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An Automatic Piping Algorithm Including Elbows and Bends

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Outline

1. Background and Purpose

- Previous Research

2. Routing Algorithm Including Bends

- Approach
- Dijkstra's Method
- Outline of "Bends"
- Experiments

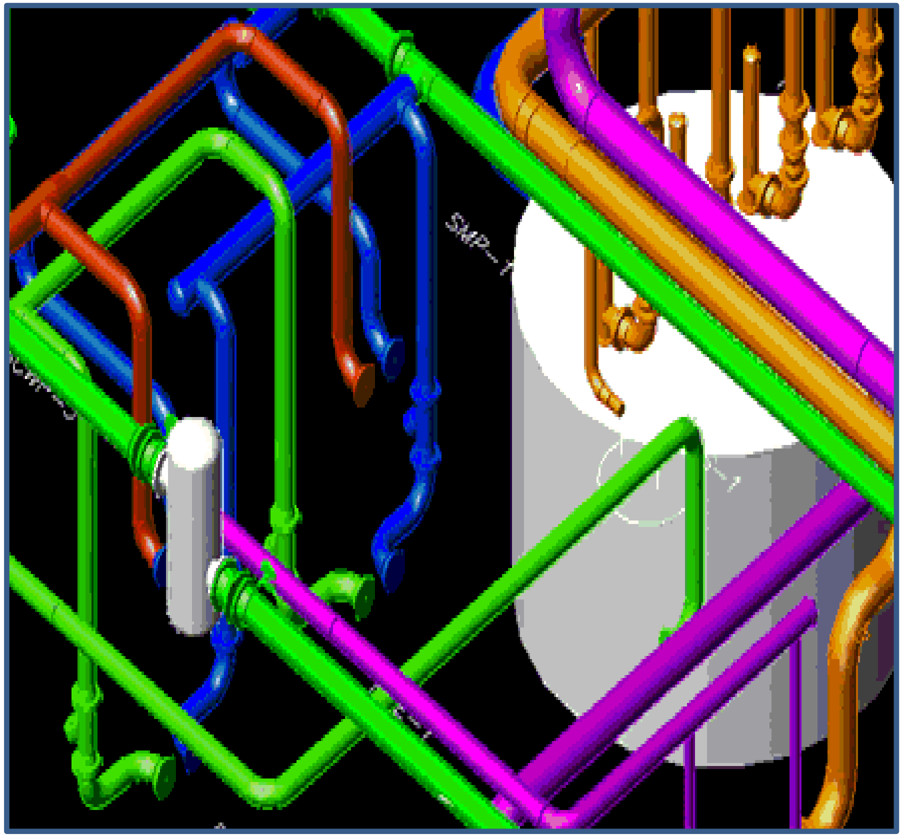
3. Conclusion and Challenges

Background

Pipe Arrangement requires …

◆ keeping to regulations

ex.
- not to set fuel oil pipelines near to electrical lines



http://www.cadpipe.com/industrial3D.html

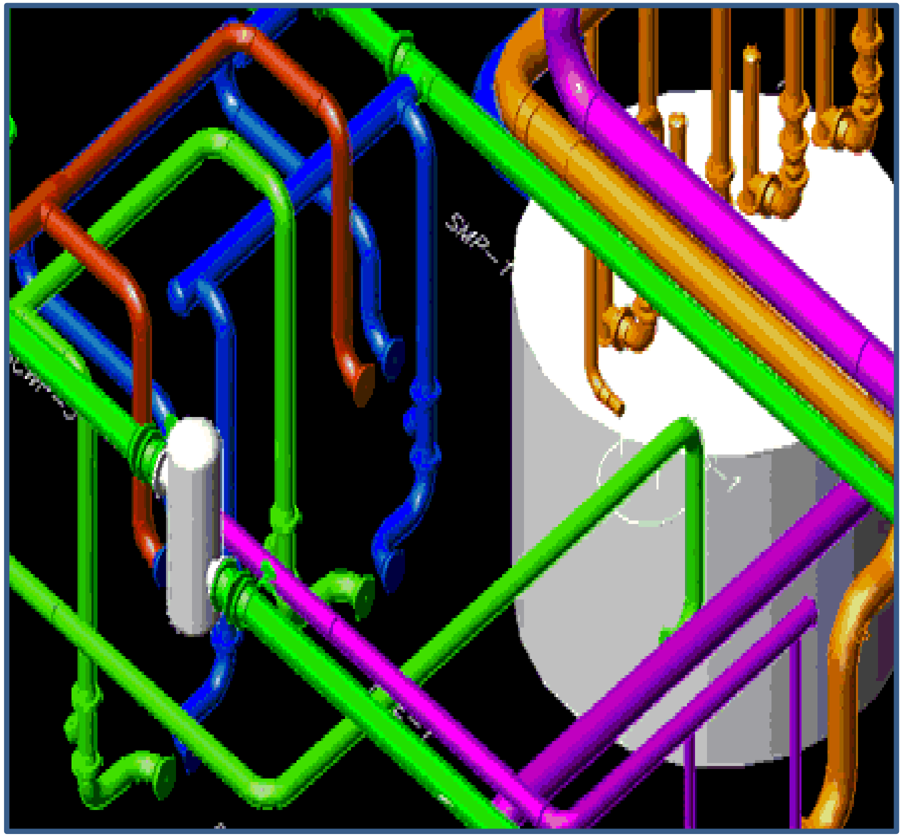
Background

Pipe Arrangement requires …

◆ keeping to regulations

◆ meeting demands

ex.
- to shorten the total length
- to set along with the ship hull



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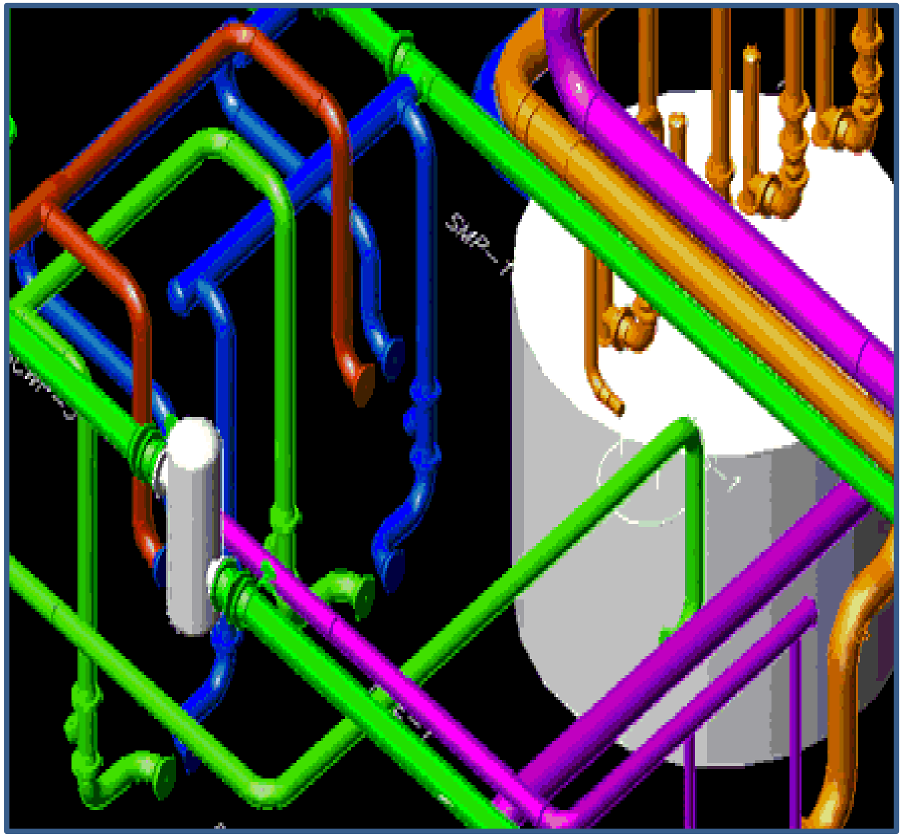
Pipe Arrangement requires …

- keeping to regulations
- meeting demands
- originality by each ship



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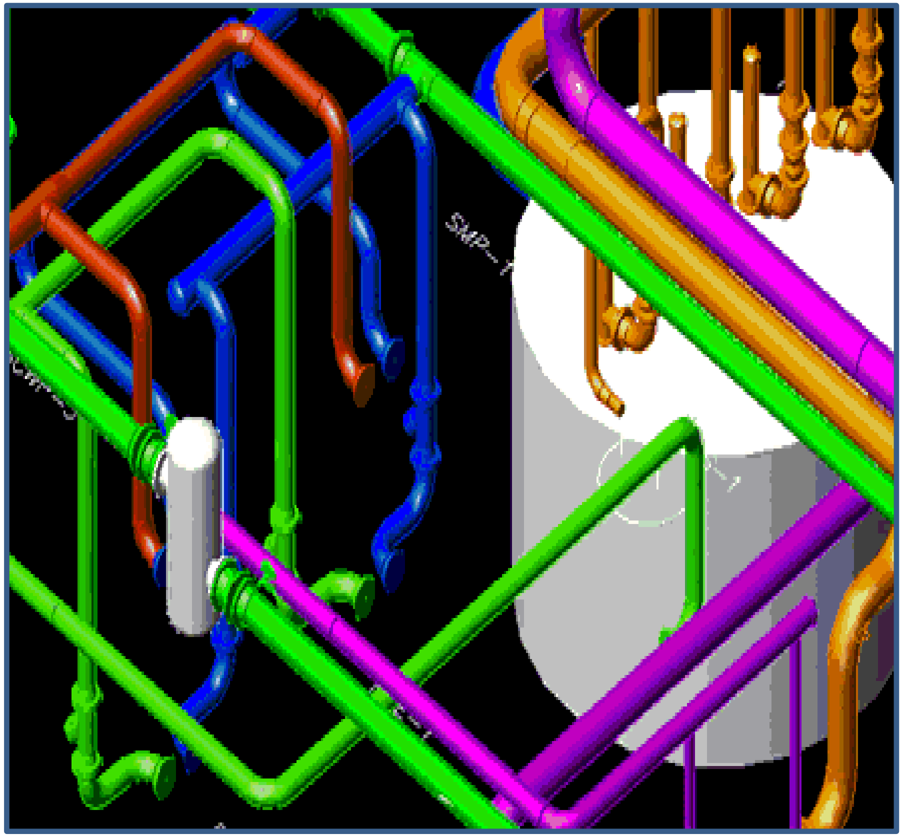
Background

Pipe Arrangement requires …

- ◆ keeping to regulations
- ◆ meeting demands
- ◆ originality by each ship

↓

Experiences of skilled designers



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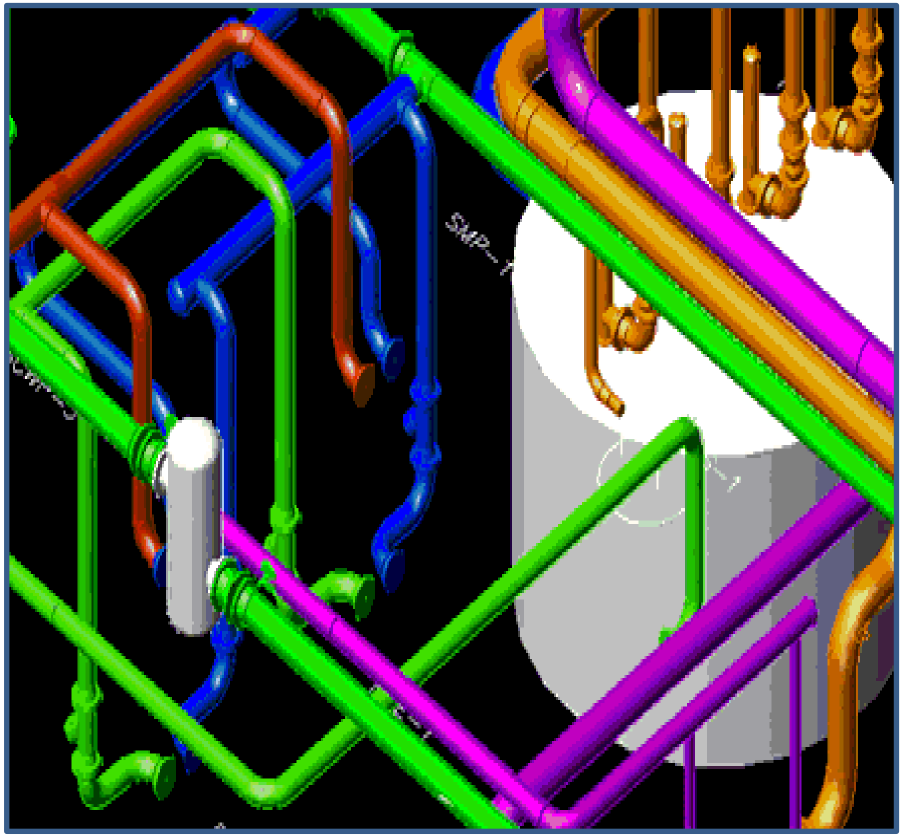

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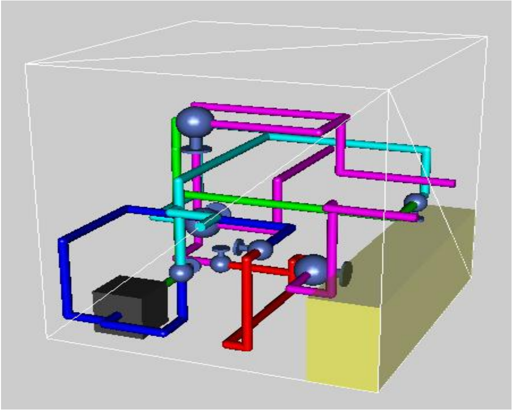
Experiences skilled designers

Automatic Design System

Purpose

Previous Researches



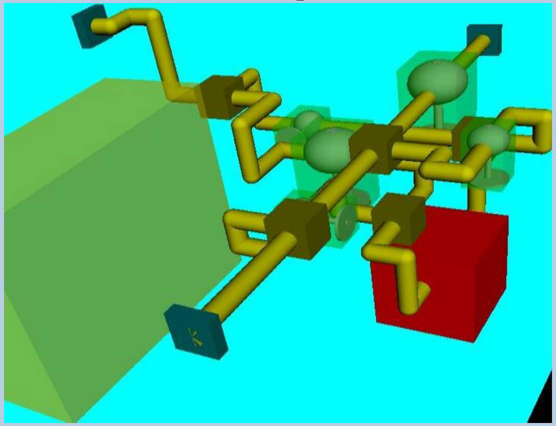
Problems are …

X optimization of piping routes

X searching of piping routes

X constraints

Our Proposal



We try for …

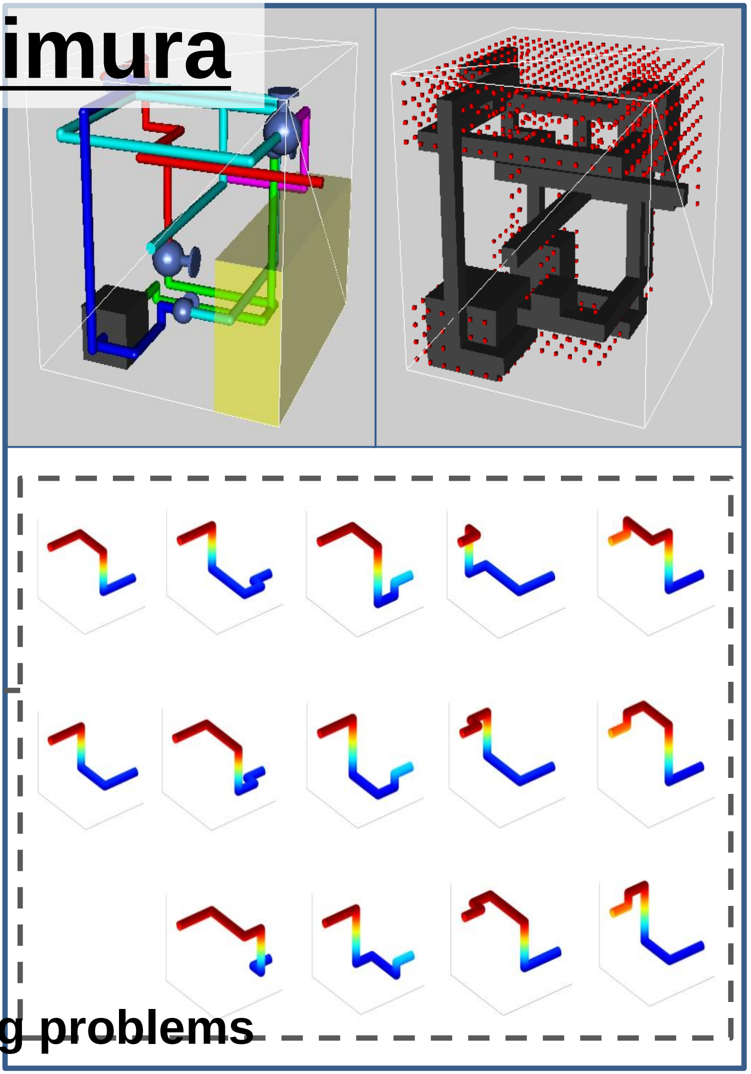
- ◆ solving these problems
- ◆ high performance system
- ◆ full automatic design

Previous Research

Approach by Ikehira and Kimura

- **taking into account of "valve operationality"**
- **dividing the pipe arrangement problem into two challenges**
  - equipments layout problem
  - routing problem

solved by "pattern match method" which joins primitive pipe parts



Disadvantages are…

- **uncertainty of optimal routing**
- **impossibility of solving a complicated routing problems**

Previous Research

<u>Approach by Asmara and Nienhuis</u>

- looking on the pipe arrangement problem as <u>a routing problem</u> in a directed and weighted graph

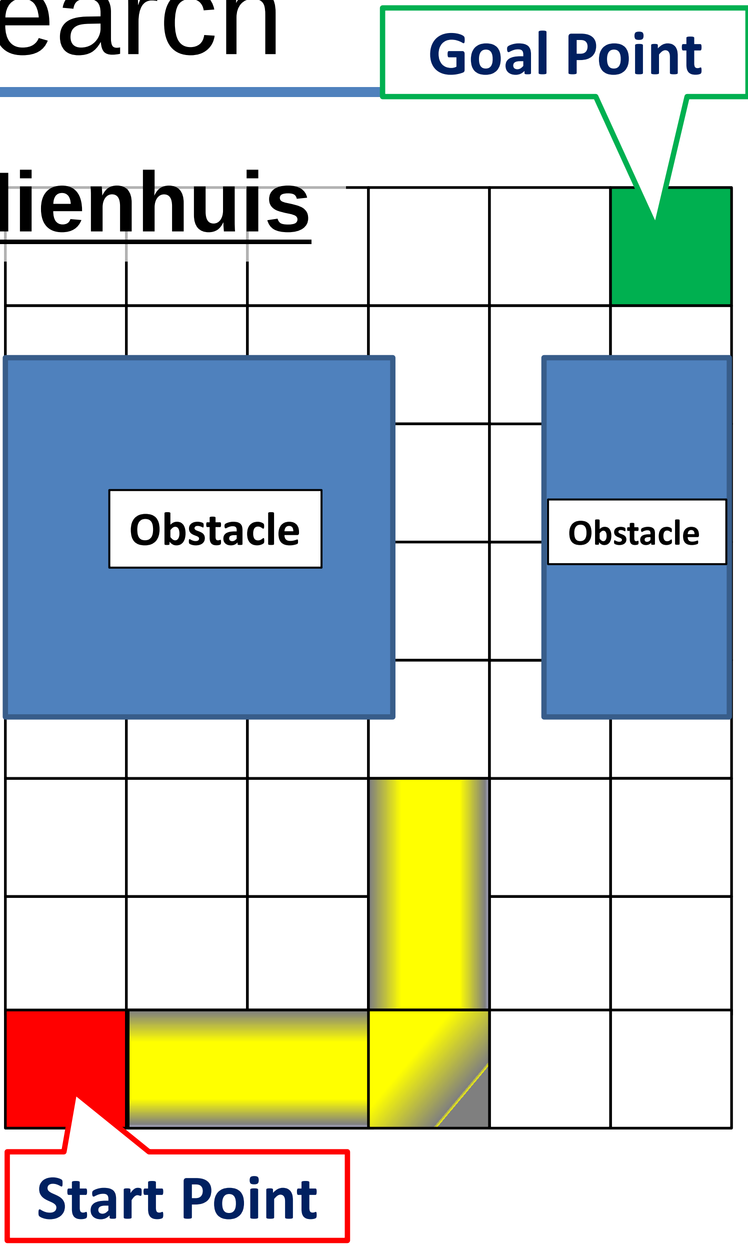
solved by "**Dijkstra's method**"

Disadvantage is …

- **the mesh size is restricted to be larger than a pipe's diameter**

especially in large pipe's diameter

Strong Constraint!



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- Dijkstra’s Method
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Approach

Problems of Previous Researches

- uncertainty of the route with minimum costs
- demanding of the mesh size on the diameter

Our Approach

◆ using “Dijkstra’s method”

◆ improvement the routing algorithm

◆ using not only elbows but “bends”

Approach

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- **using "Dijkstra's method"**
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Problems of Previous Researches

- uncertainty of the route with minimum costs

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◆ using "Dijkstra's method"

◆ **improvement the routing algorithm**

variable mesh size!

◆ using not only elbows but "bends"

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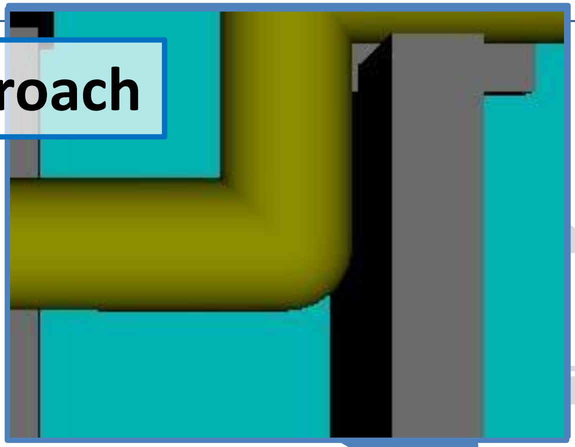
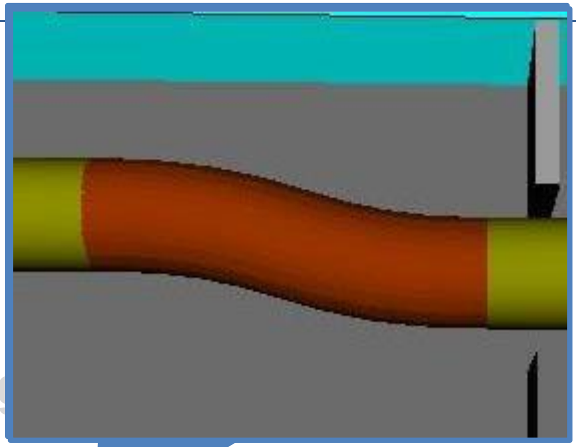


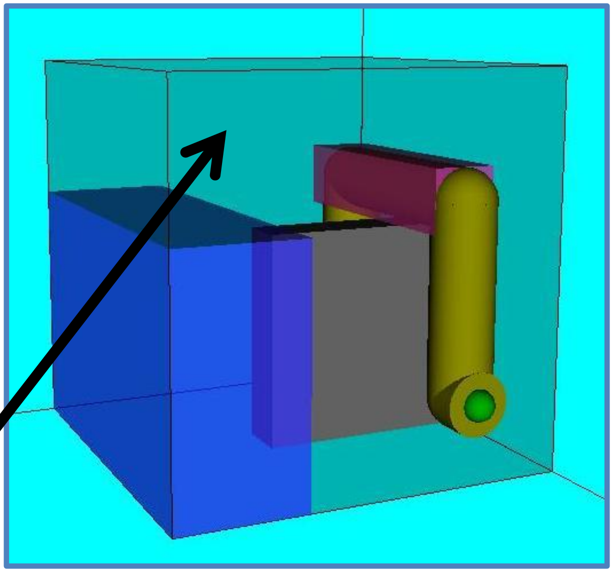


◆ …od"

◆ …ing al…

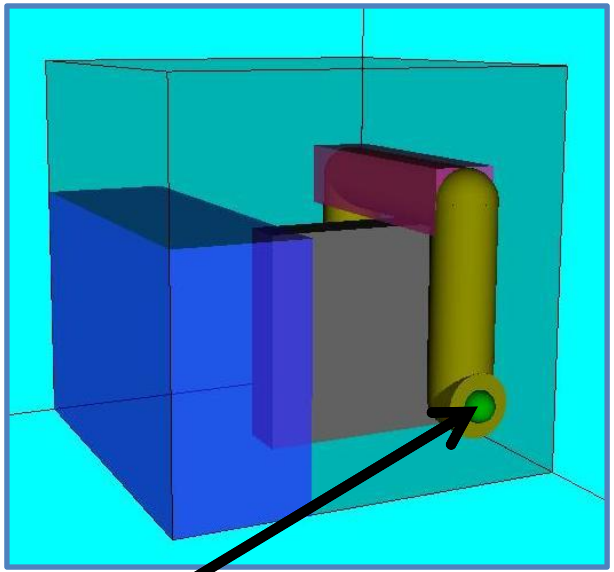
◆ **using not only elbows but "bends"**

Approach



- **Design Space** : box for pipe arrangement
- **Start and Goal** : coordinates and vectors
- **Target Pipeline** : pipes not including any branches

Approach



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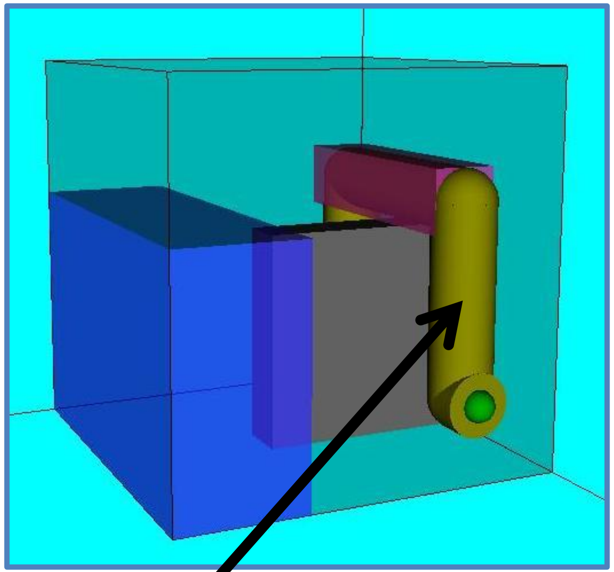

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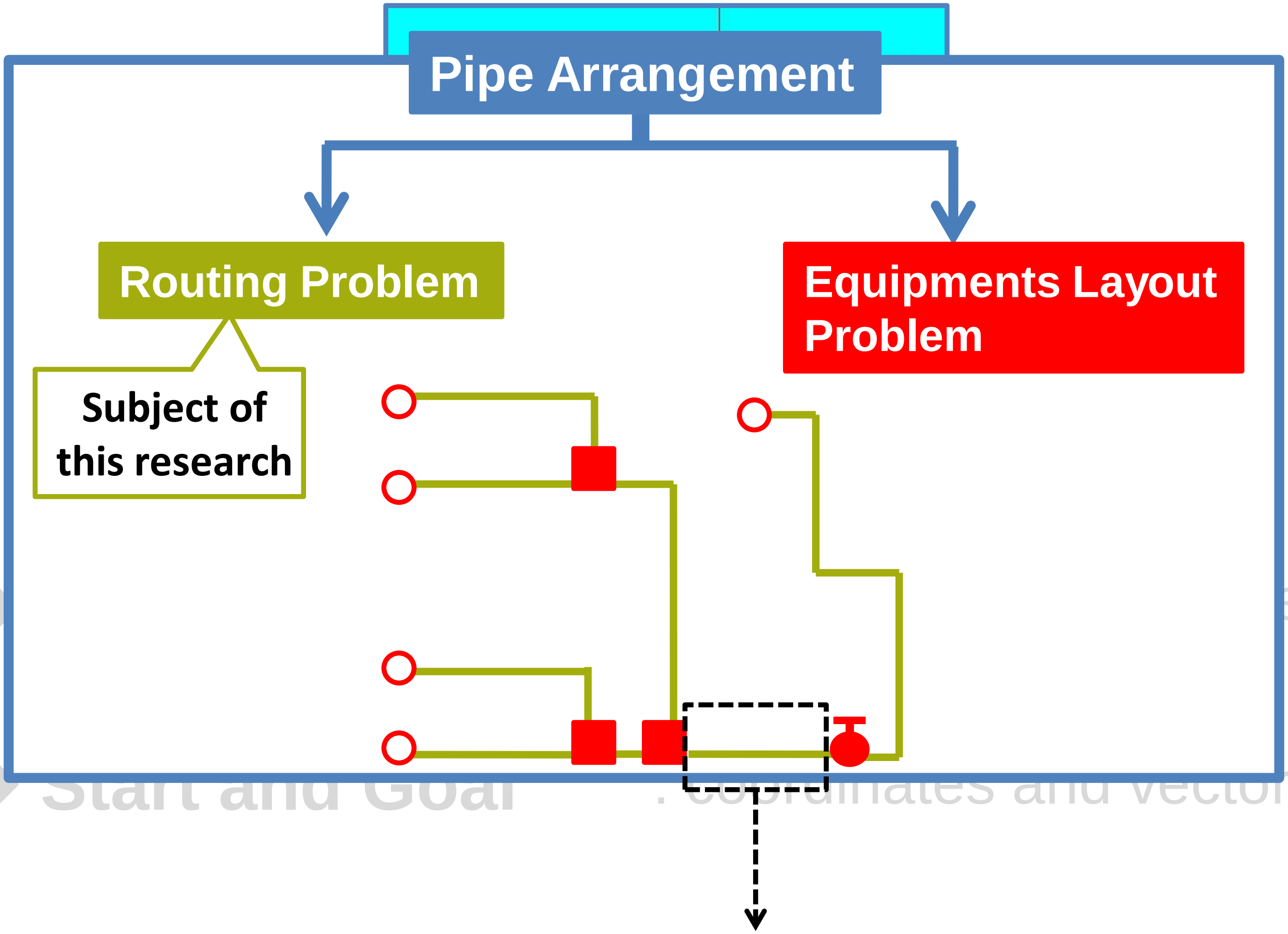
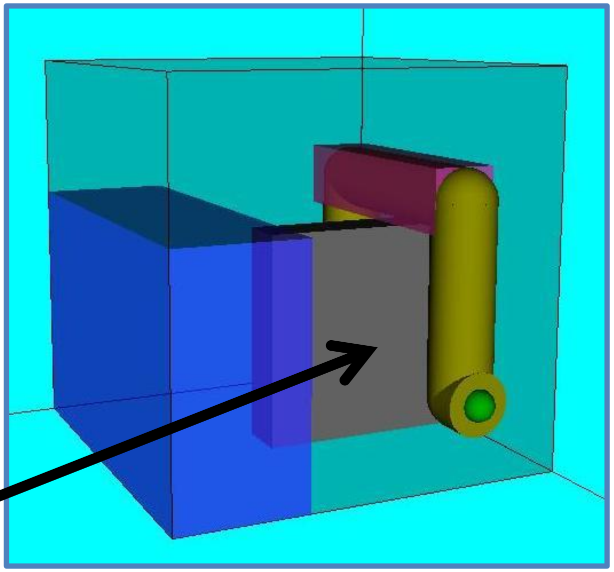


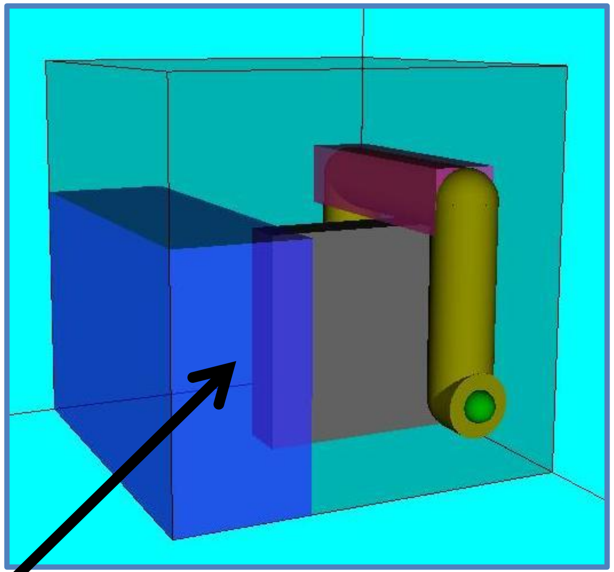
◆ **Target Pipeline** : pipes not including any branches

Approach



- **Obstacle** : structures and equipments in ships
- **Aisle Space** : space for passages
- **Pipe-rack Area** : space for pipelines

Approach



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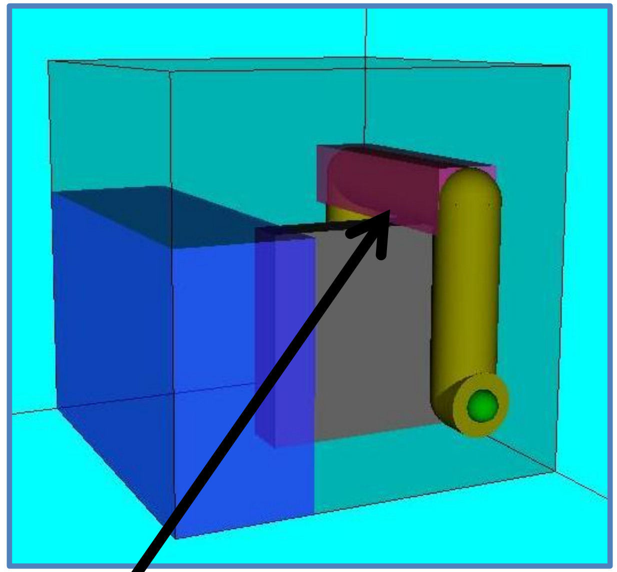


◆ **Obstacle** : structures and equipments in ships

◆ **Aisle Space** : space for passages

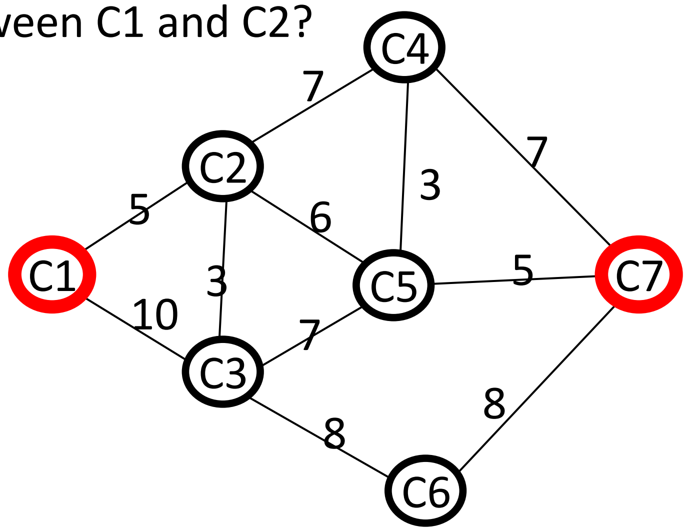
◆ **Pipe-rack Area** : space for pipelines

Dijkstra’s Method

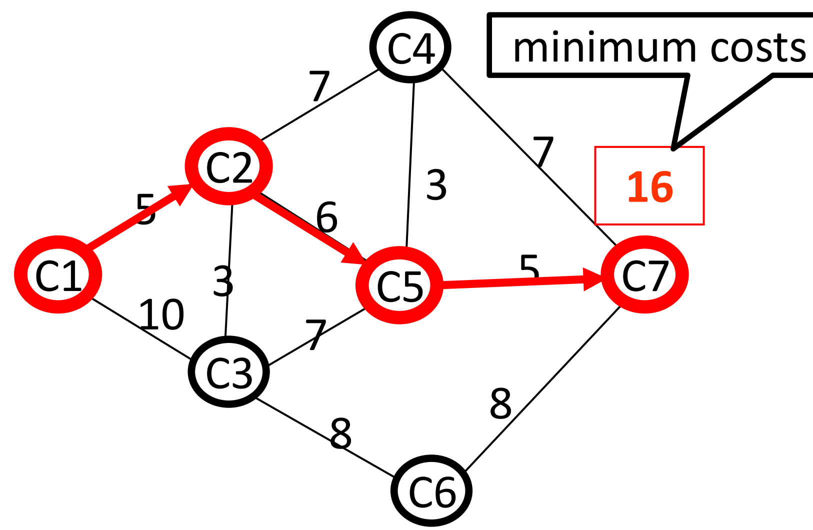
This method can …

- **find the shortest path in a directed and weighted graph**
- **guarantee a path with minimum costs**

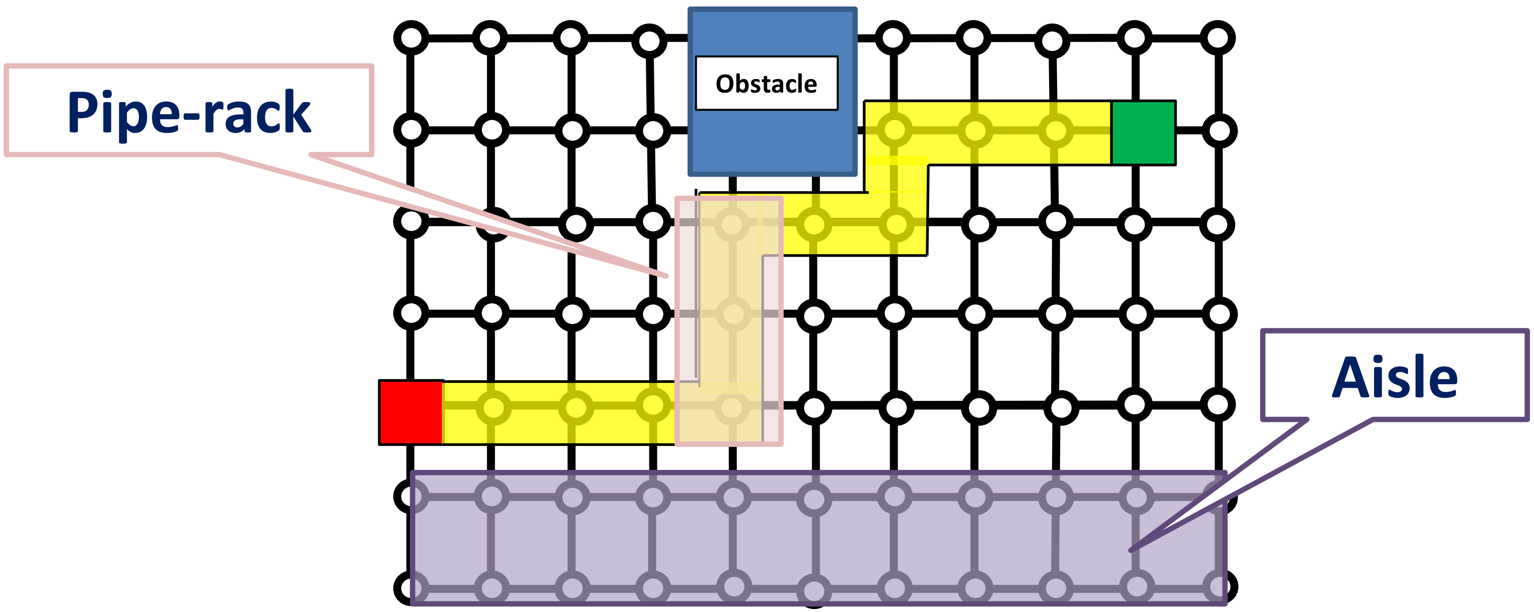
Where is the path with minimum costs between C1 and C2?



The answer is …

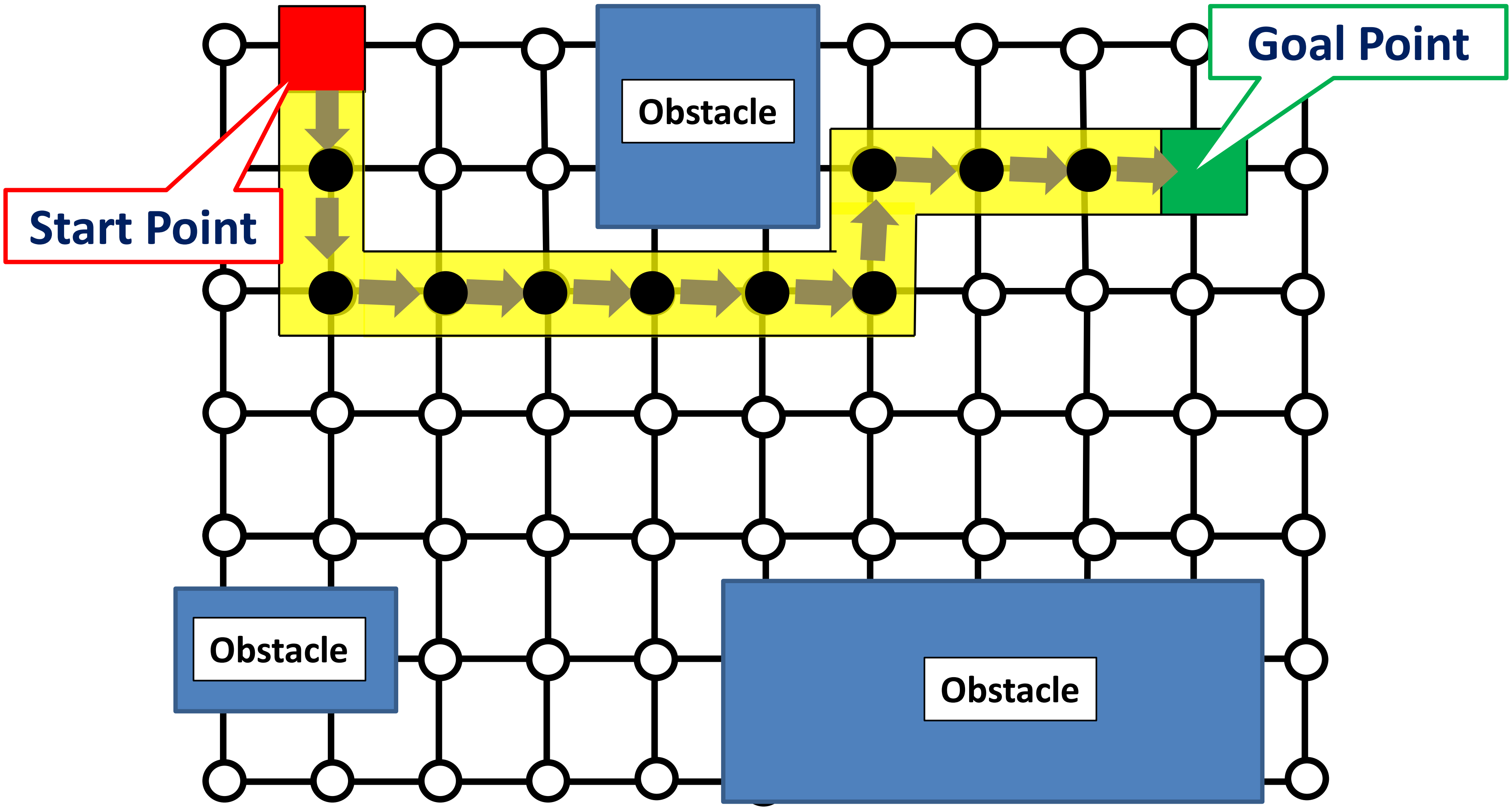


Design Objectives



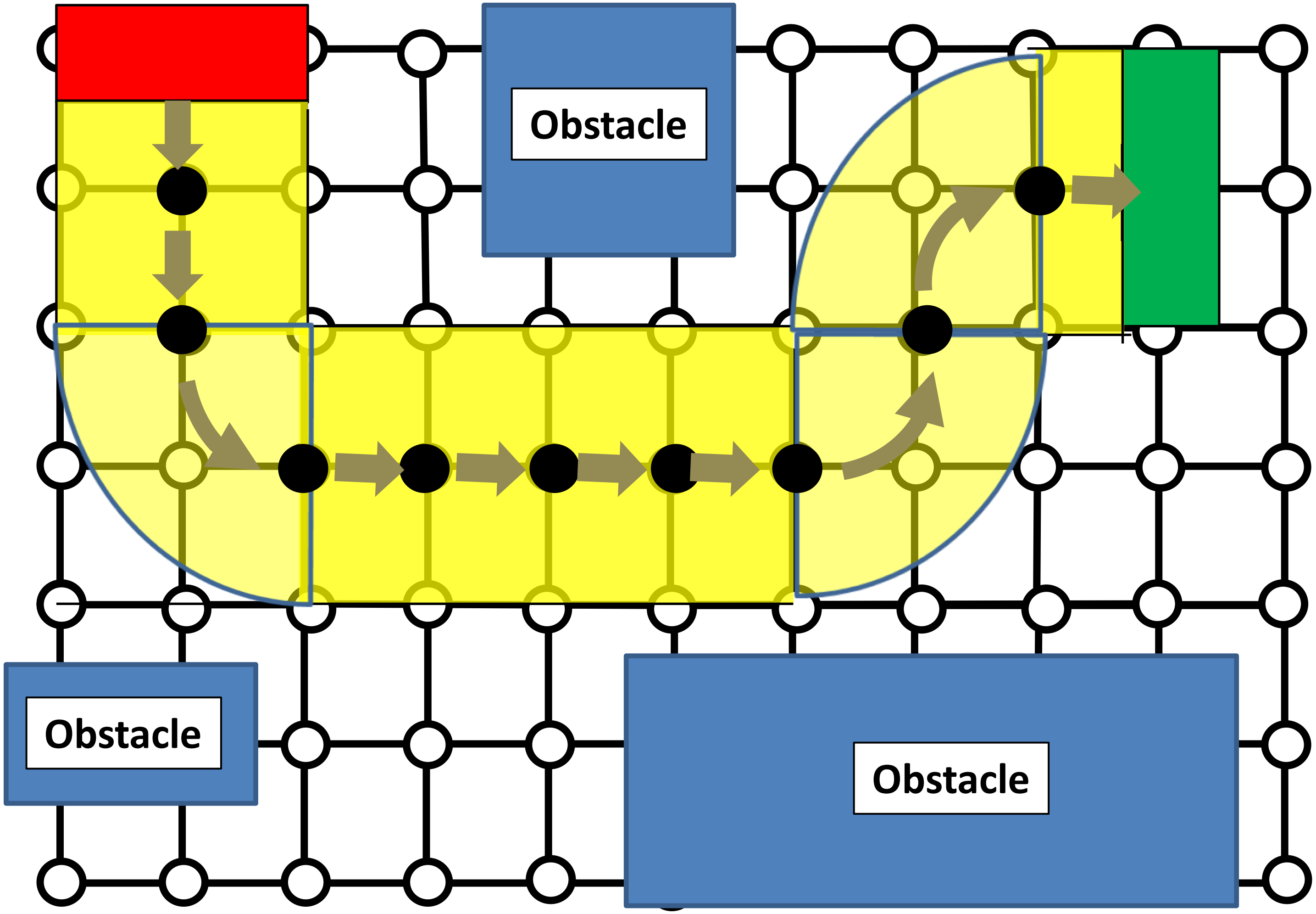
- ◆ to minimize the total length of pipes
- ◆ to minimize the number of elbows and bends
- ◆ to avoid passing aisles as possible
- ◆ to pass through pipe-rack areas as possible

Routing Algorithm



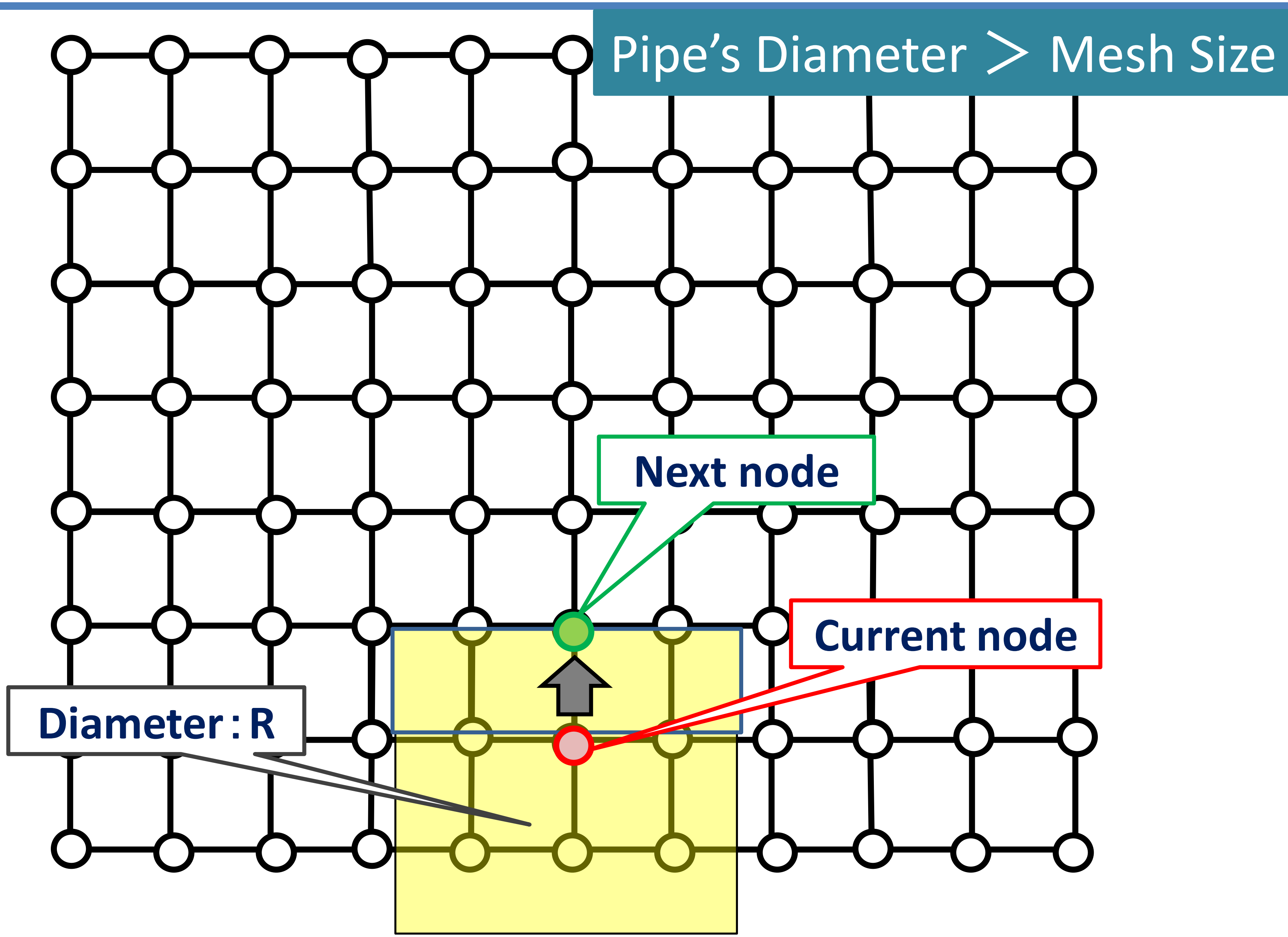
Pipe’s Diameter < Mesh Size

Routing Algorithm

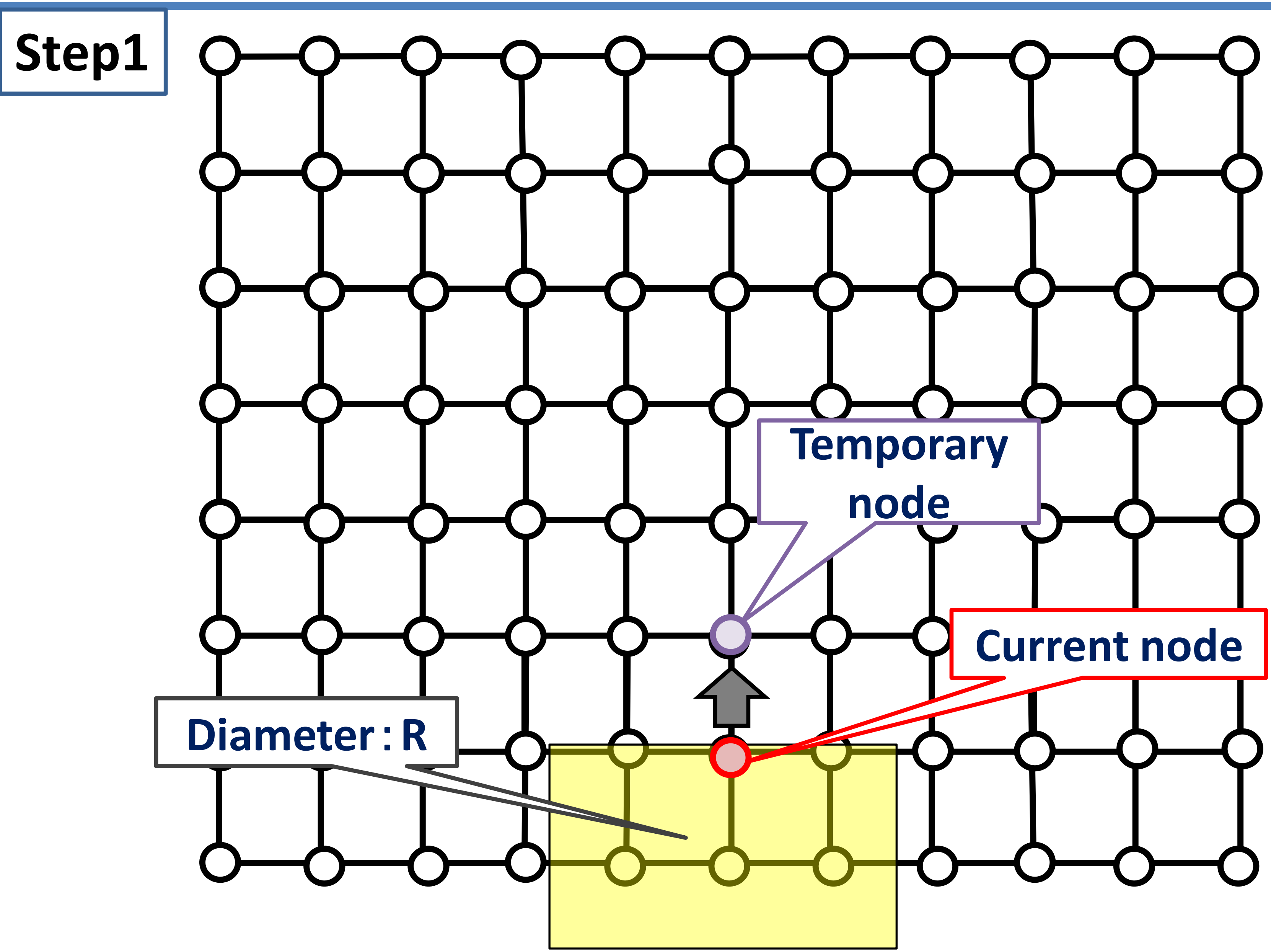


Pipe’s Diameter > Mesh Size

Searching of Straight Pipes

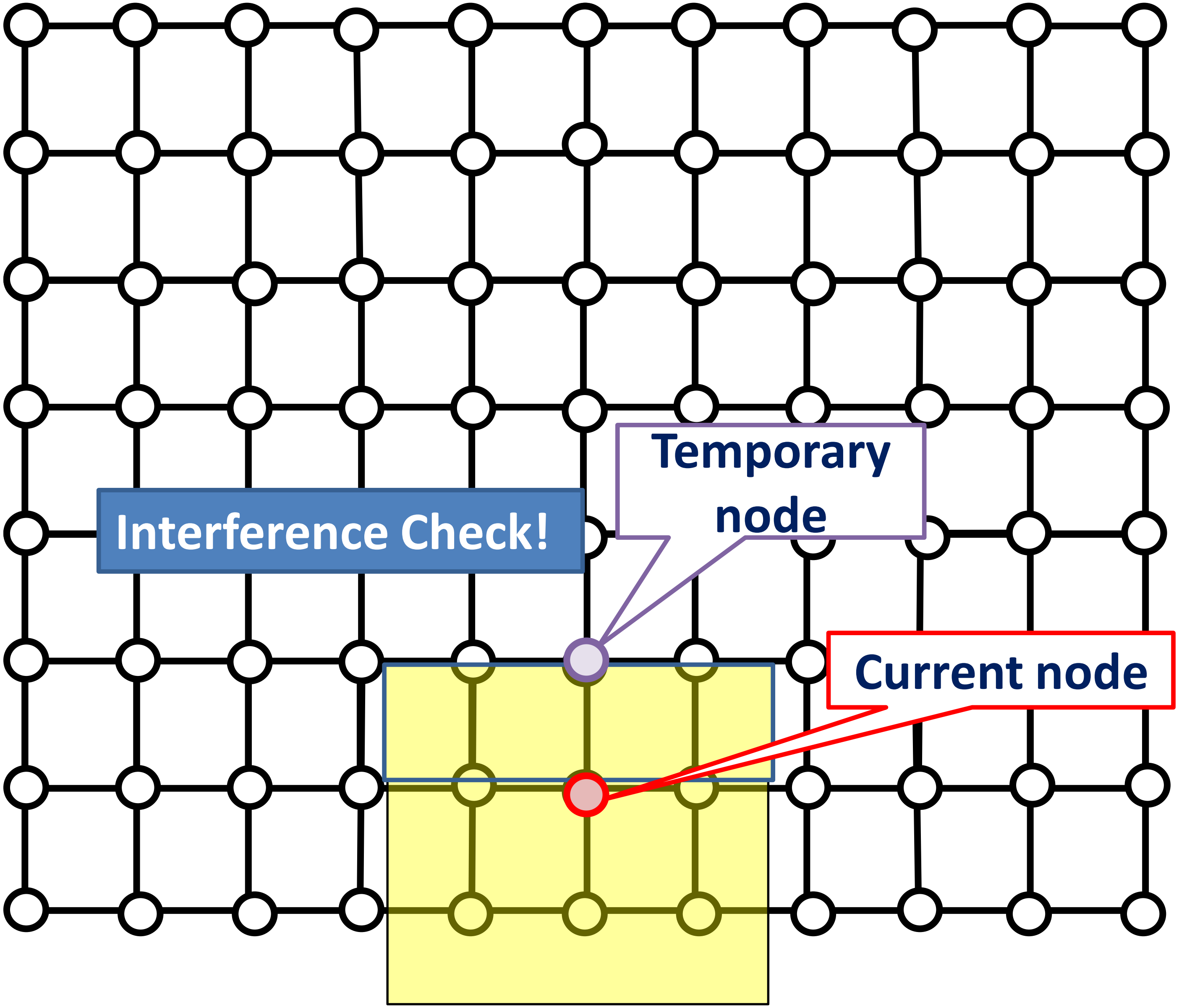


Searching of Straight Pipes



Searching of Straight Pipes

Step2



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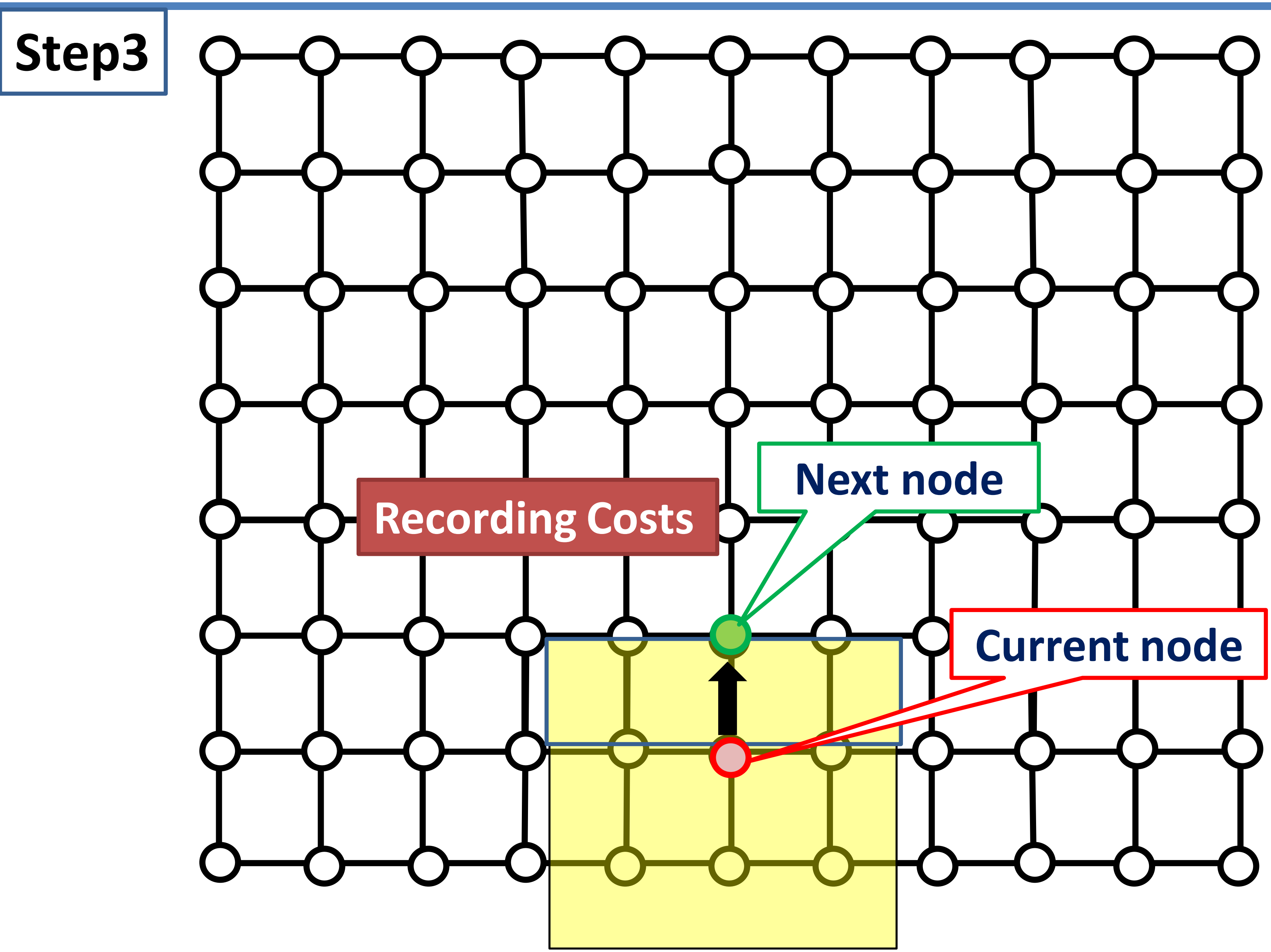
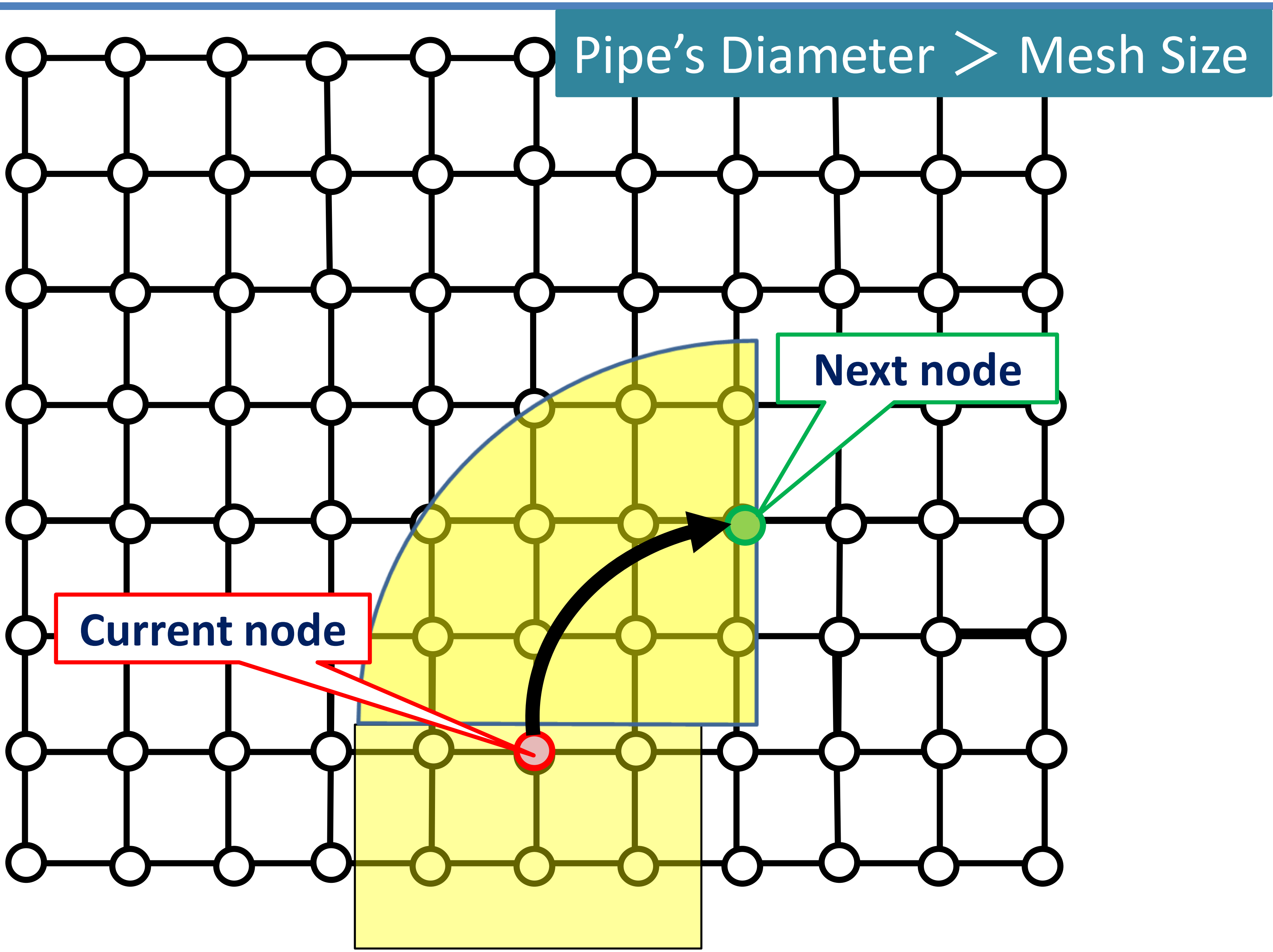
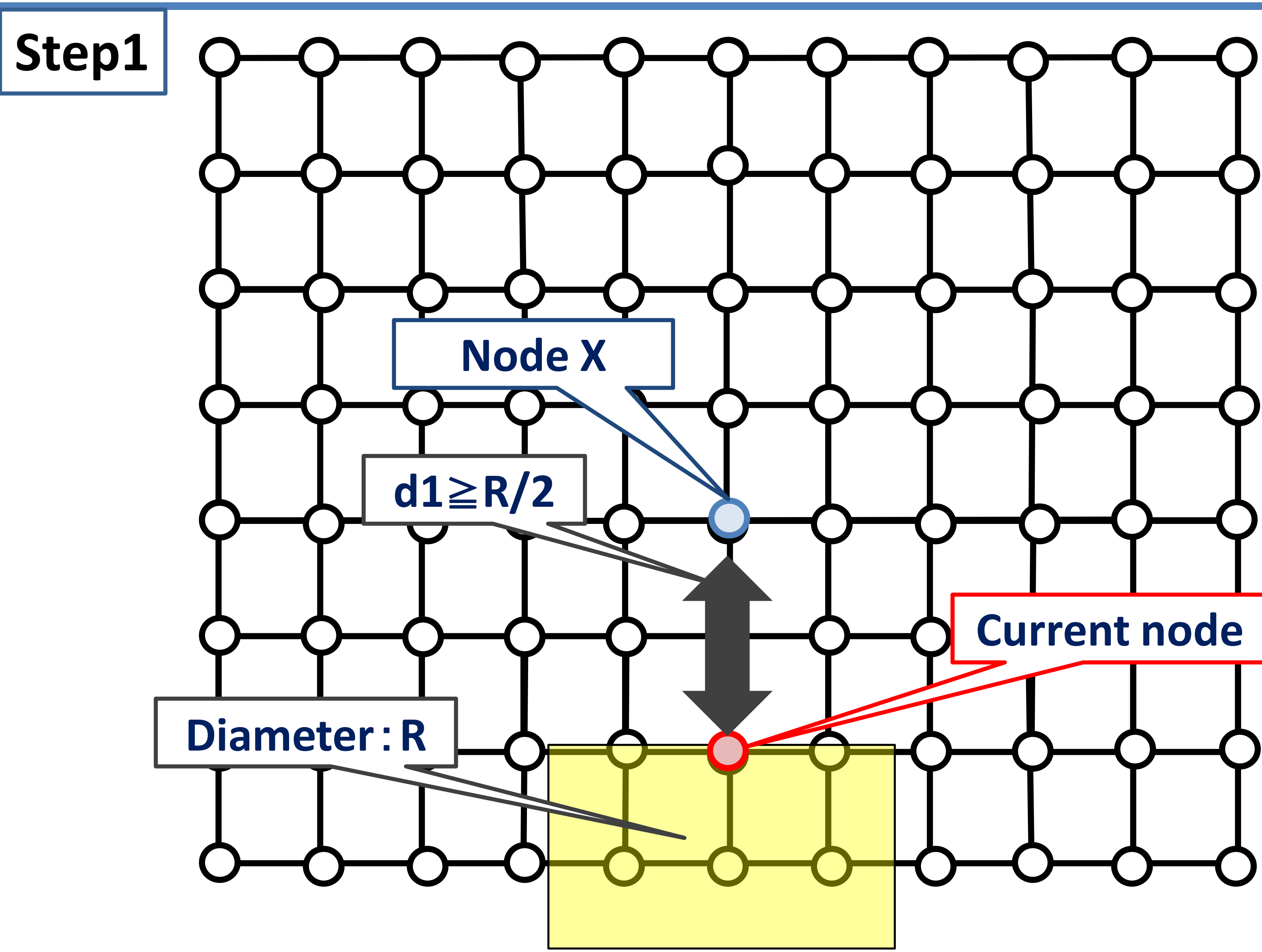


Searching of Elbows



Searching of Elbows



Searching of Elbows

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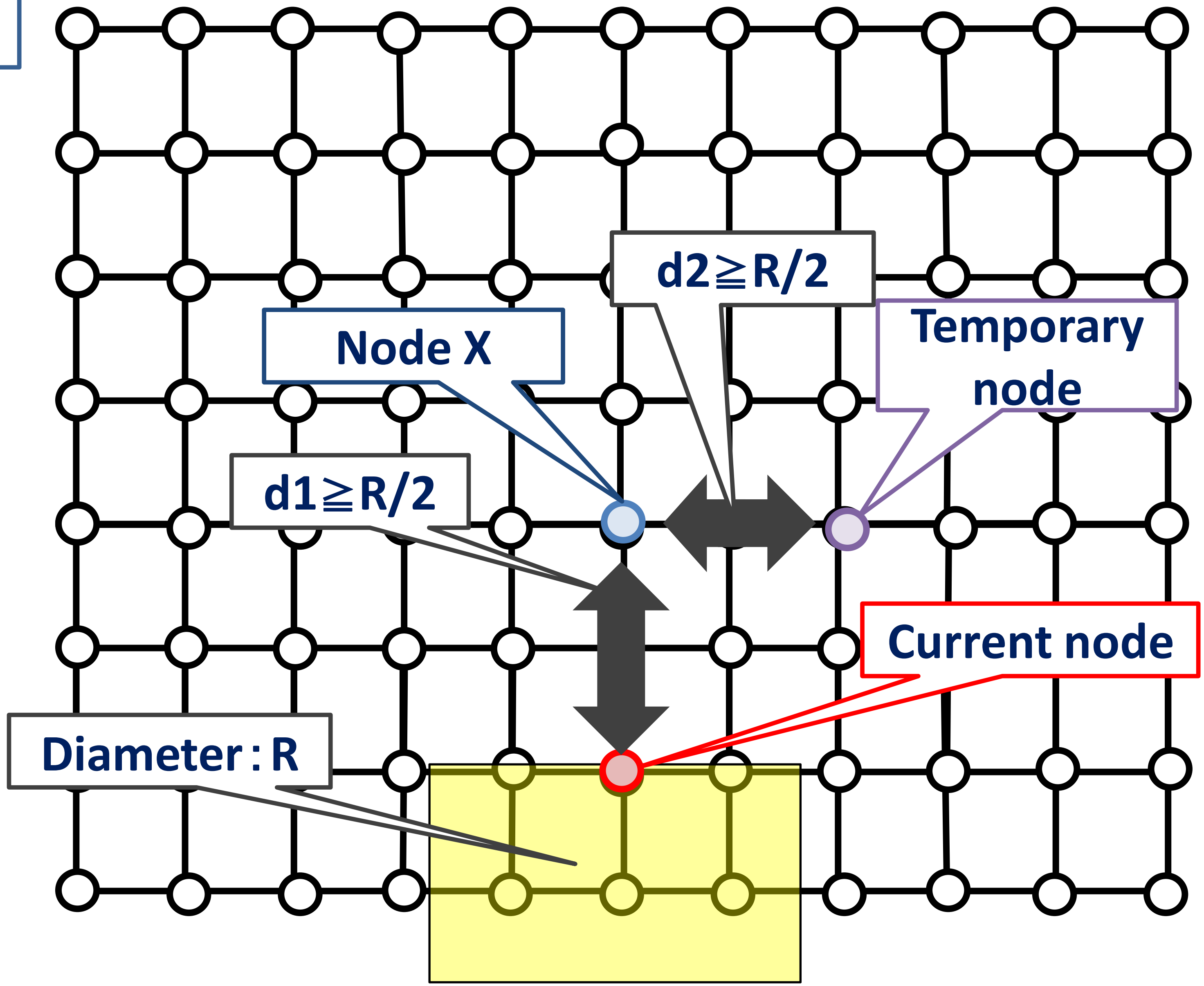
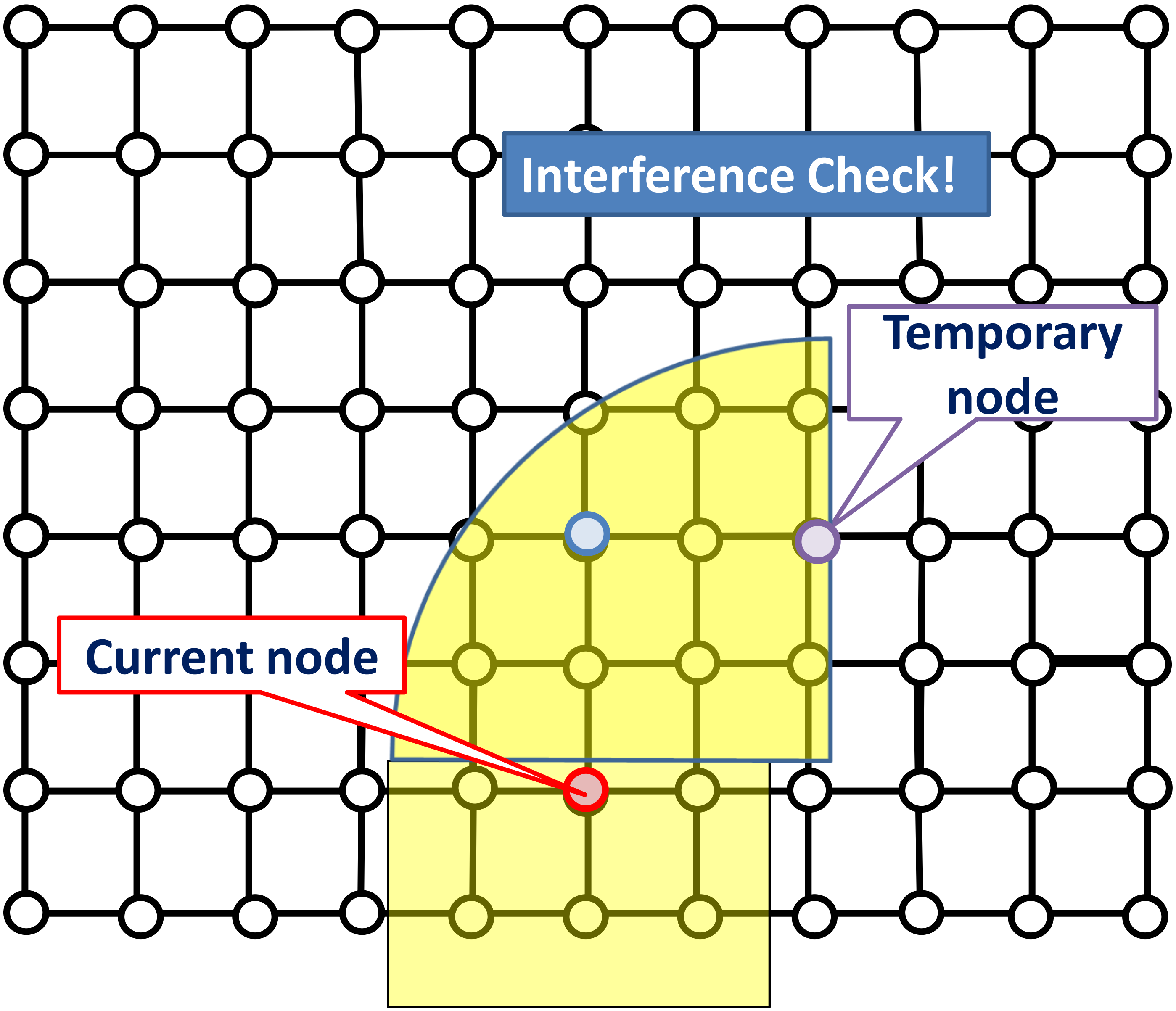


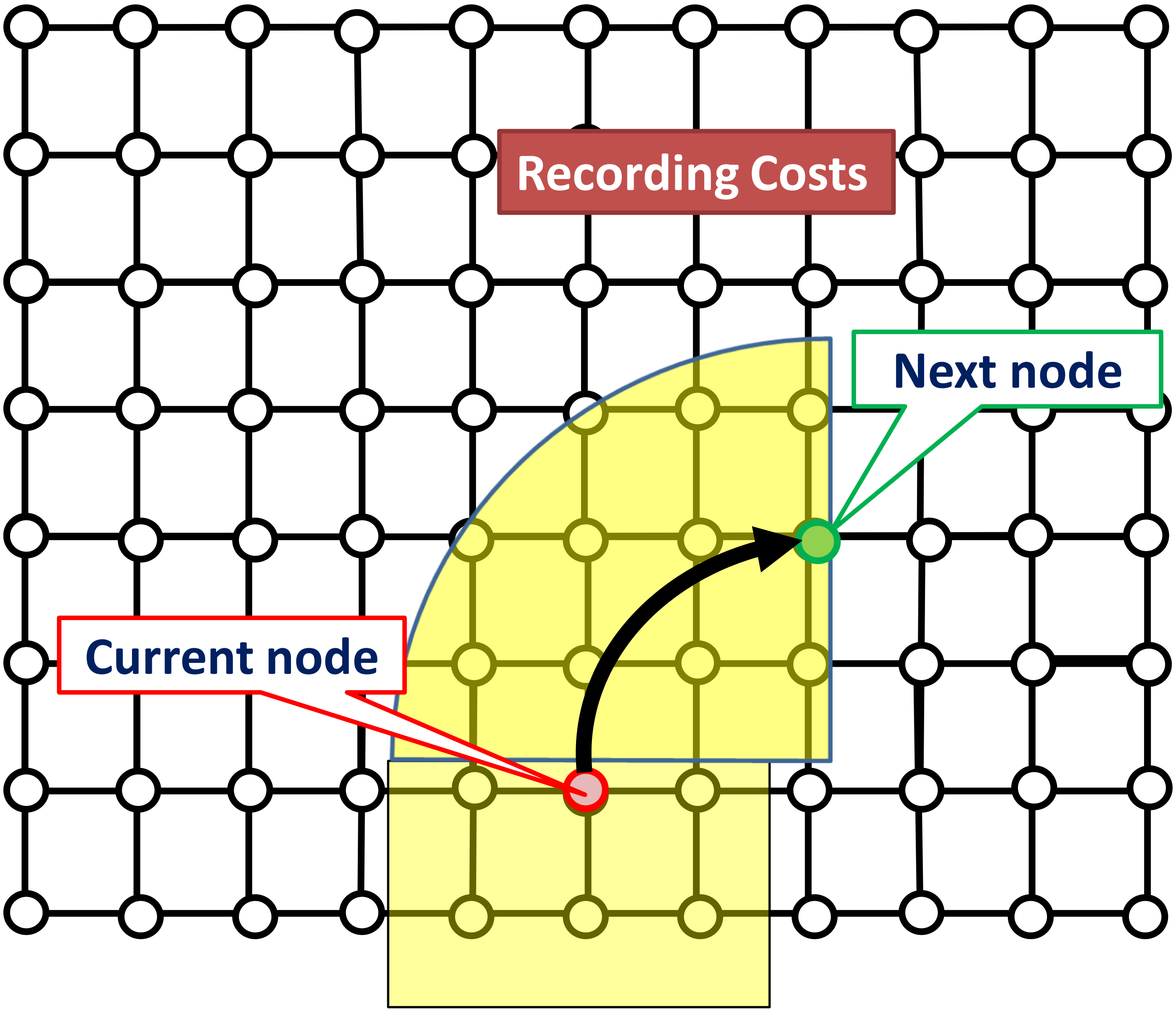
Searching of Elbows

Step3



Searching of Elbows

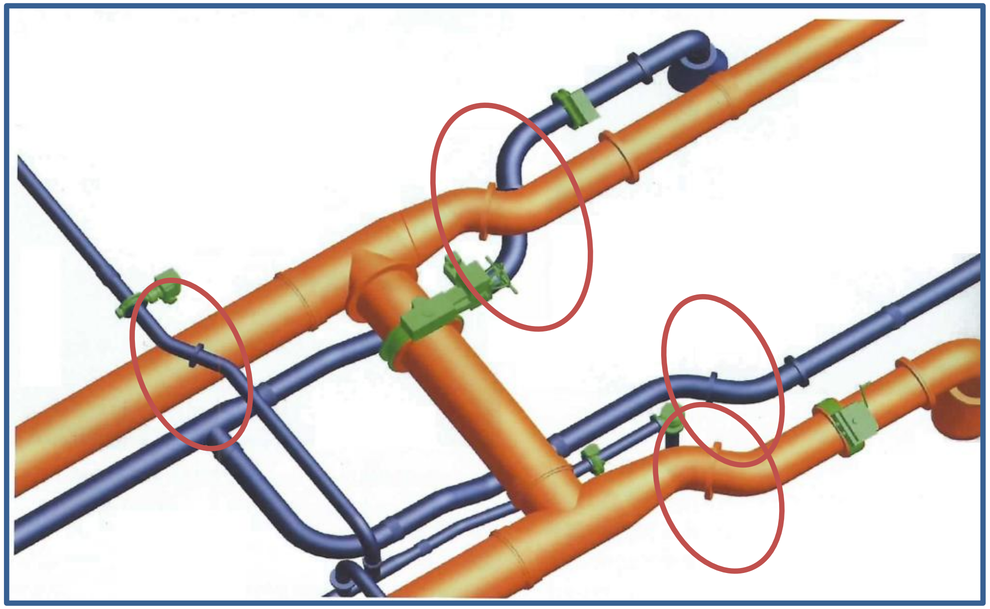
Step4



Outline of Bends

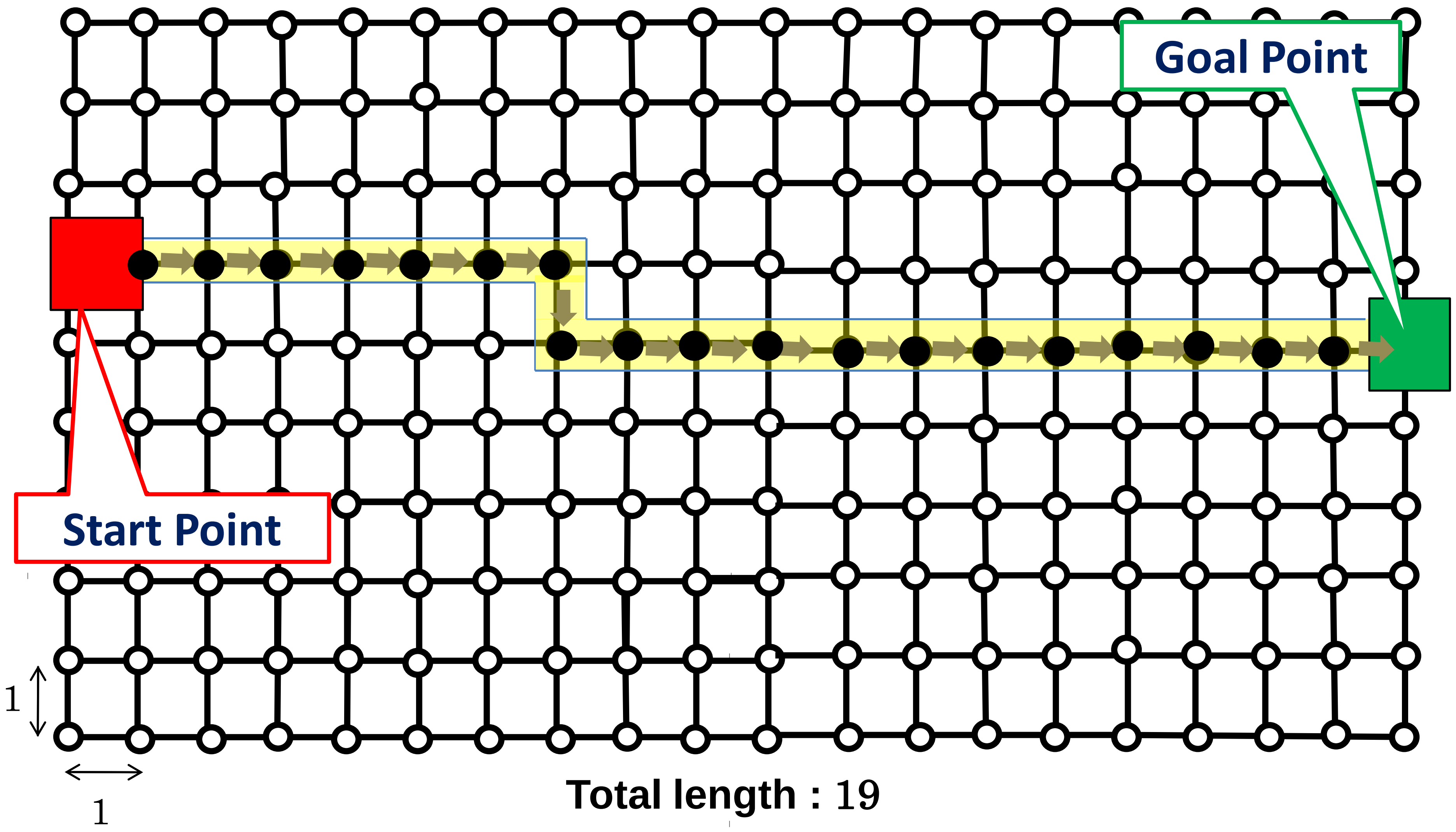
“Bends” are …

- **pipe parts to take the form of gentle S-shape**
- **connectors for gaps within the pipe’s diameter**



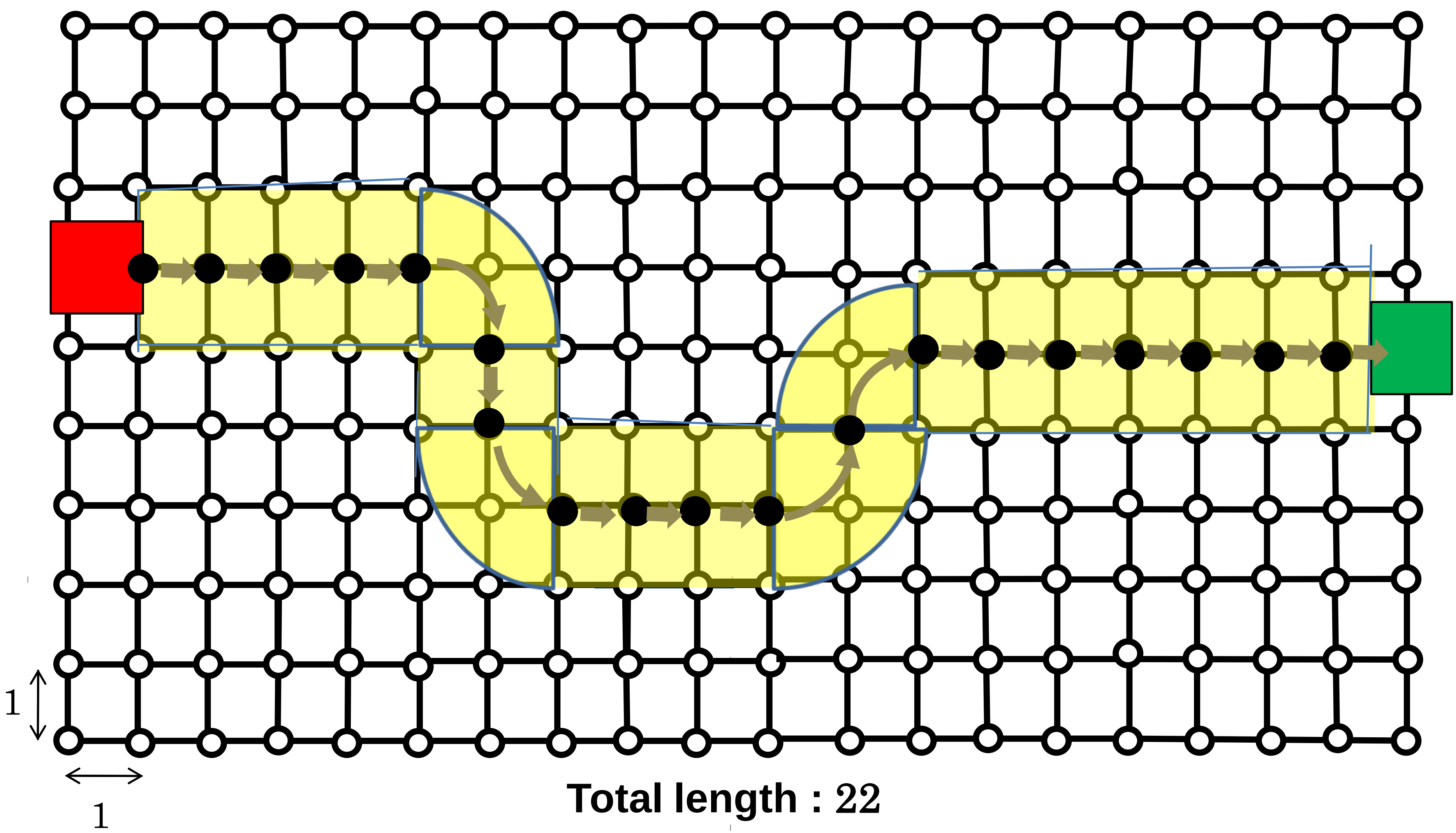
from “NAMURA TECHNICAL REVIEW No.13, 2010”

Outline of Bends

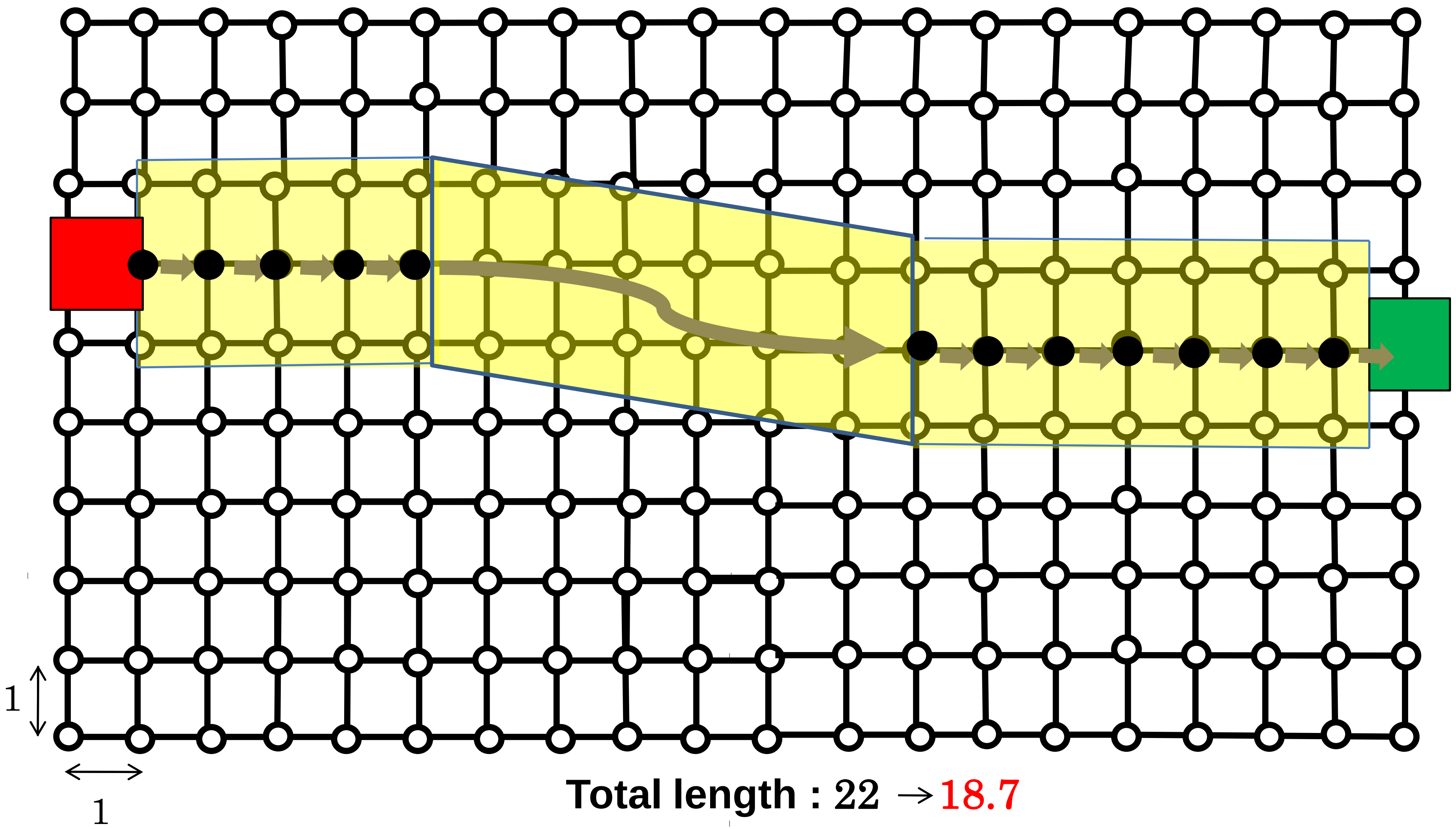


Total length : 19

Outline of Bends

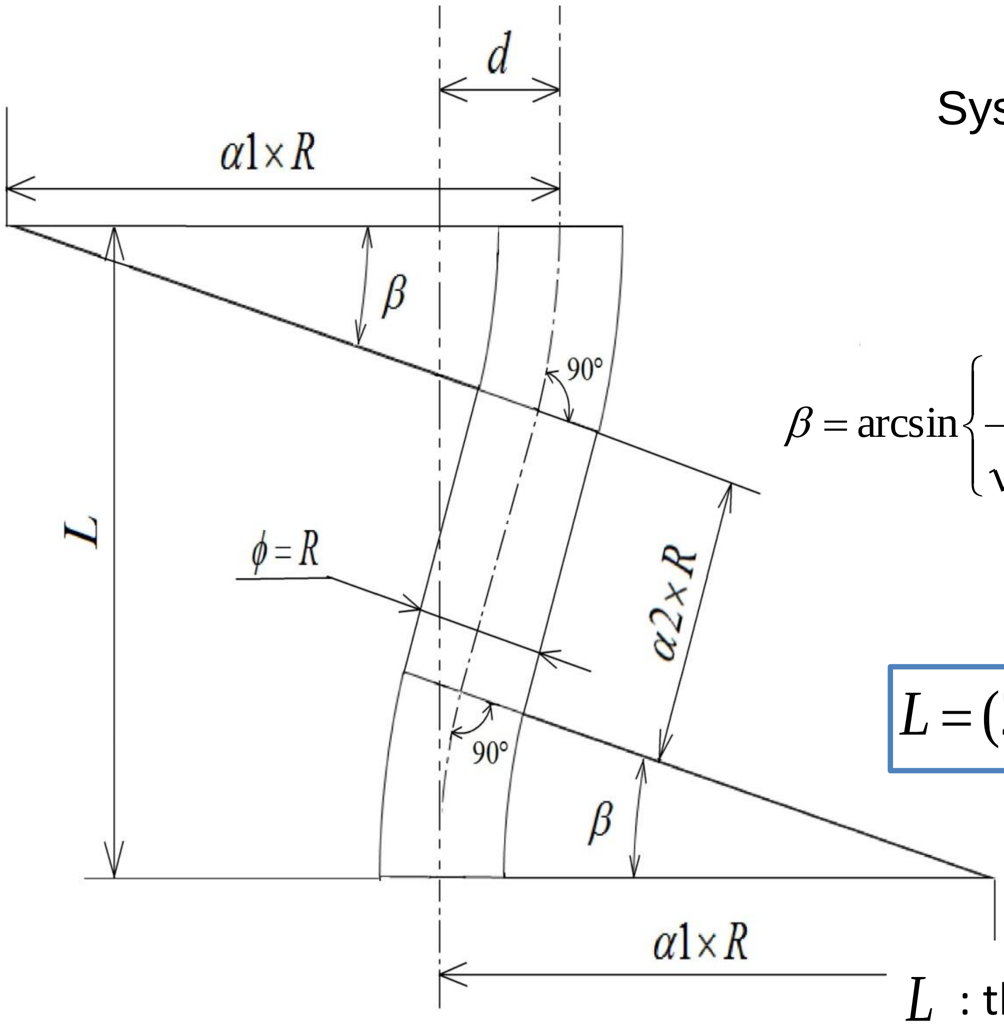


Outline of Bends



Total length : $22 \rightarrow$ **18.7**

Searching of Bends



System user sets a value of $\alpha 1, \alpha 2, d$

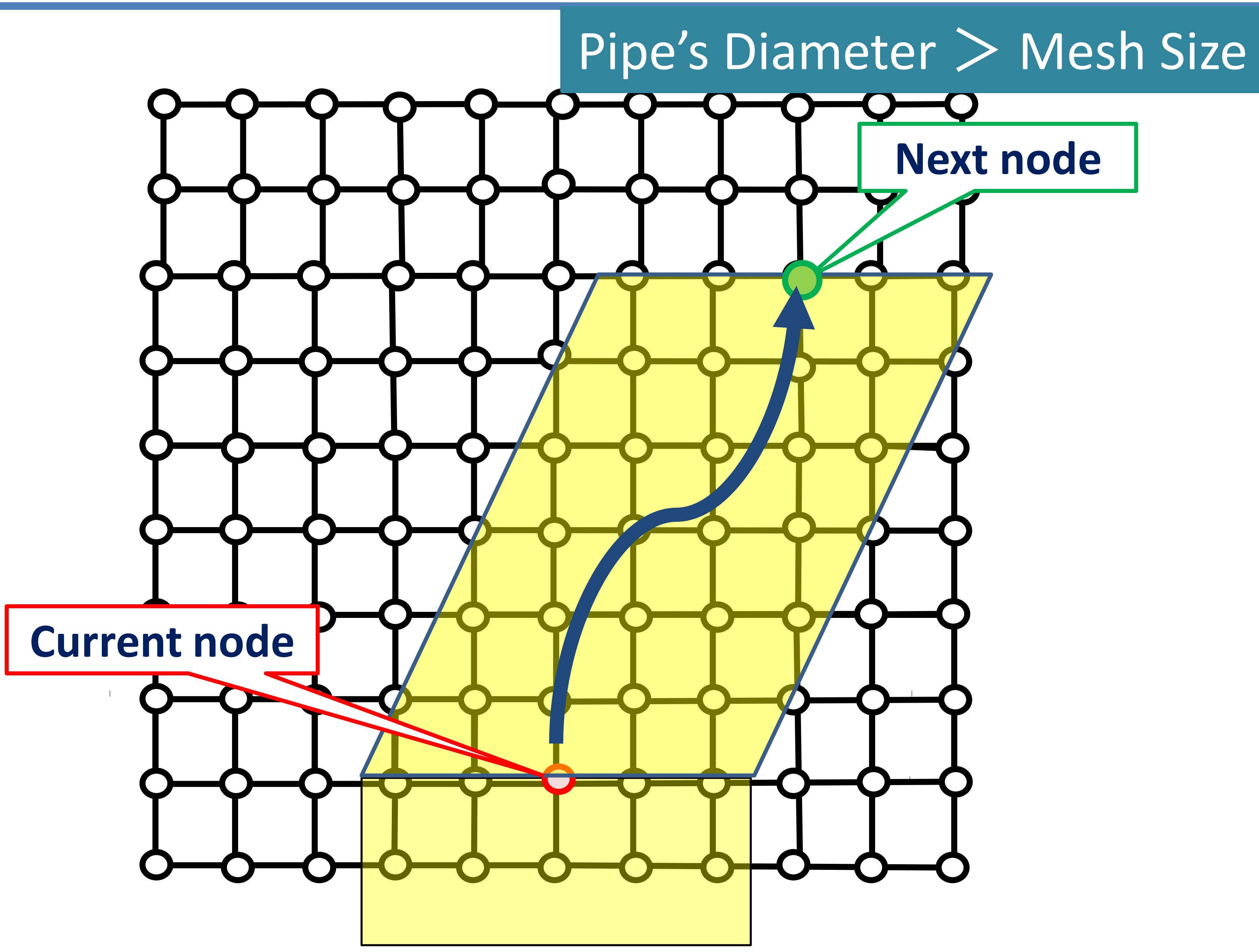
ex. $\alpha 1 = 5, \alpha 2 = 0, d < R$

$$\beta = \arcsin\left\{\frac{d - 2\times\alpha 1\times R}{\sqrt{(2\times\alpha 1)^2 + (\alpha 2)^2}}\right\} + \arcsin\left\{\frac{2\times\alpha 1}{\sqrt{(2\times\alpha 1)^2 + (\alpha 2)^2}}\right\}$$

$$L = (2\times\alpha 1\times R\times\sin\beta) + (\alpha 2\times R\times\cos\beta)$$

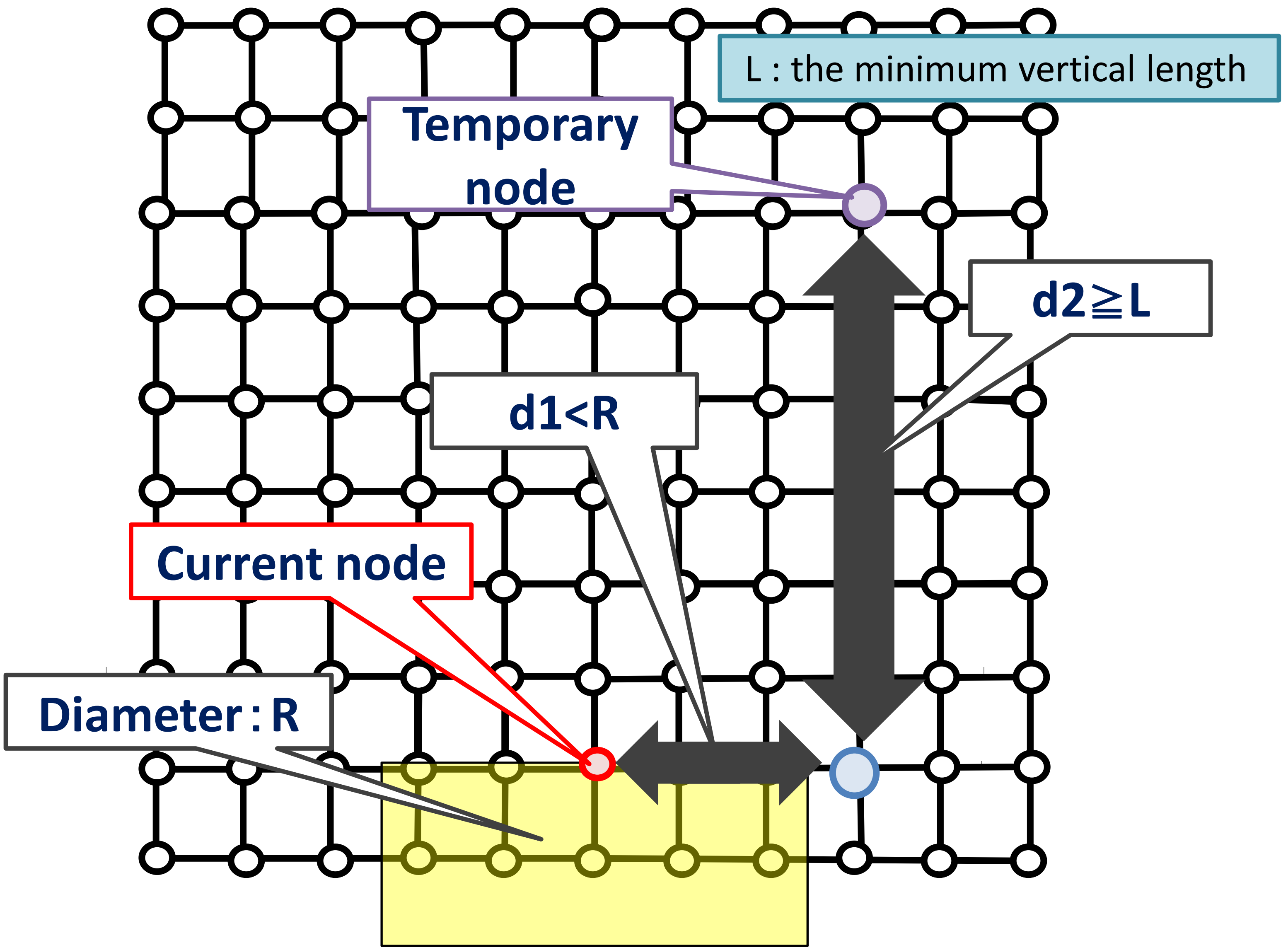
L : the minimum vertical length of the bend

Searching of Bends



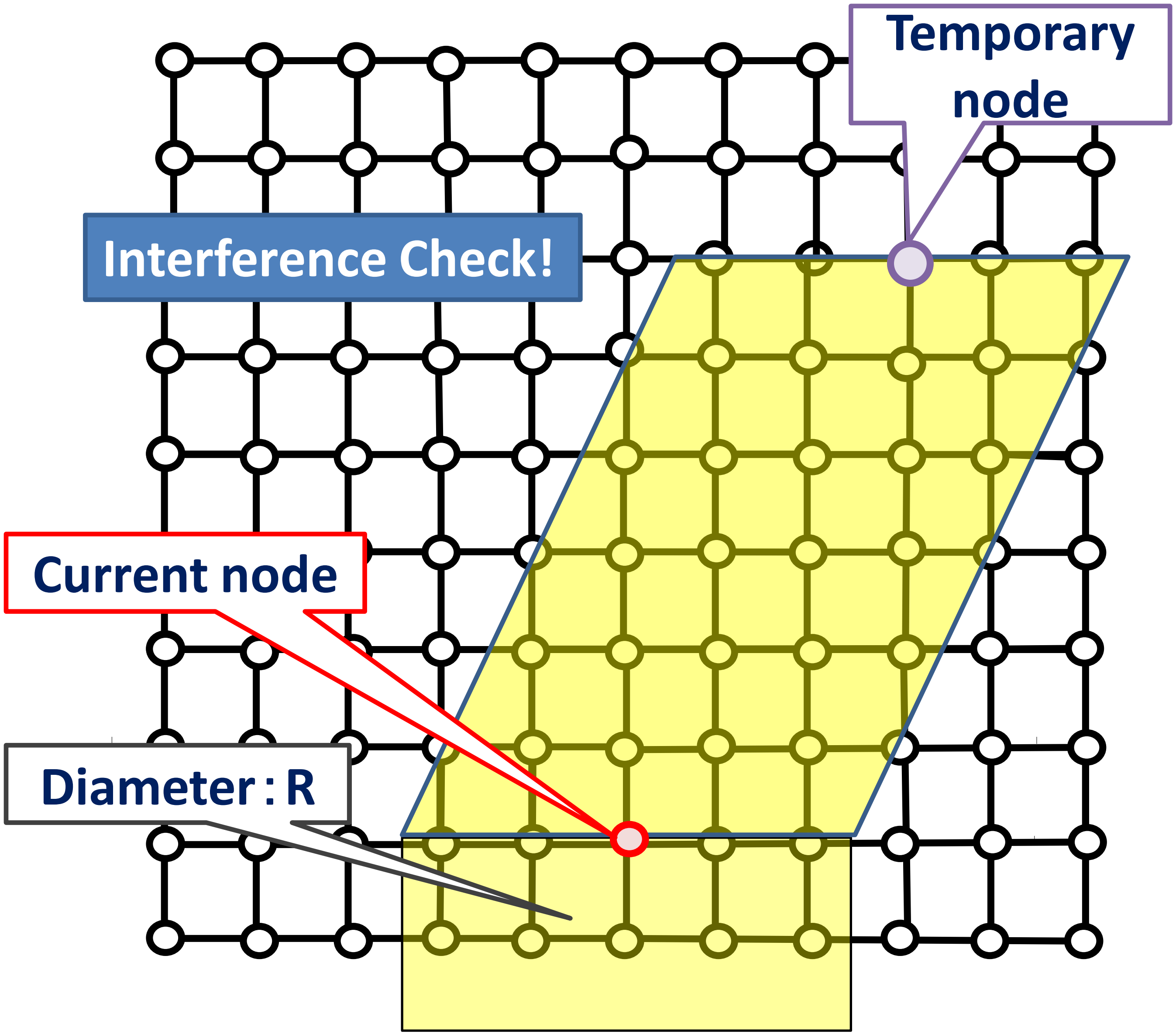
Searching of Bends

Step1



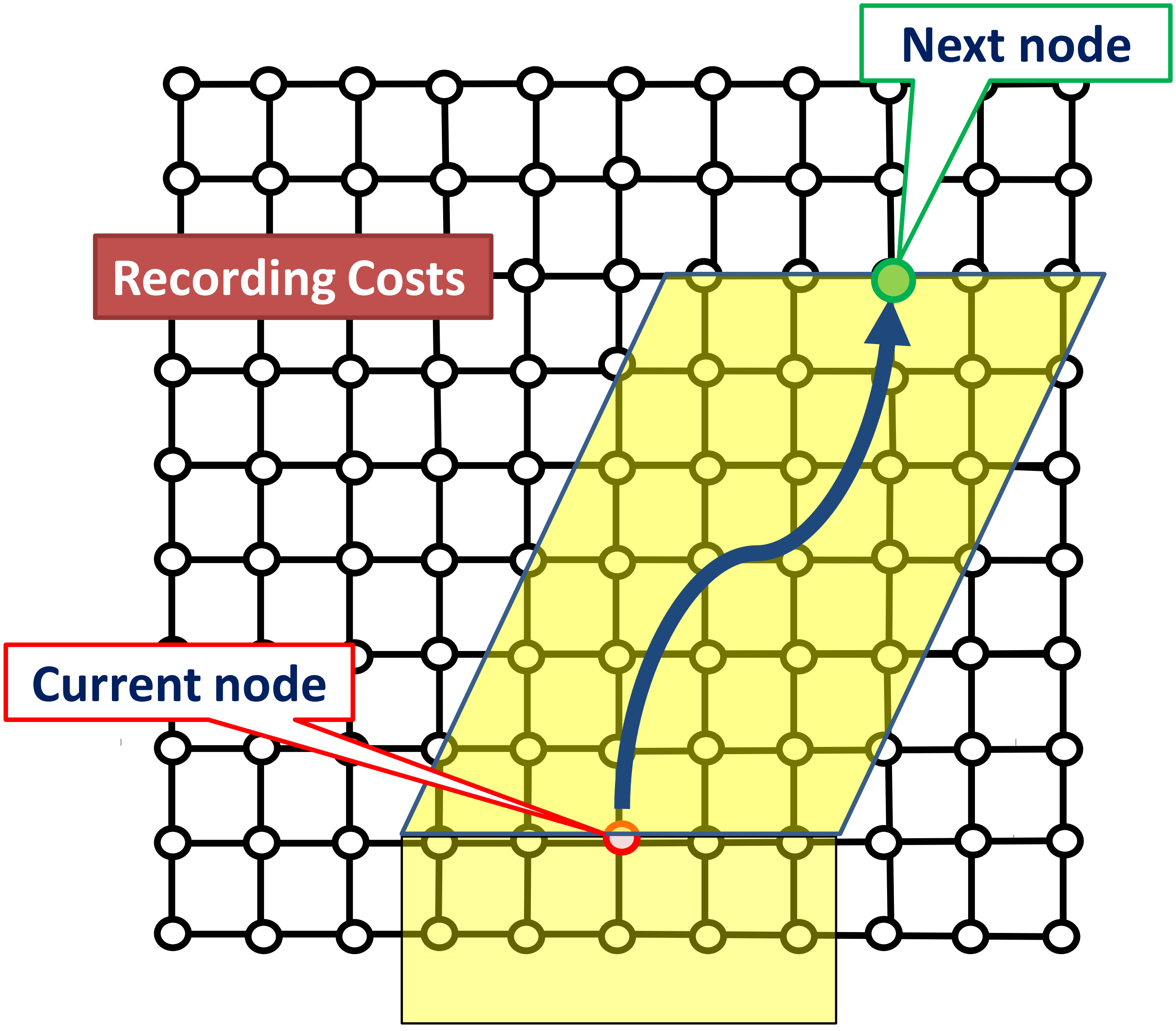
Searching of Bends

Step2



Searching of Bends

Step3



Experiments

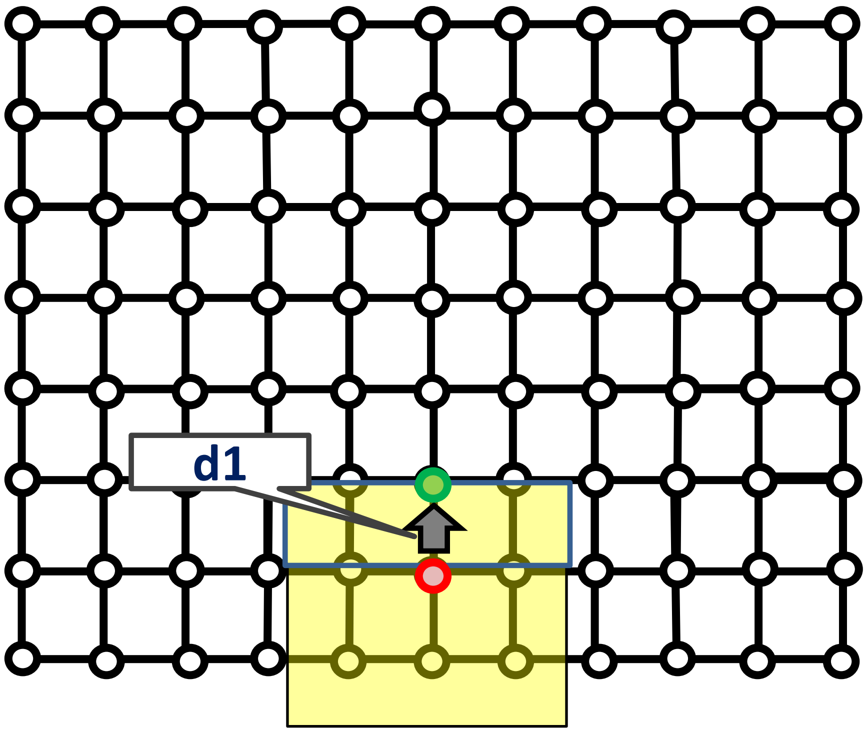
Purpose

- **to verify the useful of the algorithm**

Test Case Setting

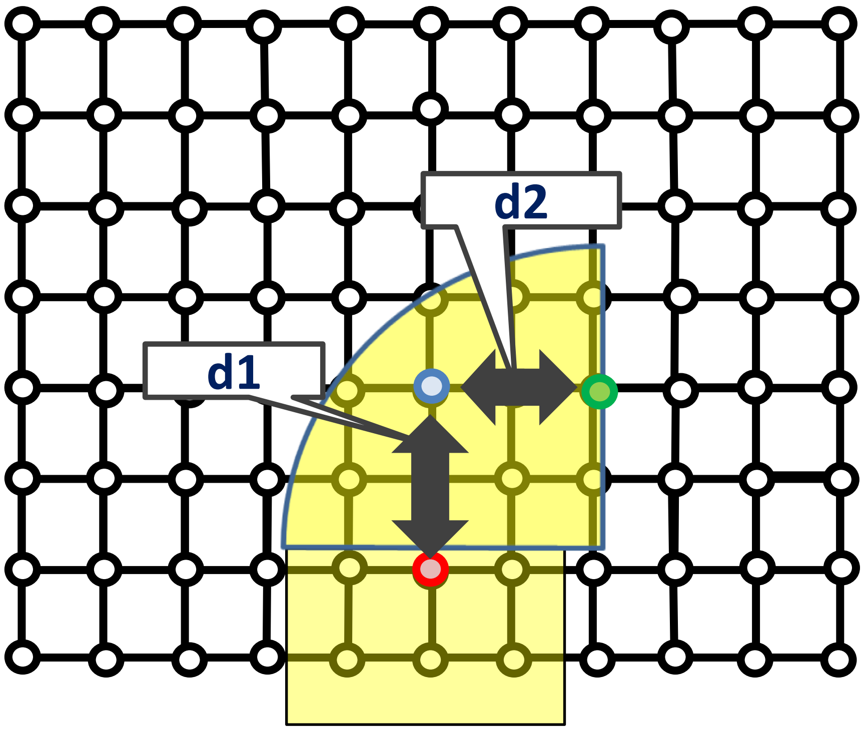
- **Design Area :** X 16.75m, Y 3m, Z 3m
- **Mesh Size :** X 0.25m, Y 0.25m, Z 0.25m
- **Start Point :** (0.5m, 1.75m, 1.5m), x+
- **Goal Point :** (16.5m, 1. 5m, 1.5m), x-
- **10 boxes as obstacles**

Experiments



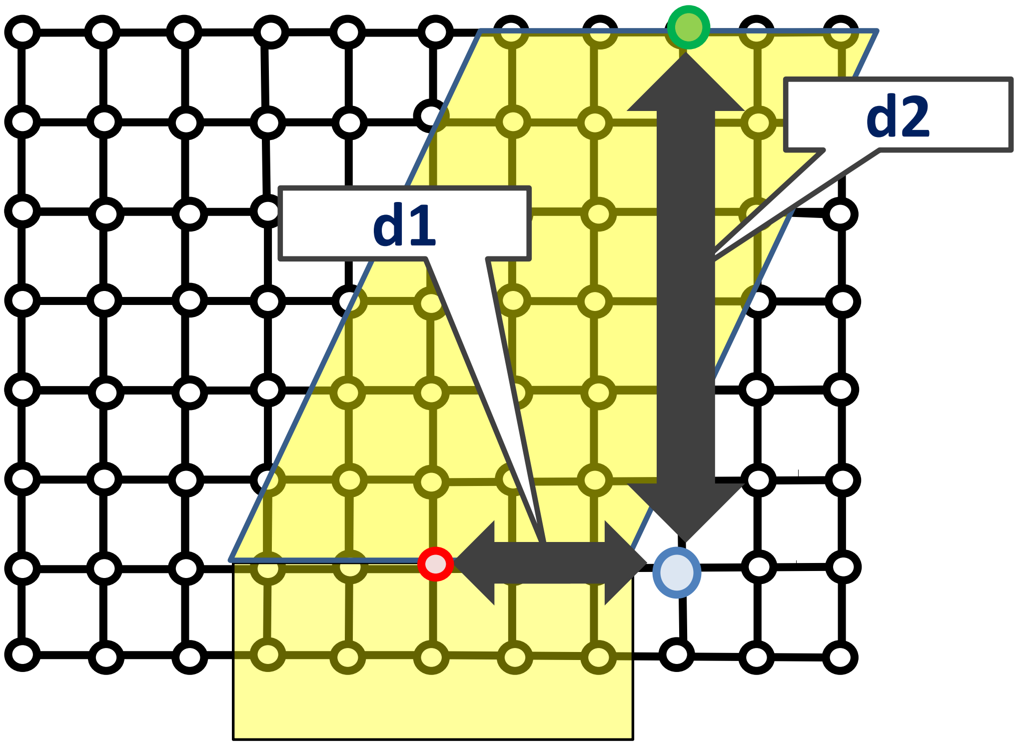
Cost of a Straight Pipe : 1 per 1m

Experiments



Cost of a Elbow : $\mathrm{d1} + \mathrm{d2} + 0.1$

Experiments



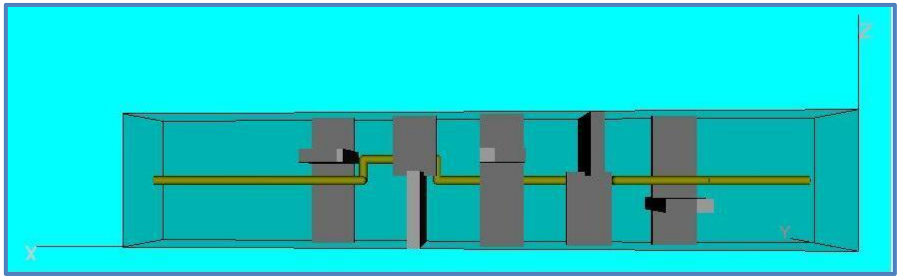
Cost of a Bend : $\mathrm{d1} + \mathrm{d2} + 0.3$

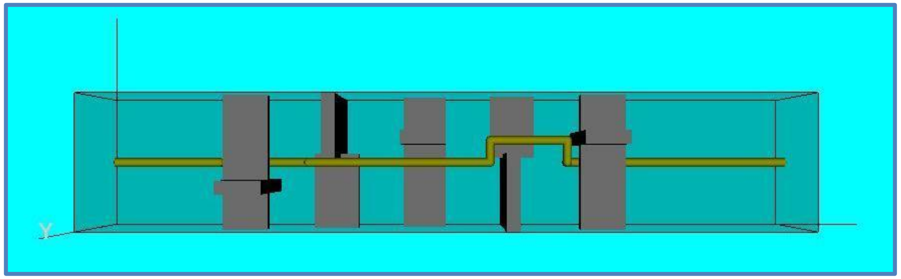
Experiments

Design Objectives for This Test

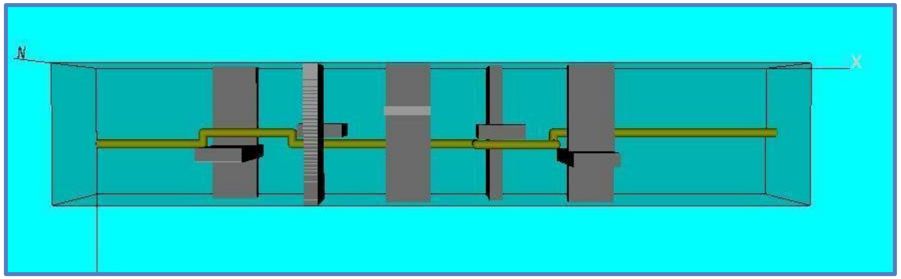
- ◆ **to minimize the total length of pipes**
- ◆ **to minimize the number of elbows and bends**
- ◆ **to avoid passing aisles as possible**
- ◆ **to pass through pipe-rack areas as possible**

Results (R=0.2m)

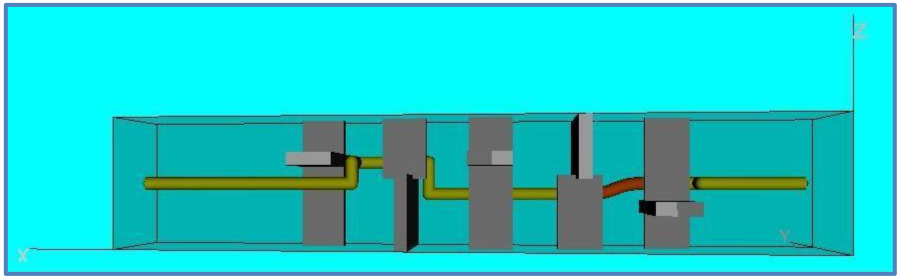


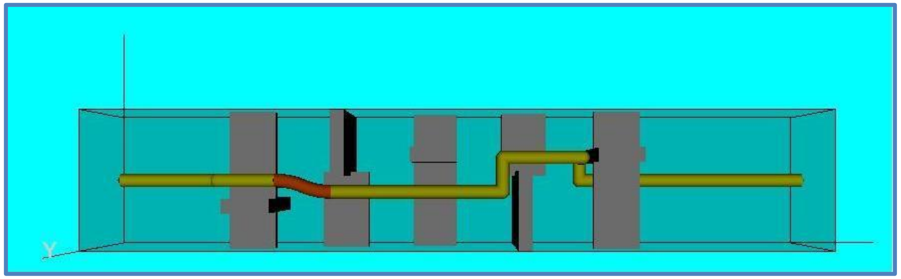


Bends	○	×
Num. of Elbows	9	9
Num. of Bends	0	
Total Costs	17.9	17.9
Time[s]	1285	1260

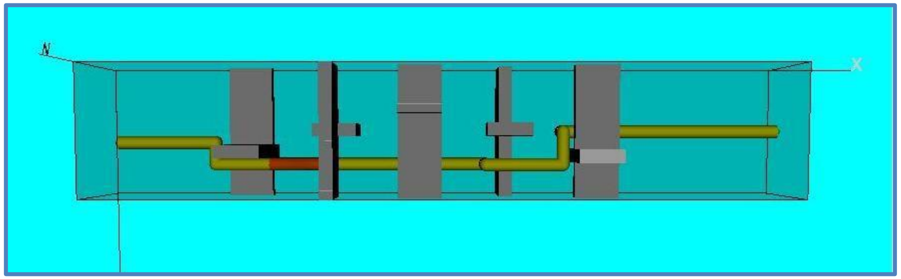


Results (R=0.3m)

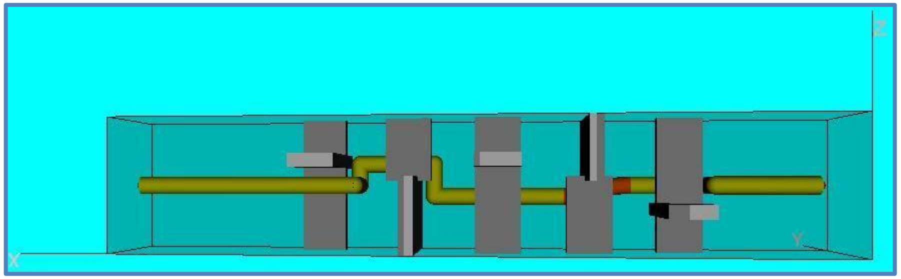


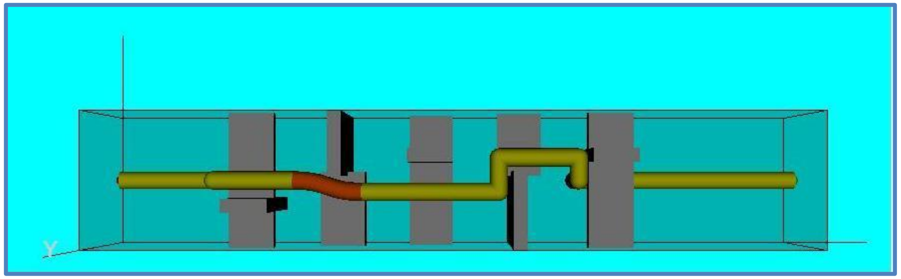


Bends	○	×
Num. of Elbows	7	9
Num. of Bends	1	
Total Costs	19.0	19.4
Time[s]	447	306

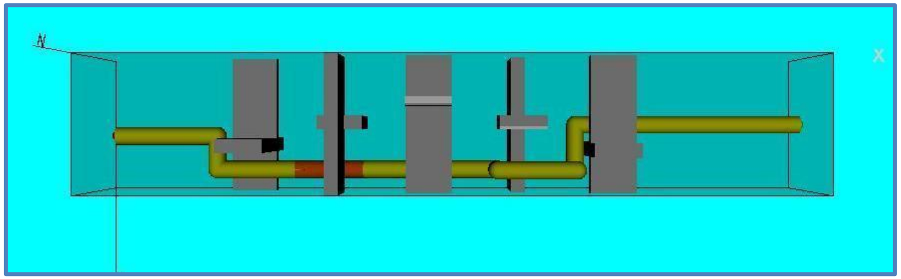


Results (R=0.4m)

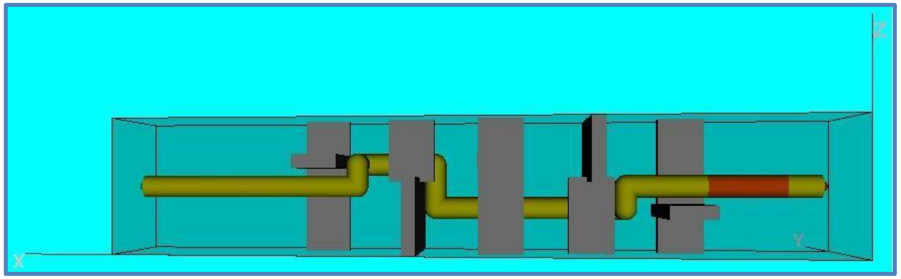


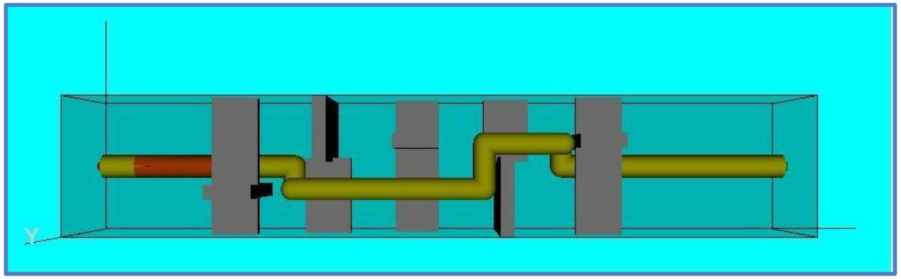


Bends	○	×
Num. of Elbows	7	9
Num. of Bends	1	
Total Costs	19.5	19.9
Time[s]	387	298

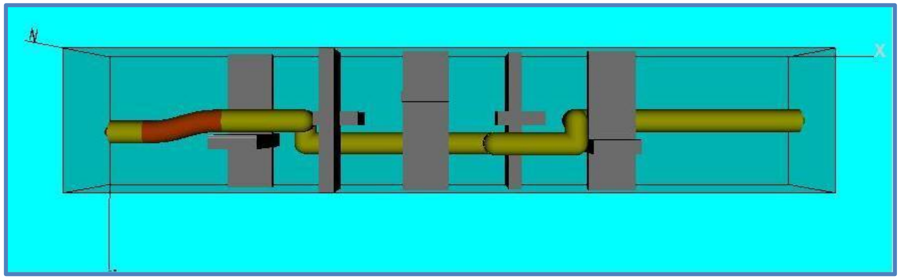


Results (R=0.5m)

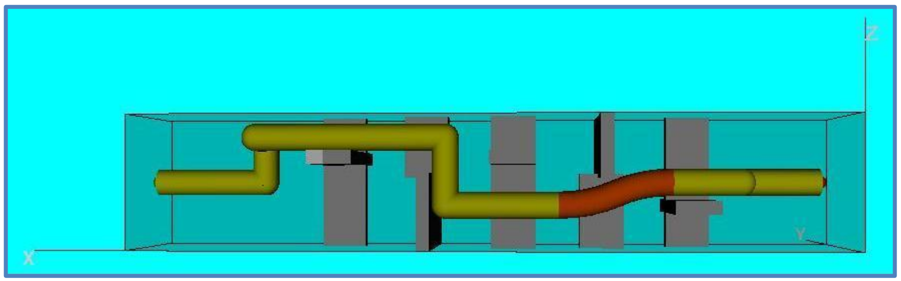


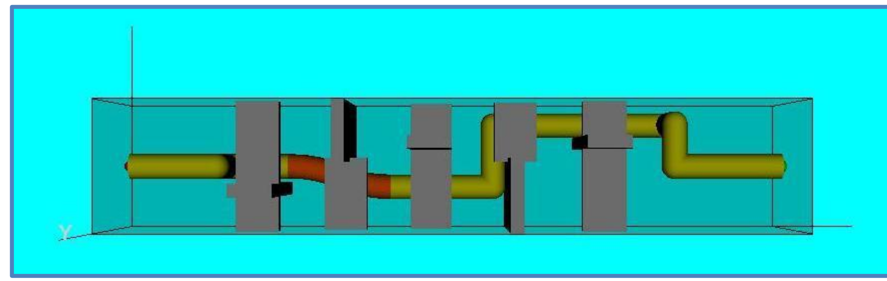


Bends	○	×
Num. of Elbows	8	9
Num. of Bends	1	
Total Costs	19.6	19.9
Time[s]	373	288

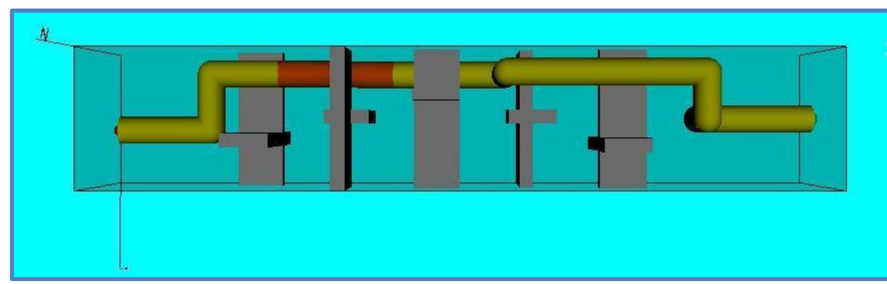


Results (R=0.6m)

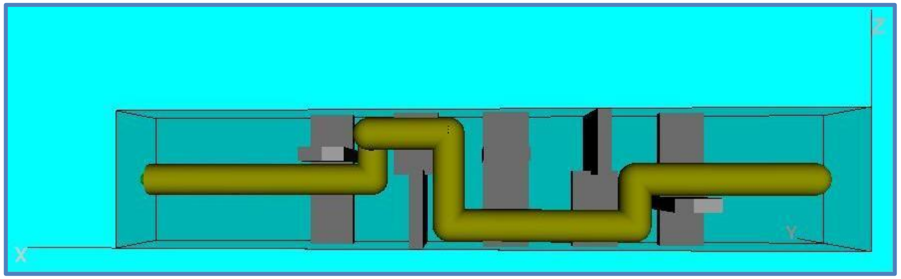


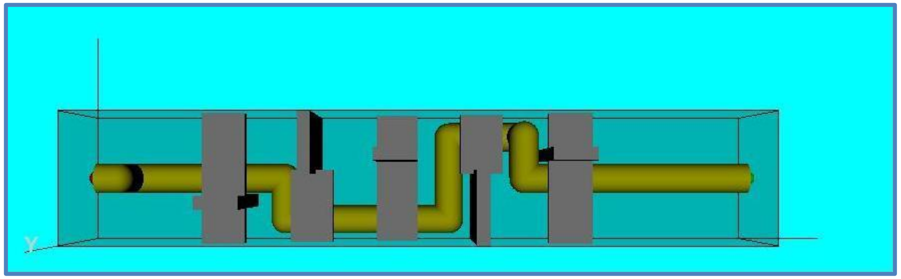


Bends	○	×
Num. of Elbows	7	8
Num. of Bends	1	
Total Costs	21.5	22.3
Time[s]	80	68

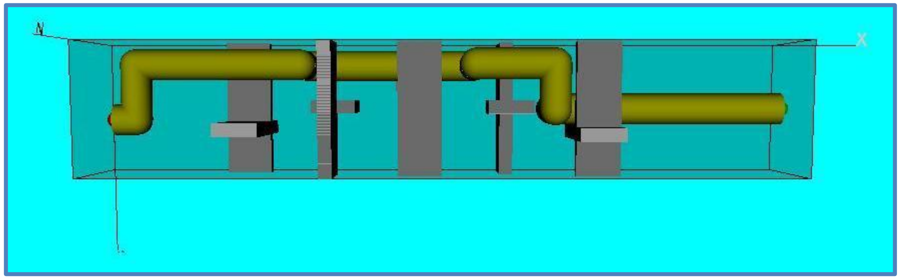


Results (R=0.7m)

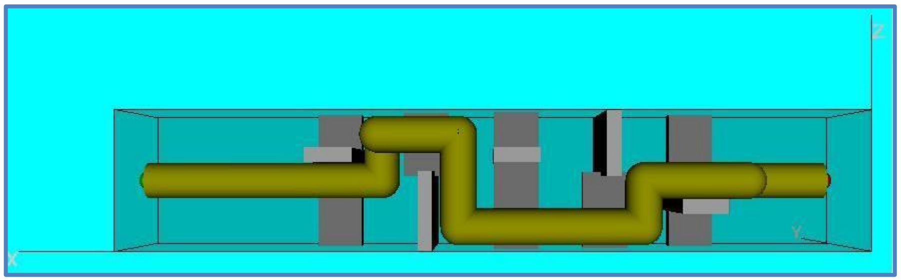


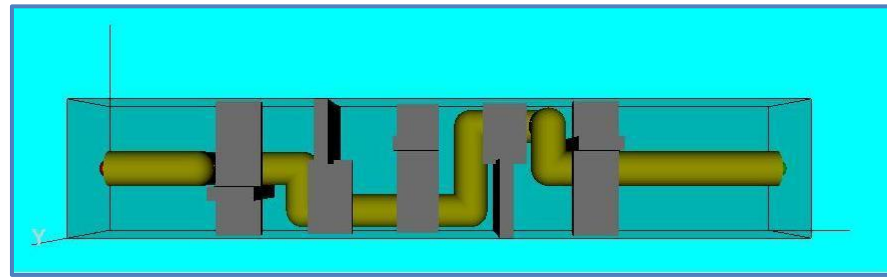


Bends	○	×
Num. of Elbows	9	9
Num. of Bends	0	
Total Costs	22.4	22.4
Time[s]	68	53

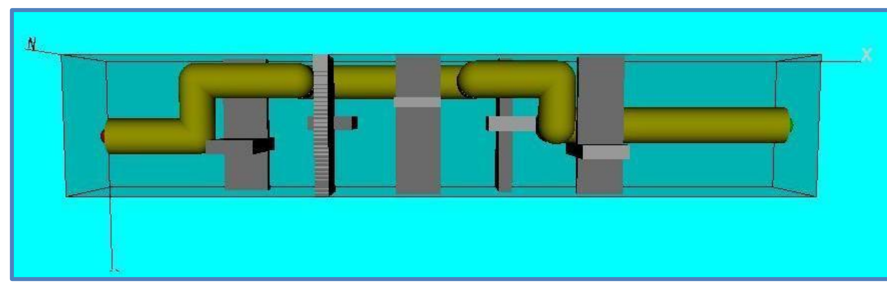


Results (R=0.8m)

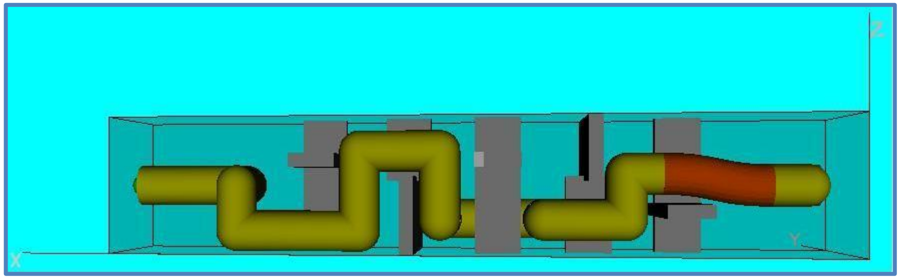


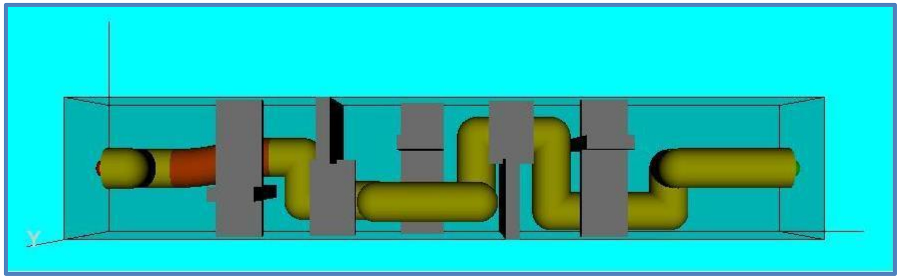


Bends	○	×
Num. of Elbows	9	9
Num. of Bends	0	
Total Costs	22.4	22.4
Time[s]	63	50

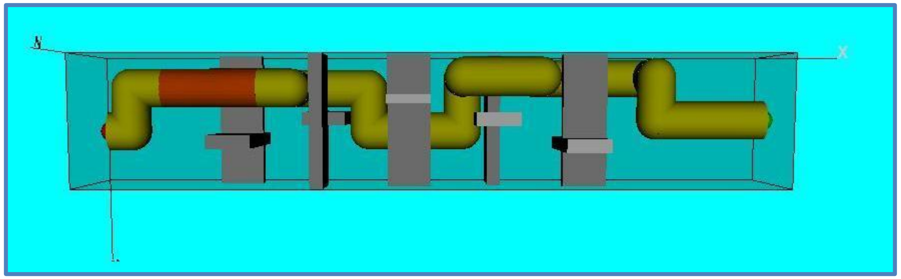


Results (R=0.9m)

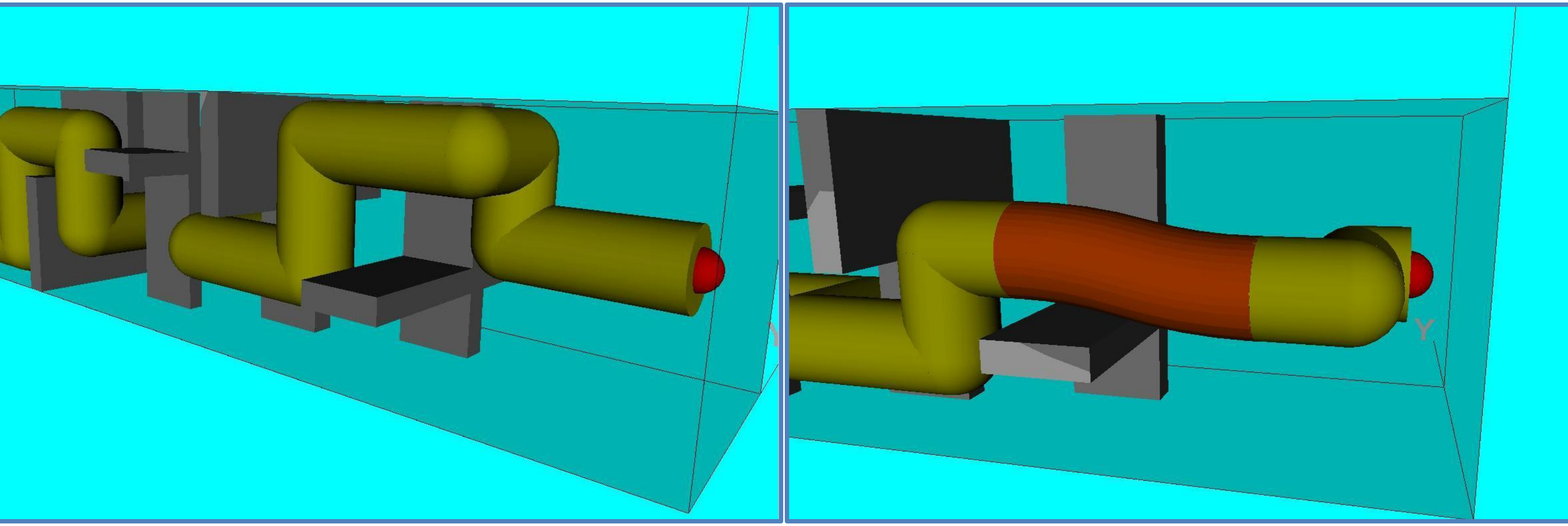




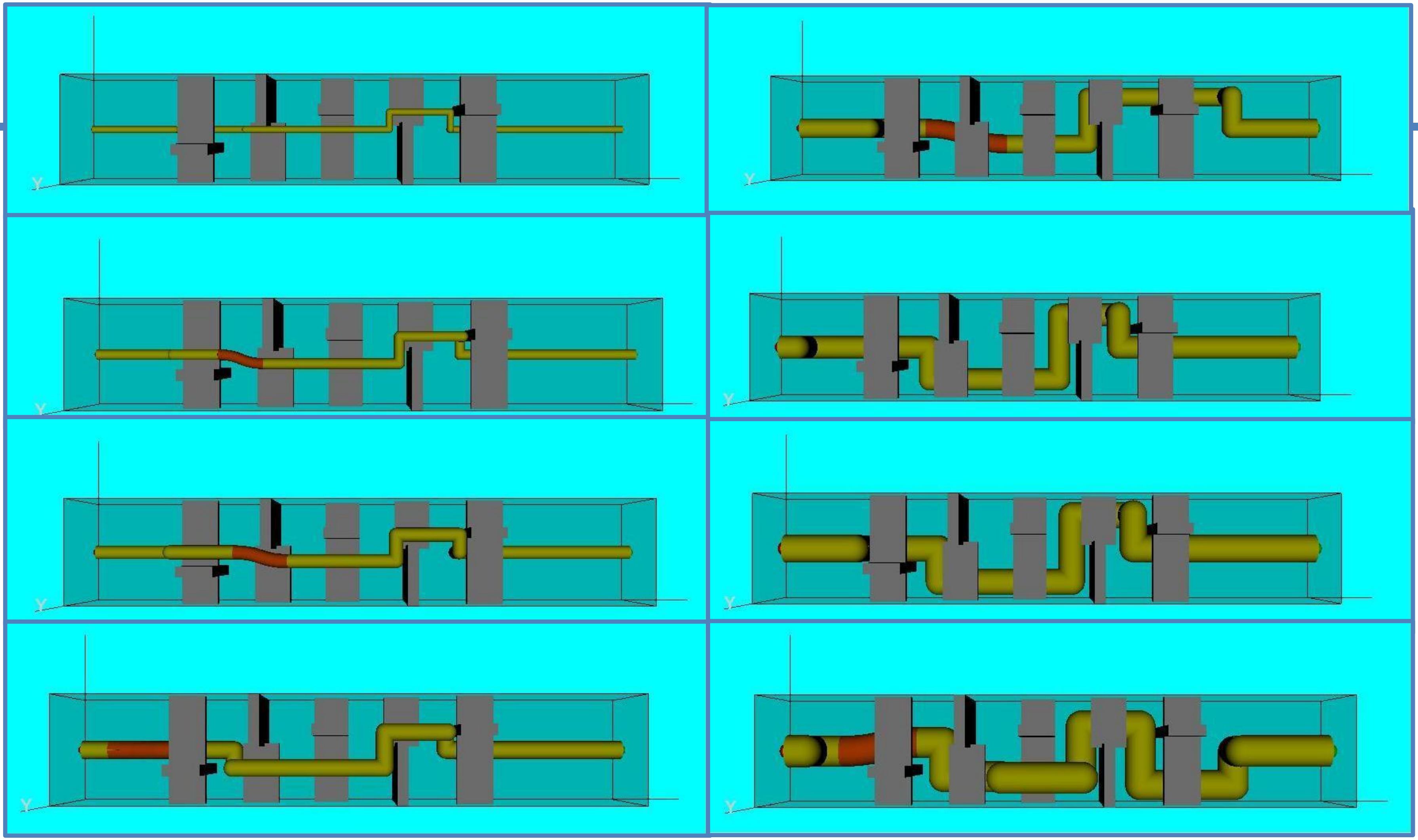
Bends	○	×
Num. of Elbows	14	15
Num. of Bends	1	
Total Costs	26.7	27.5
Time[s]	45	44



Results



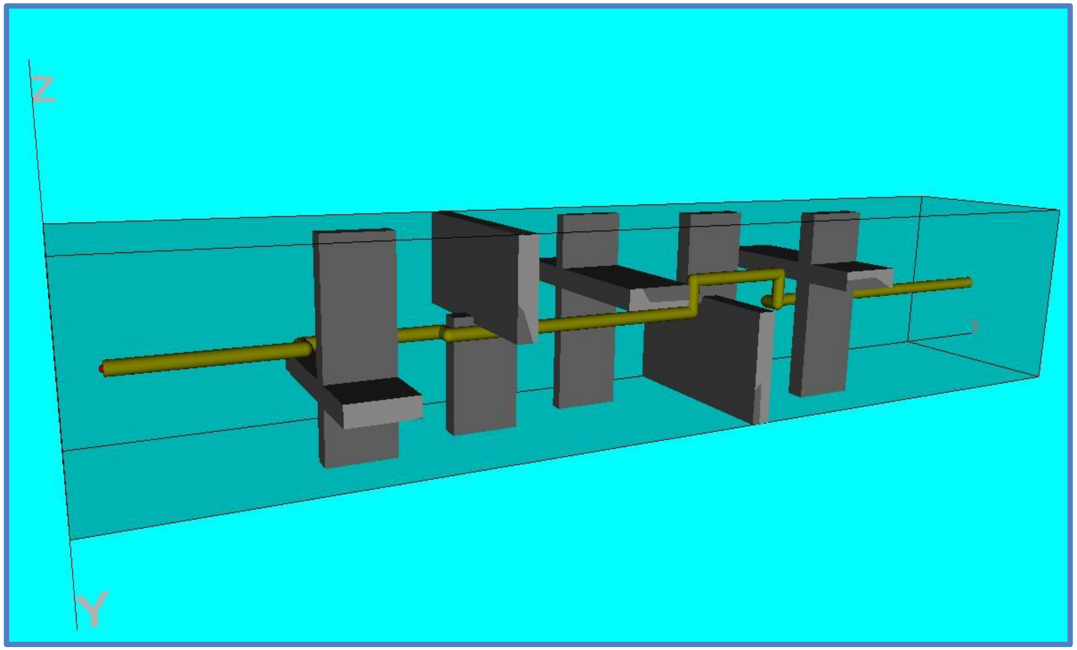
◆ The algorithm practical design including bends.



◆ The algorithm generated optimized solutions by each case.

Discussion

Pattern A	
Diameter [m]	Time[s]
0.9	45
0.8	63
0.7	68
0.6	80
0.5	373
0.4	387
0.3	447
0.2	1285



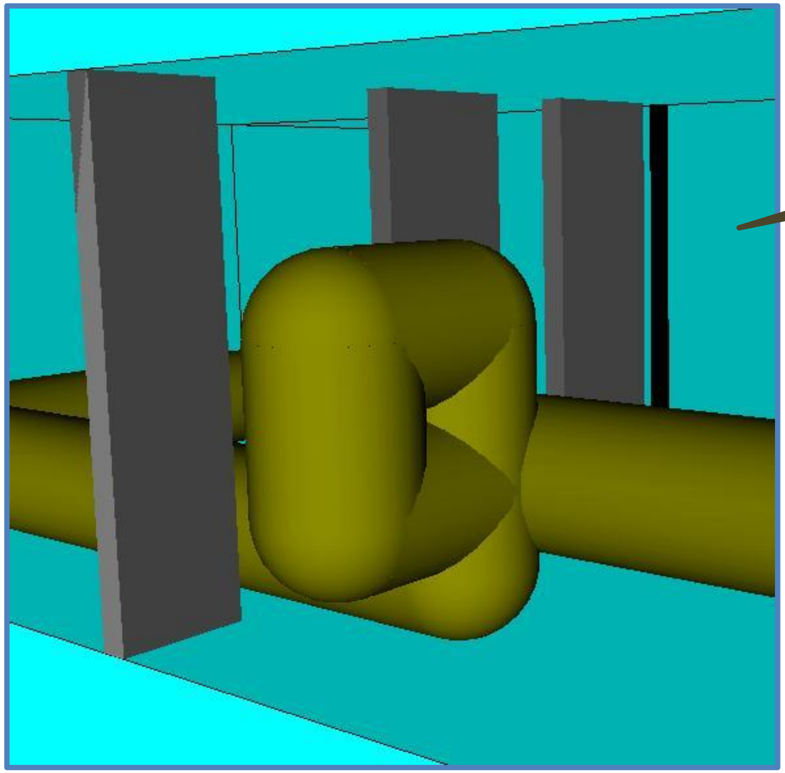
◆ It took more time to search a routing with smaller diameter.

Why?

The decrease of diameter causes
an increase of the searching space.

Discussion

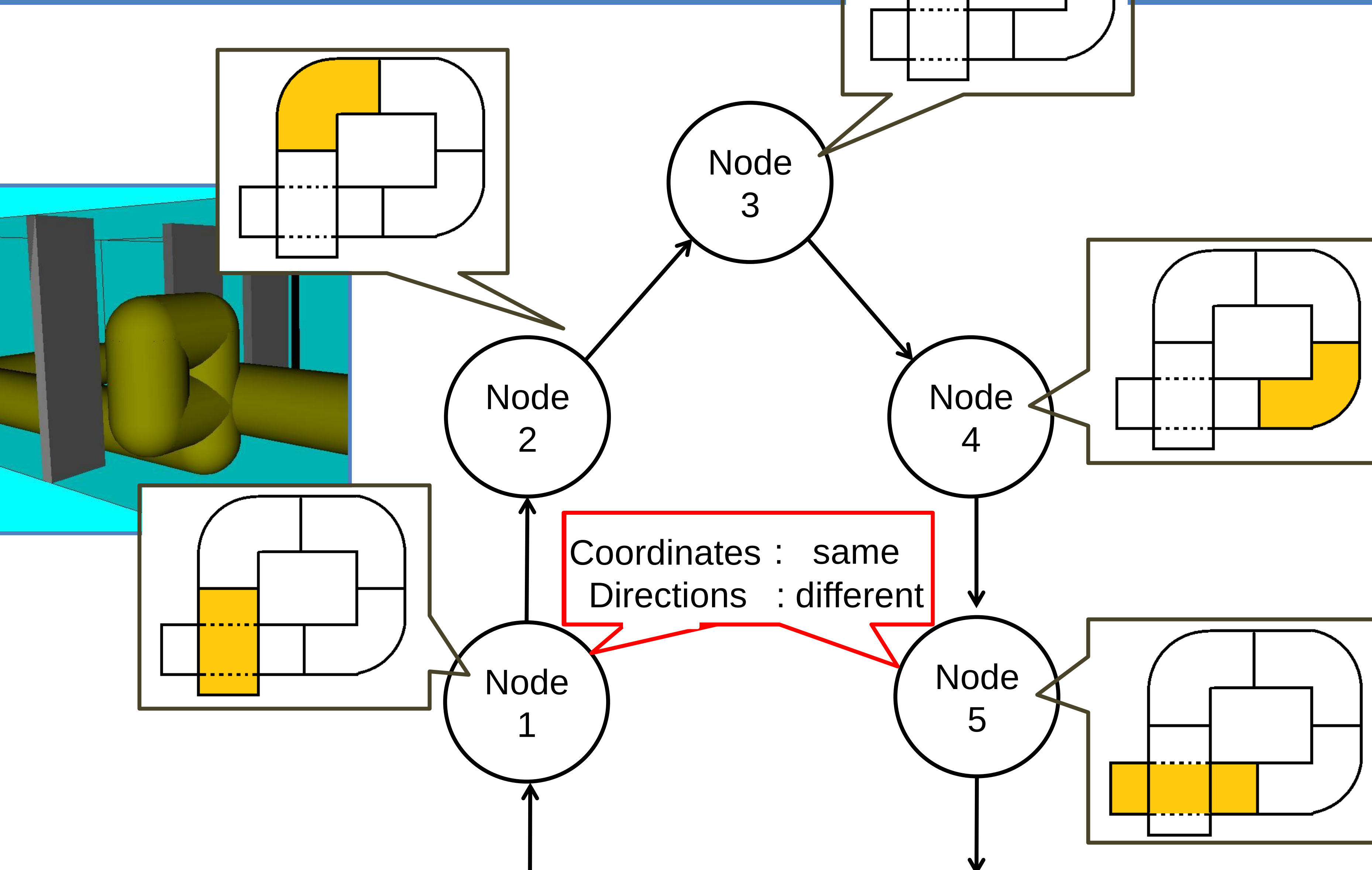
As a result in other test case…



Especially in very narrow space

◆ An obtained route interfered with itself!

Discussio


Node
3
Node
2
Node
4
Coordinates : same
Directions : different
Node
1
Node
5

Outline

1. Background and Purpose

- Previous Research

2. Routing Algorithm Including Bends

- Approach
- Dijkstra’s Method
- Outline of “Bends”
- Experiments

3. Conclusion and Challenges

Conclusions

Advantages of the algorithm

- **The mesh size is free.**
- **The algorithm generate practical designs with bends.**
- **The algorithm generate routes with minimum costs.**

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Conclusions

Advantages of the algorithm

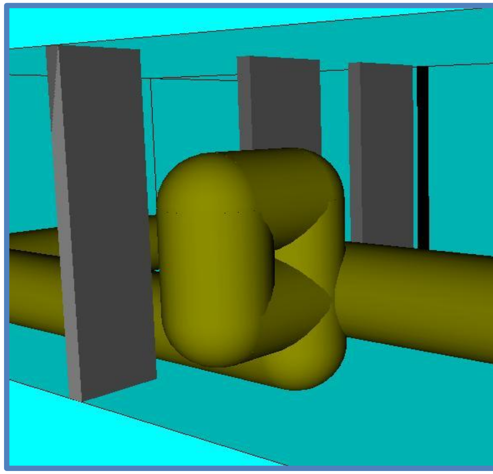
- **The mesh size is free.**
- **The algorithm generate practical designs with bends.**
- **The algorithm generate routes with optimum costs.**

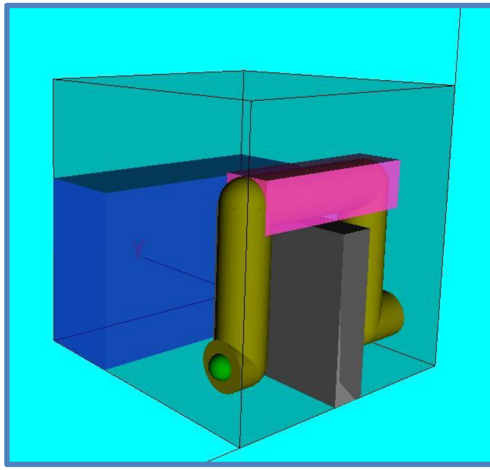
guaranteed!

Future Works

We need to …

- **improve the routing algorithm**
- **consider about pipe-rack and aisle areas**
- **make better the interference check algorithm**
- **create more maintainable system by the use of XML input / output**
- **associate the routing algorithm with the equipments layout algorithm**





This system will be opened for free at

http://sysplan.nams.kyushu-u.ac.jp/gen/index.html