

Automated Generation of Modular and Dynamic Industrial Process Plant Visualizations

Bachelor Thesis

Introduction

Motivation



Why?

Introduction

Motivation



- Frequent technical changes

- Frequent technical changes → constant increase in complexity of industrial facilities

- Frequent technical changes → constant increase in complexity of industrial facilities
- Changes propagate throughout
 - Documentation
 - Maintenance
 - Operation

- Frequent technical changes → constant increase in complexity of industrial facilities
- Changes propagate throughout → major engineering challenge
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 - Operation

- Frequent technical changes → constant increase in complexity of industrial facilities
- Changes propagate throughout → major engineering challenge
 - Documentation
 - Maintenance
 - Operation
- Due to this reasons, the development and modification of visualizations for process engineering plants requires a very high technical effort

Introduction

Problem Definition



What?

Introduction

Problem Definition



- Required:

- Required: A solution to automate the generation of modular and dynamic plant *Piping and Instrumentation Diagram (P&ID)* visualizations

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 - with **minimal user configuration** and

- Required: A solution to automate the generation of modular and dynamic plant *Piping and Instrumentation Diagram (P&ID)* visualizations
 - with **minimal user configuration** and
 - **integration to the MES** software at hand.

Introduction

Goals



How?

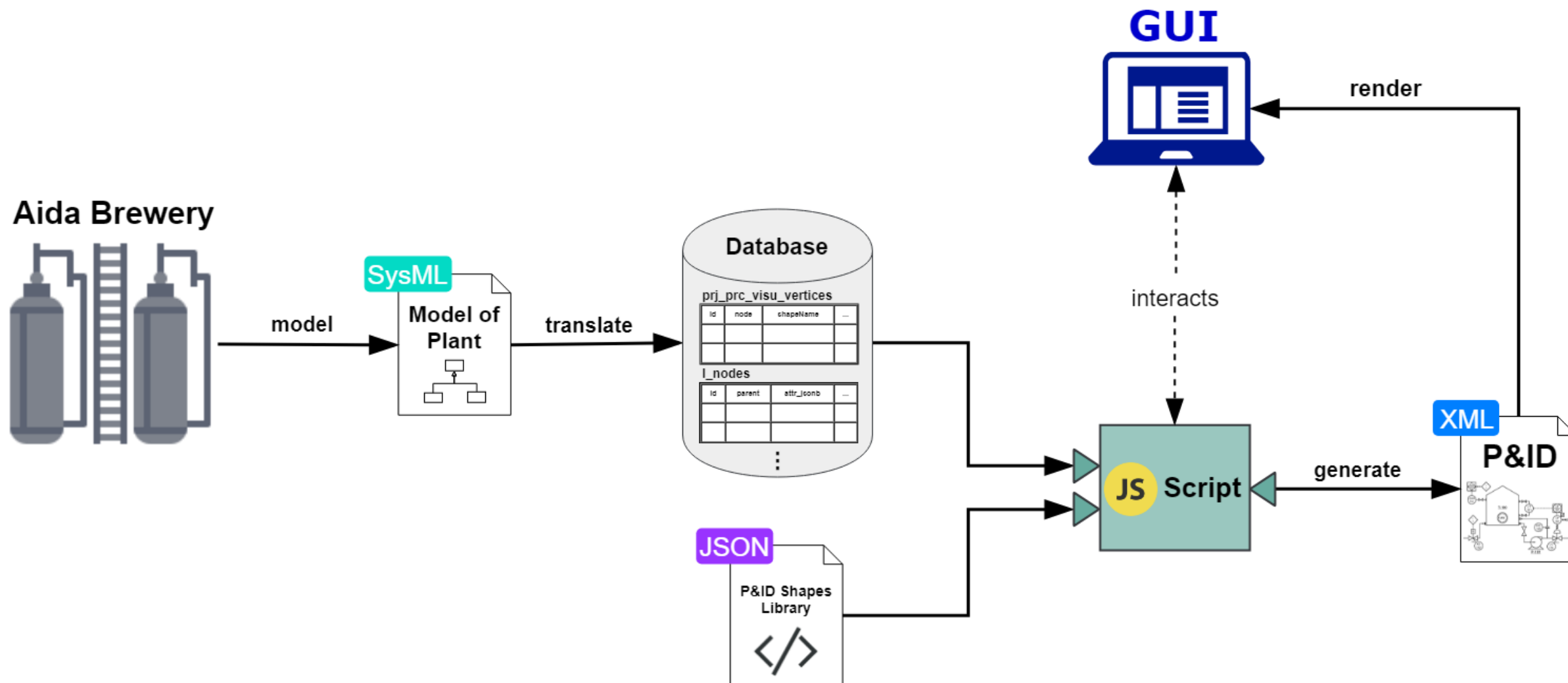
1. Reduce technical effort and accelerate creation of *Piping and Instrumentation Diagram (P&ID)* visualizations

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2. Create a library of all standardized P&ID symbols

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2. Create a library of all standardized P&ID symbols
3. Prototypal Implementation in a *Manufacturing Execution System (MES)*

Conceptual Overview

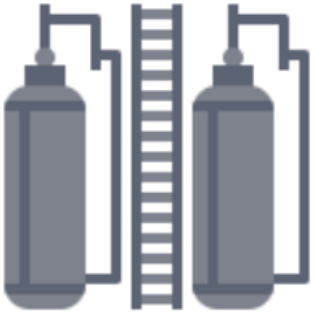
Scope of the Project



Conceptual Overview

Scope of the Project

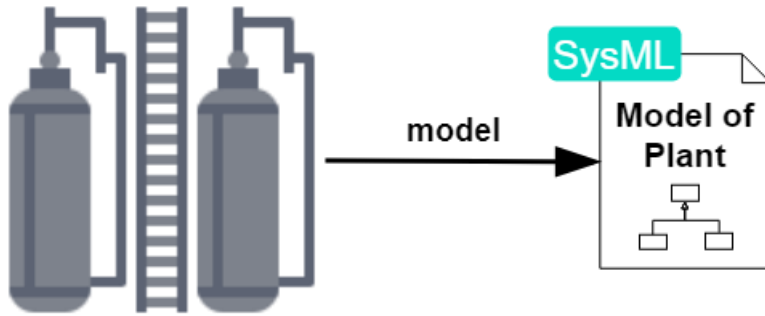
Aida Brewery



Conceptual Overview

Scope of the Project

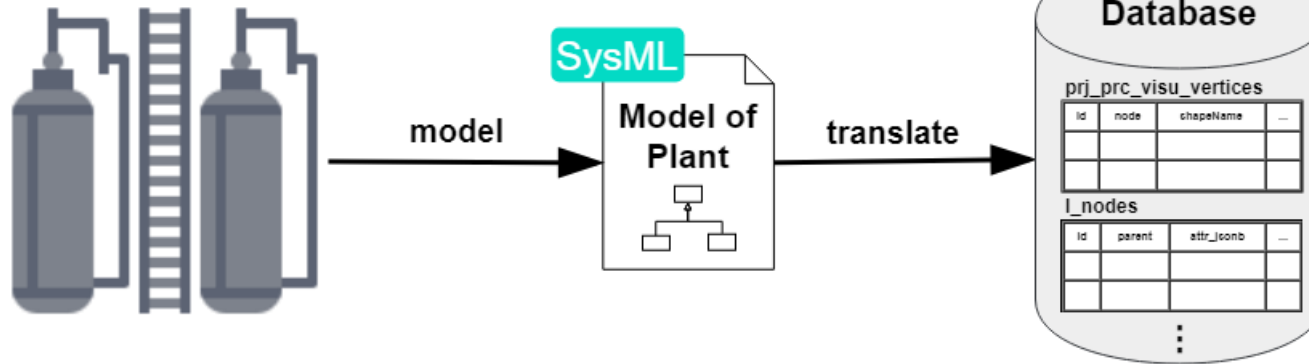
Aida Brewery



Conceptual Overview

Scope of the Project

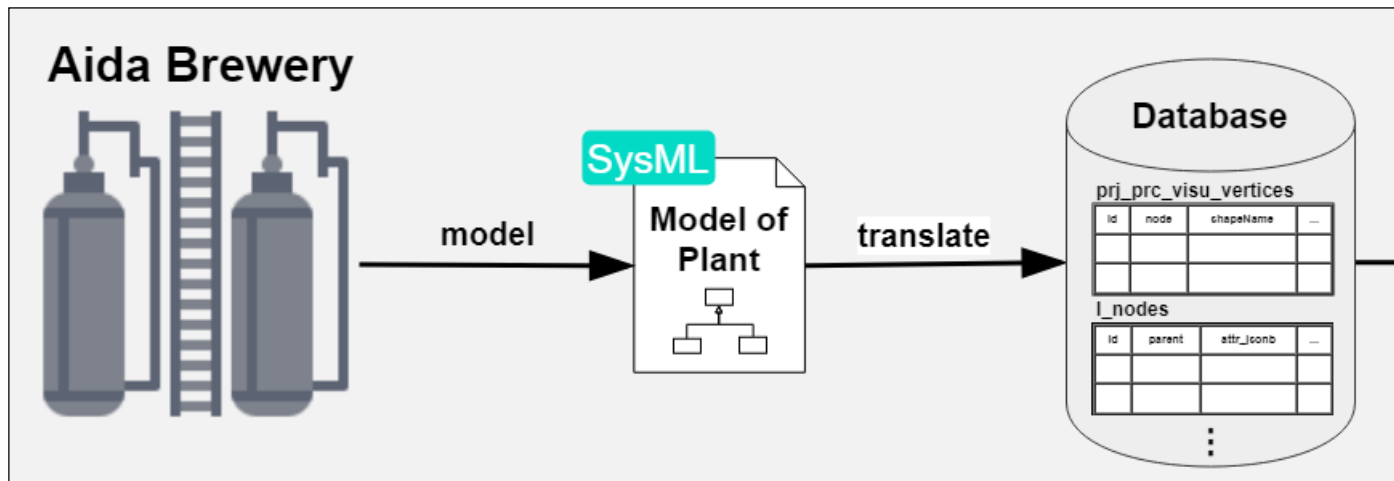
Aida Brewery



Conceptual Overview

Scope of the Project

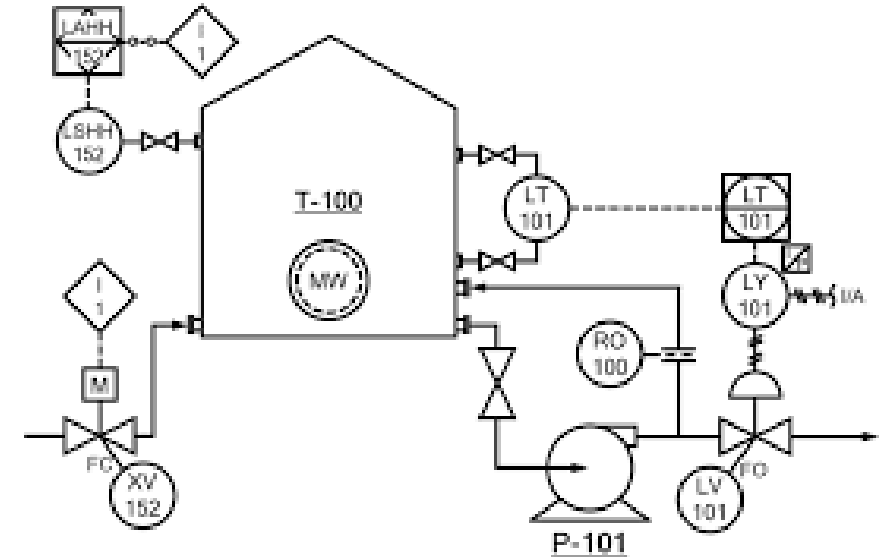
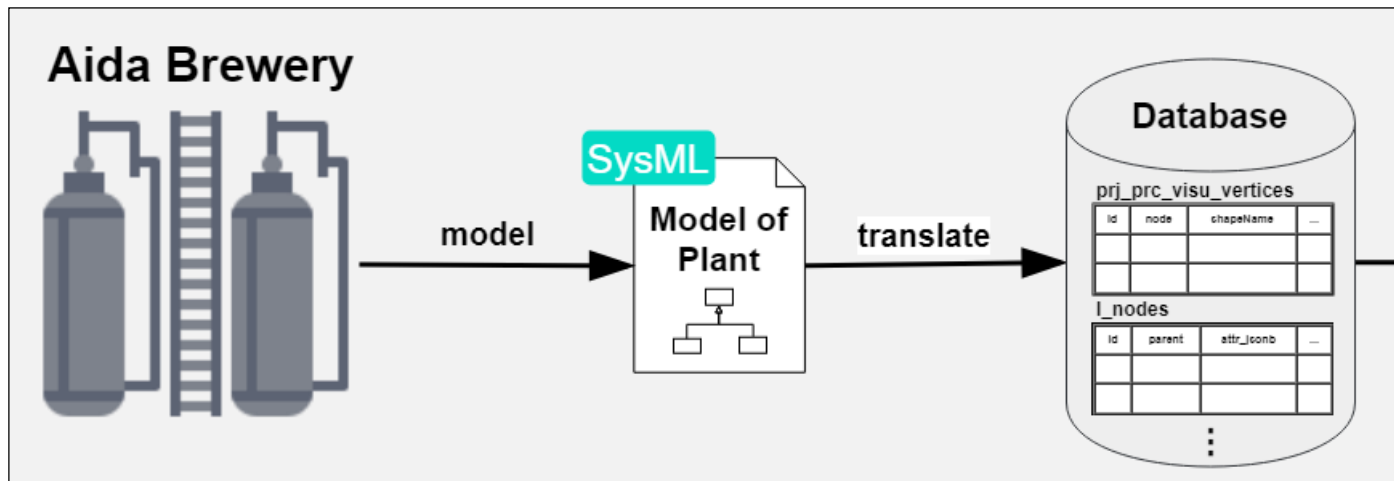
ProcAppCom



Conceptual Overview

Scope of the Project

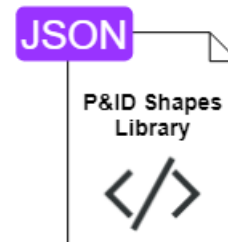
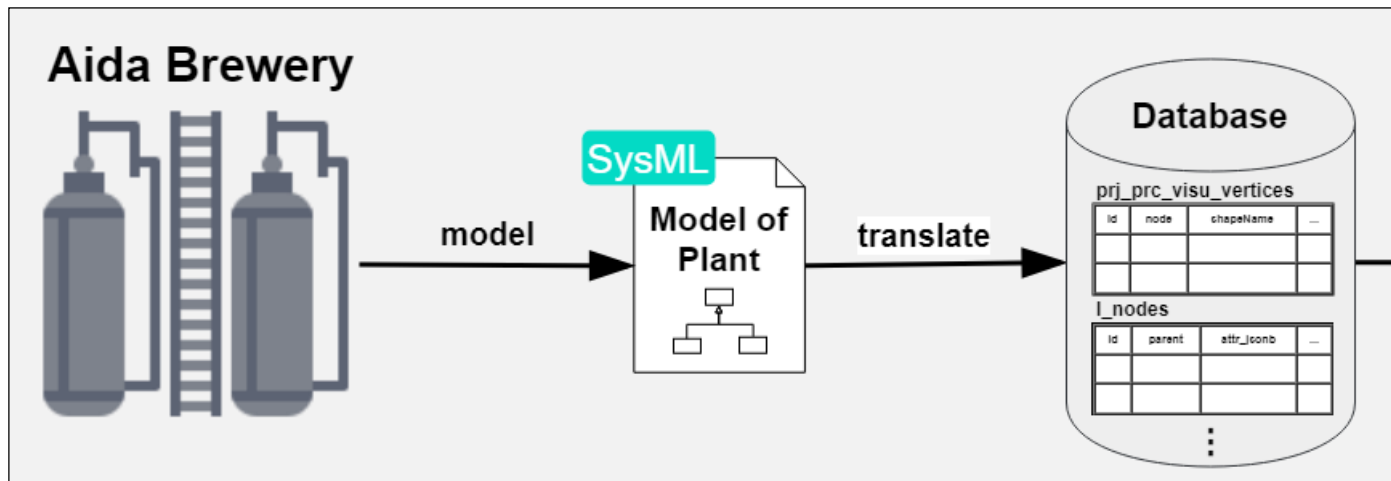
ProcAppCom



Conceptual Overview

Scope of the Project

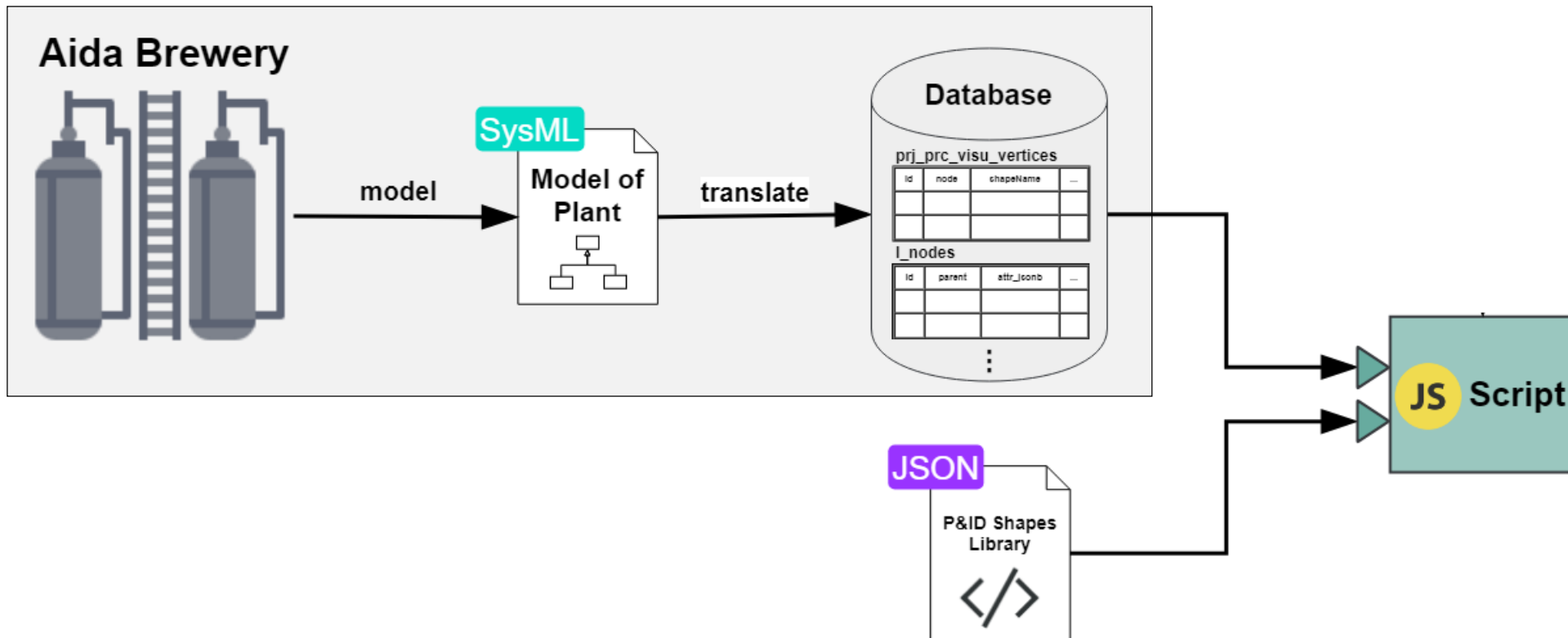
ProcAppCom



Conceptual Overview

Scope of the Project

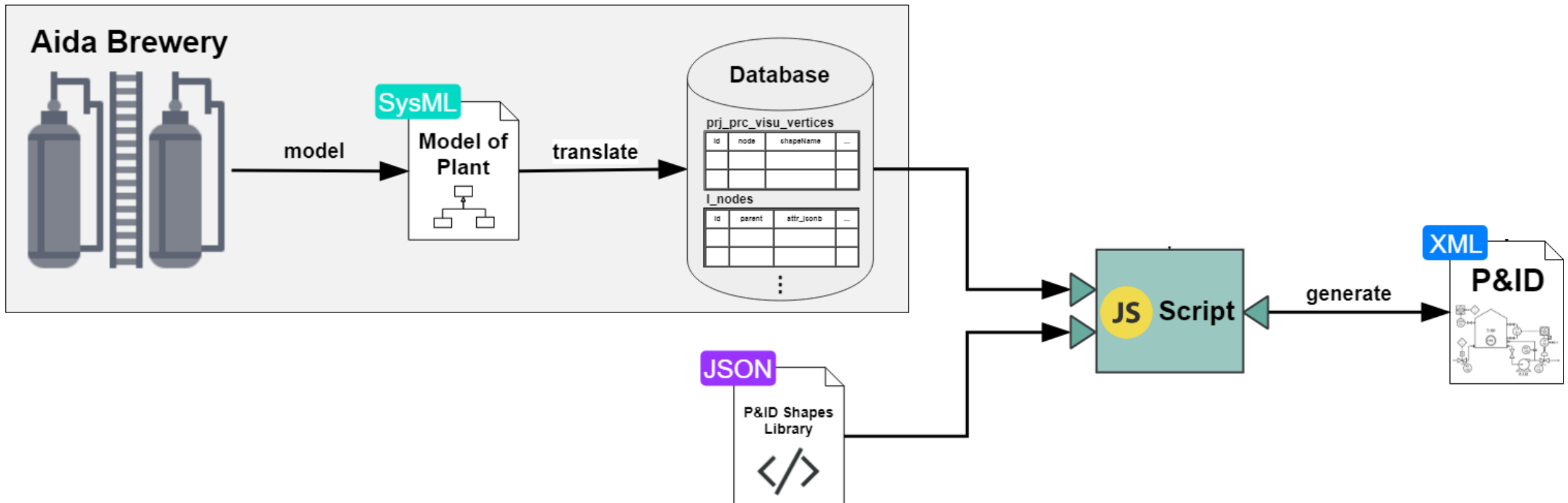
ProcAppCom



Conceptual Overview

Scope of the Project

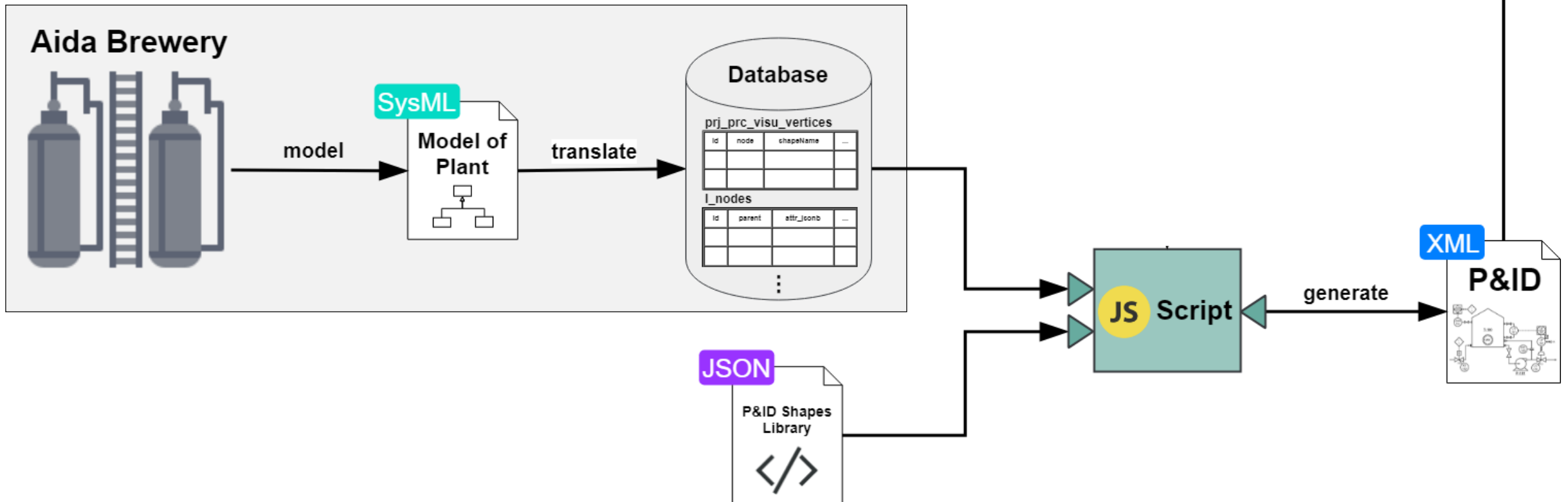
ProcAppCom



Conceptual Overview

Scope of the Project

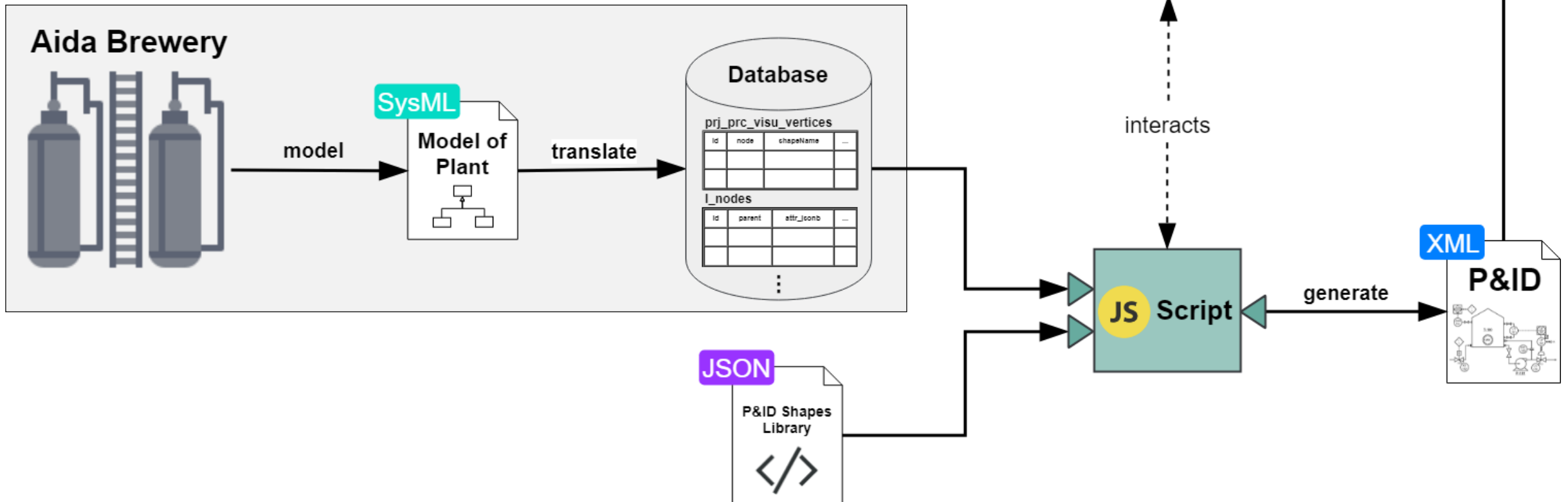
ProcAppCom



Conceptual Overview

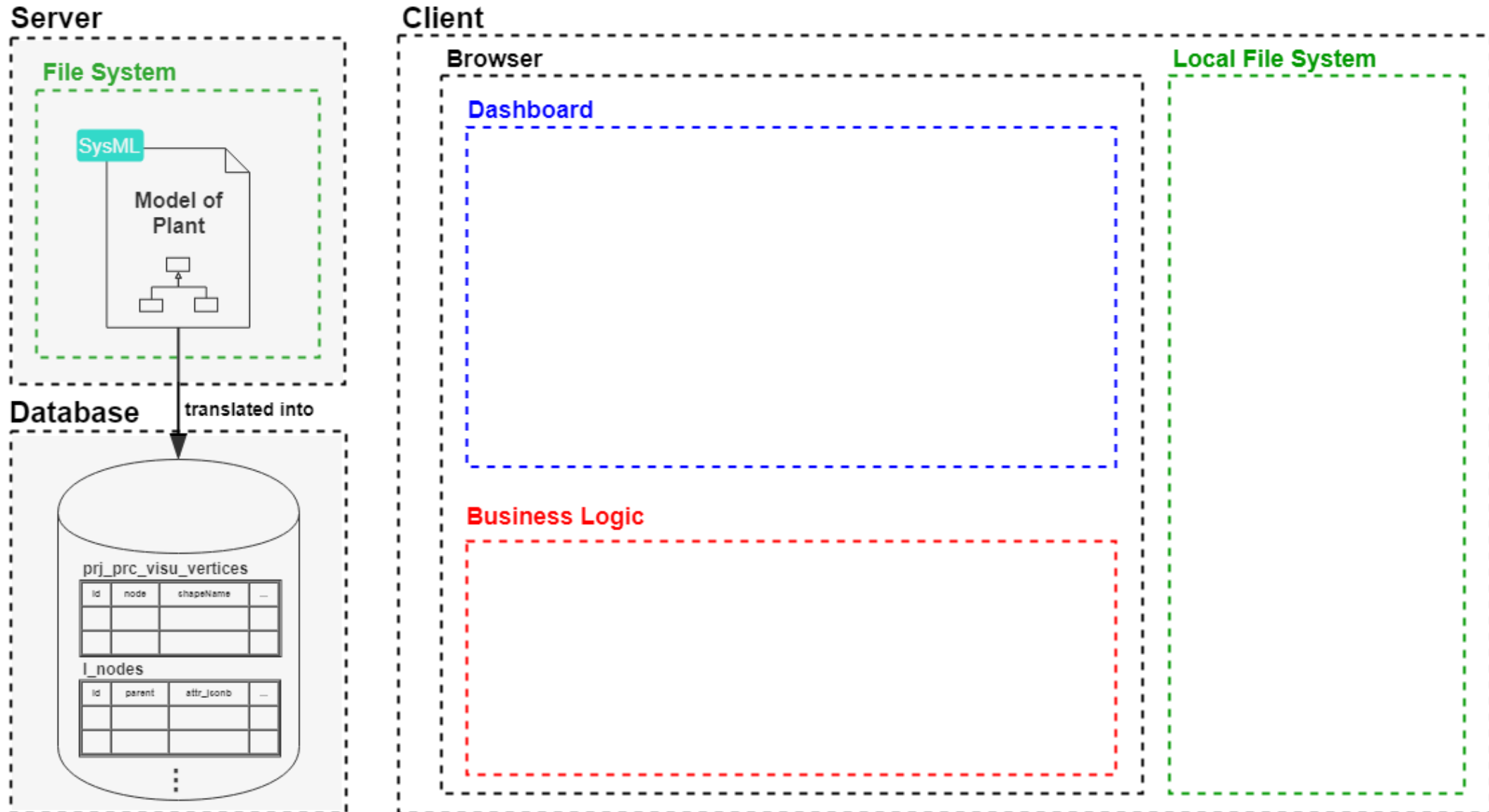
Scope of the Project

ProcAppCom



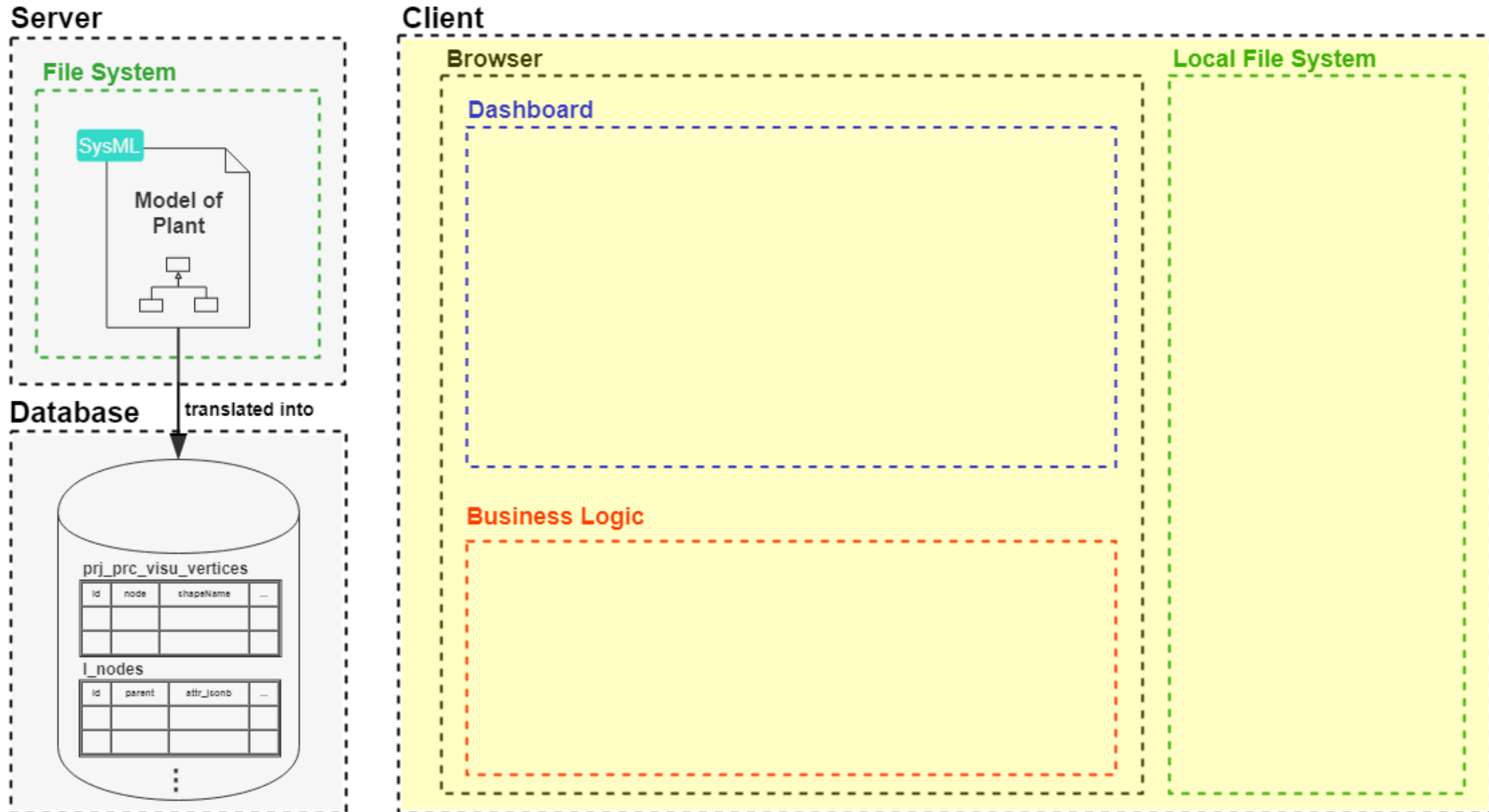
Software Architecture

Initial Situation



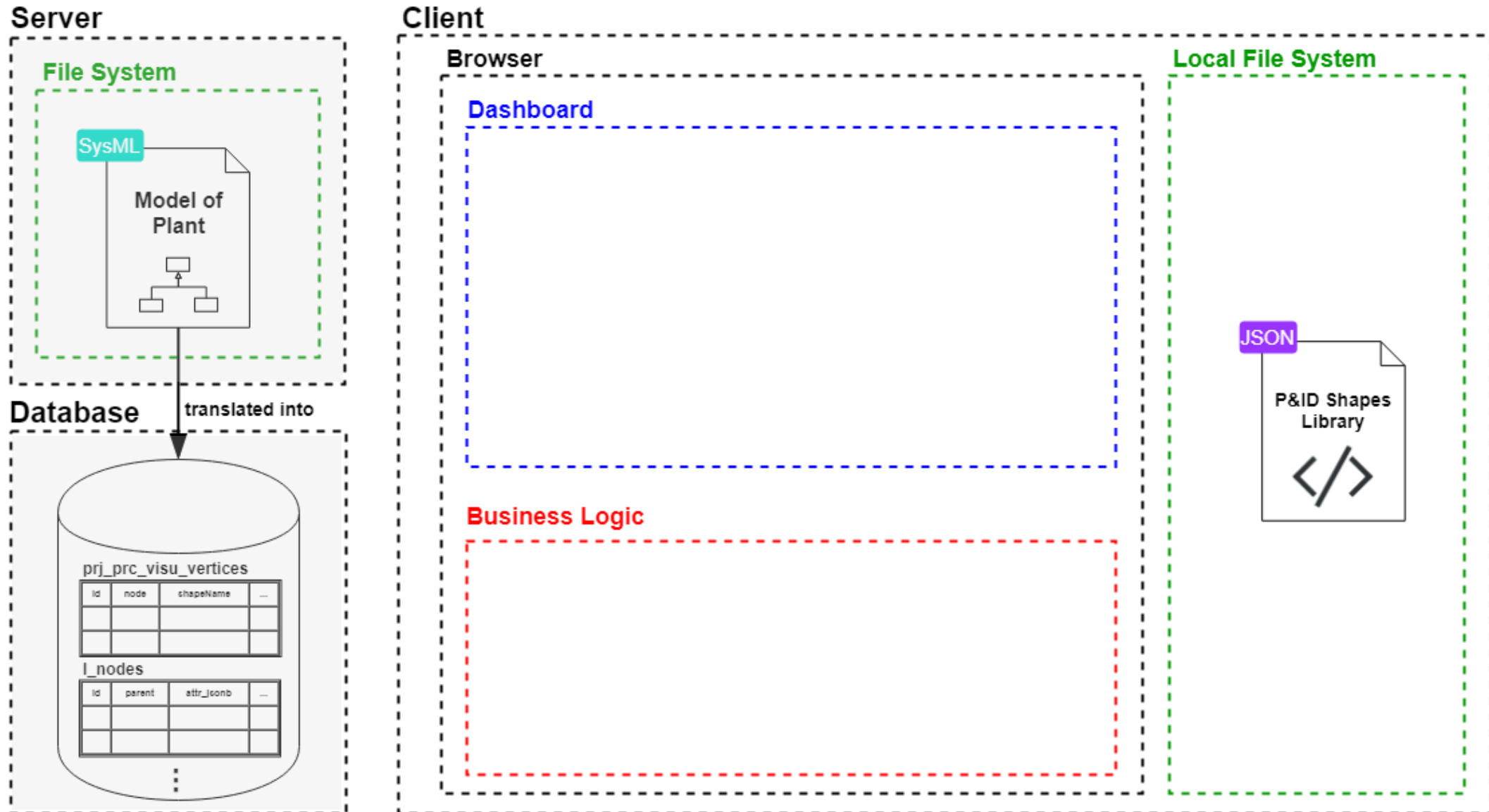
Software Architecture

Scope of this Project



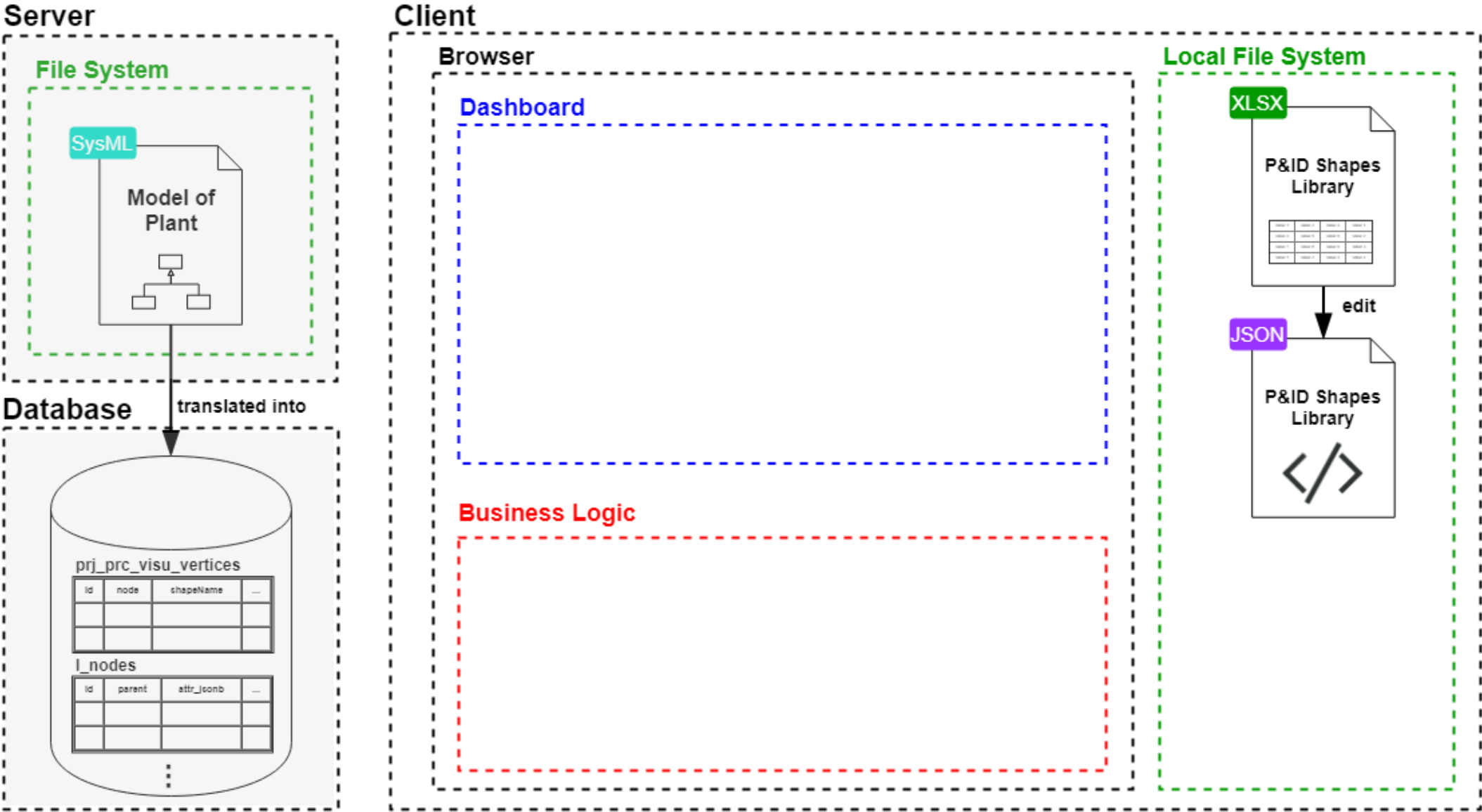
Software Architecture

P&ID Shapes Library



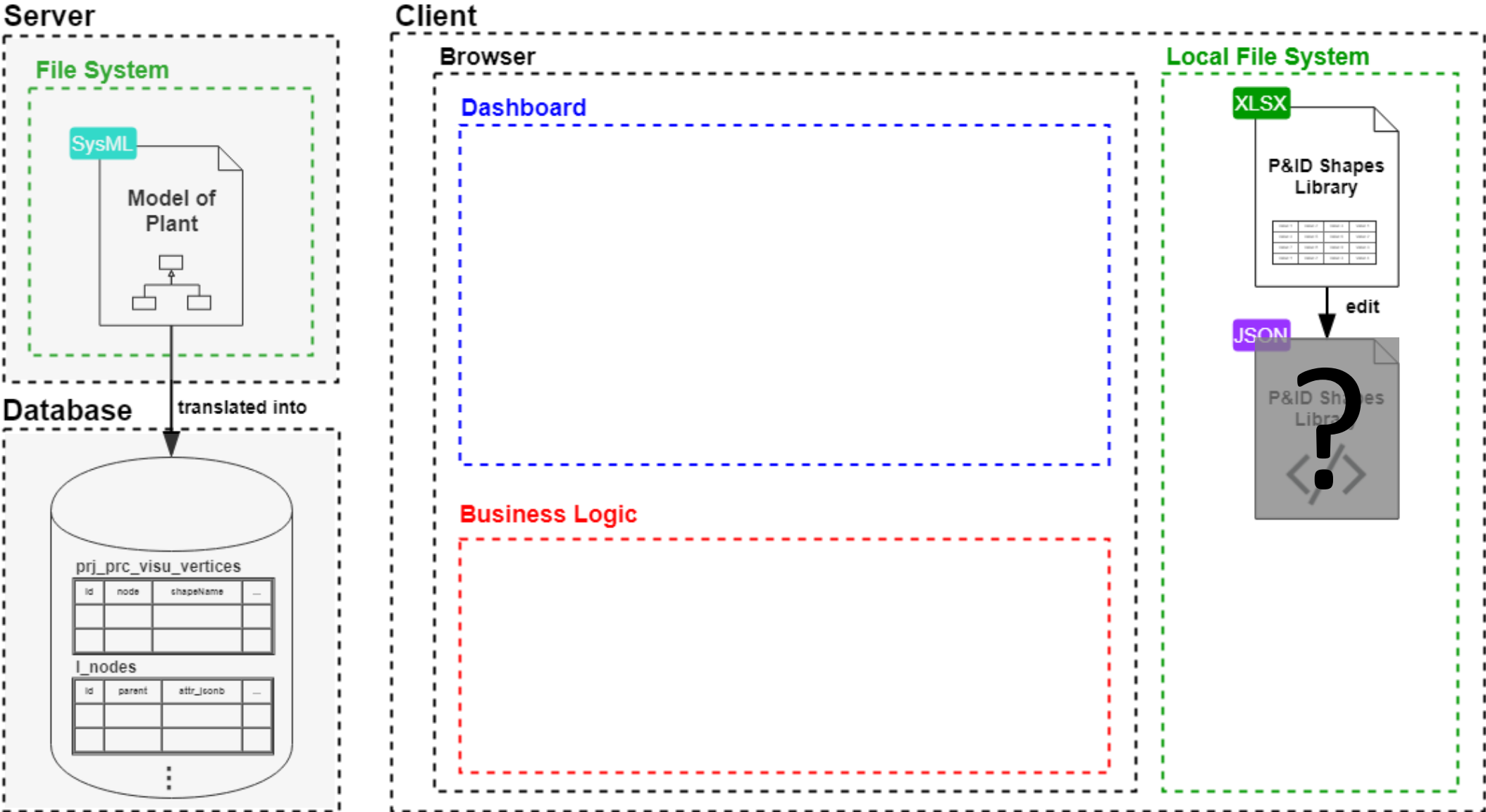
Software Architecture

P&ID Shapes Library



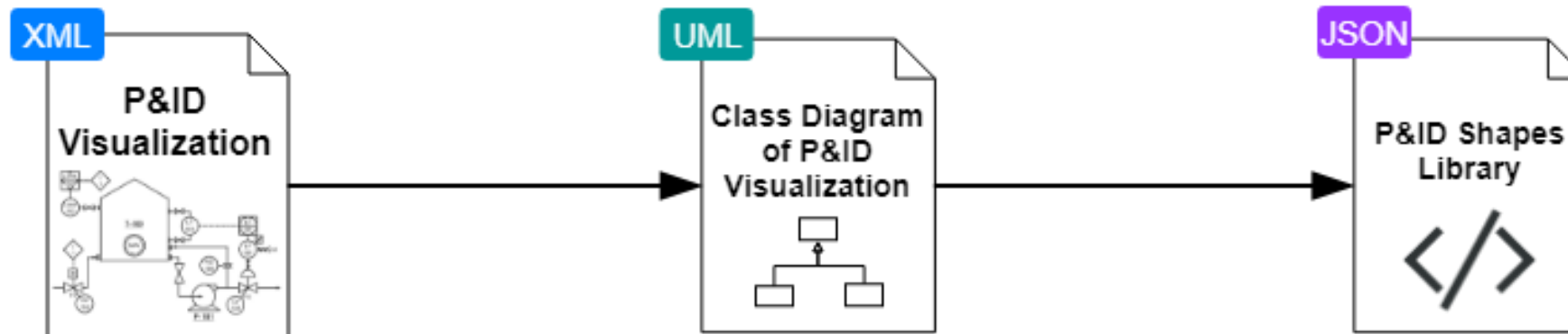
Software Architecture

P&ID Shapes Library



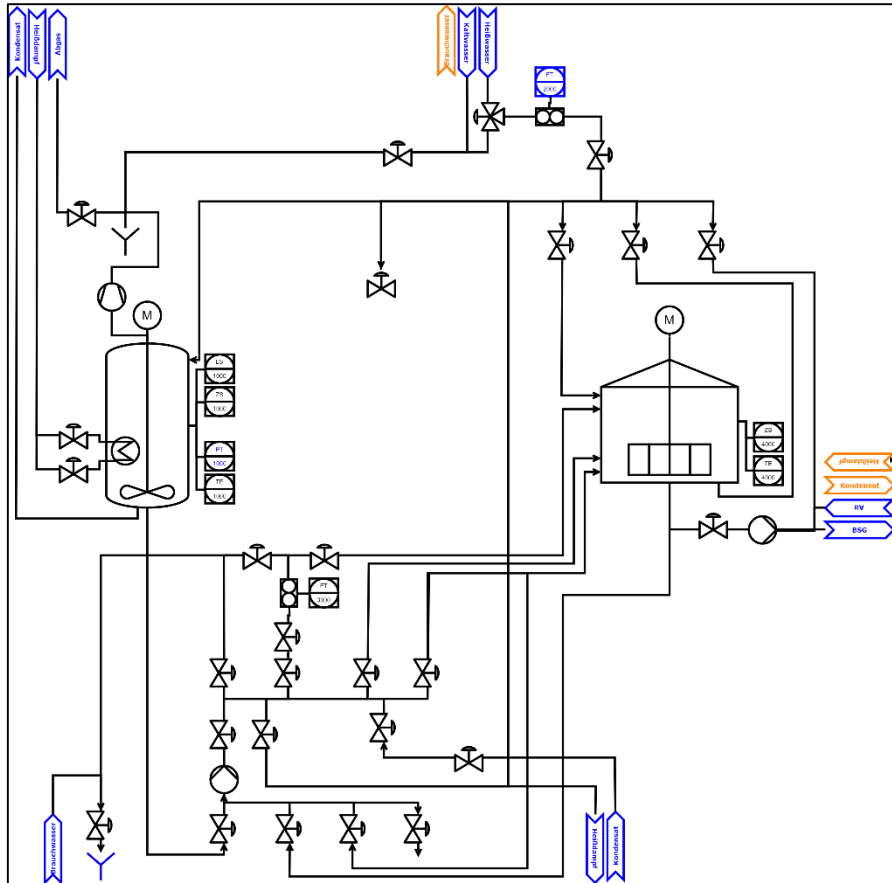
P&ID Shapes Library

Objected-oriented Abstraction of Shapes

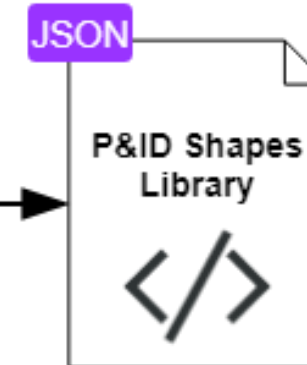
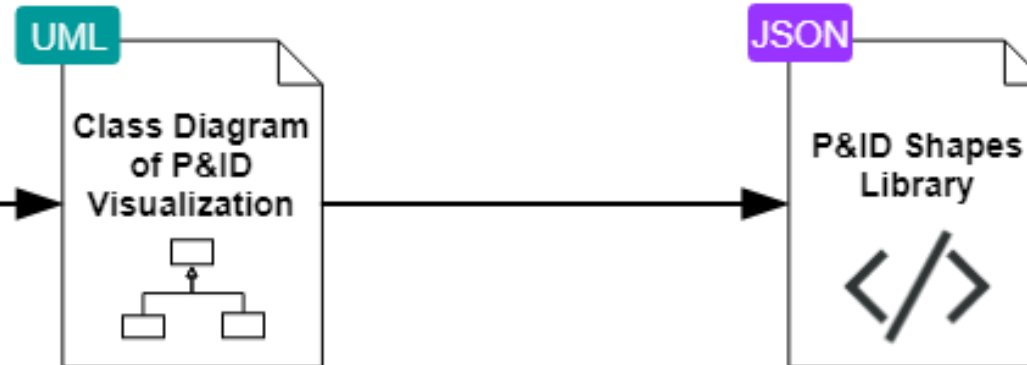


P&ID Shapes Library

Objected-oriented Abstraction of Shapes

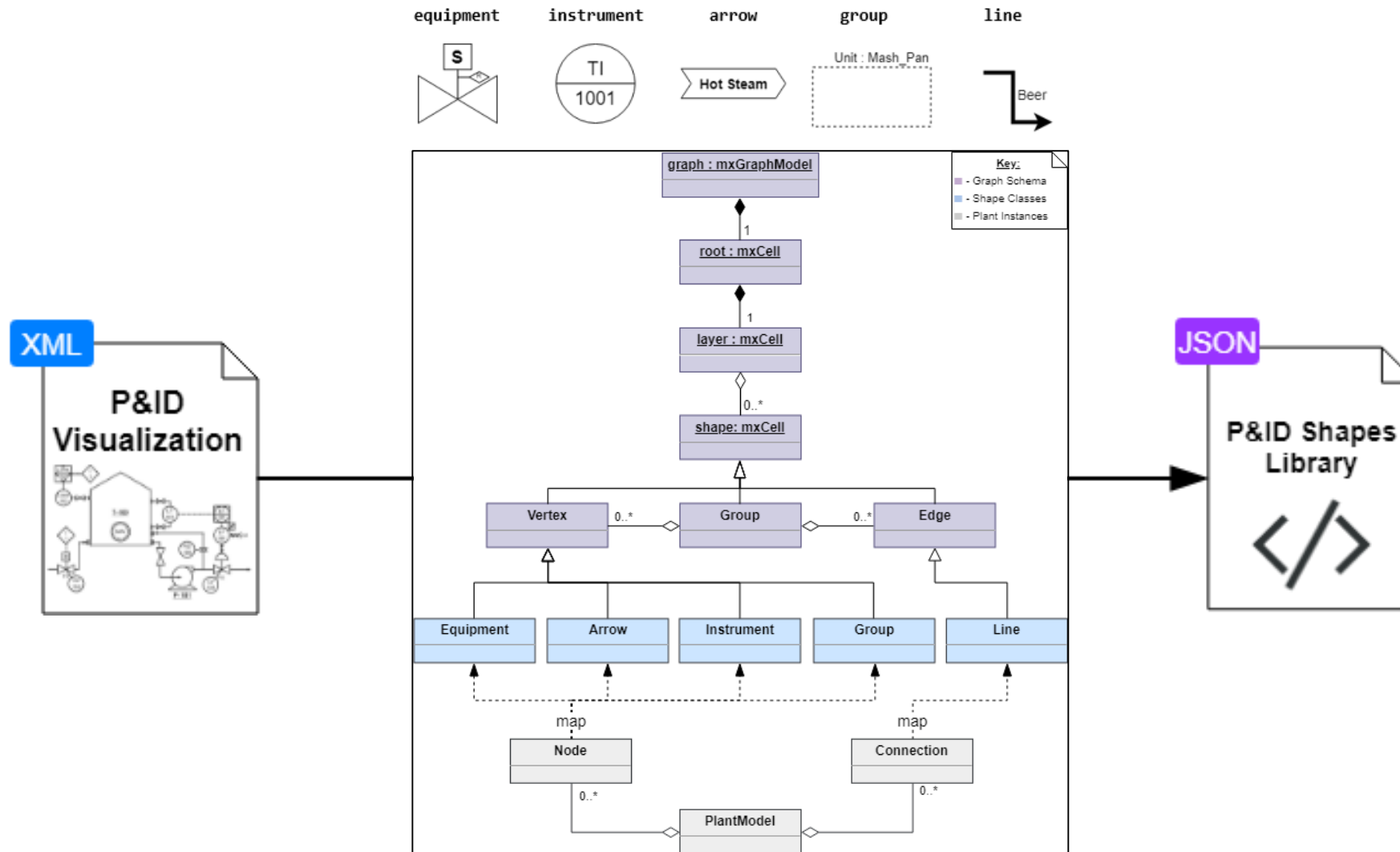


P&ID of Aida Brewery



P&ID Shapes Library

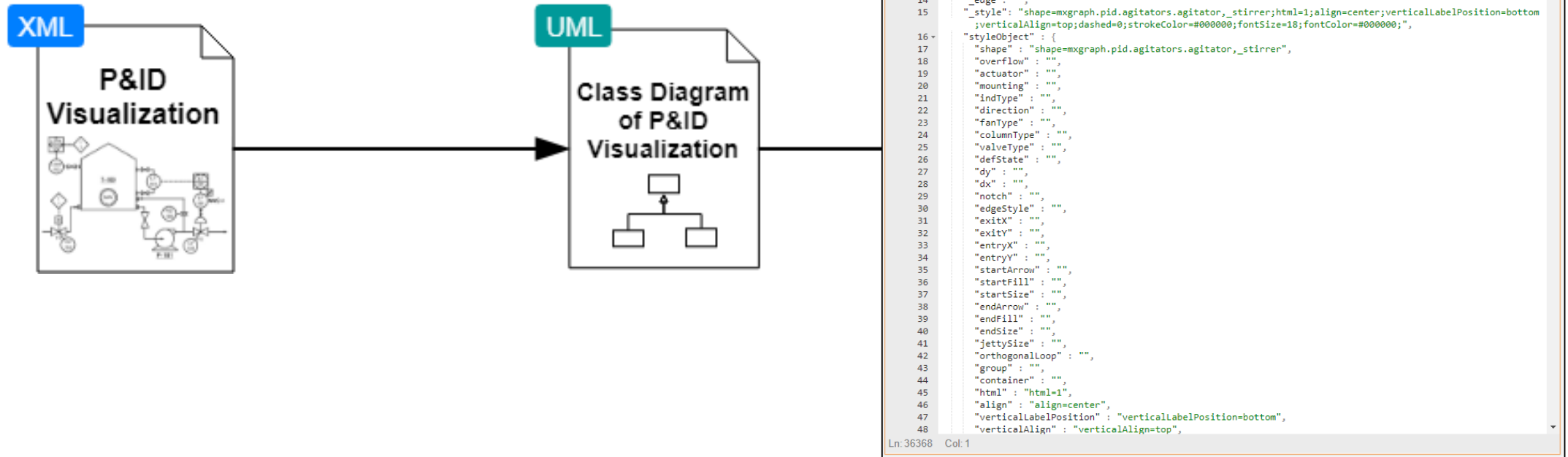
Objected-oriented Abstraction of Shapes



Class Diagram of P&ID

P&ID Shapes Library

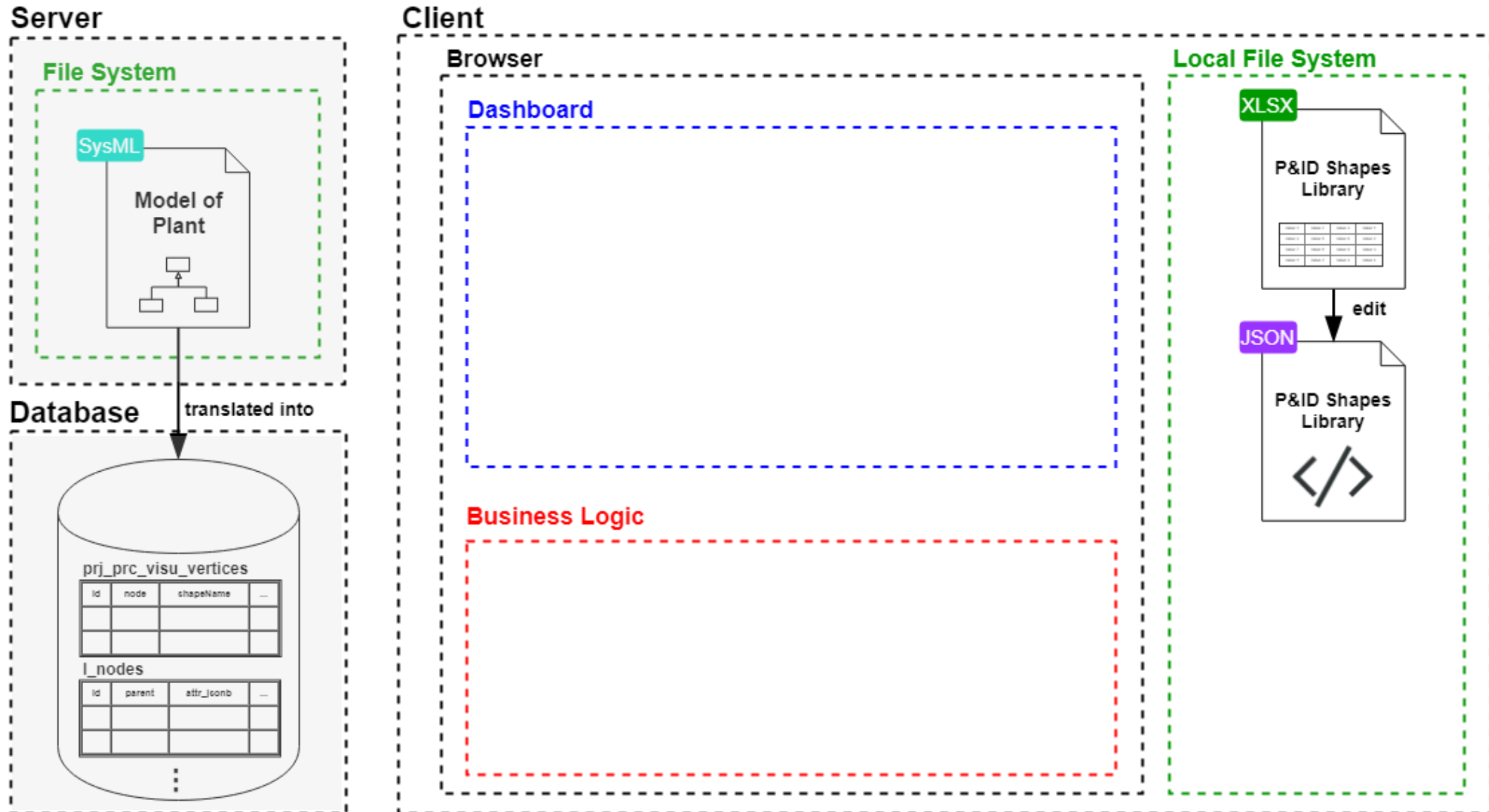
Objected-oriented Abstraction of Shapes



P&ID Shapes Library (474)

Software Architecture

P&ID Shapes Library



Software Architecture

Graphical User Interface

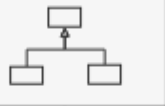


Server

File System

SysML

Model of Plant



Database

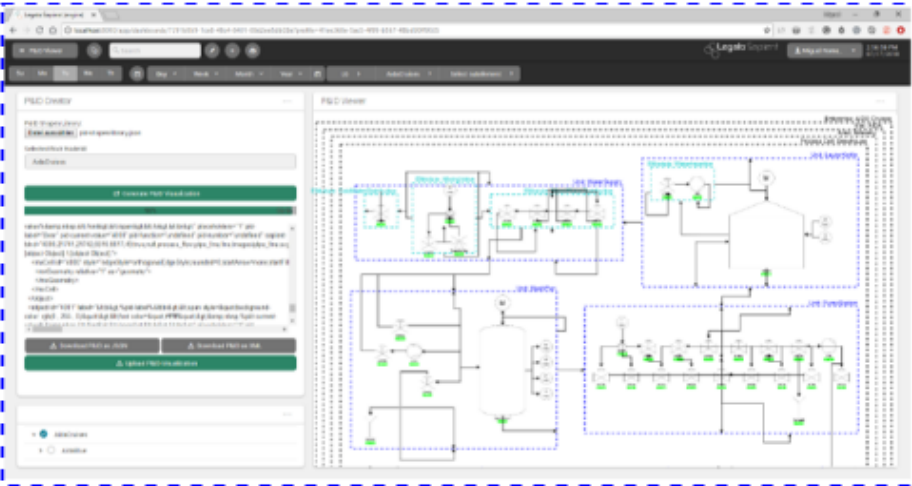
translated into

prj_prc_visu_vertices			
id	node	chapelName	...
l_nodes			
id	parent	attr_jsonb	...

Client

Browser

Dashboard



Business Logic

Local File System

XLSX

P&ID Shapes Library

shape1	shape2	shape3	shape4
shape5	shape6	shape7	shape8
shape9	shape10	shape11	shape12

edit

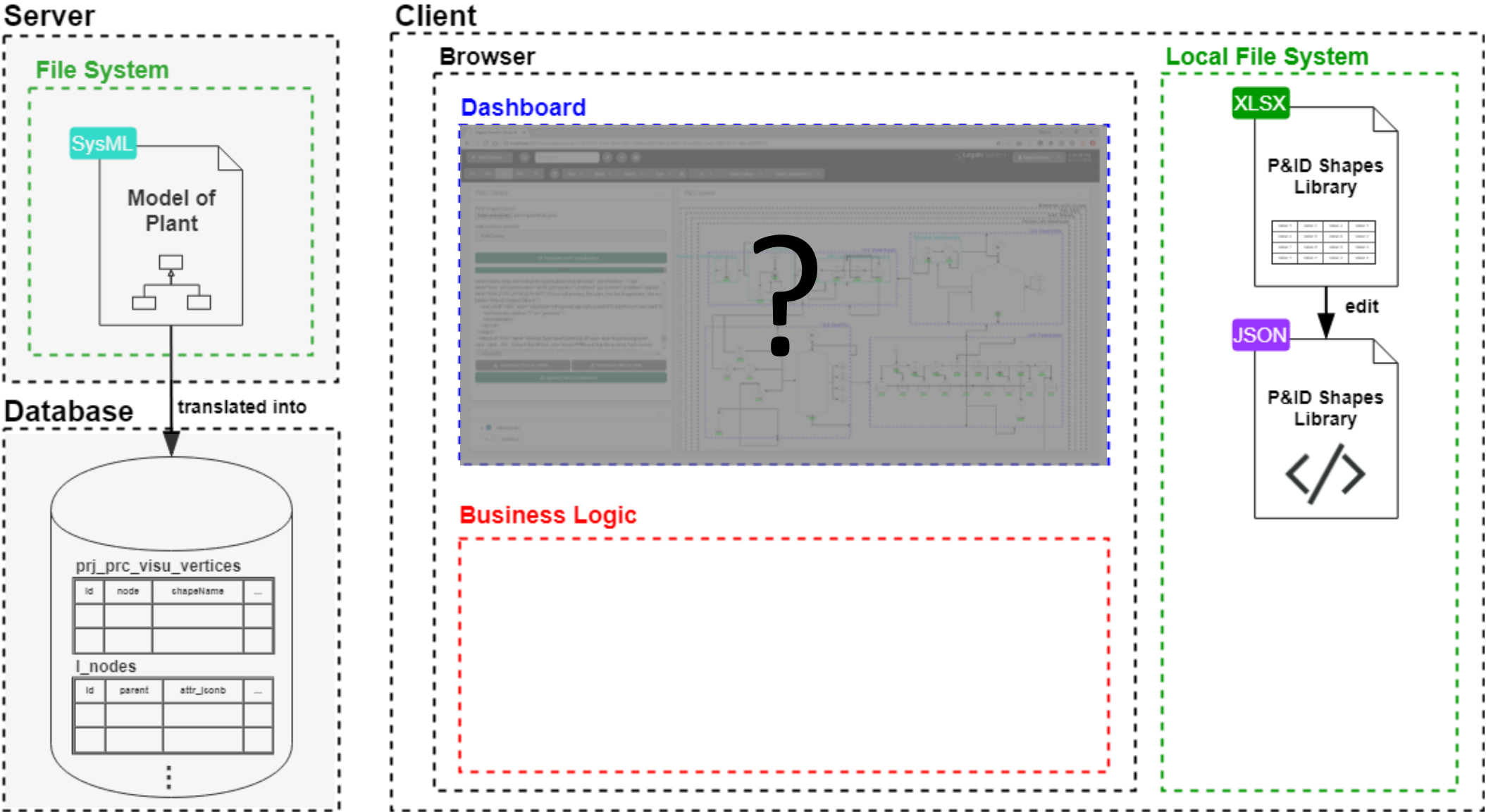
JSON

P&ID Shapes Library



Software Architecture

Graphical User Interface



GUI

P&ID Viewer Dashboard

P&ID Viewer

Search

Legato Sapient

Miguel Rome...

1:39:43 PM
06/26/2018

Su Mo Tu We Th Day Week Month Year LG AidaCruises Select subelement

P&ID Creator

P&ID Shapes Library:
Datei auswählen pid-shapes-library.json

Selected Root Node Id:
AidaCruises

Generate P&ID Visualization

```
<mxGraphModel dx="0" dy="0" grid="1" gridSize="10" guides="1" tooltips="1" connect="1" arrows="1" fold="1"
<root>
<mxCell id="0"/>
<mxCell id="1" parent="0"/>
<object id="21746" label="&lt;br>%pid-label%&lt;br>&lt;span style="background-color: rgb(0, 0, 255)&quot;&lt;br>&lt;div>


Download P&ID as JSON



Download P&ID as XML



Upload P&ID Visualization



Test_Gefasoft



Shop floor



Test-SC573



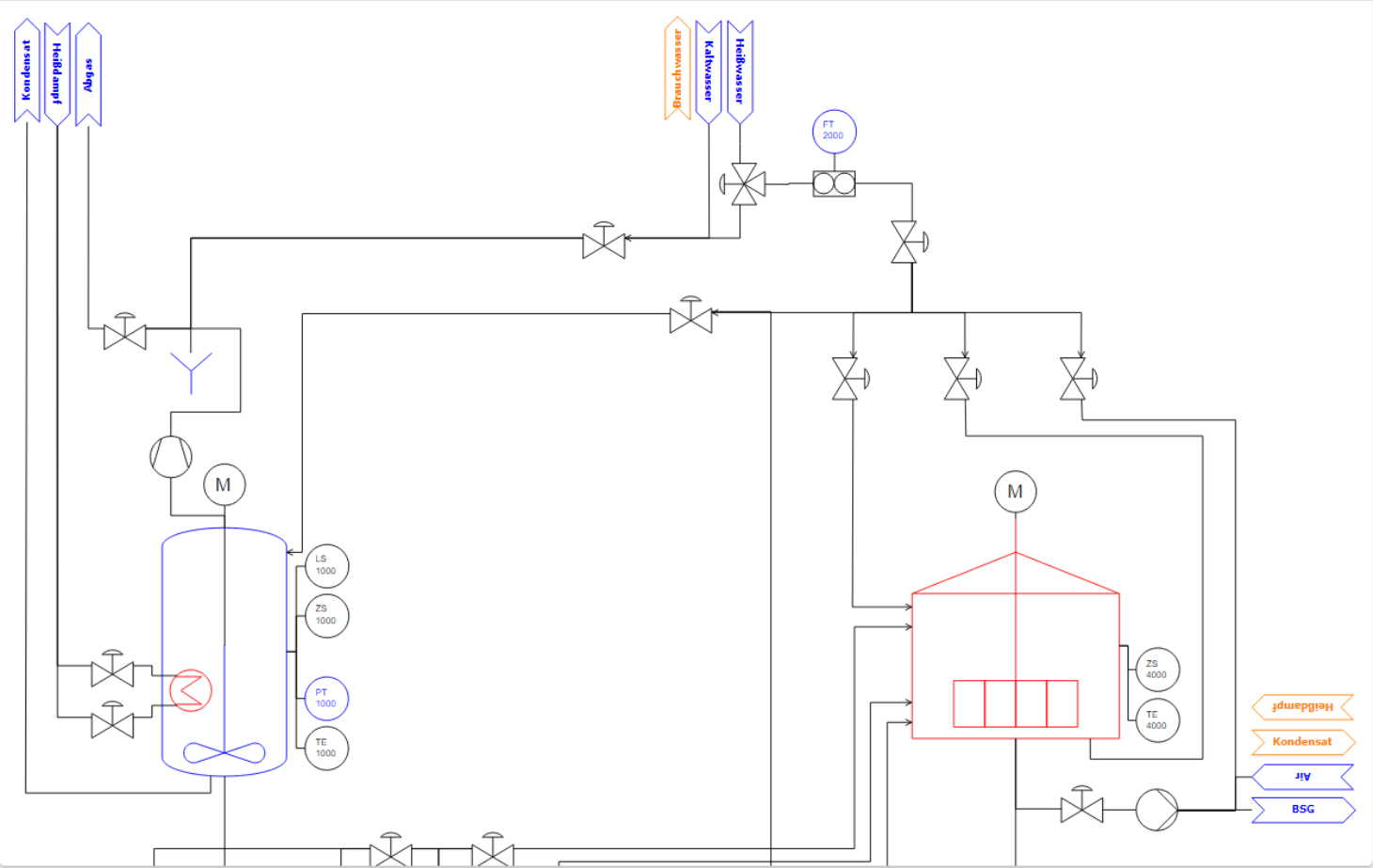
Test-SC573



AidaCruises


```

P&ID Viewer



P&ID Viewer | Search | Legato Sapient | Miguel Rome... | 1:39:43 PM 06/26/2018

Su Mo Tu We Th Day Week Month Year LG AidaCruises Select subelement

P&ID Creator

P&ID Shapes Library:
Datei auswählen pid-shapes-library.json

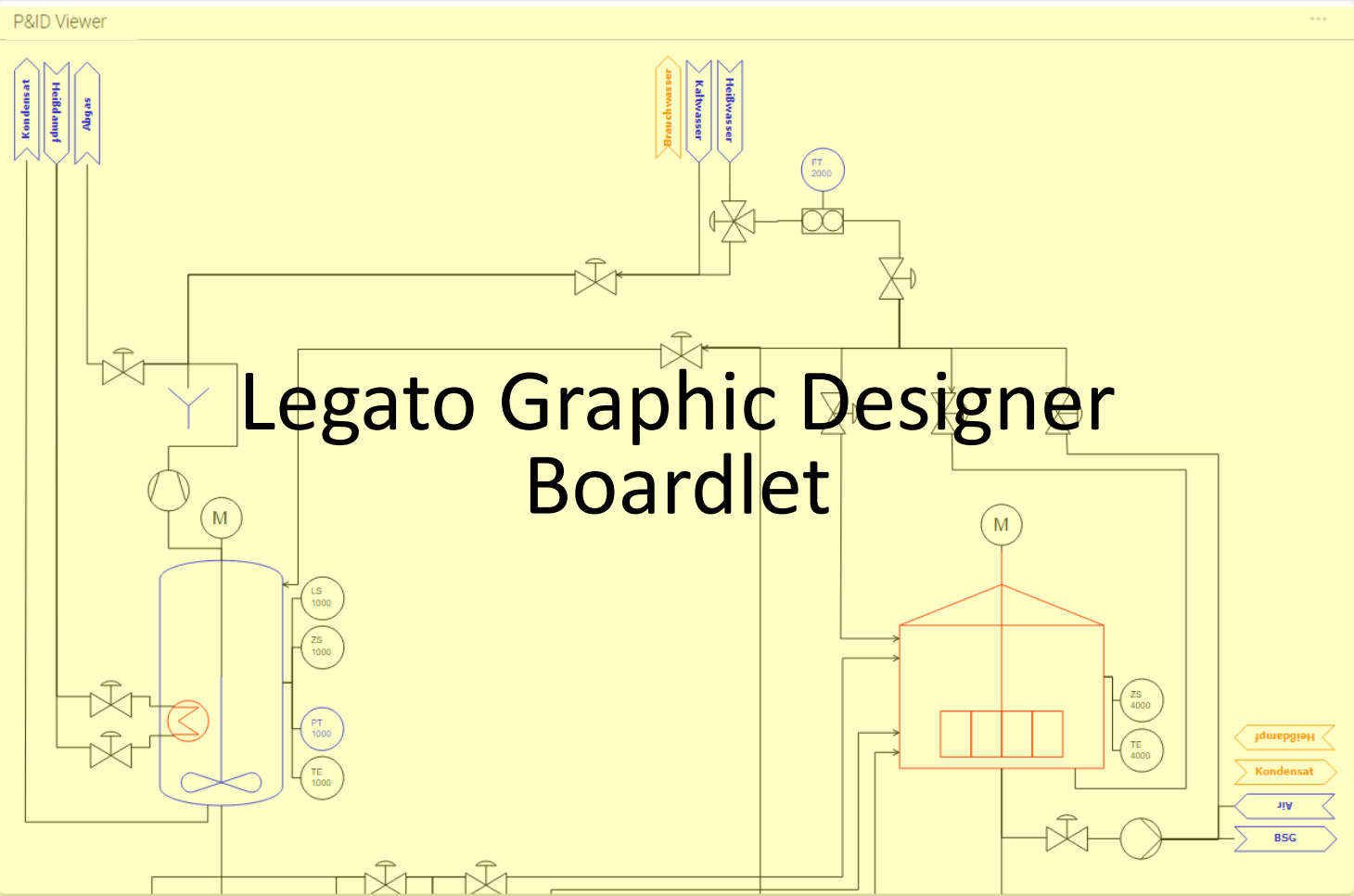
Selected Root Node Id:
AidaCruises

Generate P&ID Visualization

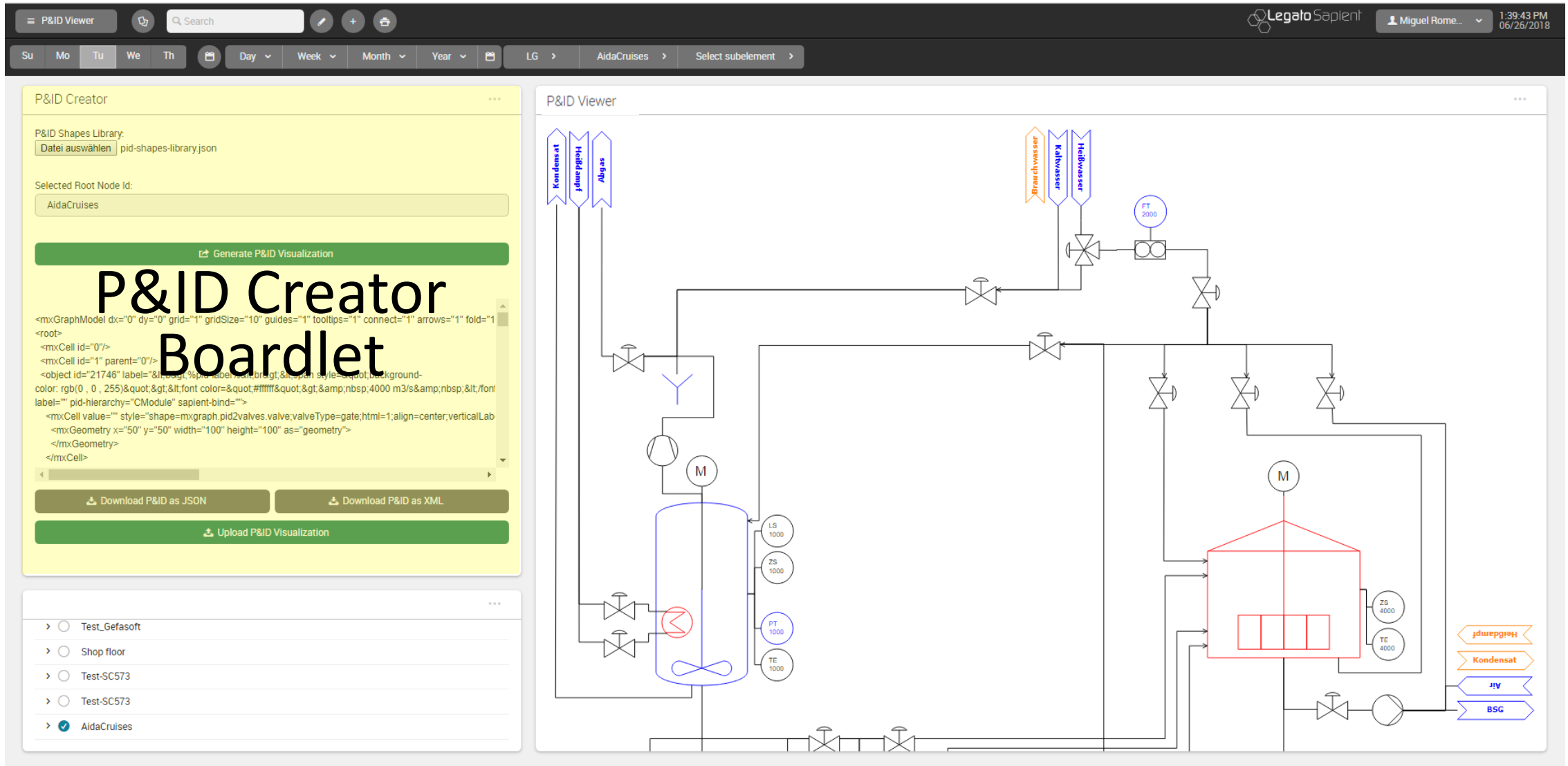
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<mxCell value="" style="shape=mxgraph.pid2valves.valve, valveType=gate, html=1, align=center, verticalLab
<mxGeometry x="50" y="50" width="100" height="100" as="geometry">
</mxGeometry>
</mxCell>
</div>
Download P&ID as JSON Download P&ID as XML
Upload P&ID Visualization
```

- Test_Gefasoft
- Shop floor
- Test-SC573
- Test-SC573
- AidaCruises

P&ID Viewer



[illegible]



1. On start

P&ID Creator

P&ID Shapes Library:
 Keine ausgewählt

Selected Root Node Id:

2. In progress

P&ID Creator

P&ID Shapes Library:
 pid-shapes-library.json

Selected Root Node Id:

0% 0/100

Generating P&ID visualization of AidaCruises ...

3. Done

P&ID Creator

P&ID Shapes Library:
 pid-shapes-library.json

Selected Root Node Id:

100% 56/56

```
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```

desktop

P&ID Creator

P&ID Shapes Library:
 pid-shapes-library.json

Selected Root Node Id:

100% 56/56

```
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```

mobile

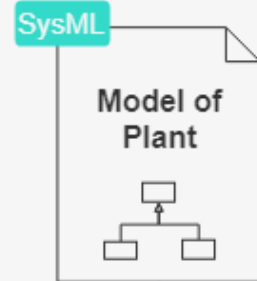
Software Architecture

Graphical User Interface



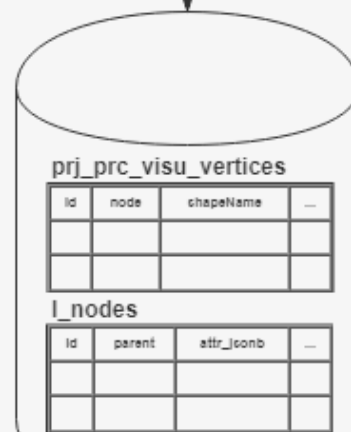
Server

File System



Database

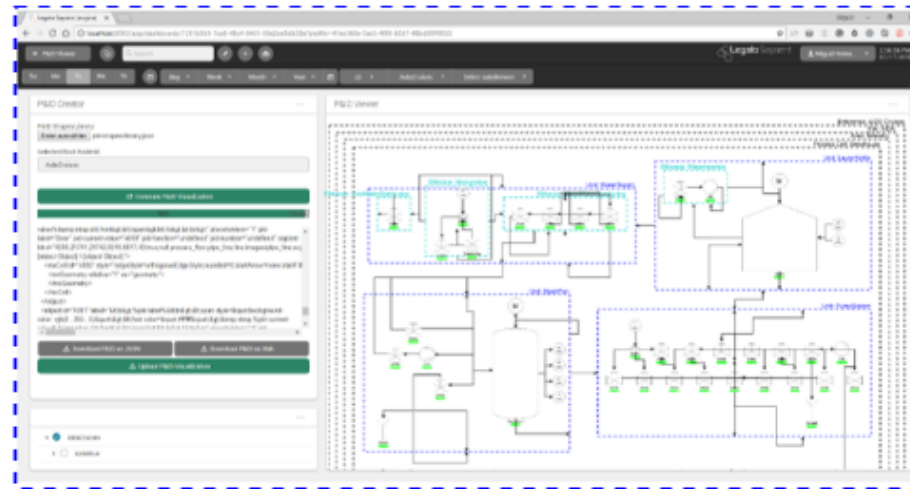
translated into



Client

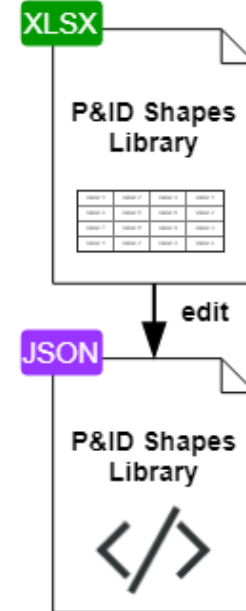
Browser

Dashboard



Business Logic

Local File System



Software Architecture

Business Logic

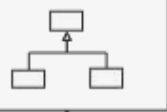


Server

File System

SysML

Model of Plant



Database

translated into

prj_prc_visu_vertices

Id	node	shapeName	...

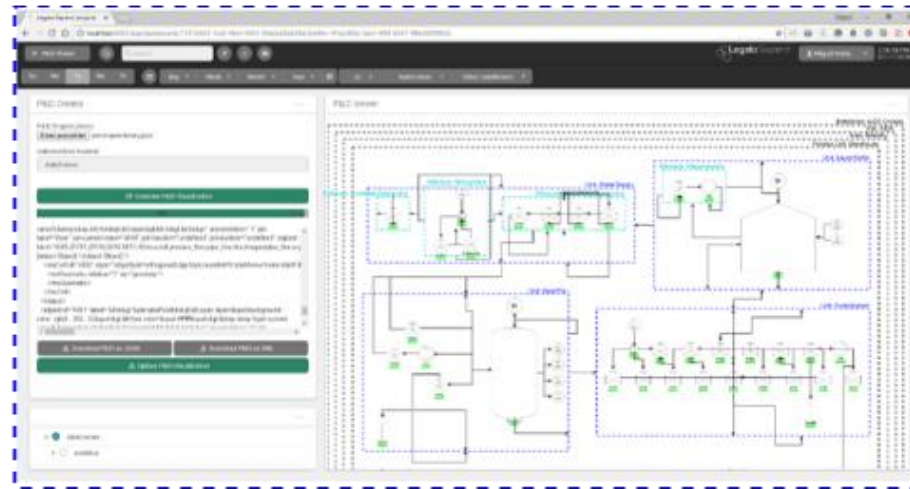
I_nodes

Id	parent	attr_jsonb	...

Client

Browser

Dashboard



Business Logic

JS

Client-side Script

```
3) databaseQueries()  
4) filterData()  
5) generatePid()  
6) Down-/Upload
```

Local File System

XLSX

P&ID Shapes Library

shape1	shape2	shape3	shape4
shape5	shape6	shape7	shape8
shape9	shape10	shape11	shape12

edit

JSON

P&ID Shapes Library



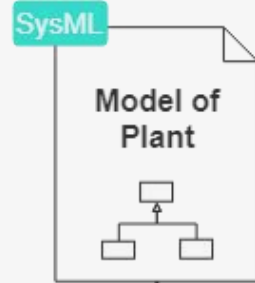
Software Architecture

Business Logic



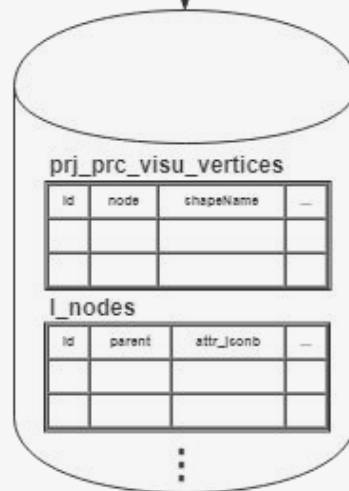
Server

File System



Database

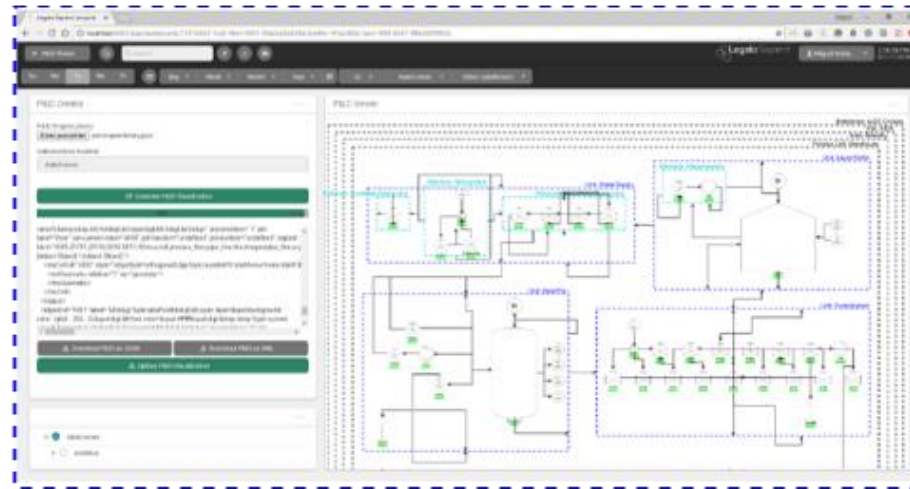
translated into



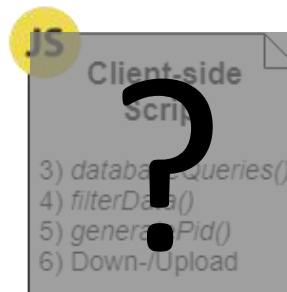
Client

Browser

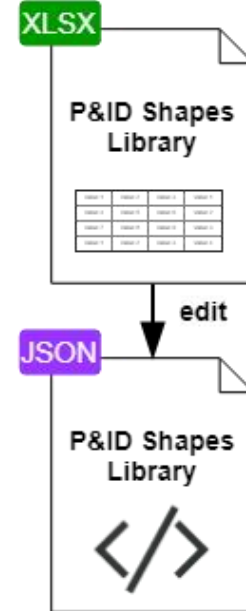
Dashboard



Business Logic

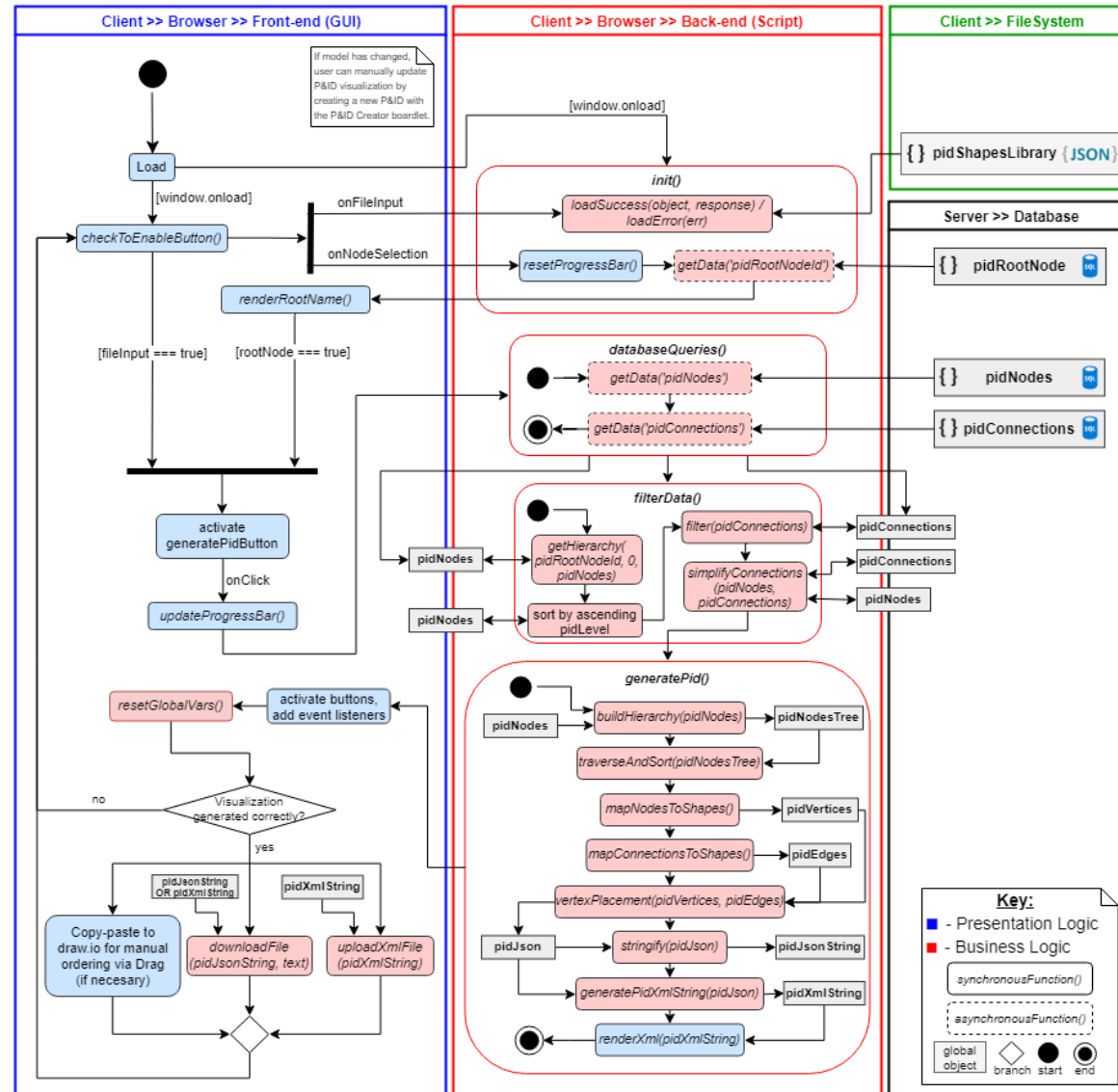


Local File System



Script

Activity Diagram



Fetching Data

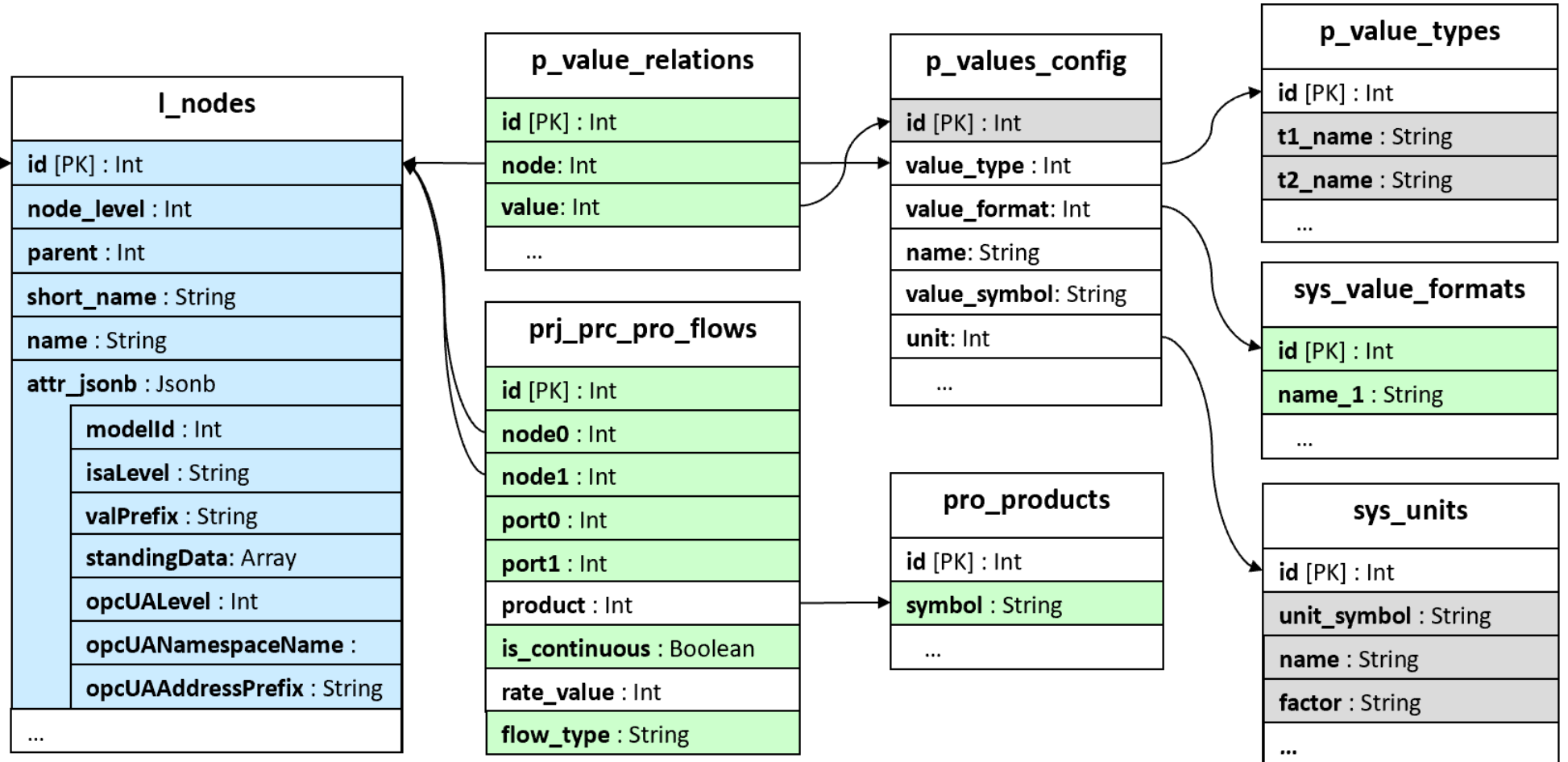
Global Data Map



new table:

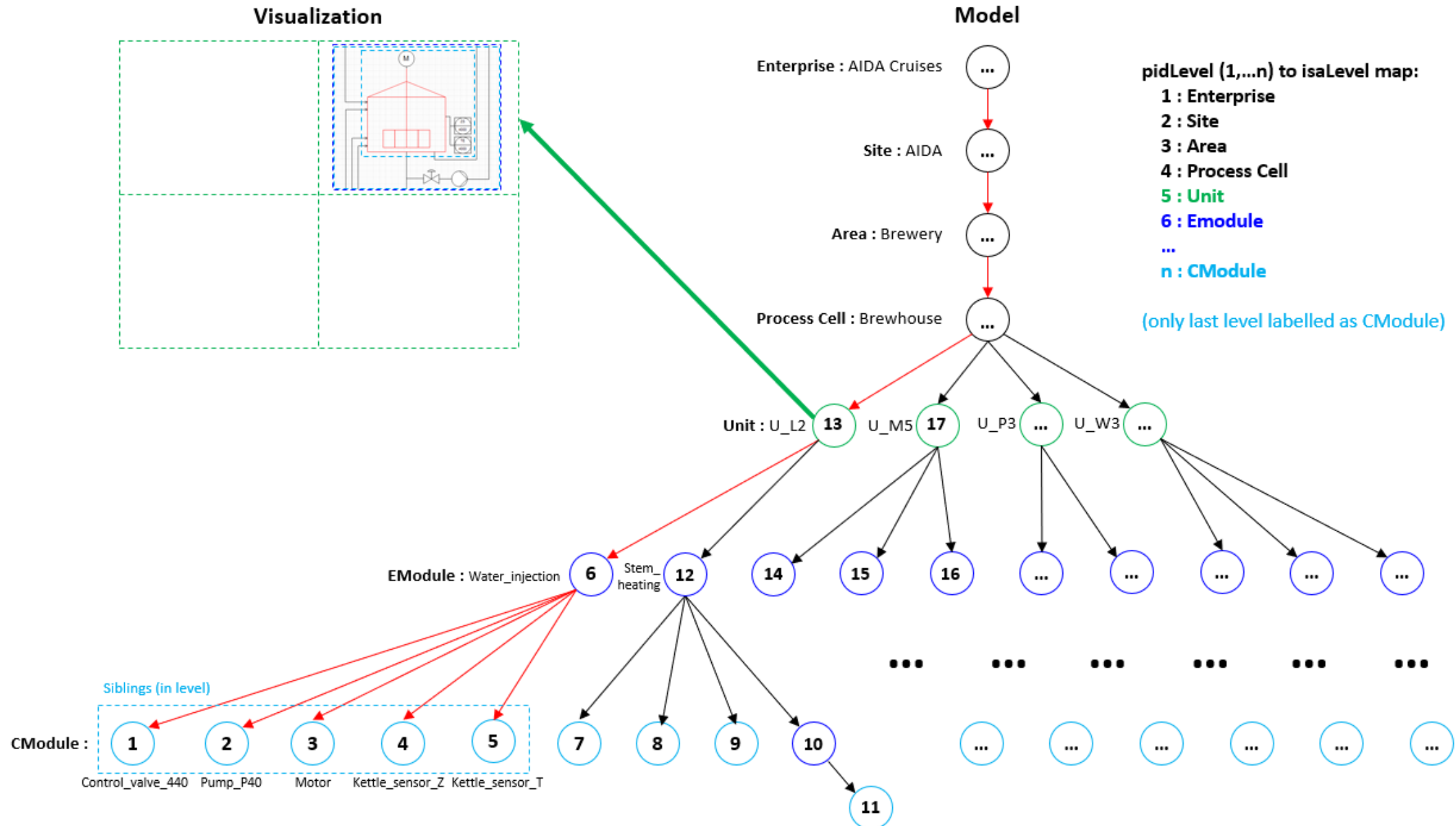
prj_prc_visu_vertices	
id [PK] : Int	
node : Int	
shape_name : String	
is_instrument : Boolean	
pid_label : String	
pid_function : String	
pid_number : String	

Key:	
	- pidNodes
	- pidConnections
	- both



Graphing Algorithm

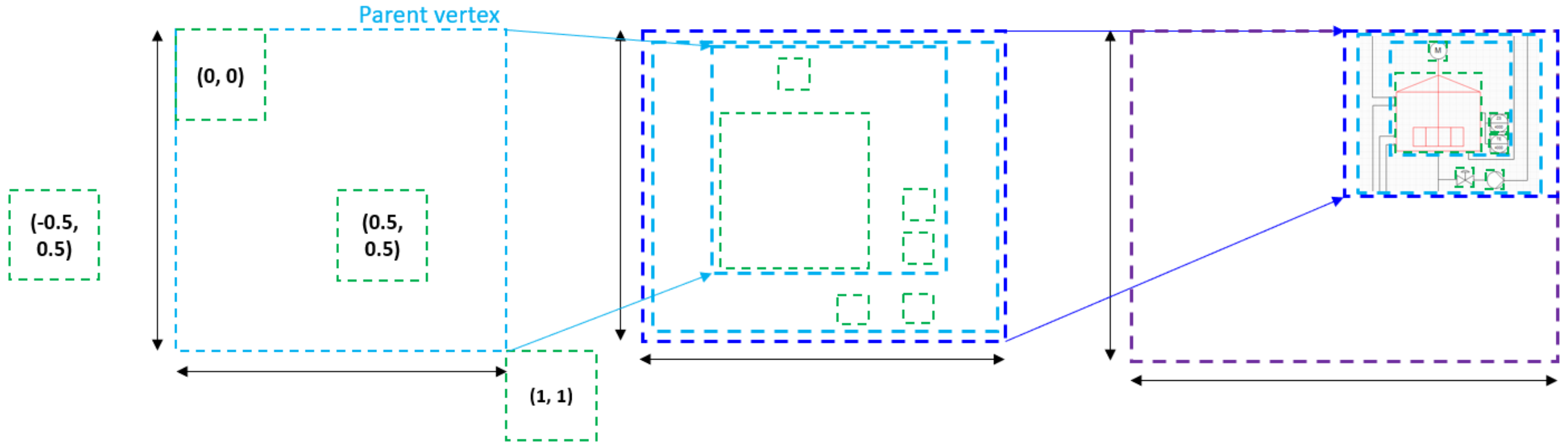
Concept: From Node Tree to Visualization



Graphing Algorithm

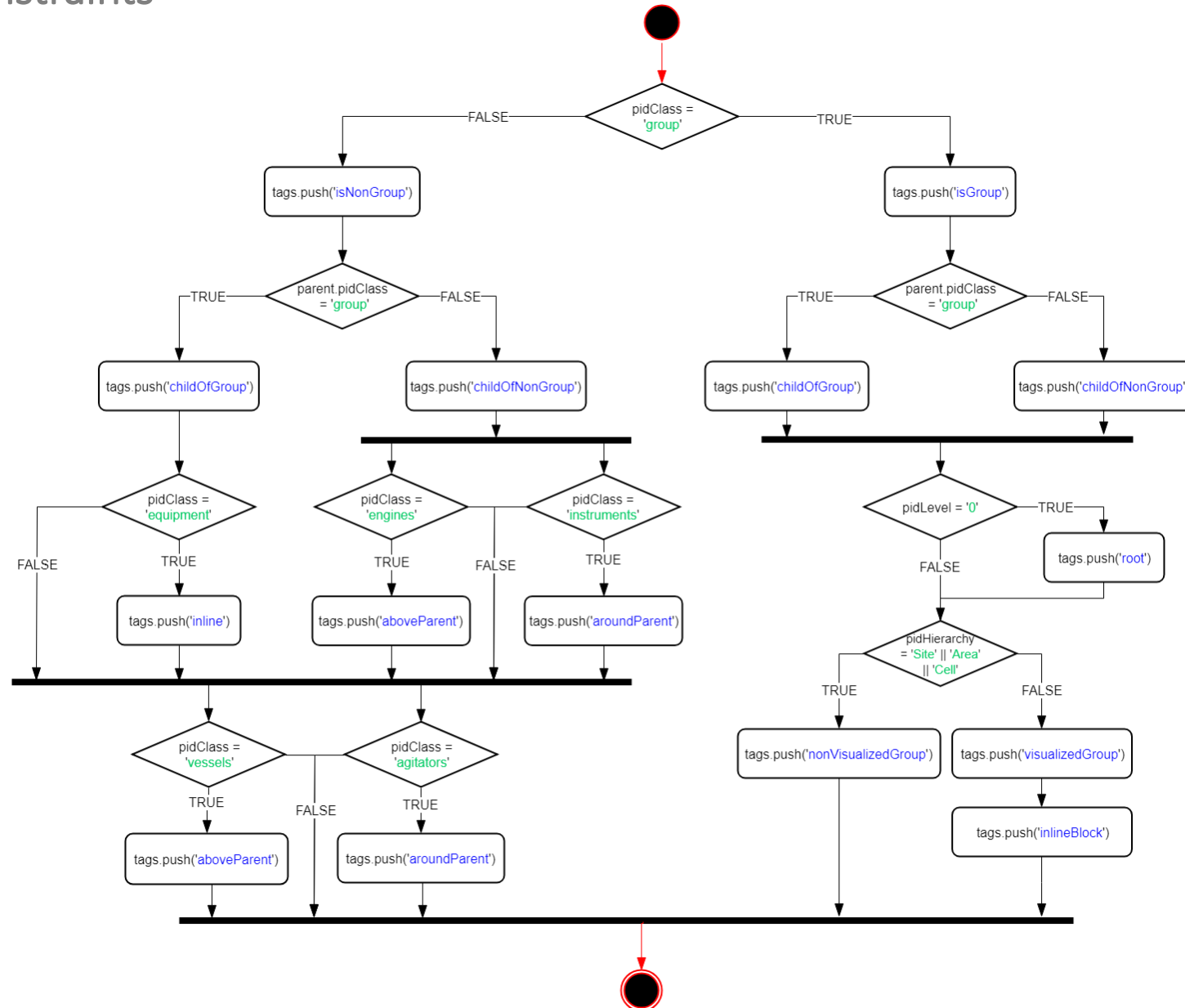
Concept: Relative Positioning

... (recursively)



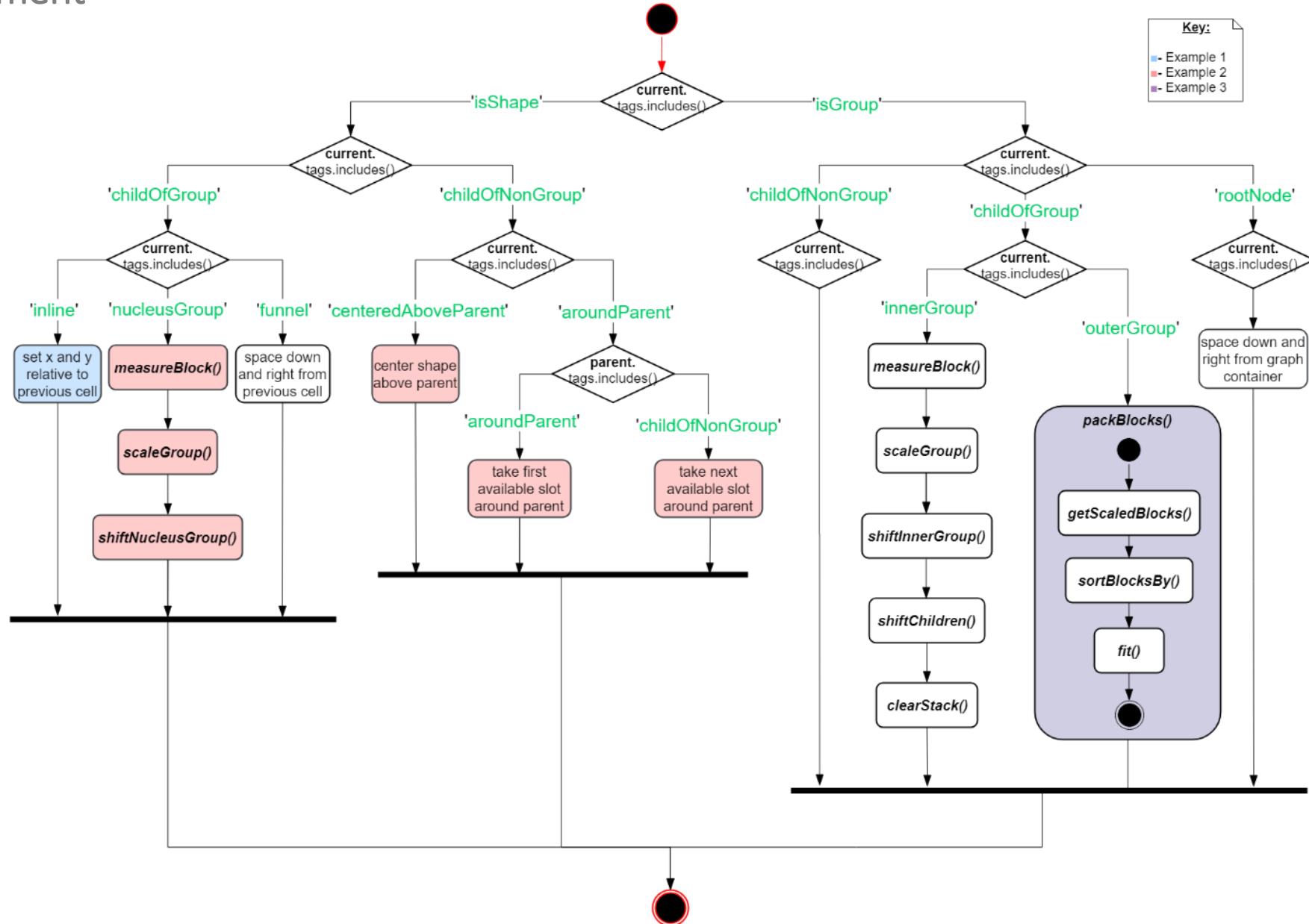
Graphing Algorithm

1. Specification of Constraints



Graphing Algorithm

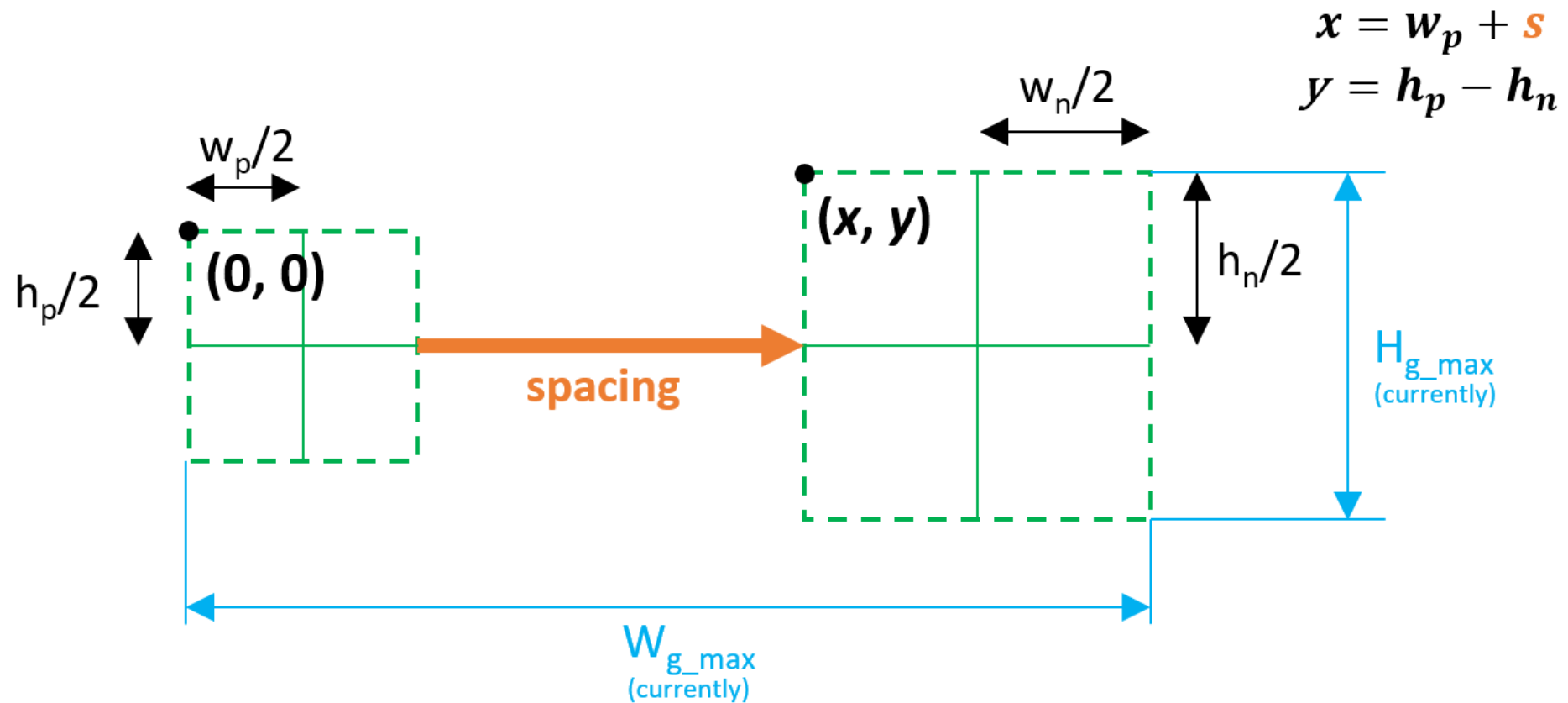
2. Vertex Placement



Example 1

Consecutive Inline Shapes

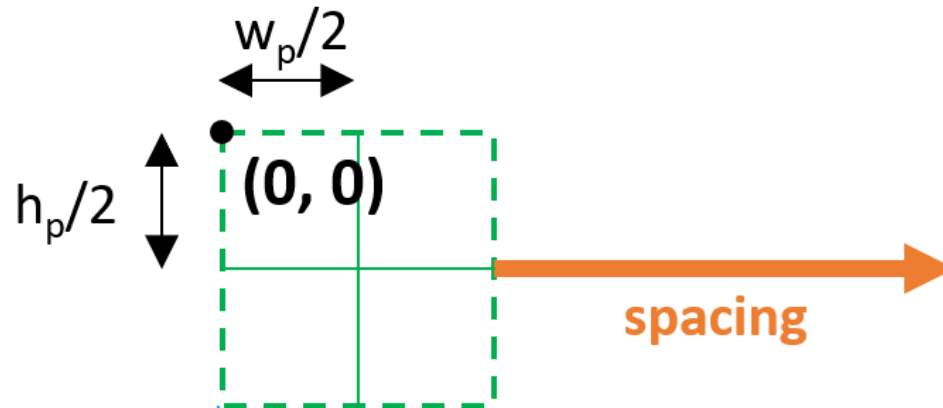
■ #inline



Example 1

Consecutive Inline Shapes

- **#inline**
 - Horizontal offset from previous by **spacing** (global variable)

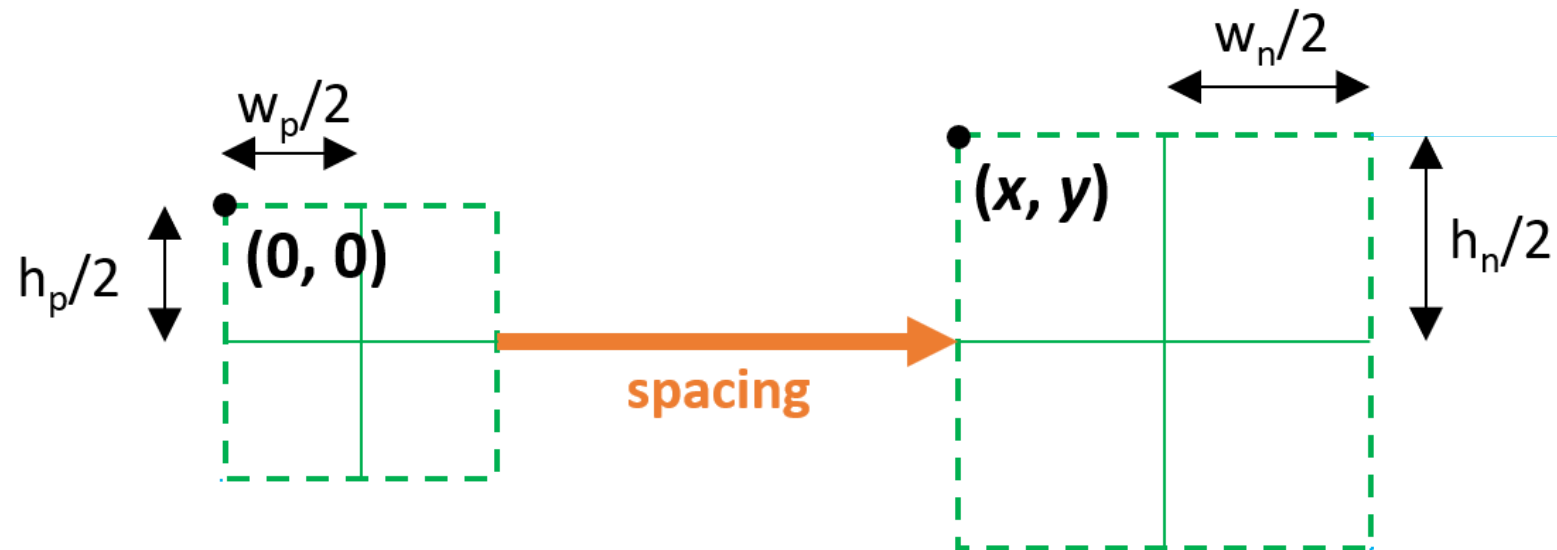


Example 1

Consecutive Inline Shapes

- **#inline**

- Horizontal offset from previous by **spacing** (global variable)
- Vertically centered

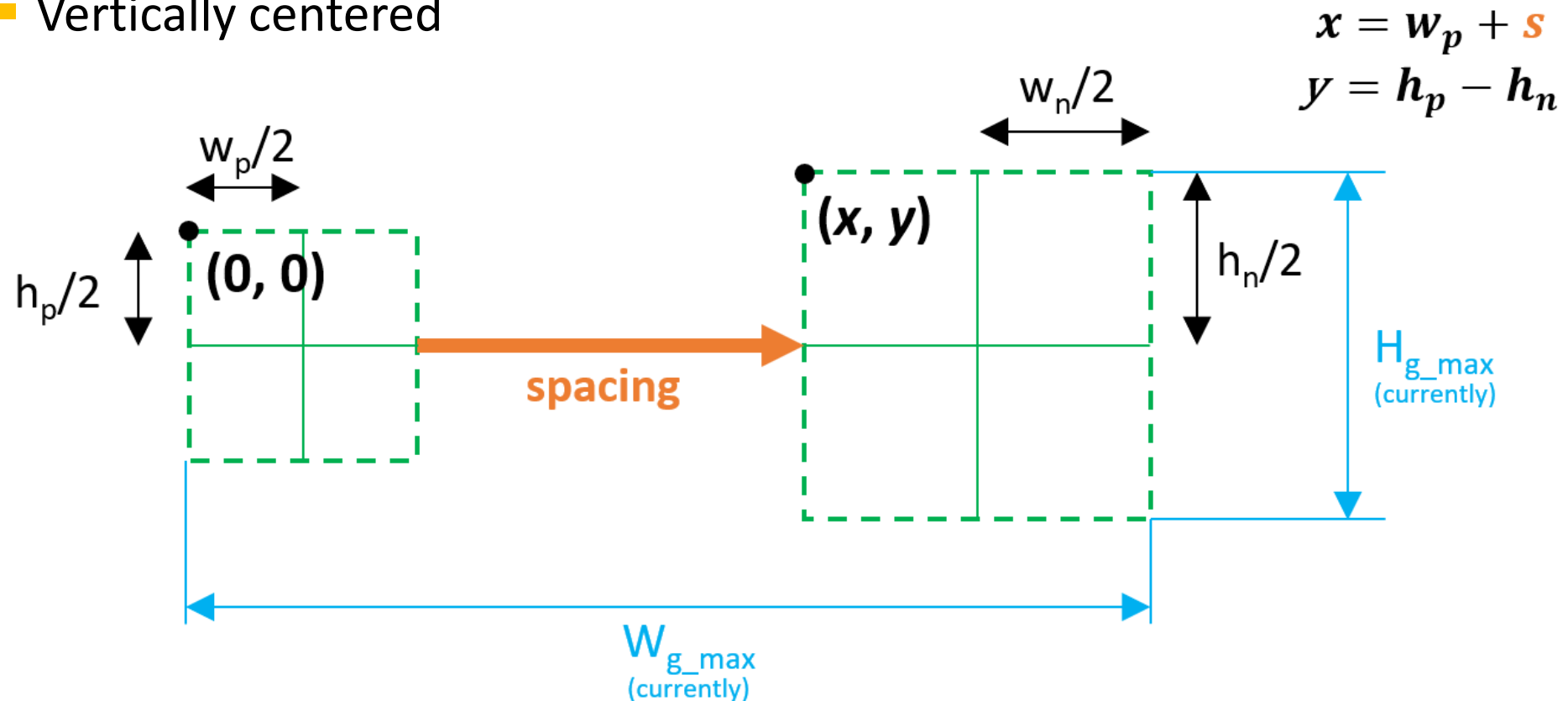


Example 1

Consecutive Inline Shapes

■ #inline

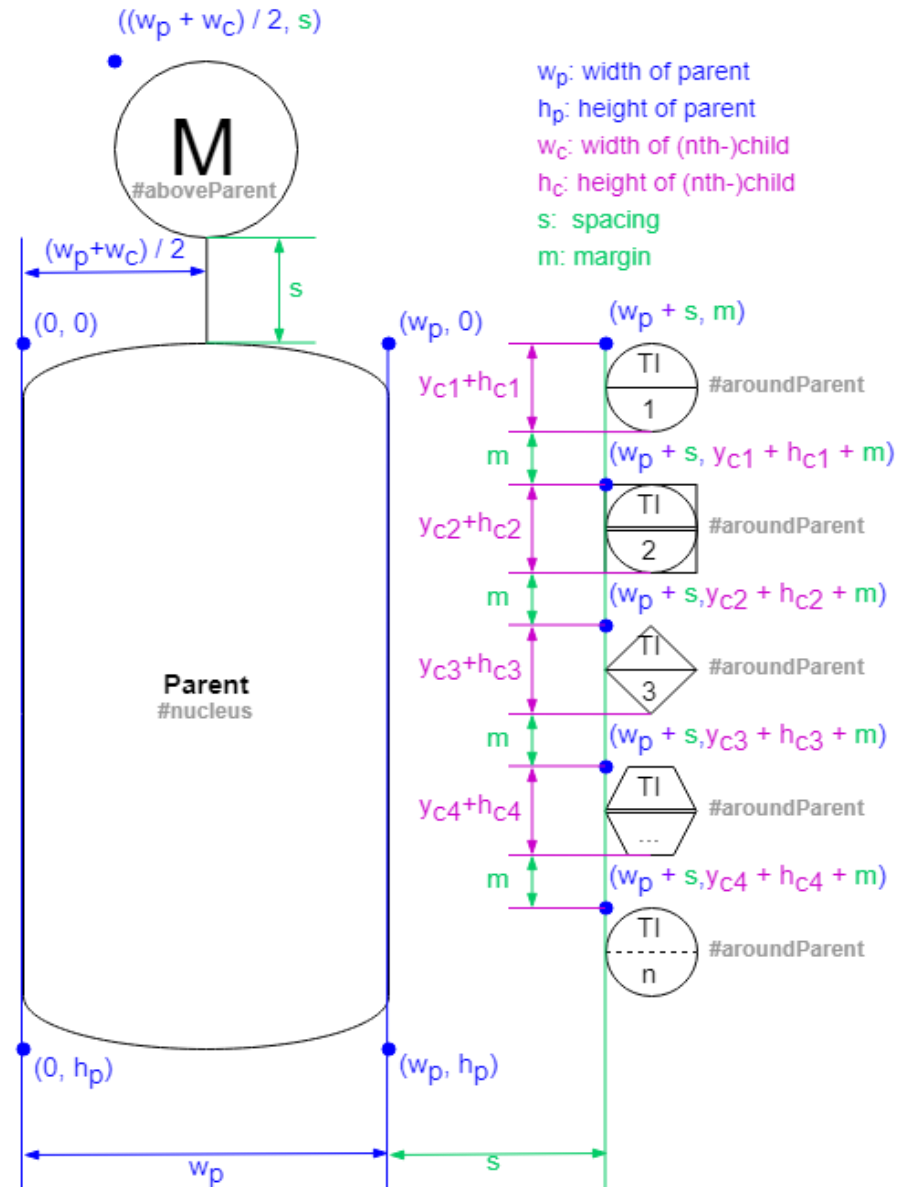
- Horizontal offset from previous by **spacing** (global variable)
- Vertically centered



Example 2

Nucleus Shape and its Children

■ #nucleus

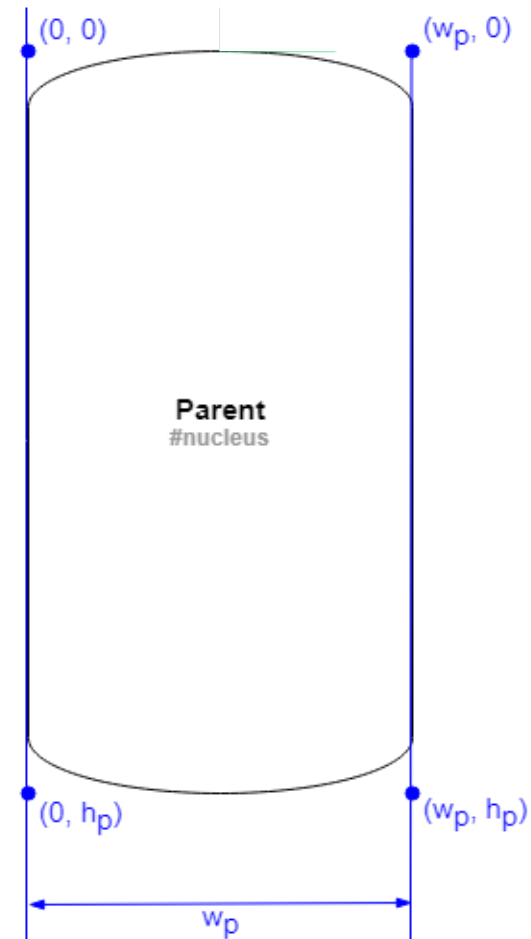


Example 2

Nucleus Shape and its Children

- #nucleus

1. Placed in center

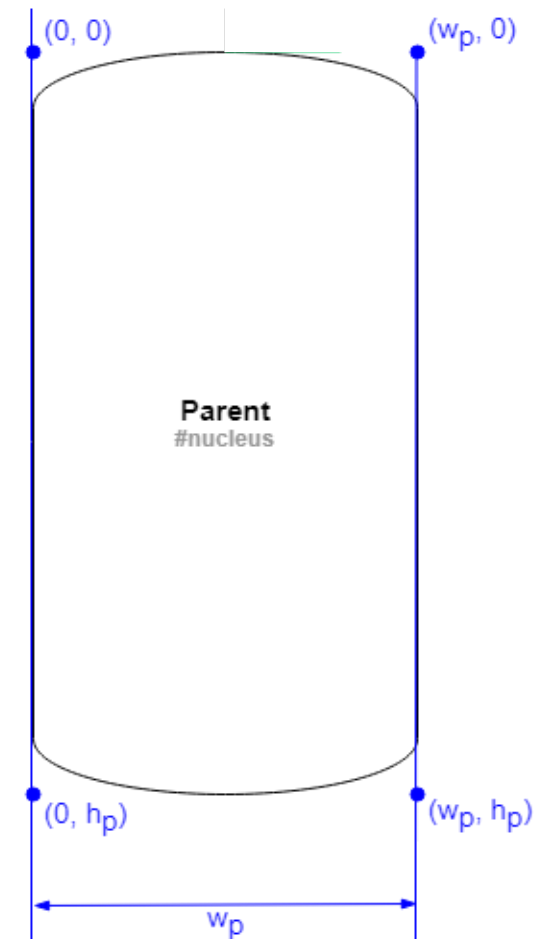


Example 2

Nucleus Shape and its Children

■ #nucleus

1. Placed in center
2. Children relatively placed based on tags:

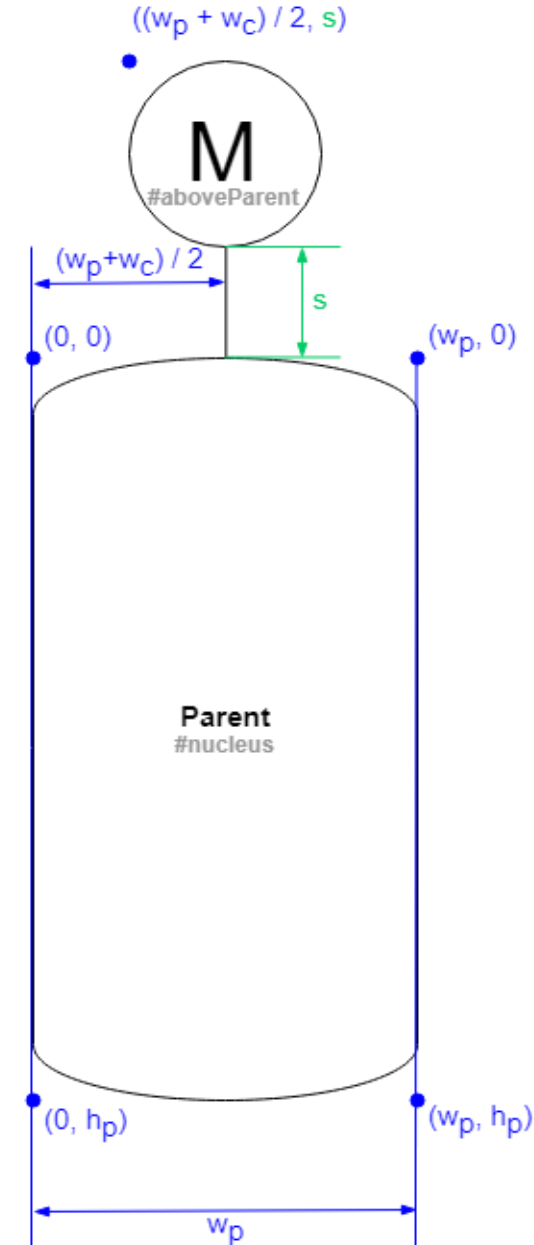


Example 2

Nucleus Shape and its Children

- **#nucleus**

1. Placed in center
2. Children relatively placed based on tags:
 - **#aboveParent**



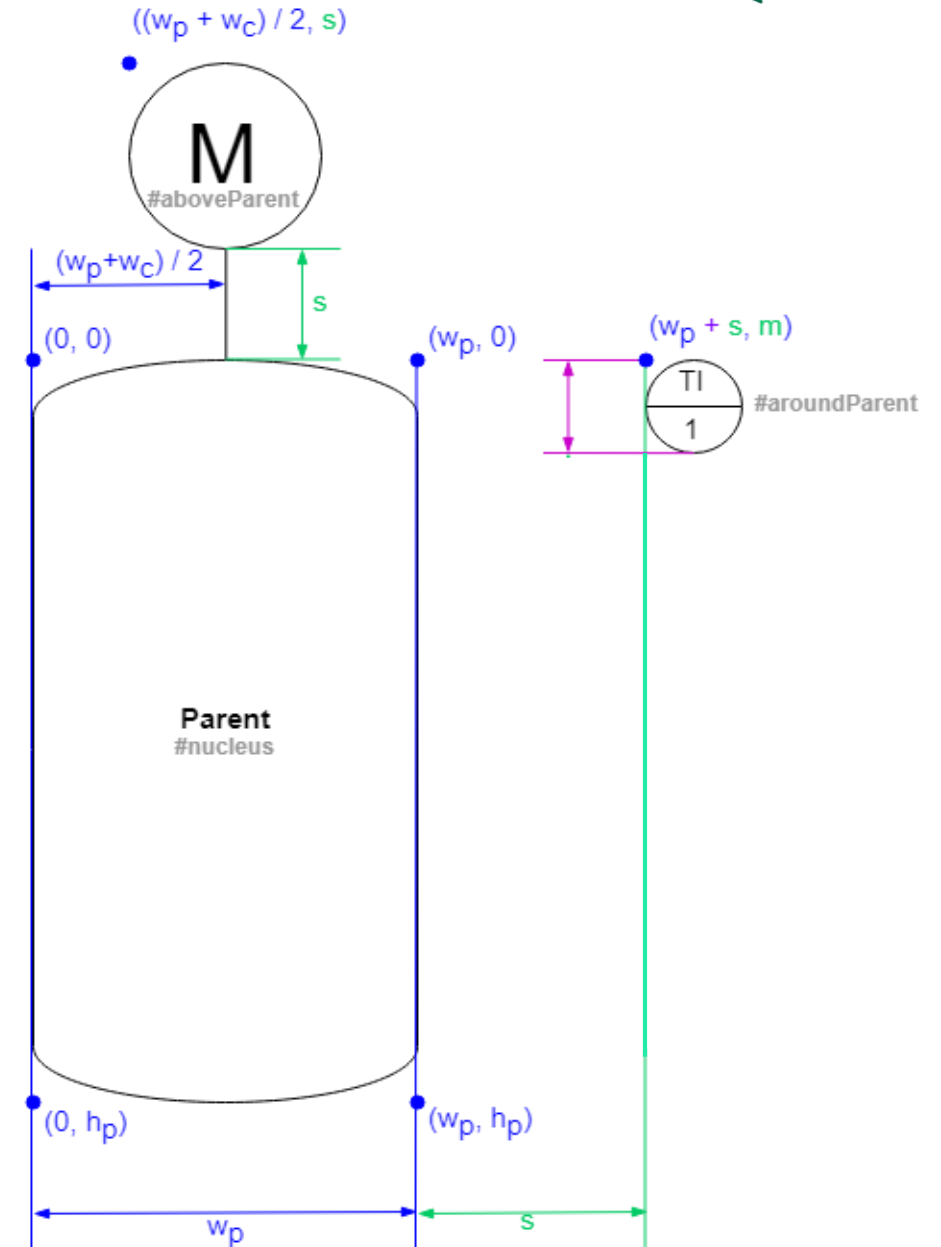
Example 2

Nucleus Shape and its Children

■ #nucleus

1. Placed in center
2. Children relatively placed based on tags:

- #aboveParent
- #aroundParent



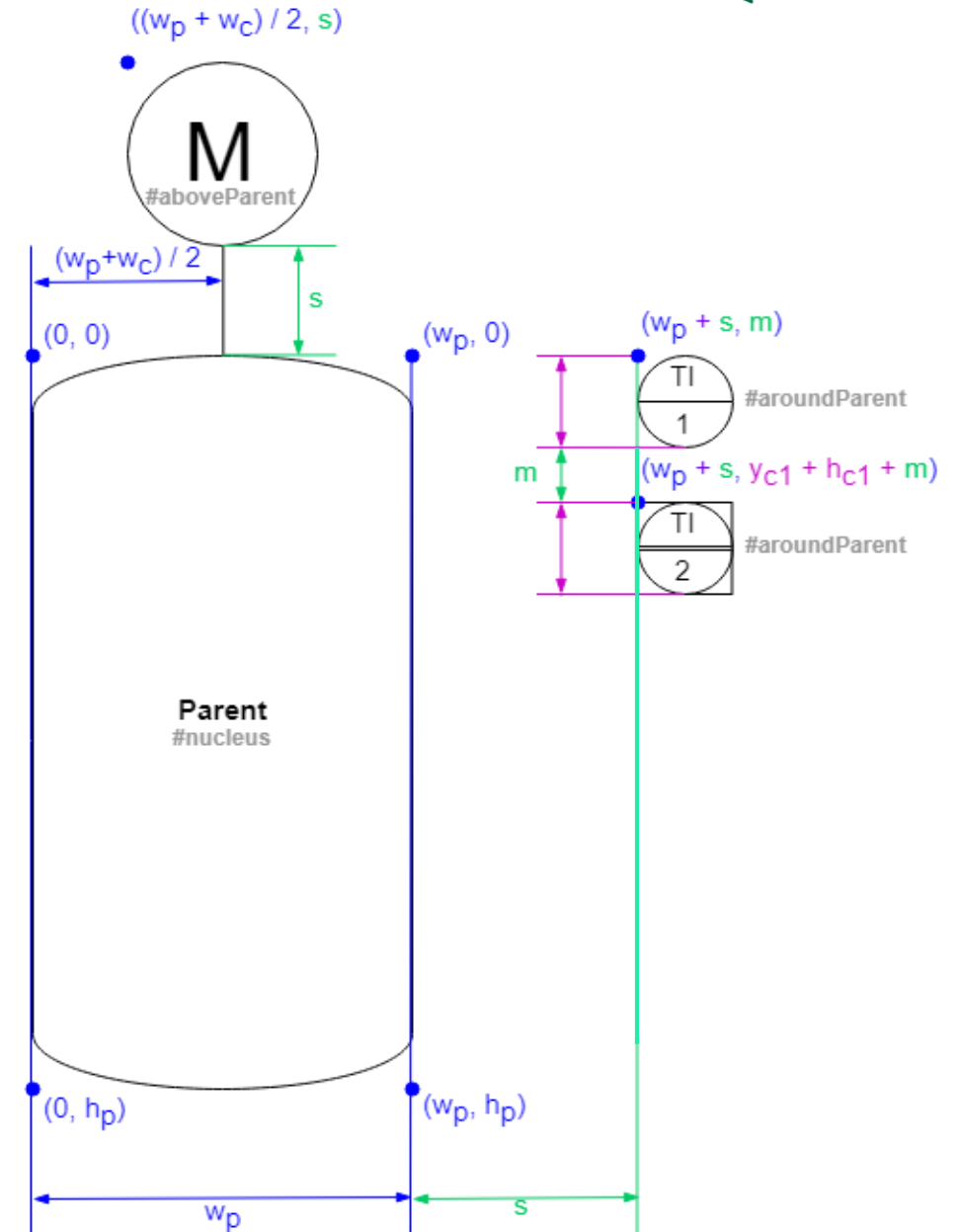
Example 2

Nucleus Shape and its Children

■ #nucleus

1. Placed in center
2. Children relatively placed based on tags:

- #aboveParent
- #aroundParent
- #aroundParent



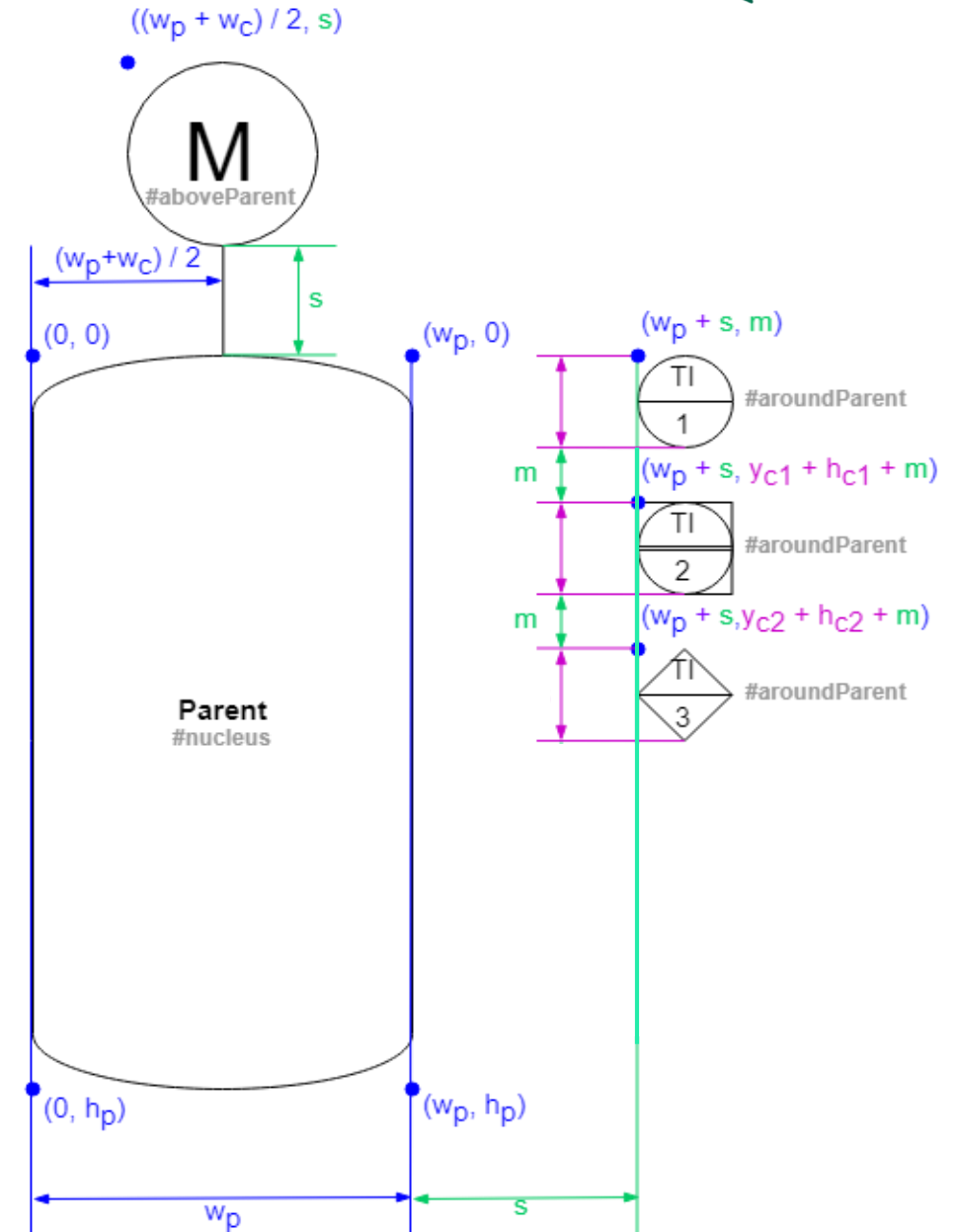
Example 2

Nucleus Shape and its Children

■ #nucleus

1. Placed in center
2. Children relatively placed based on tags:

- #aboveParent
- #aroundParent
- #aroundParent
- #aroundParent



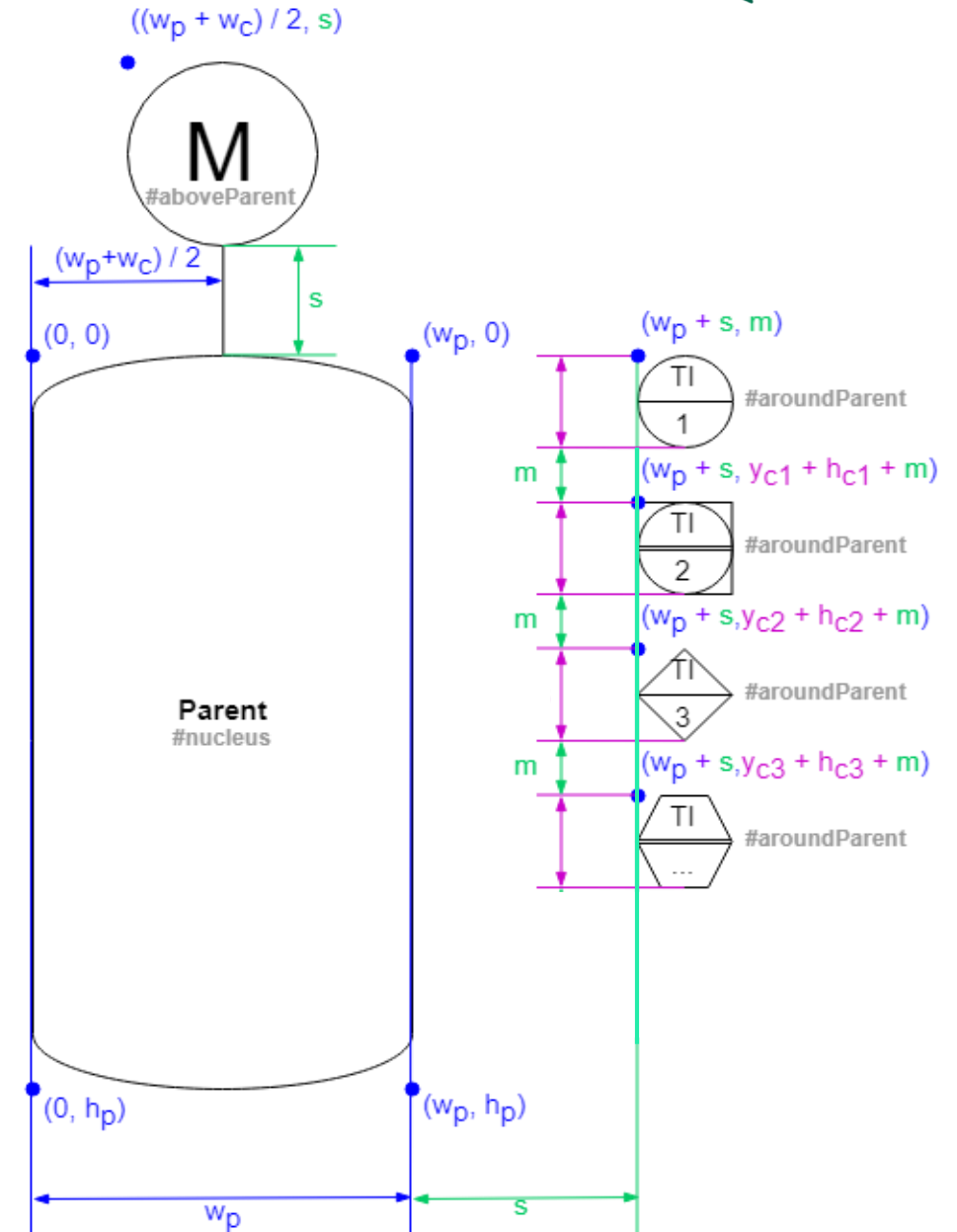
Example 2

Nucleus Shape and its Children

■ #nucleus

1. Placed in center
2. Children relatively placed based on tags:

- #aboveParent
- #aroundParent
- #aroundParent
- #aroundParent
- #aroundParent



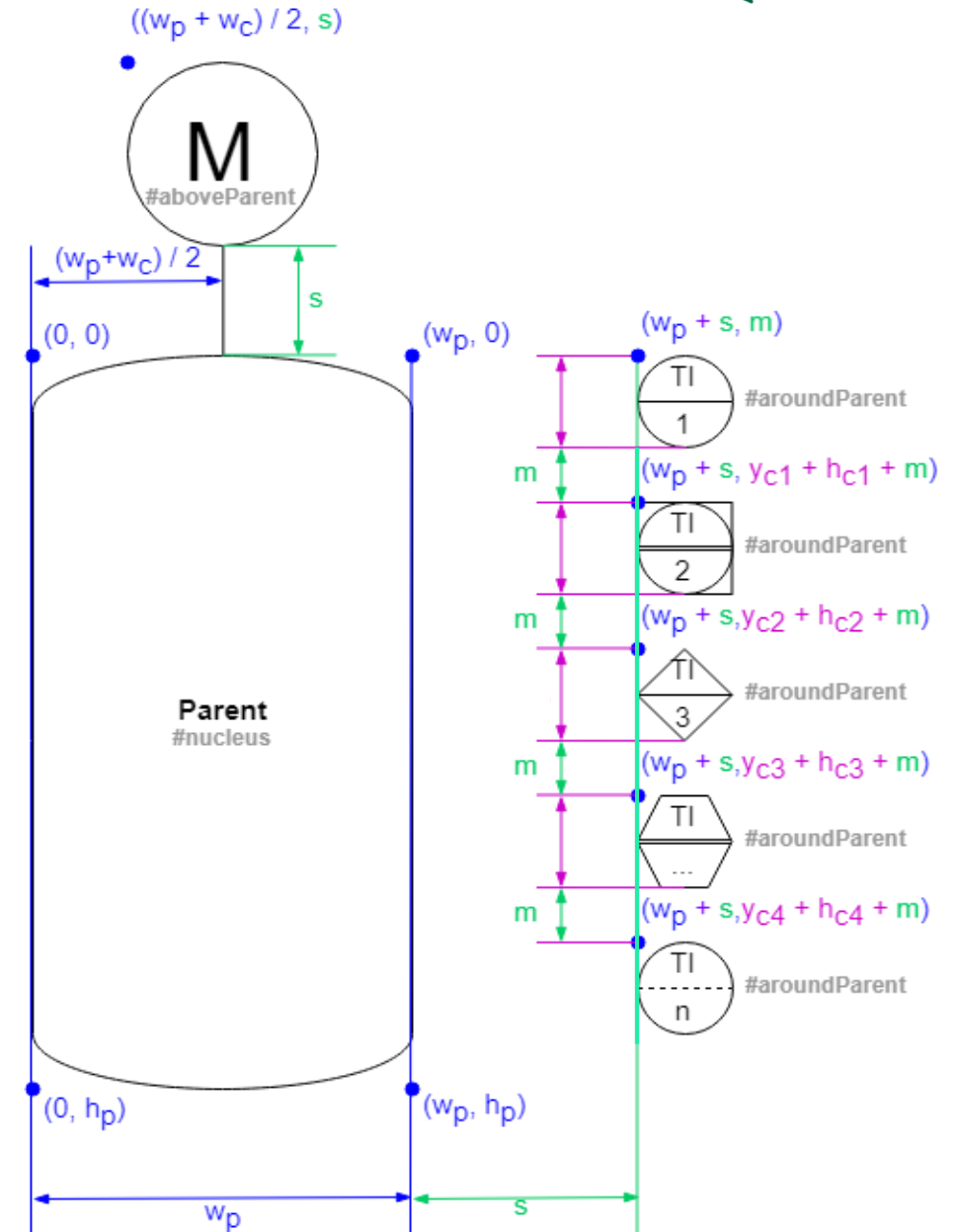
Example 2

Nucleus Shape and its Children

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1. Placed in center
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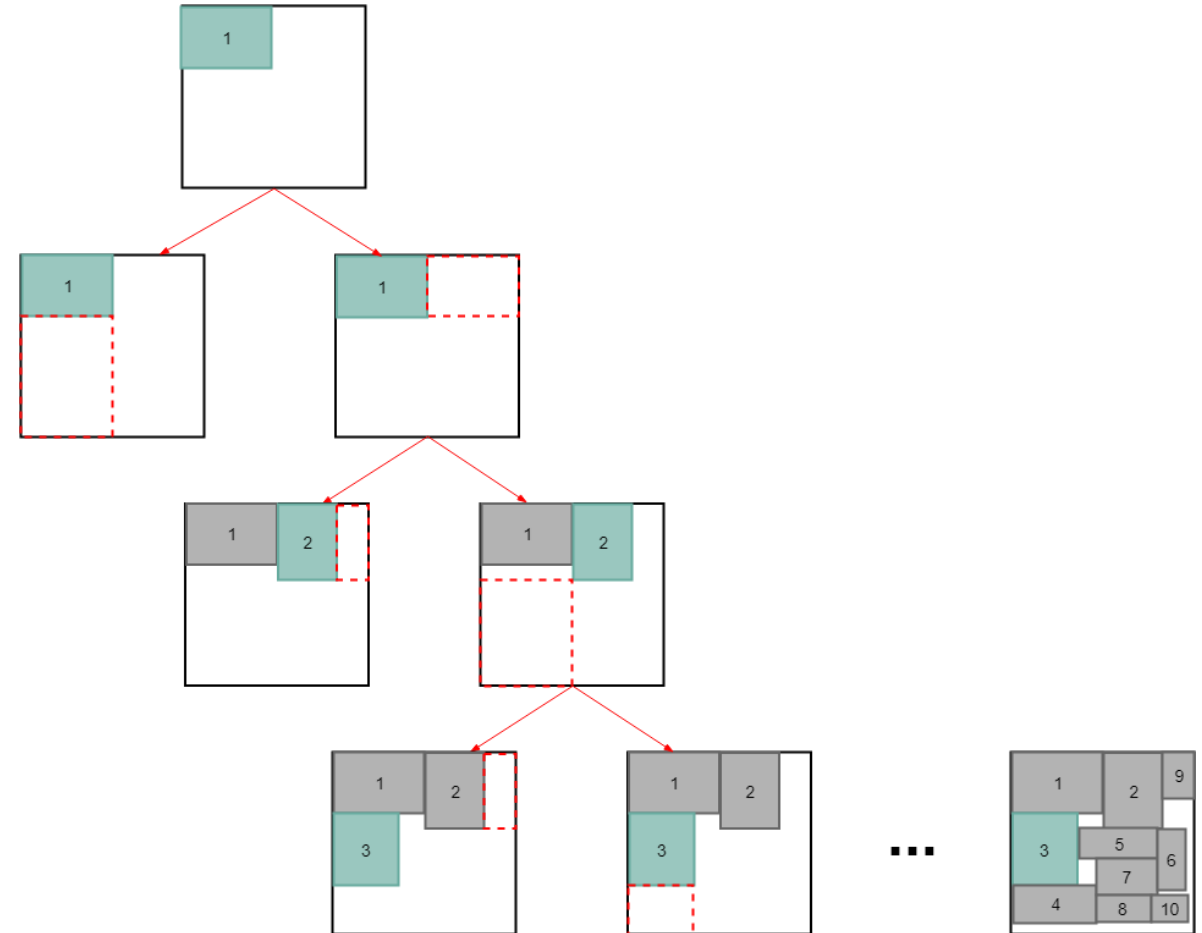
- #aboveParent
- #aroundParent
- #aroundParent
- #aroundParent
- #aroundParent
- #aroundParent



Example 3

Outer Groups with only Group Children

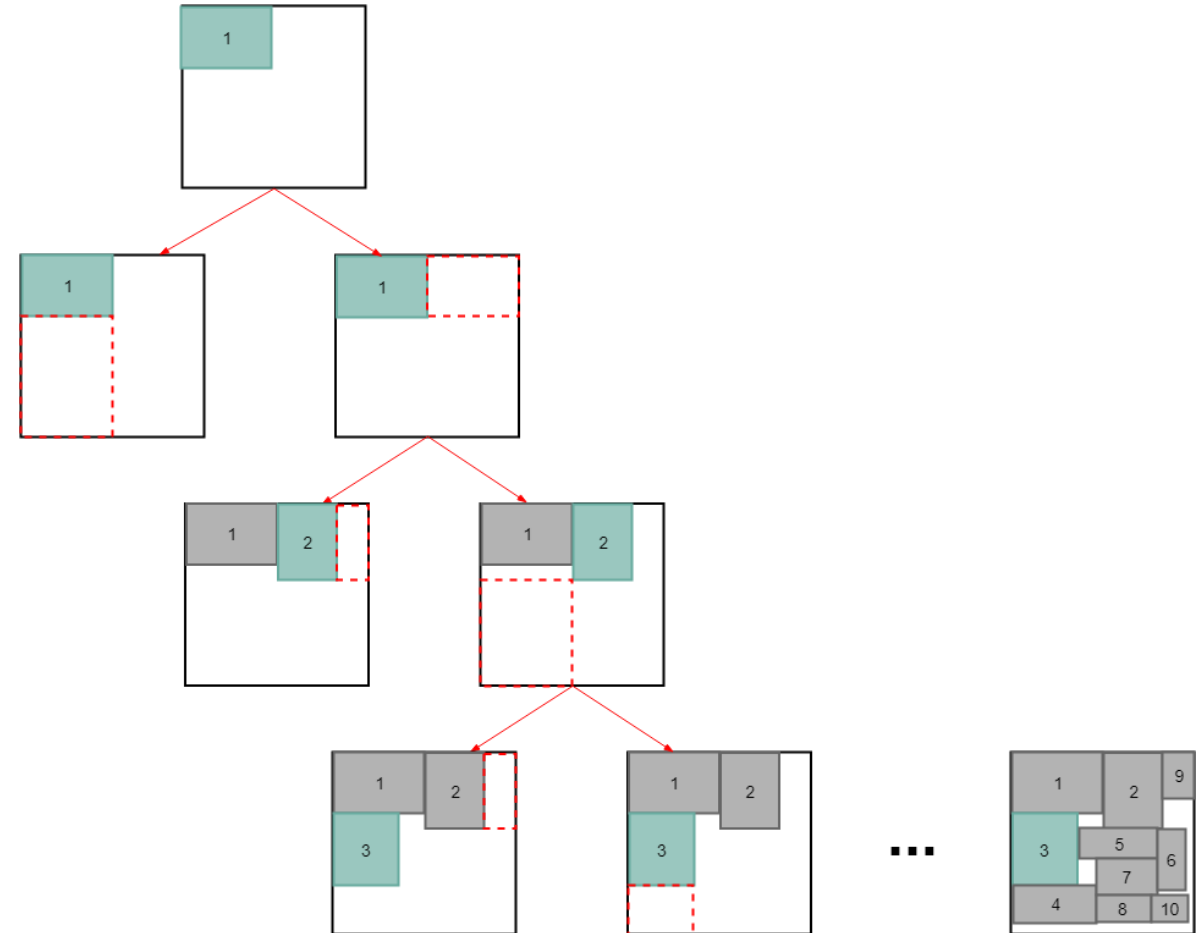
■ #OuterGroup:



Example 3

Outer Groups with only Group Children

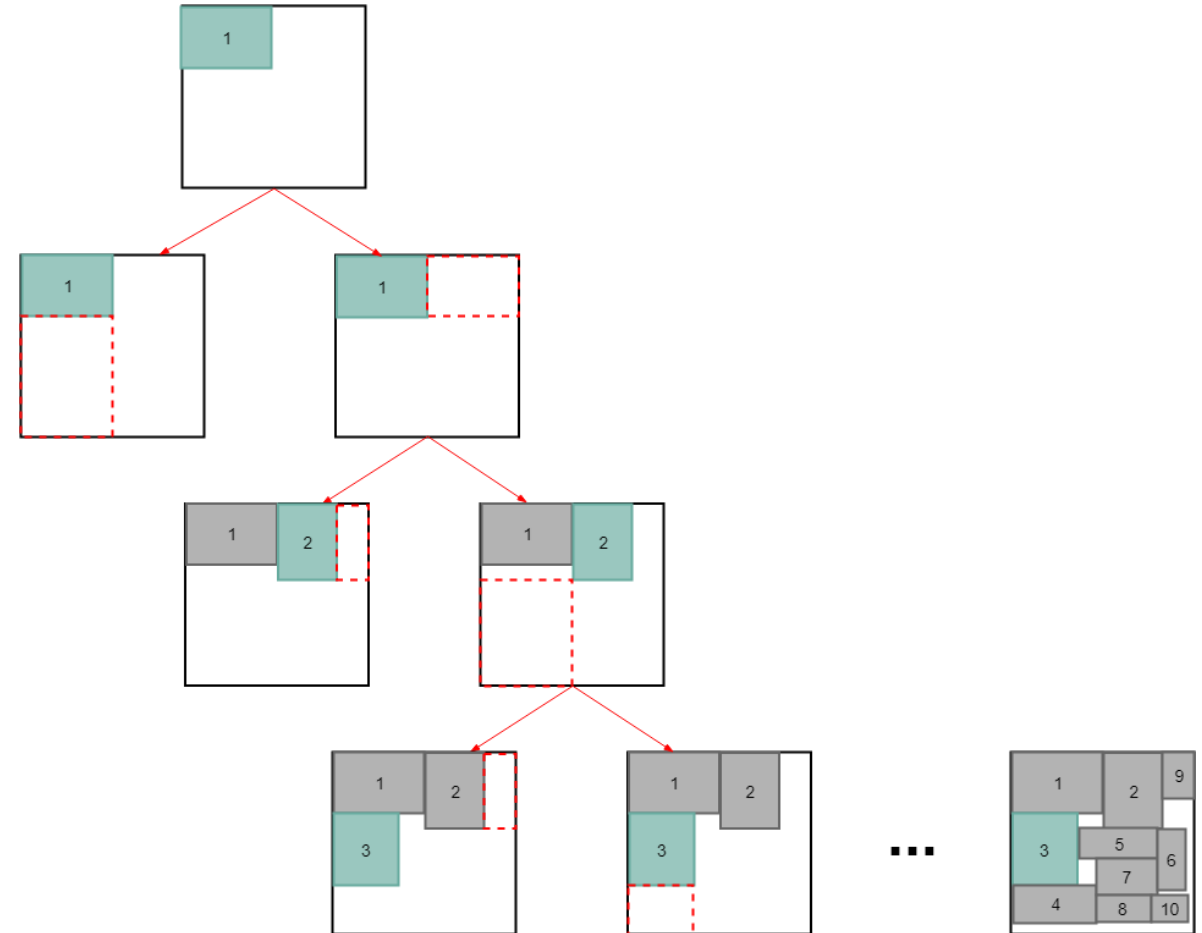
- **#OuterGroup:**
 - Groups which contain only groups and no shapes



Example 3

Outer Groups with only Group Children

- **#OuterGroup:**
 - Groups which contain only groups and no shapes
 - Placed with Block Packing Algorithm



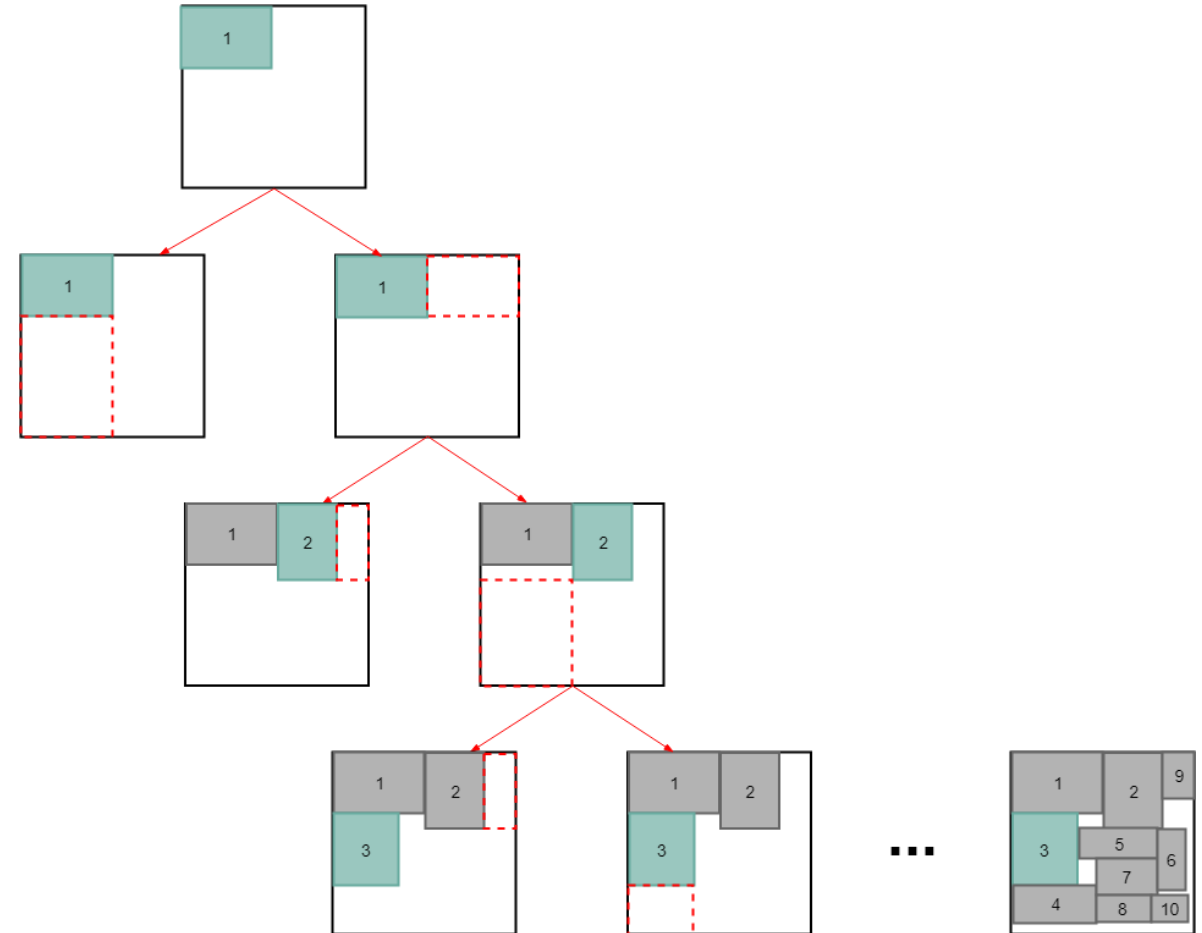
Example 3

Outer Groups with only Group Children

- **#OuterGroup:**

- Groups which contain only groups and no shapes
- Placed with Block Packing Algorithm

→ **Minimize Area**



Example 3

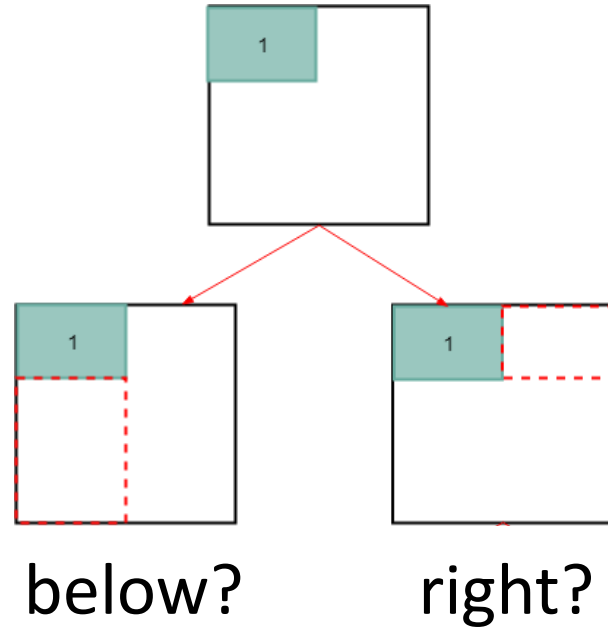
Outer Groups with only Group Children



- First group placed within **#outerGroup**

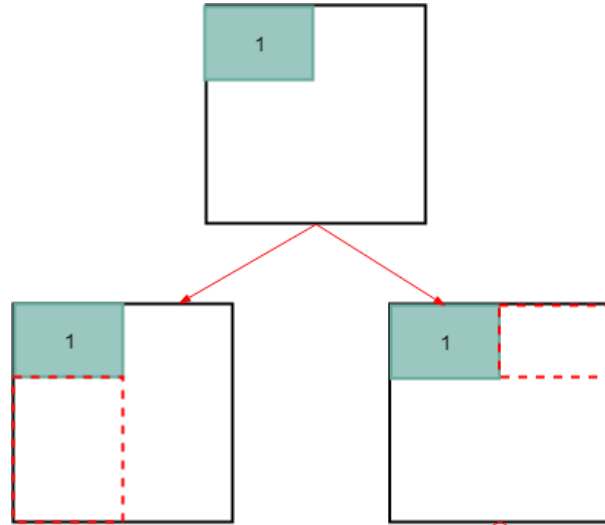
Example 3

Outer Groups with only Group Children



Example 3

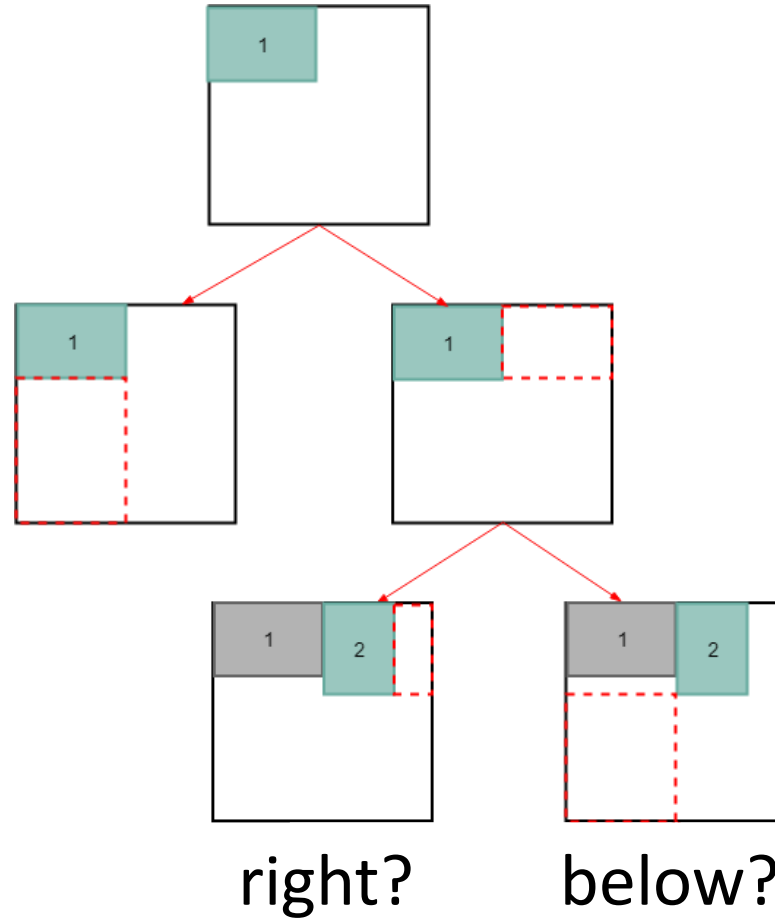
Outer Groups with only Group Children



right

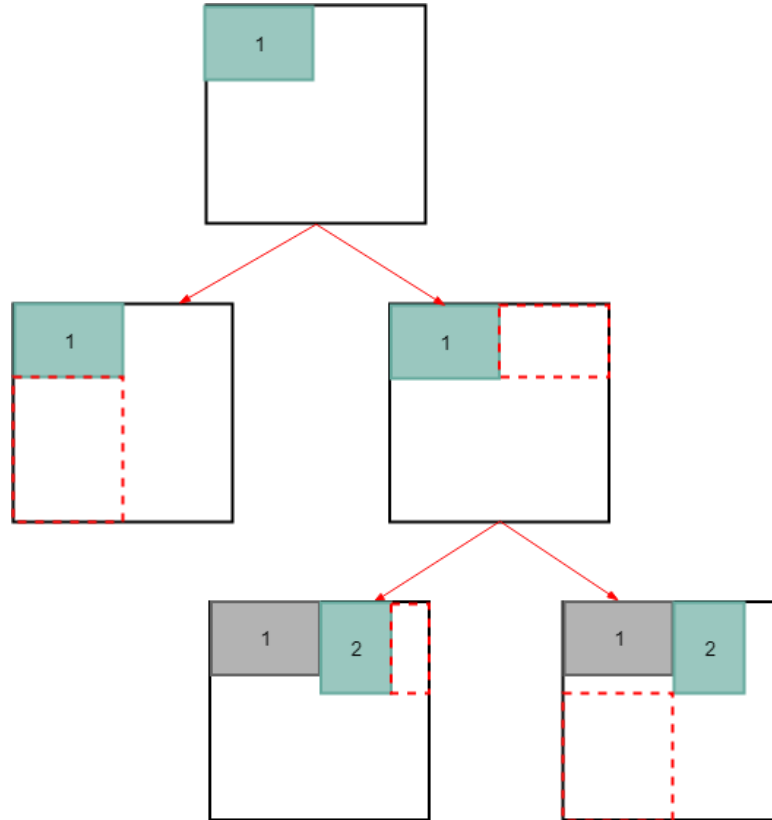
Example 3

Outer Groups with only Group Children



Example 3

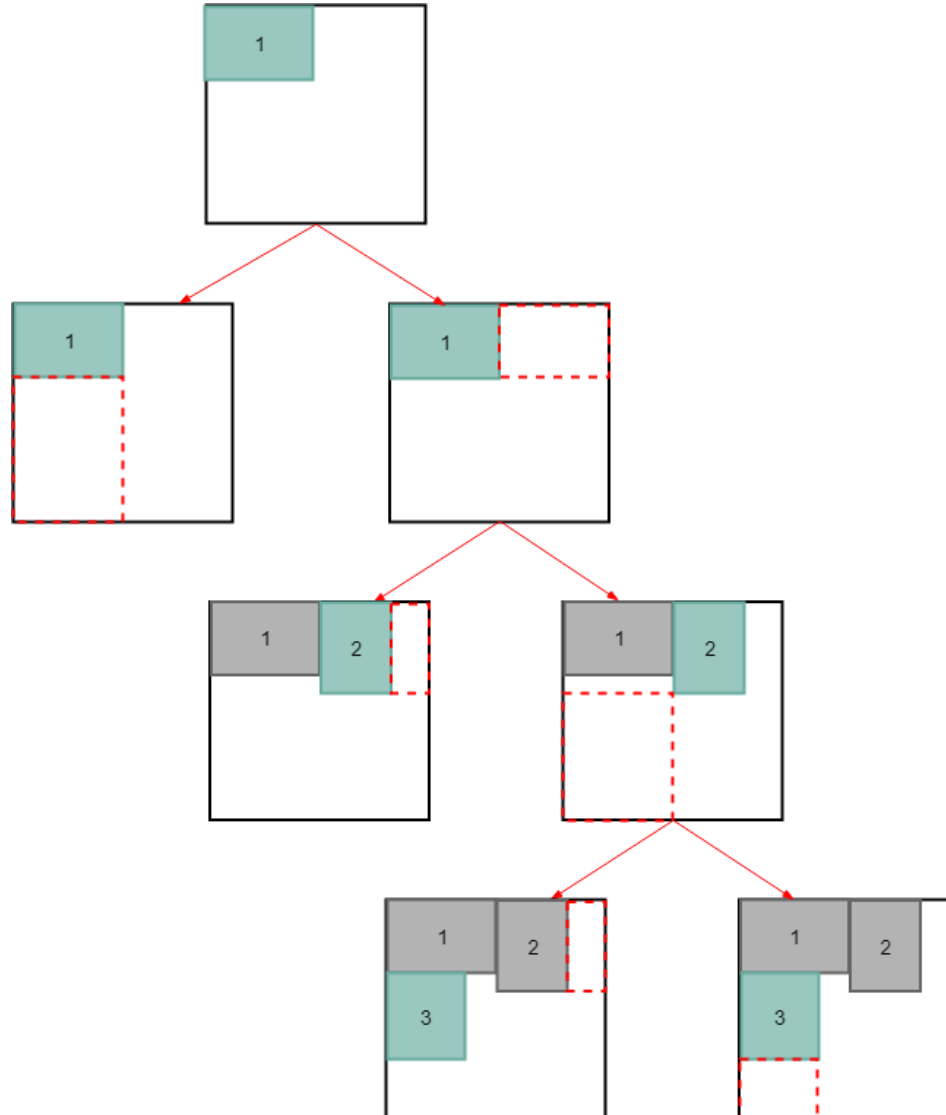
Outer Groups with only Group Children



below

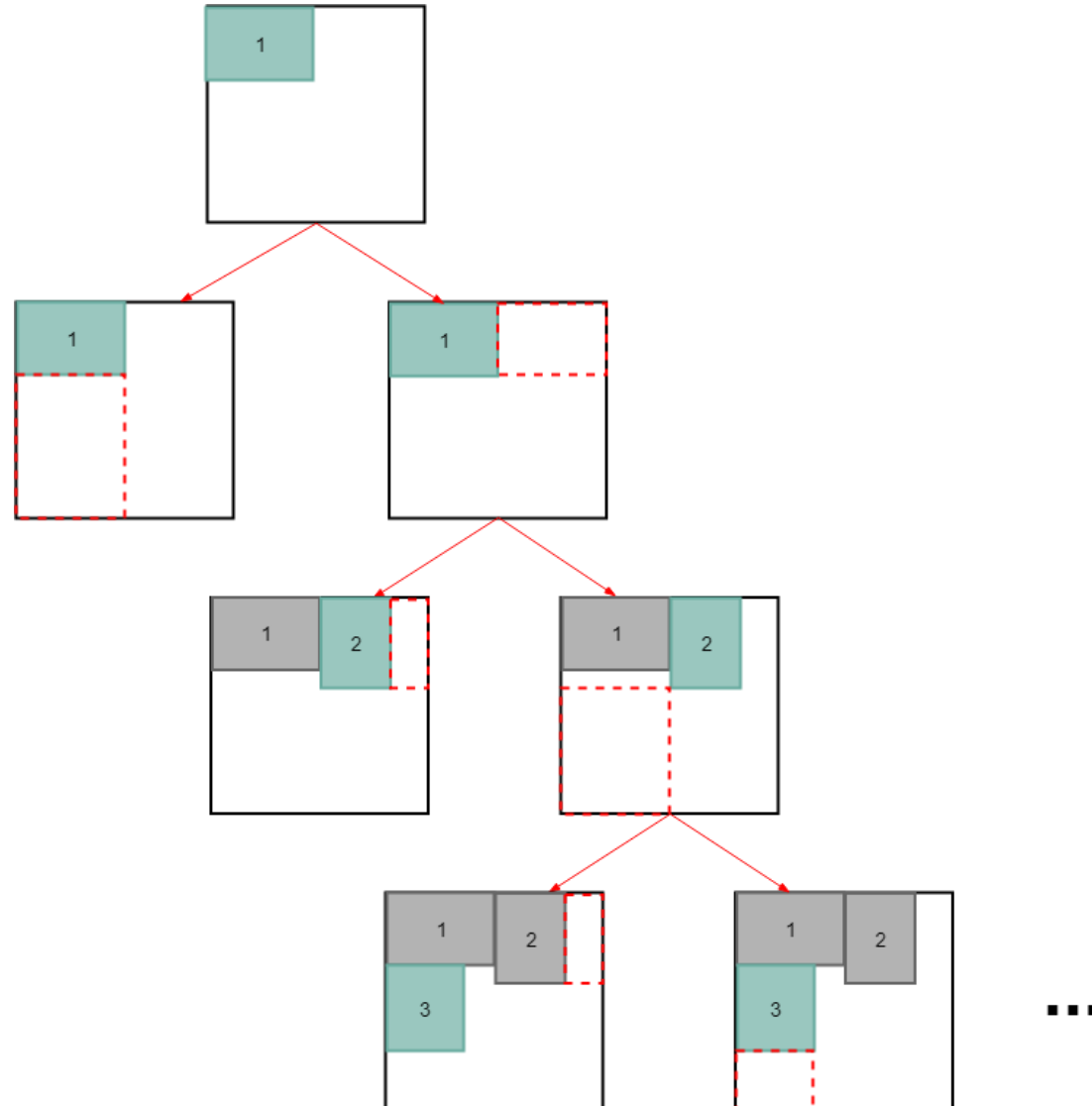
Example 3

Outer Groups with only Group Children



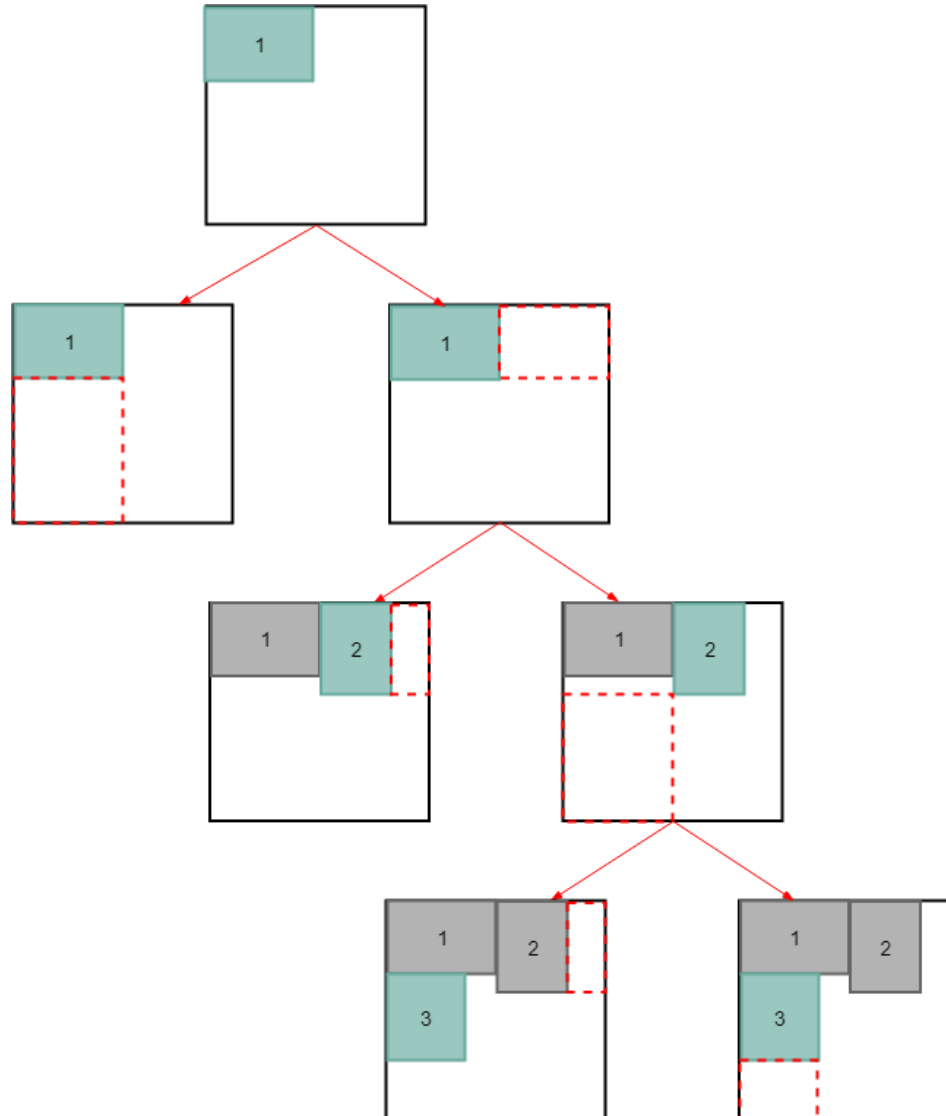
Example 3

Outer Groups with only Group Children



Example 3

Outer Groups with only Group Children



- Until all groups placed in minimum total area

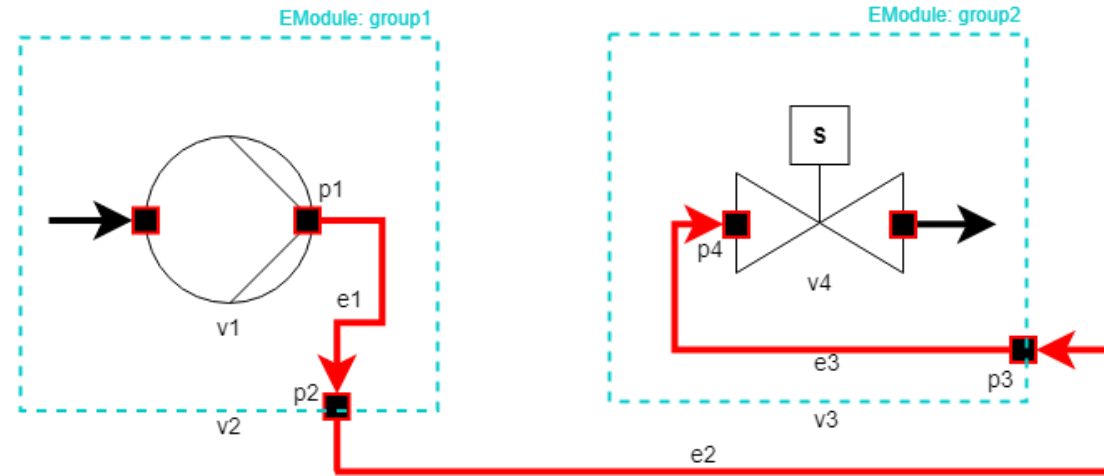
...



Graphing Algorithm

Simplification of Connections

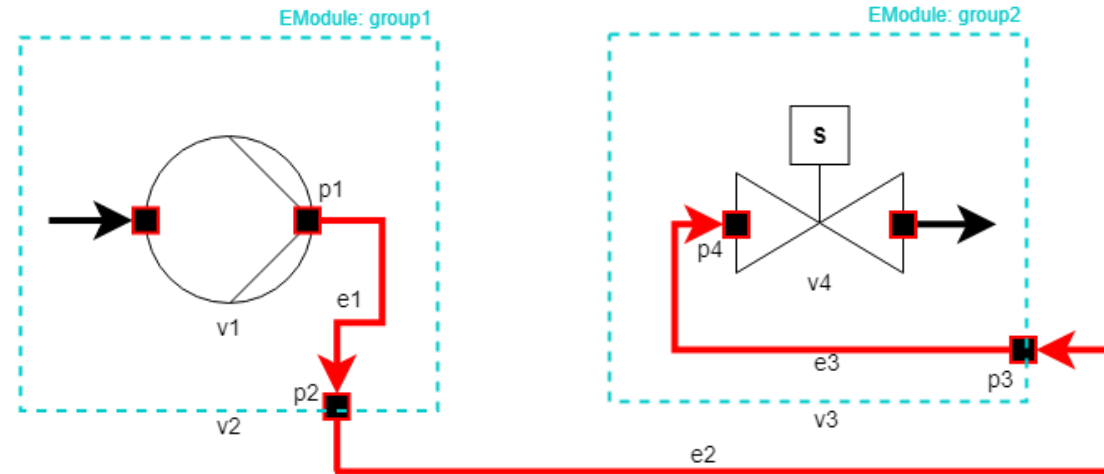
Before:



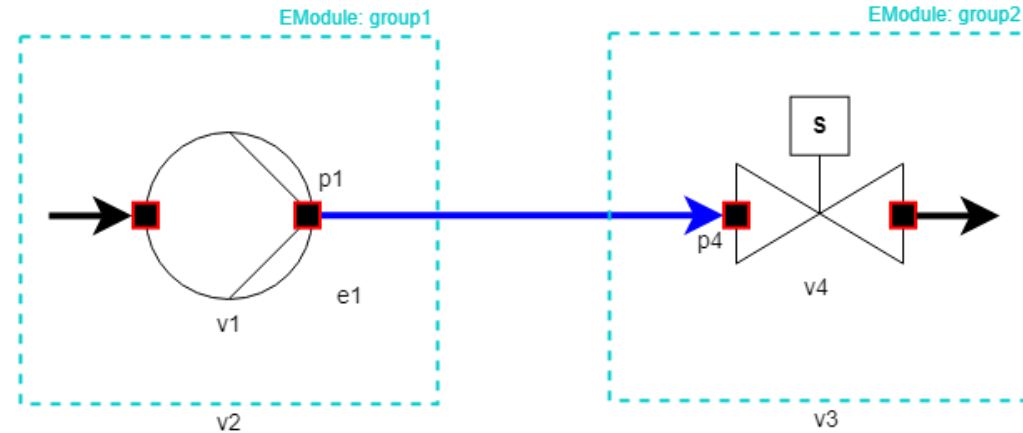
Graphing Algorithm

Simplification of Connections

Before:

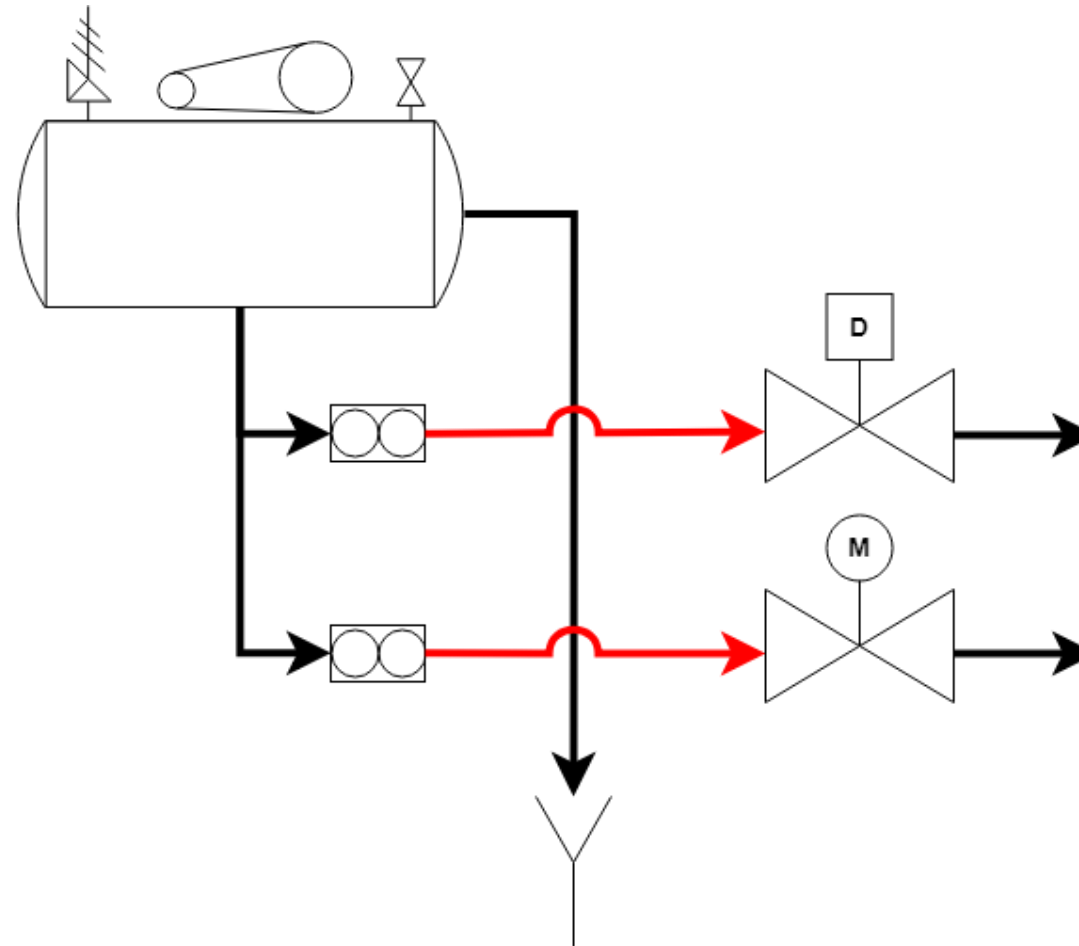


After:



Graphing Algorithm

Applying Line Jumps



Software Architecture

Overview



Software Architecture

Overview



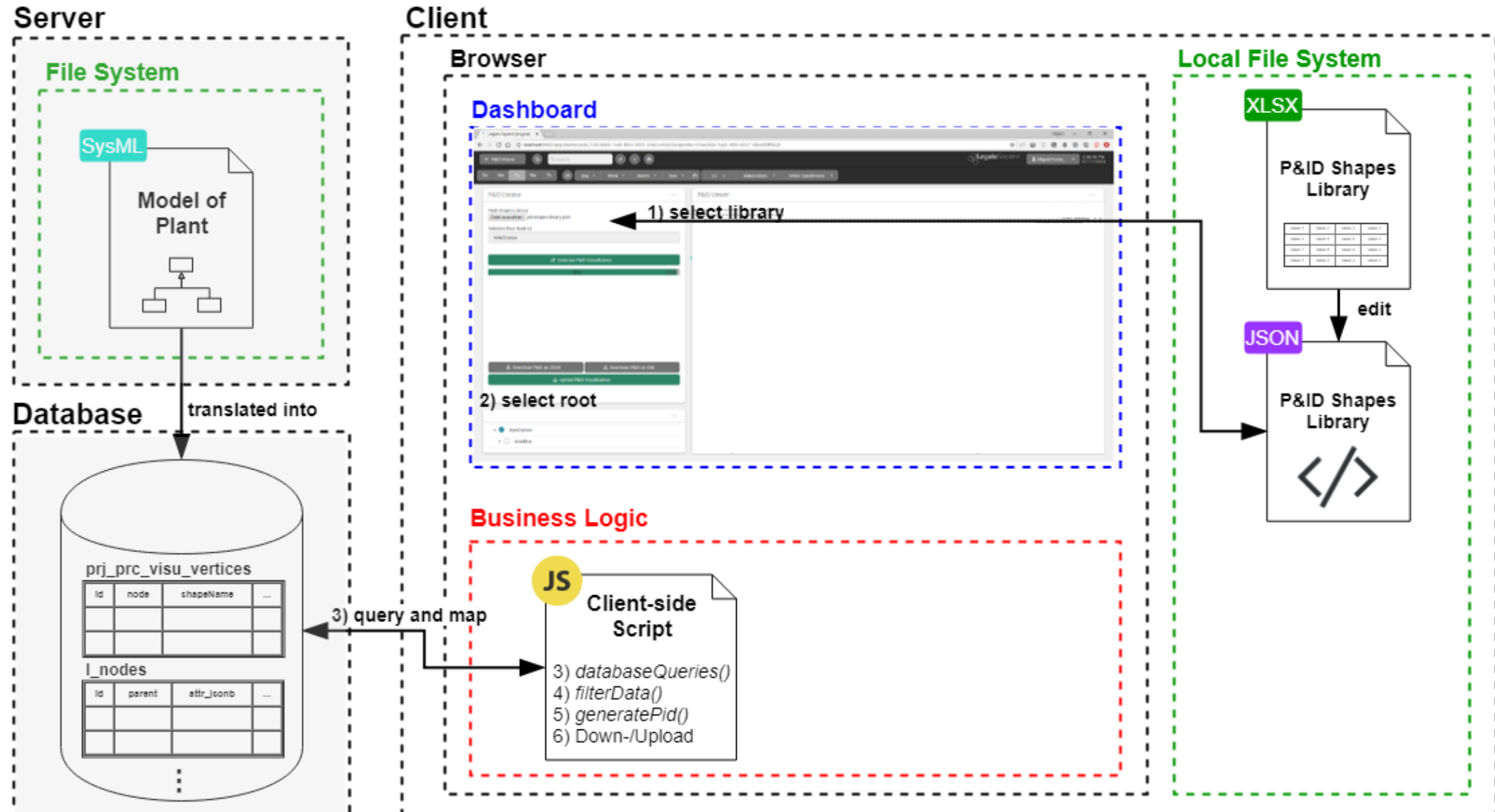
Software Architecture

Overview



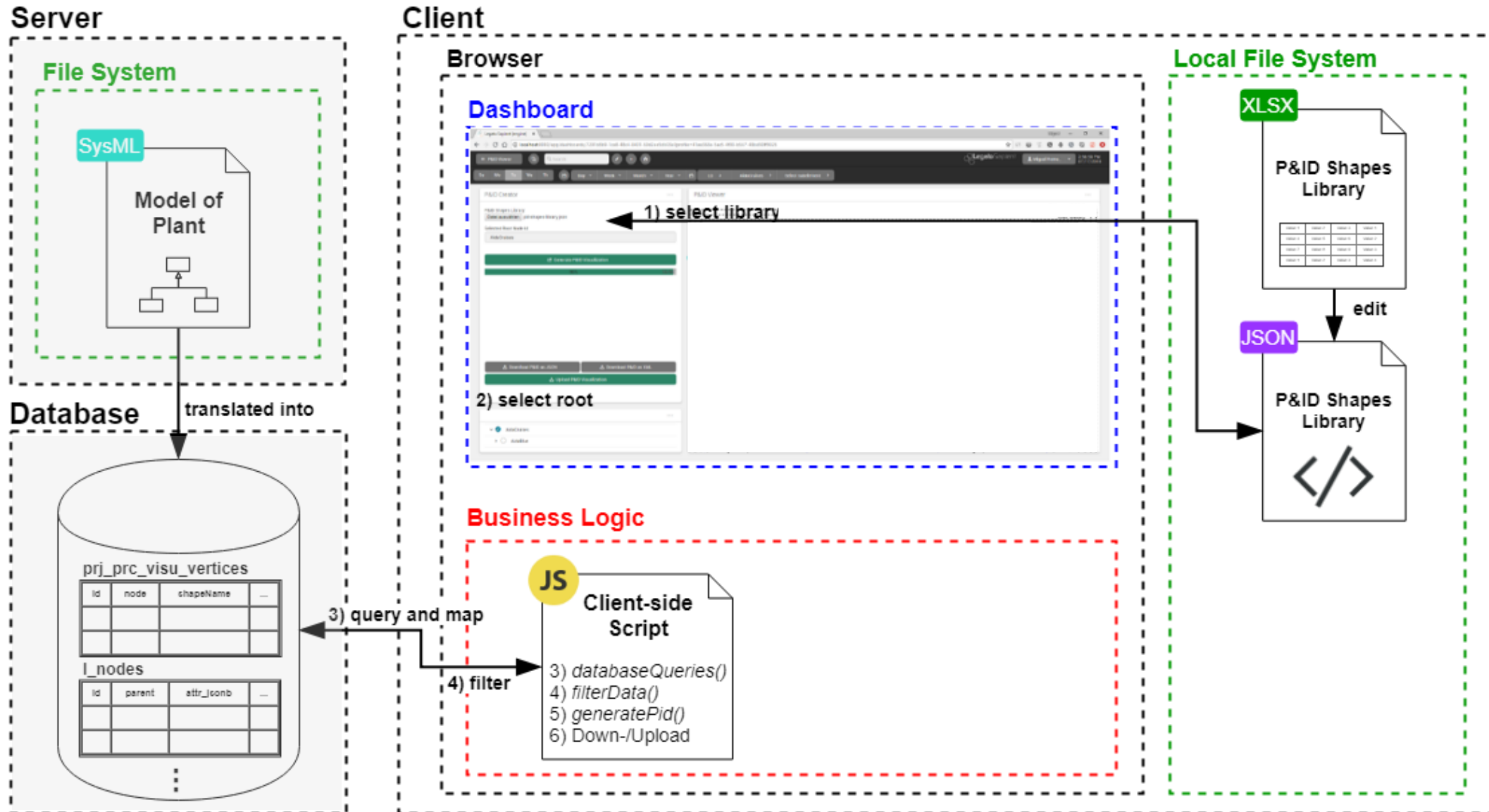
Software Architecture

Overview



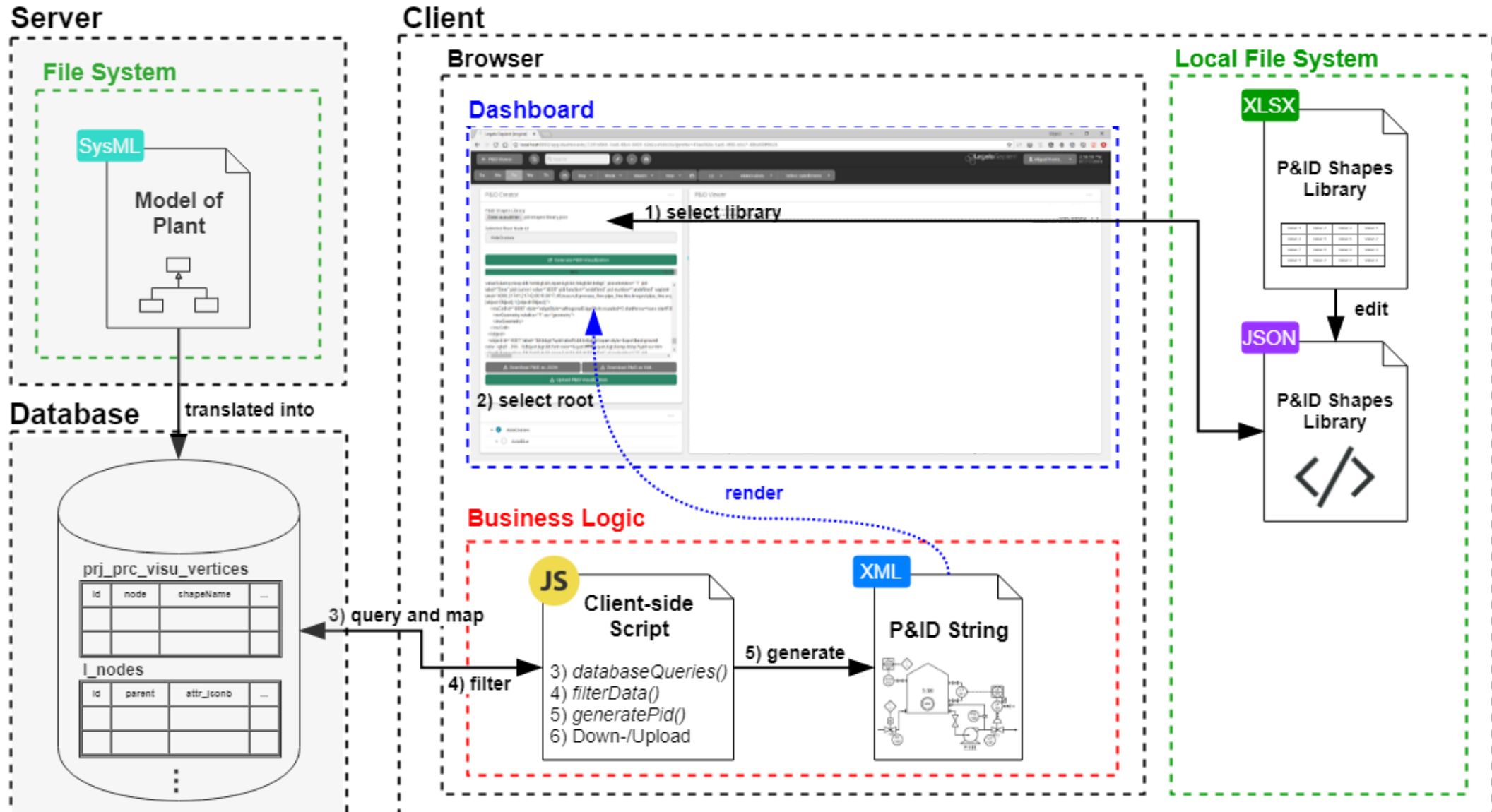
Software Architecture

Overview



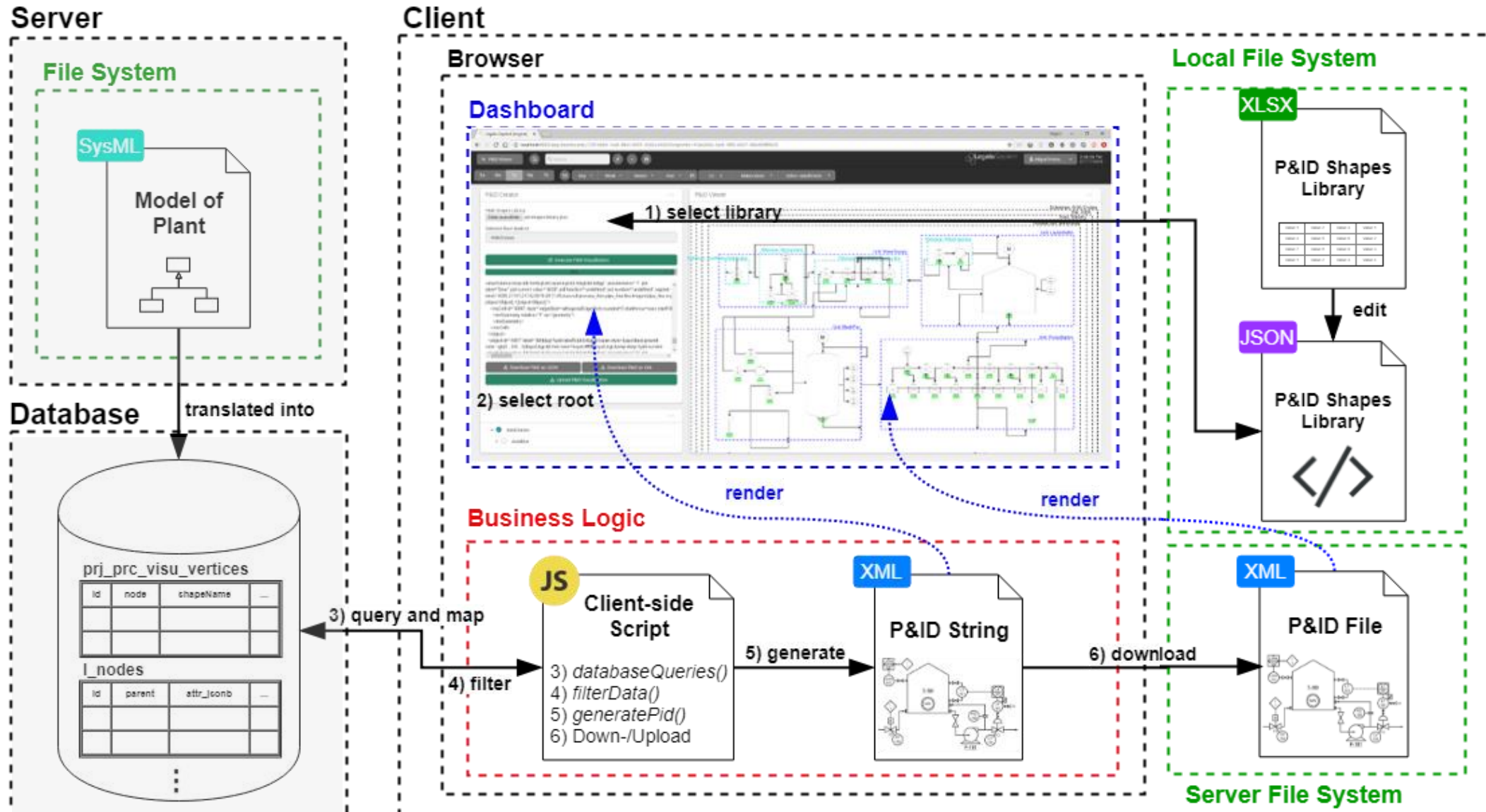
Software Architecture

Overview

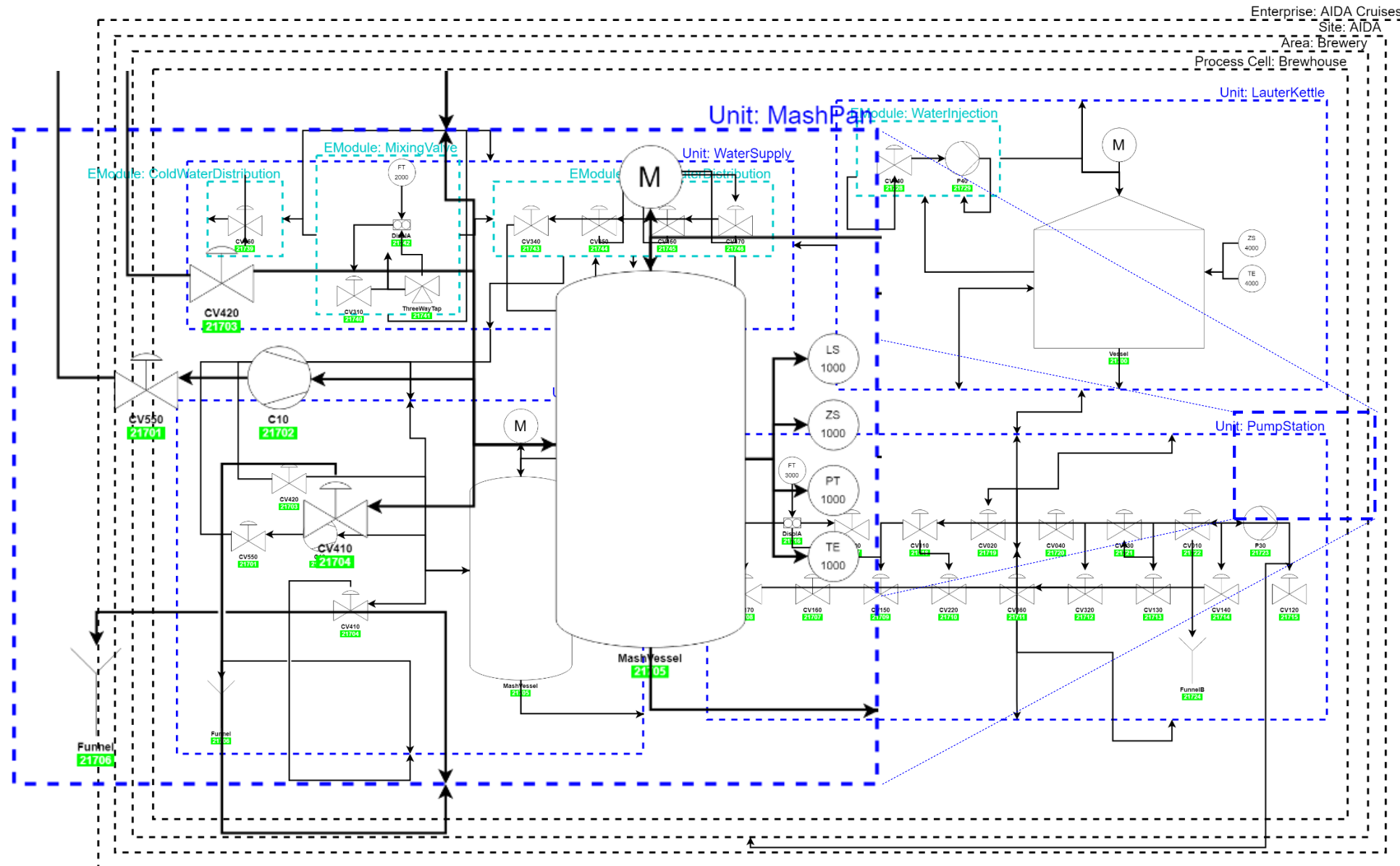


Software Architecture

Overview



P&ID of Aida Brewery



Conclusion

Bachelor Thesis



- Much room for improvement (especially in Vertex placement)

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- In terms of the project goals:
 - 1.
 - 2.
 - 3.

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 1. Creation of P&IDs is now much easier and faster ✓
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 1. Creation of P&IDs is now much easier and faster ✓
 2. A library of standardized P&ID symbols was successfully created ✓
 - 3.

- Much room for improvement (especially in Vertex placement)
- In terms of the project goals:
 1. Creation of P&IDs is now much easier and faster ✓
 2. A library of standardized P&ID symbols was successfully created ✓
 3. Solution prototypically implemented in a MES ✓

P&ID Creator

P&ID Shapes Library:
Datei auswählen pid-shapes-library.json

Selected Root Node Id:
AidaCruises

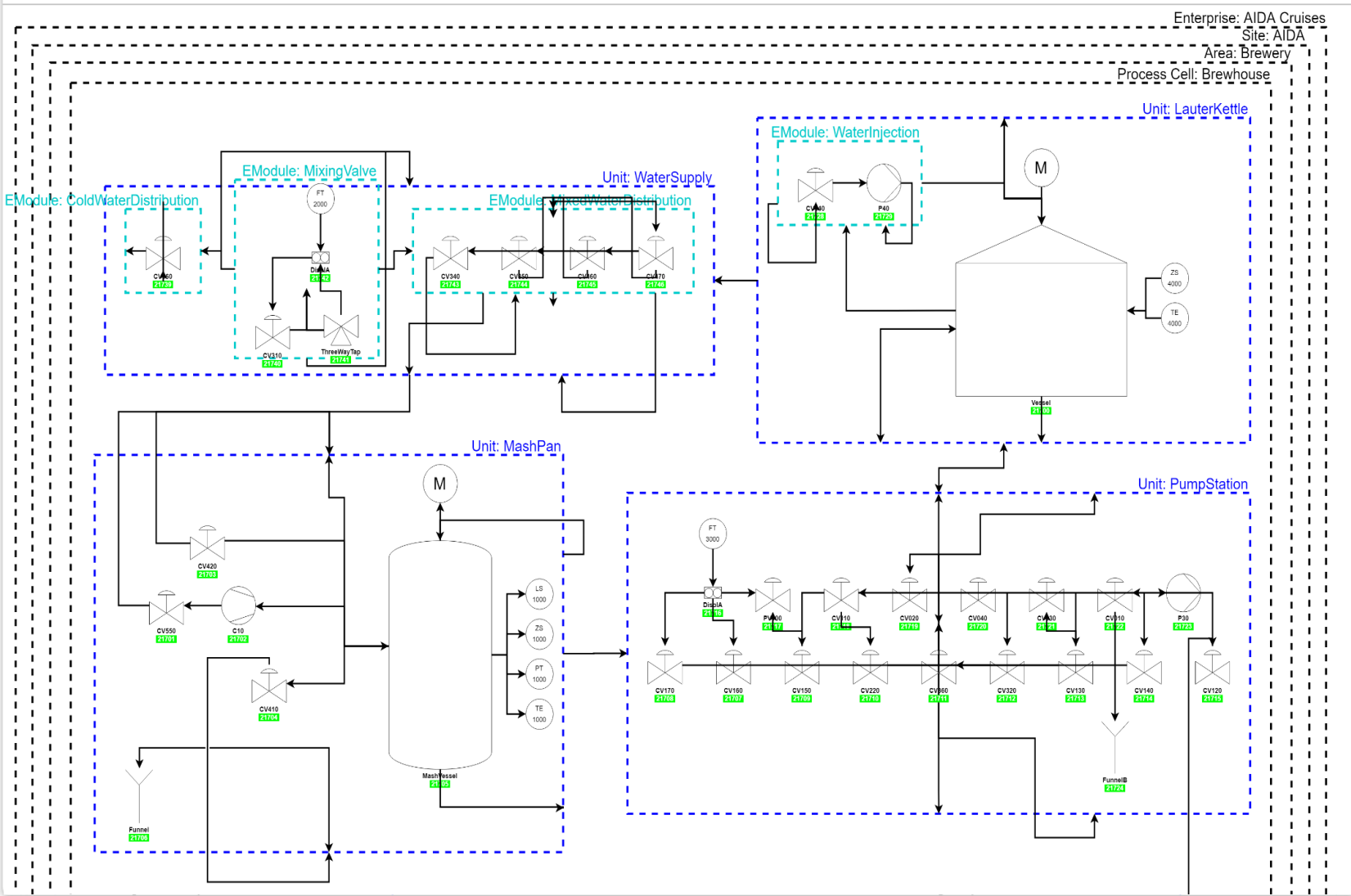
Generate P&ID Visualization
98% 55/56

```
value%&nbsp;&lt;math>\pi</math>&lt;/span>&lt;/b>&lt;br> placeholders="1" pid-label="Beer" pid-current-value="4000" pid-function="undefined" pid-number="undefined" sapient-bind="4000;21741;21742;6616;6617;49;true>null;process_flow;pipe_line;line;images\pipe_line.svg [object Object];1.[object Object];">
<mxCell id="4000" style="edgeStyle=orthogonalEdgeStyle;rounded=0;startArrow=none;startFill
<mxGeometry relative="1" as="geometry">
</mxGeometry>
</mxCell>
</object>
<object id="4001" label="&lt;math>\pi</math>&lt;/span>&lt;/b>&lt;br> pid-label%&lt;math>\pi</math>&lt;/span>&lt;/b>&lt;br> span style="background-color: rgb(0 , 255 , 0)"&lt;math>\pi</math>&lt;/span>&lt;/b>&lt;br> font color="&lt;math>\pi</math>&lt;/span>&lt;/b>&lt;br> &lt;math>\pi</math>&lt;/span>&lt;/b>&lt;br> &lt;math>\pi</math>&lt;/span>&lt;/b>&lt;br> placeholders="1" pid
```

Download P&ID as JSON Download P&ID as XML
Upload P&ID Visualization

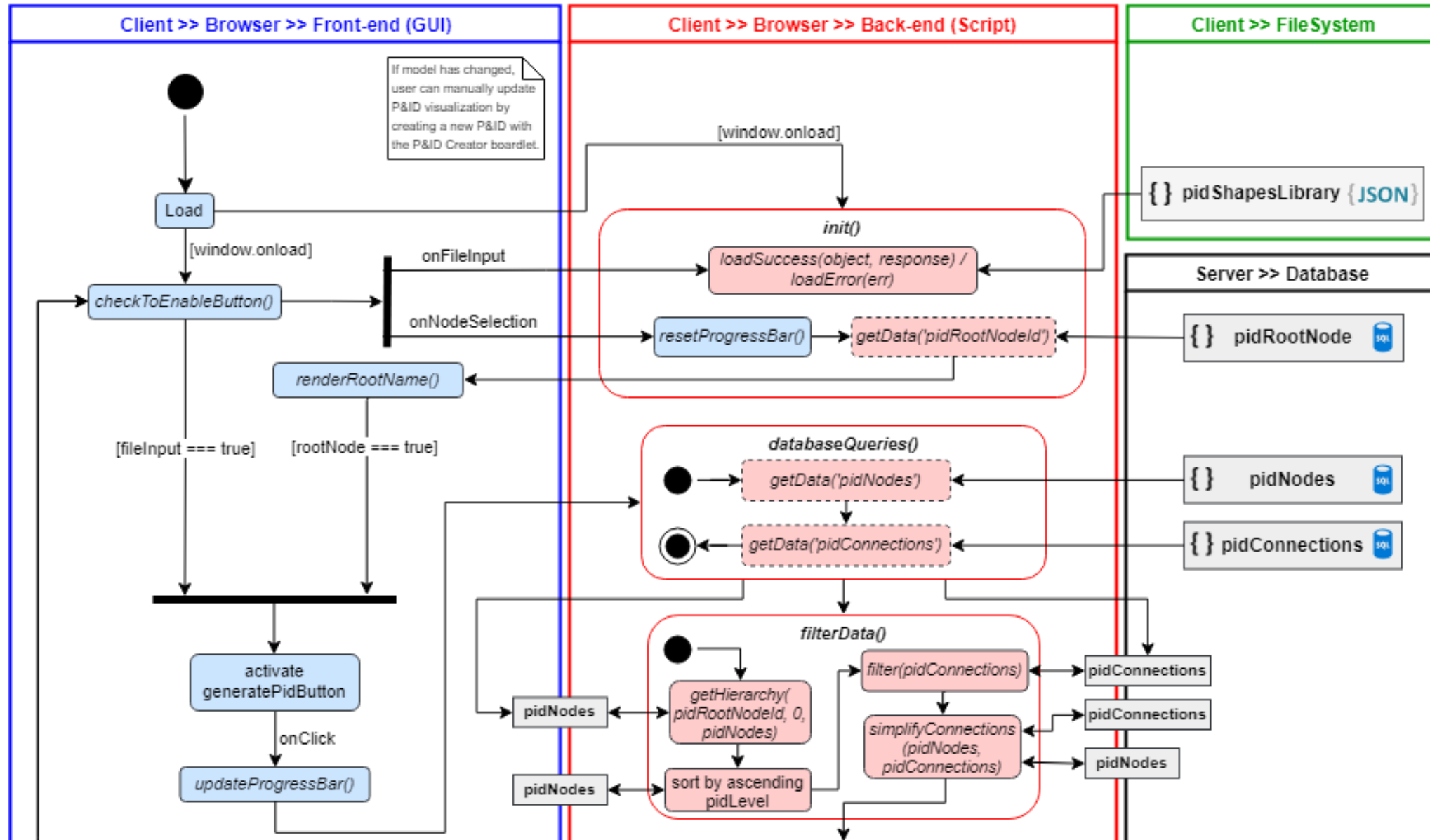
- AidaCruises
- AidaBlue

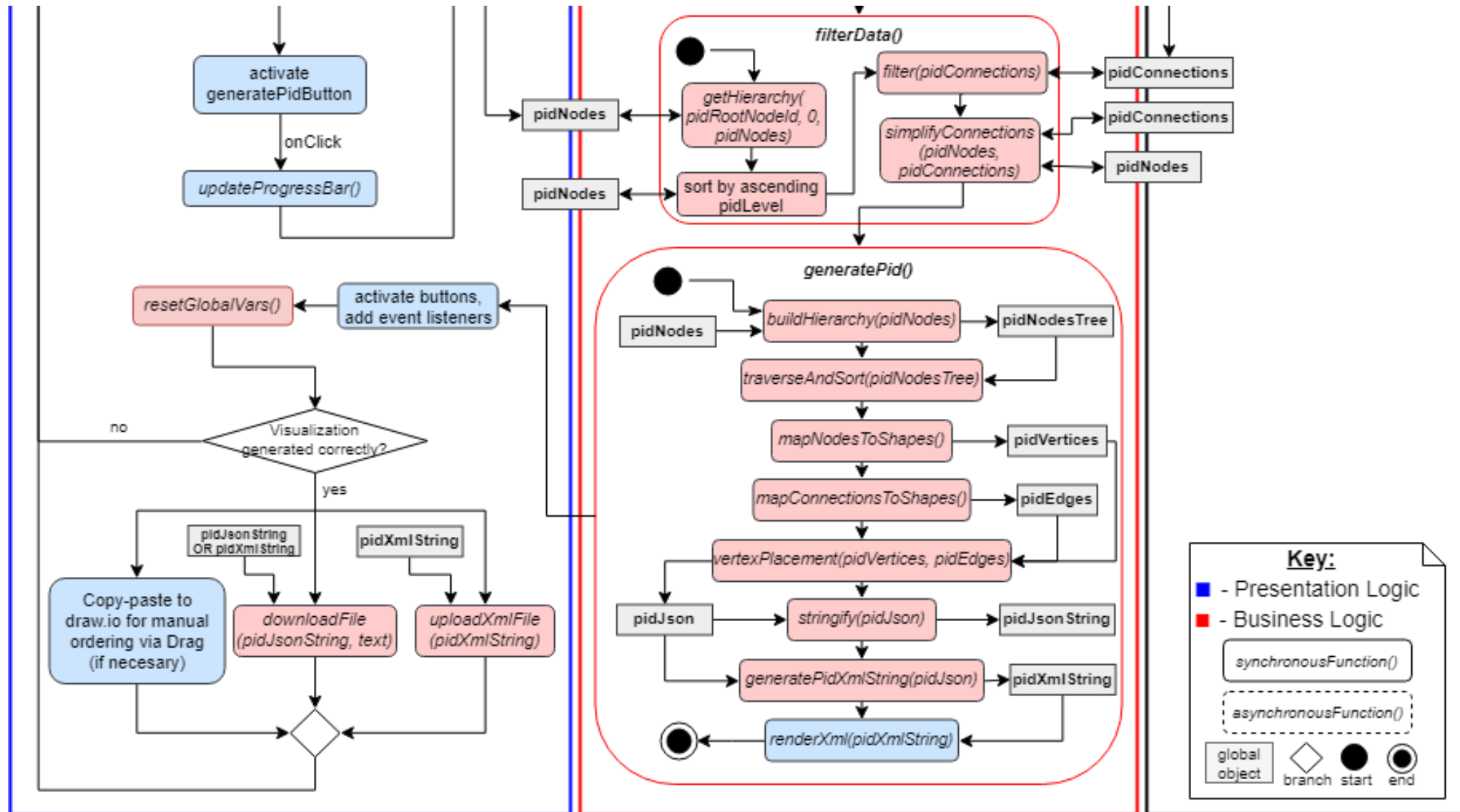
P&ID Viewer



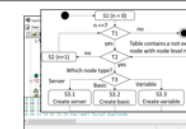
Automated Generation of Modular and Dynamic Industrial Process Plant Visualizations

Bachelor Thesis

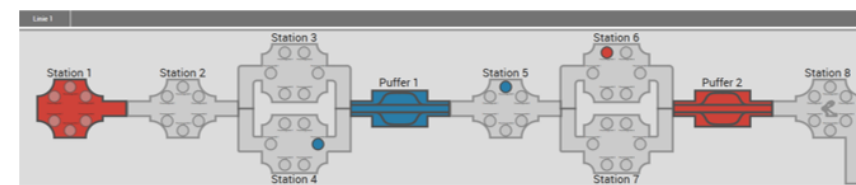




**Generation from SysML Model scripted
inside Generic Cloud Connector Config**



User Interface for Cloud Connector Control



Automatic Generation of Plant Visualizations

→ Extended SysML model with visualization symbols

Model Import in MES FrontEnd (Dashboard)
→ Systems Modeling Language (SysML) or
Automation Markup Language (AutomationML)



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