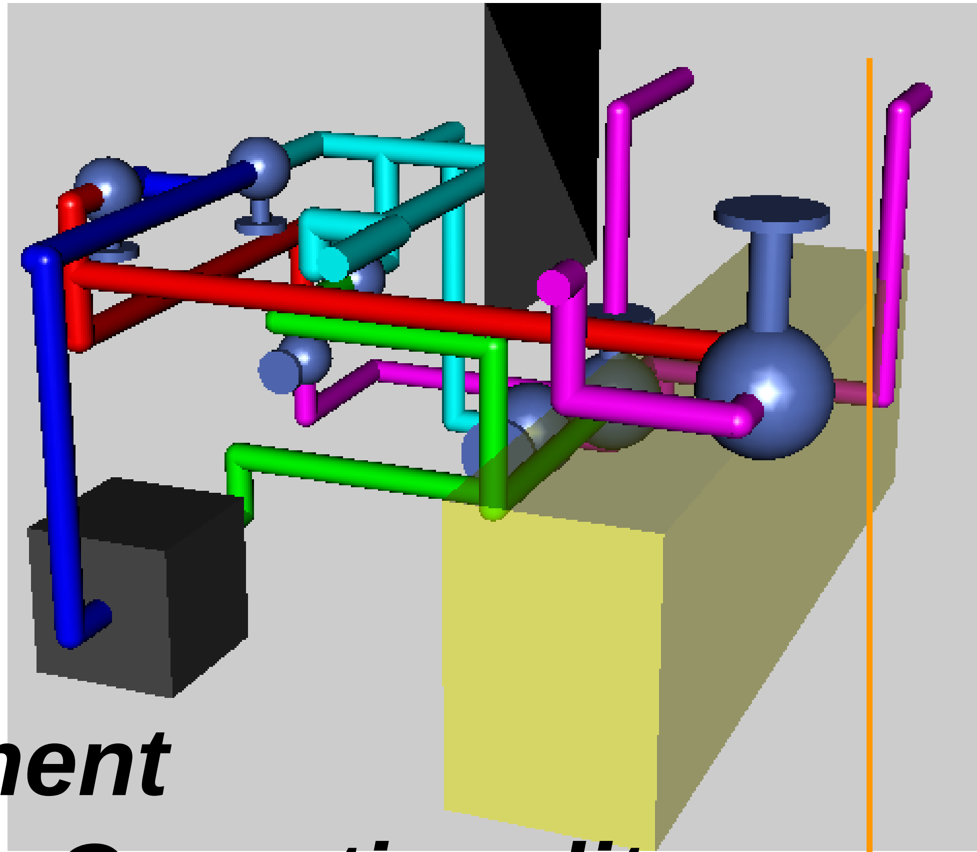


Automatic Design for Pipe Arrangement Considering Valve Operationality

Hajime Kimura (Kyushu University, Japan)
Satoshi Ikehira (Kyushu University, Japan)

Shipbuilding ICCAS 2009

Overview

1. Motivation and Purpose

2. Evaluation Algorithm for Pipe Operationality

Accessibility

Possibility of Valve Handling

3. Multi-Objective Optimization Algorithm

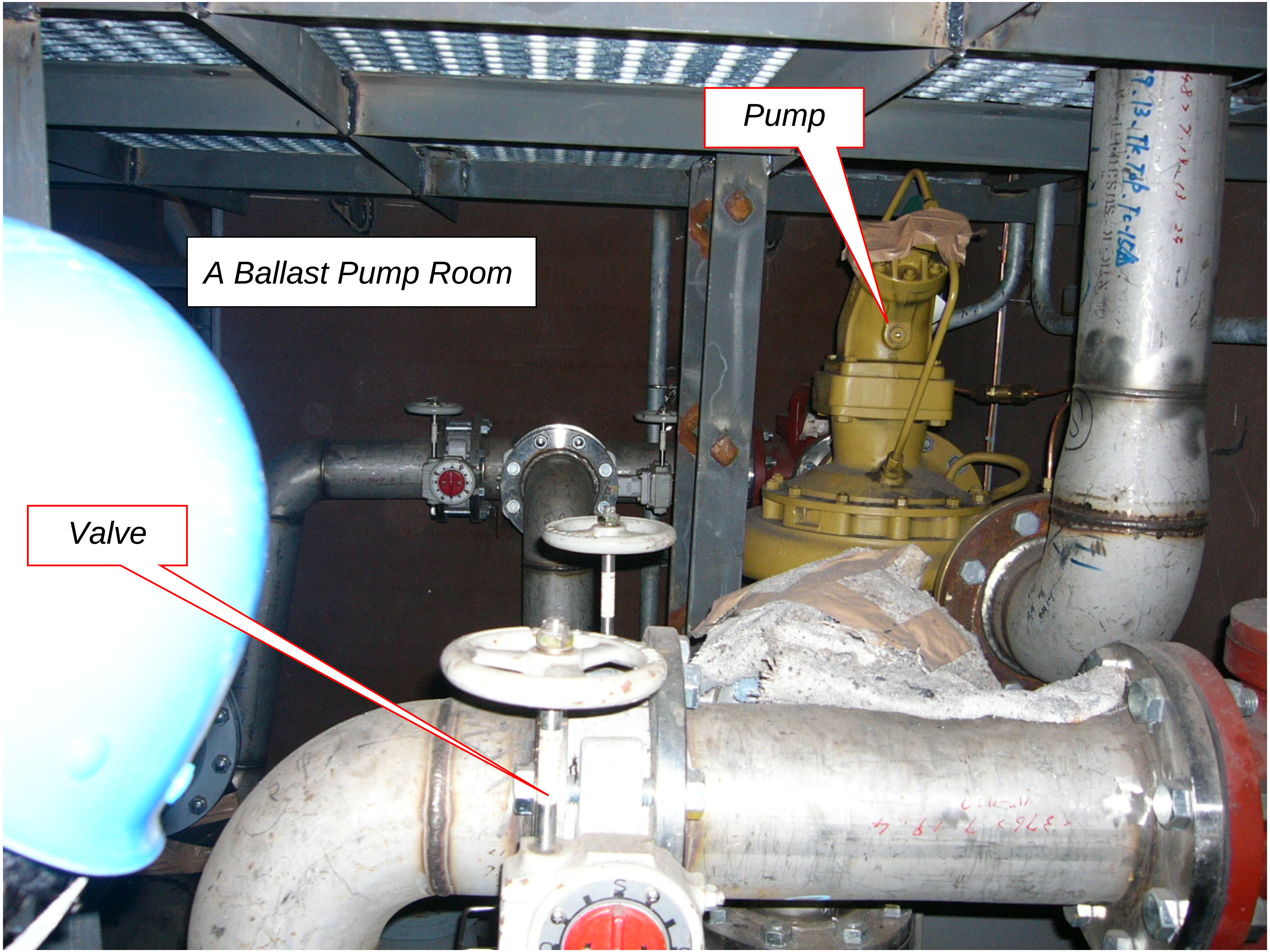
Coding for Genetic Algorithm (Only Valves)

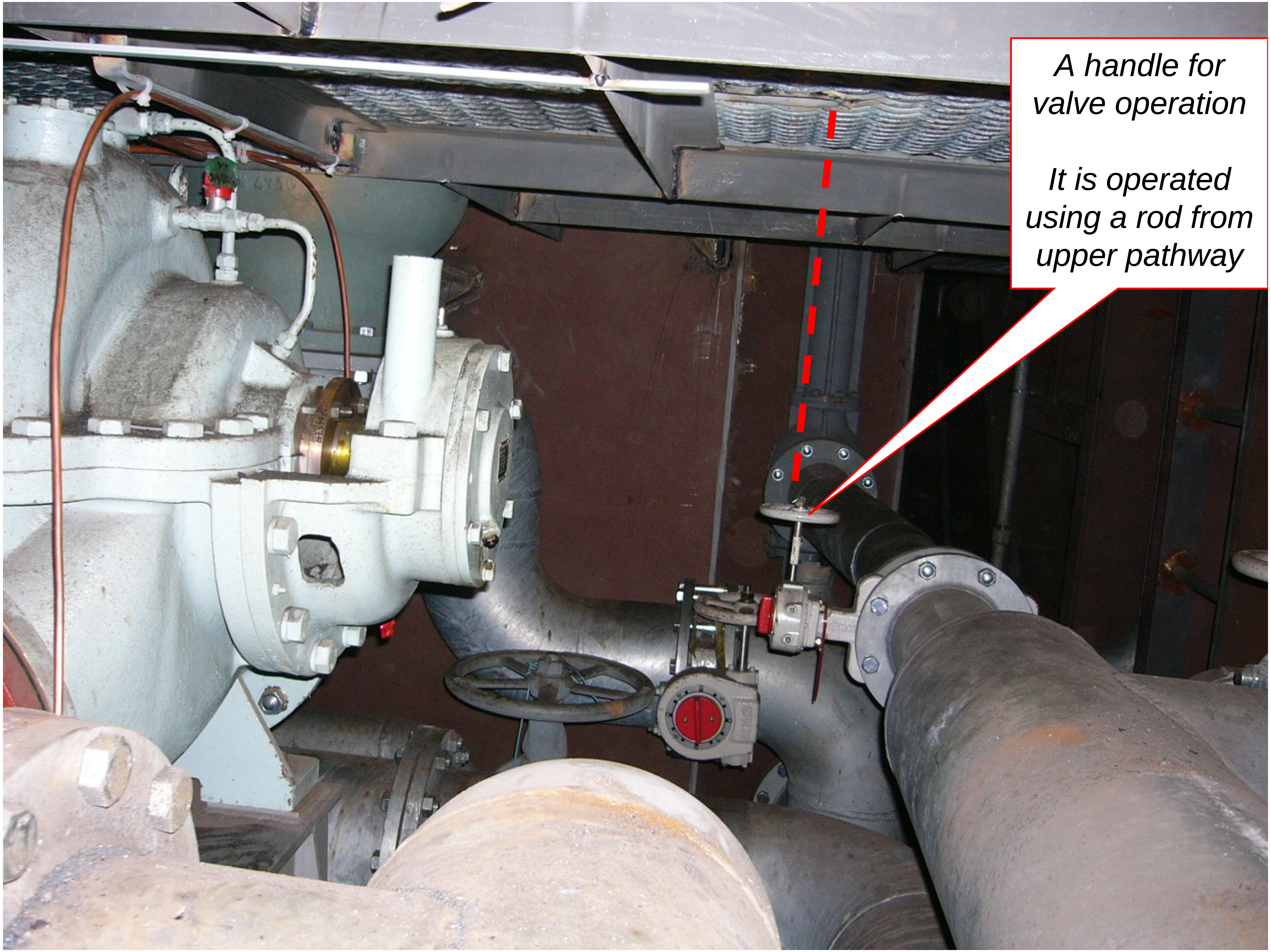
Multi-Objective Genetic Algorithm: NSGA-Ⅱ

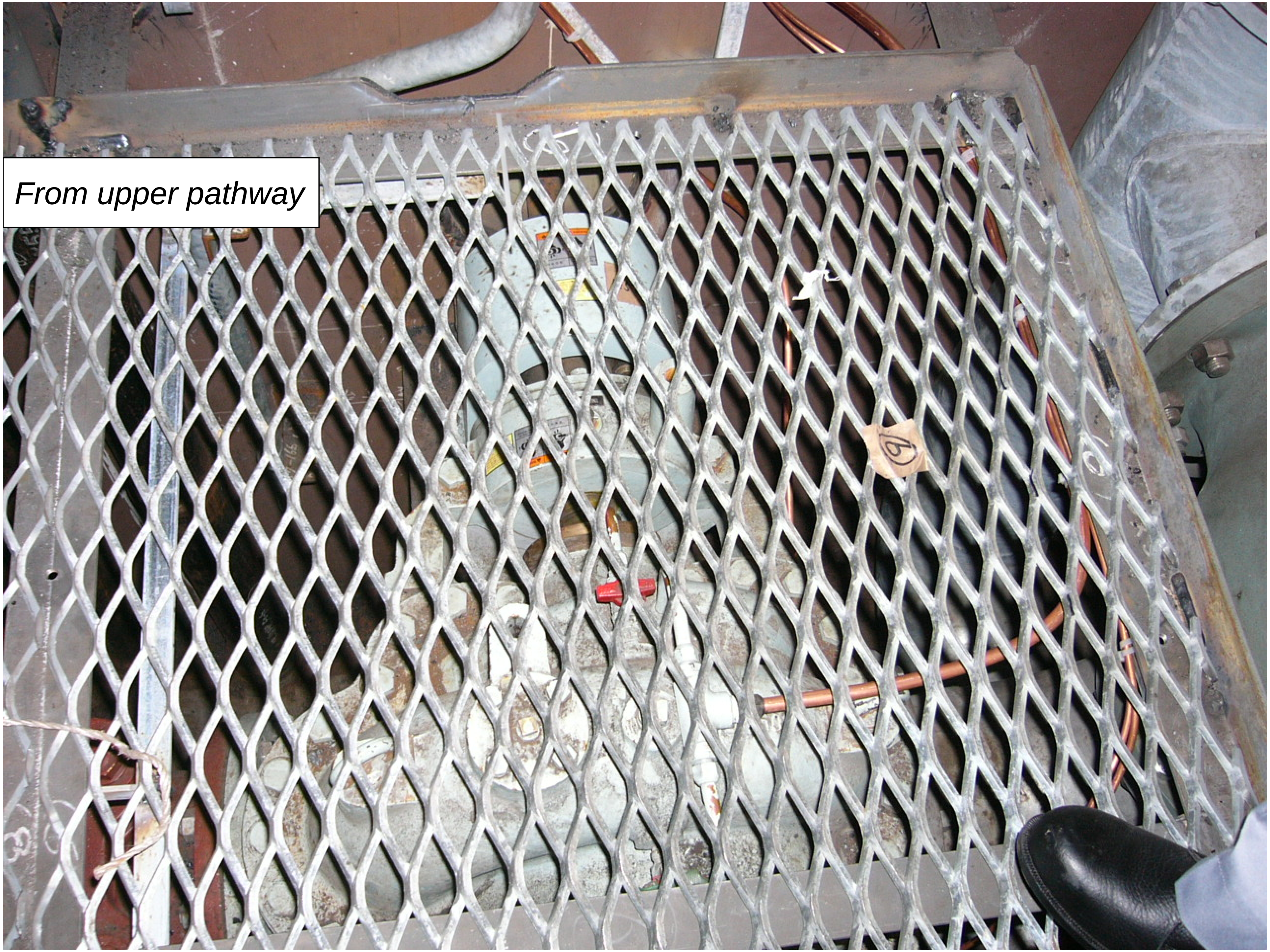
Routing Pipes and Making Branches

4. Experiments

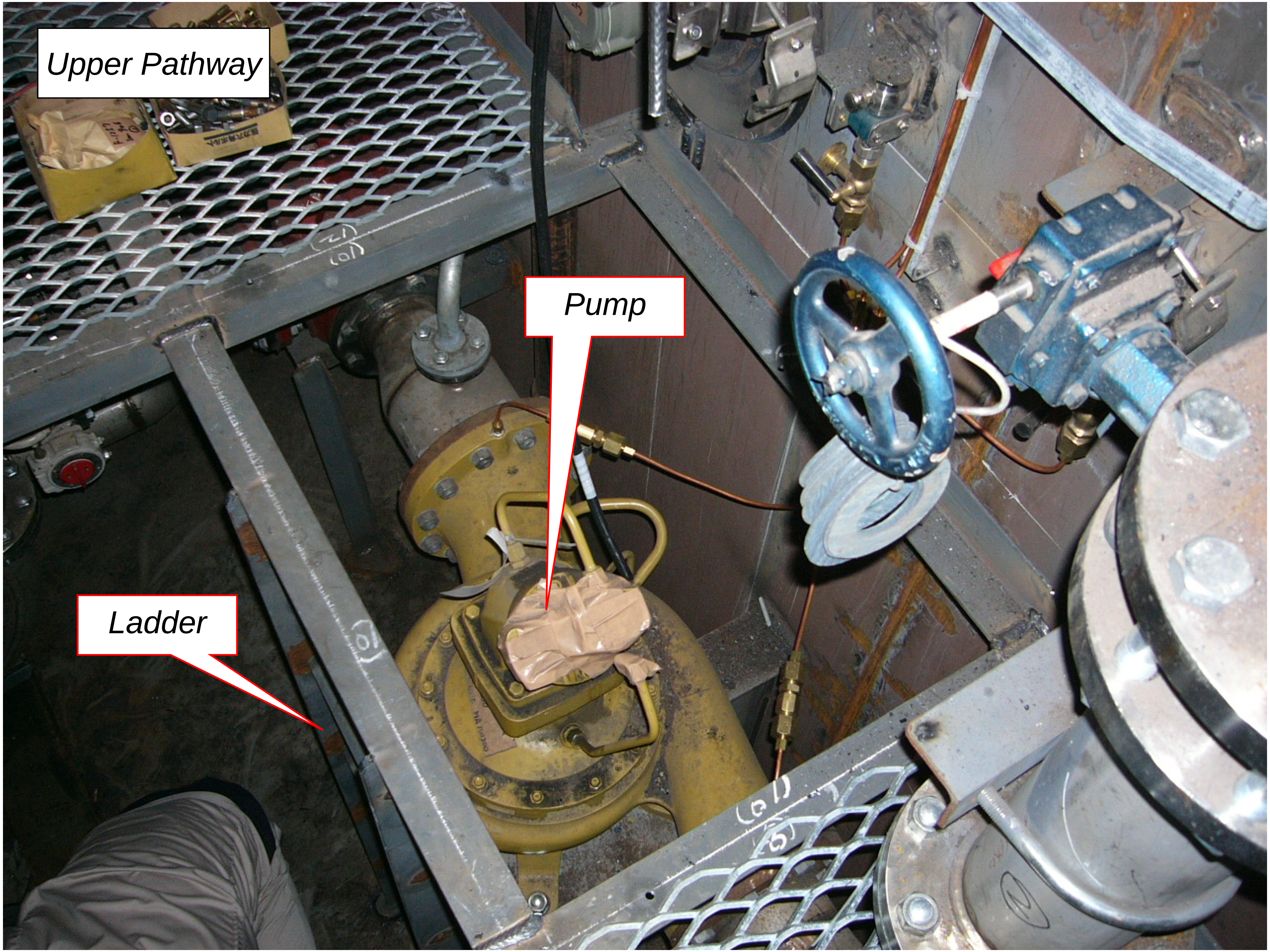
5. Conclusion and Future Works


Pump
A Ballast Pump Room
Valve


A handle for valve operation
It is operated using a rod from upper pathway



From upper pathway


Upper Pathway
Pump
Ladder

Motivation

But…

Pipe Arrangement $\xrightarrow[\text{designing efficiency}]{\text{3D-CAD contributes}}$

Needs sophisticated skills

~~Automatic design~~

Why？

Motivation

But…

Pipe Arrangement — 3D-CAD contributes designing efficiency →

- Needs sophisticated skills
- ~~Automatic design~~

Why？

[Reason 1] Obscurity of the design Criteria

Not only to arrange shortest pipes between equipments!

ex.) Easy to operate valves, easy for maintenance, etc.

Answer → 1) Define numerical evaluation for all items

2) Formulate as a multi-objective optimization

Motivation

Pipe Arrangement → (3D-CAD contributes designing efficiency)

But…

Needs sophisticated skills

~~Automatic design~~

Why？

[Reason 1] Obscurity of the design Criteria

Not only to arrange shortest pipes between equipments!
ex.) Easy to operate valves, easy for maintenance, etc.

Answer → 1) Define numerical evaluation for all items
2) Formulate as a multi-objective optimization

[Reason 2] A Problem in designing algorithms

It is no use that the algorithm gives only one solution!

Answer → Show plural solutions
Designer selects one of them as he needs.

Genetic algorithm

Motivation

Pipe Arrangement → 3D-CAD contributes designing efficiency

But…

Needs sophisticated skills

~~Automatic design~~

Why？

[Reason 1] Obscurity of the design Criteria

Not only to arrange shortest pipes between equipments!

ex.) Easy to operate valves, easy for maintenance, etc.

Answer → 1) Define numerical evaluation for all items

2) Formulate as a multi-objective optimization

[Reason 2] A Problem in designing algorithms

It is no use that the algorithm gives only one solution!

Answer → Show plural solutions

Designer selects one of them as he needs.

Genetic algorithm

Overview

1. Motivation and Purpose

2. Evaluation Algorithm for Valve Operationality

Accessibility

Possibility of Valve Handling

3. Multi-Objective Optimization Algorithm

Coding for Genetic Algorithm (Only Valves)

Multi-Objective Genetic Algorithm: NSGA-Ⅱ

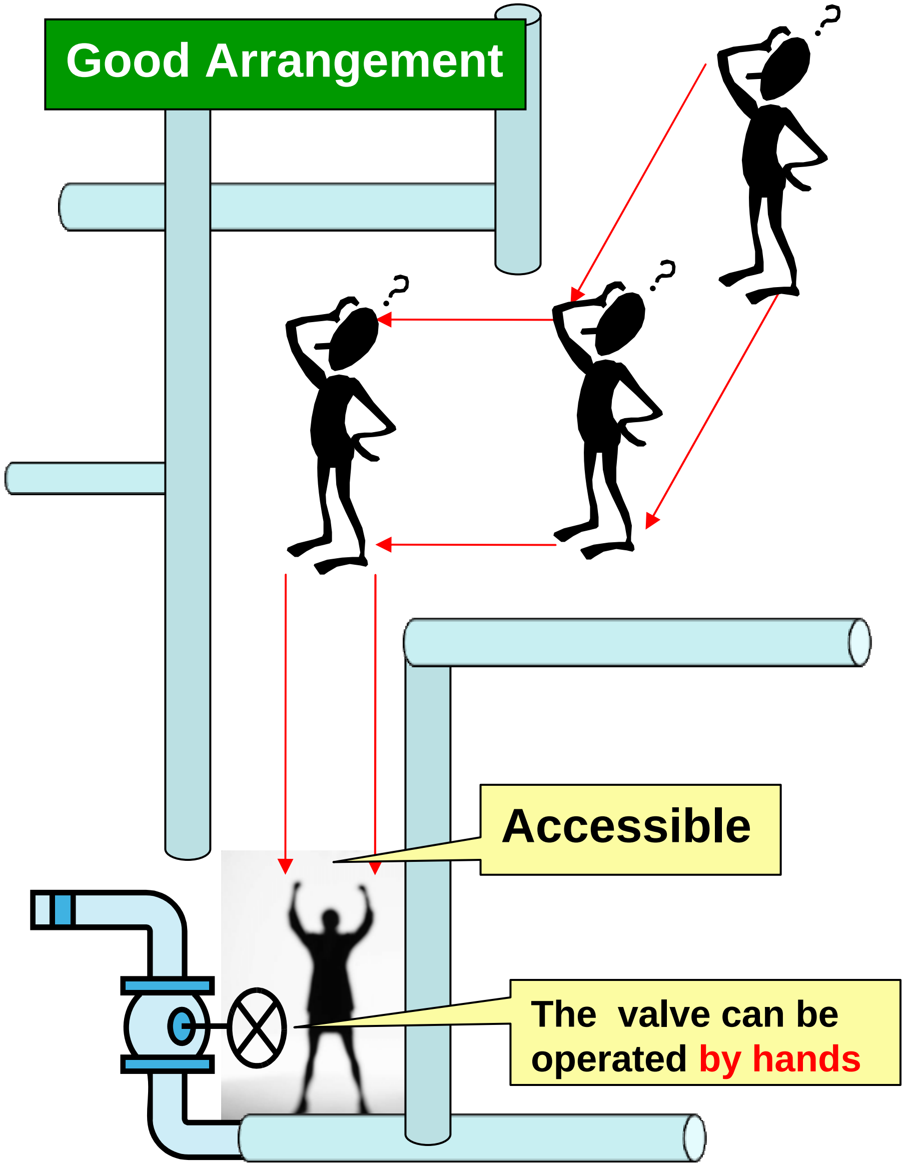
Routing Pipes and Making Branches

4. Experiments

5. Conclusion and Future Works

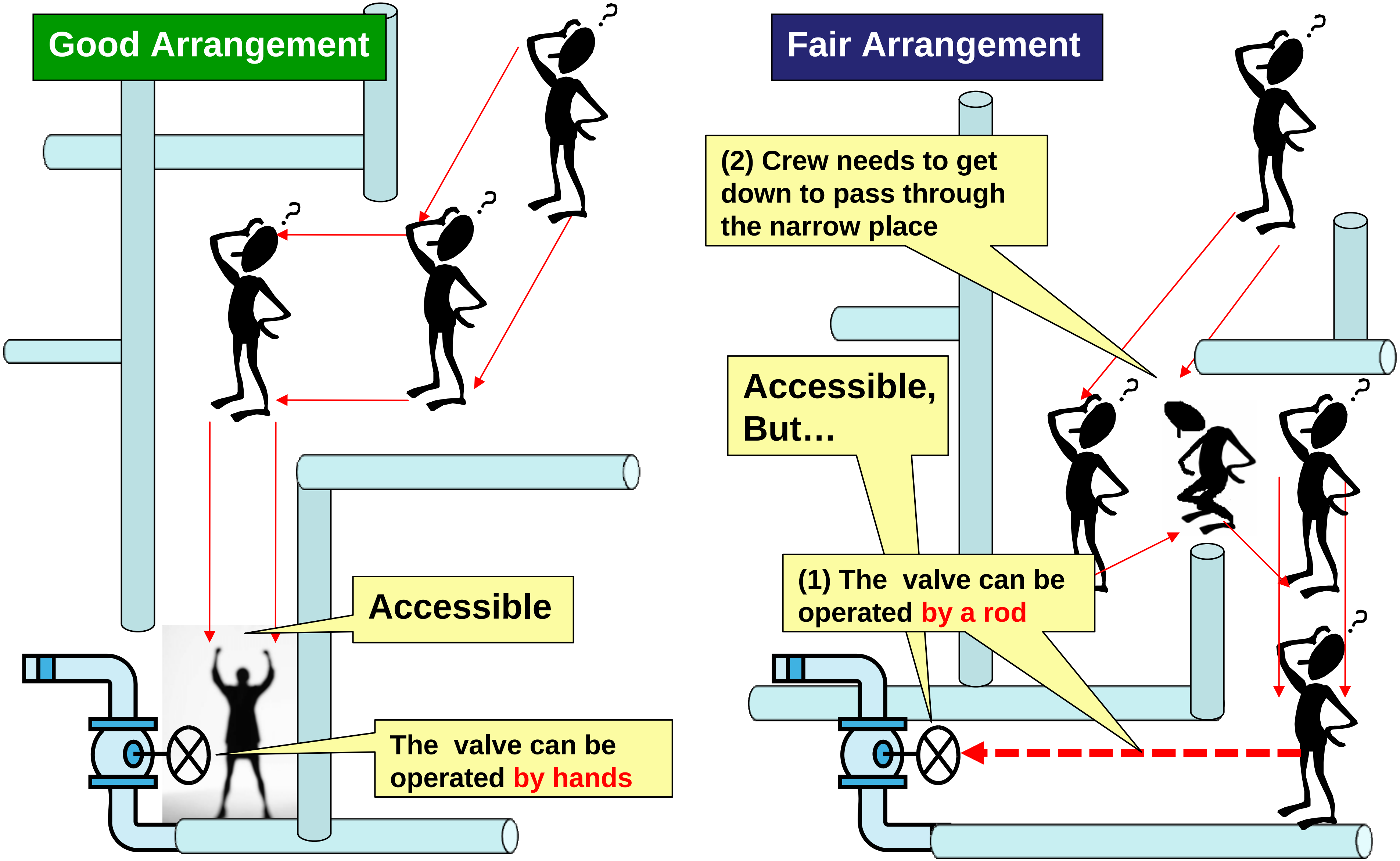
Valve Operationality

Evaluation of the space from pathways to valves



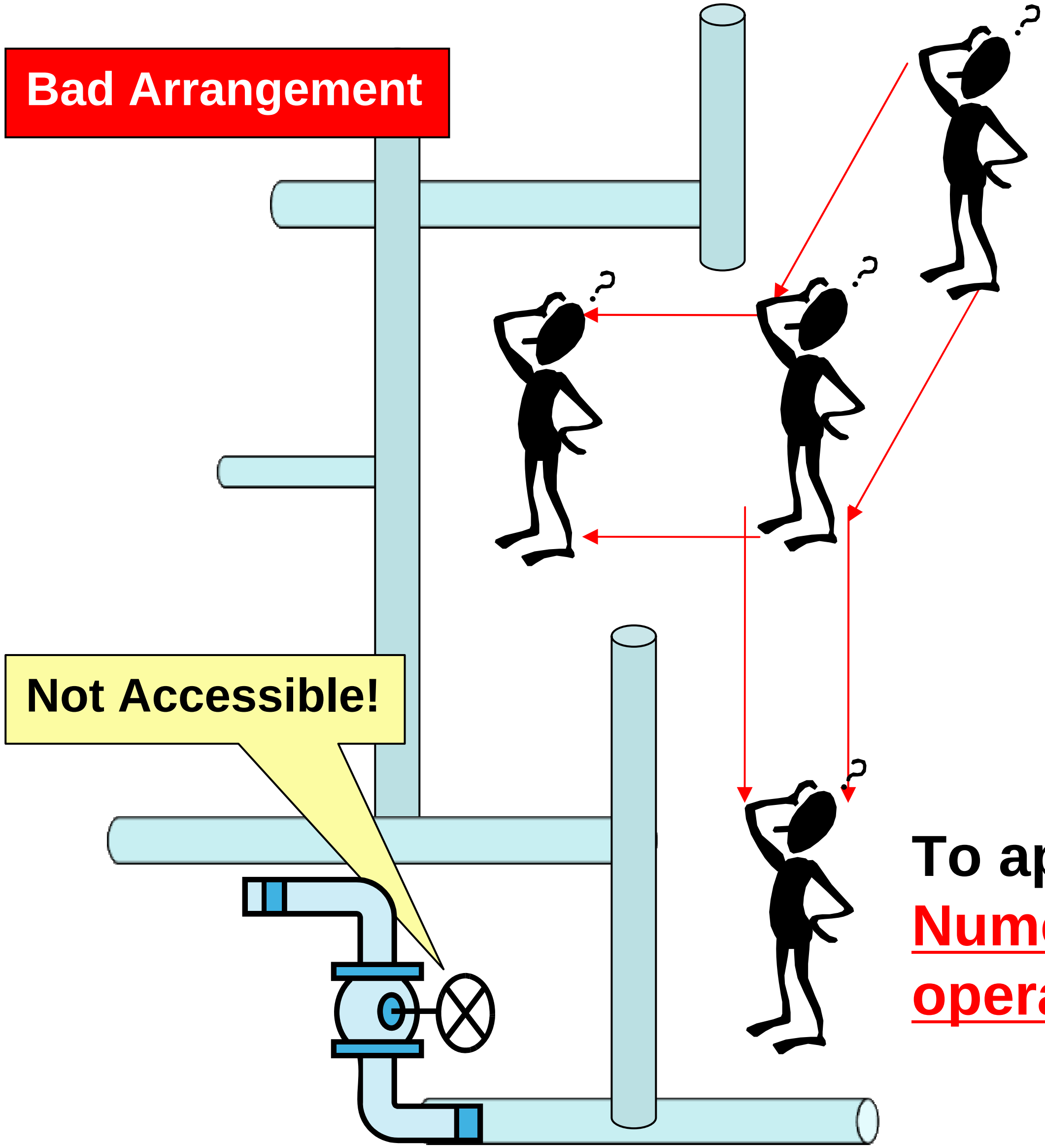
Valve Operationality

Evaluation of the space from pathways to valves



Valve Operationality

Evaluation of the space from pathways to valves

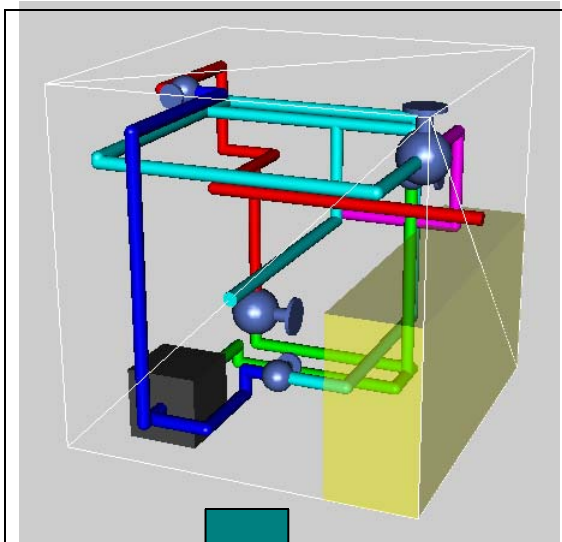


All pipes and valves must be arranged not only to put without interference each other but also to make space from pathways to valves so that crew can access the valves.

Implicit and Obscure so far!

To apply optimization algorithms, Numerical evaluation for the valve operationality is needed.

Evaluation Algorithm for Valve Operationality



Accessibility

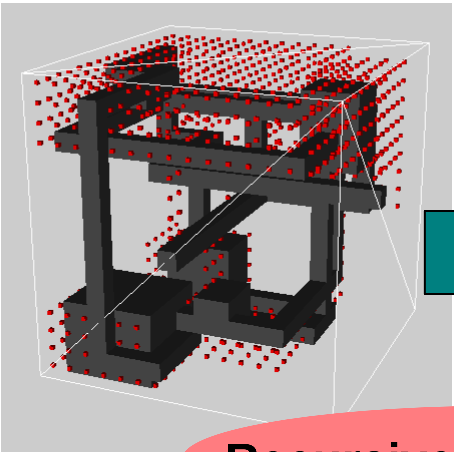
Crew can move to a position where the valve can be operated by hands or by some tools.

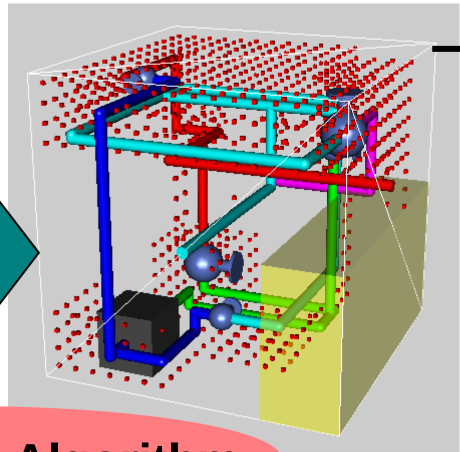
Possibility of Valve Handling

The valve can be operated by hands.

The design space is partitioned into **regular grids,**

and recognize accessible segments

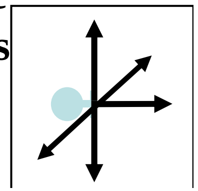




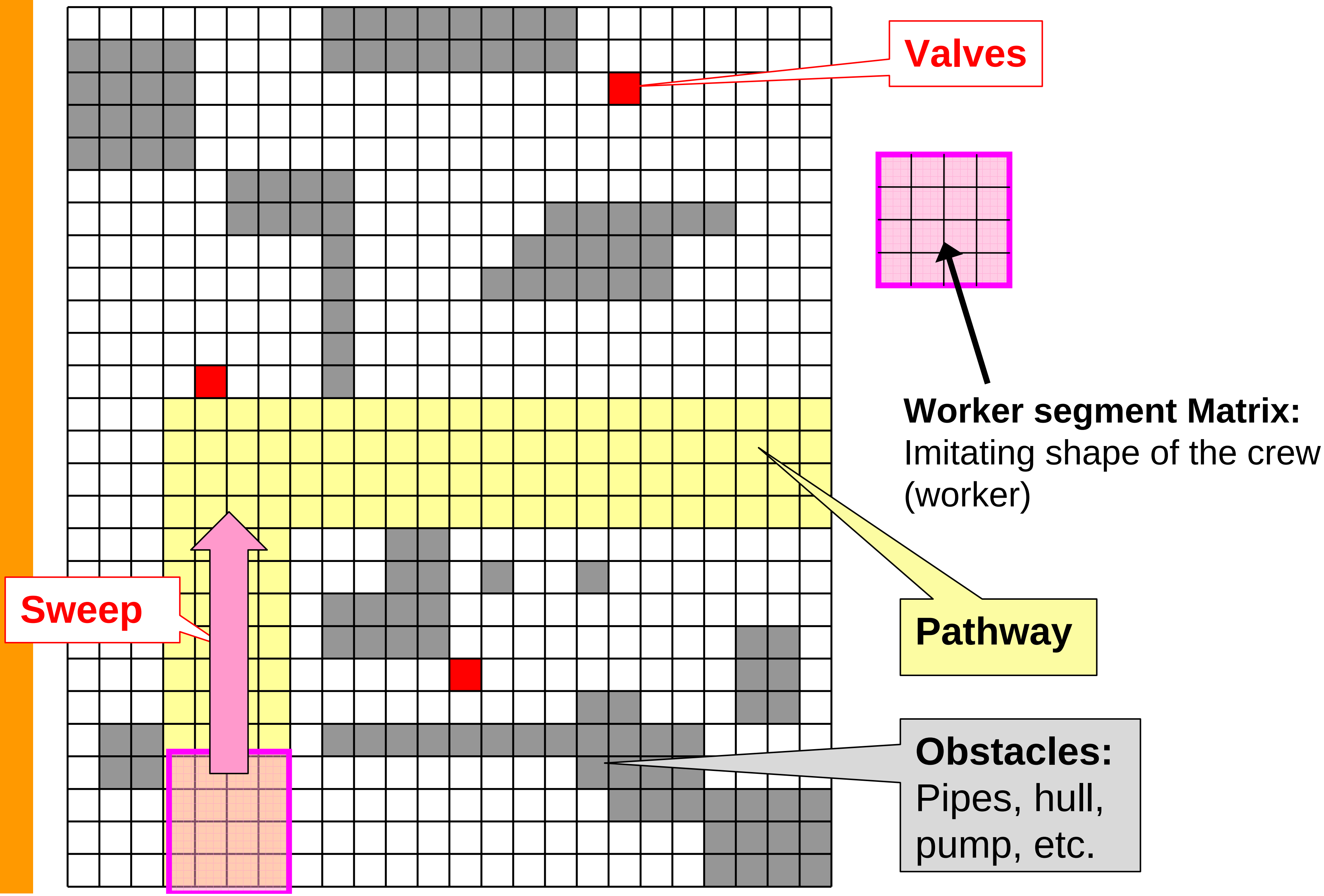
Recursive Fill Algorithm

Evaluation

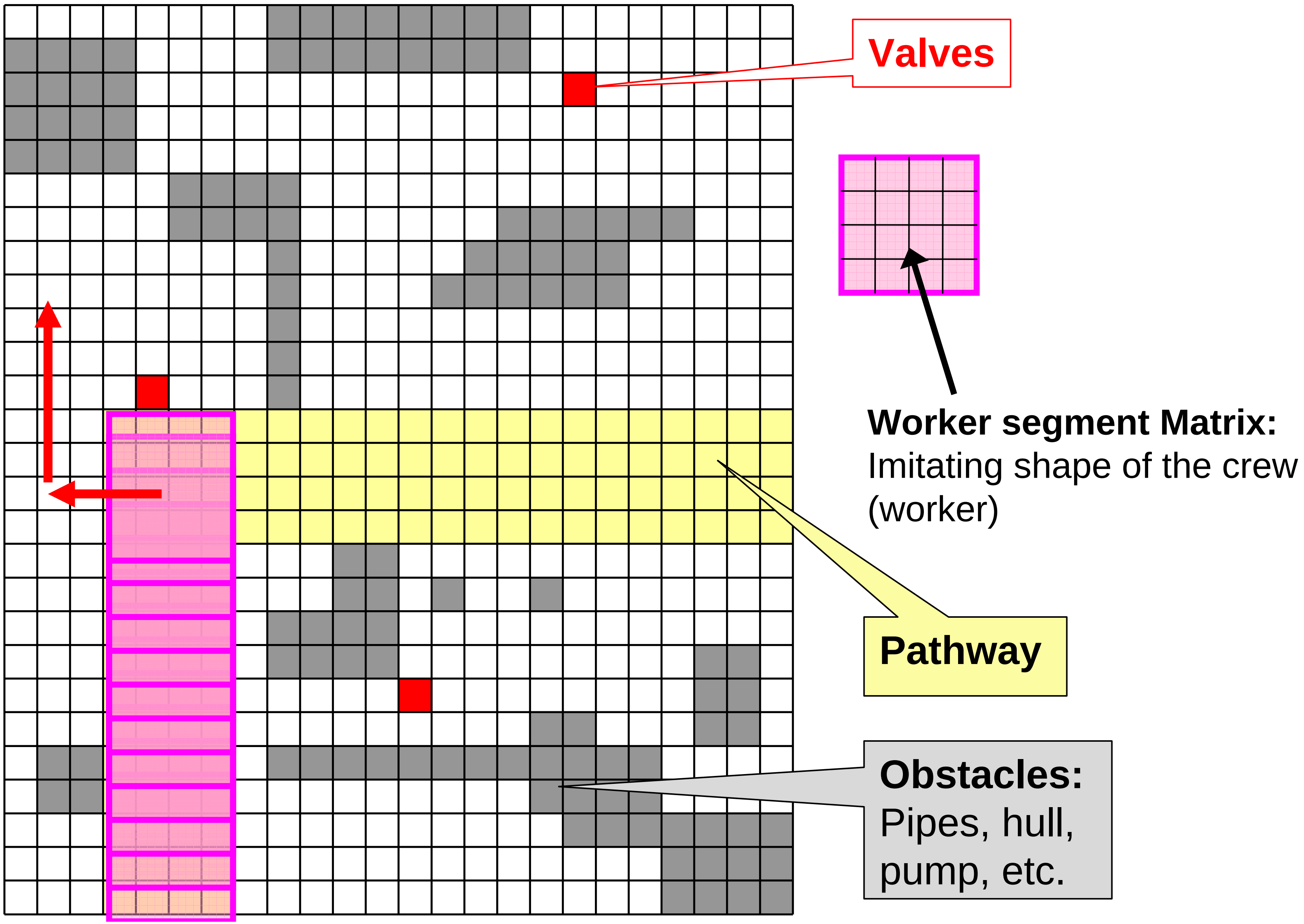
Valve operationality is calculated in this grid space by summing up the minimum distance from each valve to accessible segments that are located in the direction of the axis of the valve's handle or four directions perpendicular to that axis.



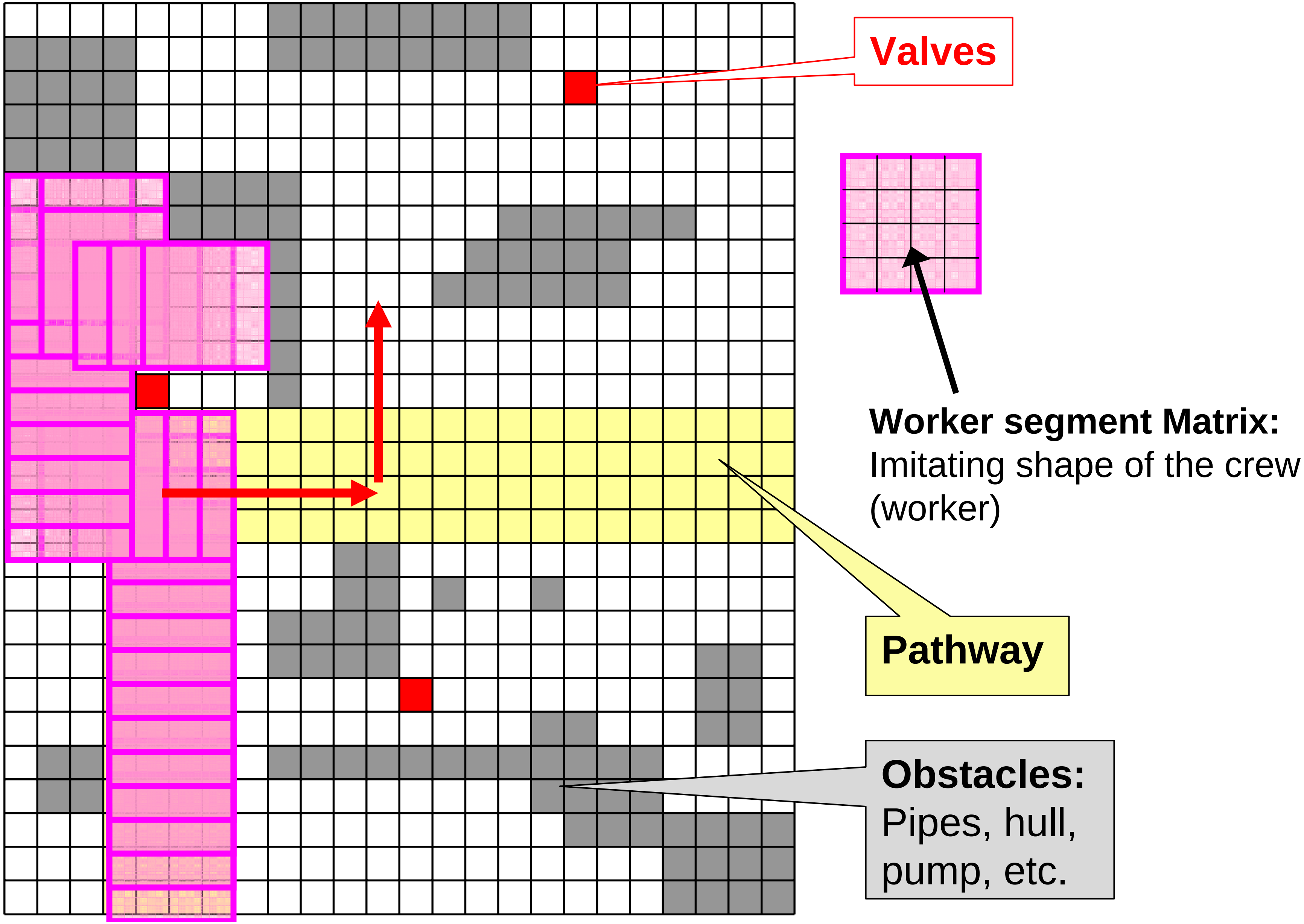
Finding Accessible Segments: Recursive Fill Algorithm



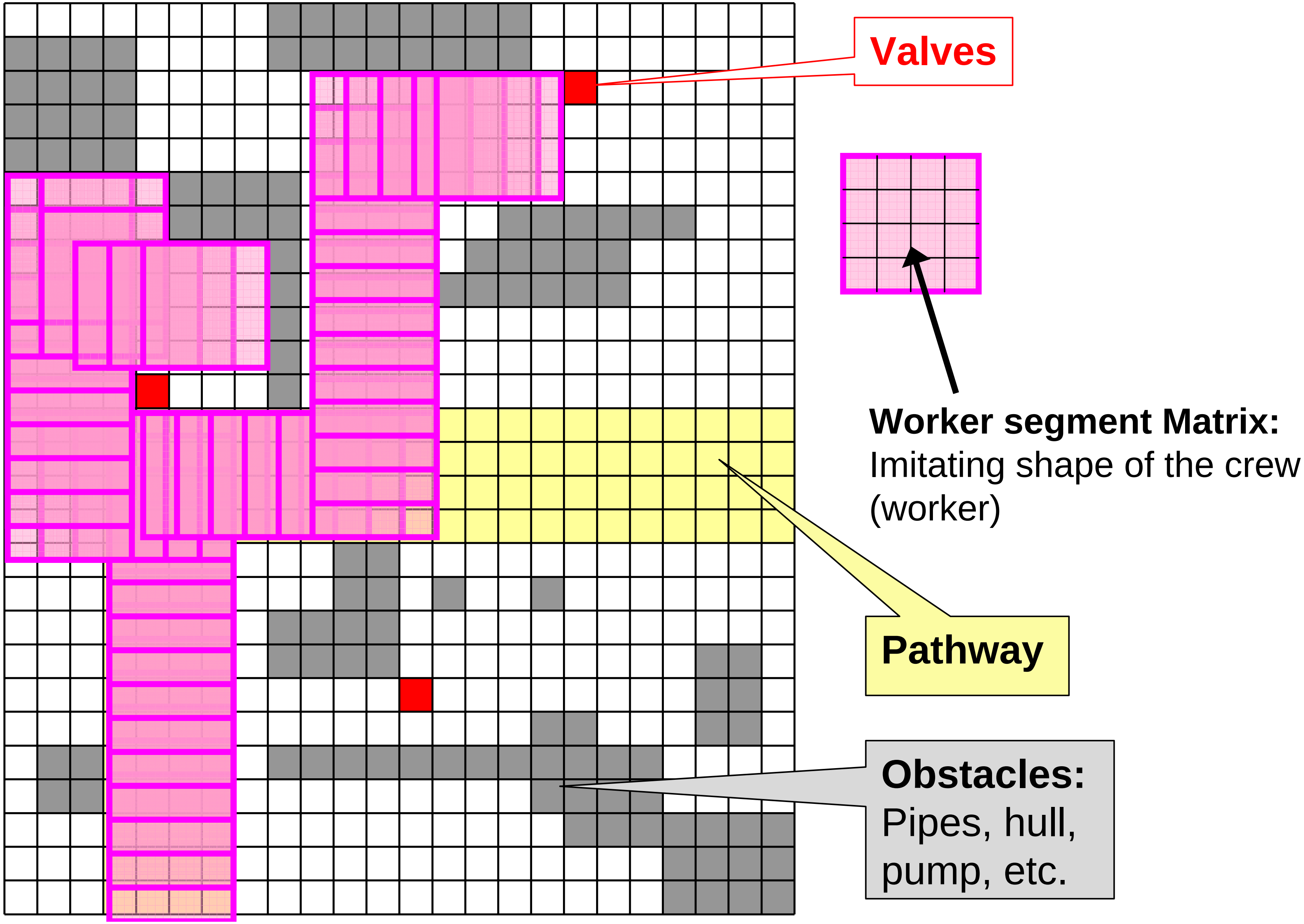
Finding Accessible Segments: Recursive Fill Algorithm



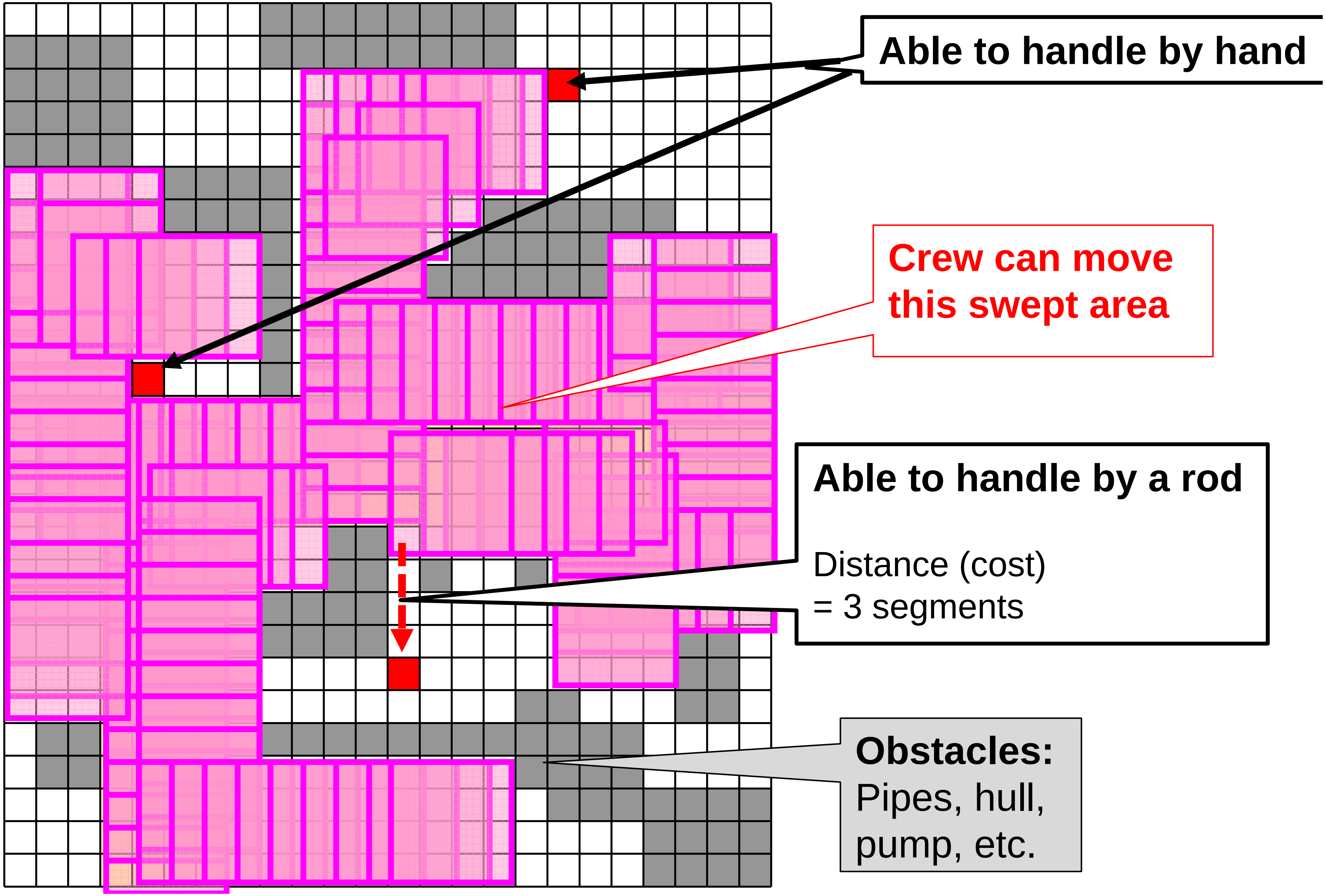
Finding Accessible Segments: Recursive Fill Algorithm

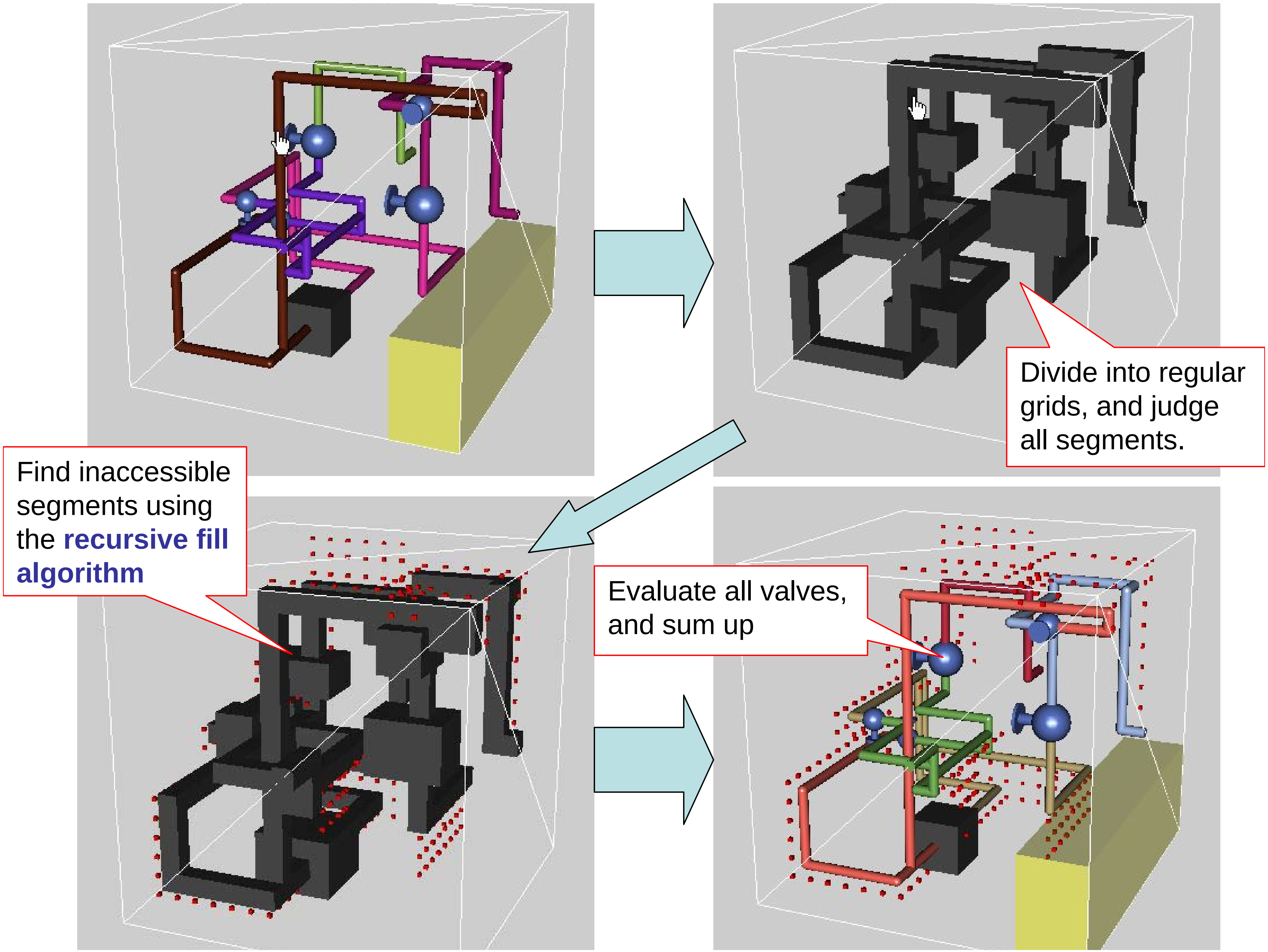


Finding Accessible Segments: Recursive Fill Algorithm



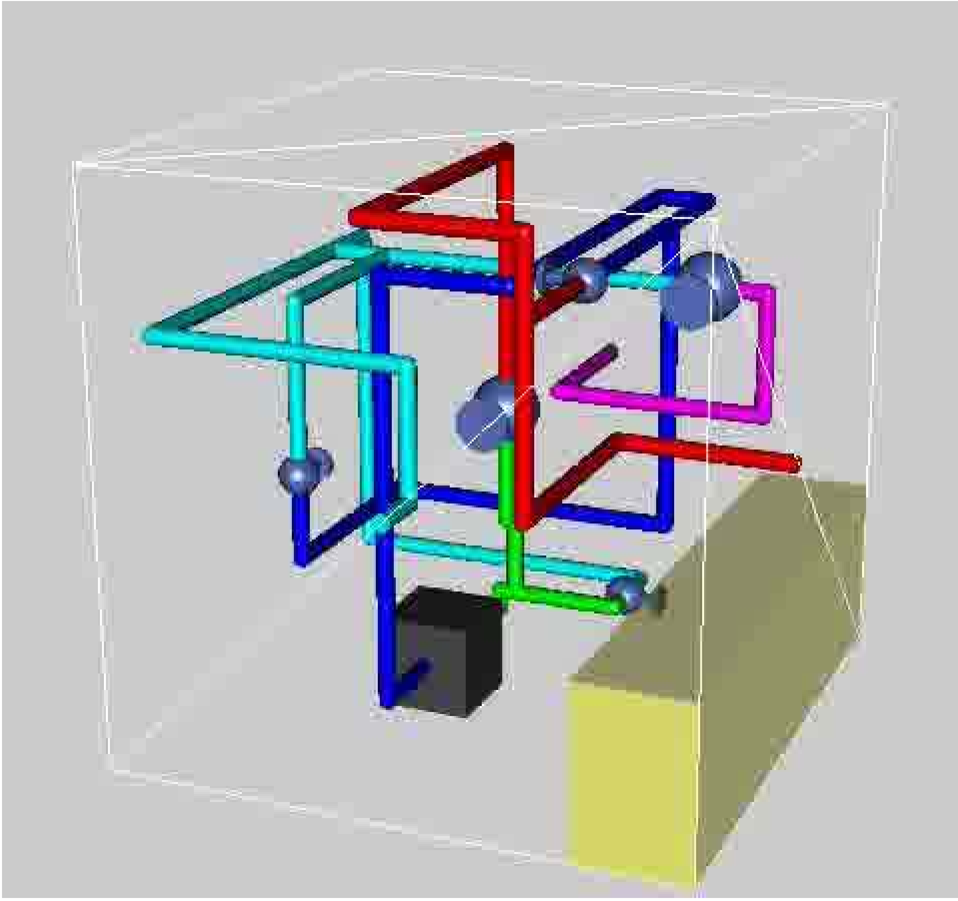
Finding Accessible Segments: Recursive Fill Algorithm

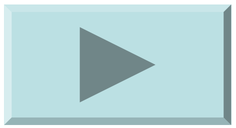




Divide into regular grids, and judge all segments.
Find inaccessible segments using the **recursive fill algorithm**
Evaluate all valves, and sum up

DEMO





Features of the Evaluation Algorithm

Accessible

1. Crew can move to a position where the valve can be operated by hands. → **Good** **Cost = 0**

2. Crew can move to a position where the valve can be operated by a rod, but cannot be operated by hands. → **Fair** **Cost = distance**

Inaccessible

Crew cannot move to a position where the valve can be operated because obstacles surround valves. → **Bad** **Cost = 10000**

Summing over all valves

Expert's Obscure or Implicit Criterion of

Valve-Operationality is clearly numerically defined.

Overview

1. **Motivation and Purpose**

2. **Evaluation Algorithm for Valve Operationality**

   Accessibility

   Possibility of Valve Handling

3. **Multi-Objective Optimization Algorithm**

   Coding for Genetic Algorithm (Only Valves)

   Multi-Objective Genetic Algorithm: NSGA-Ⅱ

   Routing Pipes and Making Branches

4. **Experiments**

5. **Conclusion and Future Works**

Motivation

Pipe Arrangement $\xrightarrow[\text{designing efficiency}]{\text{3D-CAD contributes}}$ But…

- Needs sophisticated skills
- ~~Automatic design~~

Why？

[Reason 1] Obscurity of the design Criteria

Not only to arrange shortest pipes between equipments!
ex.) Easy to operate valves, easy for maintenance, etc.

Answer → 1) Define numerical evaluation for all items
2) Formulate as a multi-objective optimization

[Reason 2] A Problem in designing algorithms

It is no use that the algorithm gives only one solution!

Answer → Show plural solutions
Designer selects one of them as he needs.

Genetic algorithm

Motivation

Pipe Arrangement —3D-CAD contributes designing efficiency→ But…
Needs sophisticated skills
~~Automatic design~~

Why？

[Reason 1] Obscurity of the design criteria

Not only to arrange shortest pipes between equipments!
ex.) Easy to operate valves, easy for maintenance, etc.

Answer → 1) Define numerical evaluation for all items
2) **Formulate as a multi-objective optimization**

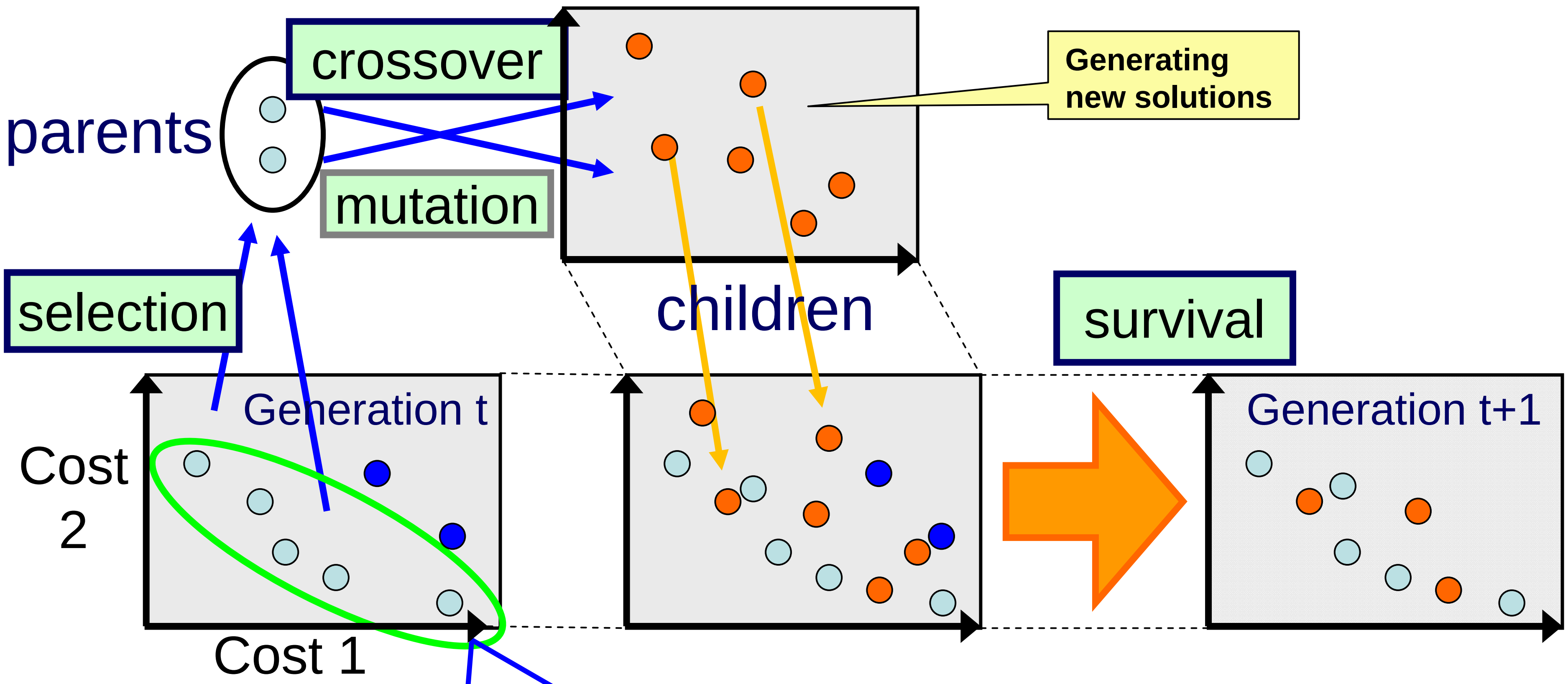
[Reason 2] A Problem in designing algorithms

It is no use that the algorithm gives only one solution!

Answer → Show plural solutions
Designer selects one of them as he needs.

Genetic algorithm

Multi-Objective Genetic Algorithm (MOGA)



<u>Pareto optimum solutions:</u>
Suited for showing plural solutions!

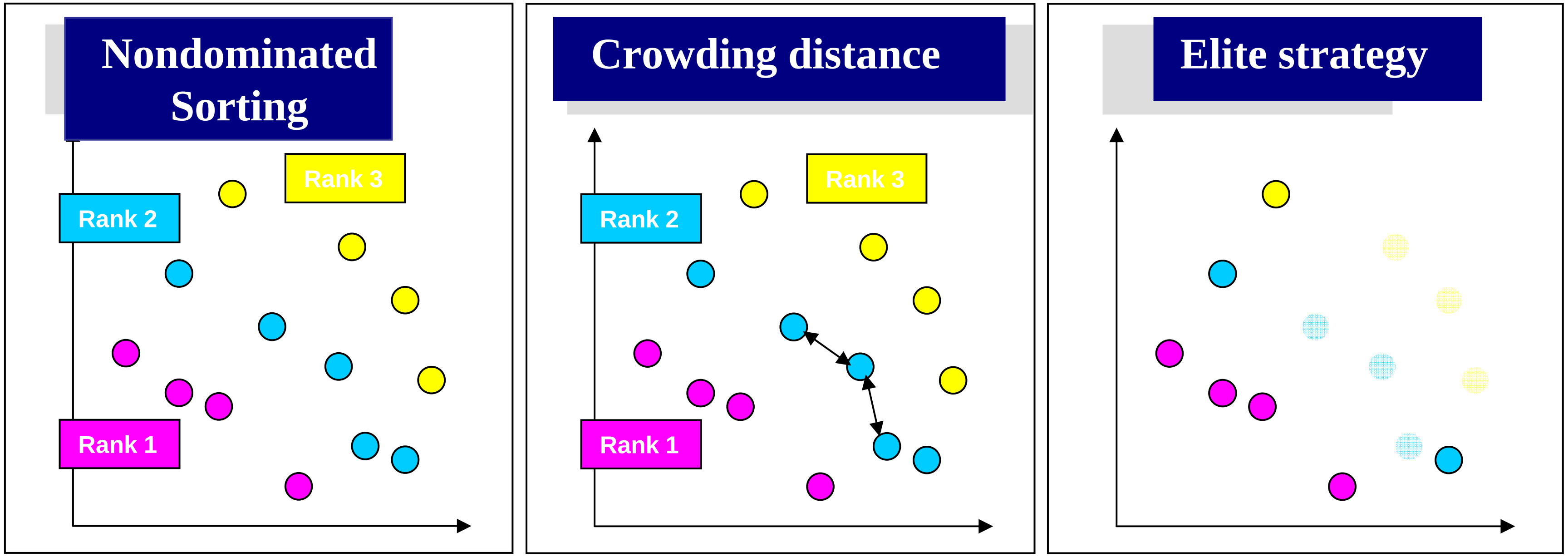
NSGA-Ⅱ

NSGA-Ⅱ： Nondominated Sorting Genetic Algorithms Ⅱ

Multi-objective Genetic algorithm

1. Efficient calculation in Nondominated Sorting
2. Crowding distance
3. Elite strategy

Reference
Kalyanmoy Deb:
A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-Ⅱ,
IEEE Transactions on Evolutionary Computation, vol. 6, No. 2, (2002)



Problem Formulation

Pipe diagram

P&ID → **Pipeline FROM – TO List**

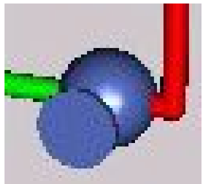
Plot Plan → **Equipment Dim. & Loc.**

Equipment arrangement list

Given

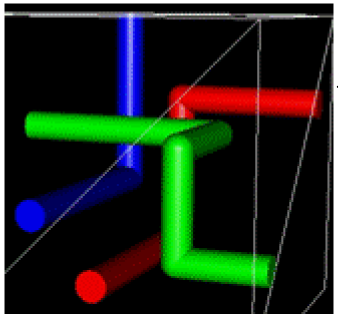
Search Space

- Parameters for VALVES



locations
directions

- Parameters for PIPES



locations
directions
branches → patterns, locations

Minimize **Valve Operationality (cost)** **and** **Cost of Materials**

Material Cost

Material Cost Function

$$f\_material = \sum_{k=1}^{n_p} W_k L_k D_k$$

W_k : **Weight of the kth pipe**

L_k : **Length of the kth pipe**

D_k : **Diameter of the kth pipe**

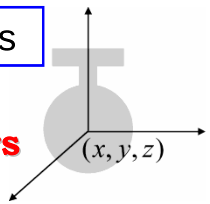
n_p : Number of pipes

Coding for the Genetic Algorithm (GA)

Parameters of Valves
- coordinates
- directions

Coordinates of valves

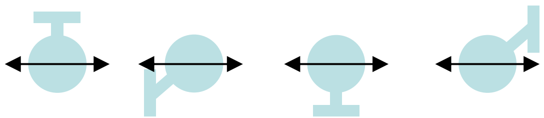
Three parameters



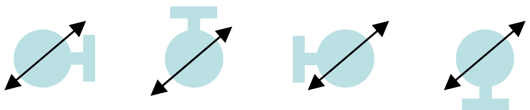
Directions of valves

12 patterns

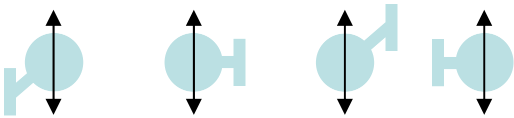
x axis



y axis



z axis



The parameters of valves are dominant to the parameters of pipes, because the pipes are routed between valves.

Only the parameters of the valves are encoded as the genes for the GA.

Gene Matrix:

$$\begin{bmatrix} \theta_1 & \theta_2 & \cdots & \theta_n \\ x_1 & x_2 & \cdots & x_n \\ y_1 & y_2 & \cdots & y_n \\ z_1 & z_2 & \cdots & z_n \end{bmatrix}$$

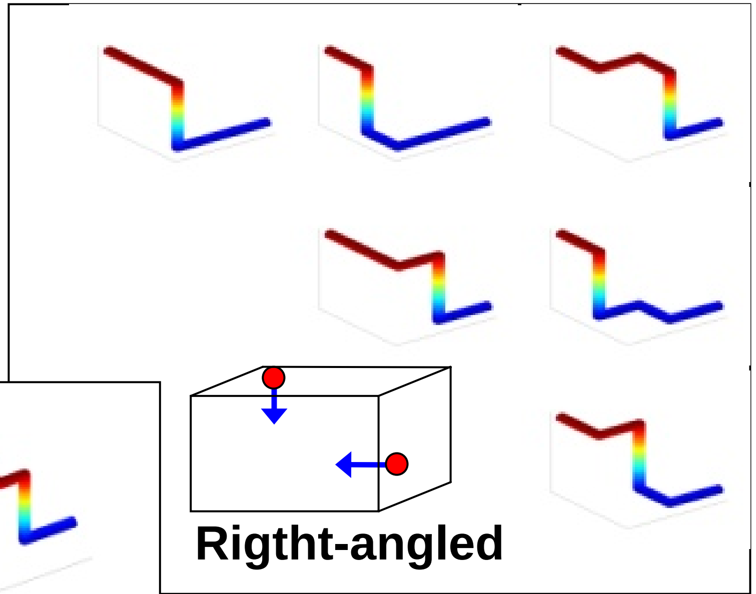
One point crossover

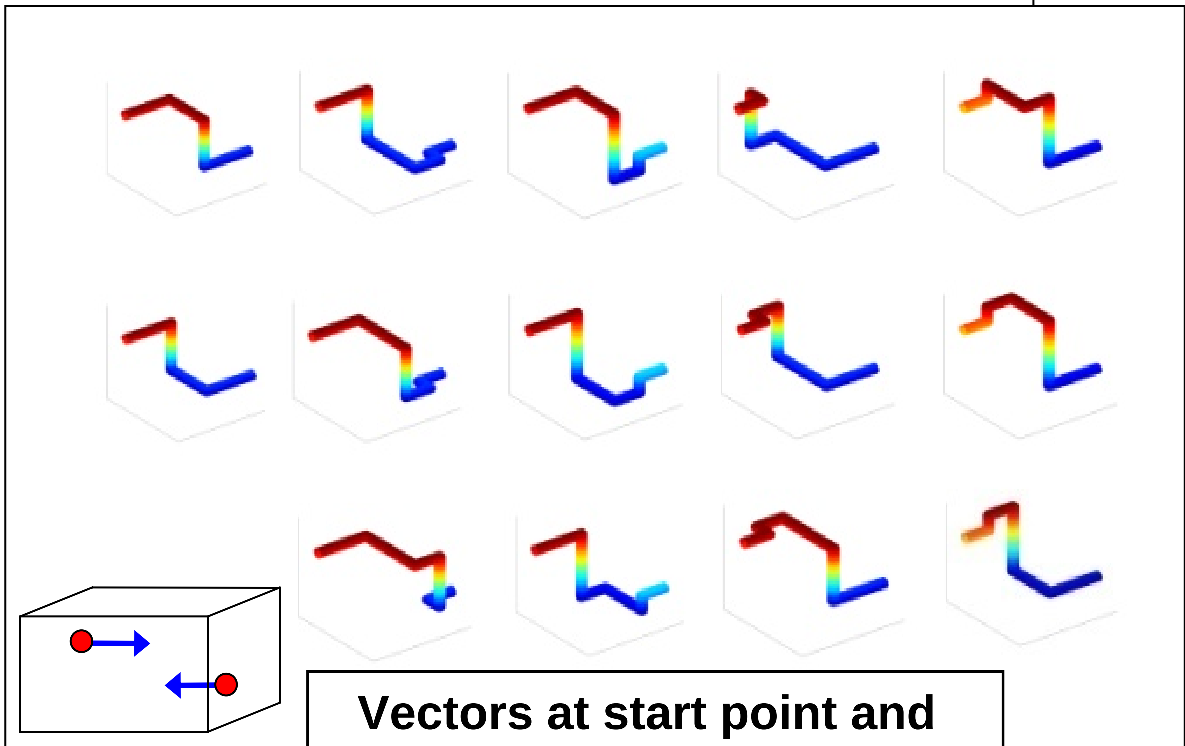
Pipes are arranged by **local search** algorithms after the parameters of valves are determined. (**Routing** and **Branching**)

Routing Pipes (1)

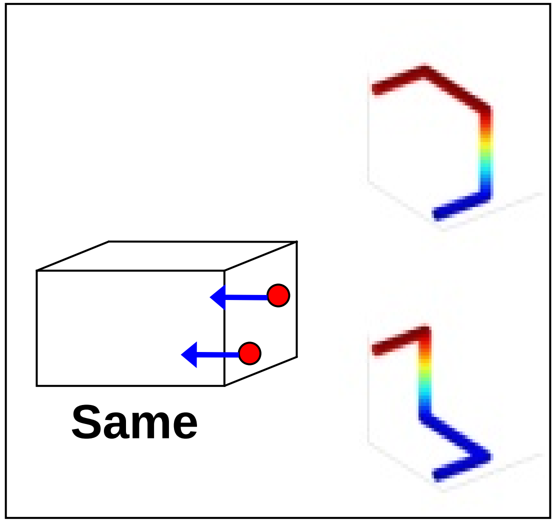
Valves, pumps, connections or branches.
Each point has location and direction

Pipe Routing between two points is limited to finite patterns





Vectors at start point and end point are opposite

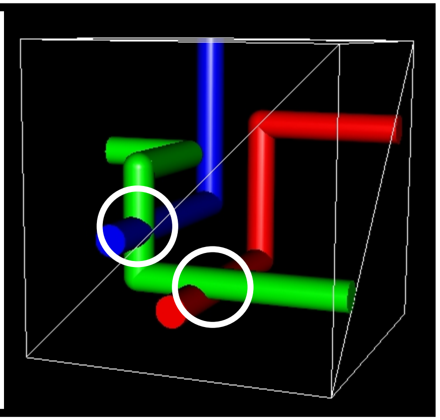


Routing Pipes (2)

Modification for Interfered Pipes

Pipes are Interfered

Infeasible!

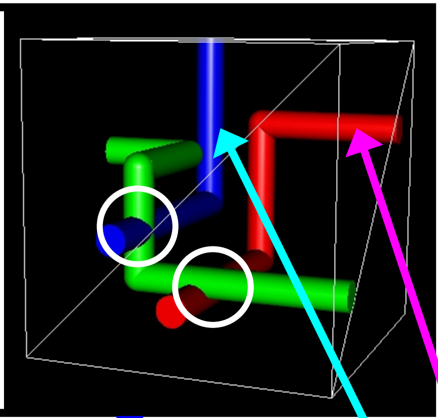


Routing Pipes (2)

Modification for Interfered Pipes

Pipes are Interfered

Infeasible!

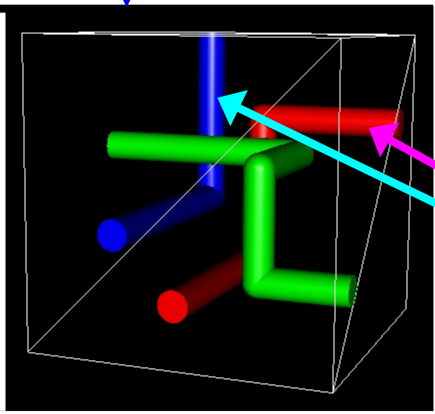


Modification Operator

The **green pipe** is removed

All Pipes are Separated

Feasible!



Also the smaller diameter pipes have the higher priority.

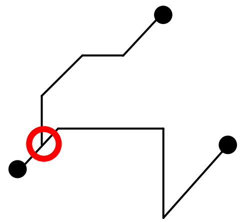
The more interfered pipes, the higher priority to remove

Maintain the shape as similar as possible

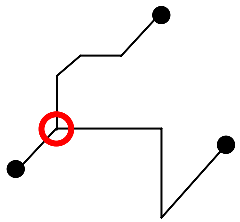
Not Changed

Generating Branches of Pipes

Problems

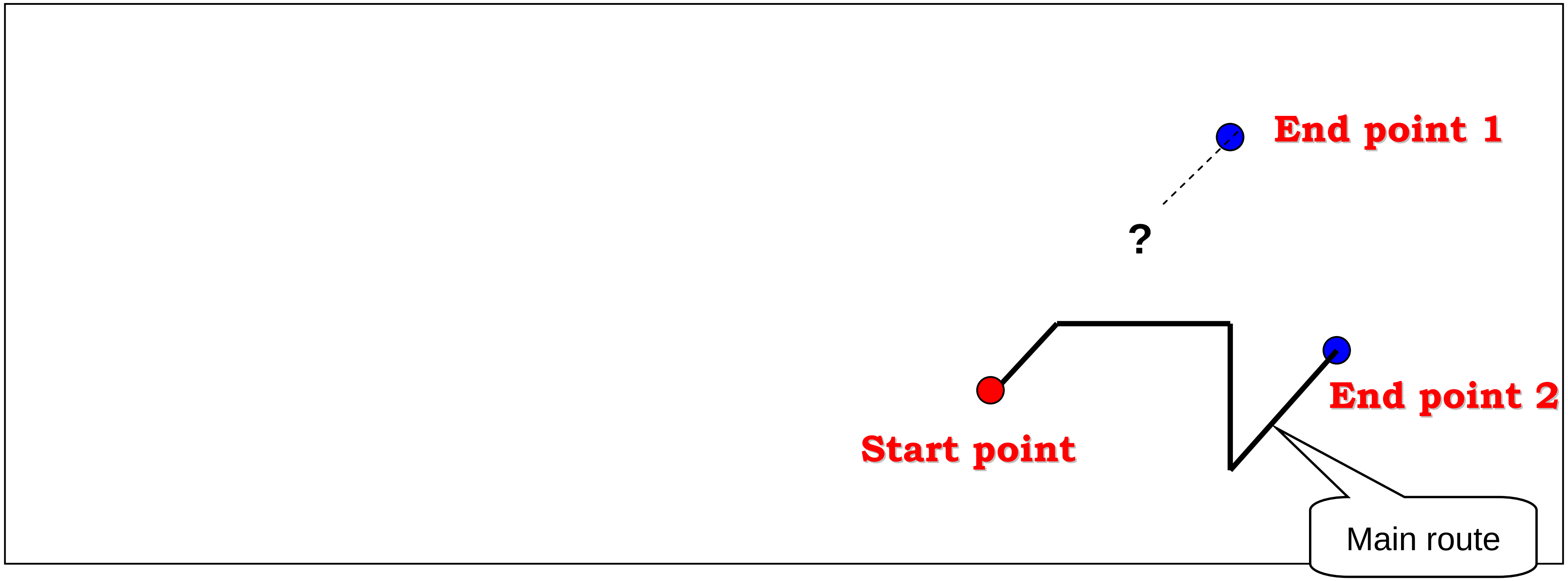


Increasing elbows



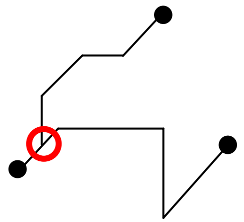
Infeasible elbow

How to Generate
T- branch efficiently?

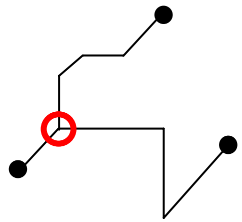


Generating Branches of Pipes

Problems



Increasing elbows

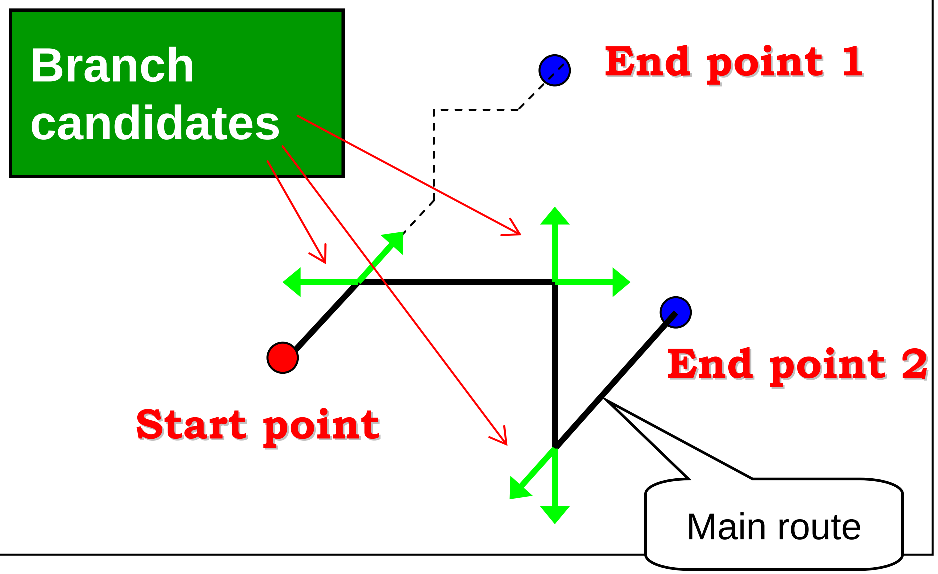


Infeasible elbow

How to Generate T- branch efficiently?

Answer:

Generate a T-branch on an elbow on the main route of the pipeline



Overview

1. Motivation and Purpose

2. Evaluation Algorithm for Valve Operationality

Accessibility

Possibility of Valve Handling

3. Multi-Objective Optimization Algorithm

Coding for Genetic Algorithm (Only Valves)

Multi-Objective Genetic Algorithm: NSGA-Ⅱ

Routing Pipes and Making Branches

4. Experiments

5. Conclusion and Future Works

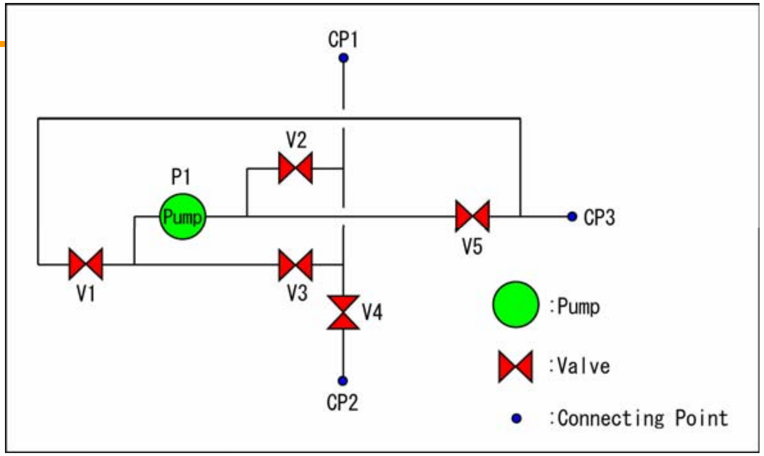
Experiments

Pipeline list

Input : From-to list

LINE NO	FLUID	SIZE	CLASS	FROM-TO					
P-001	S	150	-	V1	P1	V3	-	-	-
P-002	S	150	-	V1	V5	CP3	-	-	-
P-003	P	150	-	P1	V2	V5	-	-	-
P-004	P	150	-	V2	CP1	V3	V4	-	-
P-005	D	150	-	V4	CP2	-	-	-	-

VALVE NO	SIZE L	SIZE D	SIZE H	CLASS	AFTER			FORWARD		
V1	0.3	0.3	0.5	-	V5	CP3	-	P1	V3	-
V2	0.3	0.3	0.5	-	P1	V5	-	V3	V4	CP1
V3	0.3	0.3	0.5	-	P1	V1	-	V2	V4	CP1
V4	0.5	0.5	0.8	-	CP2	-	-	V2	V3	CP1
V5	0.5	0.5	0.8	-	P1	V2	-	V1	CP3	-



Equipment arrangement list

Input : Equipment list

EQUIP-NO	CATEGORY	TYPE	X	Y	Z	DIR	AFTER			FORWARD		
P1	PUMP	RK2	1.5	2.0	0.0	90.0	V1	V3	-	V2	V5	-

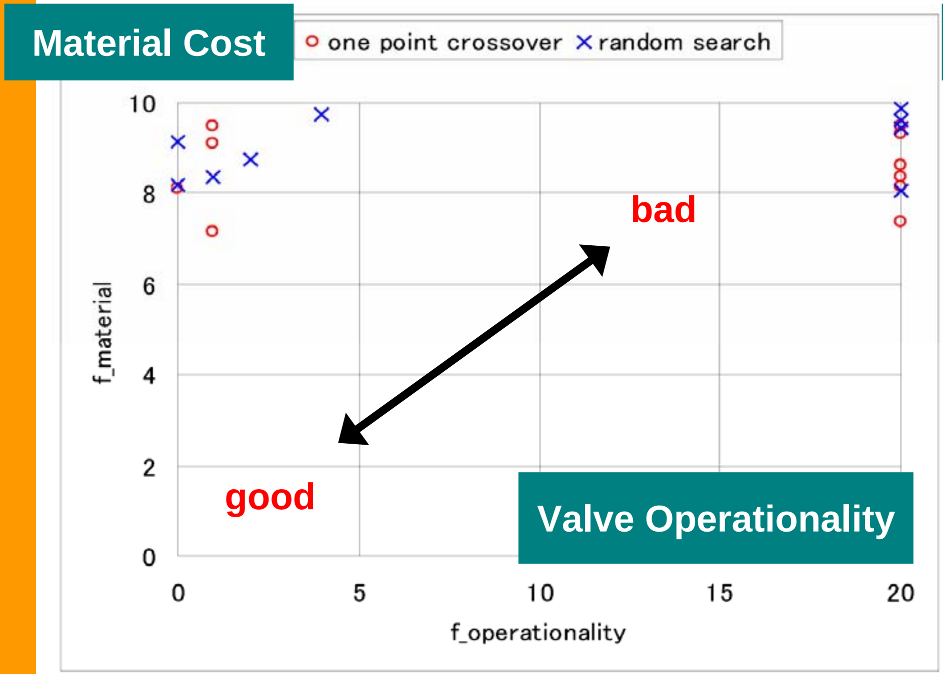
CATEGORY	TYPE	SIZE X	SIZE Y	SIZE Z
PUMP	RK2	0.8	0.8	0.8

V1			V2		
X	Y	Z	X	Y	Z
0.4	0.0	0.4	0.4	0.8	0.4
V3			**V4**		
X	Y	Z	X	Y	Z
0.4	0.0	0.4	-	-	-
V5			**CP1**		
X	Y	Z	X	Y	Z
0.4	0.8	0.4	-	-	-
CP2			**CP3**		
X	Y	Z	X	Y	Z
-	-	-	-	-	-

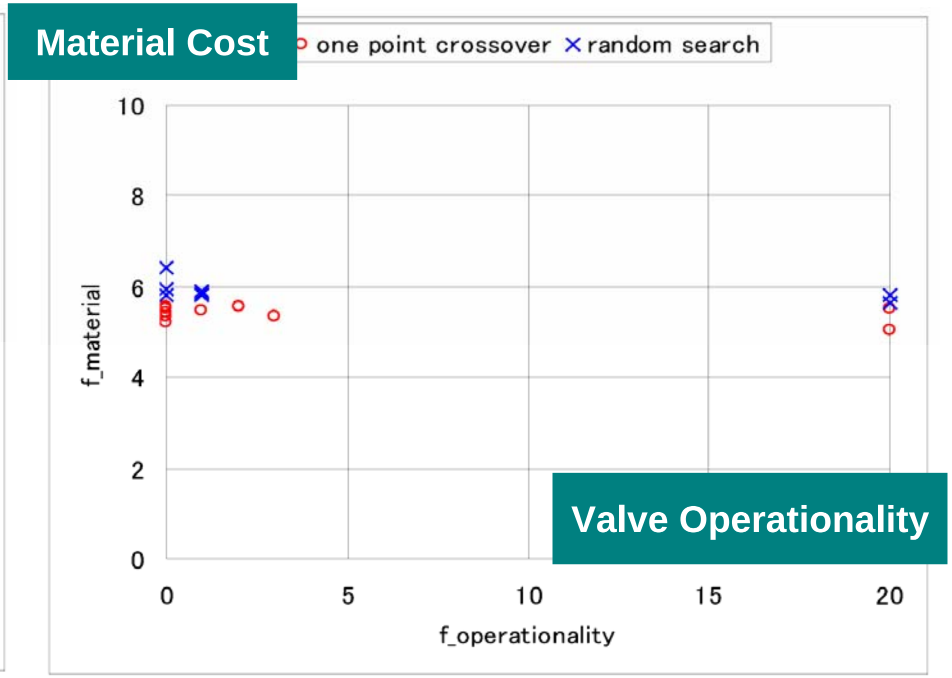
Total

Valves:	5
Equipments:	1
Connections:	3
Pipelines:	5
Pipes:	10
Parameters:	**45**
Combination	over 10^{12}

Results



Initial Population



After 400 generations
（calculation time: 60 minutes）

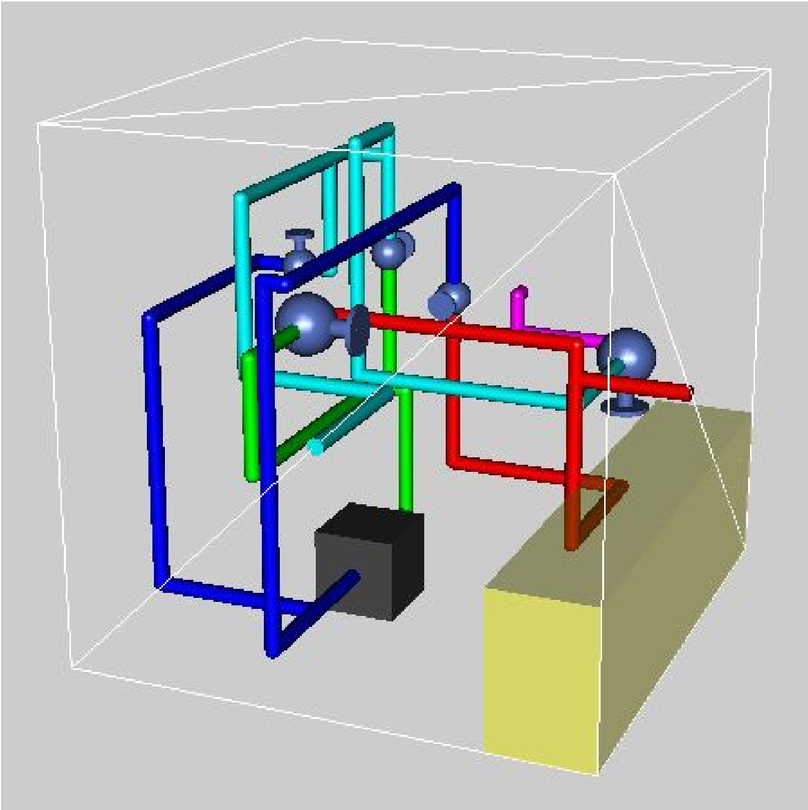
In the MOGA, children are generated by:

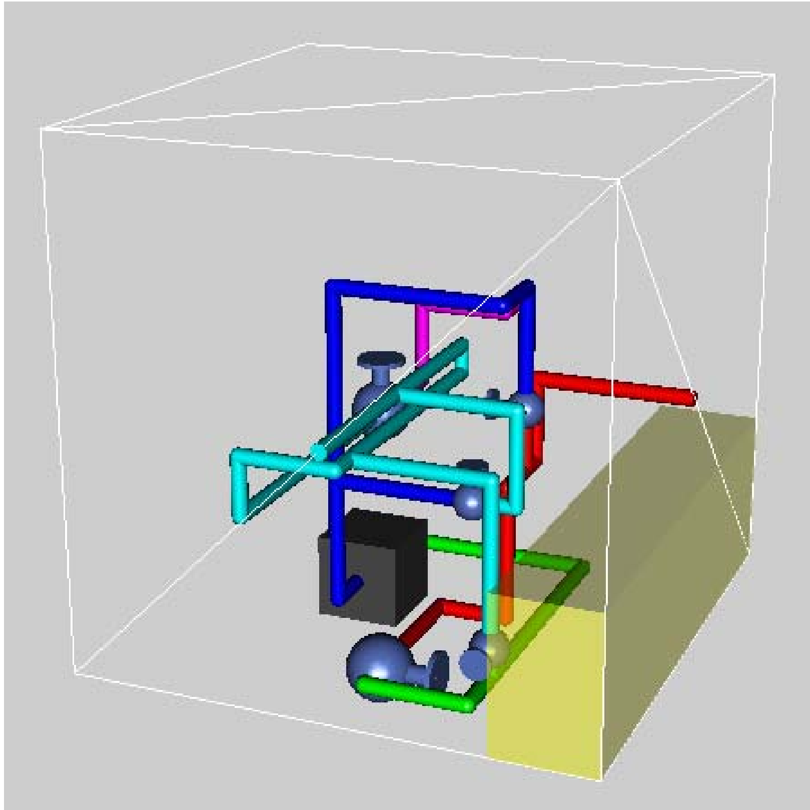
○ : One Point Crossover

× : Randomly Generated

Calculation Environment	
CPU:	Pentium 4 2.40GHz
Memory:	512MB
OS:	Windows XP
Program Language：	Java

Obtained 3D Models



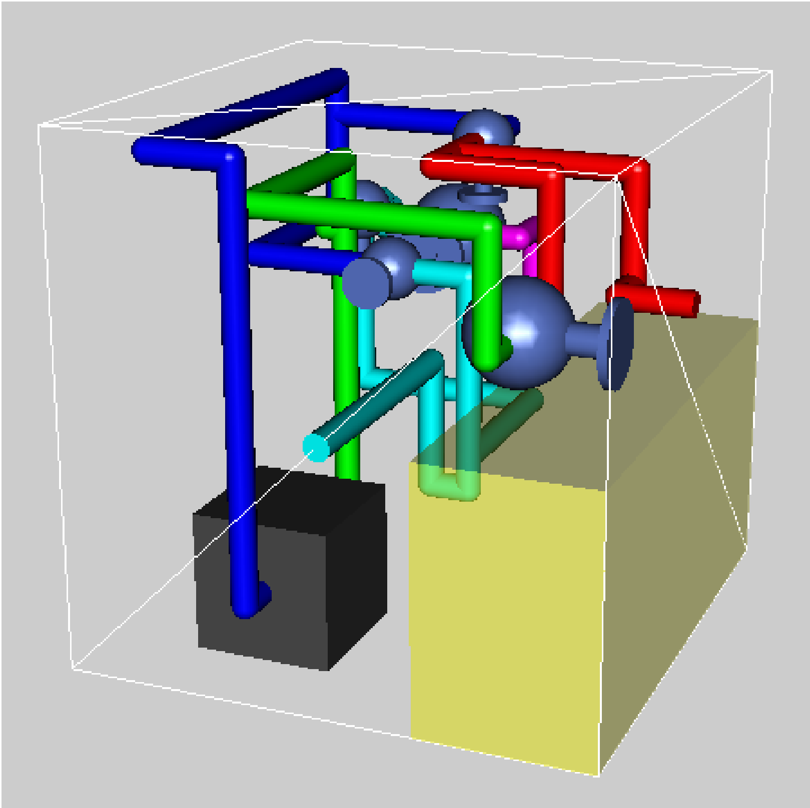


Material Cost = 8.12
Cost of Valve Operationality = 0

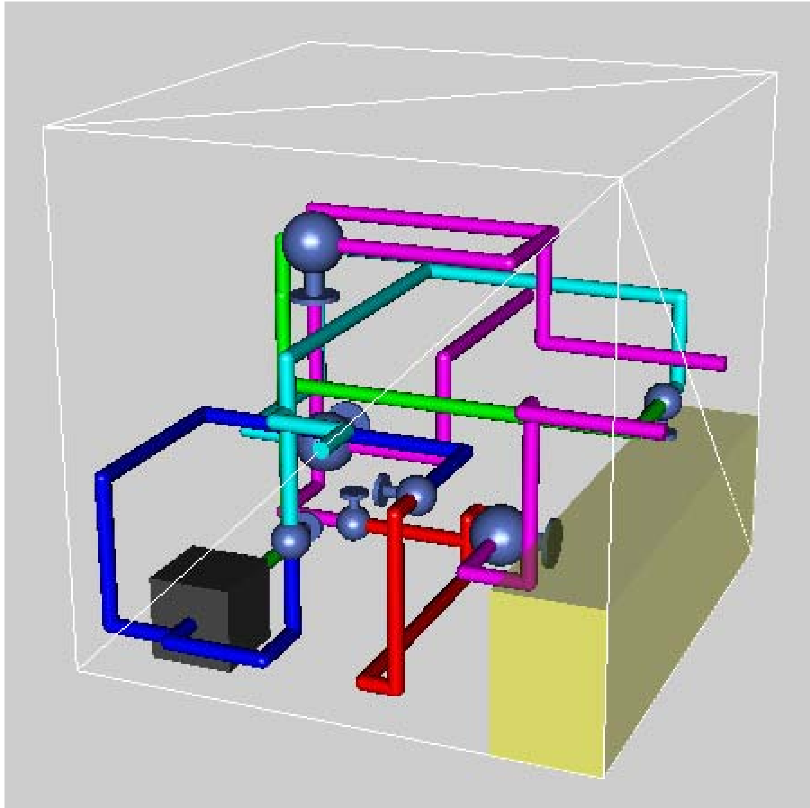
Material Cost = 5.50
Cost of Valve Operationality = 10001

Multi-Objective Optimization algorithm enables us to show plural Pareto-Optimal solutions simultaneously.

3D Models in the other settings



Narrow space



More Complex Pipeline

<u>The more Improvement of the optimization algorithm is needed.</u>

Overview

1. Motivation and Purpose

2. Evaluation Algorithm for Valve Operationality

Accessibility

Possibility of Valve Handling

3. Multi-Objective Optimization Algorithm

Coding for Genetic Algorithm (Only Valves)

Multi-Objective Genetic Algorithm: NSGA-Ⅱ

Routing Pipes and Making Branches

4. Experiments

5. Conclusion and Future Works

Conclusions and Future Works

Conclusions

1. supposition in <u>Automatic Pipe Arrangement</u> :

Make obscure criteria to be clear

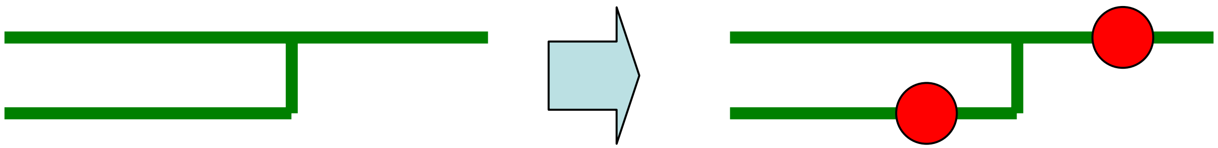
Treat as multi-objective problem

2. Valve Operationality Evaluation Algorithm is proposed.

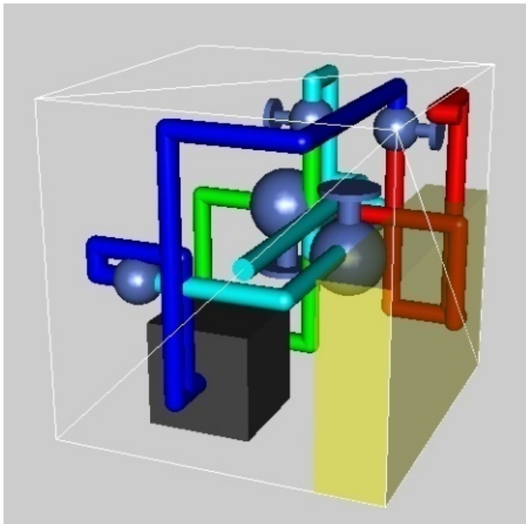
3. An Implementation of **Multi-objective GA for pipe arrangement** is proposed.

Future Works

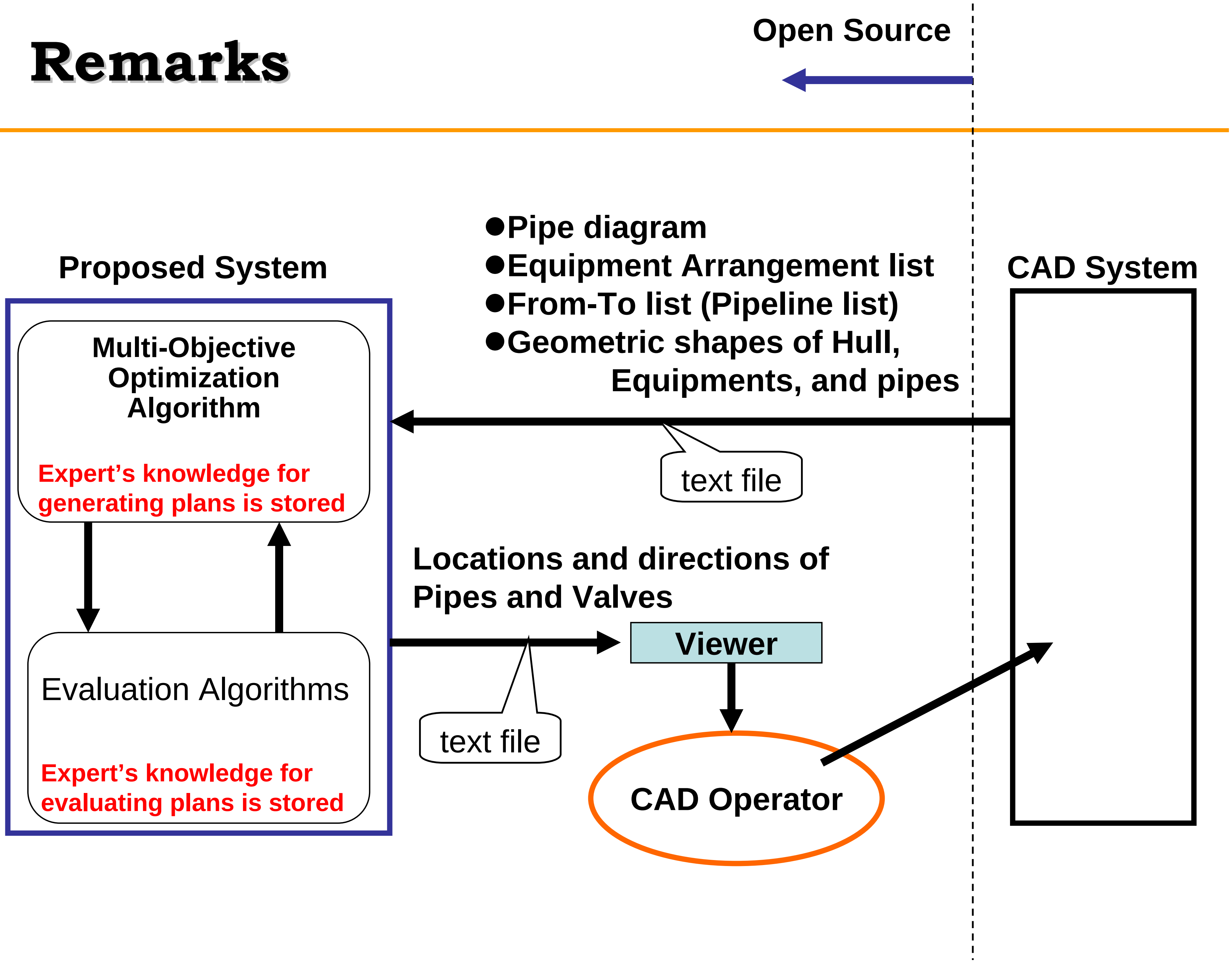
1. Algorithm Improvement taking in the expert's designing procedure that the pipe routing is determined first, thereafter, valves are set in the arranged pipes.



2. Evaluation Algorithm for Easiness of Pipe Maintenance



Remarks


Open Source
Pipe diagram
Equipment Arrangement list
From-To list (Pipeline list)
Geometric shapes of Hull, Equipments, and pipes
Proposed System
CAD System
Multi-Objective Optimization Algorithm
Expert's knowledge for generating plans is stored
text file
Locations and directions of Pipes and Valves
Viewer
Evaluation Algorithms
Expert's knowledge for evaluating plans is stored
text file
CAD Operator