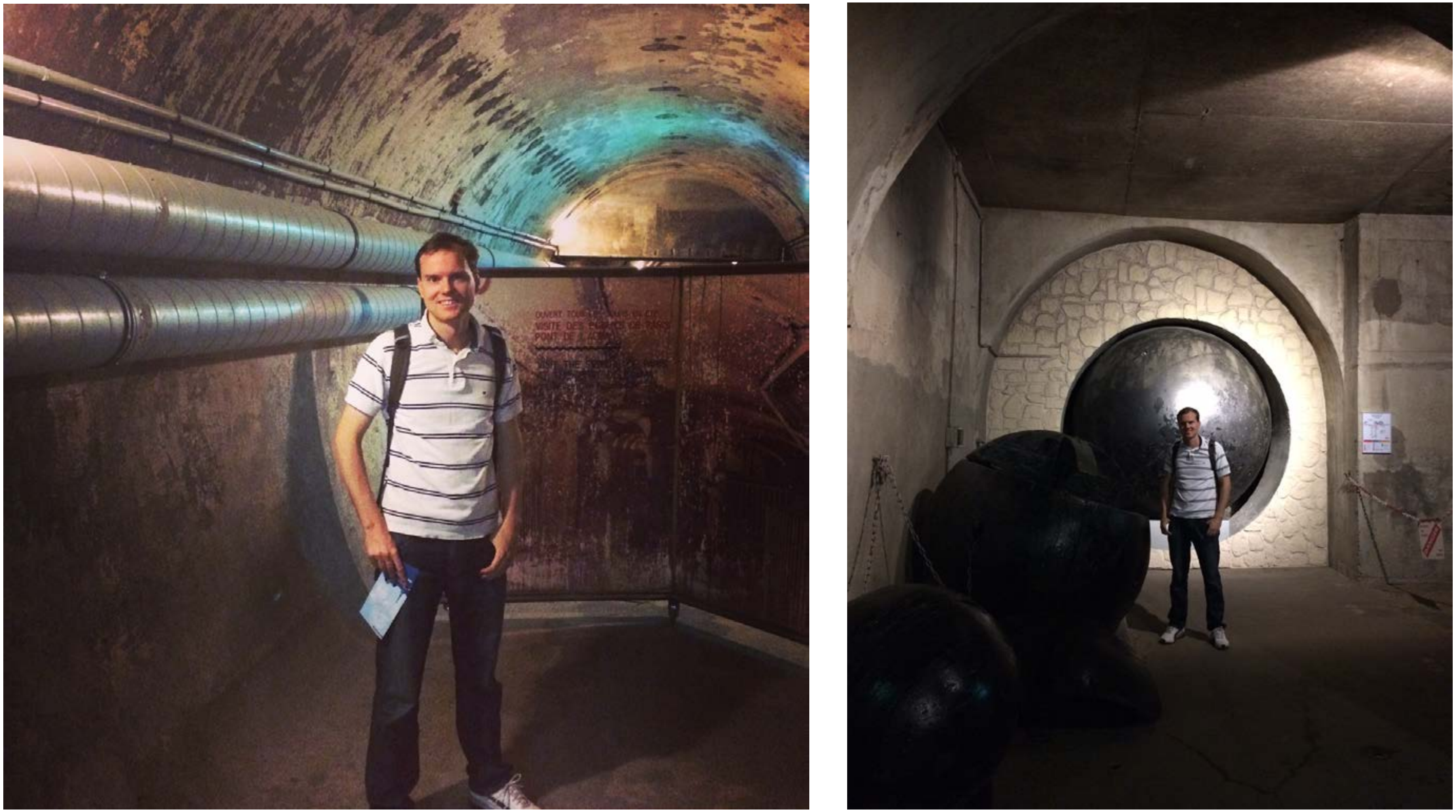
- “It's really interesting to see how the different levels breed different traits, and how the best cars are a mix of hand-made and evolved designs, or both”
- Because of the random nature of Evolutionary Algorithms, optimality can not be ensured.
- Because of the nature of the search, that explores and exploits the large portions of the decision space, local optima traps can be avoided.

Evolution Art: Mona Lisa Evolution

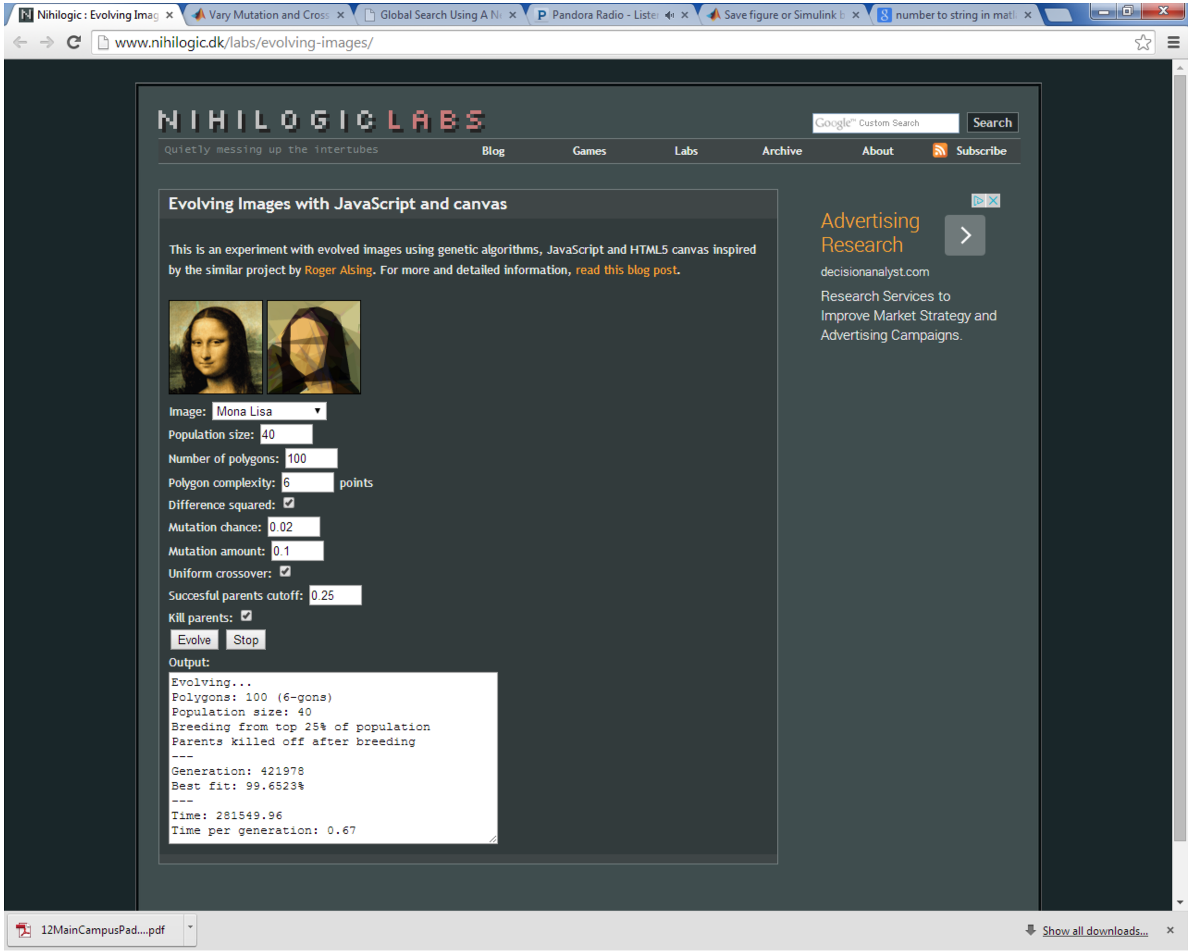
How to paint a replica of the Mona Lisa using semi transparent polygons?

What is the best touristic attraction in Paris?

- Sewers Museum of Paris



Evolution Art: Mona Lisa Evolution



Evolving Images with JavaScript and canvas

This is an experiment with evolved images using genetic algorithms, JavaScript and HTML5 canvas inspired by the similar project by Roger Alsing. For more and detailed information, read this blog post.

Image: Mona Lisa
Population size: 40
Number of polygons: 100
Polygon complexity: 6 points
Difference squared: ☑
Mutation chance: 0.02
Mutation amount: 0.1
Uniform crossover: ☑
Succesful parents cutoff: 0.25
Kill parents: ☑

Evolve Stop

Output:

```
Evolving...
Polygons: 100 (6-gons)
Population size: 40
Breeding from top 25% of population
Parents killed off after breeding
---
Generation: 421978
Best fit: 99.6523%
---
Time: 281549.96
Time per generation: 0.67
```

http://www.nihilogic.dk/labs/evolving-images/

What problems can be solved using Evolutionary Algorithms?

Accute Issues

- Immediate response

DEVELOPMENT OF AN OPTIMIZATION FRAMEWORK FOR SANITARY SEWER OVERFLOW REDUCTION

Chronicle Issues

- Recurring or prolonged

USE OF MULTIOBJECTIVE EVOLUTIONARY ALGORITHM OPTIMIZATION FOR LOW IMPACT DEVELOPMENT PLACEMENT

Emerging Issues

- Recurring or prolonged

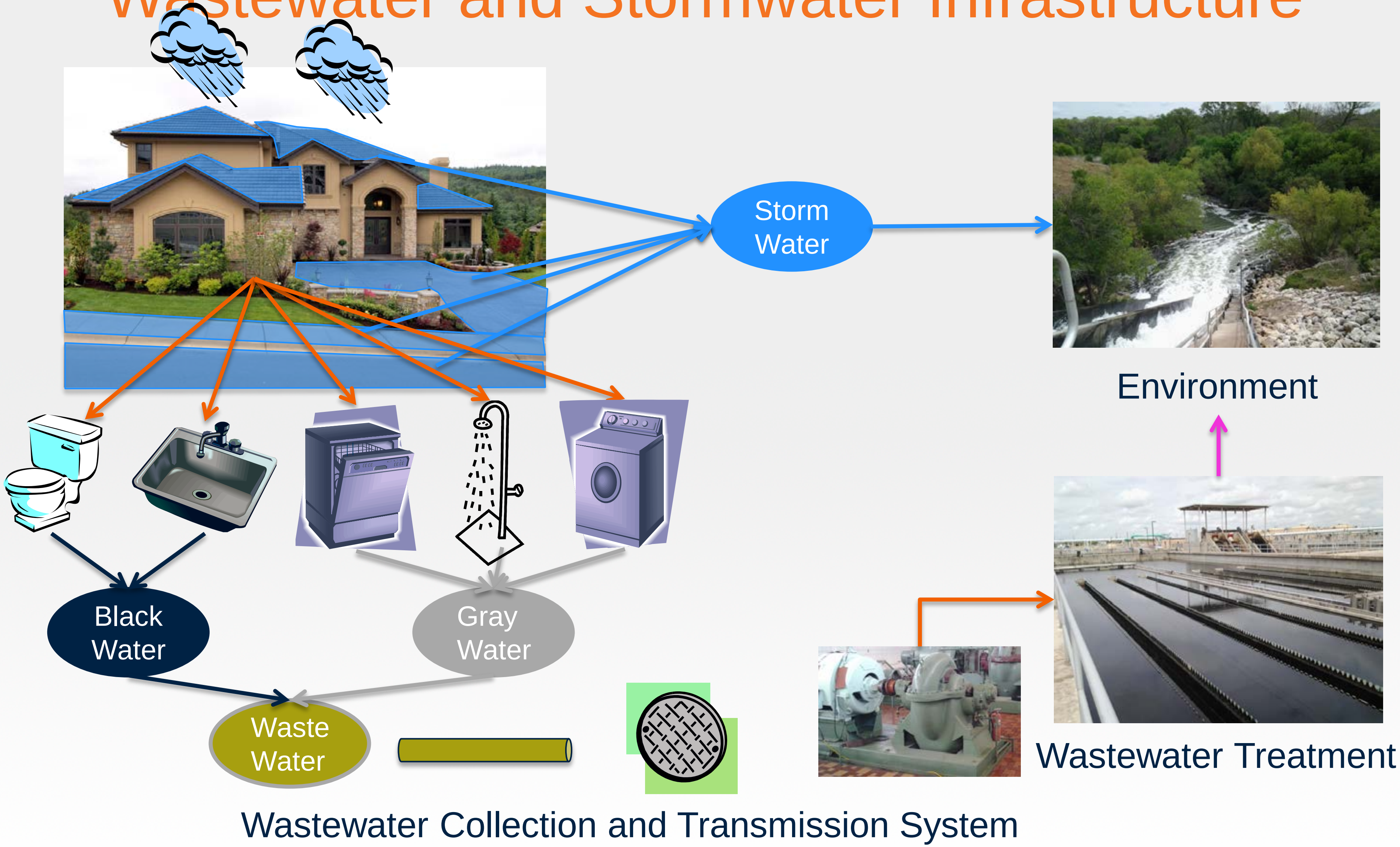
MULTIOBJECTIVE EVOLUTIONARY OPTIMIZATION OF ADAPTIVE DEMAND MANAGEMENT STRATEGIES FOR AN URBAN WATER RESOURCE SYSTEM

Sanitary Sewer Overflows

- SSOs are unpermitted and unintentional discharges of untreated sanitary sewage prior to arriving at the wastewater treatment plant.
- The EPA estimates an occurrence of 23,000 to 75,000 SSOs in the U.S. annually.

ASCE. (2000). "Protocols for Identifying Sanitary Sewer Overflows ", ASCE/EPA Cooperative Agreement # CX 826097-01-0, 146.

Wastewater and Stormwater Infrastructure



Storm Water

Environment

Black Water

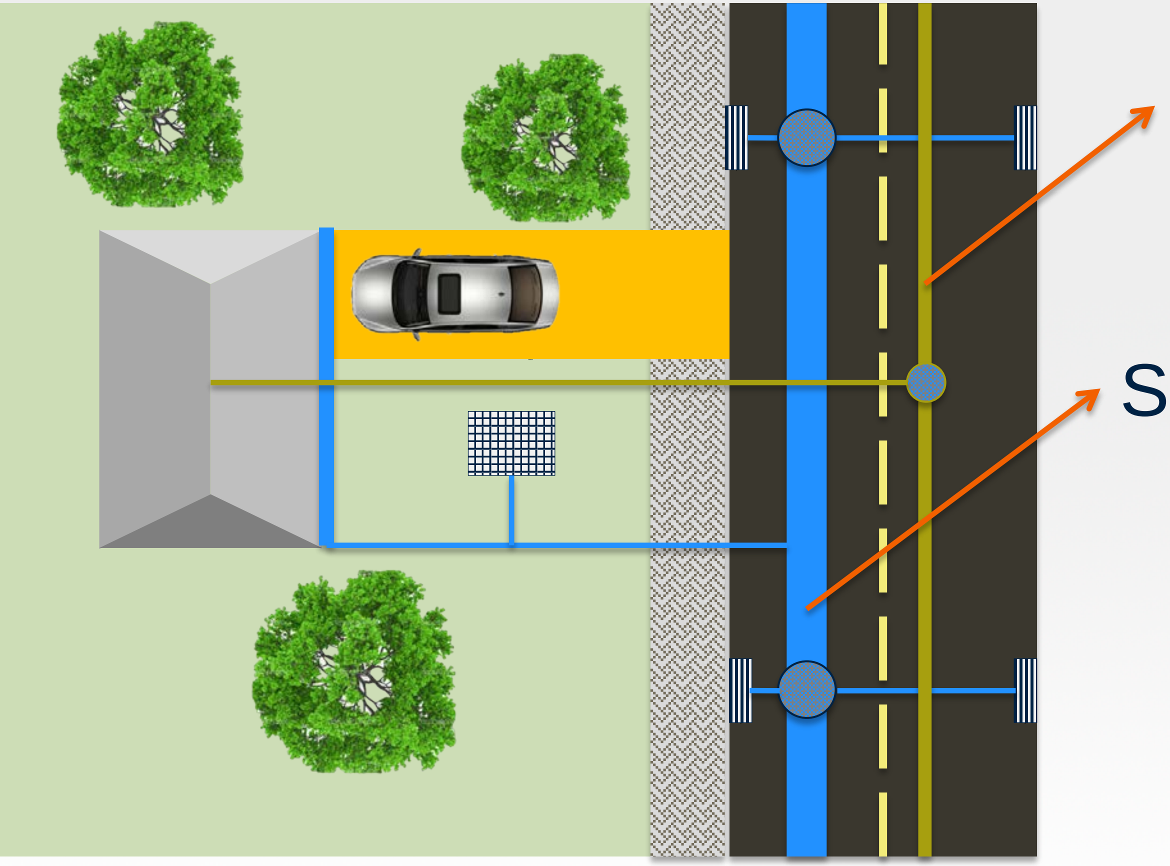
Gray Water

Waste Water

Wastewater Treatment

Wastewater Collection and Transmission System

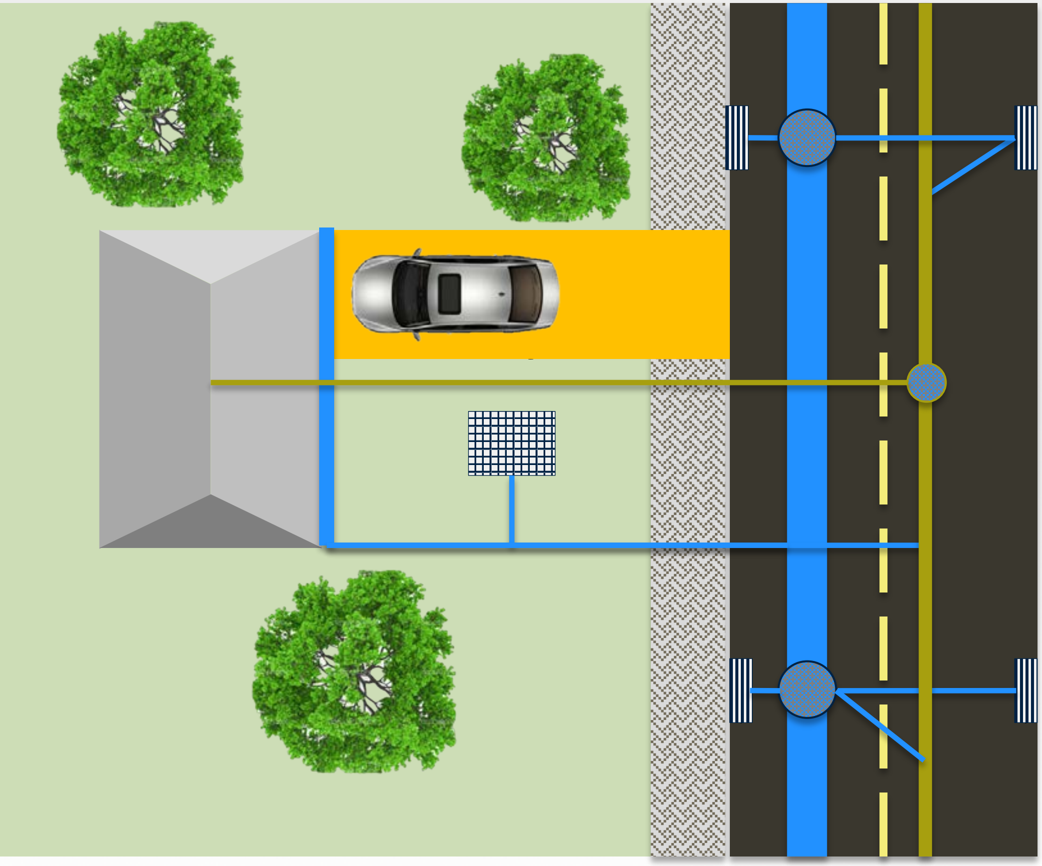
Separate Sanitary and Stormwater Systems



Sanitary System

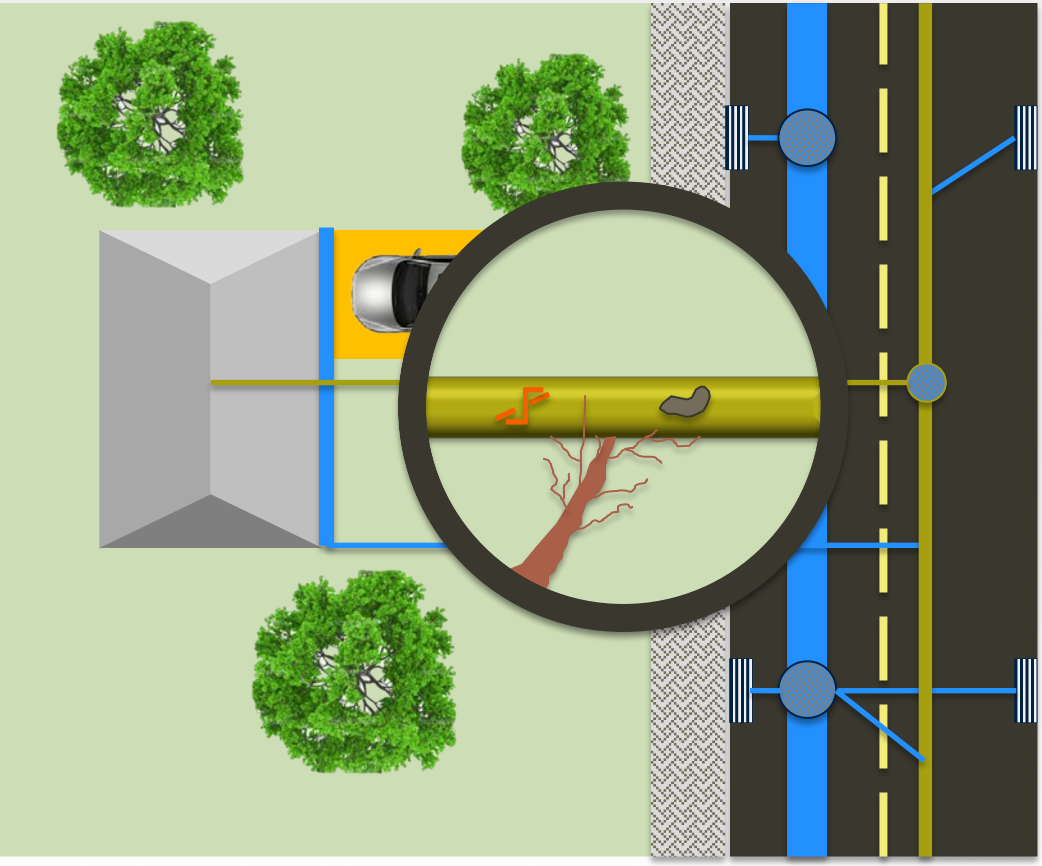
Stormwater System

Sanitary and Stormwater Systems Defects



- Roof drain connection
- Storm cross-connection

Sanitary and Stormwater Systems Defects



- Roof drain connection
- Storm cross-connection
- Broken lateral
- Root intrusion
- Cracked or broken pipe or manhole

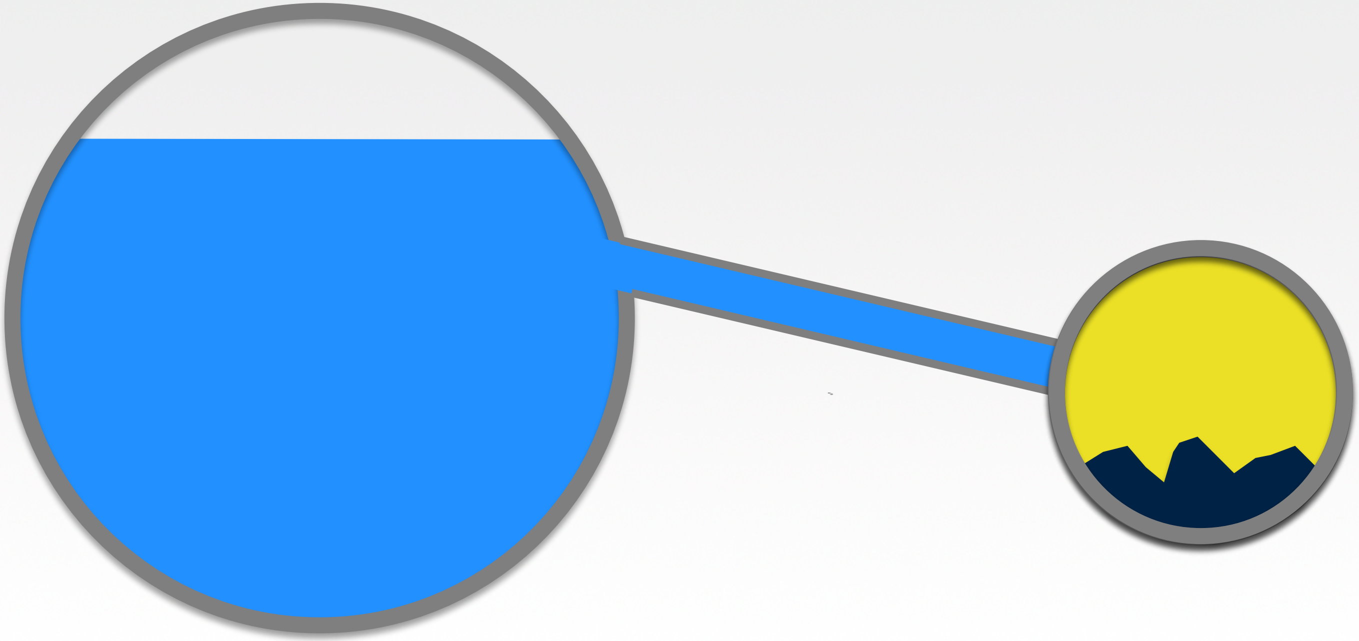
Pipe Flow Capacity

Stormwater Main

- Rainfall Intensity
- Drainage Area
- Land cover

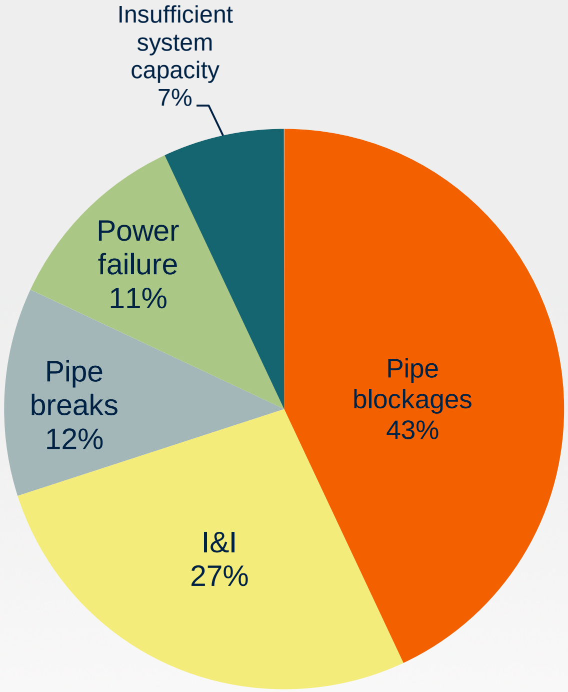
Wastewater Main

- Volume of water consumption
- Type of Development
- Population



Sanitary Sewer Overflows

- Dry weather SSO:
  - blockages caused by grease, roots and debris, pipe collapses and pump failures.
- Wet weather SSO:
  - high infiltration and inflow (I&I) resulting from intense rainfall events, inadequate hydraulic capacity, system bottlenecks caused by blockages or broken lines



EPA. (1996). "Sanitary Sewer Overflows. What are they and how can we reduce them? ." Office of Wastewater Management, Washington DC.

SAWS SSO Reduction Program

- SAWS and EPA signed a Consent Decree to reduce Sanitary Sewer Overflows (SSOs)
- Comprehensive program to be developed in the next 10 years including a series of activities:
  - sewer system inspection
  - pipe cleaning, repair or replacement
  - lift station fixing or removal

How is UTSA helping SAWS?

- Research Study
  - Develop an optimization model to help SAWS decrease the occurrence of SSOs
- Tasks:
  1. Develop a computer simulation model of the sewer systems;
  2. Apply an optimization algorithm;
  3. Train SAWS technical staff to use the optimization framework to other sewersheds

Optimization of SSOs Problem in San Antonio

- Where within the San Antonio wastewater collection and conveyance system, pipe capacity enhancement and peak flow attenuation structures should be locate to minimize the occurrence of SSO and minimize Cost?

- Single Objective

$$Minimize\ z = Number\ of\ SSOs$$

$$subject\ to:$$

$$Total\ Costs \leq Maximum\ Cost$$

- Multi Objective

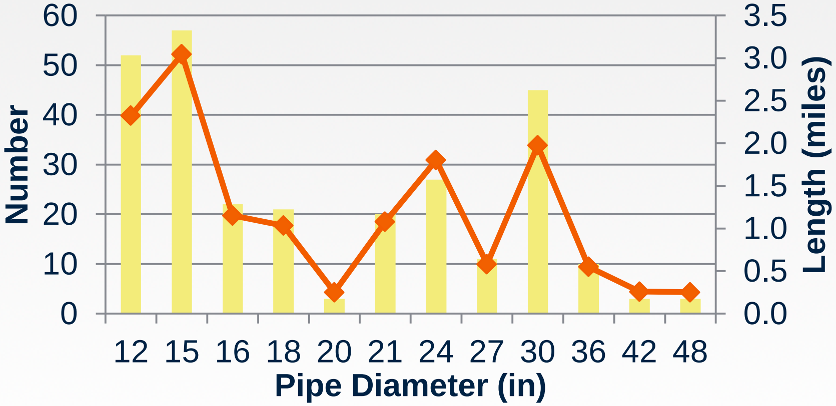
$$Minimize\ z = Number\ of\ SSOs$$

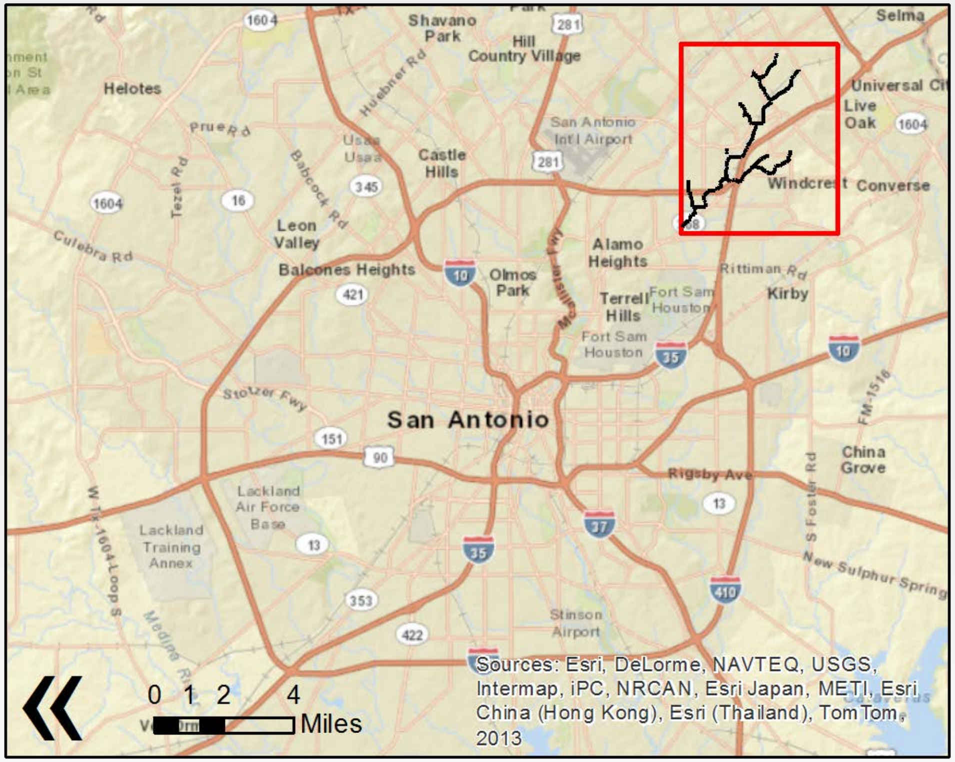
$$Minimize\ y = Total\ Costs$$

Pilot Case Study

- CIP East 07 and 15
- Area 7,500 acres
- 274 pipes
- 14. 3 miles

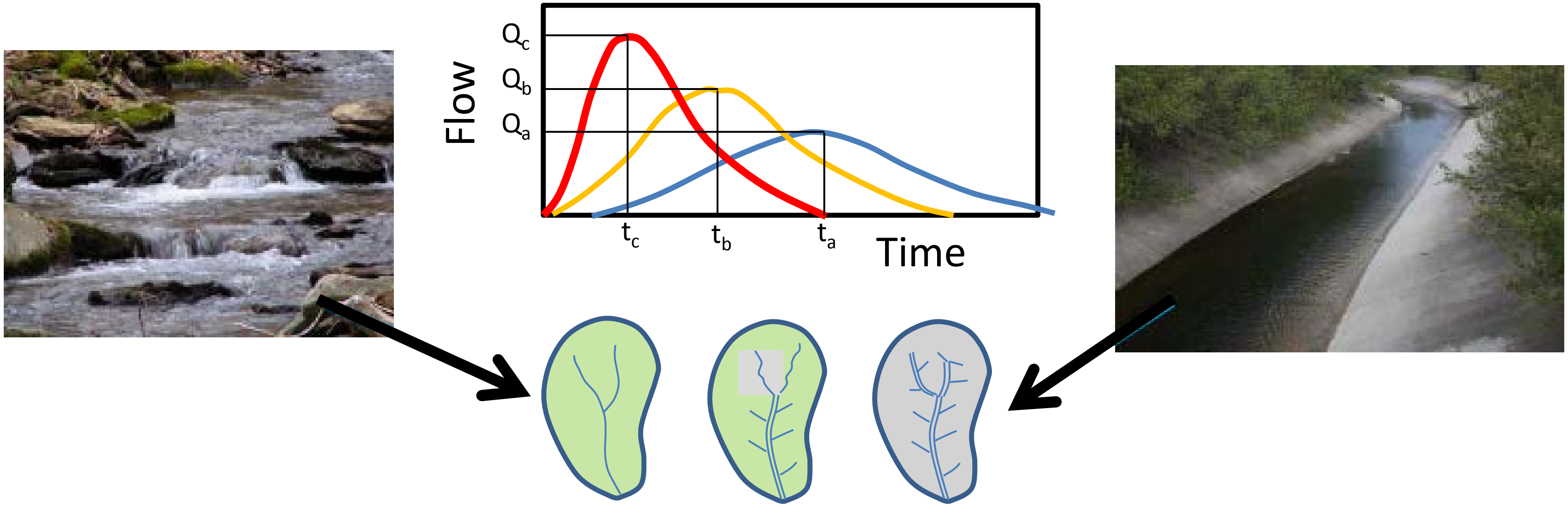
Pipe Diameter: Number and Length





Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

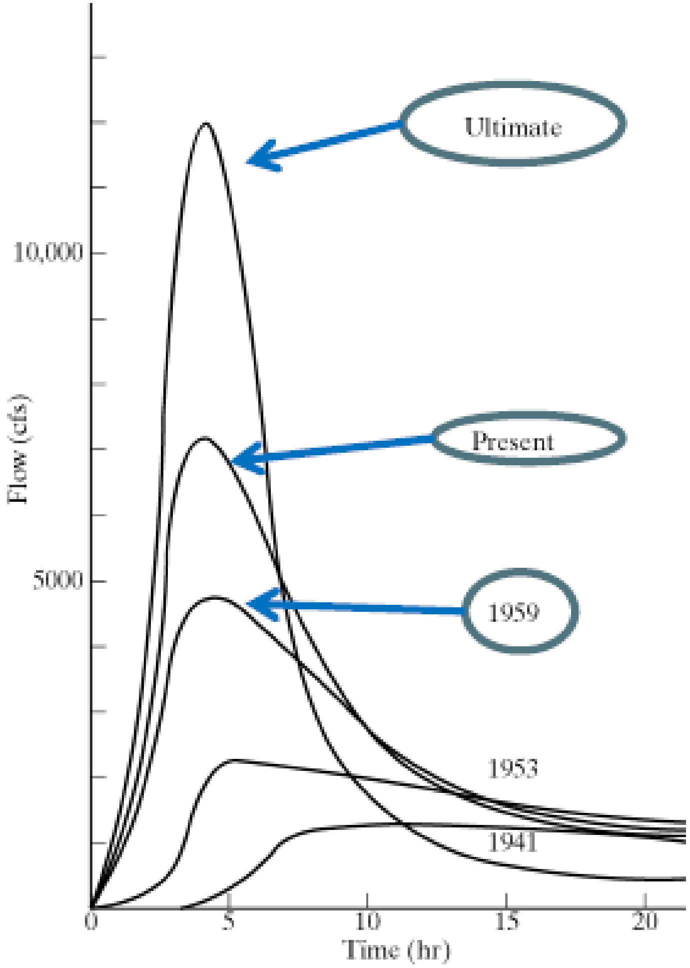
Impact of Urbanization on Hydrograph



(a) Natural (b) Partially Developed (c) Fully Developed

Impacts of Development

- Three Hydrological Impacts
  - Increase of Runoff volumes
  - Decrease of Time to peak
  - Increase of Peakflow
- Actual Unit Hydrographs for Brays Bayou in Houston, Texas

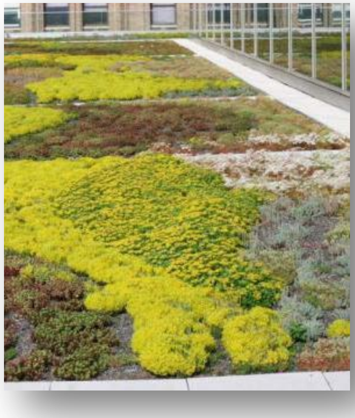


How to mitigate the impacts of Urbanization in the Hydrological Cycle?

- Low Impact Development:
  - land planning and engineering design approach to managing stormwater runoff
  - Small-scale hydrologic controls to replicate the pre-development hydrologic regime
  - Infiltration, filtering, storing, evaporation, and detaining runoff close to its source

LID Examples

- Permeable Pavements
- Green roofs
- Bioretentions/Rain gardens
- Sand filters
- Vegetated Swales
- Infiltration trences
- Rainwater harvesting

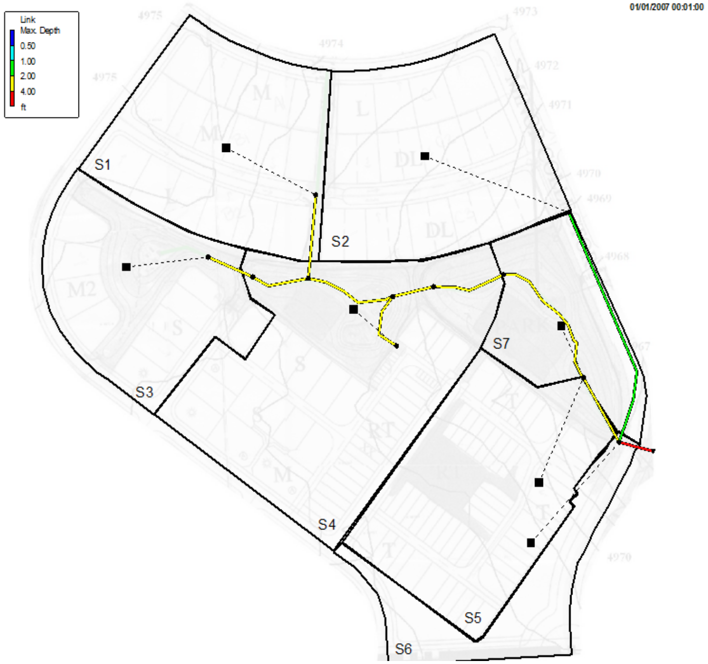


www.metaefficient.com, http://www.wild-wonderings.blogspot.com/
http://www.physics.tamu.edu/NewPB.html, TAMU Campus Masterplan, p 140

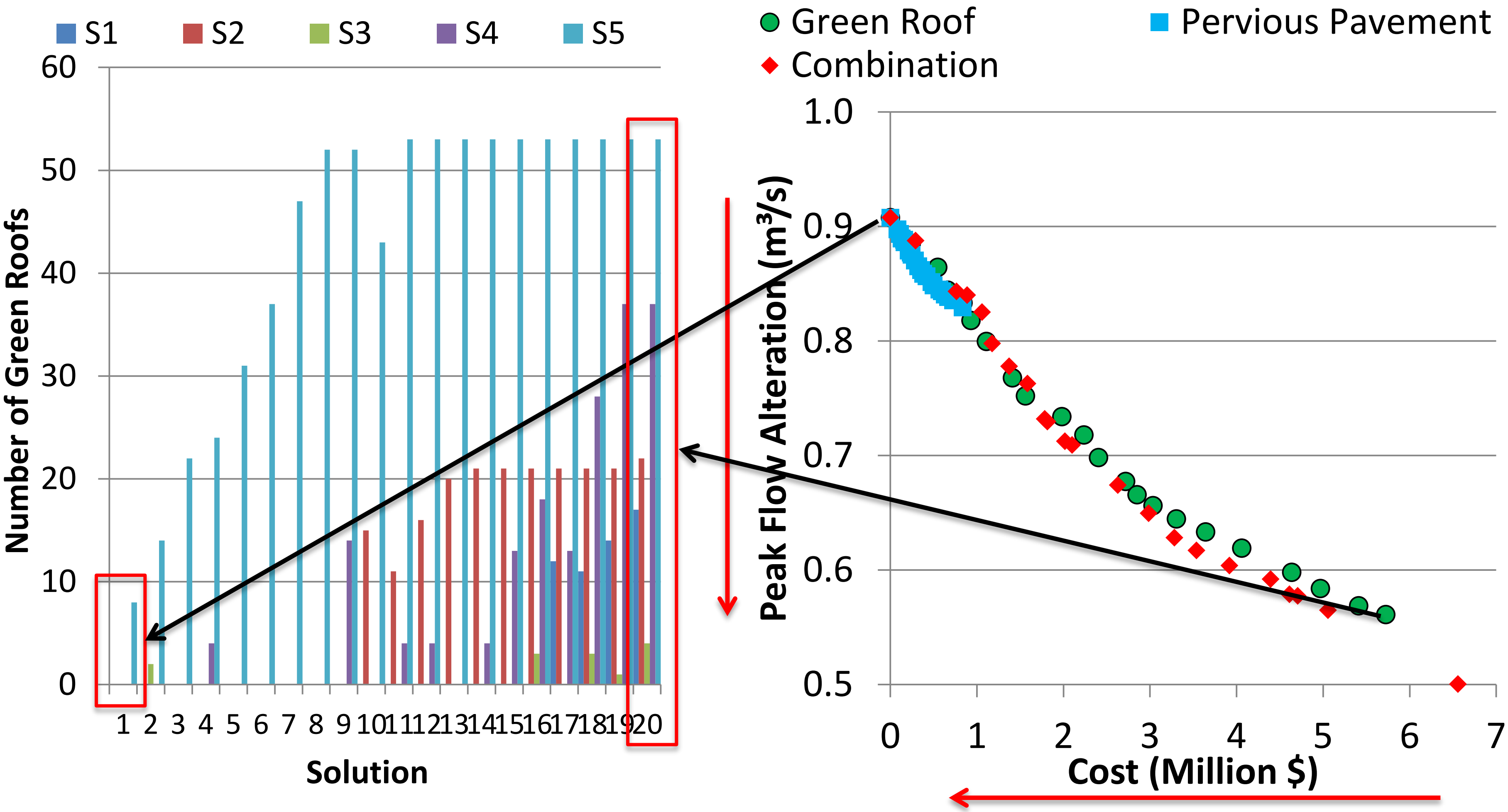
Use of Multi-Objective Evolutionary Algorithm Optimization for Low Impact Development Placement

- Hydrologic simulation with a multi-objective optimization algorithm
- Solutions in terms of green roofs and pervious pavements location in urban catchments
- Characterize the tradeoffs between LID performance indicators and costs.
- Costs, peak flow reduction, and the Hydrologic Footprint Residence (HFR).

Where in urban catchments is best to install LIDs?

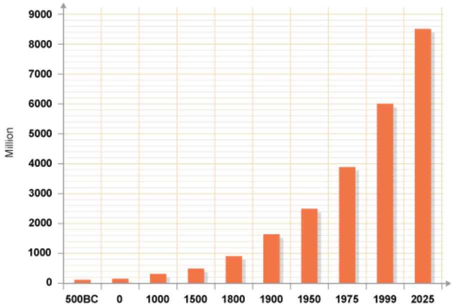


Trade-off between Cost vs Peakflow Alteration

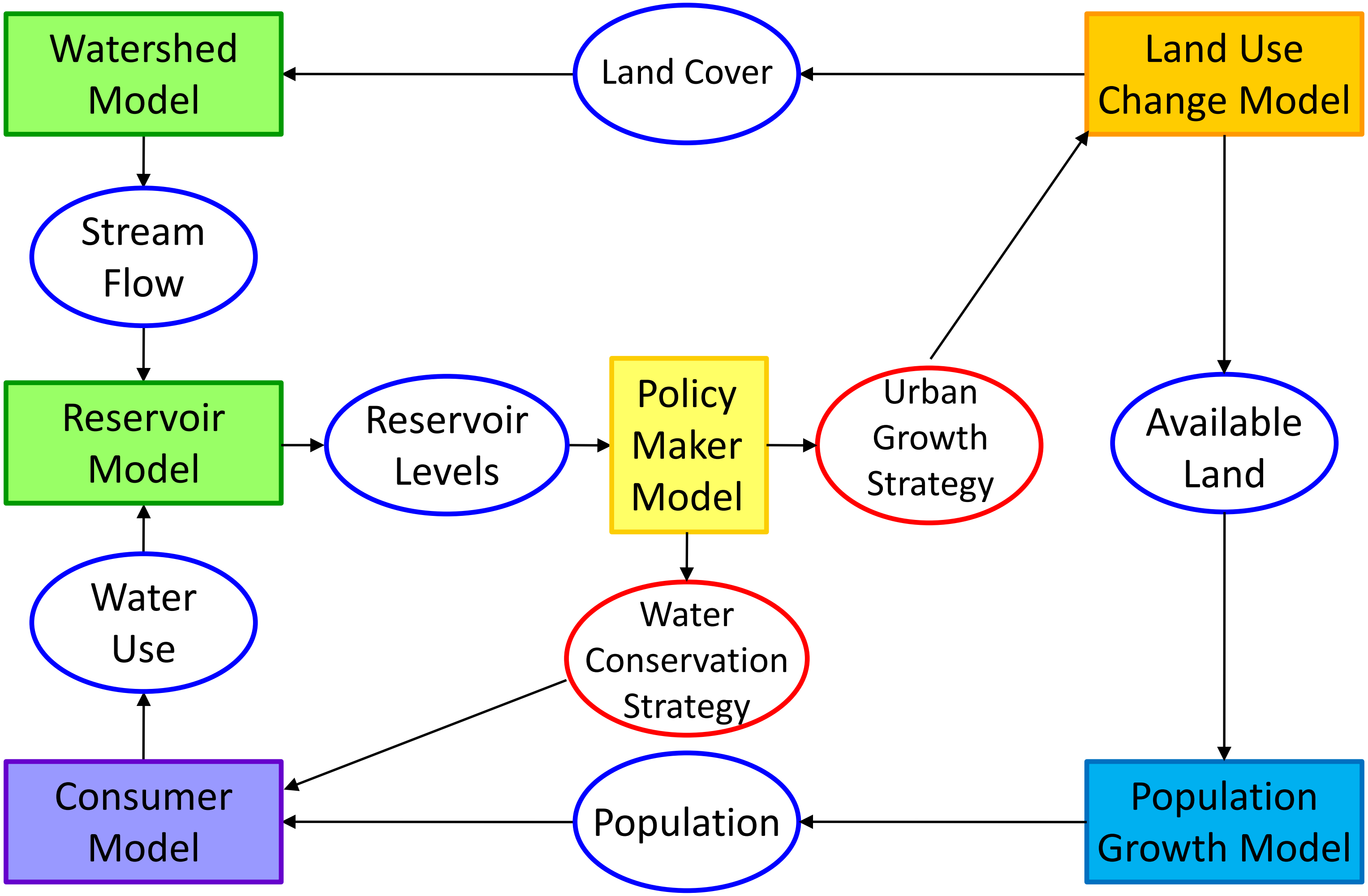


MULTIOBJECTIVE EVOLUTIONARY OPTIMIZATION OF ADAPTIVE DEMAND MANAGEMENT STRATEGIES FOR AN URBAN WATER RESOURCE SYSTEM

- Population growth, Urbanization and Climate Change
- Unbalancing supply and demands
- Traditionally supply enhancement has been adopted
- Demand management:
  - Drought management
  - Water Conservation



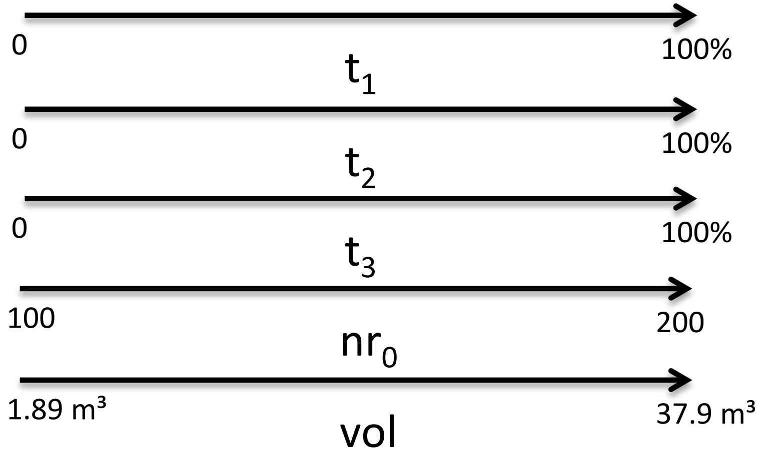
Complex Adaptive System Modeling Framework

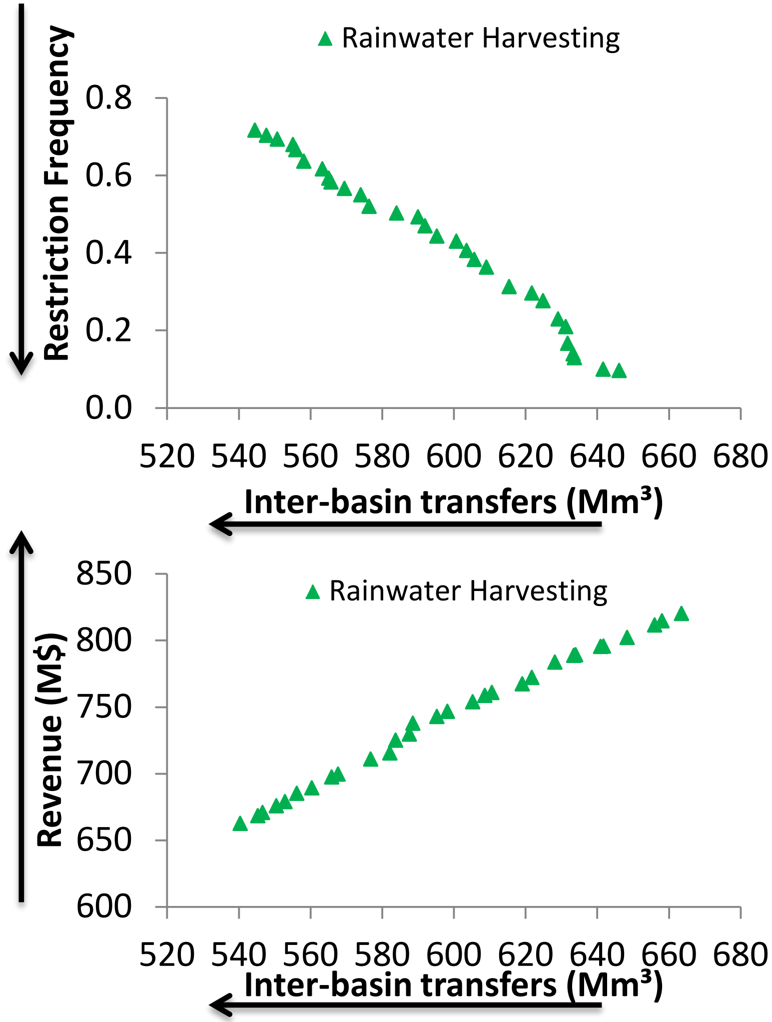


Decision and Objective Space

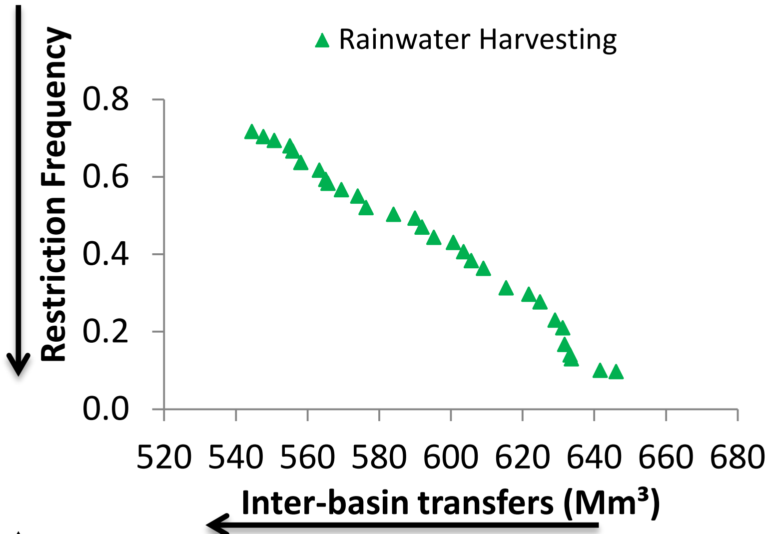
Water Conservation Problem

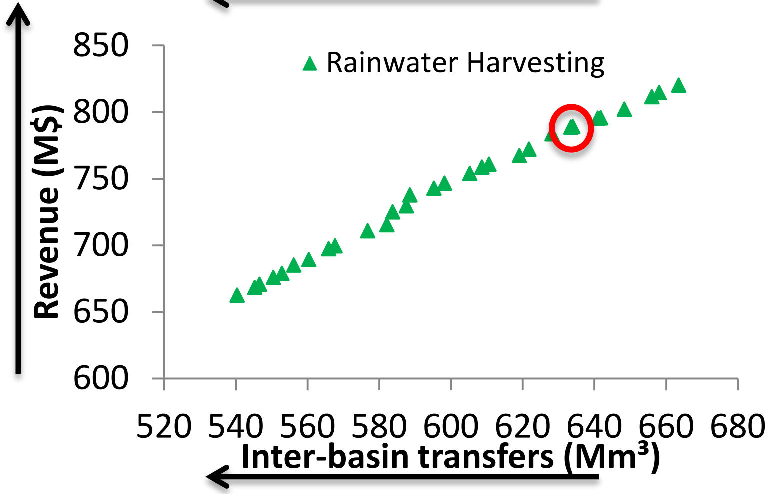
- Drought triggers
  - [$1<t_1<t_2<t_3<0$]
- Number of rebates at each drought stage
  - [$100<nr_0<200$]
- Size of rainbarrels
  - [$1.89<vol<37.9\ m^3$]





Decision and Objective Space

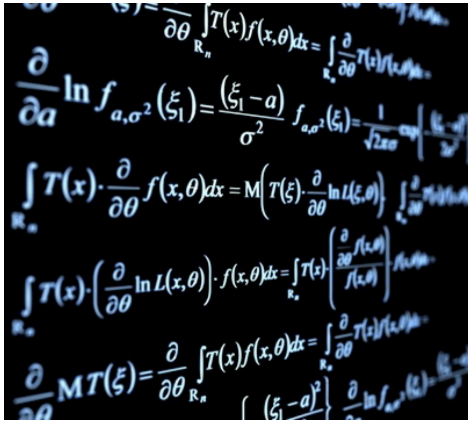




Decision Variable	Rainwater Harvesting
Inter-basin Transfers (Mm³)	634
Utility Revenue (M$)	789
Trigger 1 (%)	72
Trigger 2 (%)	39
Trigger 3 (%)	7
Number of Rebates	196
Average Rainbarrel Volume (gal.)	6840

Water Systems Analyst Skills

- Mathematical background
- Computer Language
  - – Coding/Excell/
- Curiosity!!!



THANK YOU FOR YOUR ATTENTION

CONSERVE WATER!!!

Keep grease out of the Grease Monster's hands by properly disposing cooking oil, grease residue and fat trimmings in the trash and not down the drain