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Automatic Design for Pipe Arrangement using Multi-objective Genetic Algorithms

Satoshi IKEHIRA*
Hajime KIMURA
Hiroyuki KAJIWARA

** Department of Maritime Engineering*
Graduate School of Engineering
Kyushu University
Fukuoka, Japan

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Background

Reduce labor requirements

Advances in CAD

- efficiency improvement
- labor saving

Automation of pipe arrangement design has not yet achieved.

Objective

Design pipe arrangement automatically

1. Formulating pipe arrangement design problem

Large-scale multi-objective optimization problem

2. Designing multi-objective genetic algorithms

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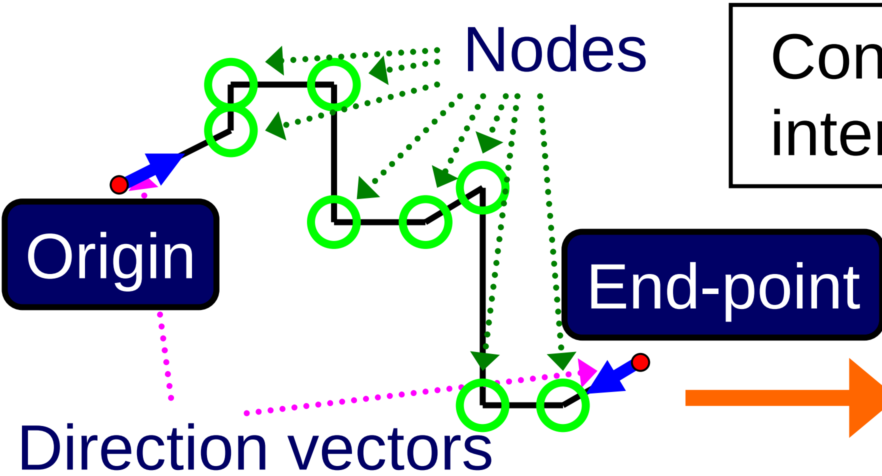
1. Introduction
2. Formulating Pipe Arrangement Design Problem
3. Designing Multi-objective Genetic Algorithms
4. Experiments and Results
5. Conclusions and Remarks

Designing Pipe Arrangement

When both origin and endpoint coordinates
and direction vectors are provided,

<u>Piping route is automatically designed.</u>

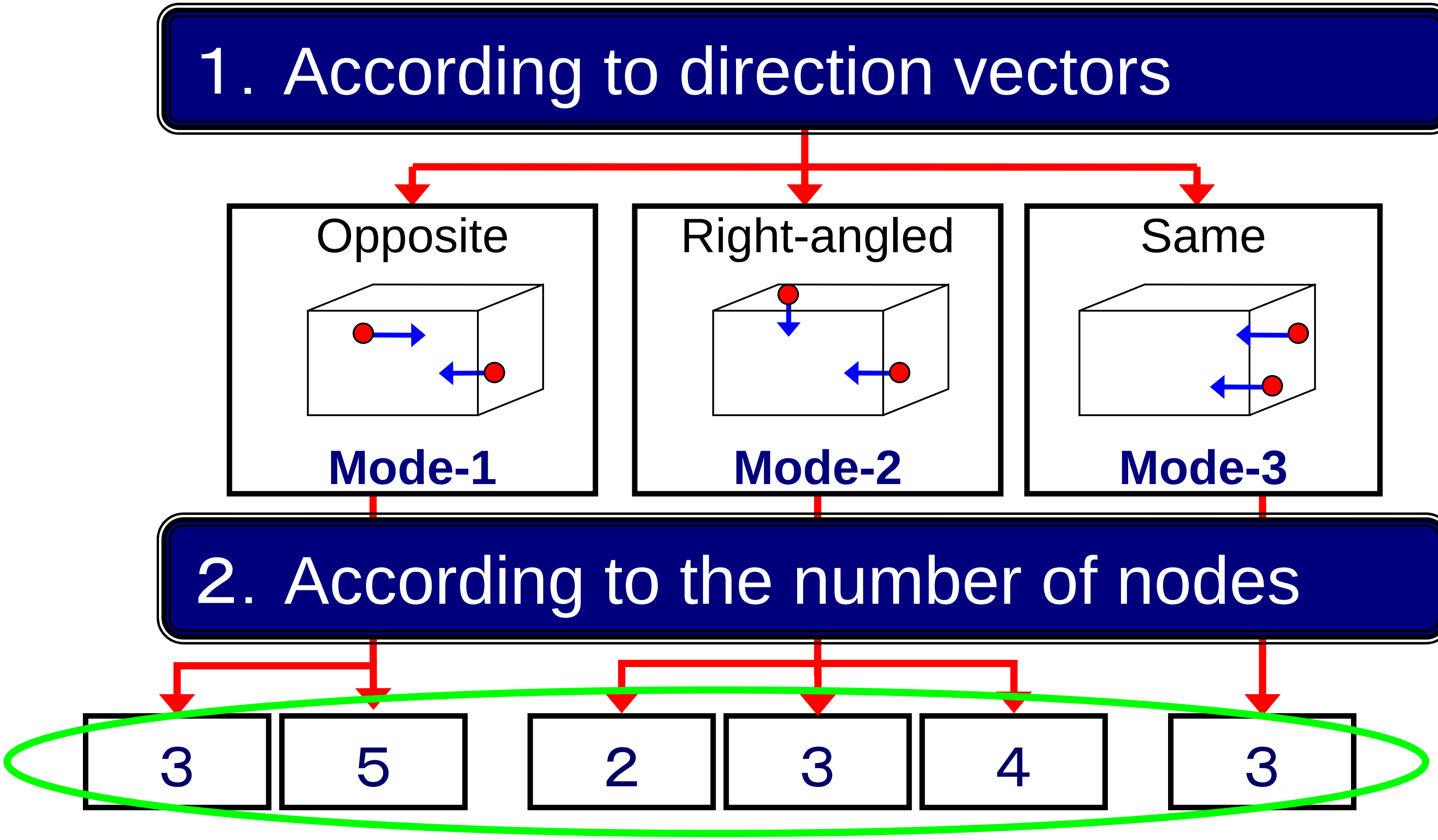
Considering
interference with pipes and obstacles



An infinite number of piping route

<u>A limit is imposed on the degrees-of-freedom for the route.</u>

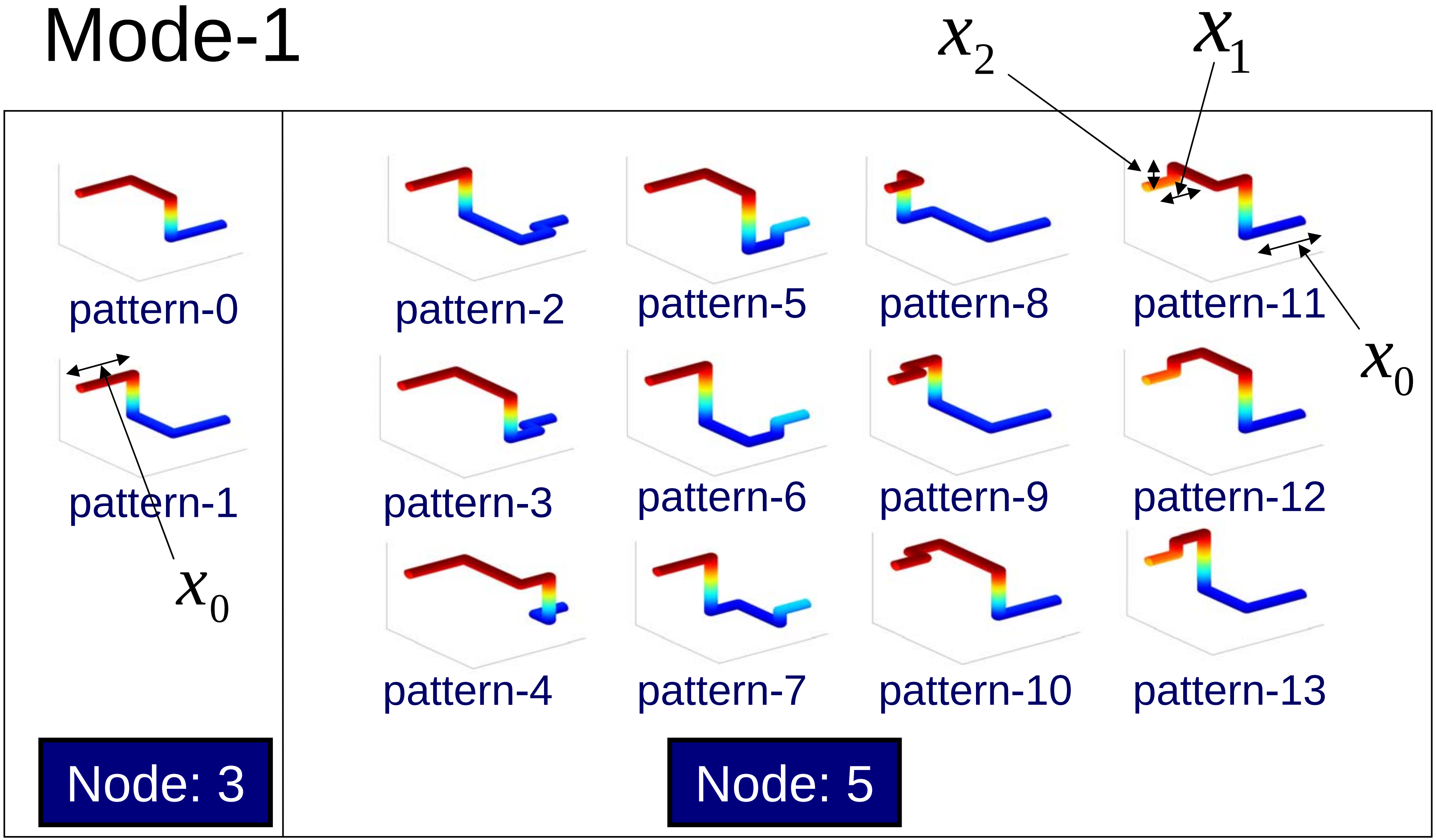
Generation pattern



The number of nodes increases → Degrees-of freedom expands

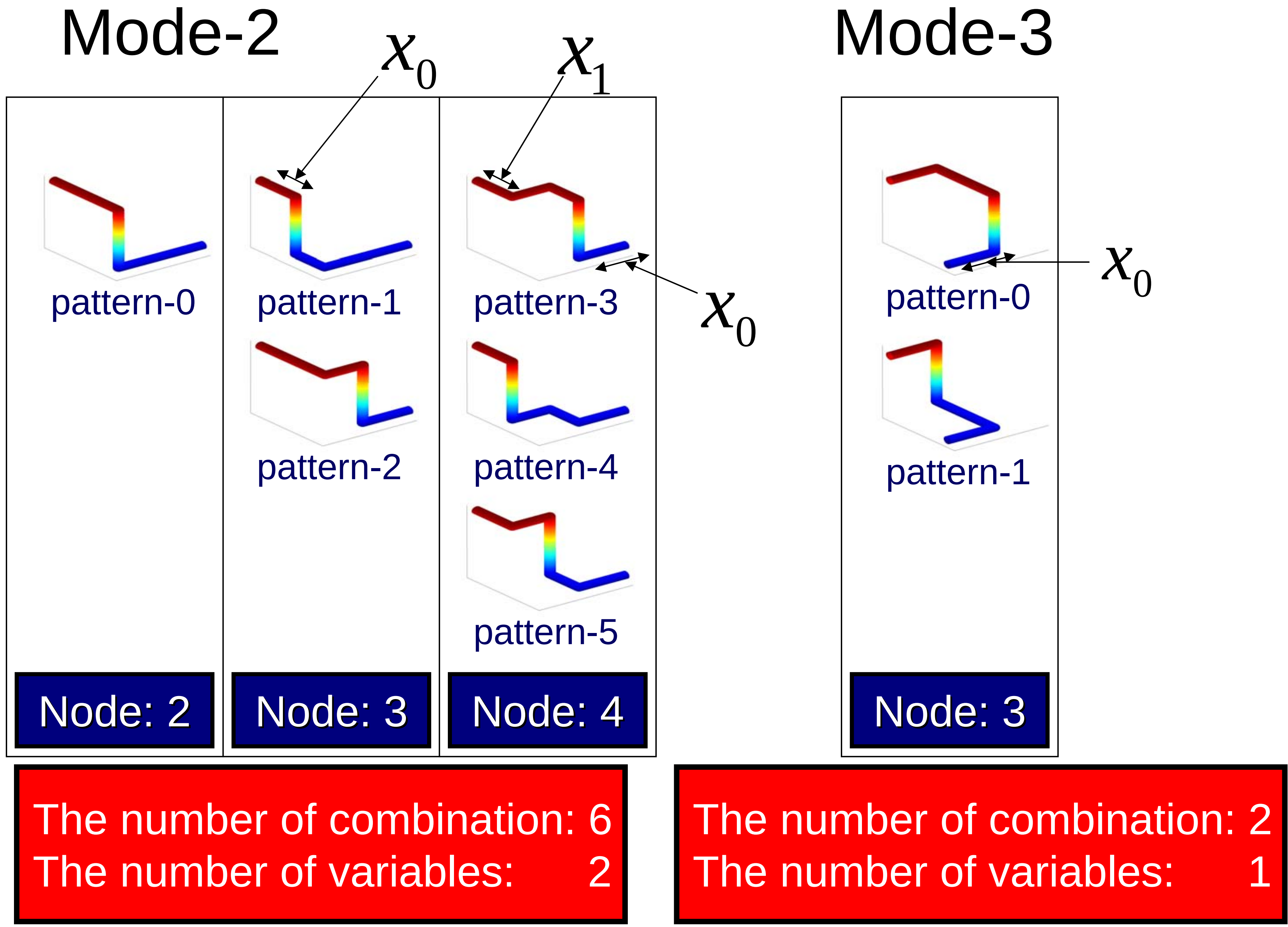
The number of nodes should be minimized
while avoiding interference with other pipes and obstacles.

Mode-1



The number of combination: 14
The number of variables: 3

A pipe is characterized uniquely.



Mode-2
Mode-3
x_0
x_1
x_0
x_0
pattern-0
pattern-1
pattern-2
pattern-3
pattern-4
pattern-5
Node: 2
Node: 3
Node: 4
pattern-0
pattern-1
Node: 3
The number of combination: 6
The number of variables: 2
The number of combination: 2
The number of variables: 1

Evaluation function for obstacle（1）

A space set aside to allow for maintenance people to pass

This space is considered as an obstacle.

Need not completely avoid the obstacle

Avoid the obstacle as much as possible

Evaluation function

Minimize the evaluation value

Optimization problem

Evaluation value for obstacle（2）

$$f_{\_obstacle} = \sum_{l=1}^{n_o} \sum_{k=1}^{n_p} (b_{kl} - \overline{a}_{kl} + A_l)$$

b_{kl} : The length of intersection when the pipe k intersects the obstacle l

$\overline{a}_{kl}$: The averaged length between the center of the gravity of the obstacle k and the part divided by each node of the pipe l

A_l : The length between the center of the gravity and the top of the obstacle l

n_o : The number of obstacles

n_p : The number of pipes

Minimum value ＝ 0
（All pipes not interfering with obstacles）

Evaluation values are worse when a pipe passes through the center of an obstacle and the length of the intersection is long.

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Characteristic of this problem

This problem includes
numerical optimization and
combination optimization problems.

Using GA, which is
direct search method

It is difficult to optimize this problem
using usual optimization techniques.

- Annealing method
- Downhill simplex method, etc.

The length of pipe

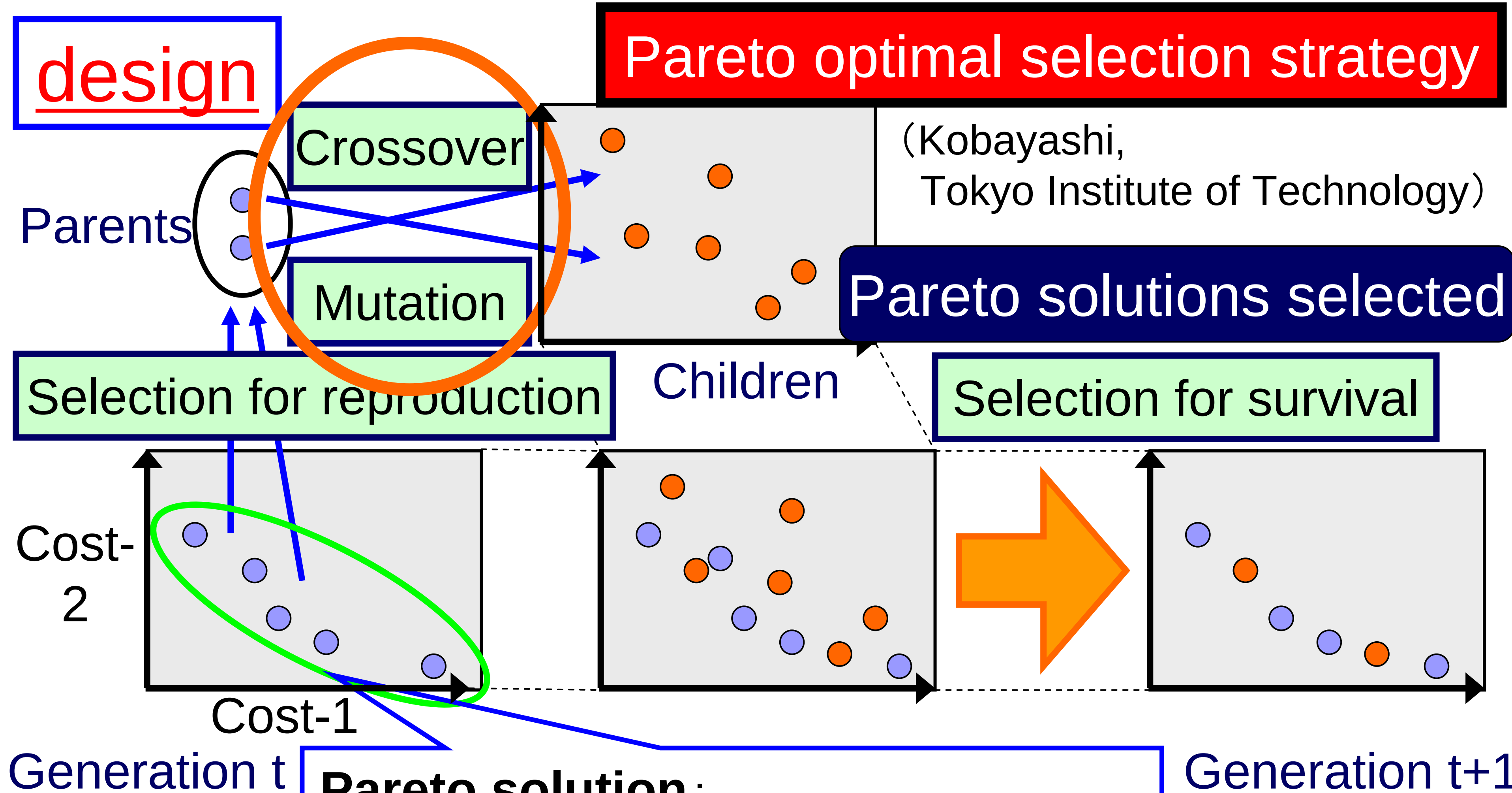
Trade-off

Multi-objective
optimization problem

The Evaluation value for obstacle

Multi-objective GA

Multi-objective genetic algorithms



Pareto solution:
A solution that is superior to all other solutions in at least one criterion.

Representation

Pattern of generation

Numerical parameters

A pipe is characterized by them

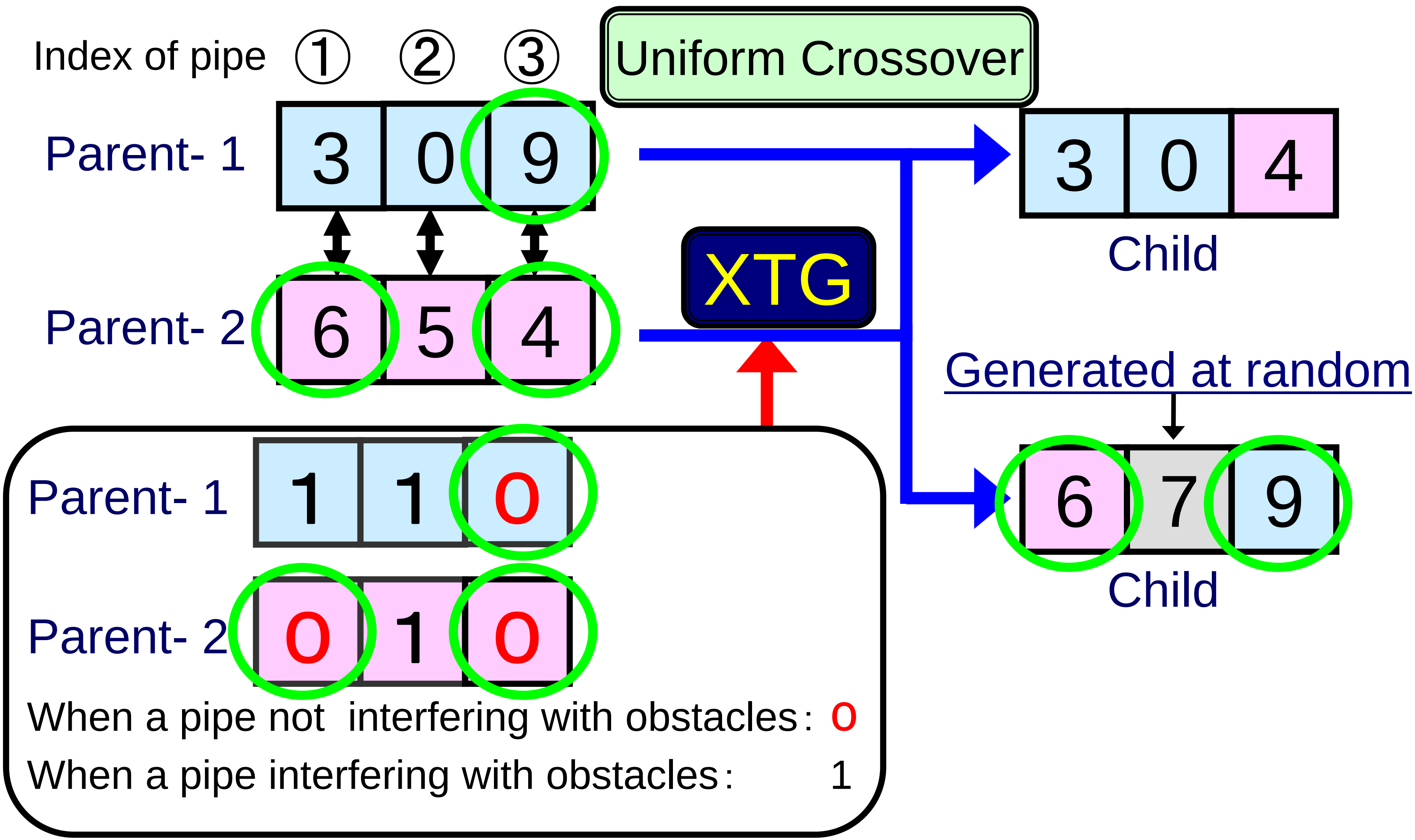
A combination of them are used as the solution representation

Solution structure

$$
\begin{array}{l}
\text{Pattern of generation} \\
\\
\text{Numerical parameters} \\
\\
\end{array}
\left[
\begin{array}{c|c|c|c}
pattern_1 & pattern_2 & \cdots\cdots\cdots & pattern_n \\
x_{10} & x_{20} & \cdots\cdots\cdots & x_{n0} \\
x_{11} & x_{21} & \cdots\cdots\cdots & x_{n1} \\
x_{12} & x_{22} & \cdots\cdots\cdots & x_{n2}
\end{array}
\right]
$$

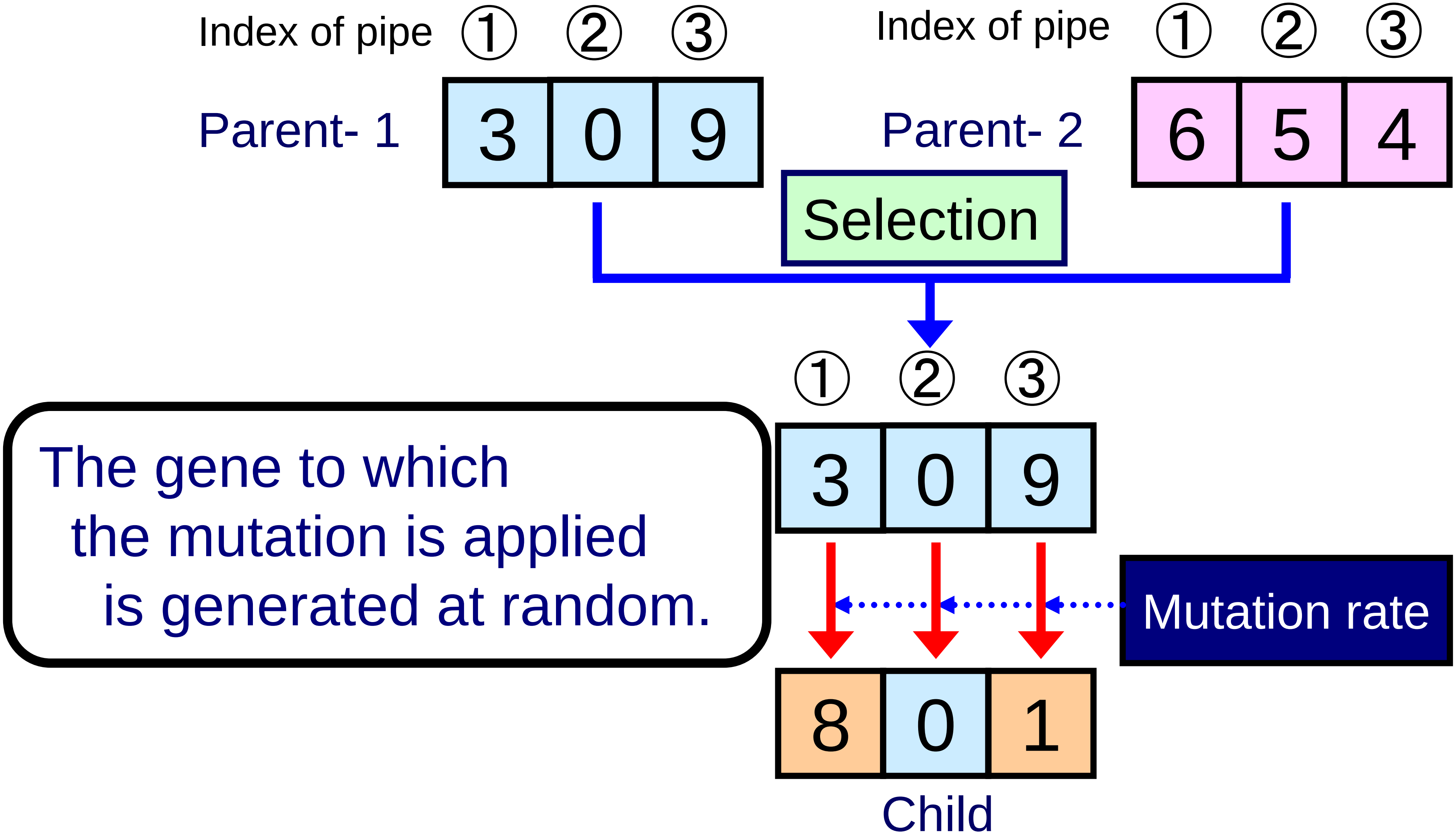
$$
\begin{array}{cccc}
\text{pipe 1} & \text{pipe 2} & & \text{pipe } n
\end{array}
$$

Crossover with Two Gene: XTG



The evaluation value for obstacle can be expected to be improved.

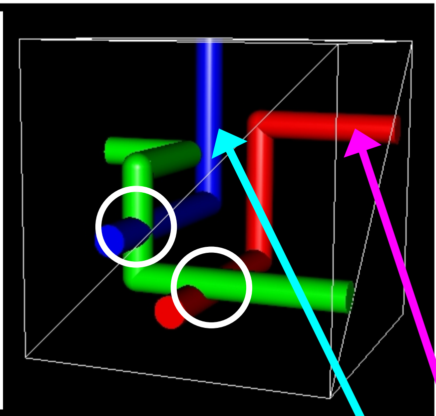
Mutation


Index of pipe ① ② ③
Parent- 1
3 0 9
Index of pipe ① ② ③
Parent- 2
6 5 4
Selection
① ② ③
3 0 9
The gene to which the mutation is applied is generated at random.
Mutation rate
8 0 1
Child

Modification operator on Contact: MOC

Pipes interfere with each other.

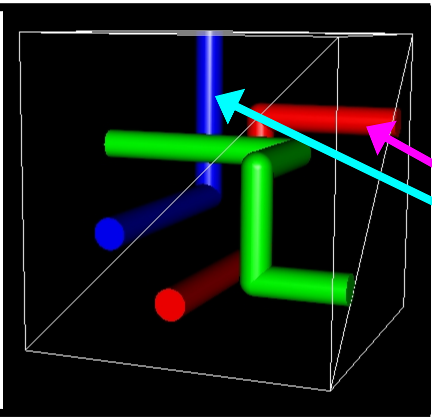
Infeasible solution



MOC

Pipes do not interfere with each other.

Feasible solution

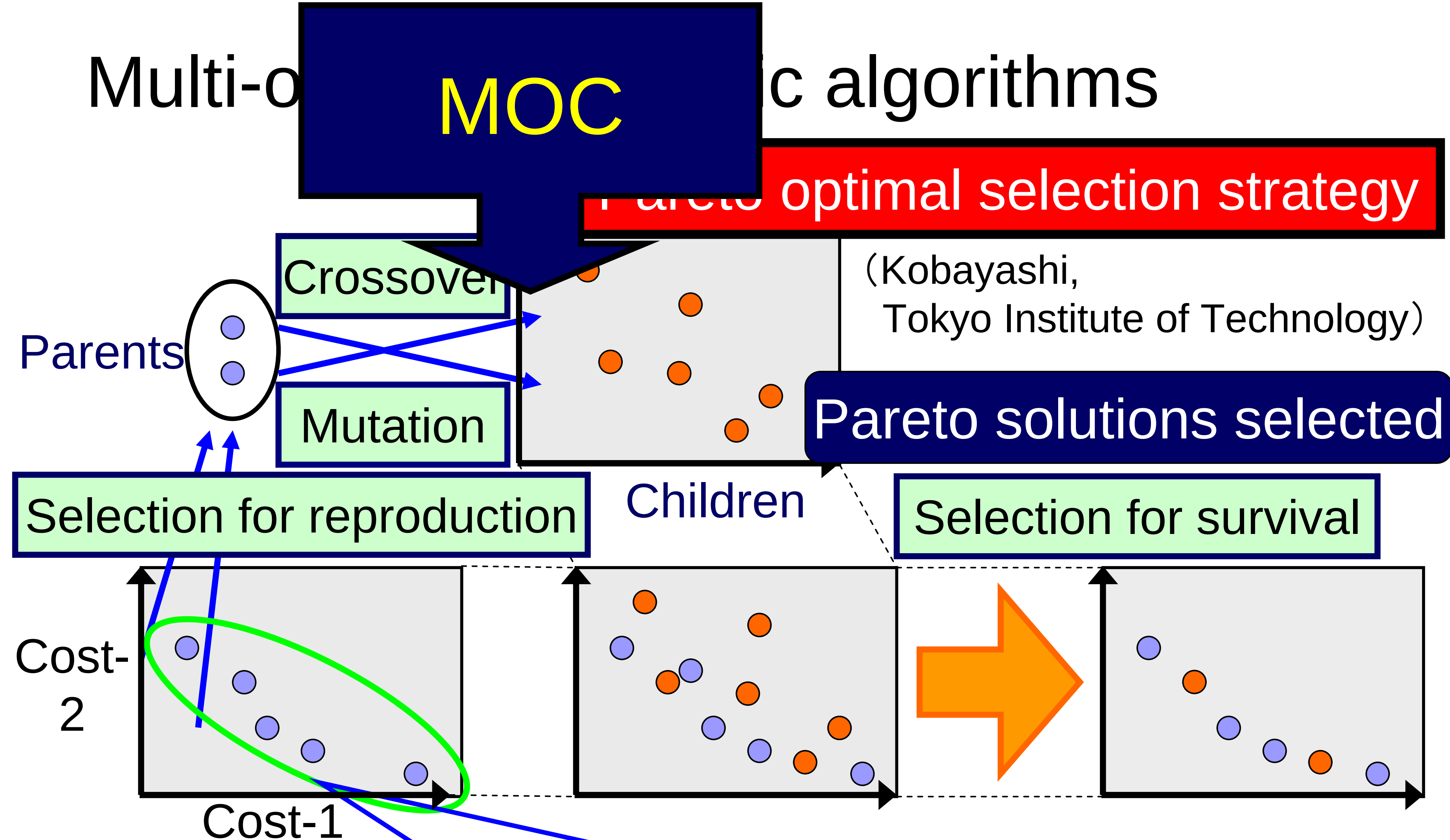


Pipes having a lot of interferences are modified

Change the properties of the original solution candidates as little as possible

Not changed

Multi-o ic algorithms



Pareto solution:
A solution that is superior to all other solutions in at least one criterion.

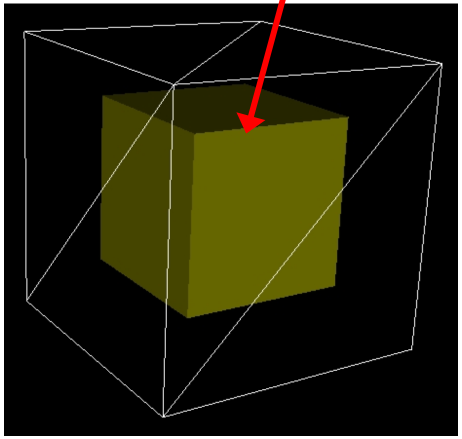
Contents

Experiments

	Mode-1	Mode-2	Mode-3
The number of pipes	5	7	3
The number of variables	3	2	1
The number of combinations	14	6	2
The total number of variables	15	14	3
The total number of combinations	537,824	279,936	8
The number of all variables	32		
The number of all combinations	Approximately 1.2 trillion		

The space where a obstacle exists

Large-scale optimization problems

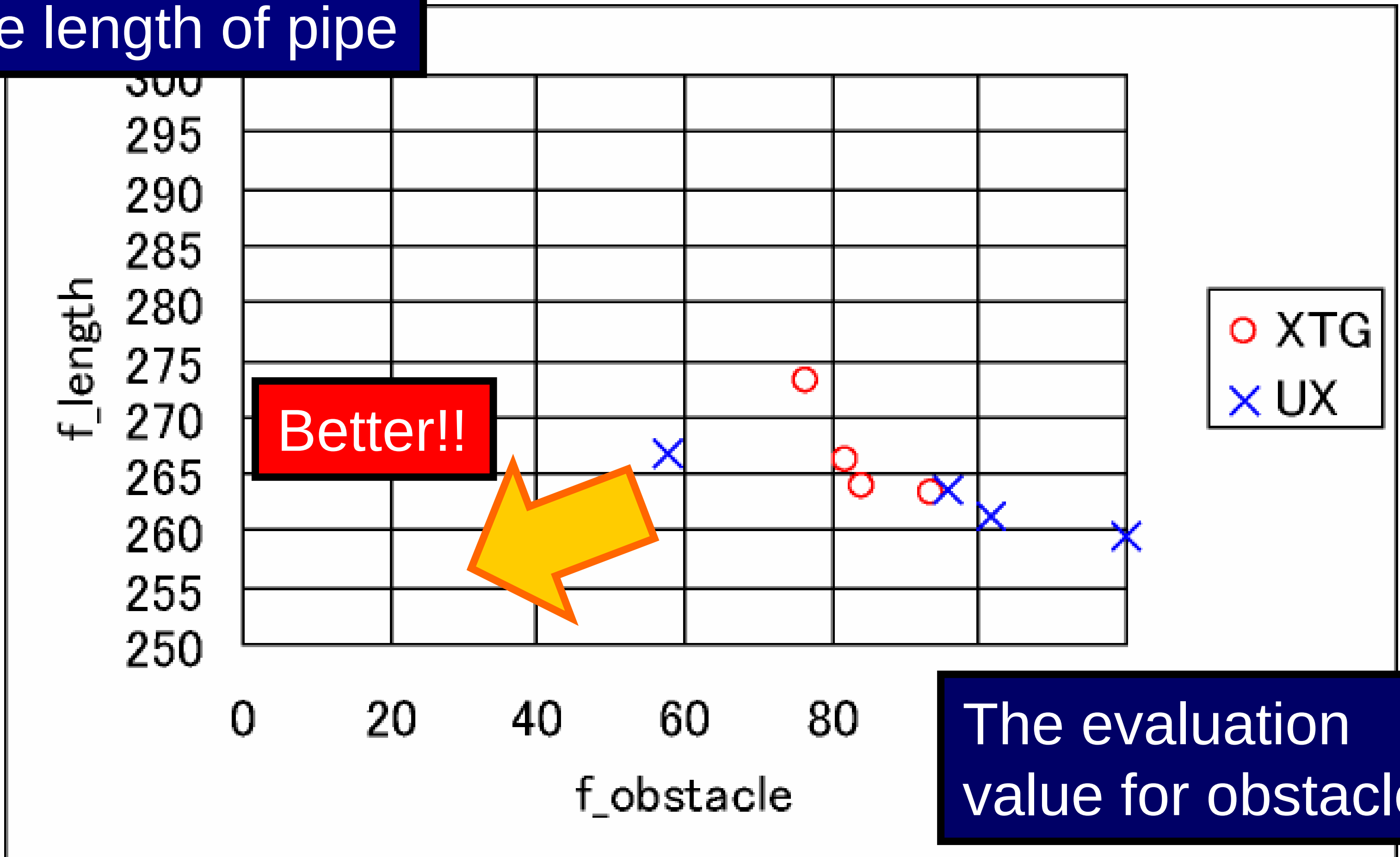


We set the problem where many pipes exist closely and a big obstacle exists.

Initial Pareto solutions

Calculation environment
Pentium 4 2.40GHz
512MB
Windows XP
Java

The sum total of the length of pipe

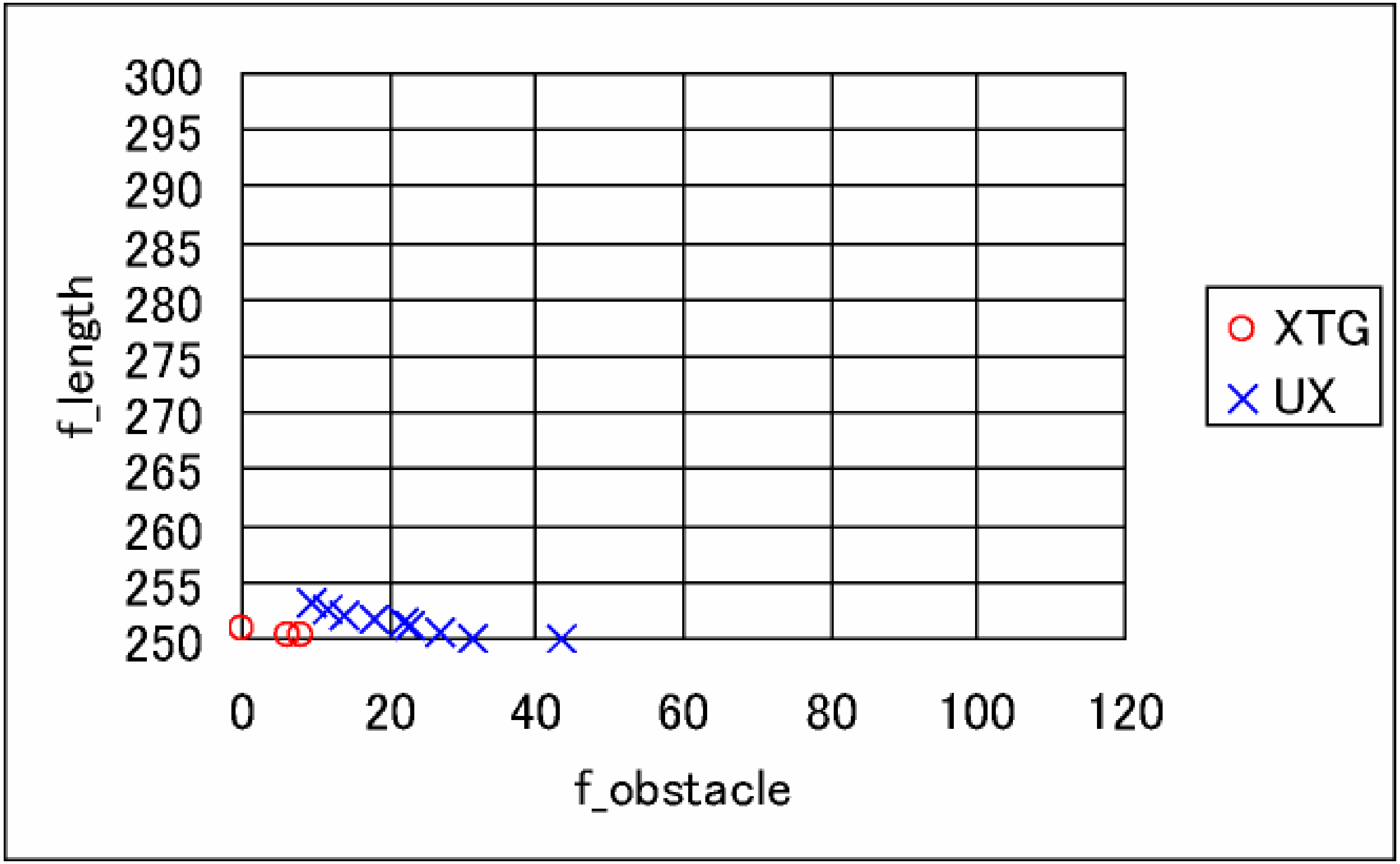


The evaluation value for obstacle

Pareto solutions in 100^{th} generation

（1.0×10^4 solution candidates evaluated.）

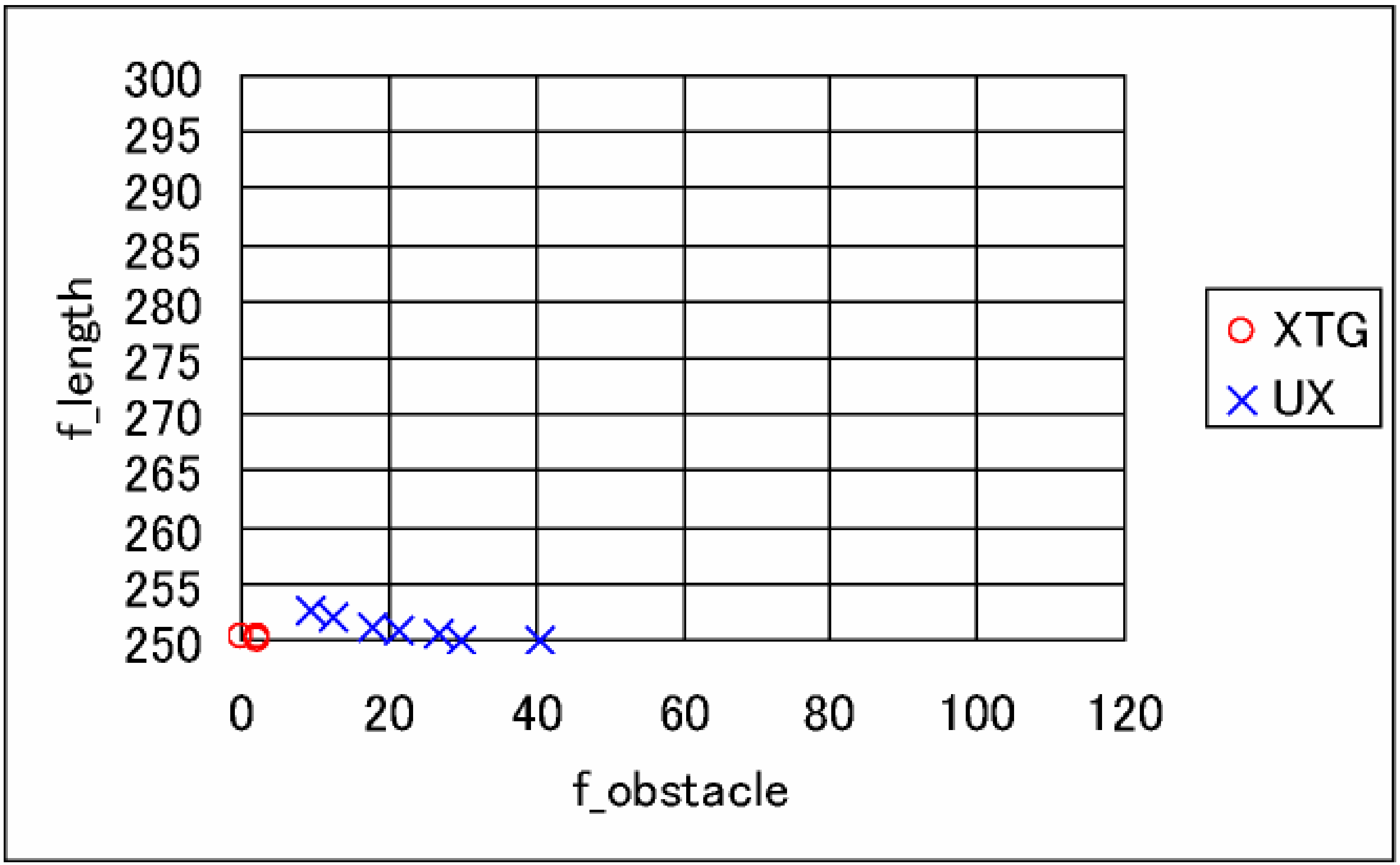
About 10 minutes for searching



Pareto solutions in 1000th generation

(1.0×10^5 solution candidates evaluated.)

About 60 minutes for searching



Results

Programming language： Java3D

start

The number of pipes: 15
The number of obstacles: 2

15_2

The number of pipes: 20
The number of obstacles: 1

20_1

The number of pipes: 20
The number of obstacles: 3

20_3

Contents

Conclusions

- A design problem for pipe arrangement was formulated.
- A multi-objective Genetic Algorithms suitable for this problem was developed.
- The effectiveness of the proposed method was verified through several experiments.

Future works

- Applying this methodology to a practical design
- Improvements to the proposed algorithms