東京大学大学院工学系研究科
SCHOOL OF ENGINEERING
THE UNIVERSITY OF TOKYO

DEPARTMENT OF
SYSTEMS INNOVATION

IDETC2016-60101

System-Level Design Tools Utilizing OPM and Modelica

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Presentation Overview

1. Problems to address
2. Proposed solution
3. Proposed solution – Detailed description
4. Discussion

An example product lifecycle on a V

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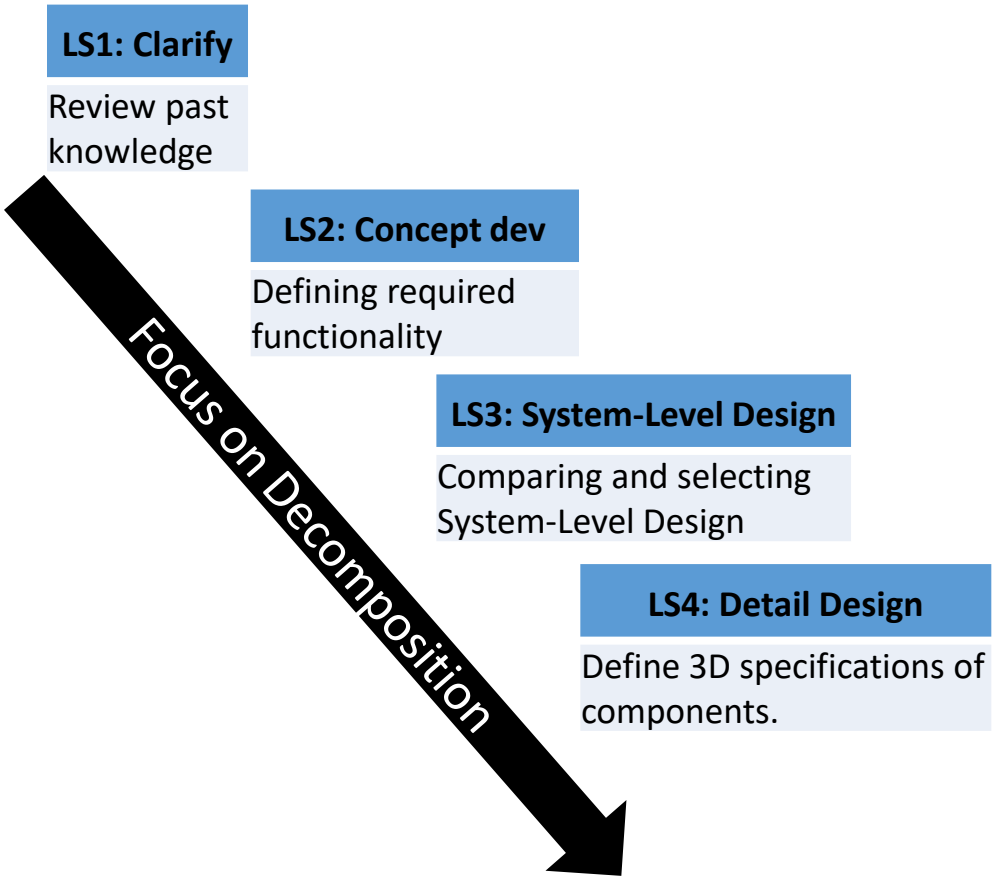

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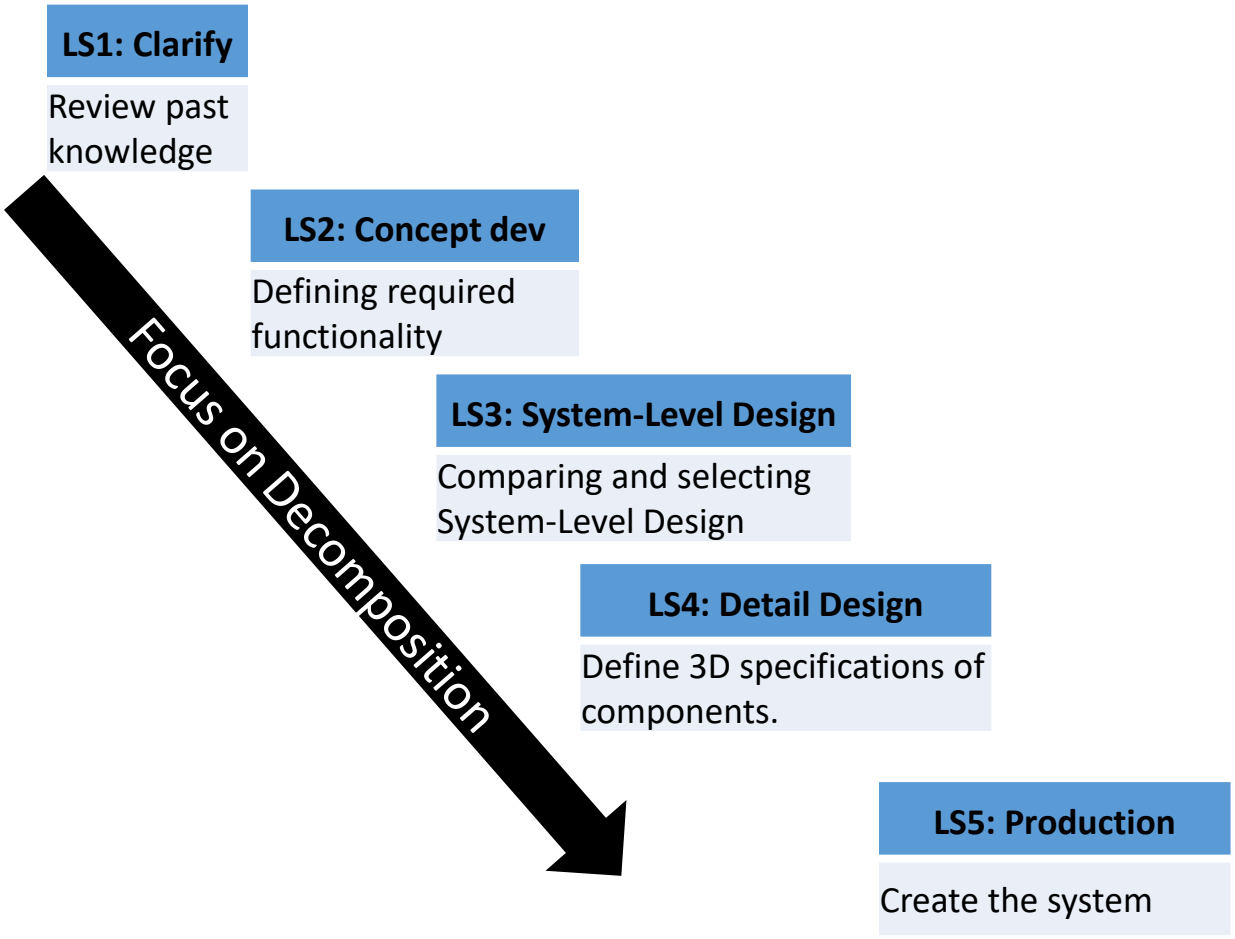

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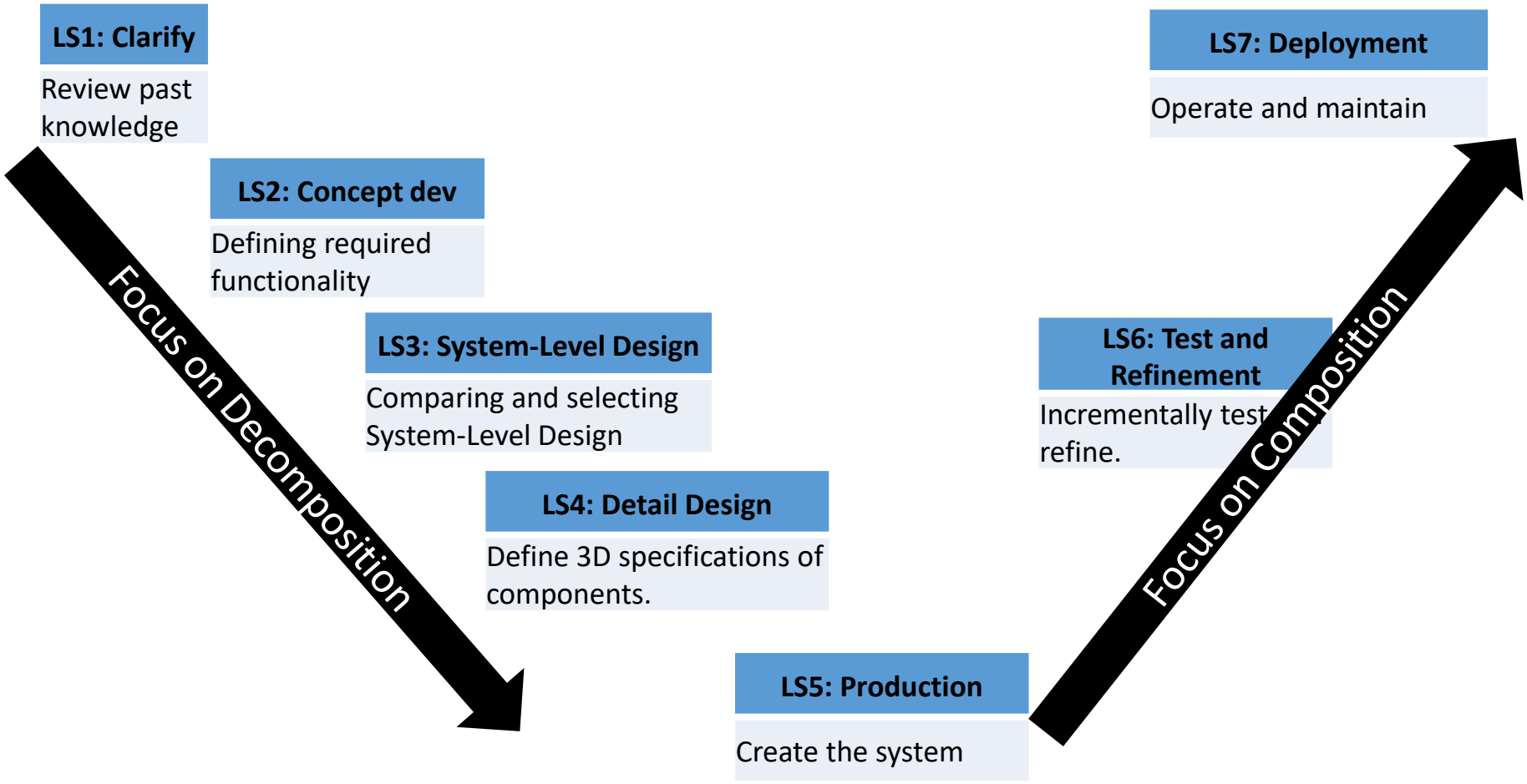

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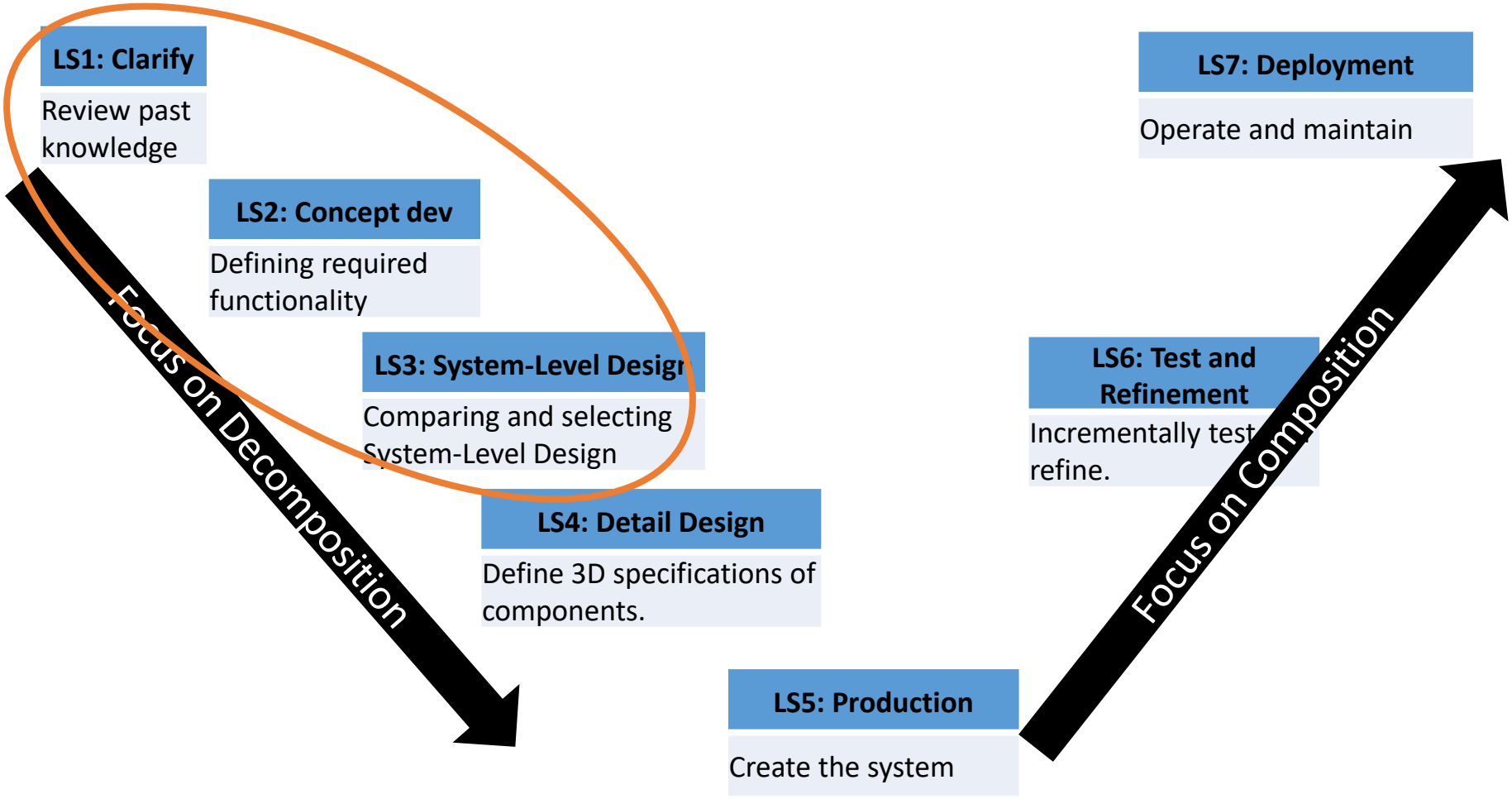

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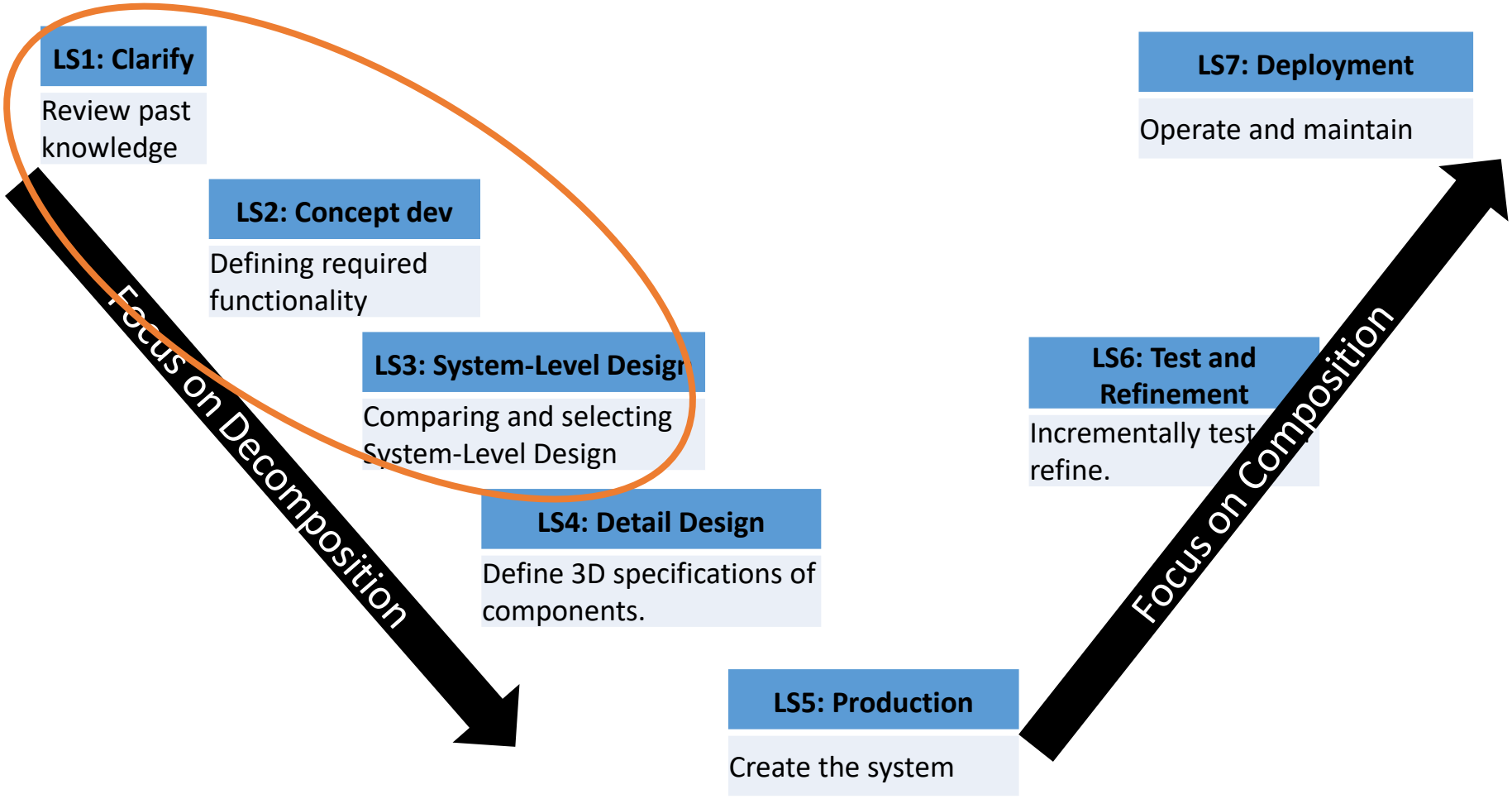

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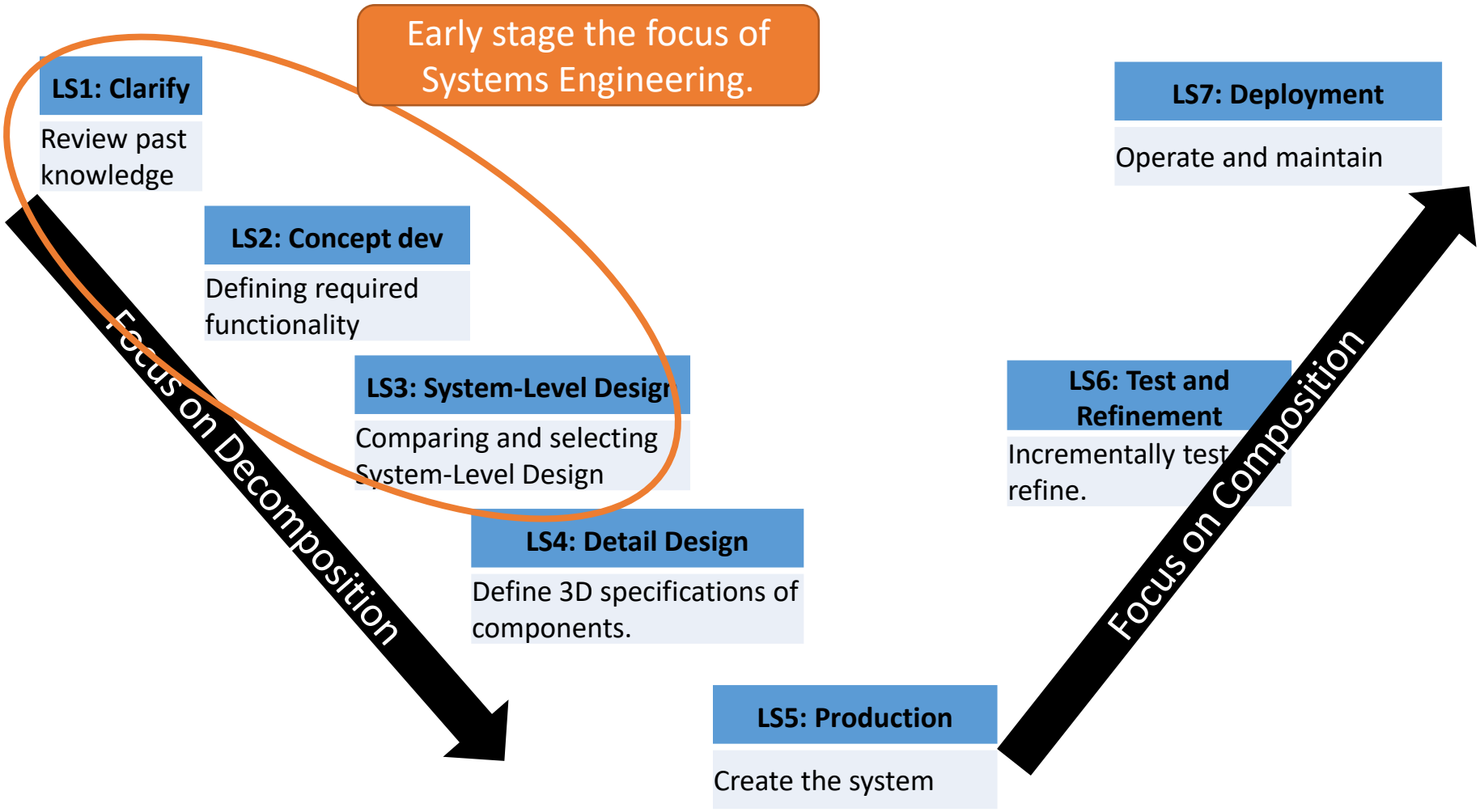

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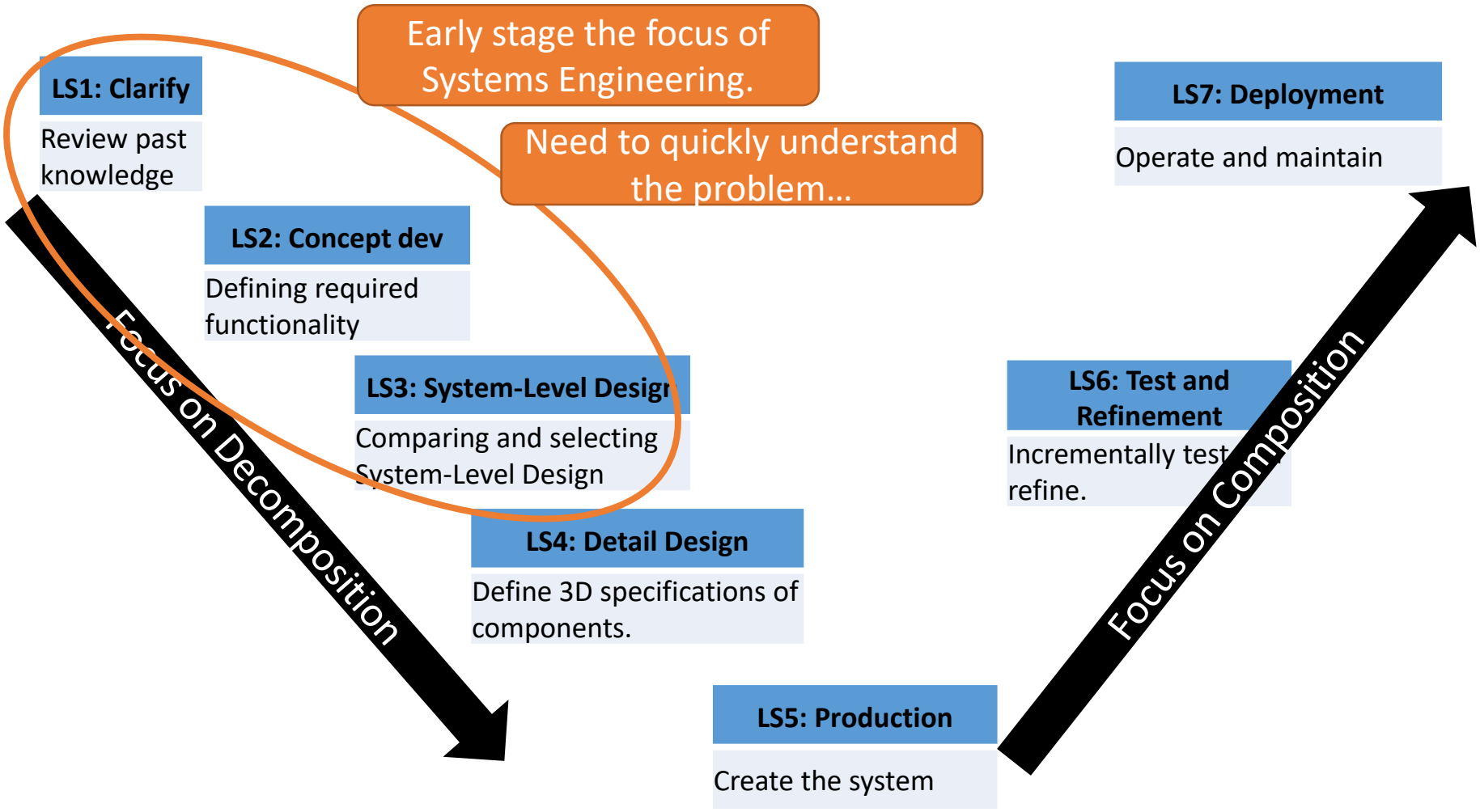

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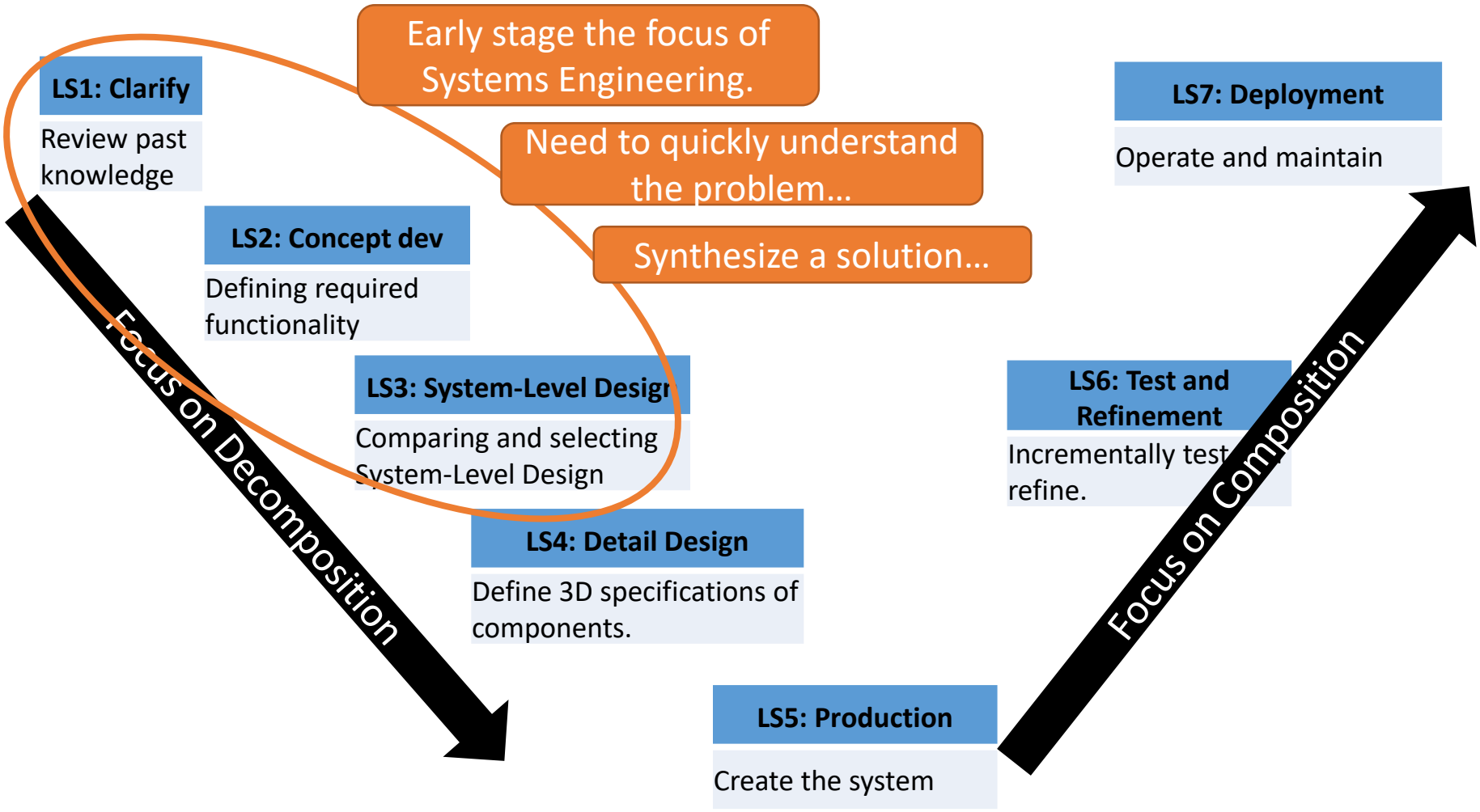

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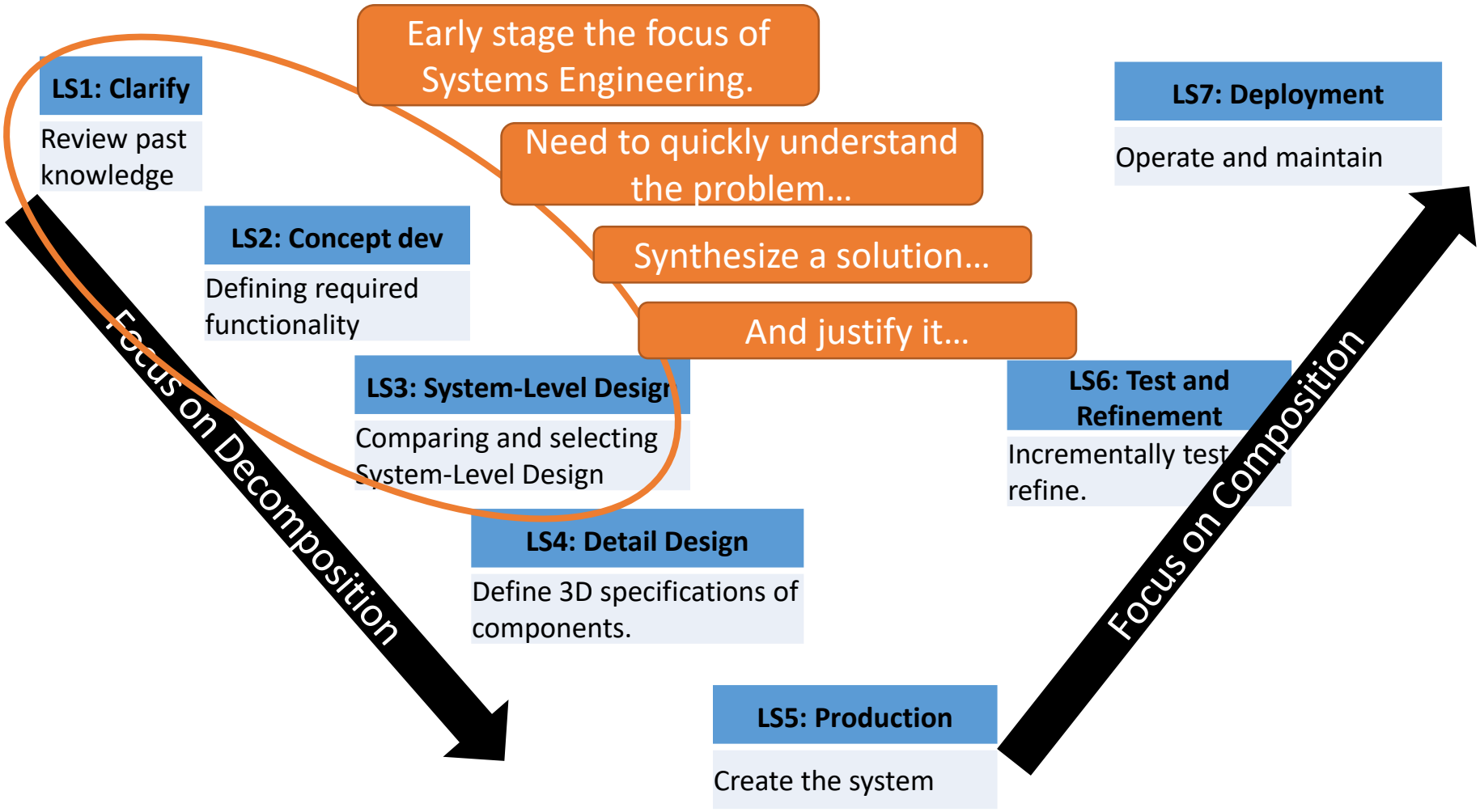

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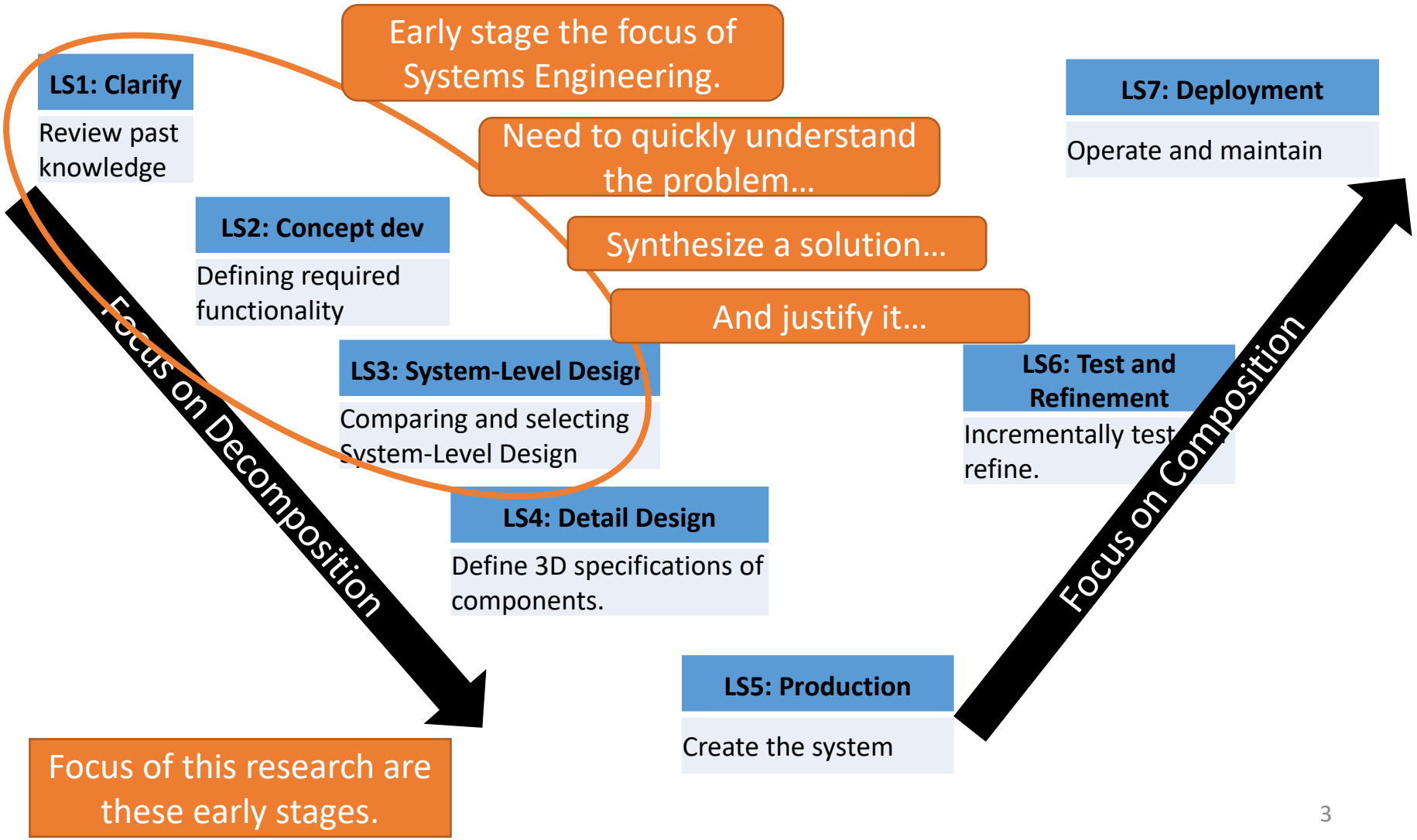

Some specific problems from a student project

Lifecycle Stage:	LS1: Clarify	LS2: Concept dev	LS3: System-Level Design
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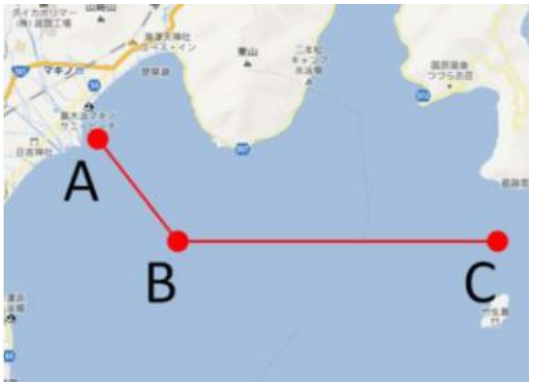

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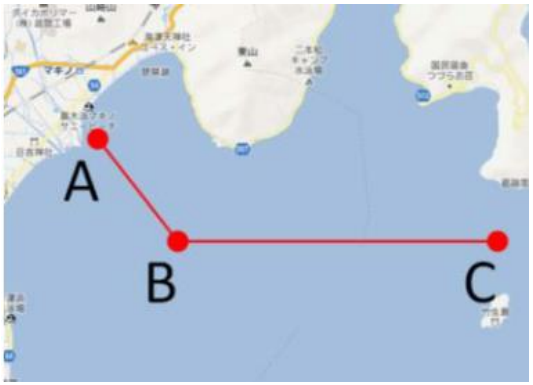

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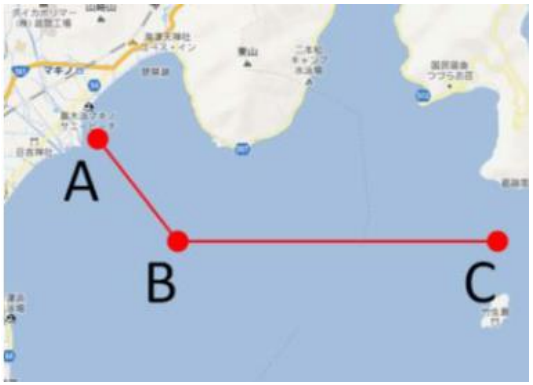

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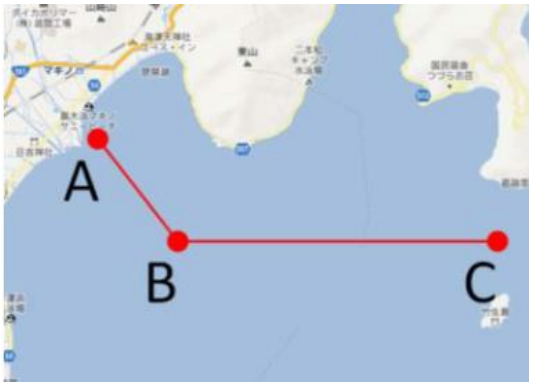

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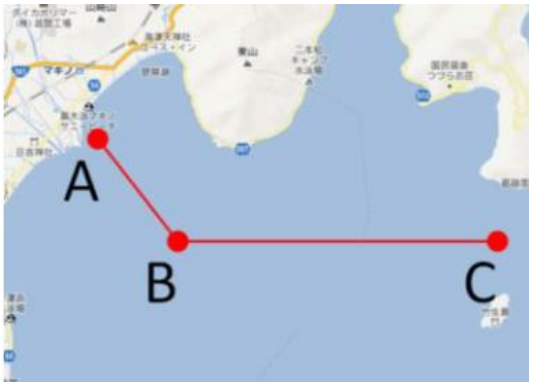

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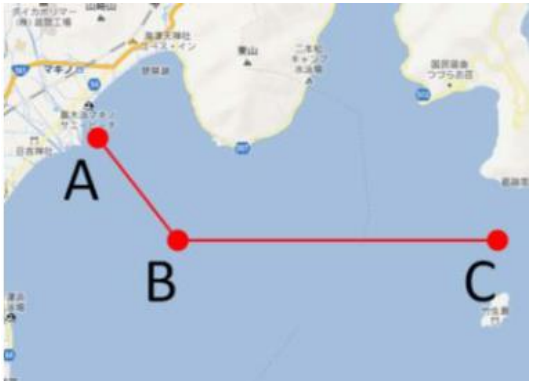

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- **Provide a consistent way to assess designs**
- **Manage numerical model creation**

Problems / Solutions at Early Life Cycle Stages

Lifecycle Stage:	LS1: Clarify	LS2: Concept dev	LS3: System-Level Design
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Goal:	To propose tools and methodologies to help in a Model Based way: • Synthesize, assess and select System-Level Designs		

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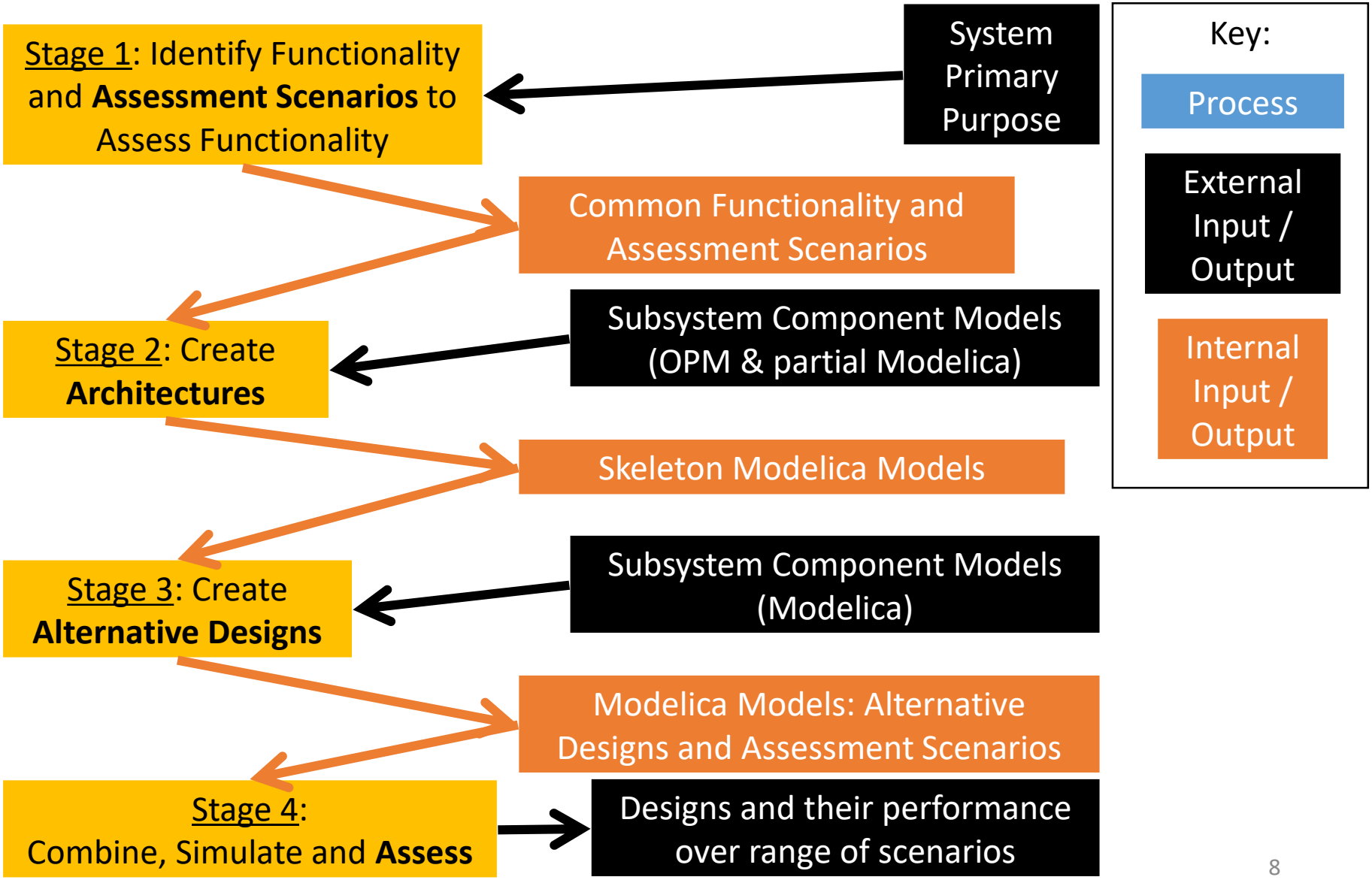
High Level Flow Diagram



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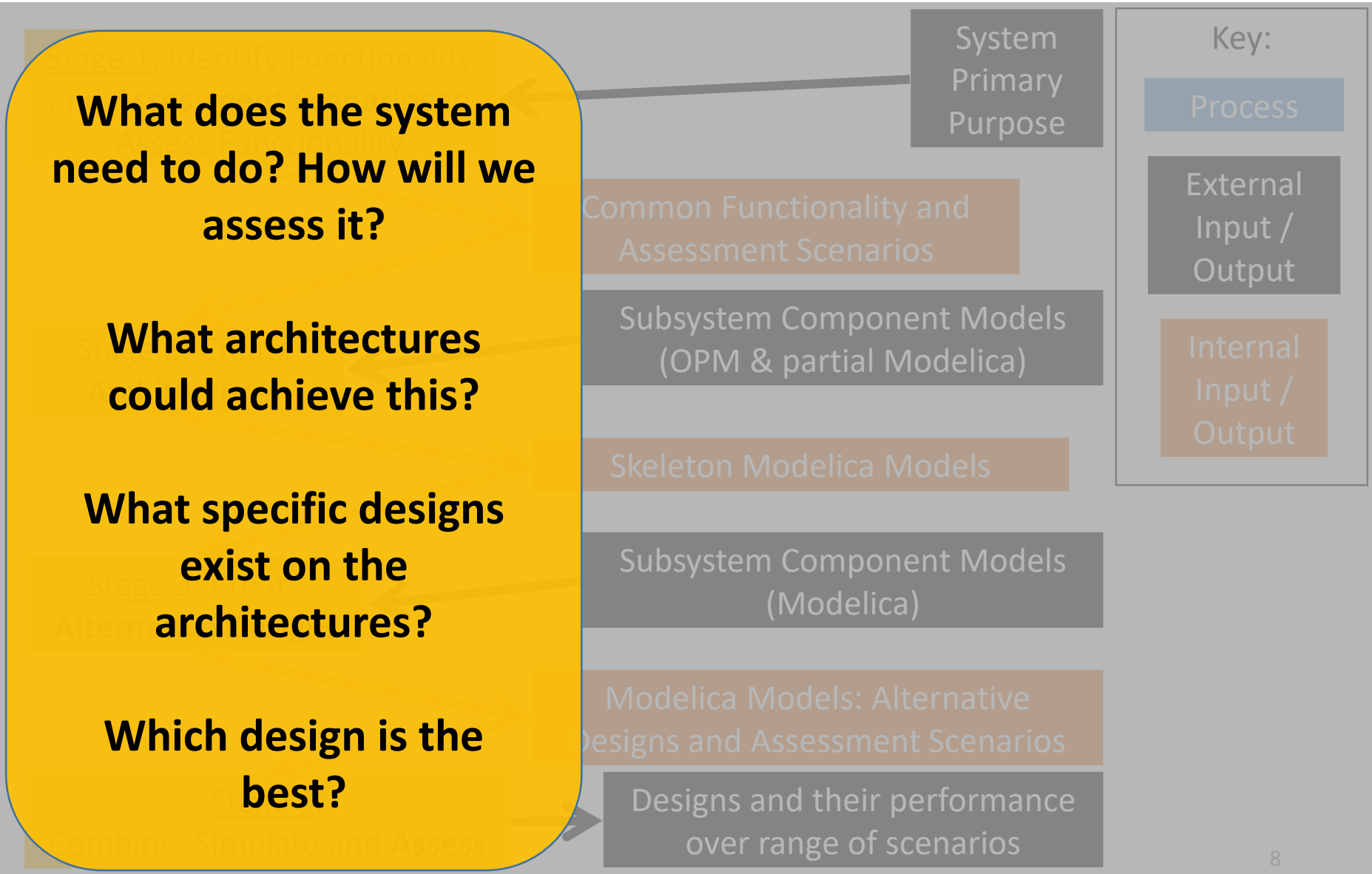

Problems at Early Life Cycle Stages

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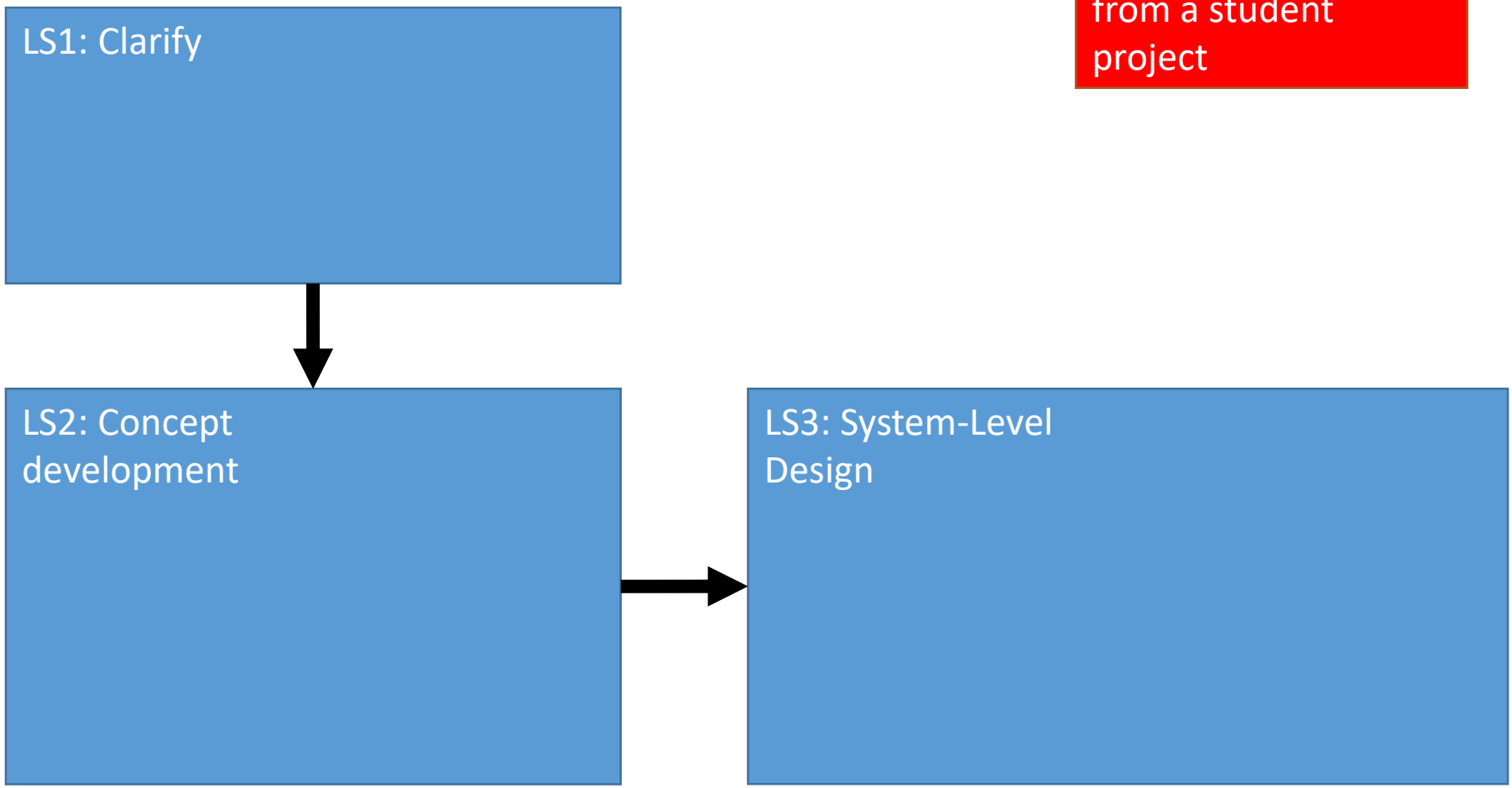

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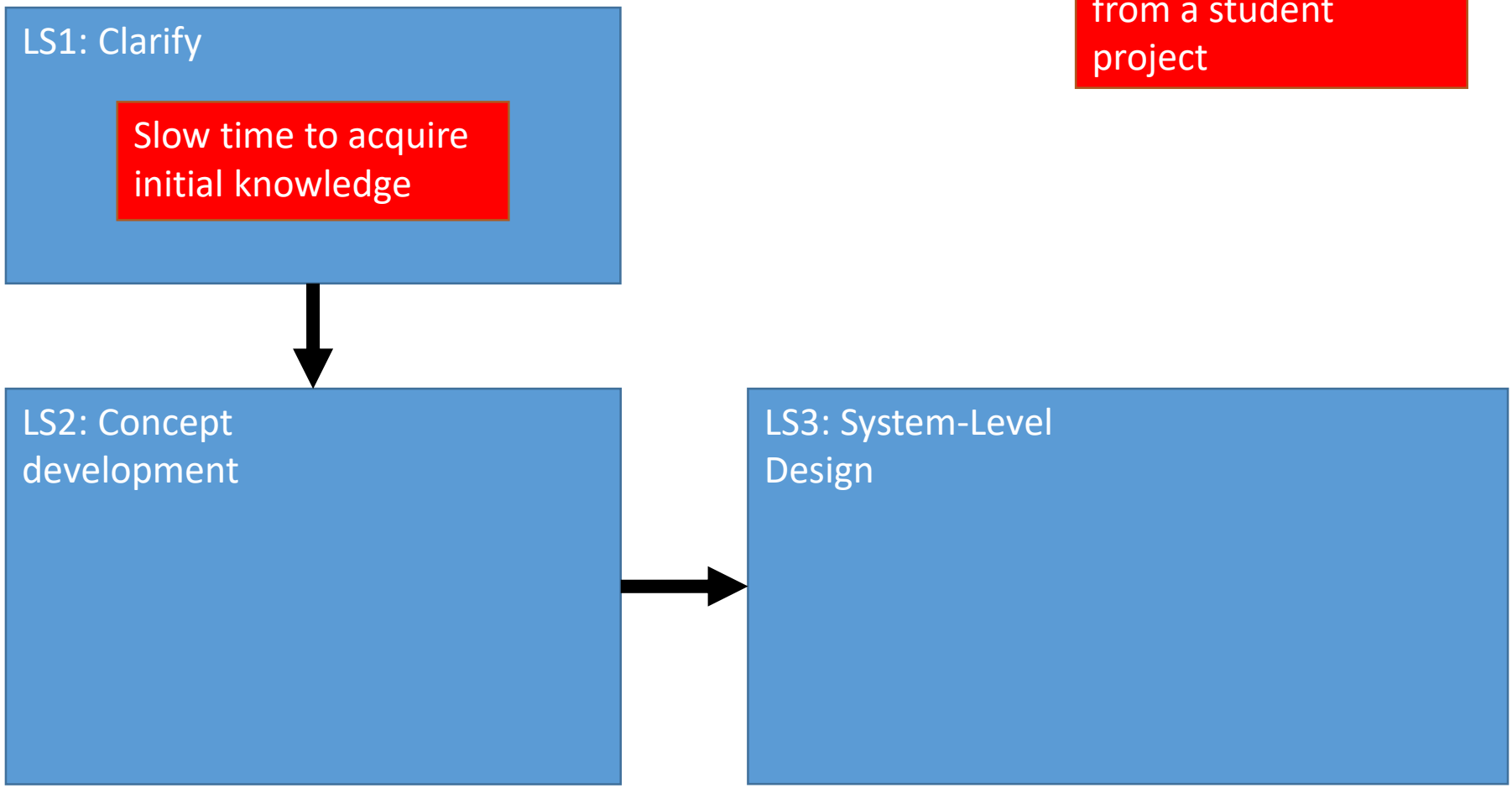

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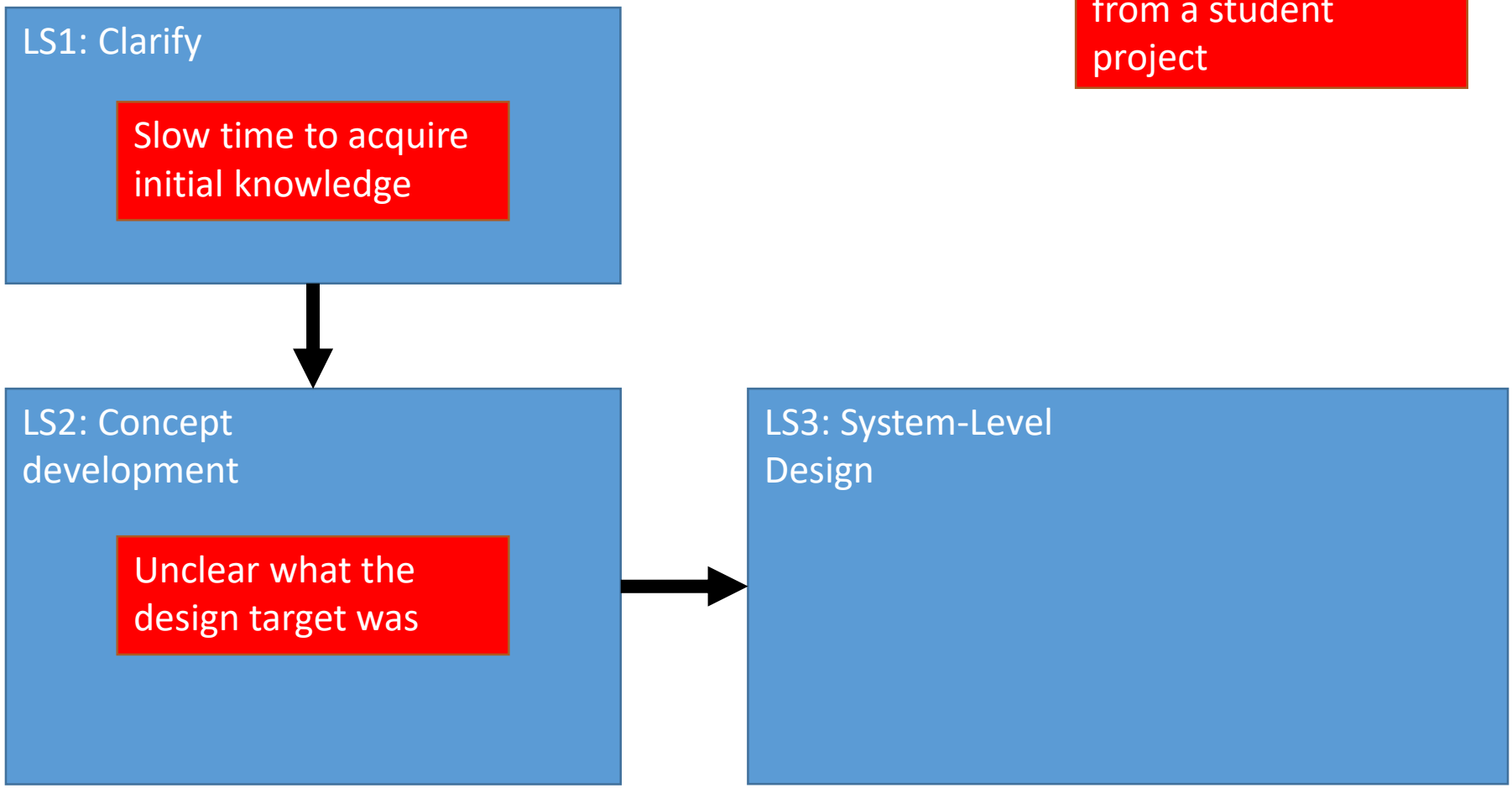

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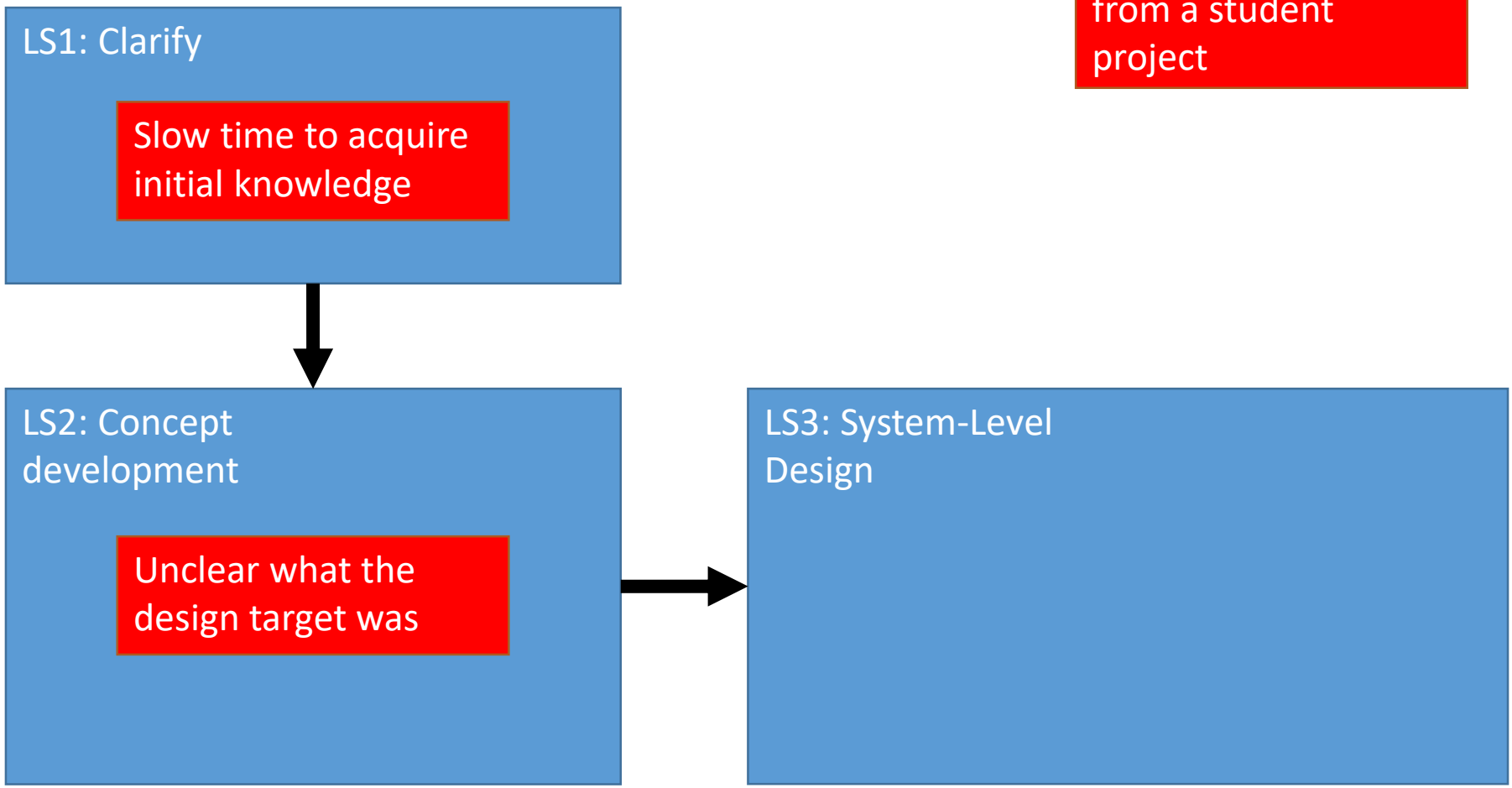

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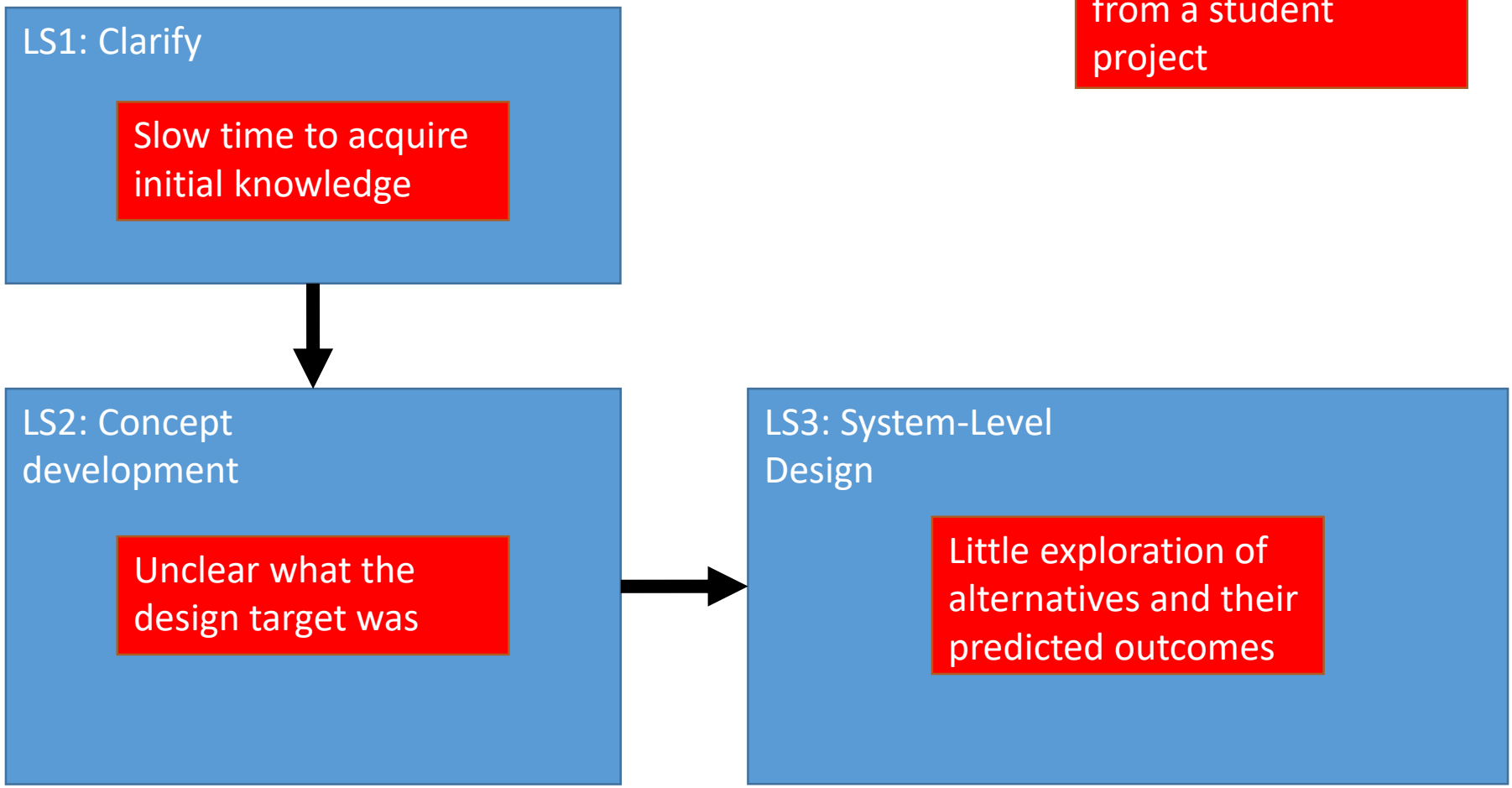

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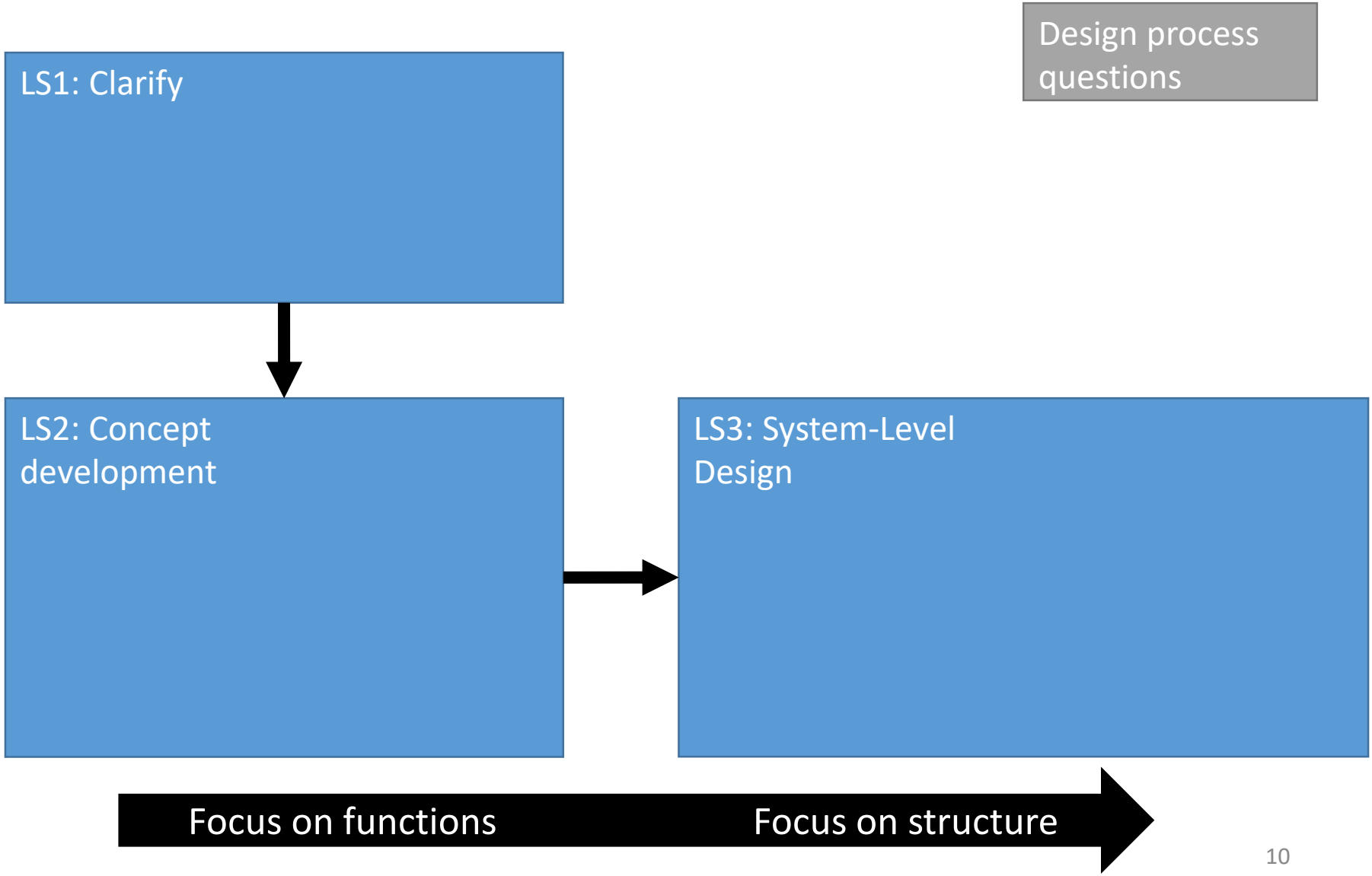

Questions to Answer at Early Life Cycle Stages

Design process questions

LS1: Clarify

1. Project **value**?
2. **Measures of performance?**
3. What **resources** are available?

LS2: Concept development

LS3: System-Level Design

Focus on functions → Focus on structure

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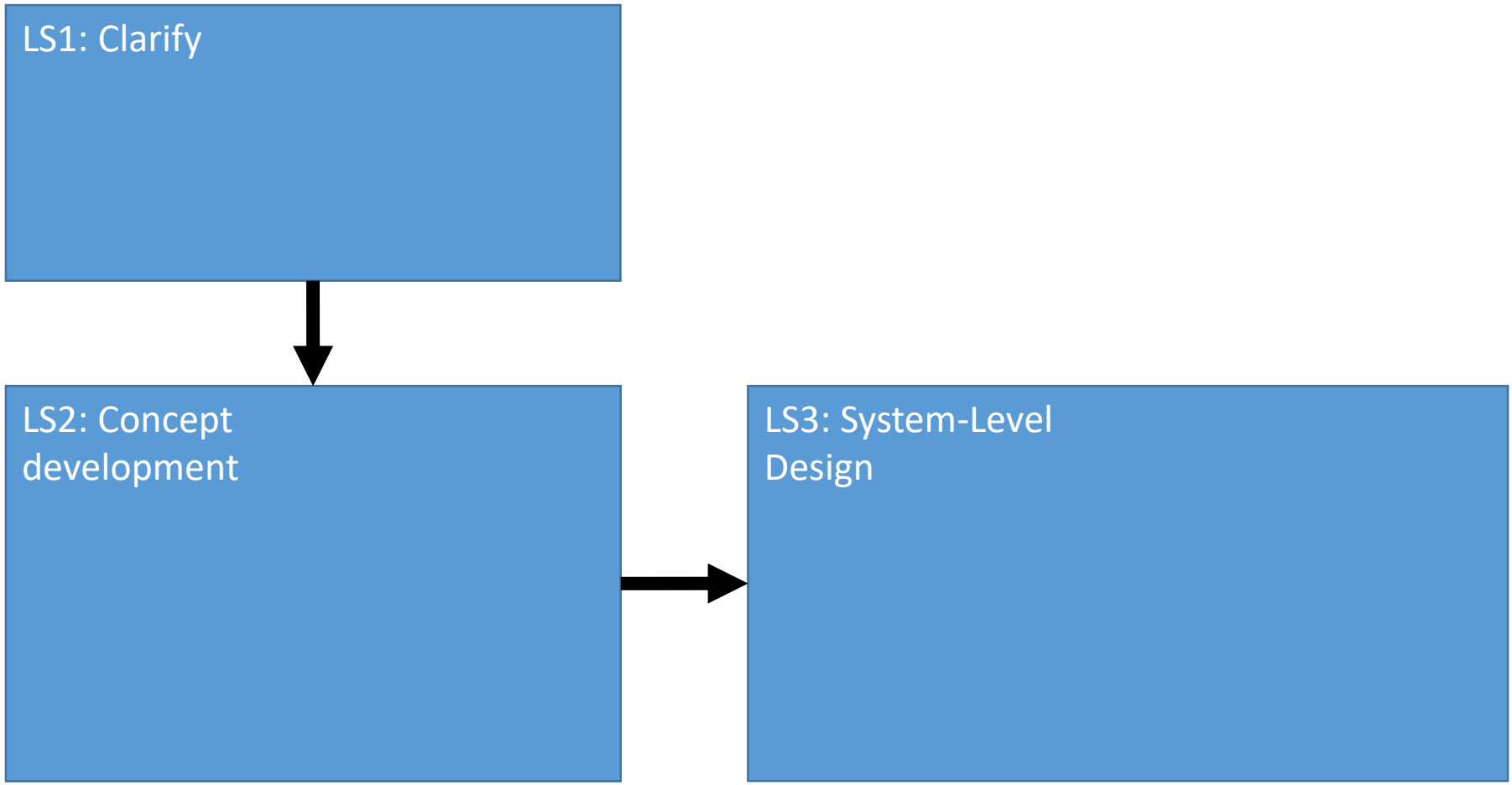
LS3: System-Level Design

1. Valid **alternative designs?**
2. What is the **designs predicted performance** how do they **compare**?
3. Are there any **better designs**?

Focus on functions → Focus on structure

Proposed High Level Activities



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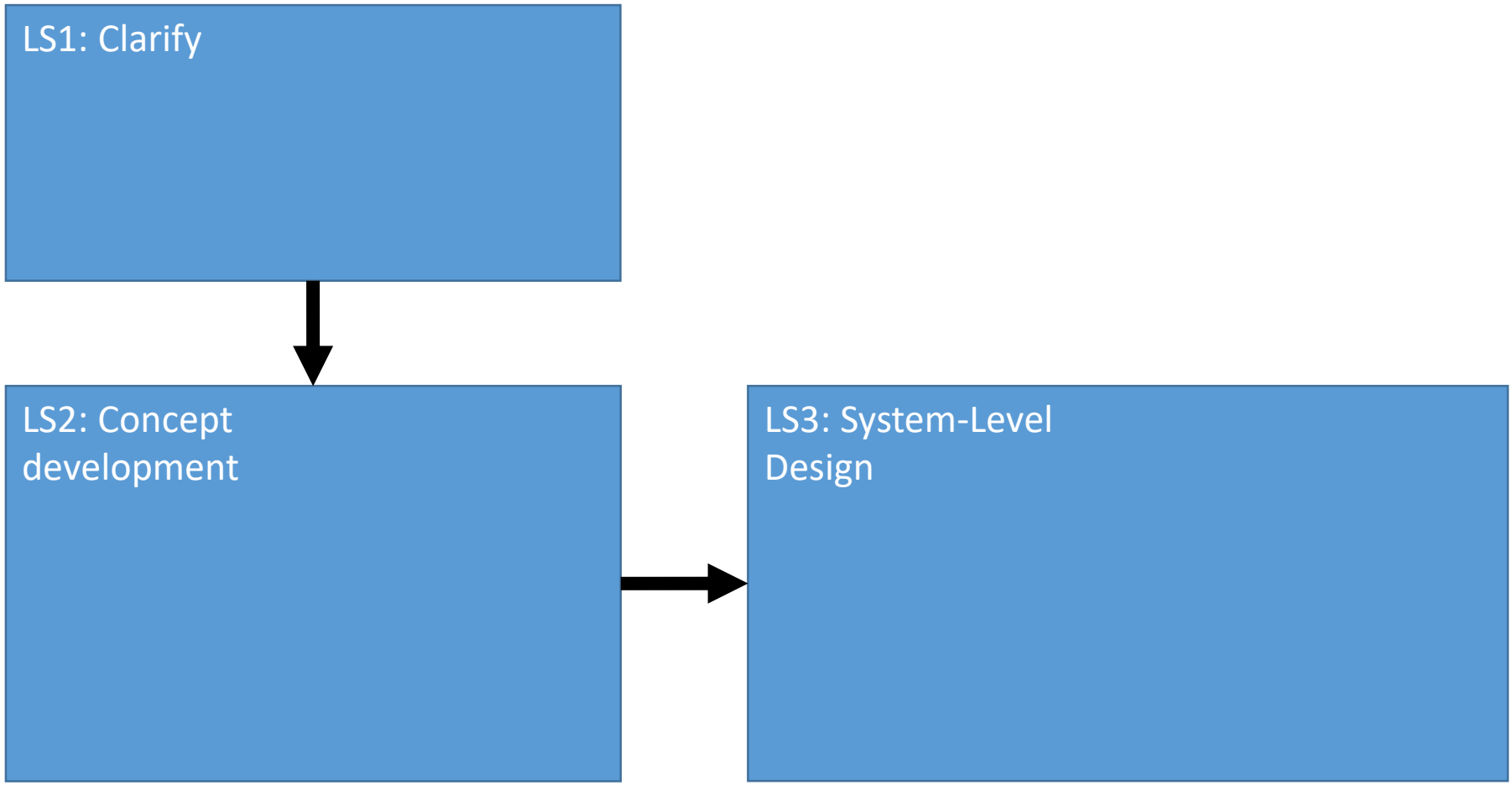

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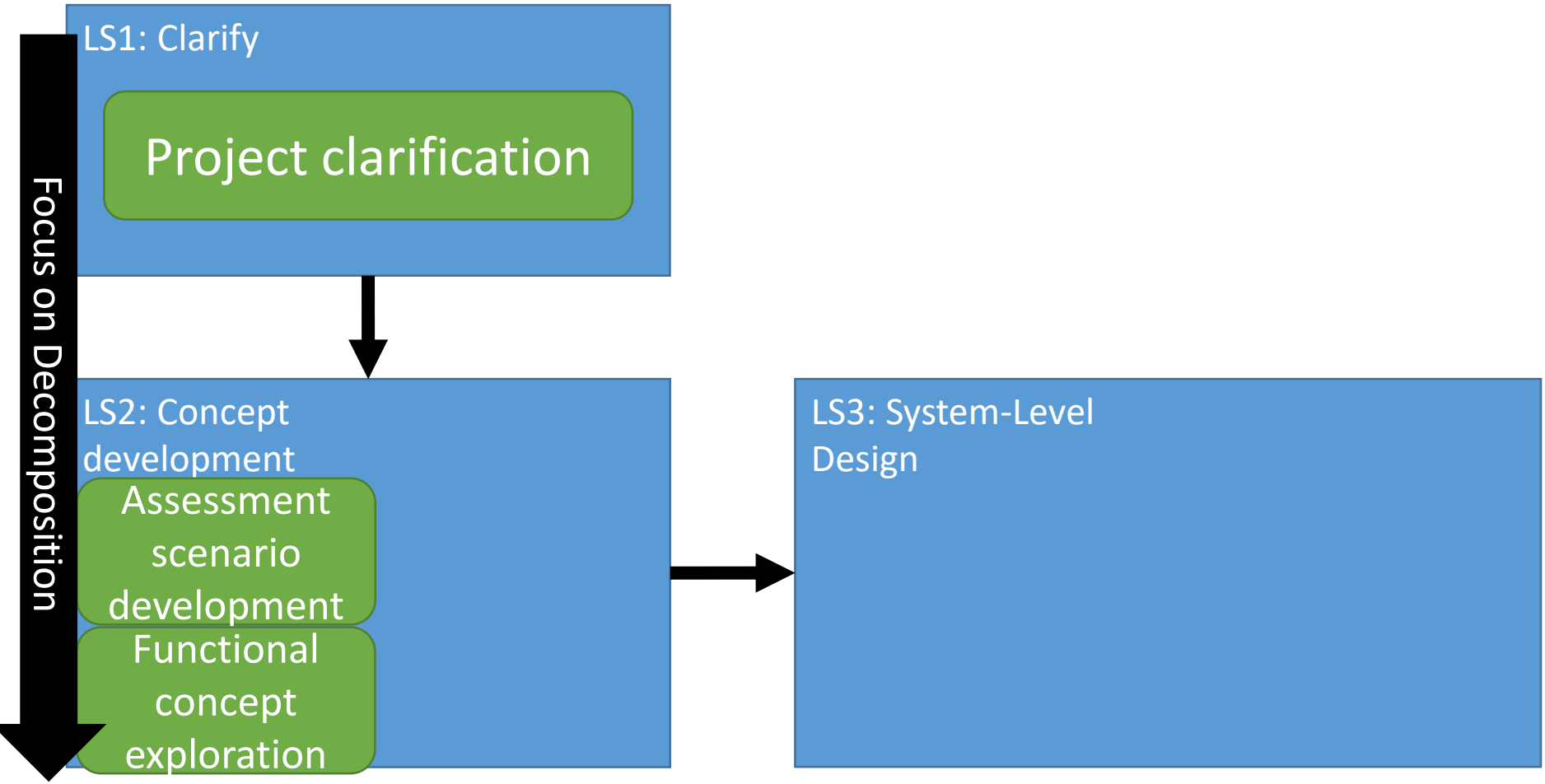

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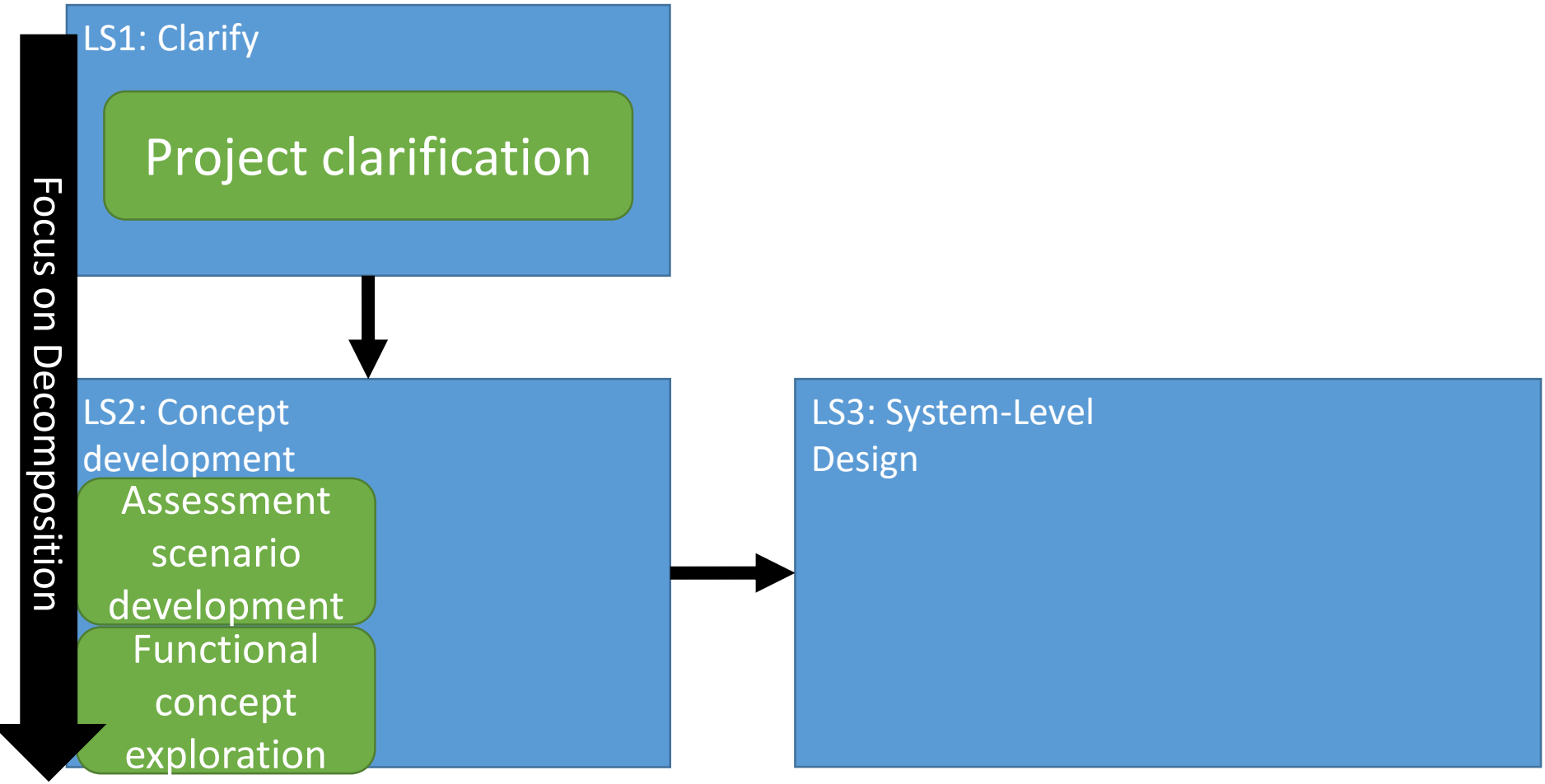

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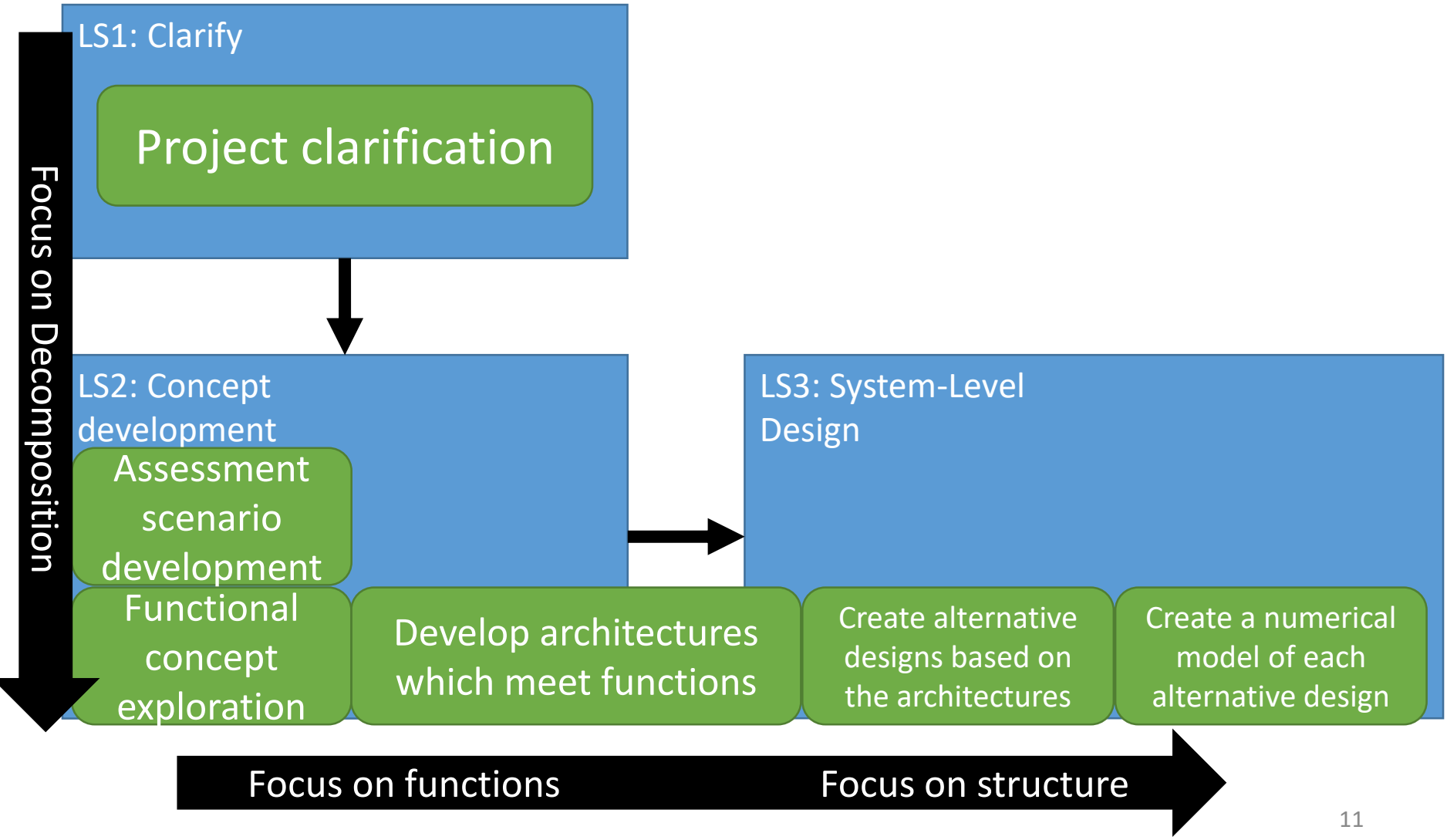

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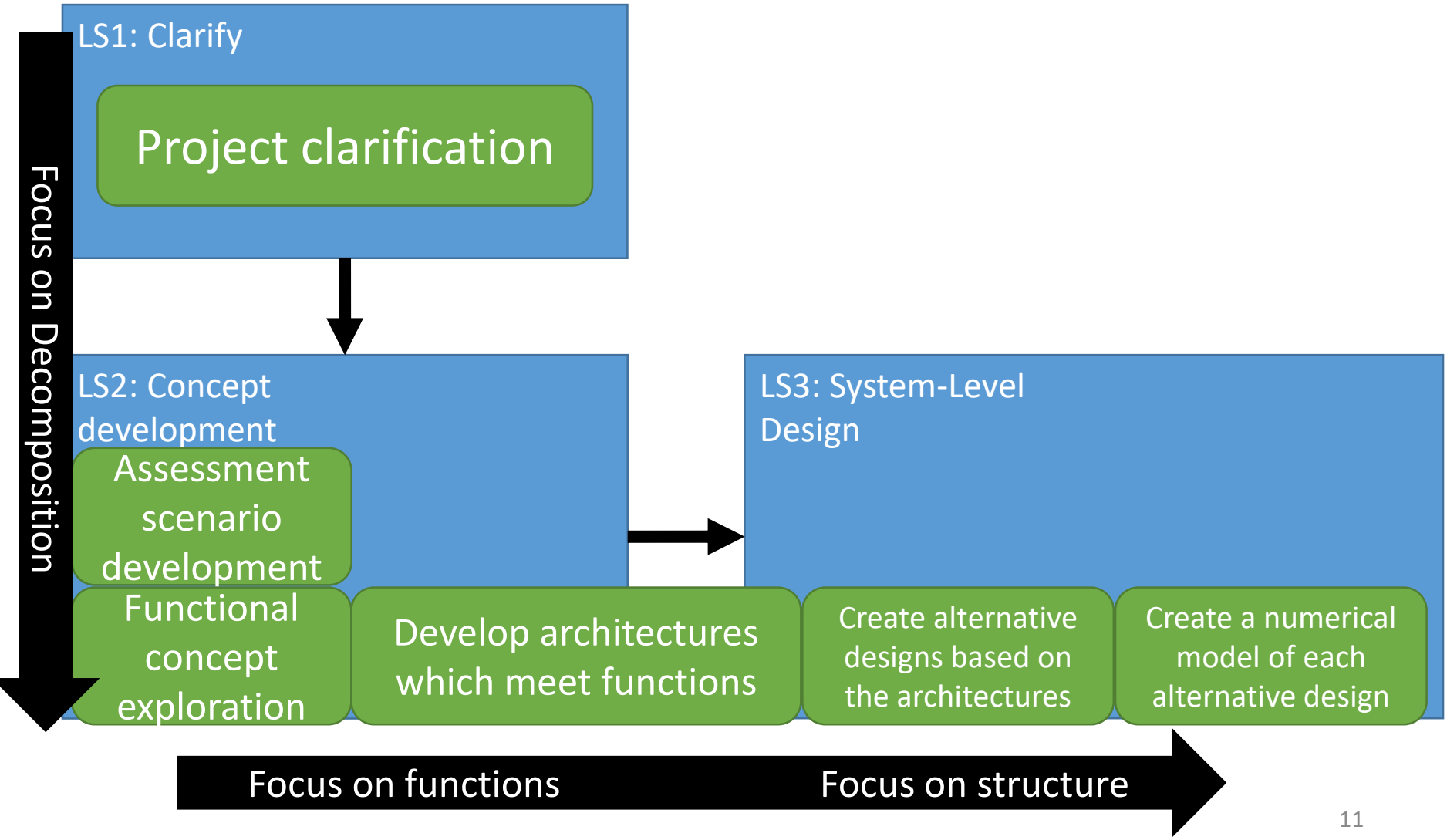

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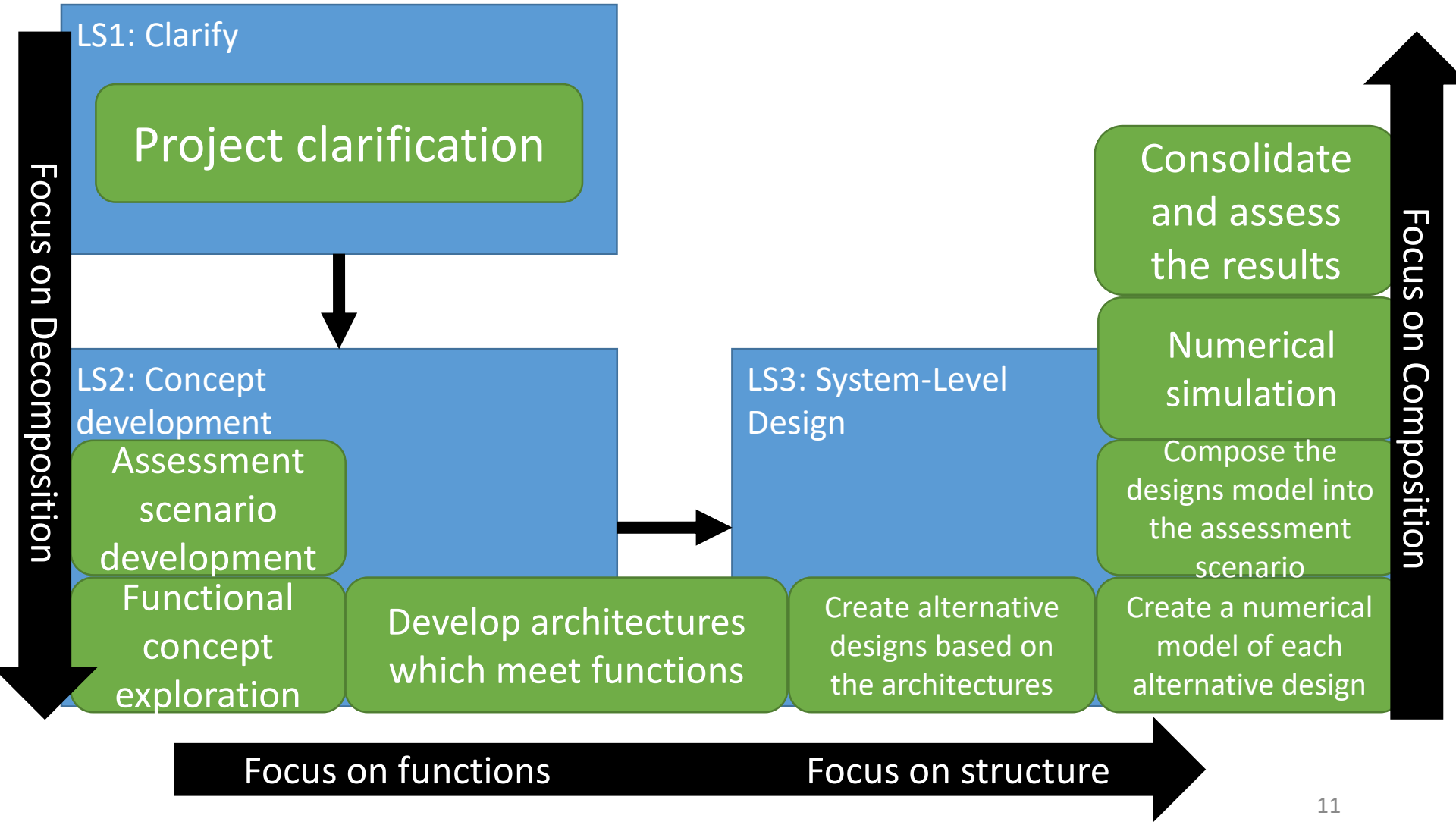

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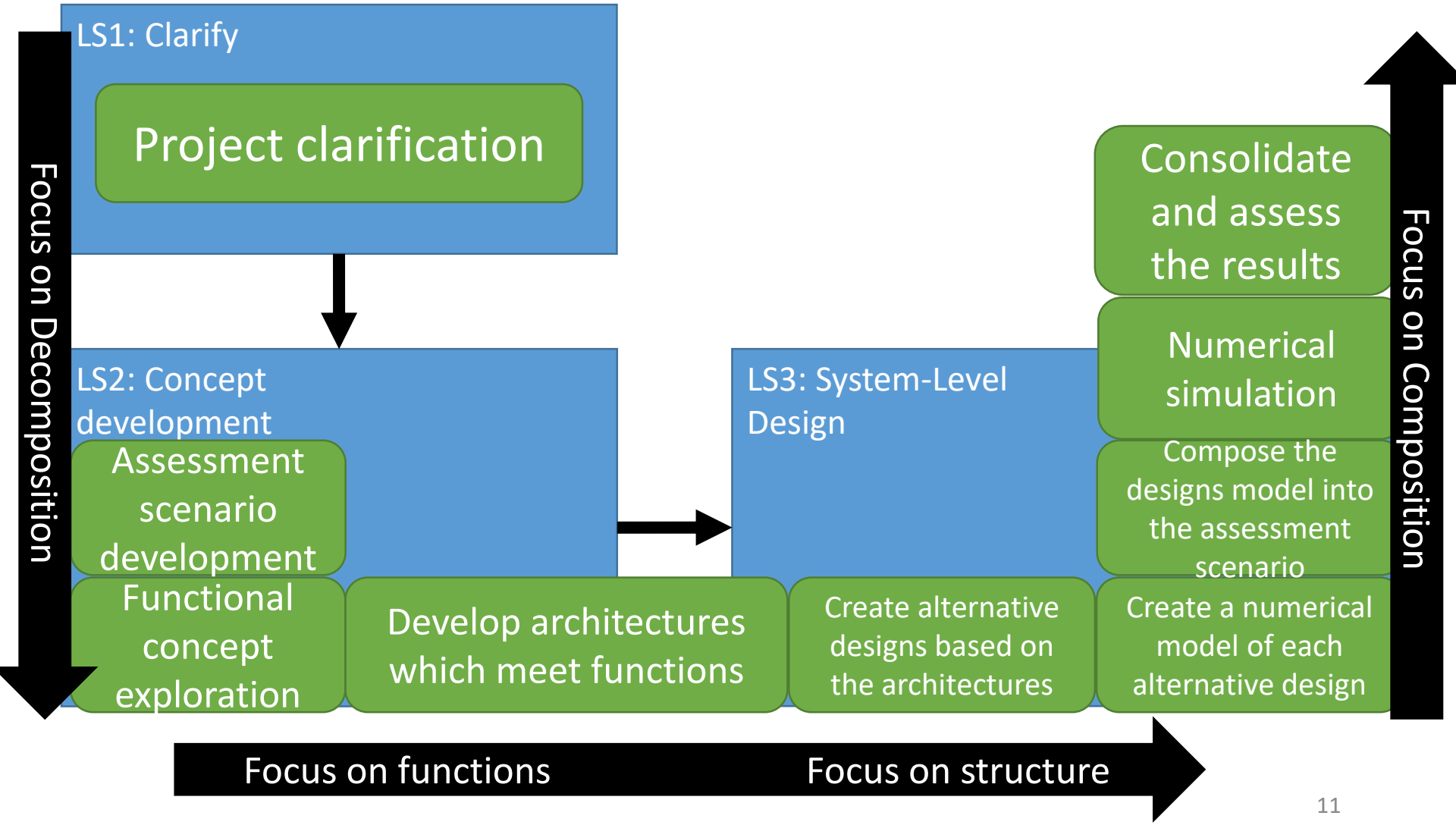

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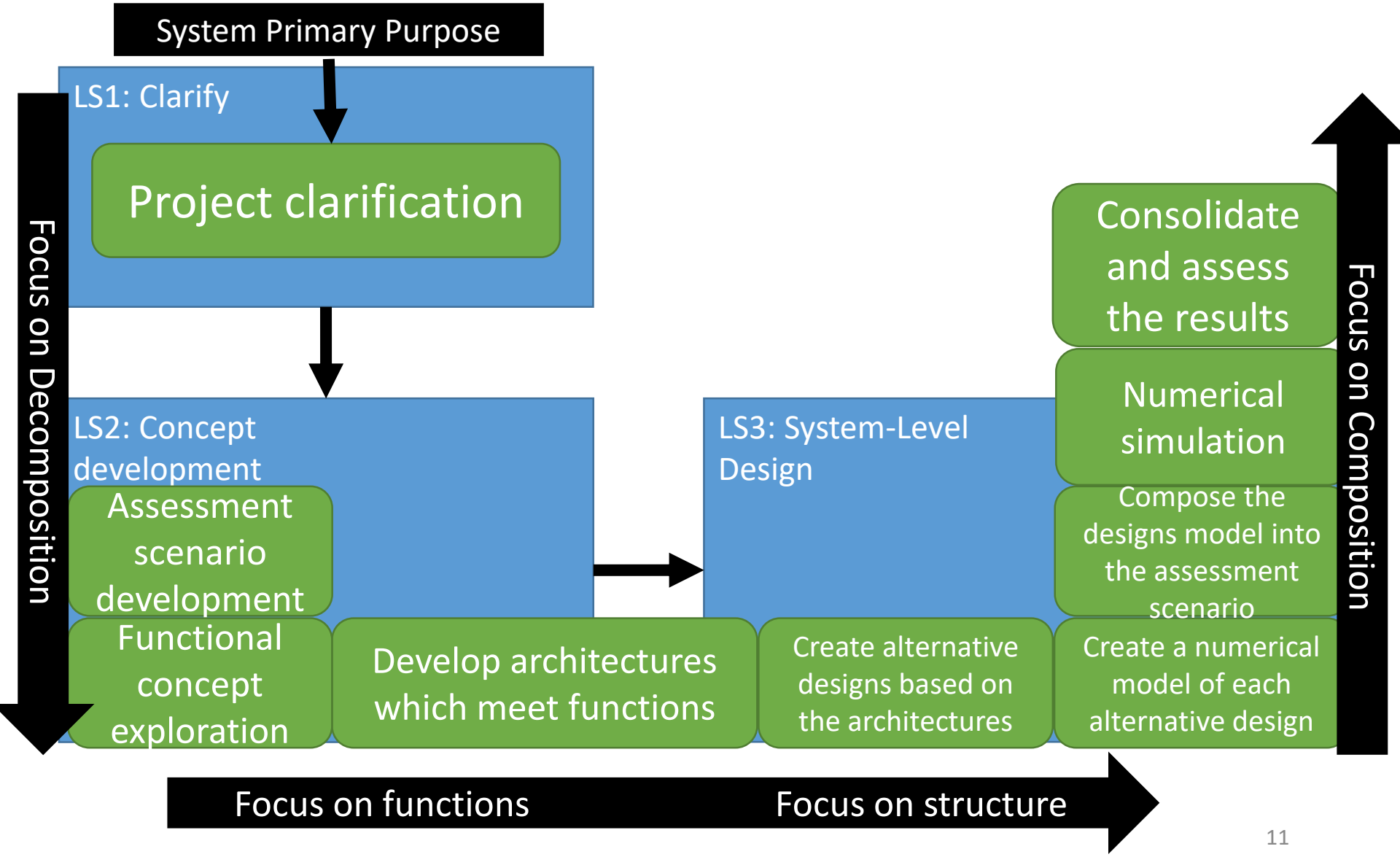

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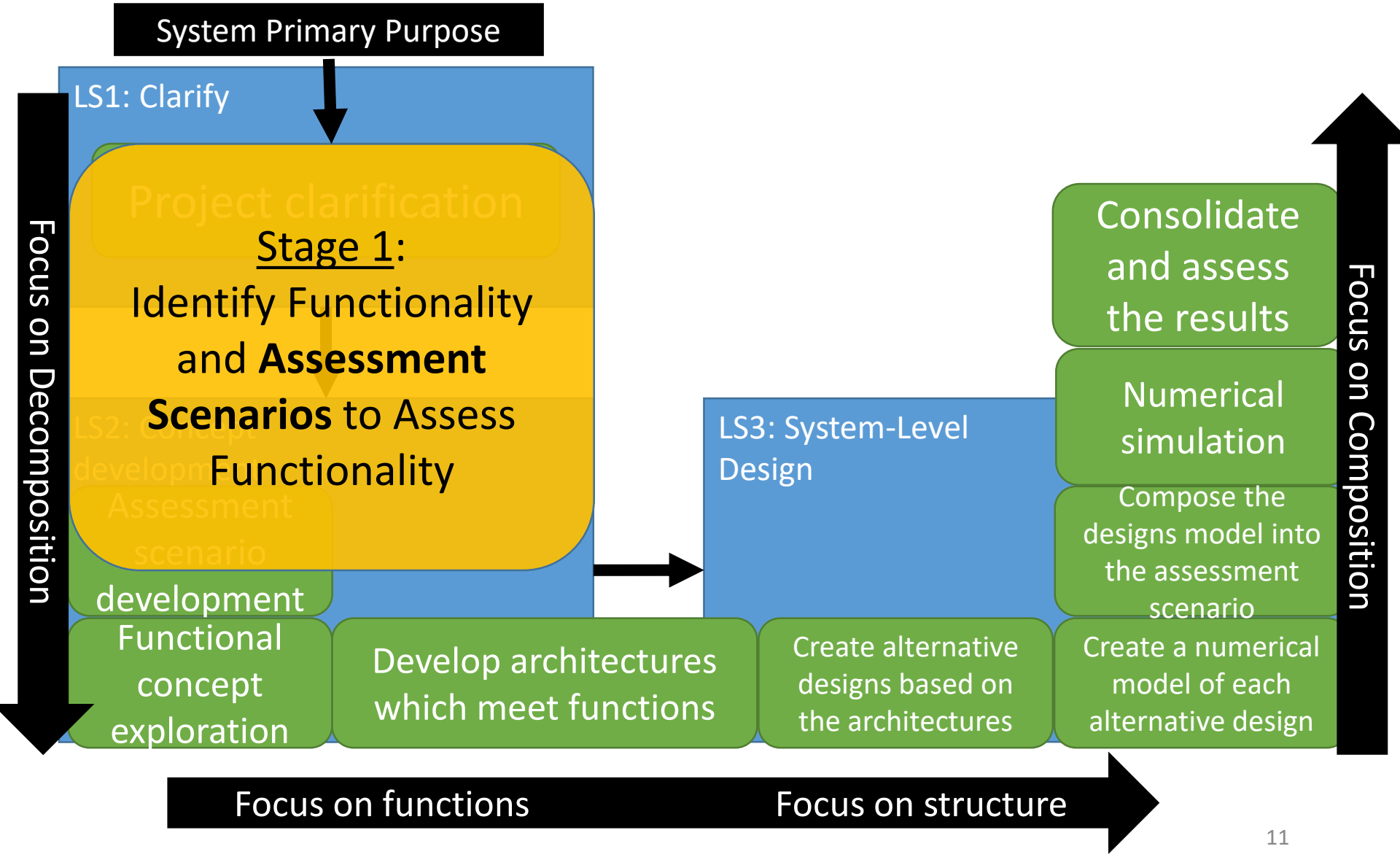

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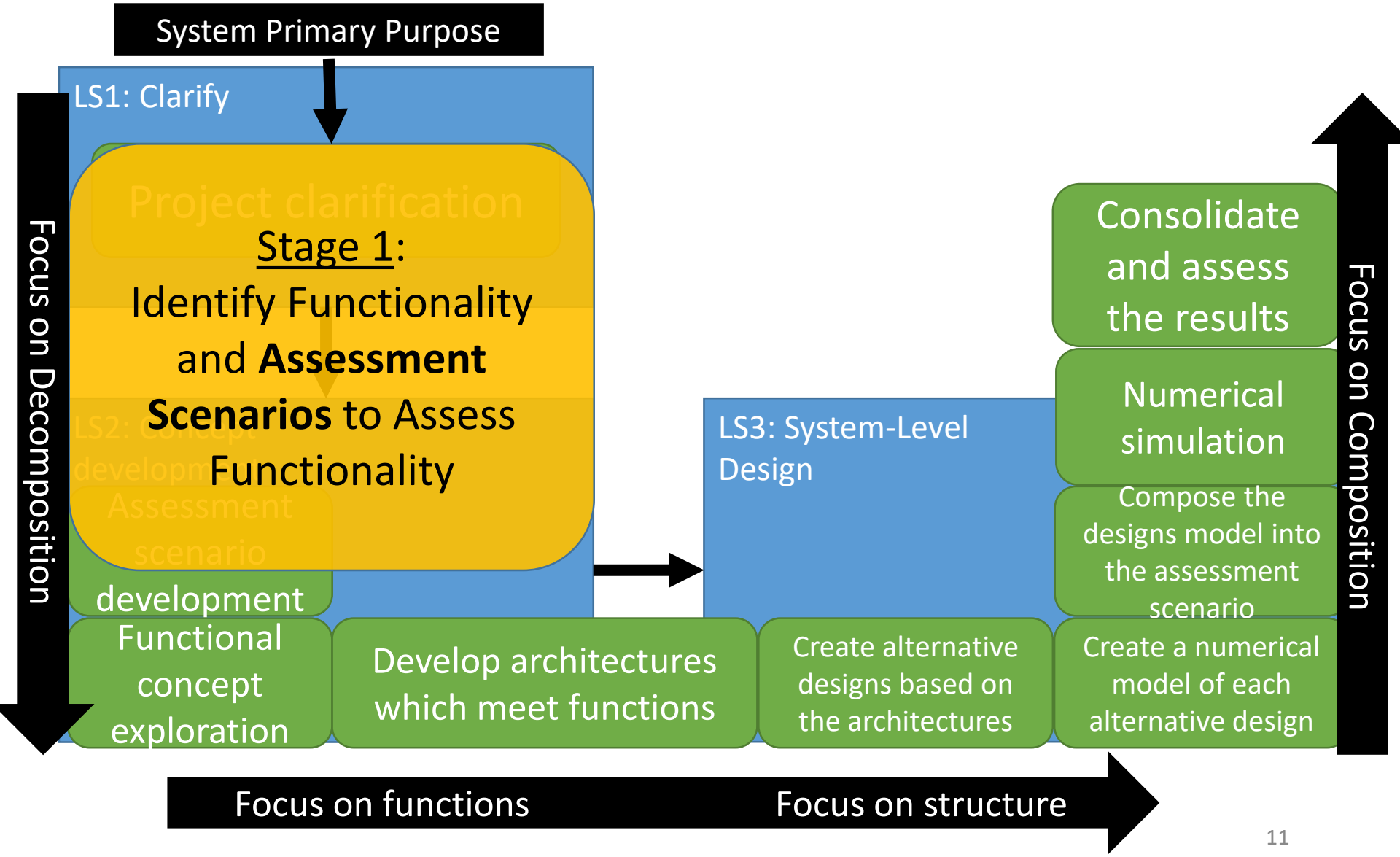

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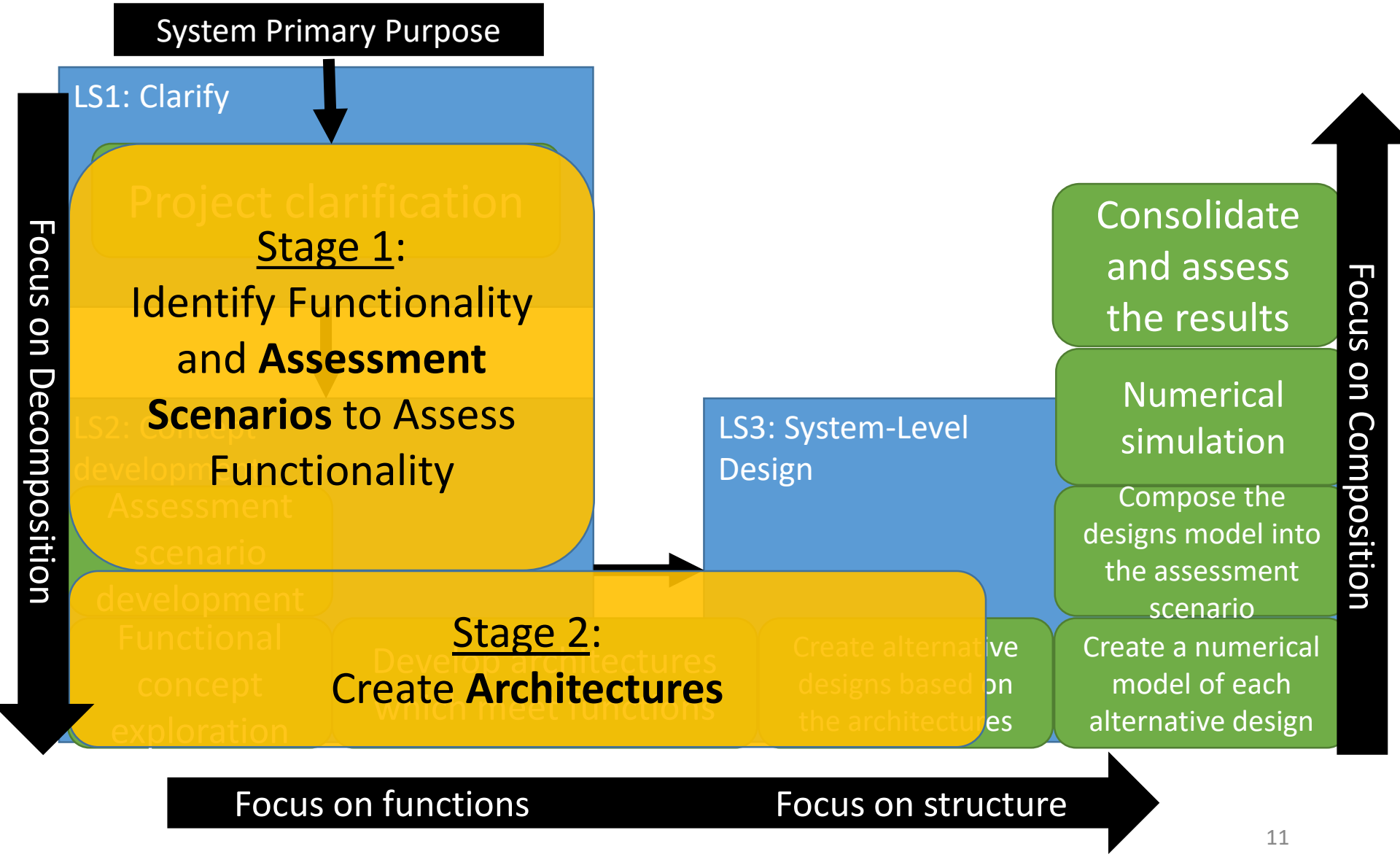

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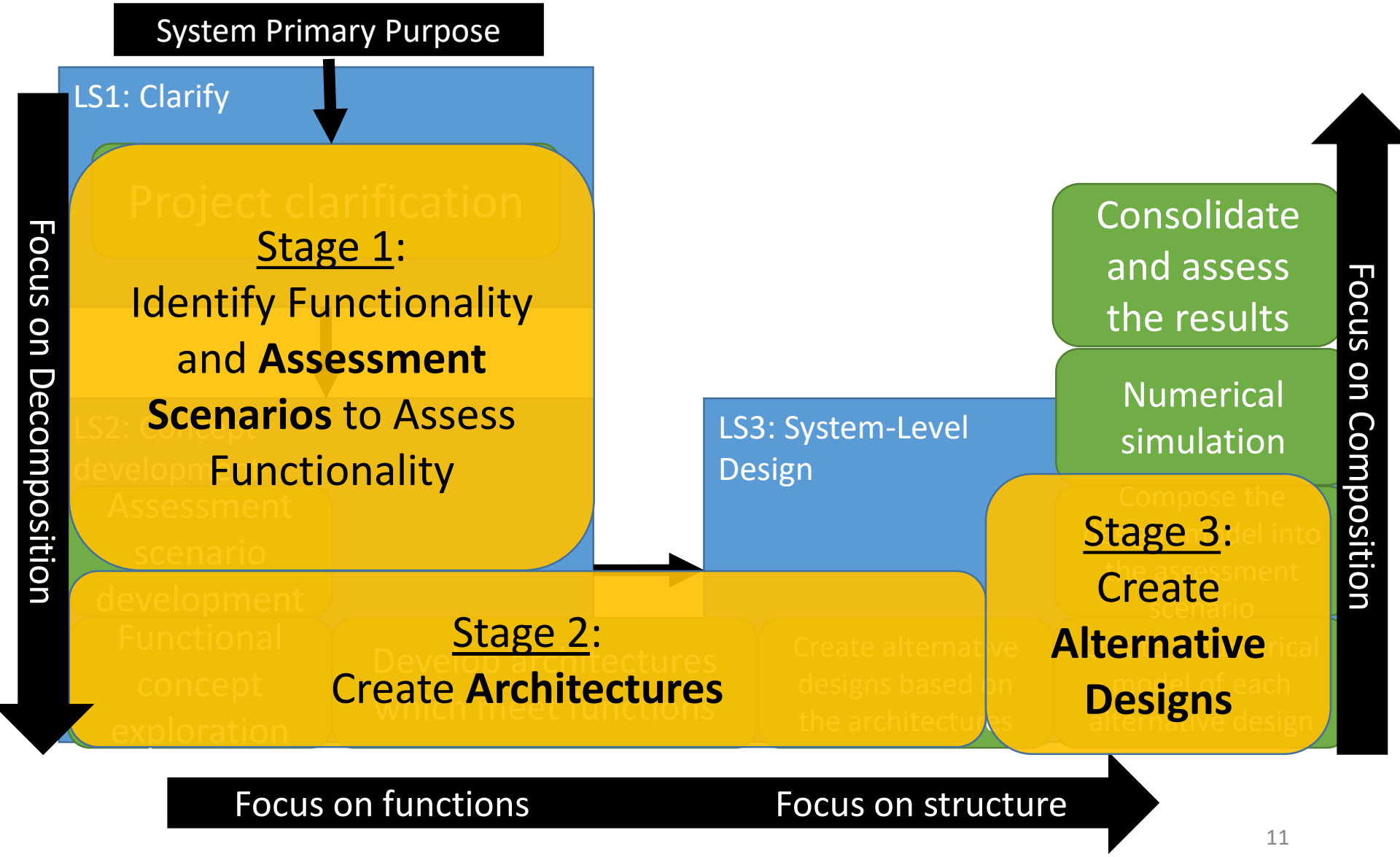

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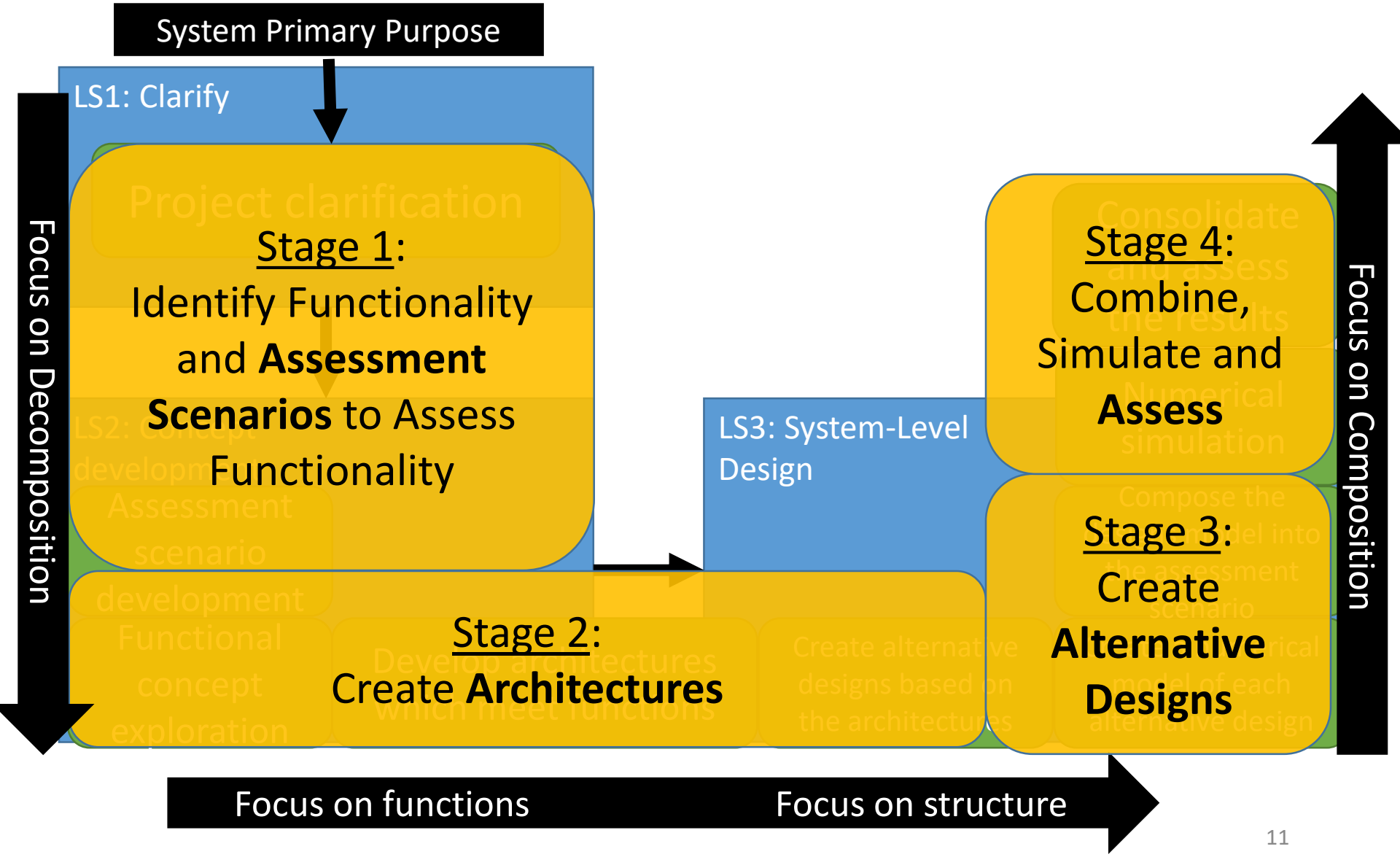
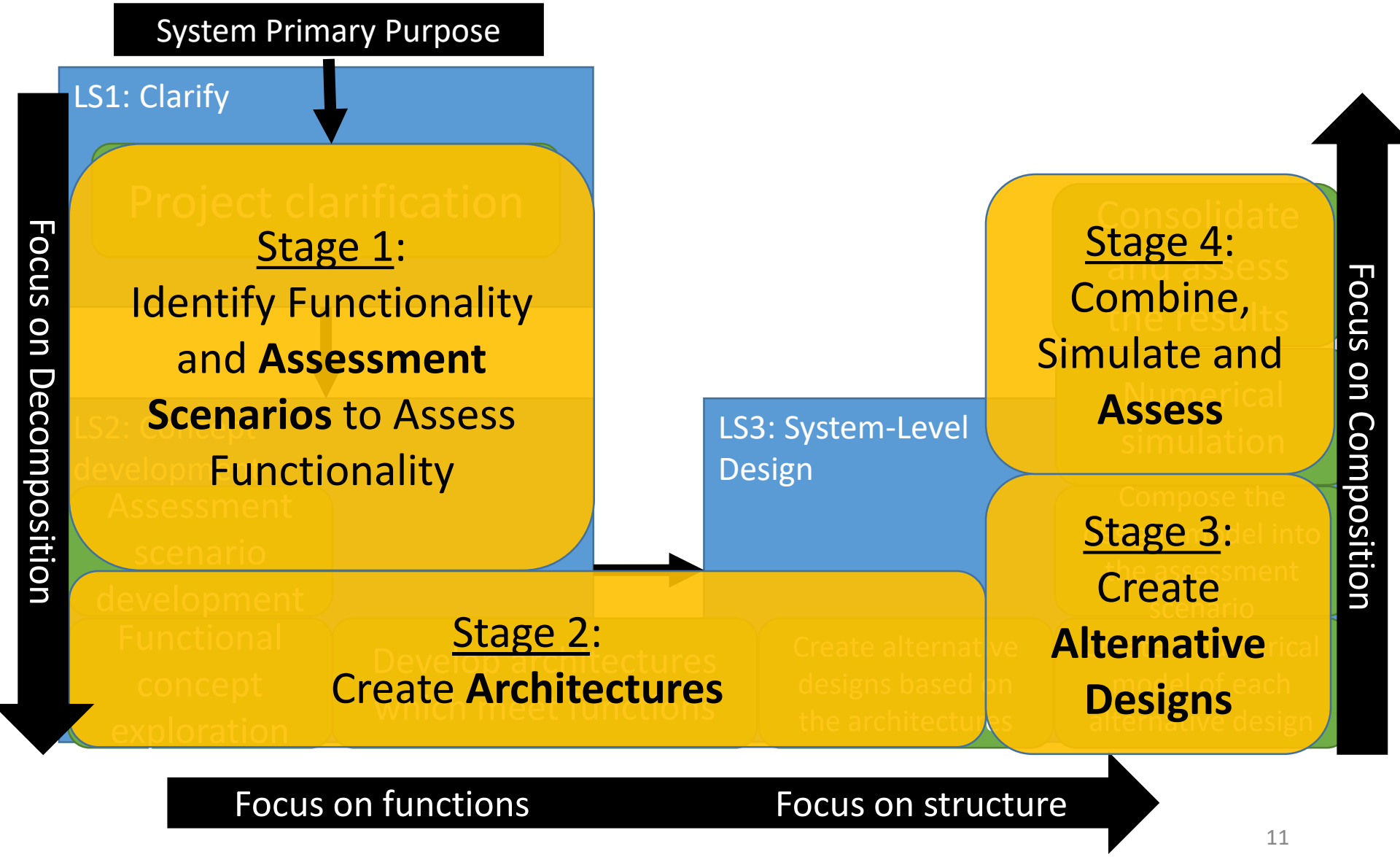


Proposed High Level Activities



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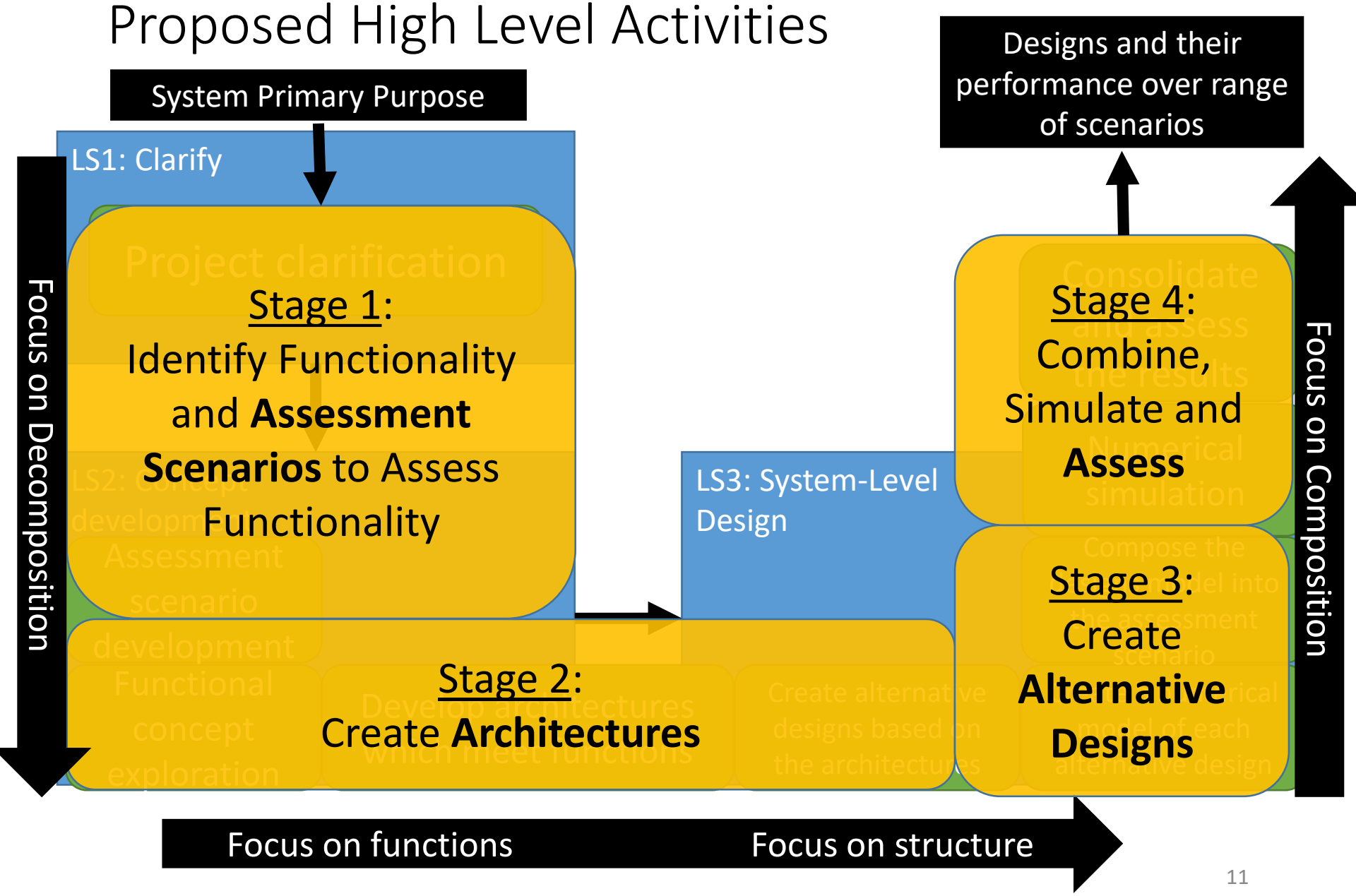

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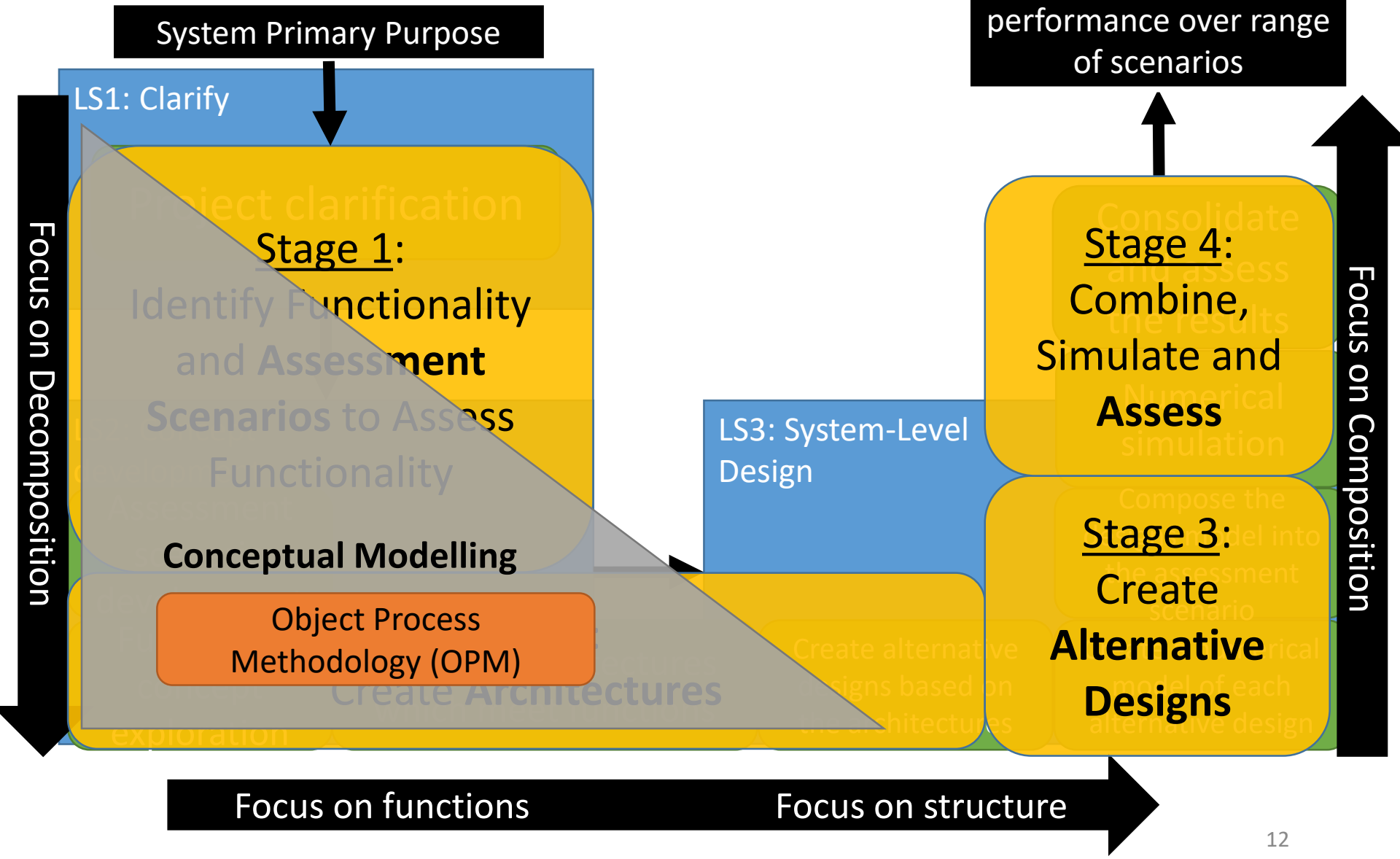

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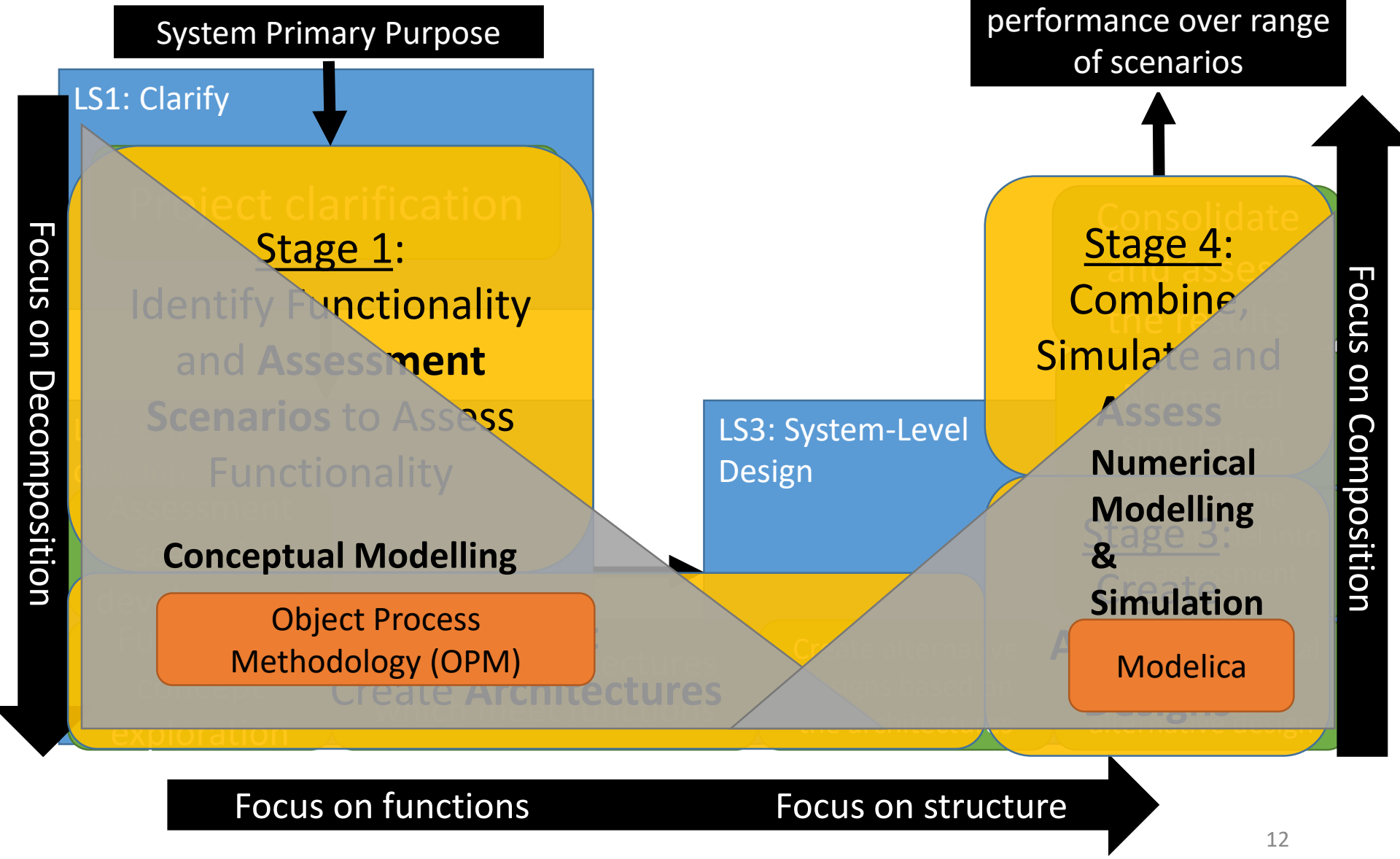
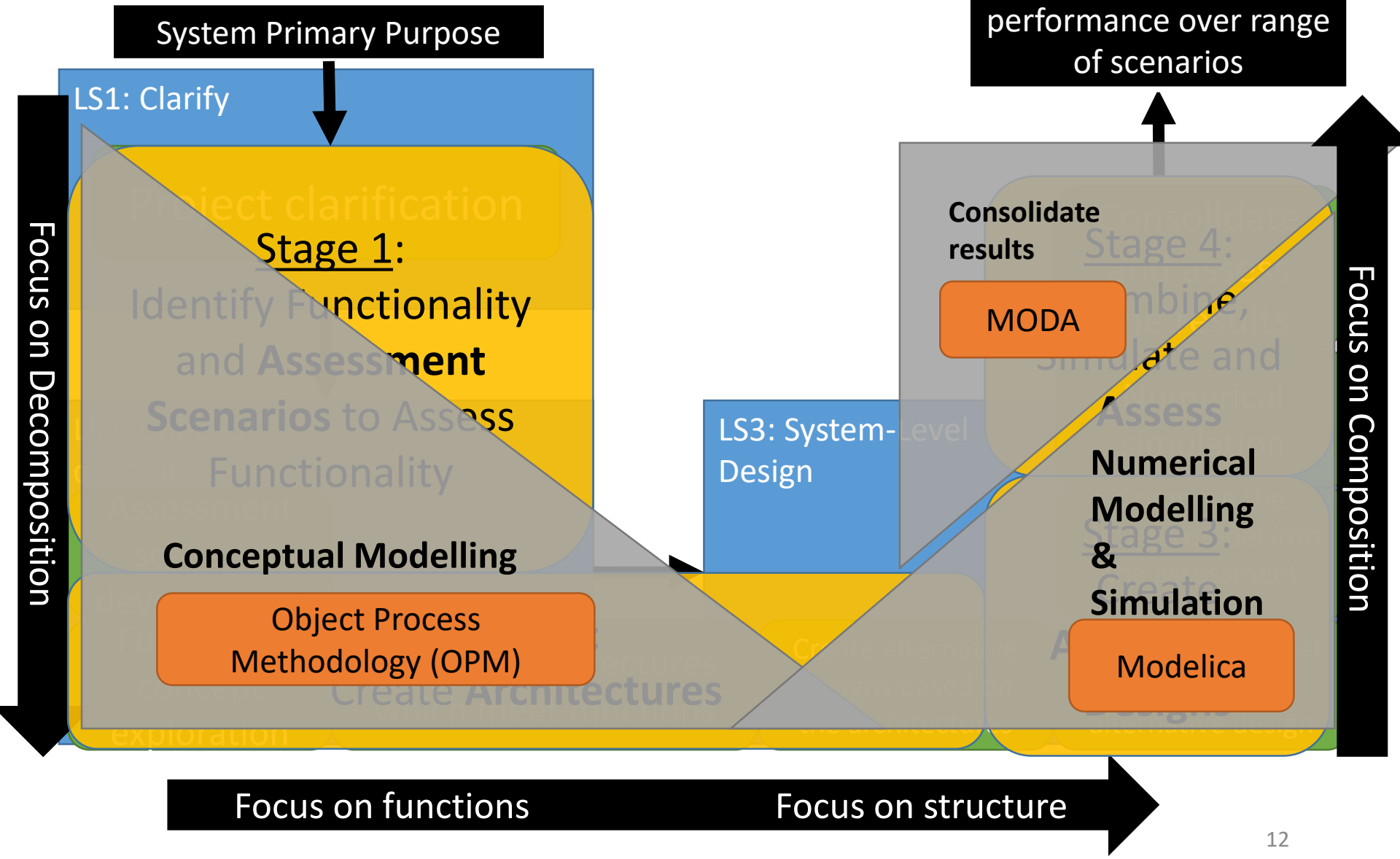


Proposed High Level Activities



Summary

東京大学大学院工学系研究科
SCHOOL OF EN
THE UNIVERSIT
DEPARTMENT OF
STEM

System Architecture (OPM)

Formal Structure (OPM)

Formal Structure (Modelica)

Modelica Models and Simulation Results

Level 0 [Functional Architecture Primary Value]

Level 1 [Assessment Scenarios]

Level 2 [System of Interest]

Level 3 [Subsystem]

Level 4 [Subsystem Components]

Racing in Solar-Boat Race Event

Solar-Boat

Driving forward

Floating

Sub process

Subsystem

Converting electrical to thrust

Electrical to Thrust Subsystem

Converting electrical to rotation

Mechanical rotation

Converting rotation to thrust

Electrical to Rotation Component

Electrical to Rotation Component

Key:

Process

Object

Exhibits

Consumes

Effects

Enables

Acausal

Causal

Solar

Solar-Boat

x velocity

Sub system

Electrical to Thrust Subsystem

Electrical to Rotation Component

Electrical to Thrust Component

Electrical to Rotation Component

Electrical to Thrust Component

Value

Design B

Design A

Design C

Scenario 1

Scenario 2

Scenario 3

Scenario 4

Combine and simulate

Solar

Solar-Boat

Sub system

Electrical to Thrust Subsystem

Electrical to Rotation Component

Electrical to Thrust Component

Electrical to Rotation Component

Electrical to Thrust Component

Electrical to Rotation

Component 1

Component 2

Electrical to Thrust

Component 1

Component 2

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Electrical to Rotation Component

Electrical to Thrust Component

Electrical to Rotation

Component 1

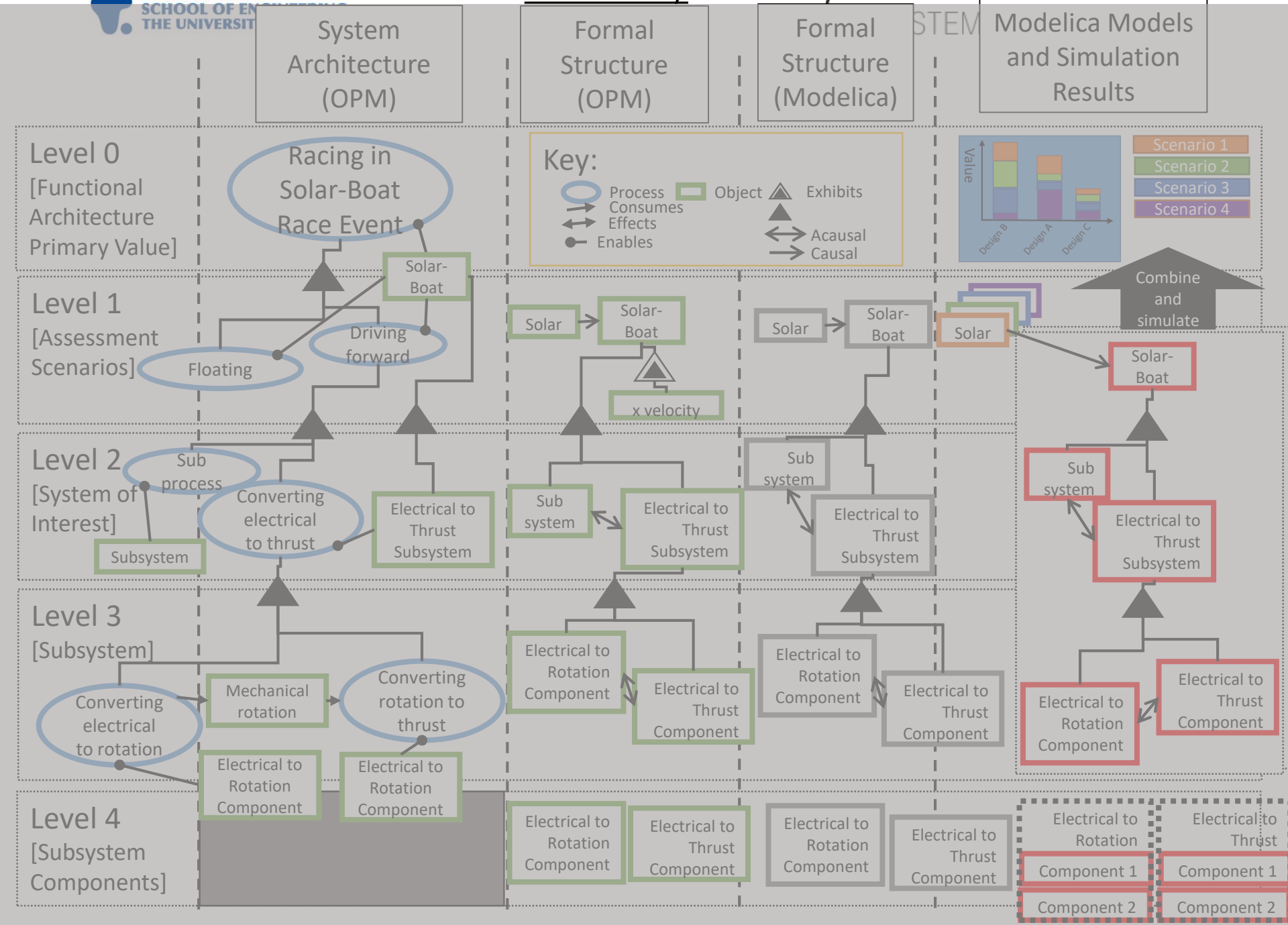
Component 2

Electrical to Thrust

Component 1

Component 2

Summary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Solar-Boat
Sub system
Electrical to Thrust Subsystem
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Electrical to Thrust Component
Value
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Design A
Design C
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Scenario 3
Scenario 4
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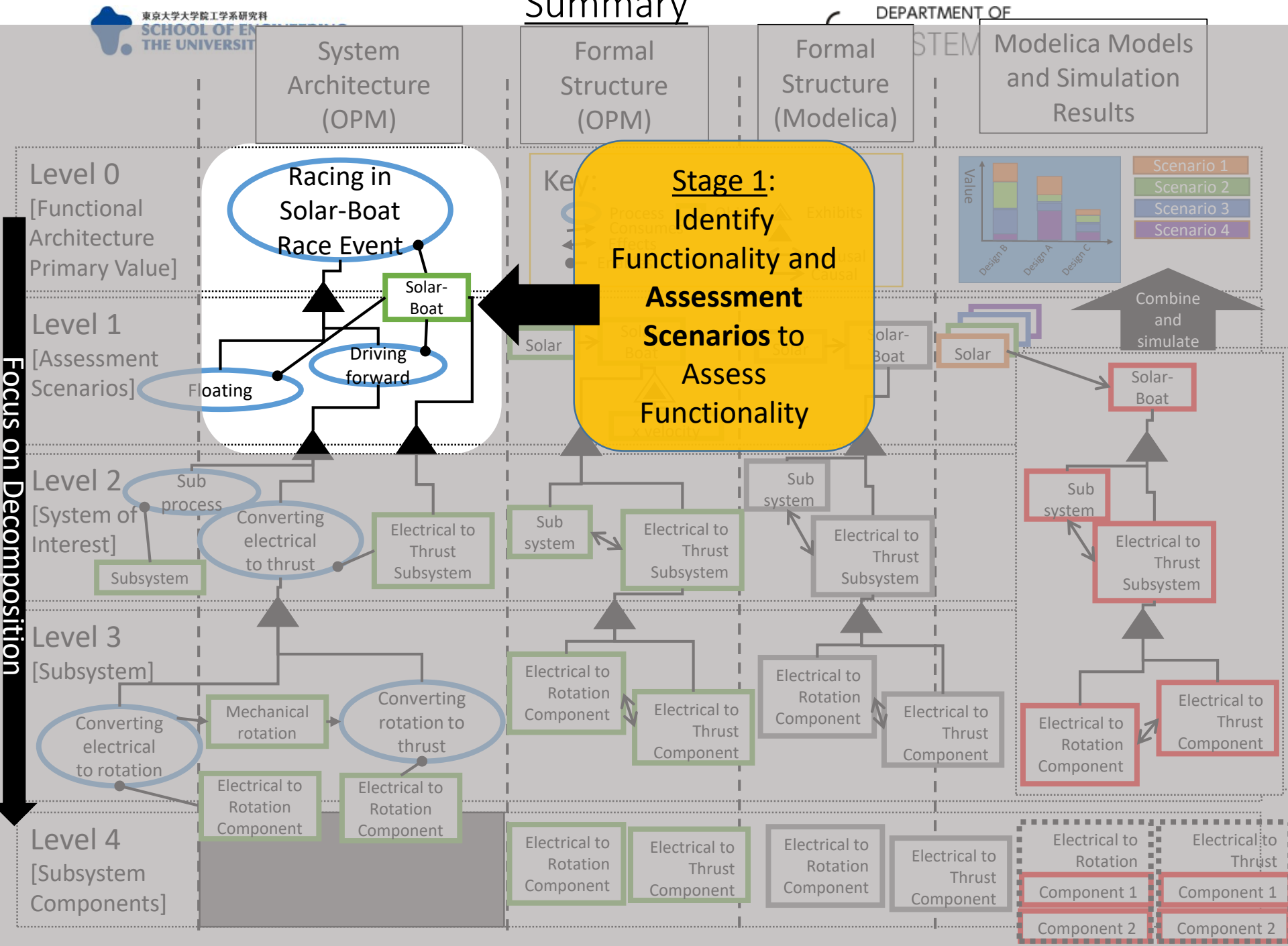
Solar
Solar-Boat
Sub system
Electrical to Thrust Subsystem
Electrical to Rotation Component
Electrical to Thrust Component
Electrical to Rotation Component
Electrical to Thrust Component
Electrical to Rotation
Component 1
Component 2
Electrical to Thrust
Component 1
Component 2

Summary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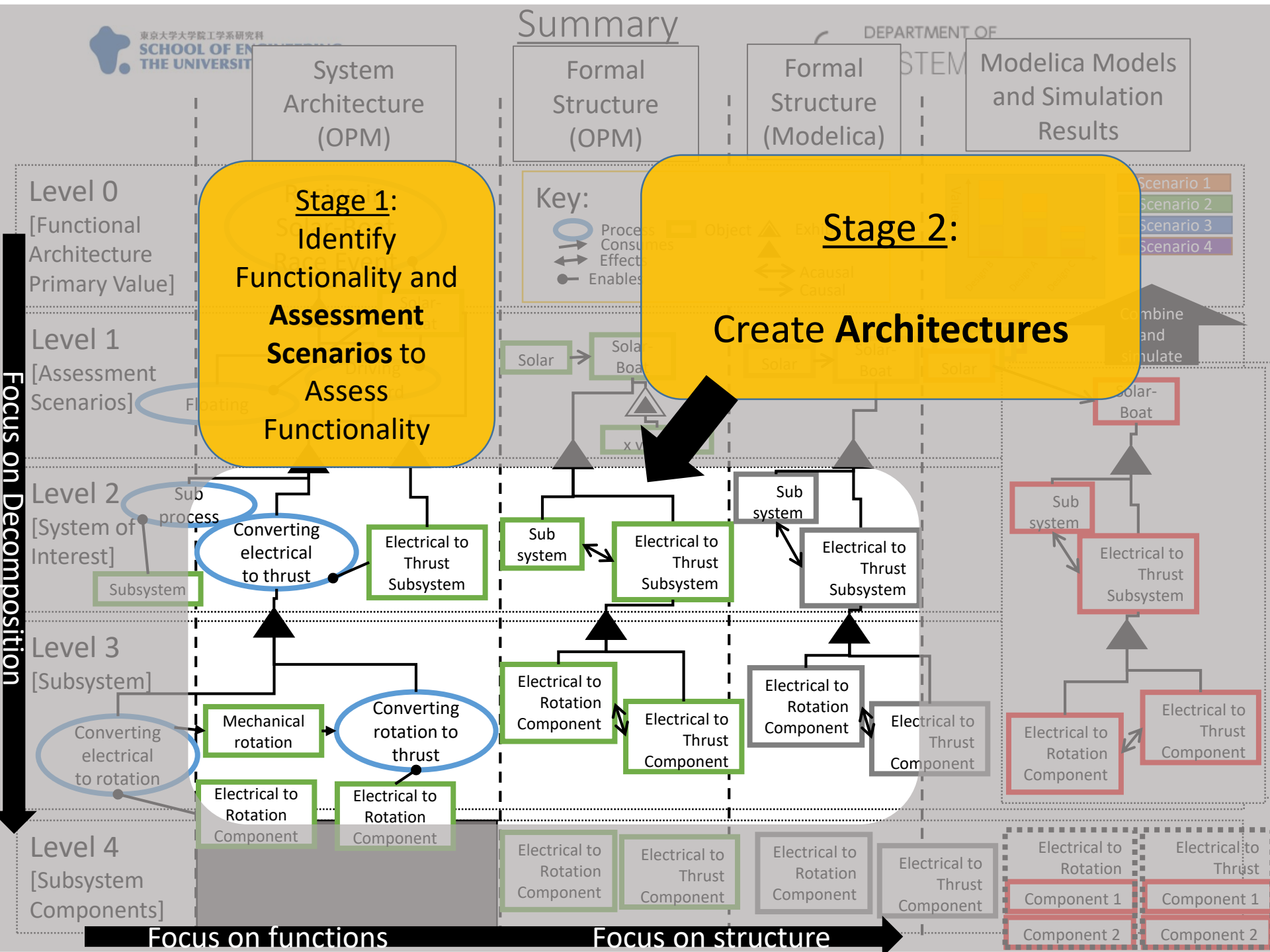
Focus on Decomposition
Racing in Solar-Boat Race Event
Solar-Boat
Driving forward
Floating
Stage 1: Identify Functionality and Assessment Scenarios to Assess Functionality
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Value
Design B
Design A
Design C
Combine and simulate
Sub process
Subsystem
Converting electrical to thrust
Electrical to Thrust Subsystem
Converting electrical to rotation
Mechanical rotation
Converting rotation to thrust
Electrical to Rotation Component
Sub system
Electrical to Thrust Component
Solar
Solar-Boat
Component 1
Component 2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Stage 2: Create Architectures
Key:
Process
Consumes
Effect
Enables
Object
Acausal
Causal
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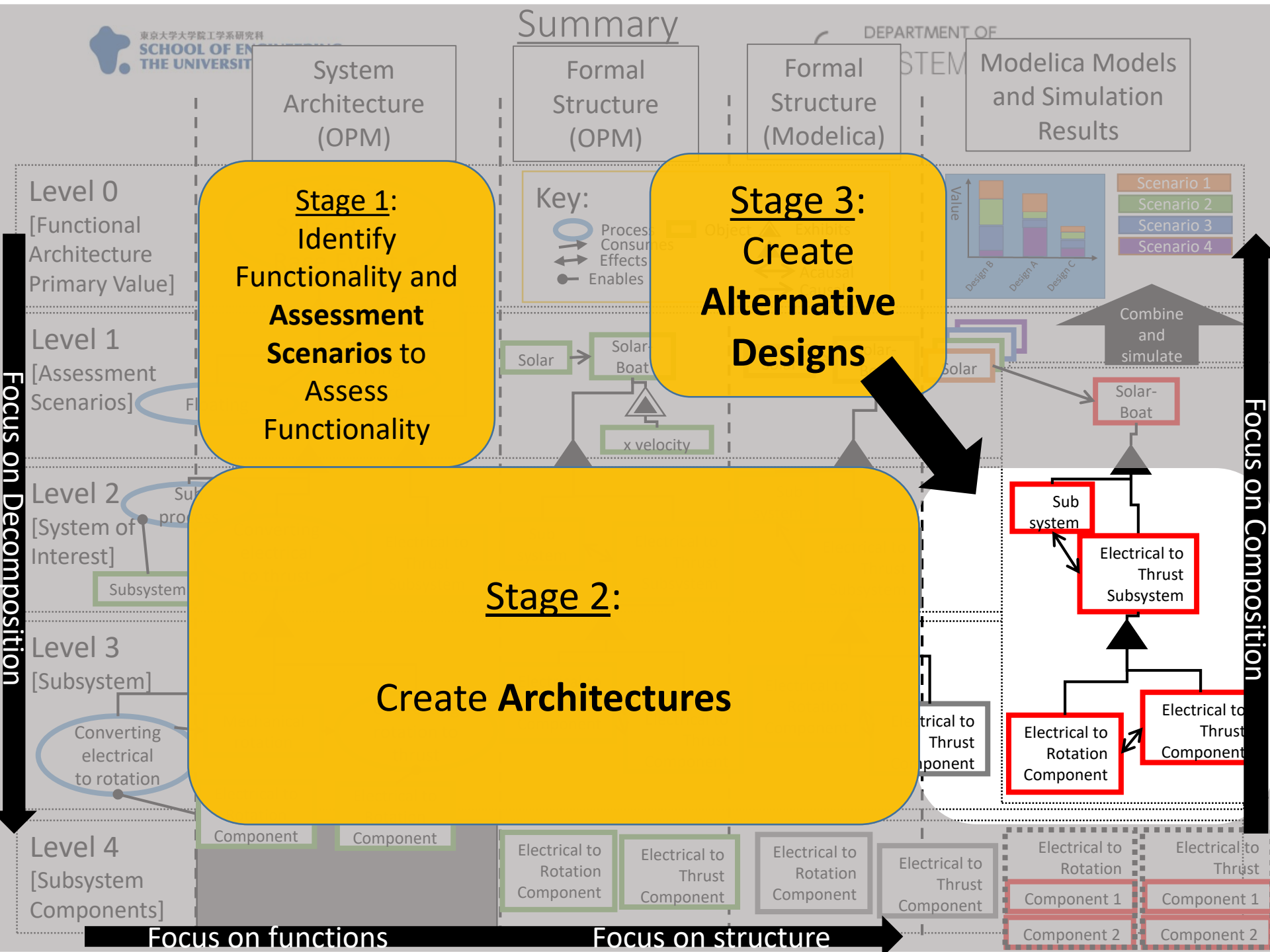
Scenario 2
Scenario 3
Scenario 4
Combine and simulate
Solar
Solar-Boat
Sub process
Subsystem
Converting electrical to thrust
Electrical to Thrust Subsystem
Sub system
Converting electrical to rotation
Mechanical rotation
Converting rotation to thrust
Electrical to Rotation Component
Electrical to Thrust Component
Focus on Decomposition
Focus on functions
Focus on structure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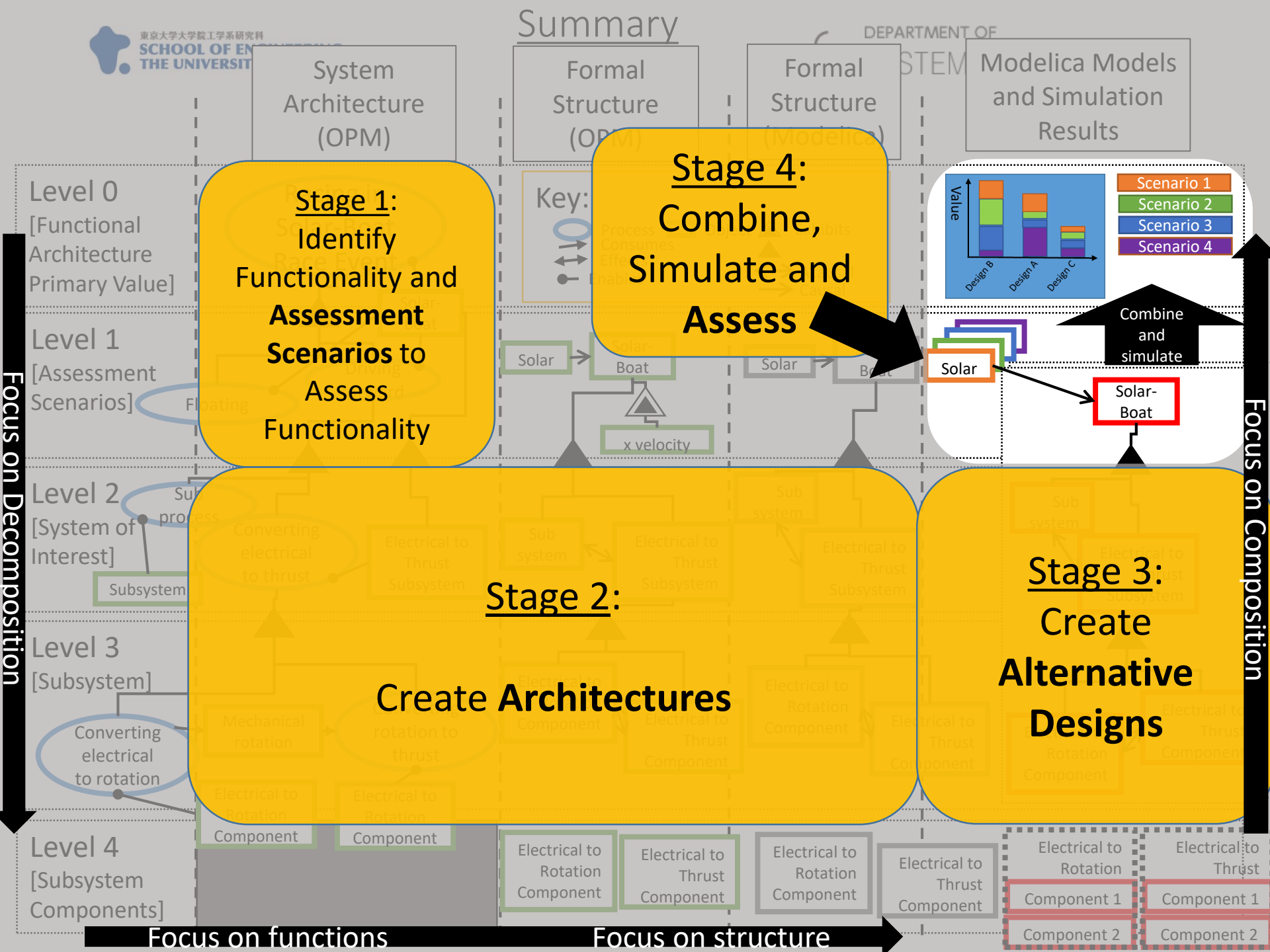
Enables
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Value
Design B
Design A
Design C
Combine and simulate
Solar
Solar-Boat
x velocity
Subsystem
Converting electrical to rotation
Component
Component
Sub system
Electrical to Thrust Subsystem
Electrical to Rotation Component
Electrical to Thrust Component
Electrical to Rotation Component
Electrical to Thrust Component
Electrical to Rotation Component
Electrical to Thrust Component
Component 1
Component 2
Component 1
Component 2
Stage 1: Identify Functionality and Assessment Scenarios to Assess Functionality
Stage 2: Create Architectures
Stage 3: Create Alternative Designs
Focus on Decomposition
Focus on Composition
Focus on functions
Focus on structure

Summary


System Architecture (OPM)
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Formal Structure (Modelica)
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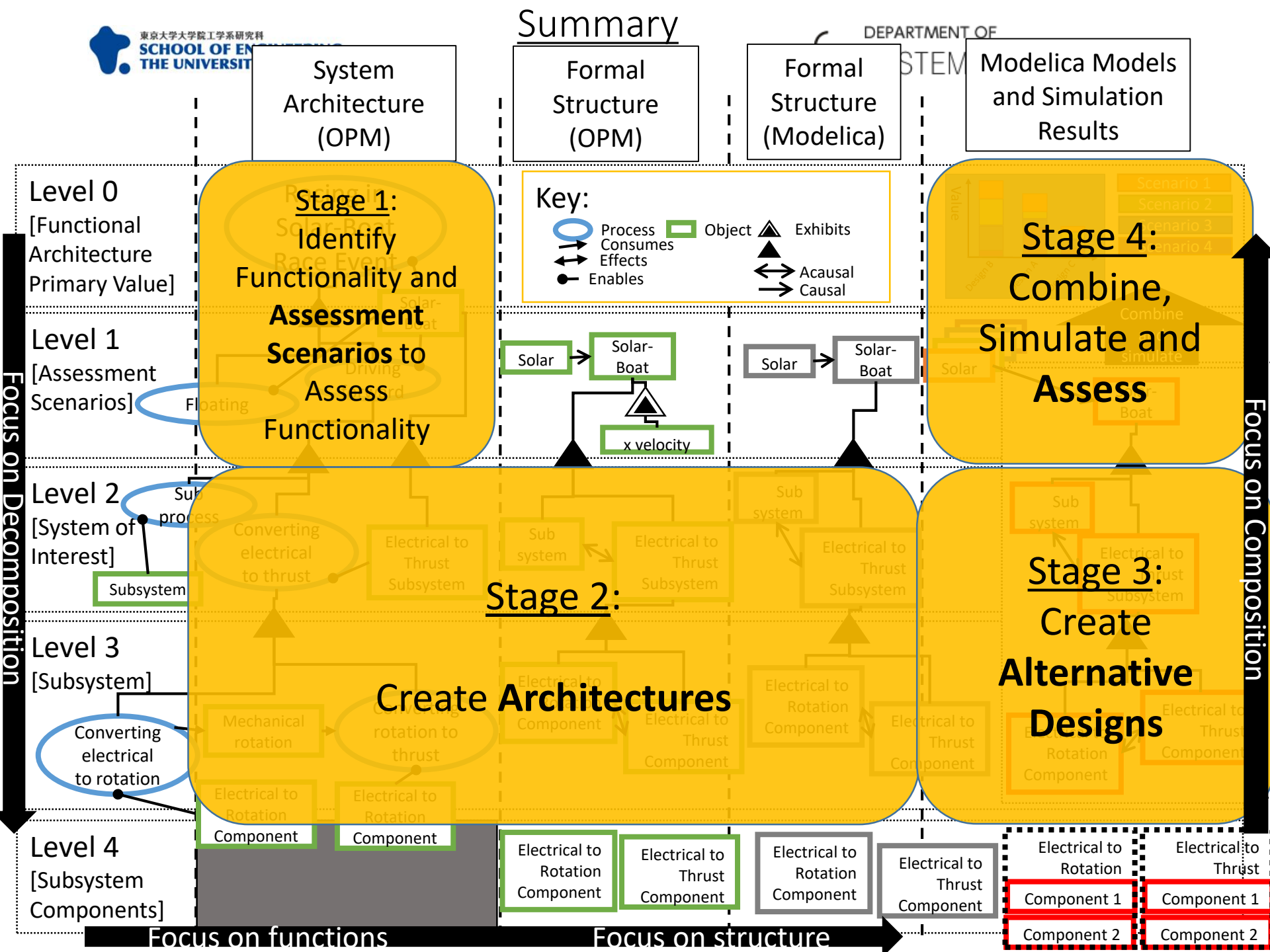
Stage 4: Combine, Simulate and Assess
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Value
Design B
Design A
Design C
Combine and simulate
Solar
Solar-Boat
Focus on Decomposition
Focus on Composition
Focus on functions
Focus on structure

Summary


System Architecture (OPM)
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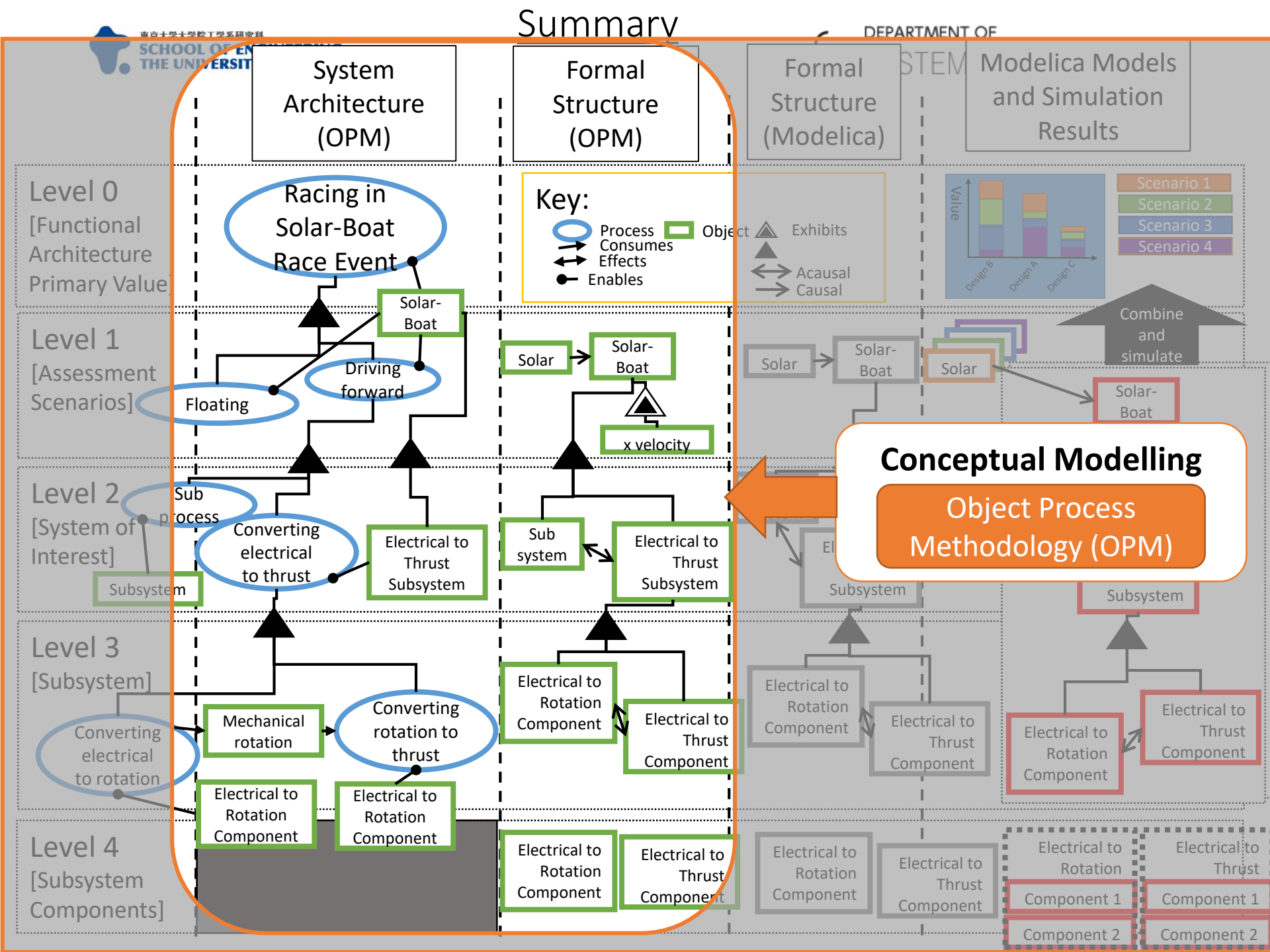
Process
Object
Exhibits
Consumes
Effects
Enables
Acausal
Causal
Solar
Solar-Boat
x velocity
Stage 2: Create Architectures
Subsystem
Converting electrical to rotation
Converting electrical to thrust
Mechanical rotation
Converting rotation to thrust
Electrical to Thrust Subsystem
Sub system
Electrical to Rotation Component
Electrical to Thrust Component
Stage 3: Create Alternative Designs
Stage 4: Combine, Simulate and Assess
Component 1
Component 2
Focus on Decomposition
Focus on Composition
Focus on functions
Focus on structure

Summary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Solar-Boat
Driving forward
Floating
Sub process
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Subsystem
Converting electrical to rotation
Mechanical rotation
Converting rotation to thrust
Electrical to Rotation Component
Electrical to Rotation Component
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Consumes
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Solar
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x velocity
Sub system
Electrical to Thrust Subsystem
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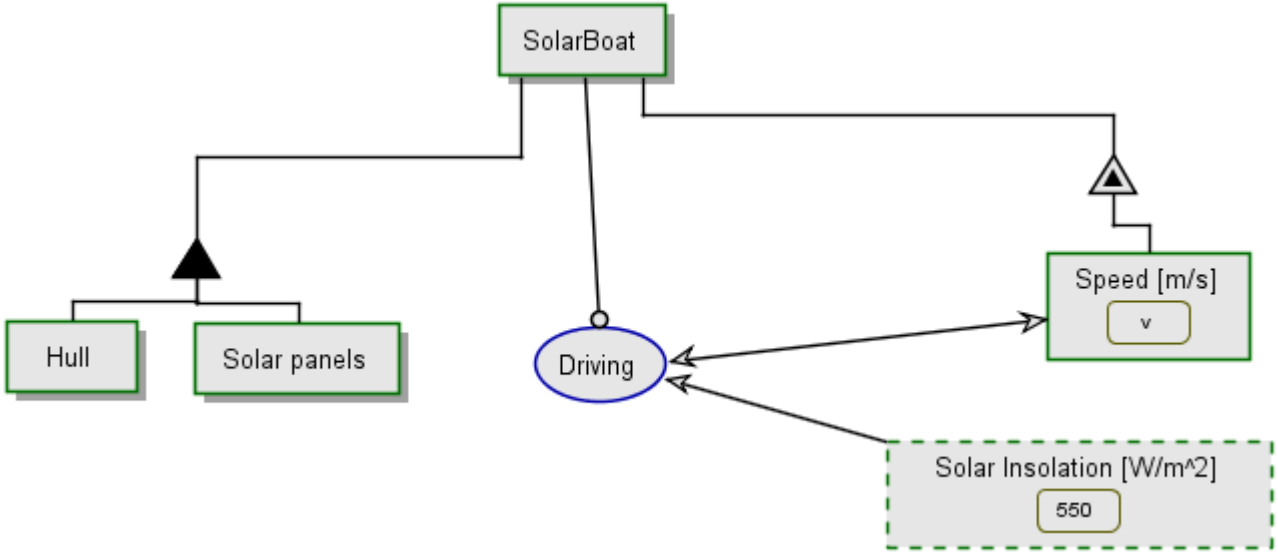
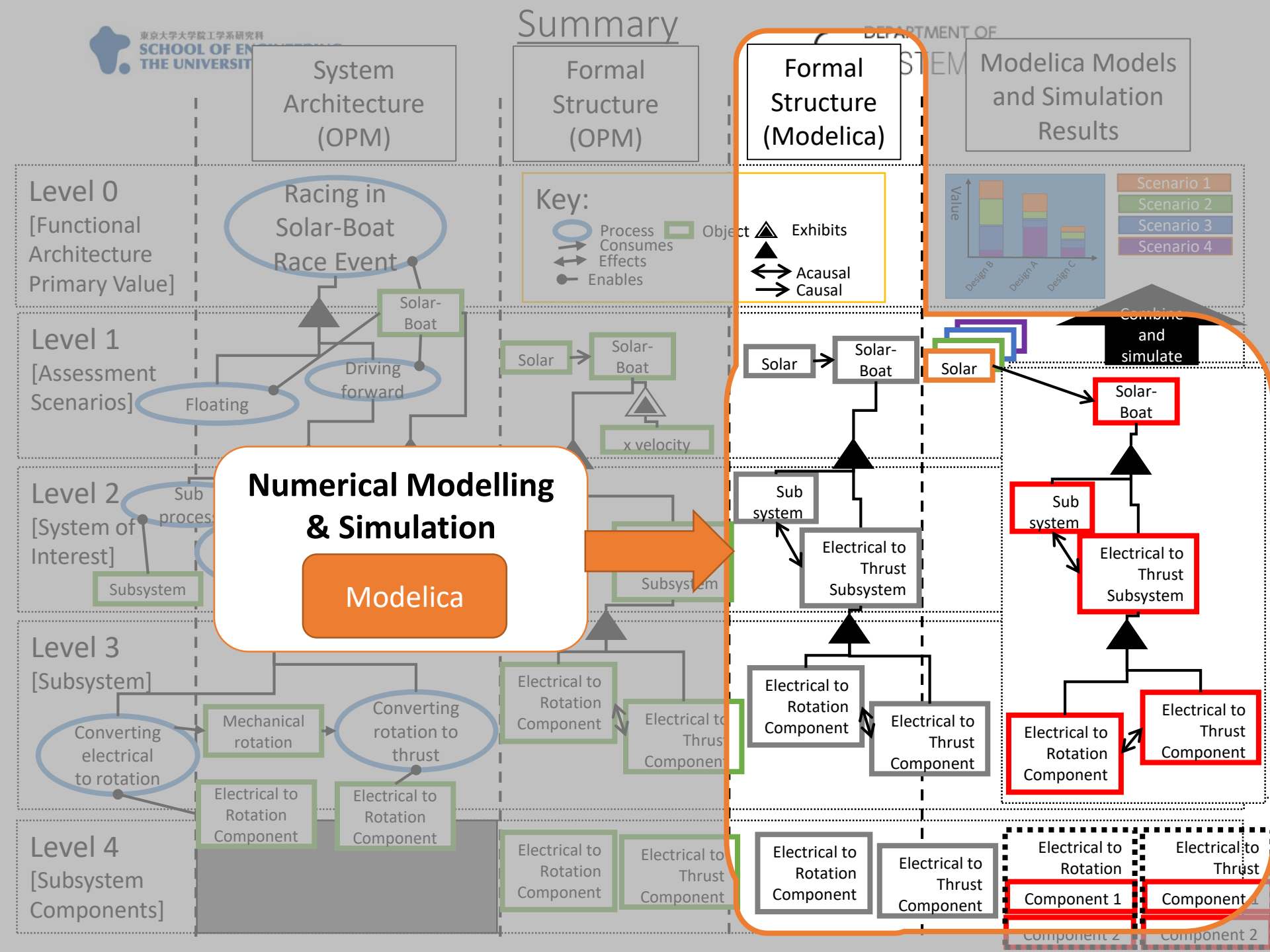
Electrical to Thrust Component
Electrical to Rotation Component
Electrical to Thrust Component
Value
Design B
Design A
Design C
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Combine and simulate
Solar
Solar-Boat
Solar
Solar-Boat
Subsystem
Subsystem
Electrical to Rotation Component
Electrical to Thrust Component
Electrical to Rotation Component
Electrical to Thrust Component
Electrical to Rotation
Component 1
Component 2
Electrical to Thrust
Component 1
Component 2
Conceptual Modelling
Object Process Methodology (OPM)

Object Process Methodology (OPM)

- ISO standardized conceptual modeling language
- **Single diagram type** accompanied with text models **behavior** and **structure**
- **Complexity managed** by **hierarchical decomposition**



SolarBoat is physical.
SolarBoat exhibits Speed [m/s].
Speed [m/s] is v.
SolarBoat consists of Hull and Solar panels.
Hull is physical.
Solar panels is physical.
Solar Insolation [W/m^2] is environmental.
Solar Insolation [W/m^2] is 550.
Driving requires SolarBoat.
Driving affects Speed [m/s].
Driving consumes Solar Insolation [W/m^2].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Solar-Boat
Floating
Driving forward
Subsystem
Converting electrical to rotation
Mechanical rotation
Converting rotation to thrust
Electrical to Rotation Component
Key:
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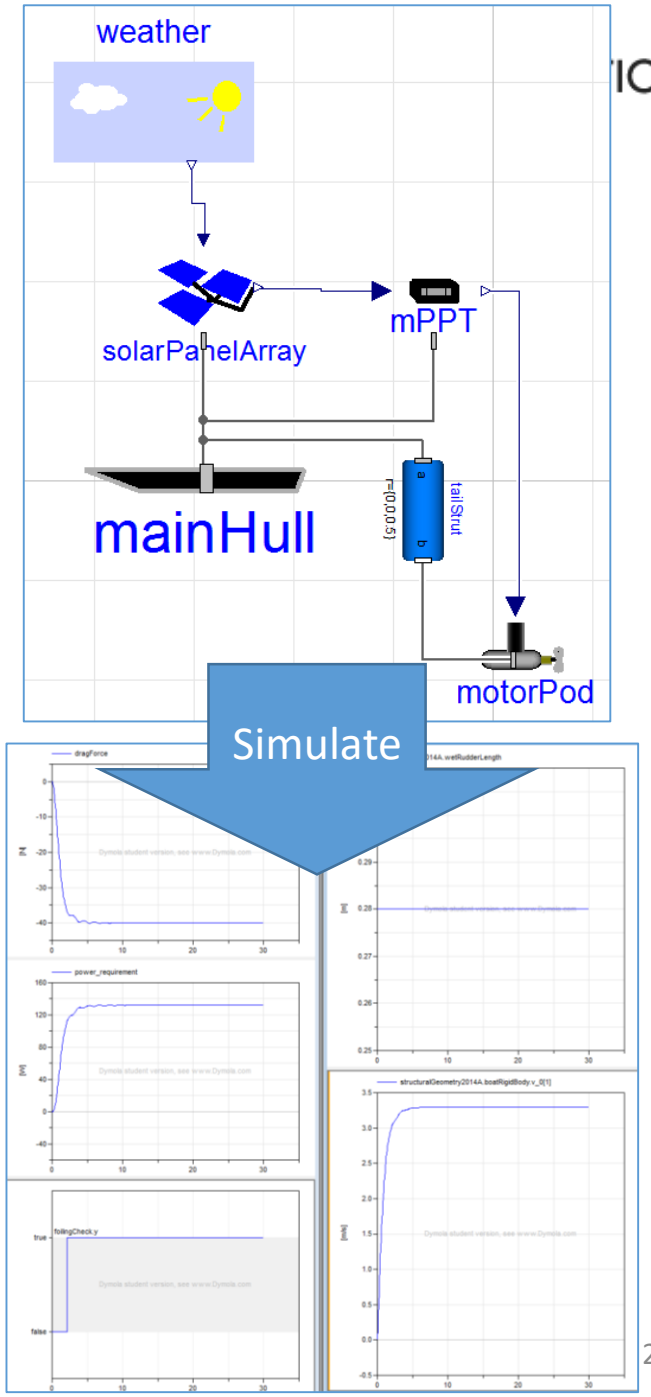
Object
Consumes
Effects
Enables
Exhibits
Acausal
Causal
Solar
x velocity
Numerical Modelling & Simulation
Modelica
Sub system
Electrical to Thrust Subsystem
Electrical to Thrust Component
Value
Design B
Design A
Design C
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Combine and simulate
Component 1
Component 2

Modelica

- **Multi domain numerical** simulation **modeling** system
- Supports **acausal component interactions**
- **Compose** using existing parts libraries or make your own
- Supports **hierarchy**



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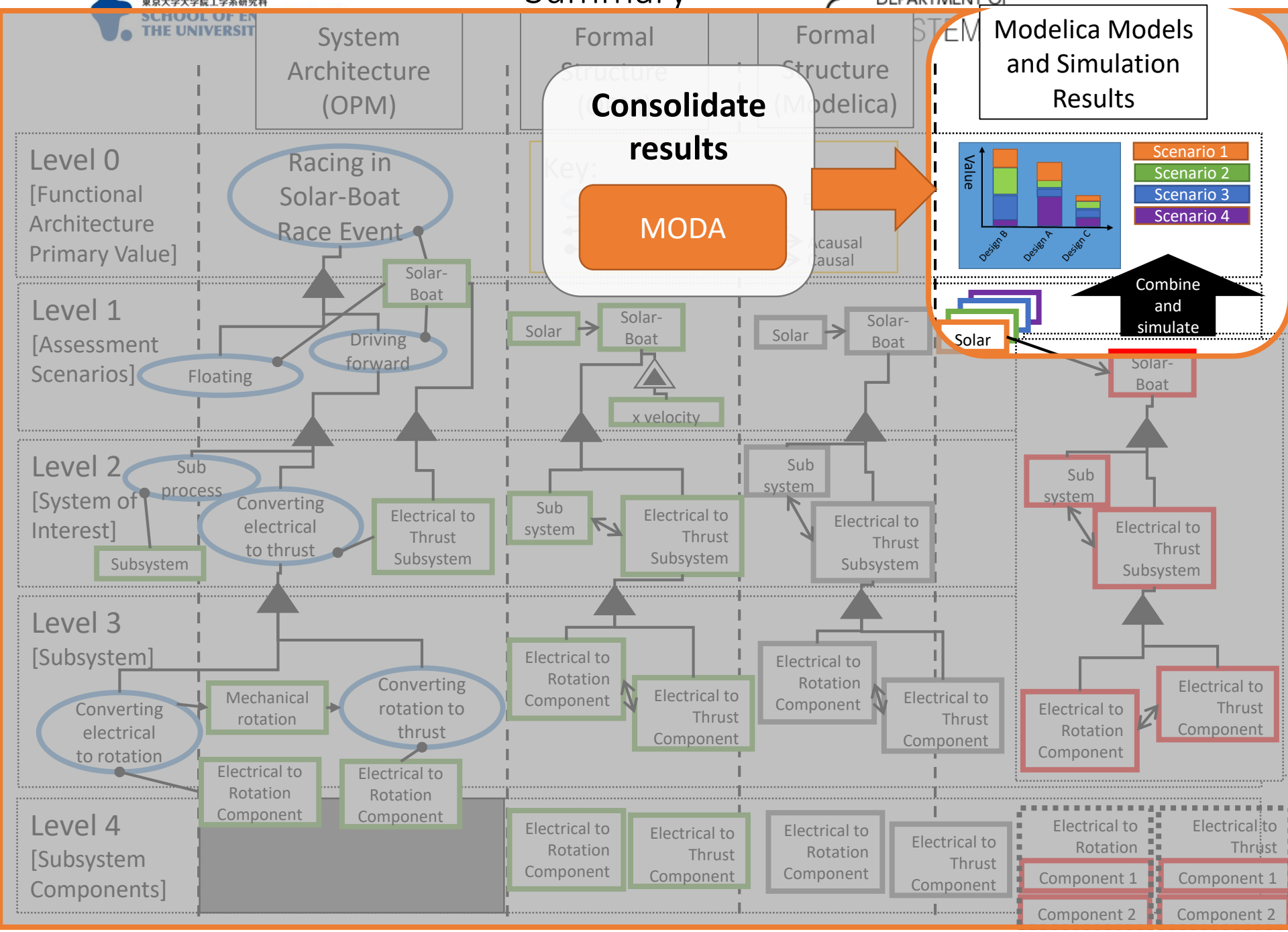
System Architecture (OPM)
Formal Structure (Modelica)
Consolidate results
MODA
Modelica Models and Simulation Results
Value
Design B
Design A
Design C
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Combine and simulate
Solar
Level 0 [Functional Architecture Primary Value]
Racing in Solar-Boat Race Event
Level 1 [Assessment Scenarios]
Solar-Boat
Floating
Driving forward
x velocity
Level 2 [System of Interest]
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Subsystem
Electrical to Thrust Subsystem
Sub system
Level 3 [Subsystem]
Converting electrical to rotation
Mechanical rotation
Converting rotation to thrust
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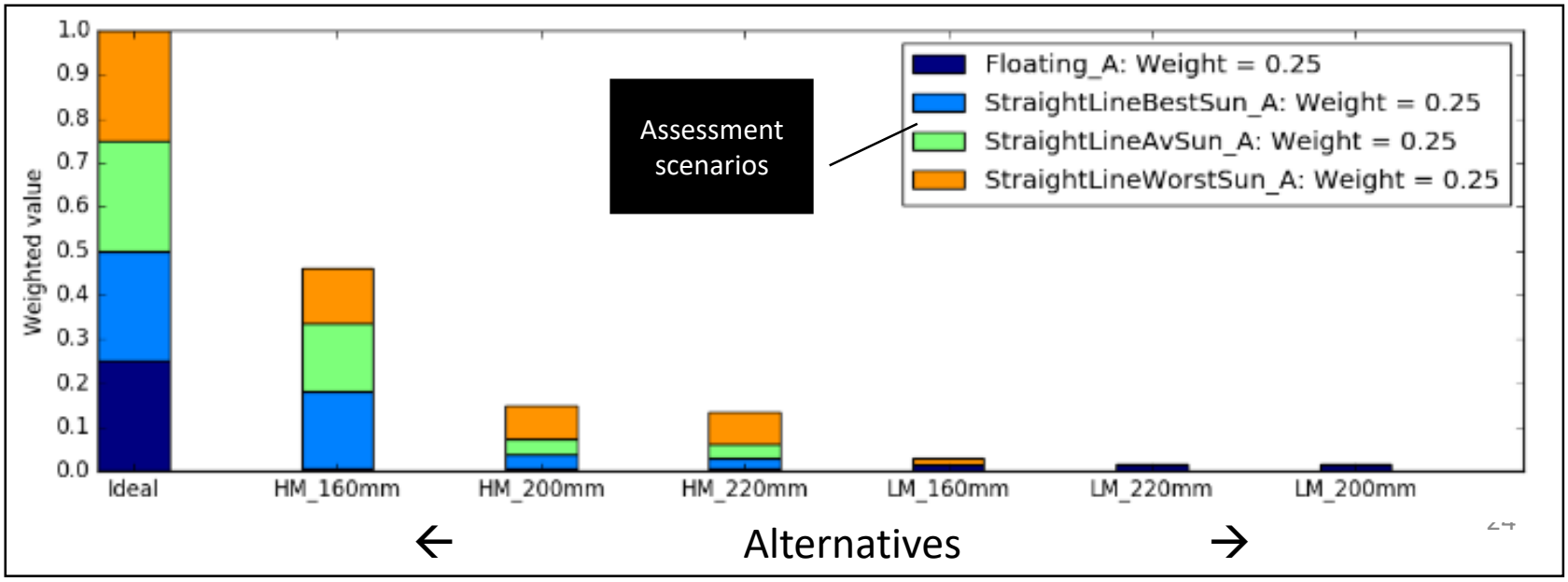
Electrical to Thrust Component
Level 4 [Subsystem Components]
Component 1
Component 2

Multi Objective Decision Analysis (MODA)

- For simplicity used weighted sum from Cilli & Parnell, 2014



Multi Objective Decision Analysis (MODA)

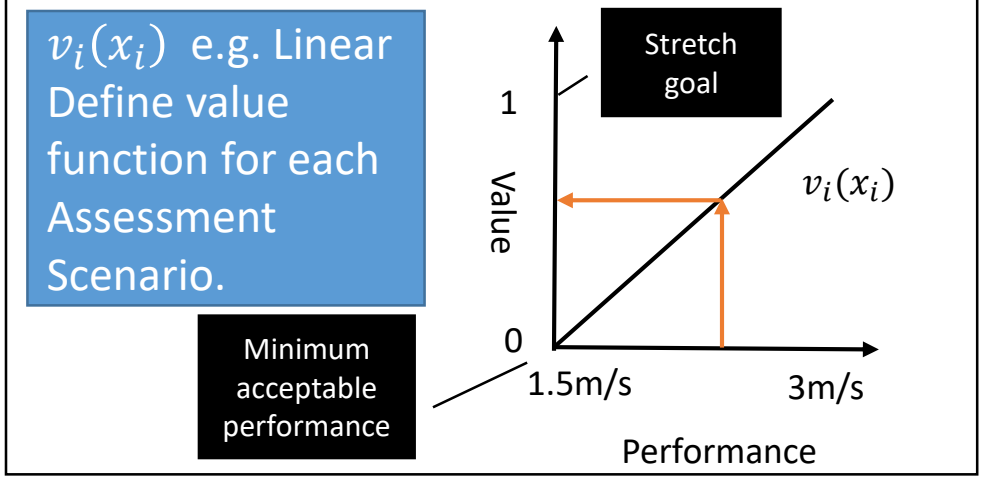
- For simplicity used weighted sum from Cilli & Parnell, 2014

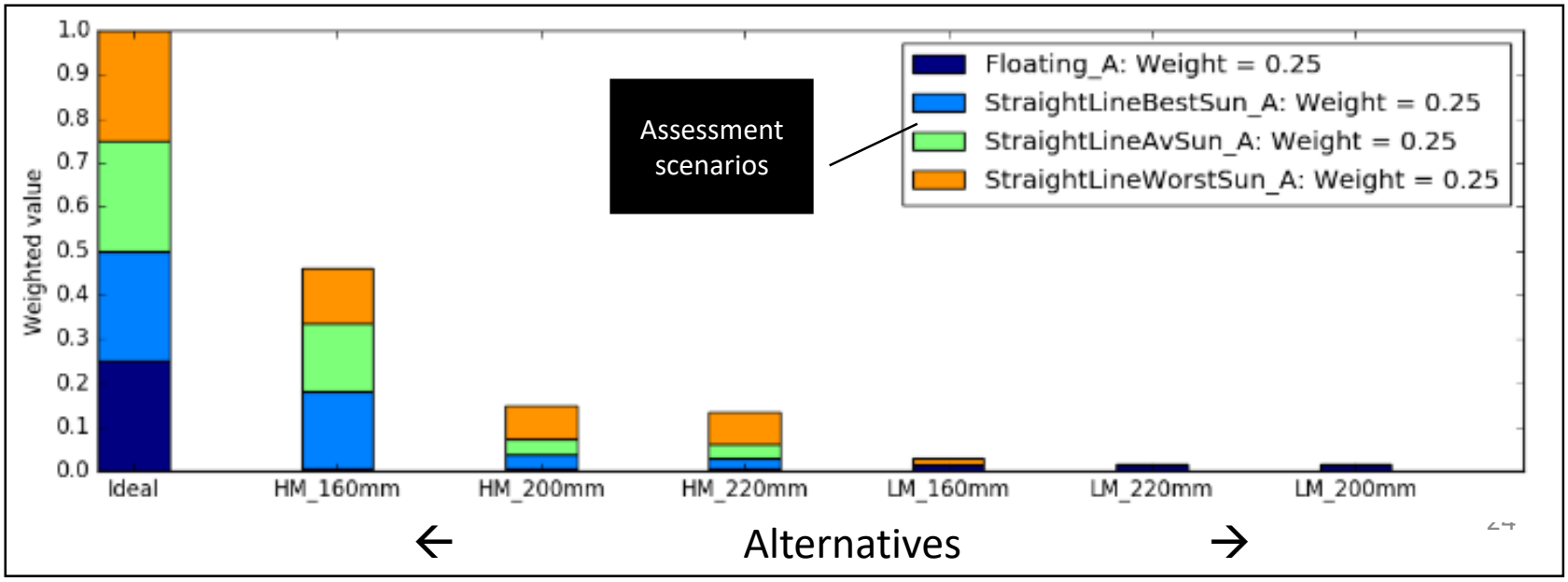
For each alternative design:

Alternative's value = $v(x) = \sum_{i=1}^{n} w_i v_i(x_i)$

- i is Assessment Scenario
- x_i is Measure of Interest for Assessment Scenario
- w_i is weight for the Assessment Scenario
- $\sum_{i=1}^{n} w_i = 1$

$v_i(x_i)$ e.g. Linear Define value function for each Assessment Scenario.





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東京大学大学院工学系研究科
SCHOOL OF ENGINEERING
THE UNIVERSITY OF TOKYO
DEPARTMENT OF SYSTEM

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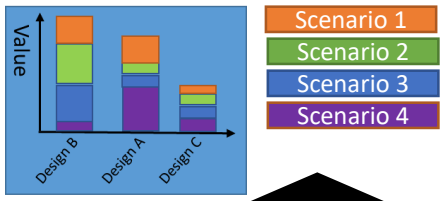
Key Point 1: Assessment Scenarios Common To all Designs



Combine and simulate

Level 0 [Functional Architecture Primary Value]

Racing in Solar-Boat Race Event

Level 1 [Assessment Scenarios]

Floating

Driving forward

Solar-Boat

Level 2 [System of Interest]

Sub process

Subsystem

Converting electrical to thrust

Electrical to Thrust Subsystem

Solar

Solar-Boat

x velocity

Sub system

Electrical to Thrust Subsystem

Solar

Solar-Boat

Sub system

Electrical to Thrust Subsystem

Solar

Solar-Boat

Sub system

Electrical to Thrust Subsystem

Level 3 [Subsystem]

Converting electrical to rotation

Mechanical rotation

Converting rotation to thrust

Electrical to Rotation Component

Electrical to Rotation Component

Electrical to Rotation Component

Electrical to Thrust Component

Electrical to Rotation Component

Electrical to Thrust Component

Electrical to Rotation Component

Electrical to Thrust Component

Level 4 [Subsystem Components]

Electrical to Rotation Component

Electrical to Thrust Component

Electrical to Rotation Component

Electrical to Thrust Component

Electrical to Rotation

Component 1

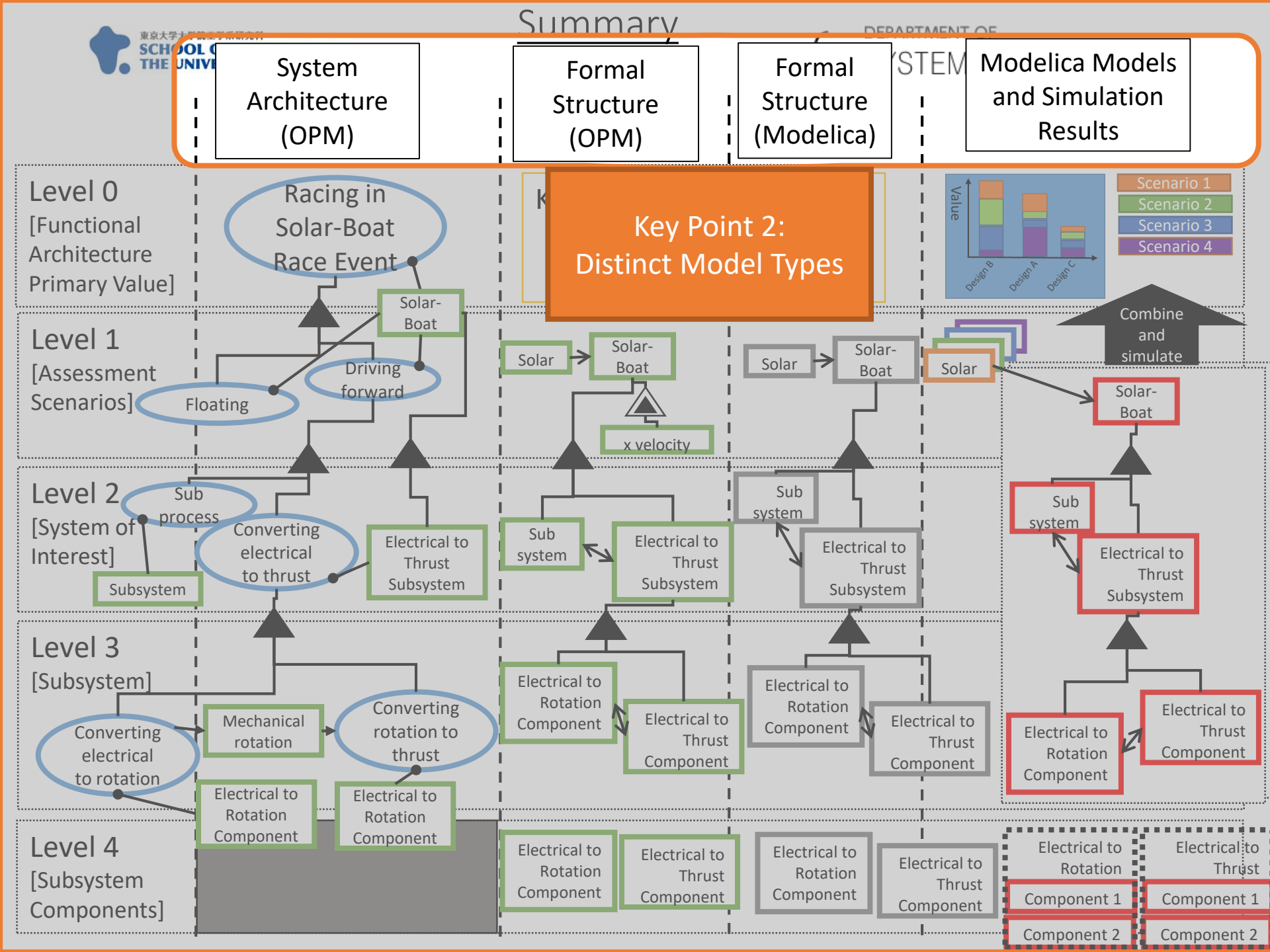
Component 2

Electrical to Thrust

Component 1

Component 2

Summary


System Architecture (OPM)
Formal Structure (OPM)
Formal Structure (Modelica)
Modelica Models and Simulation Results
Key Point 2: Distinct Model Types
Level 0 [Functional Architecture Primary Value]
Level 1 [Assessment Scenarios]
Level 2 [System of Interest]
Level 3 [Subsystem]
Level 4 [Subsystem Components]
Racing in Solar-Boat Race Event
Solar-Boat
Floating
Driving forward
Sub process
Converting electrical to thrust
Subsystem
Electrical to Thrust Subsystem
Converting electrical to rotation
Mechanical rotation
Converting rotation to thrust
Electrical to Rotation Component
Electrical to Rotation Component
Solar
Solar-Boat
x velocity
Sub system
Electrical to Thrust Subsystem
Electrical to Rotation Component
Electrical to Thrust Component
Electrical to Rotation Component
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Solar
Solar-Boat
Sub system
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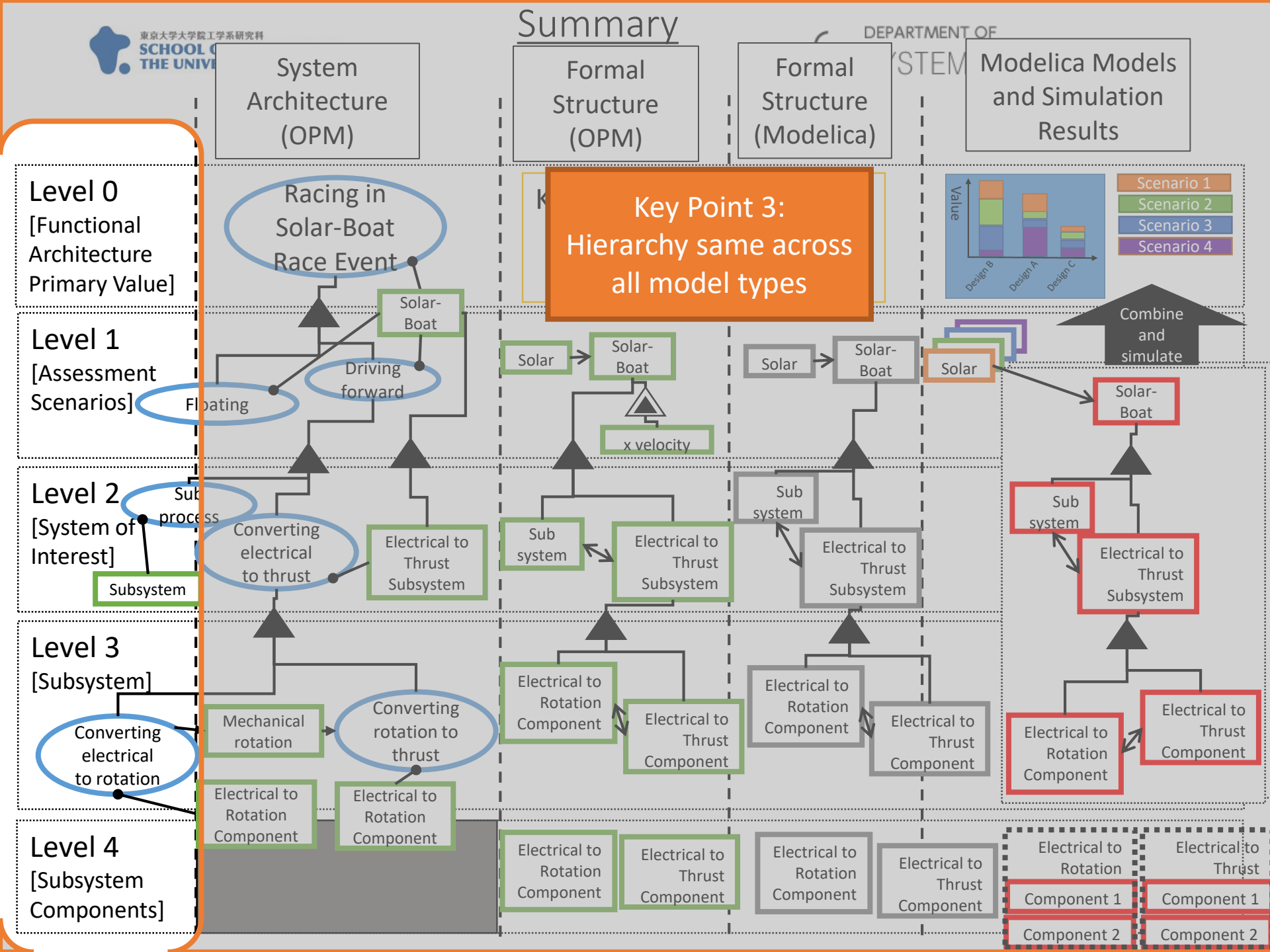
Electrical to Thrust Component
Electrical to Rotation Component
Electrical to Thrust Component
Value
Design B
Design A
Design C
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Combine and simulate
Solar-Boat
Sub system
Electrical to Thrust Subsystem
Electrical to Rotation Component
Electrical to Thrust Component
Electrical to Rotation
Component 1
Component 2
Electrical to Thrust
Component 1
Component 2

Summary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Formal Structure (Modelica)
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Level 0 [Functional Architecture Primary Value]
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Level 4 [Subsystem Components]
Key Point 3: Hierarchy same across all model types
Racing in Solar-Boat Race Event
Solar-Boat
Driving forward
Floating
Sub process
Subsystem
Converting electrical to thrust
Electrical to Thrust Subsystem
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Presentation Overview

1. Problems to address
2. Proposed solution
3. Proposed solution – Detailed description
4. Discussion

Presentation Overview

1. Problems to address

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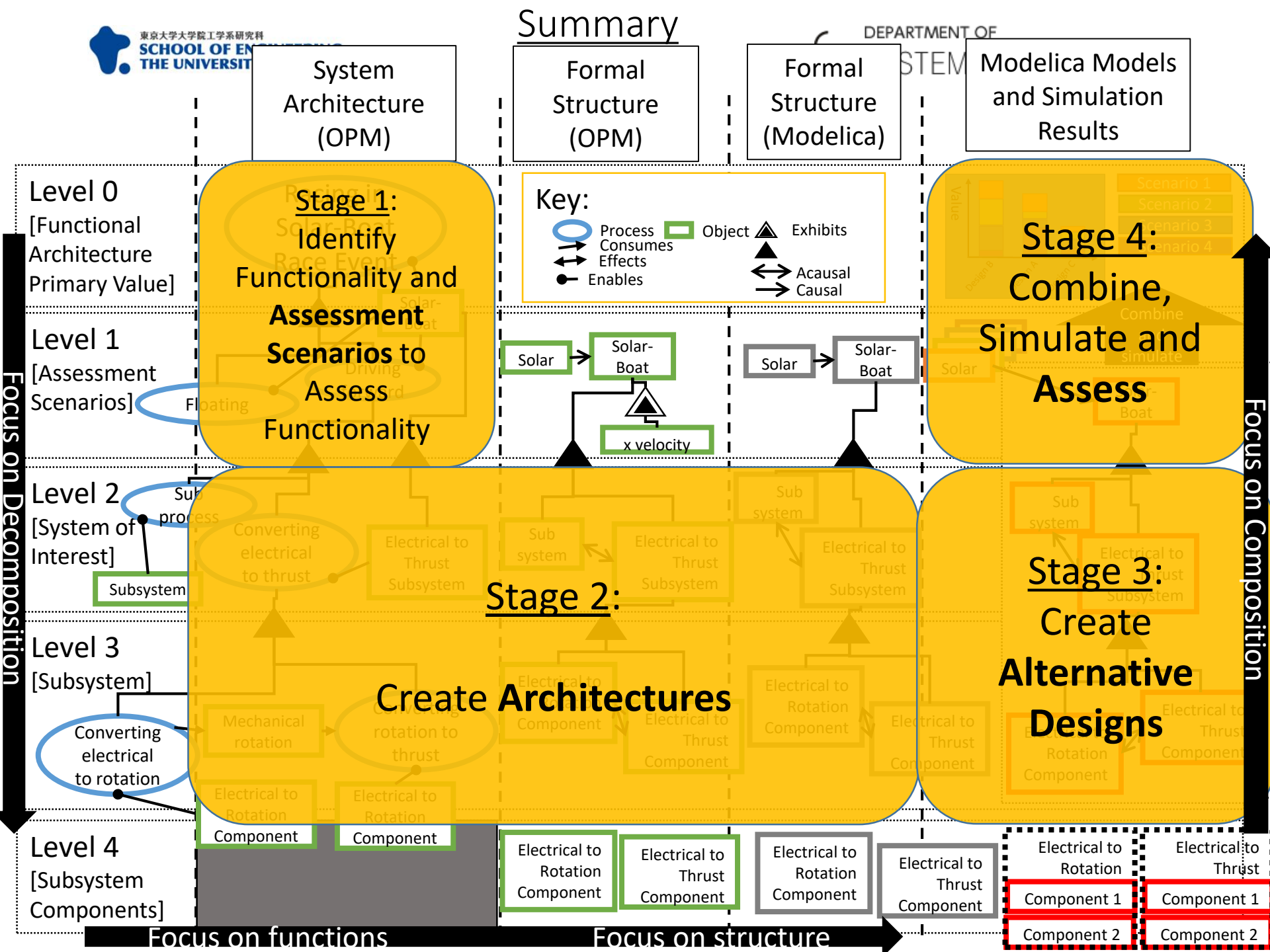
3. Proposed solution – Detailed description

4. Discussion

Summary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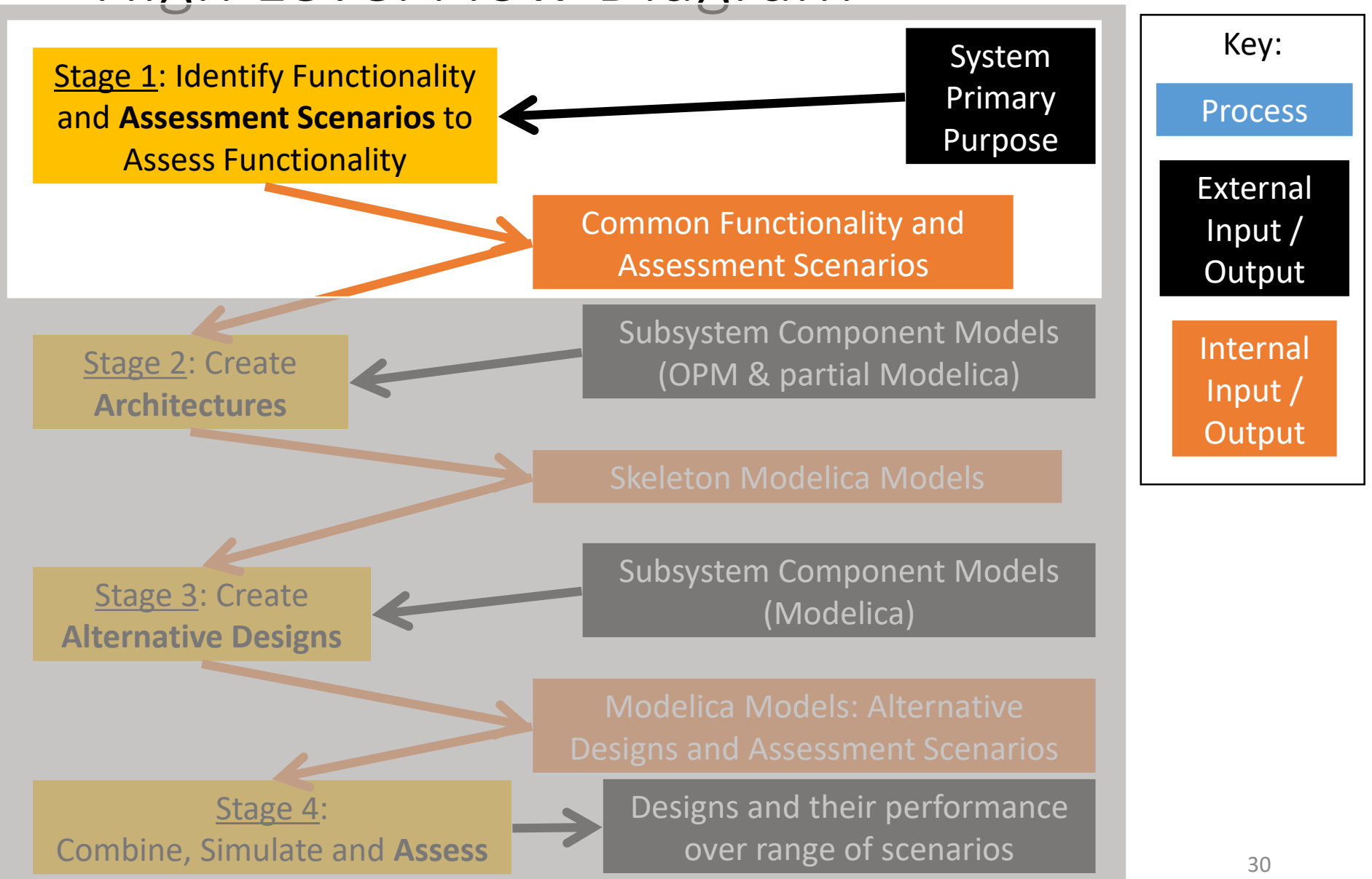
Stage 1: Identify Functionality and Assessment Scenarios to Assess Functionality
Key:
Process
Object
Exhibits
Consumes
Effects
Enables
Acausal
Causal
Solar
Solar-Boat
x velocity
Stage 4: Combine, Simulate and Assess
Stage 2: Create Architectures
Stage 3: Create Alternative Designs
Subsystem
Converting electrical to rotation
Mechanical rotation
Converting rotation to thrust
Converting electrical to thrust
Electrical to Thrust Subsystem
Sub system
Electrical to Rotation Component
Electrical to Thrust Component
Component 1
Component 2
Focus on Decomposition
Focus on Composition
Focus on functions
Focus on structure

High Level Flow Diagram



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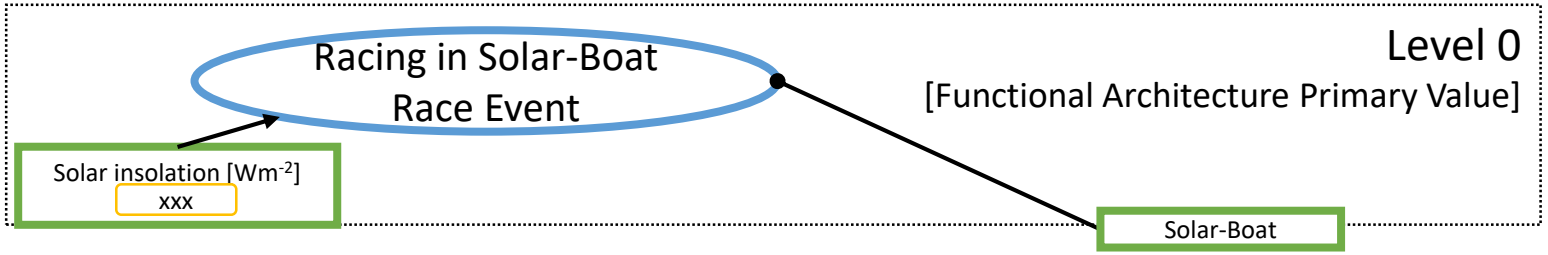

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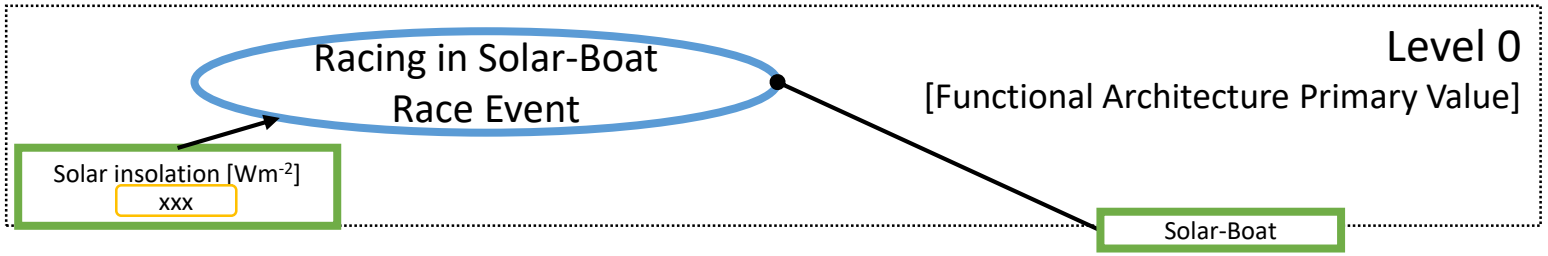
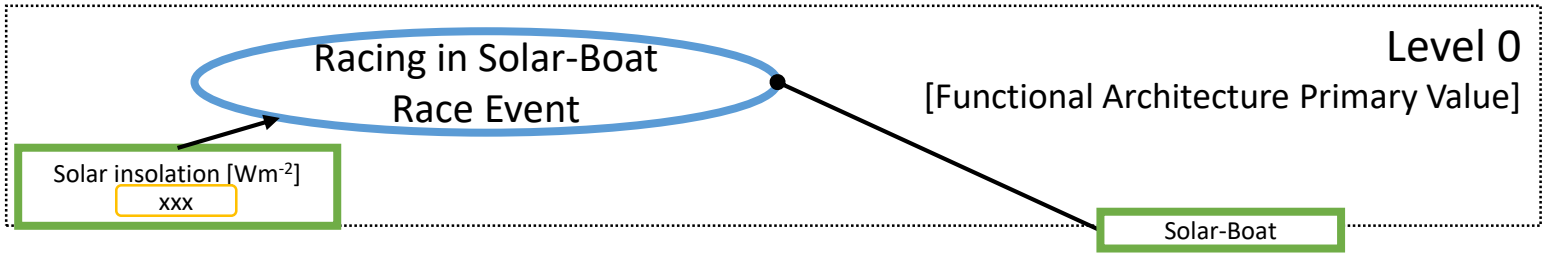


Focus on Decomposition

Stage 1: Identify Functionality and Assessment Scenarios to Assess Functionality



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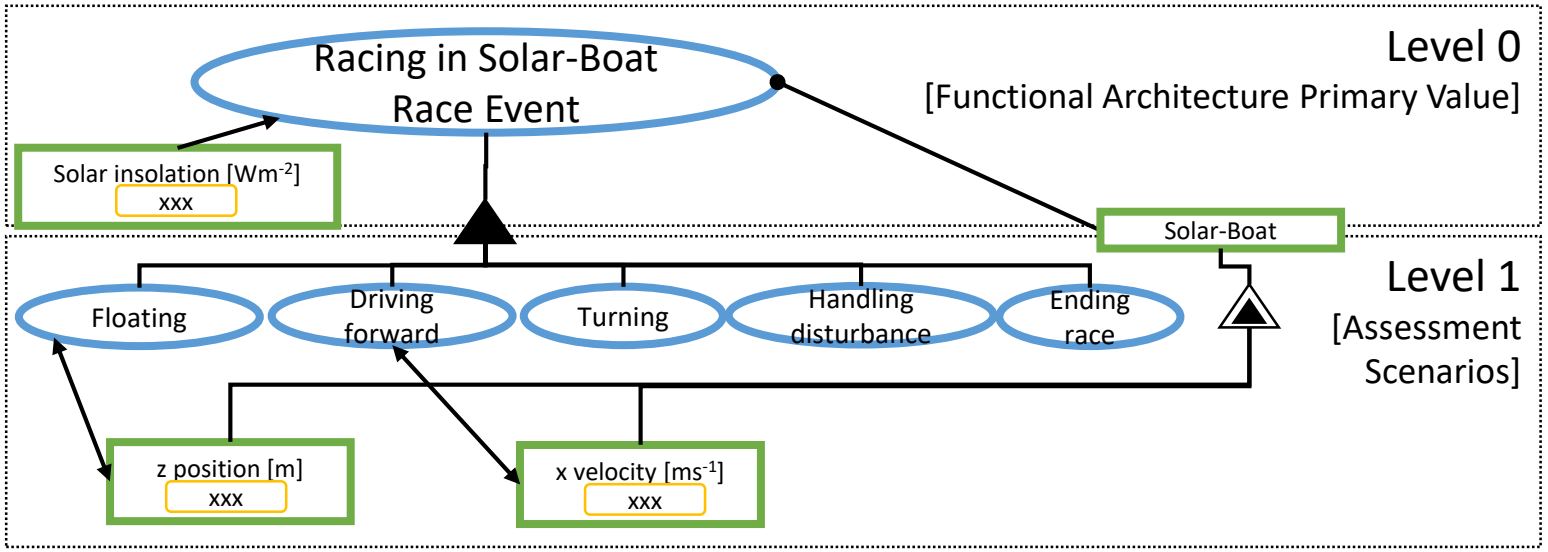

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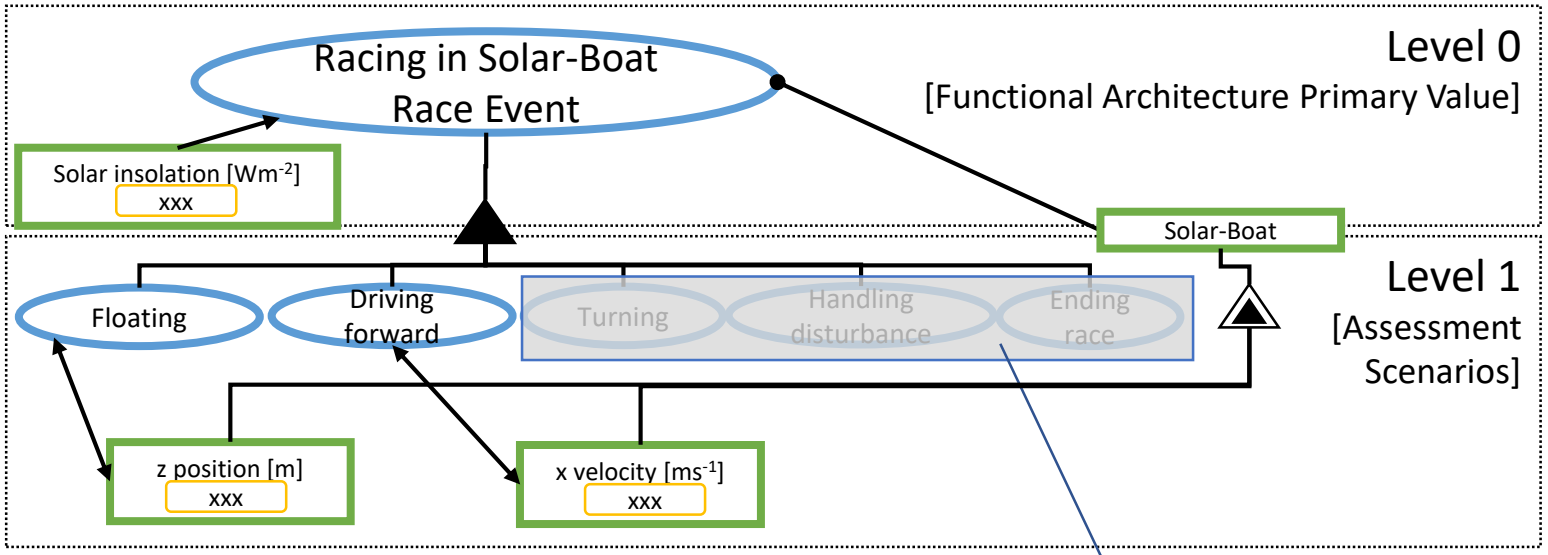

Assume want to create a simple design which cannot perform these functions. Therefore do not decompose.

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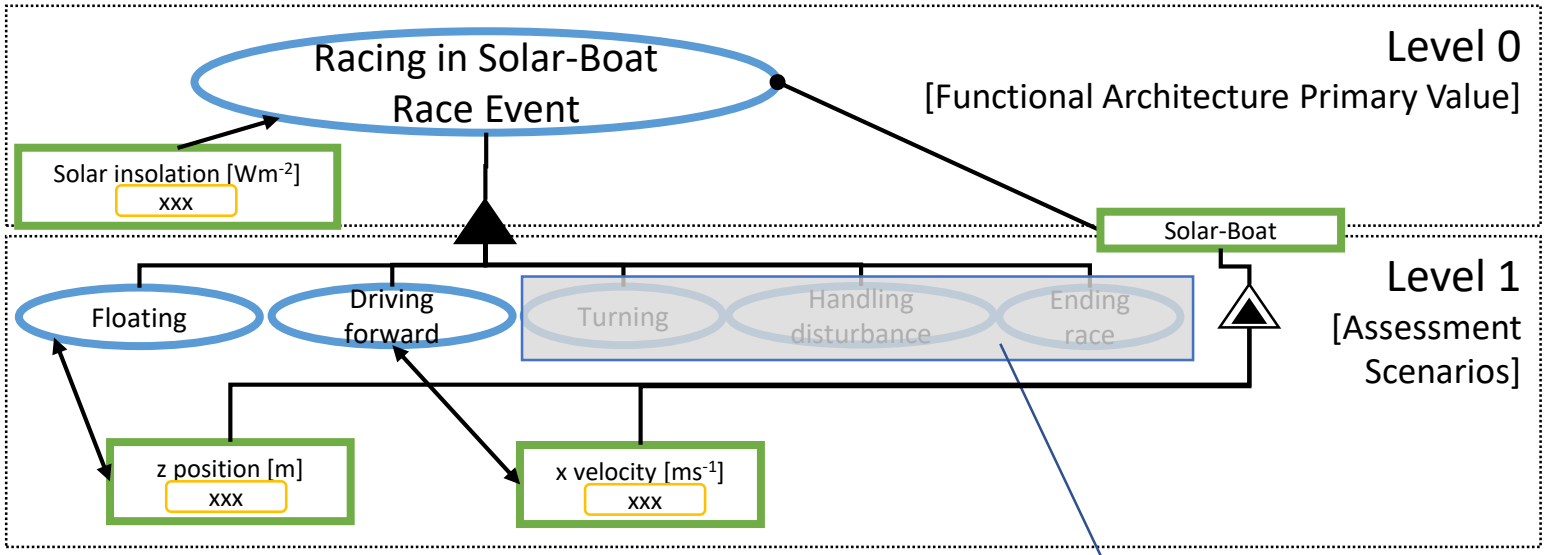

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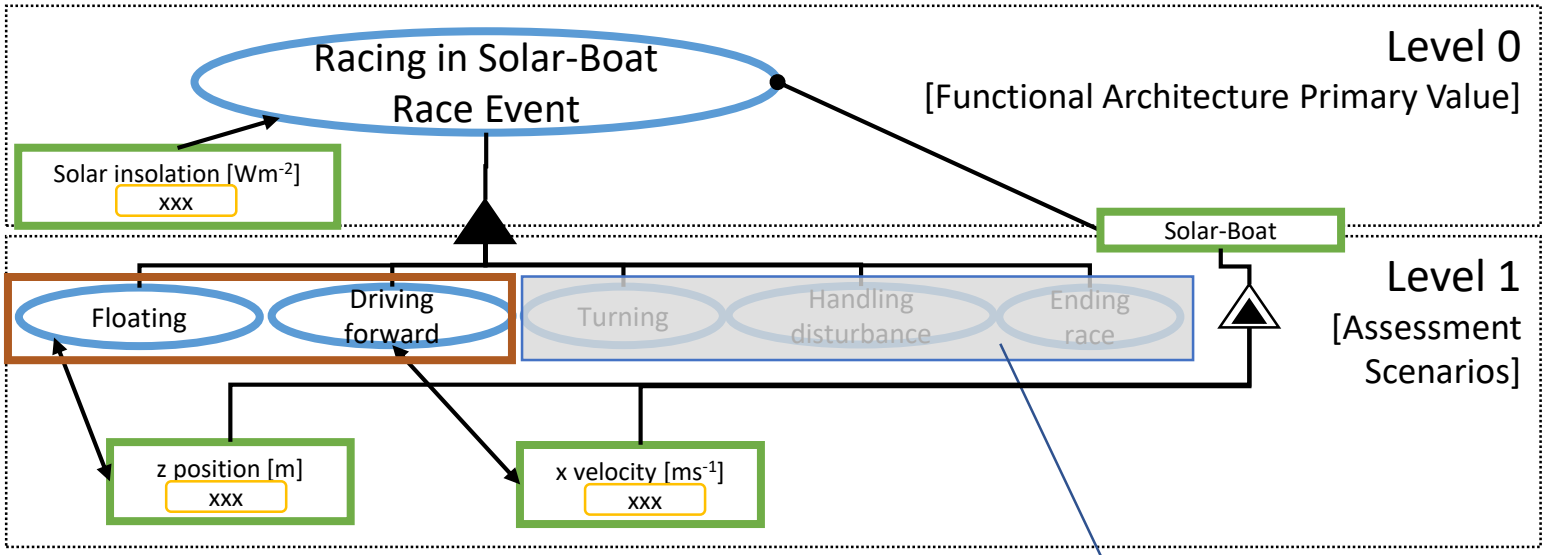

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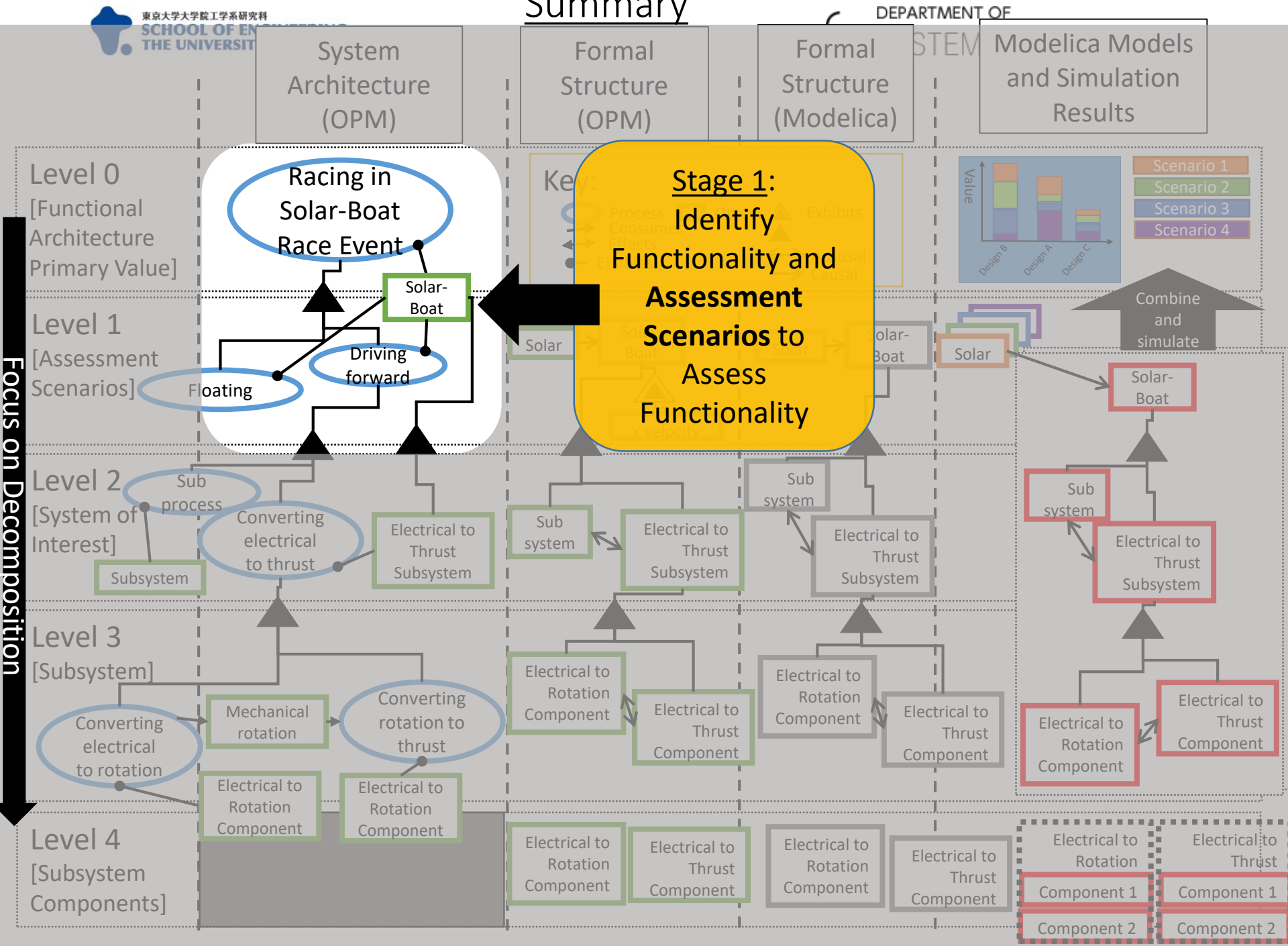
Focus on Decomposition

Summary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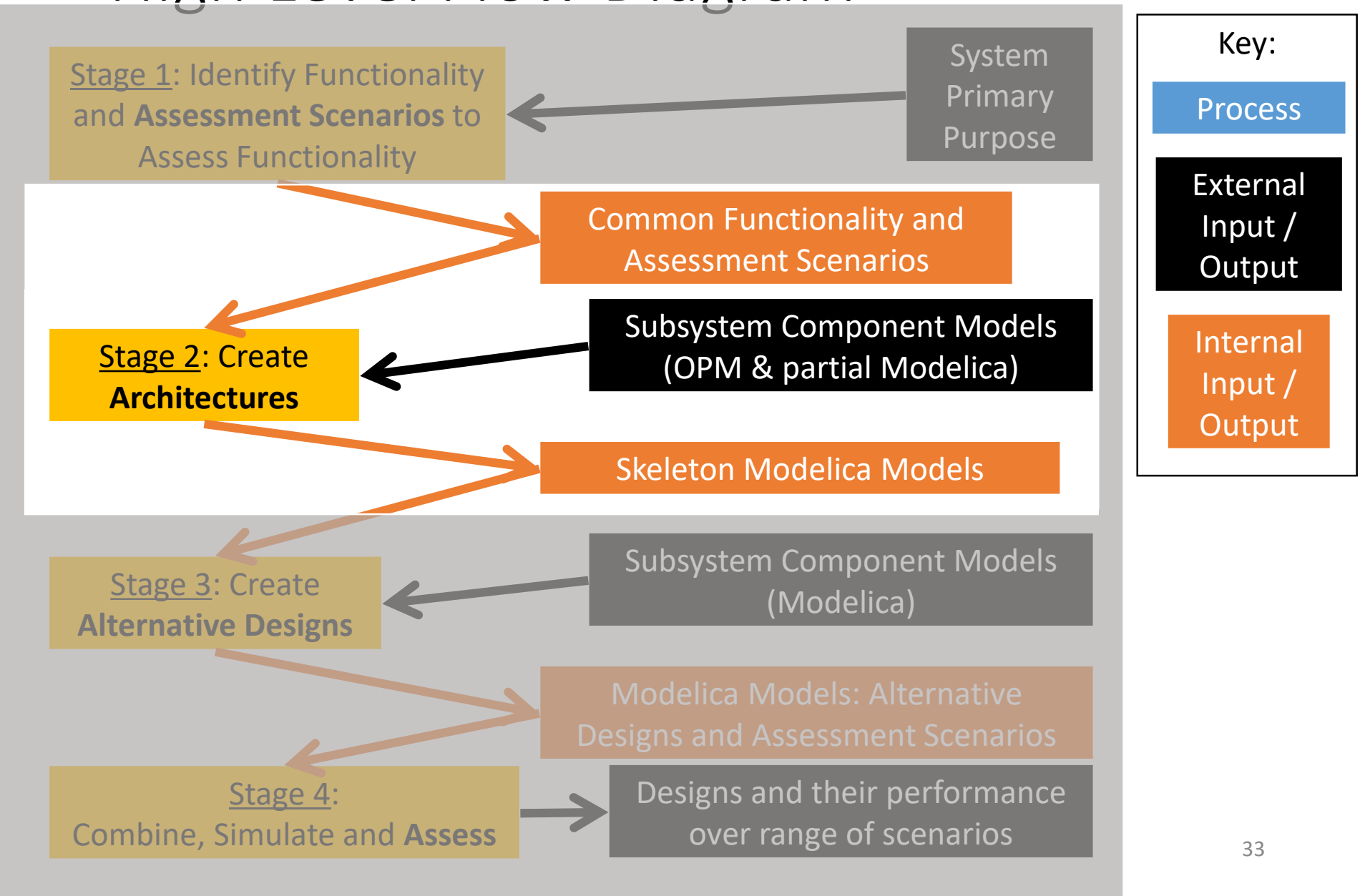
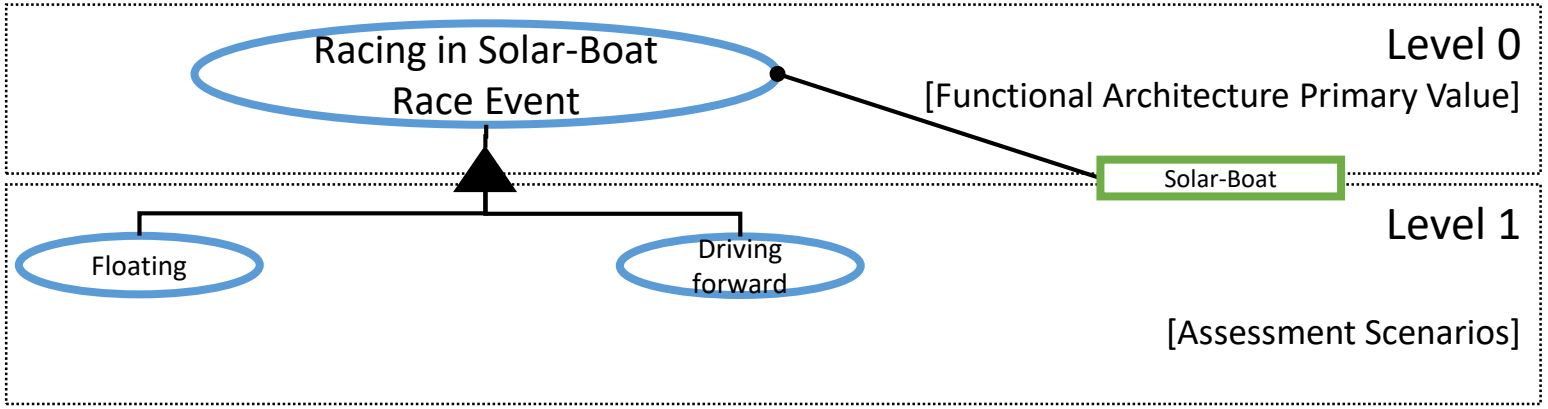
High Level Flow Diagram



Stage 2: Create Architectures
a. Decompose the Assessment Scenario Processes



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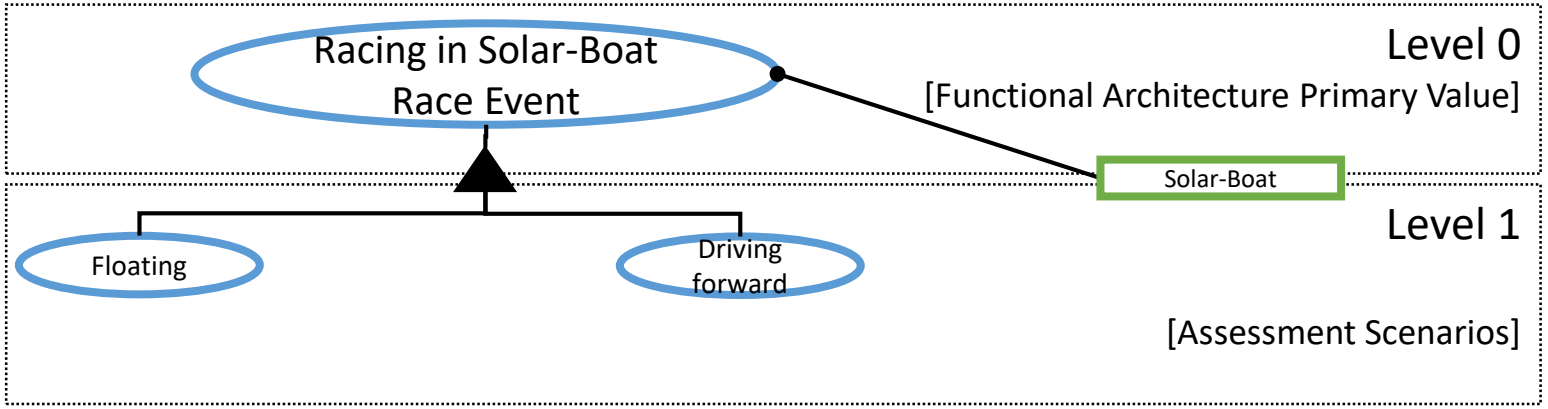

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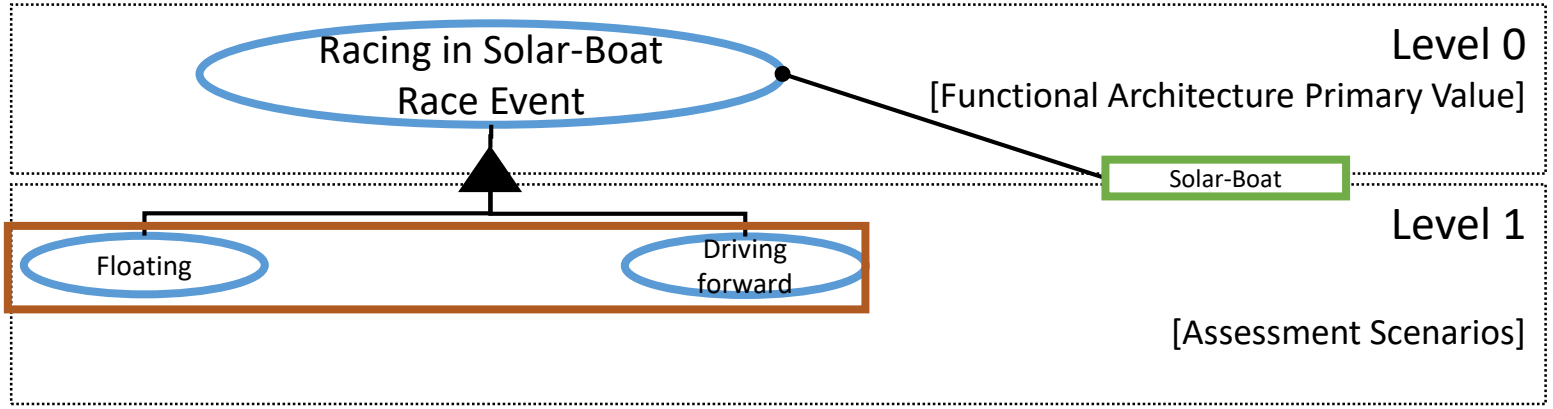

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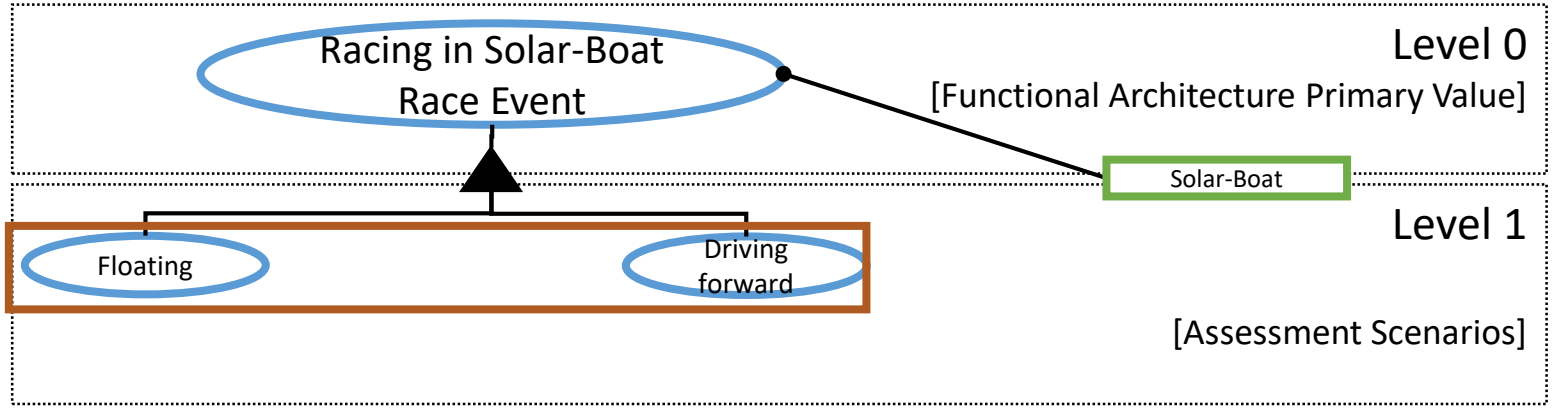

Focus on Decomposition

Stage 2: Create Architectures
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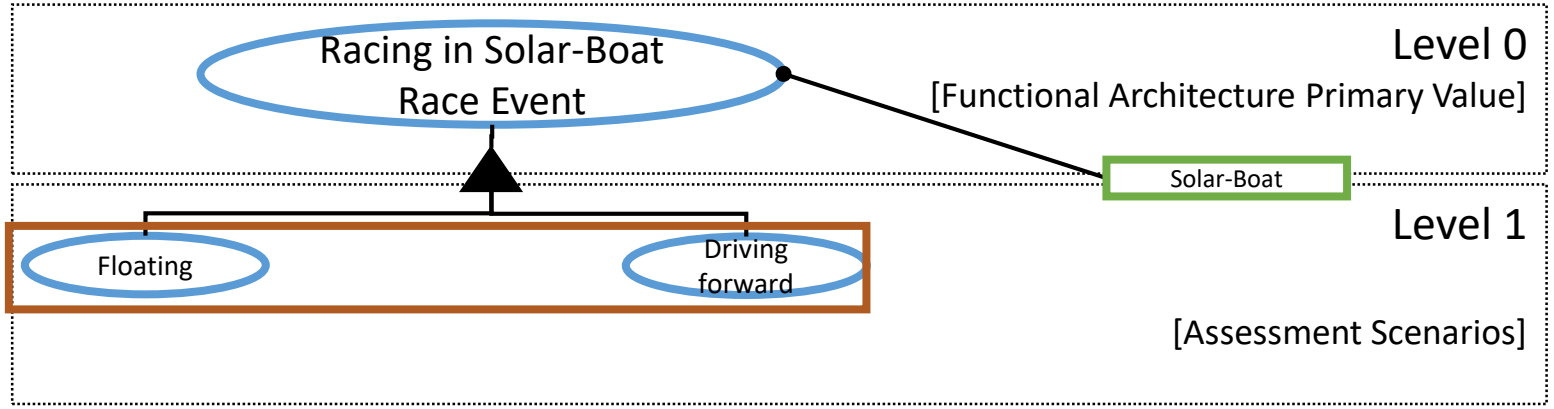

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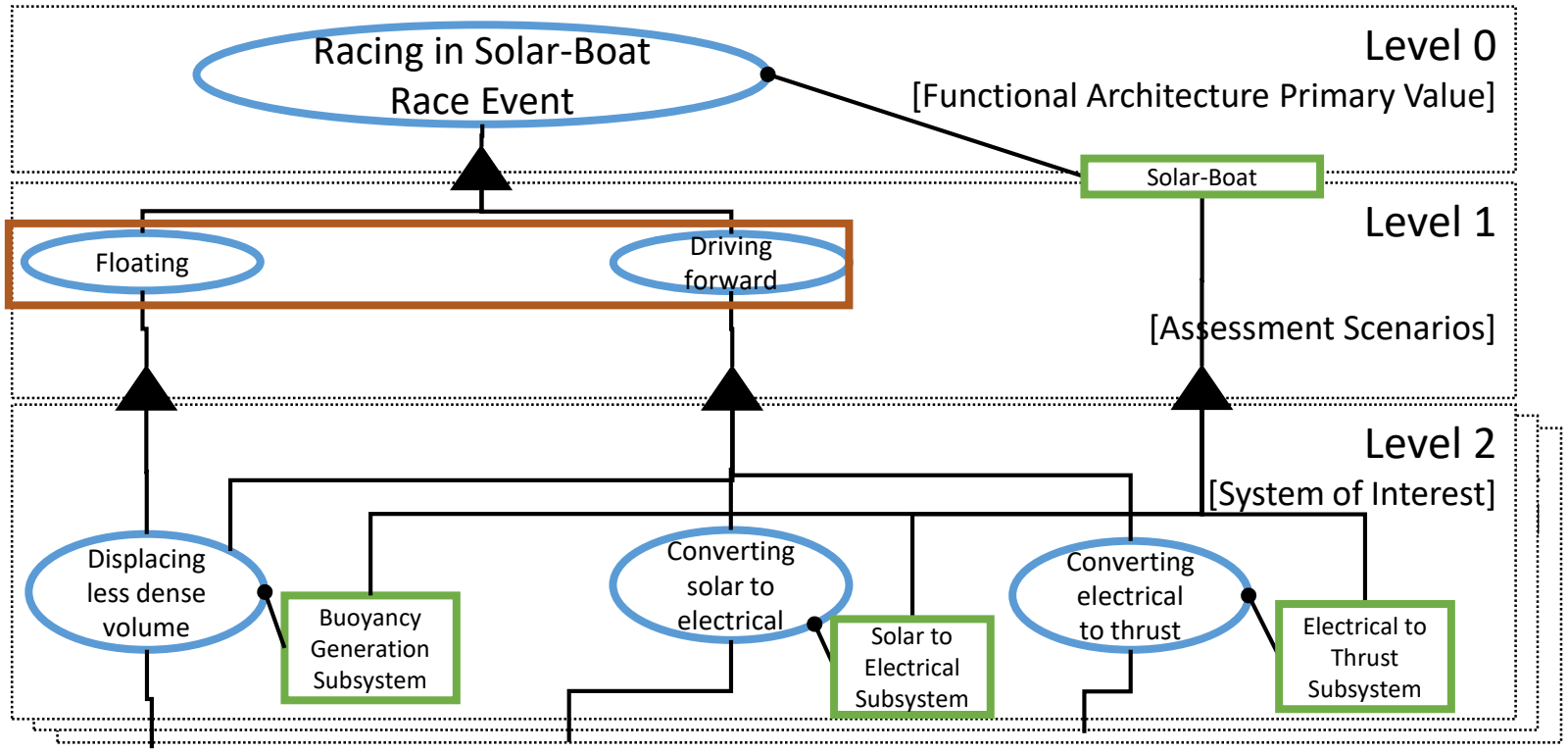

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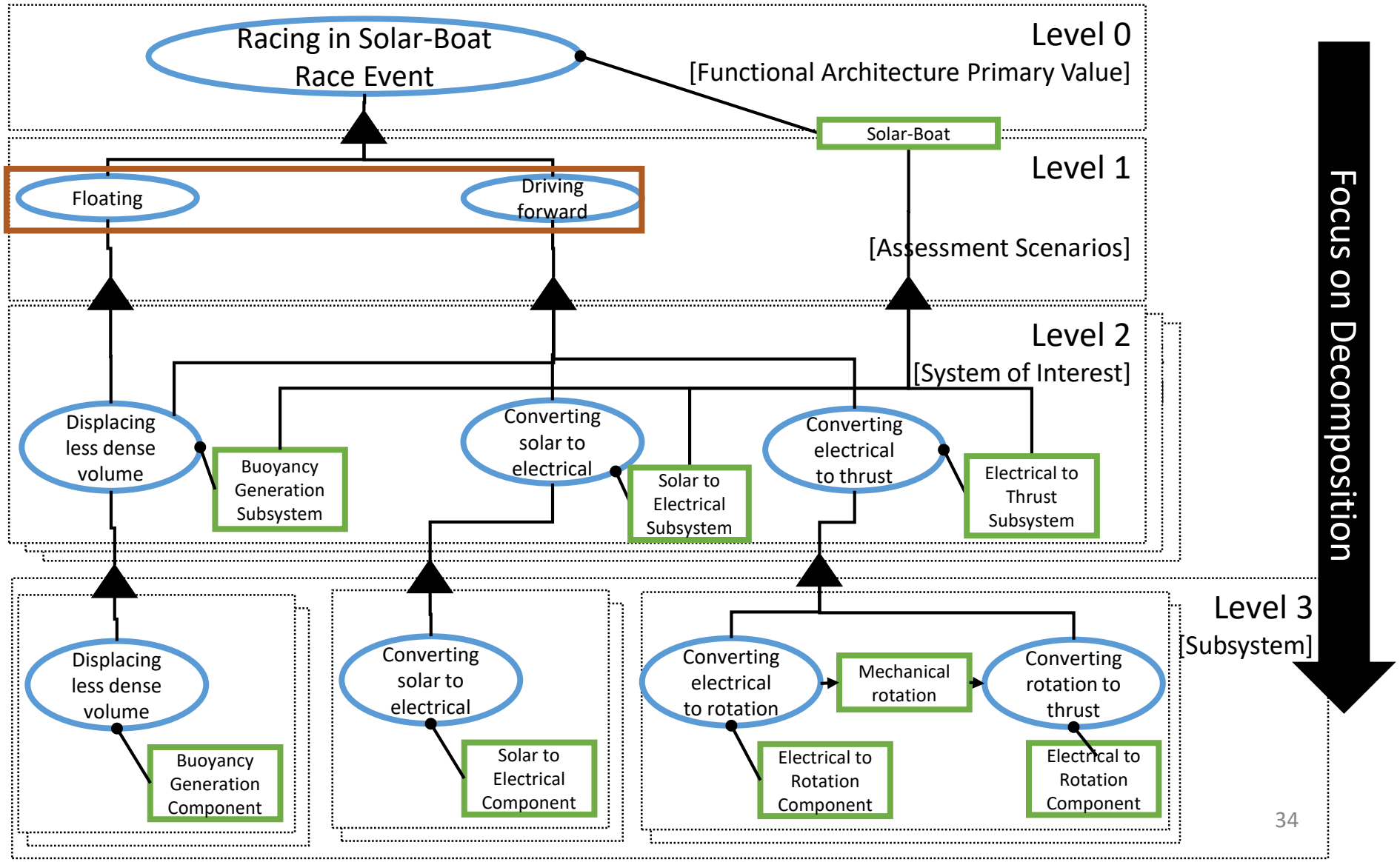

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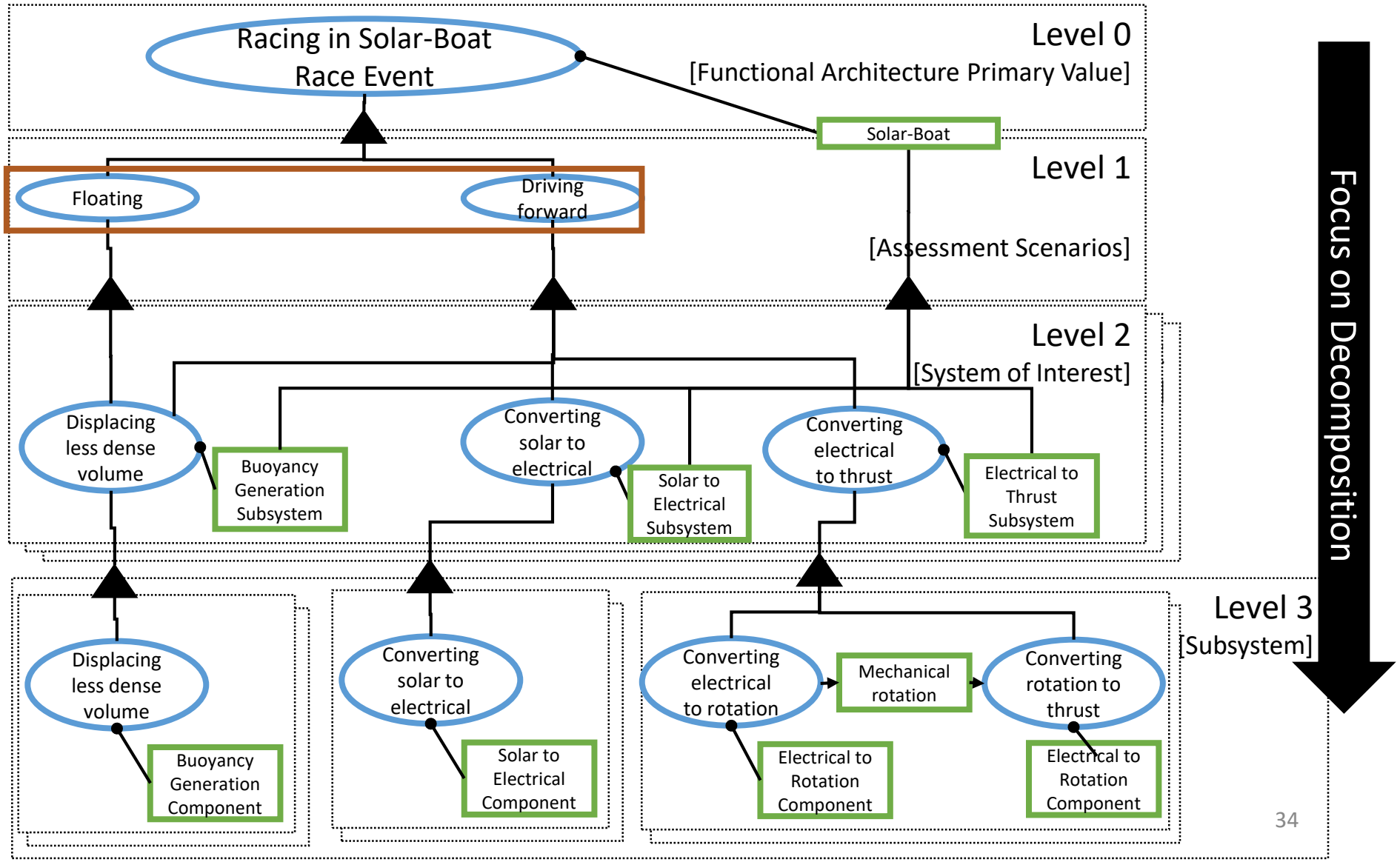

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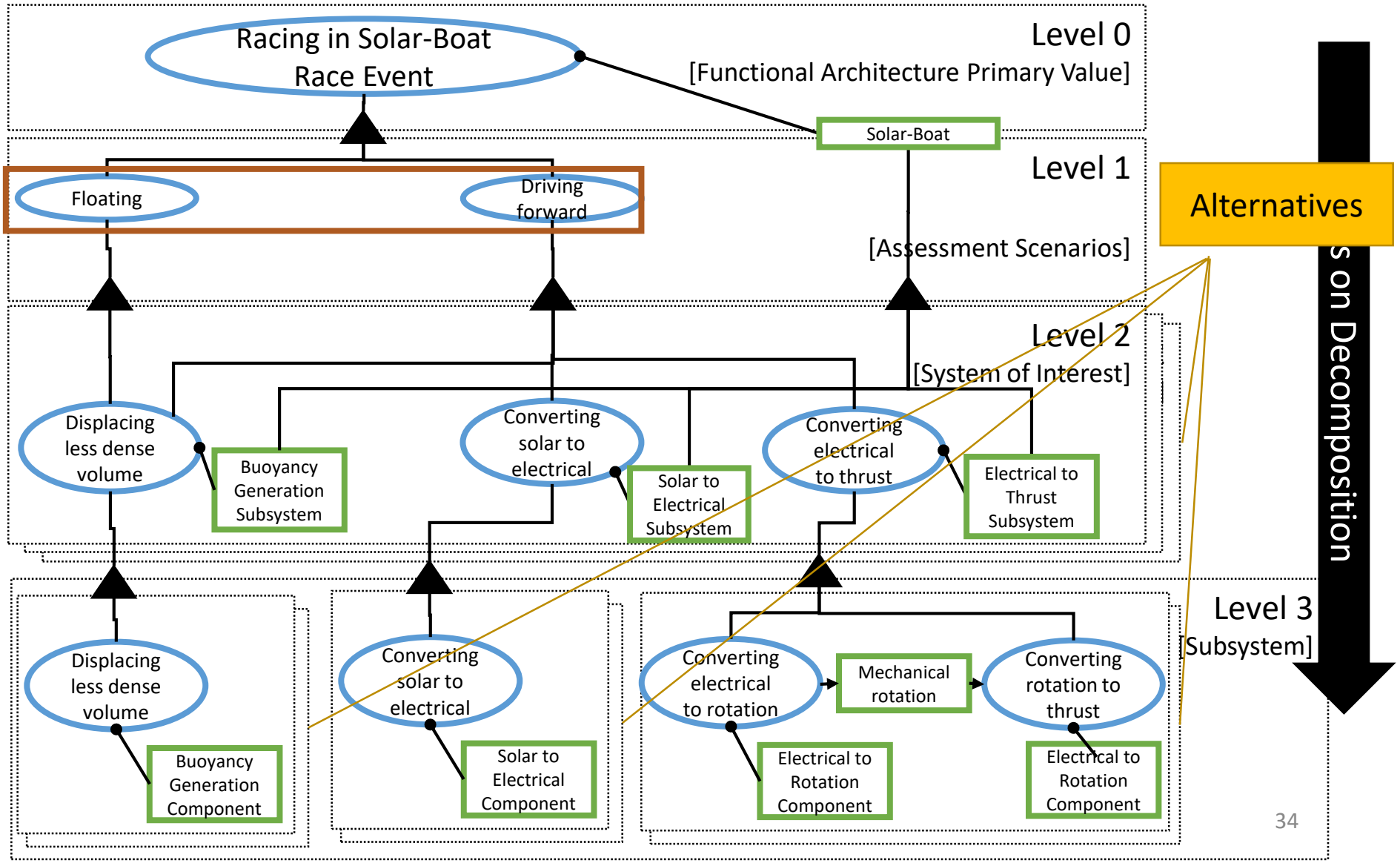
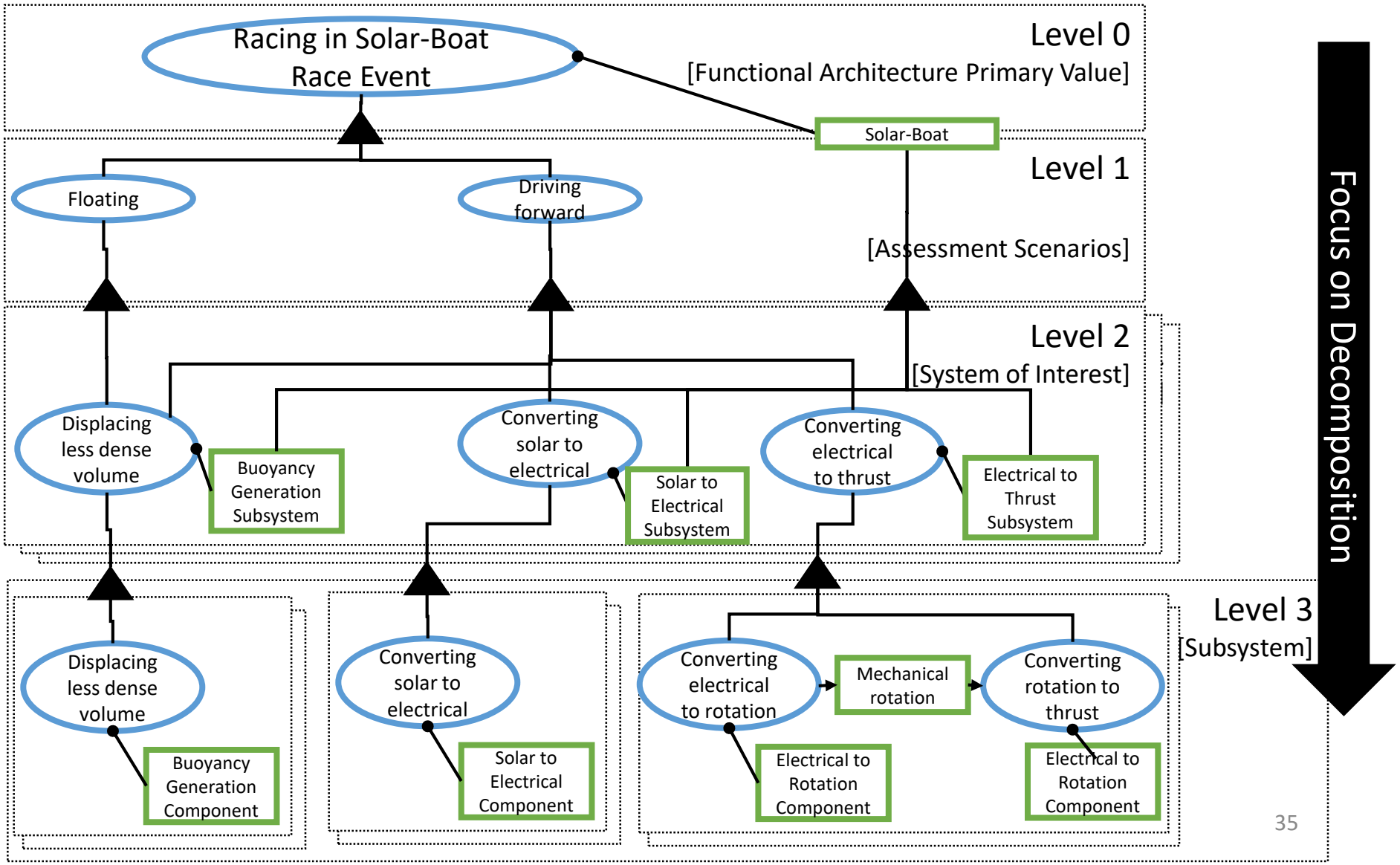


Stage 2: Create Architectures
b. Create a Formal Structure (in OPM)



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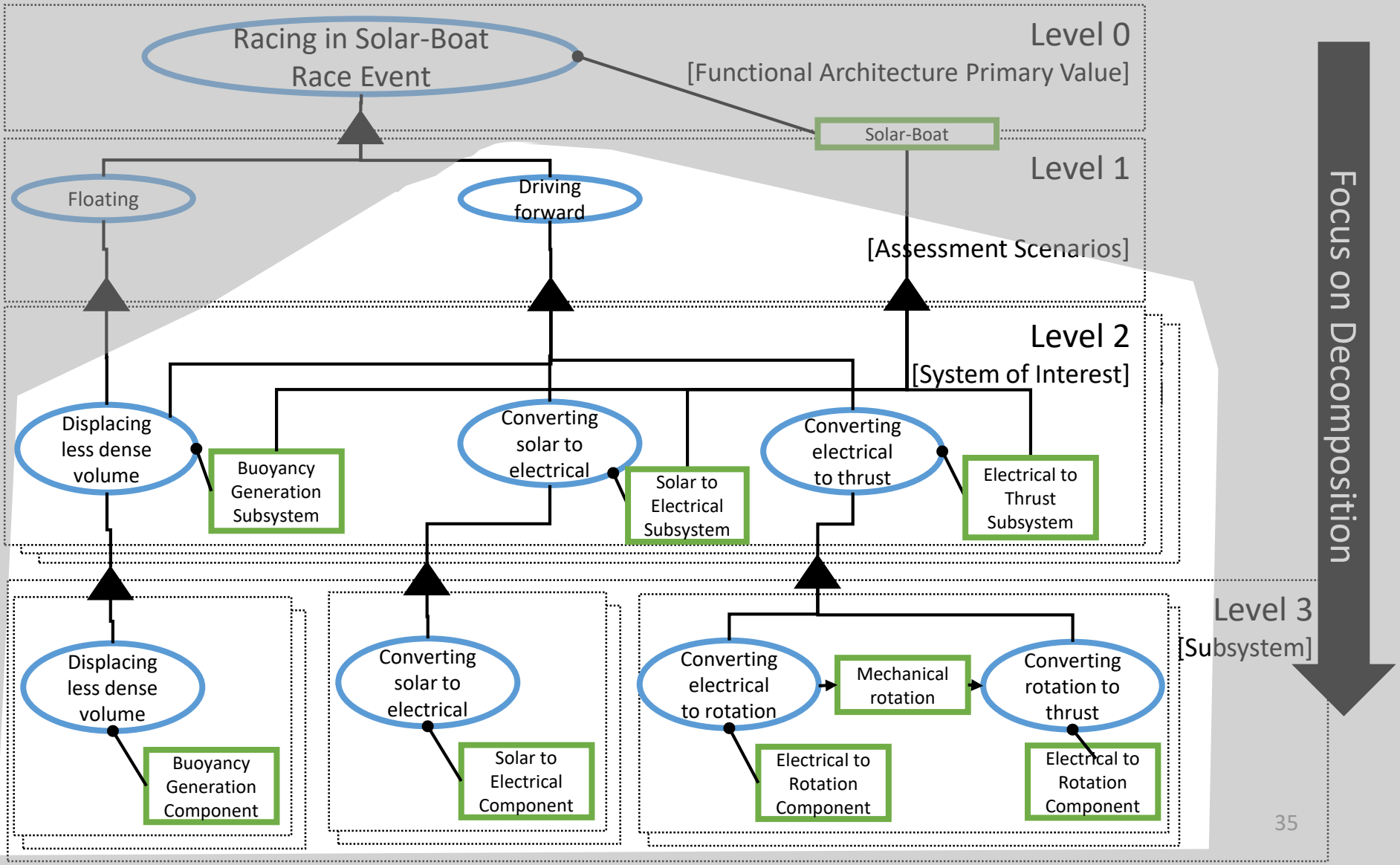

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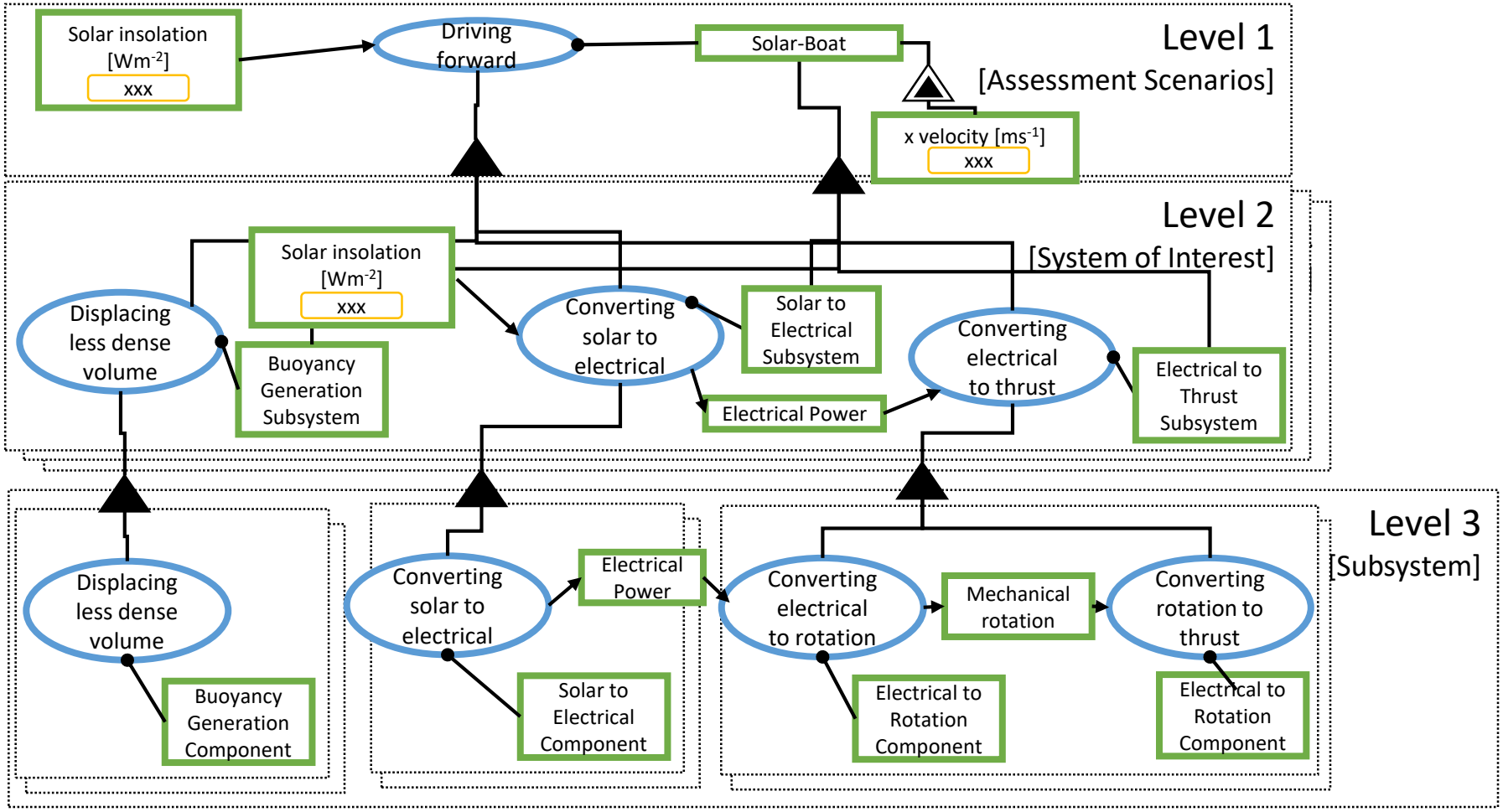

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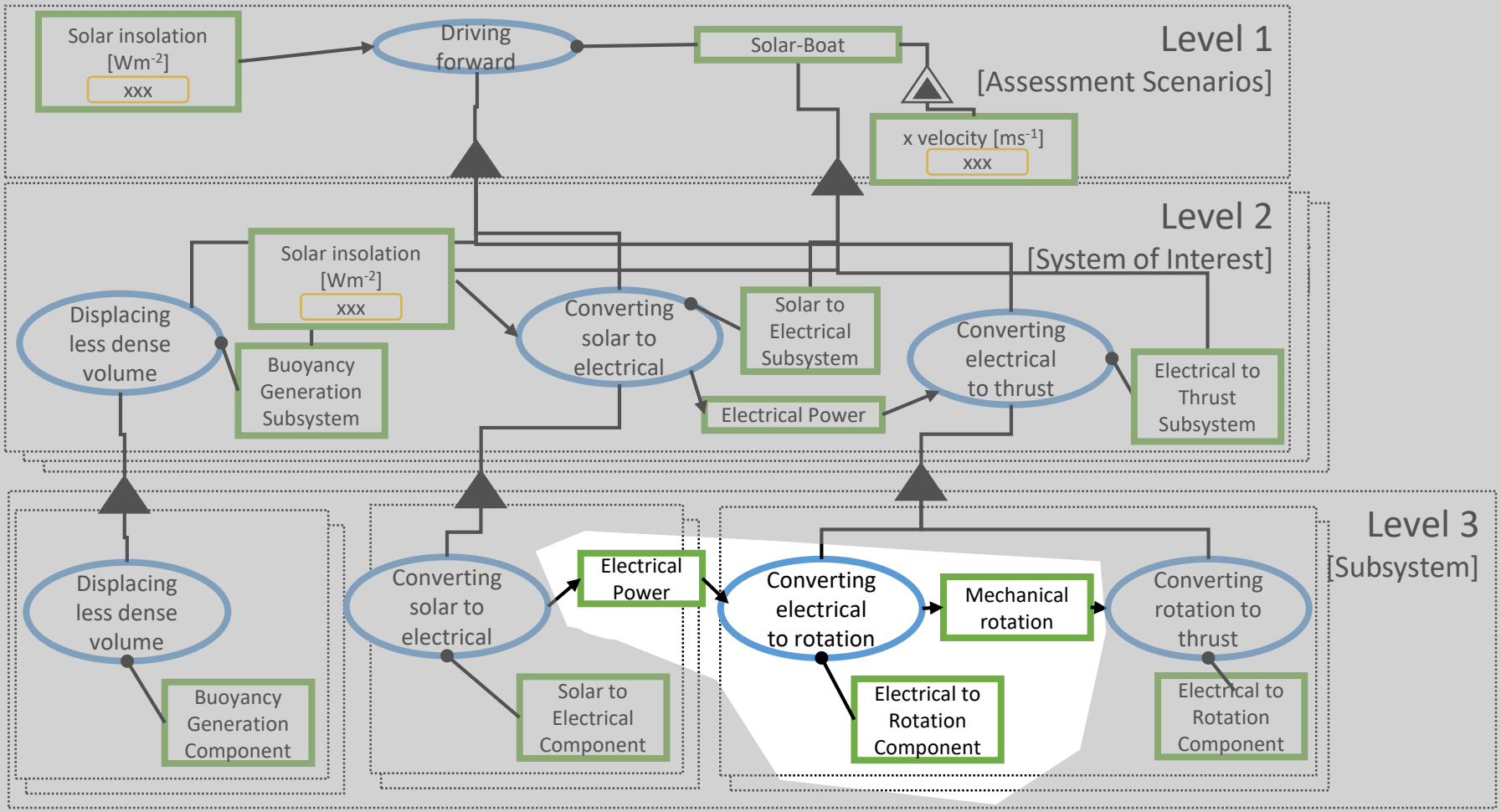
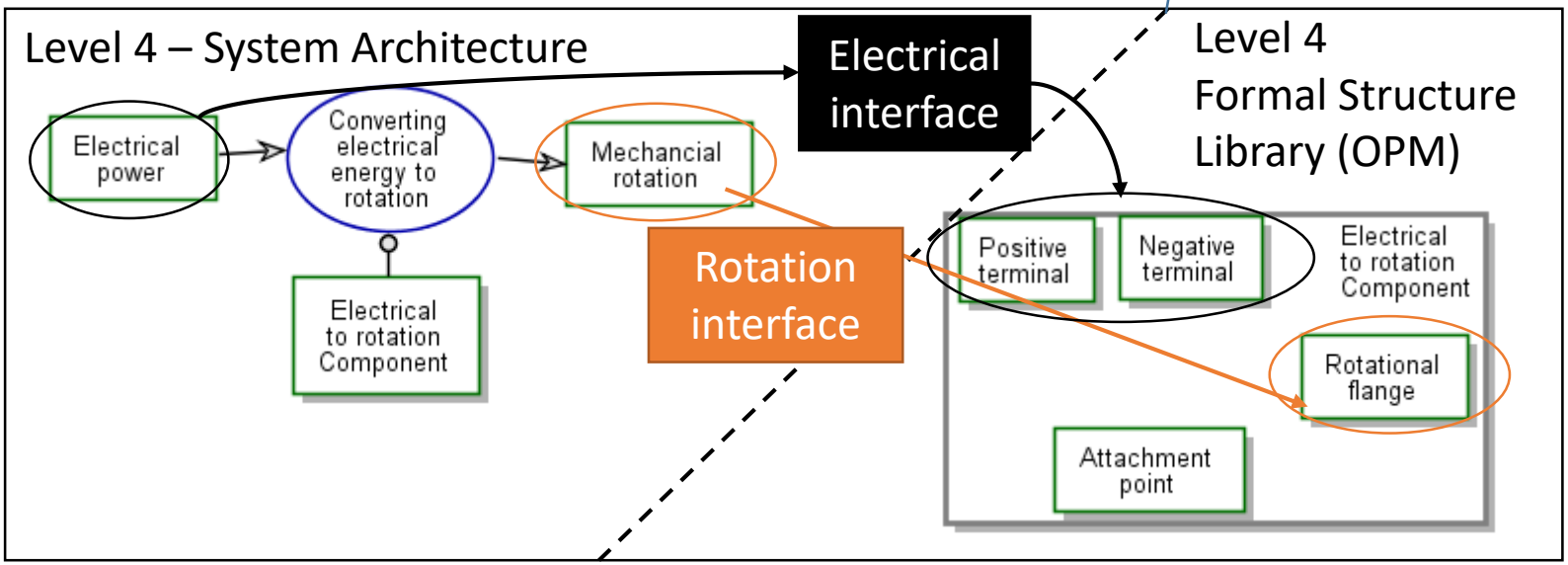


Stage 2: Create Architectures
b. Create a Formal Structure (in OPM)

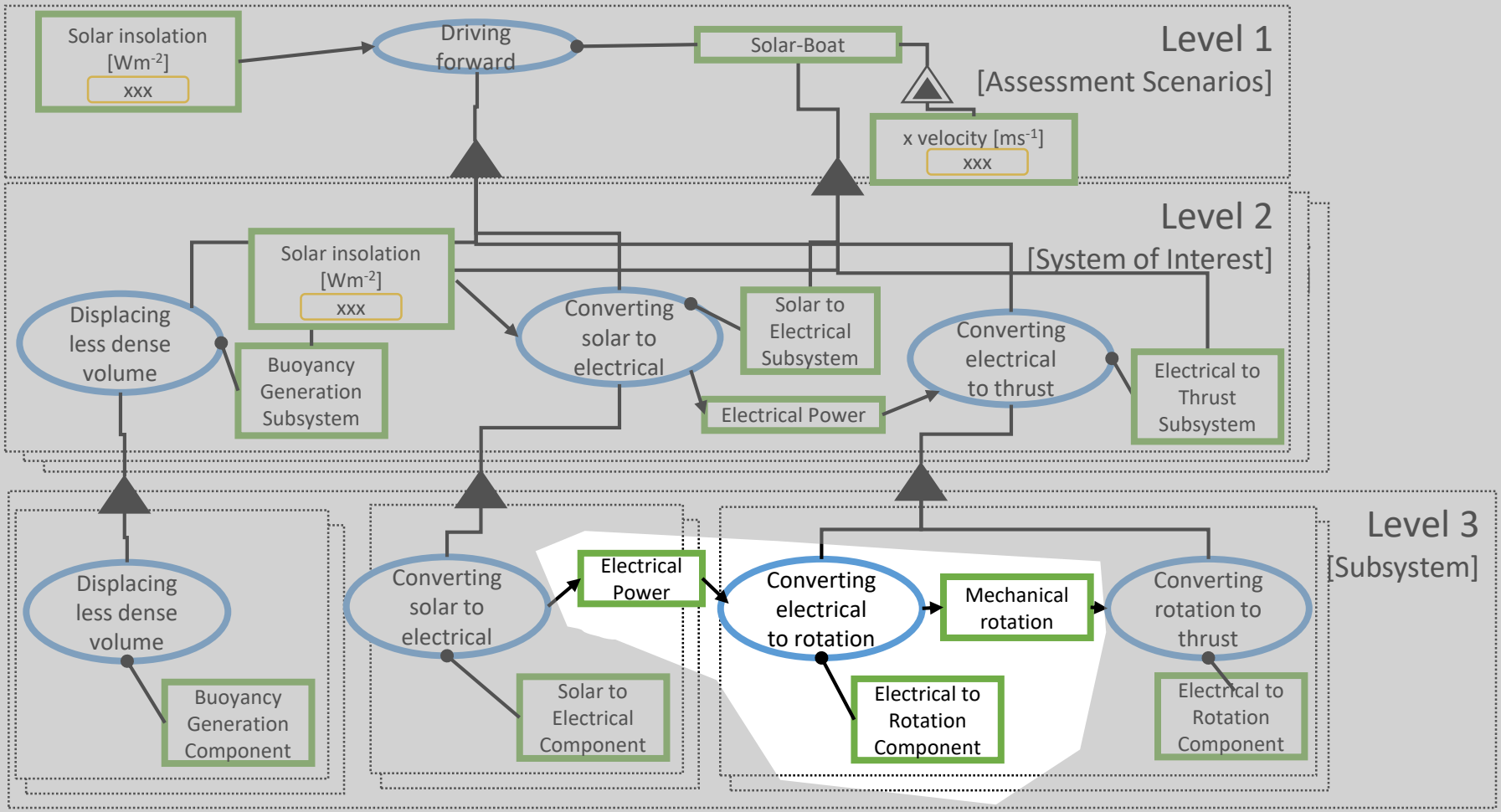
Assume there is a library of Level 4 Formal Structures in OPM keyed on the equivalent System Architecture.

Enables us to find the right interface.



Focus on functions → Focus on structure

Stage 2: Create Architectures
b. Create a Formal Structure (in OPM)



Stage 2: Create Architectures
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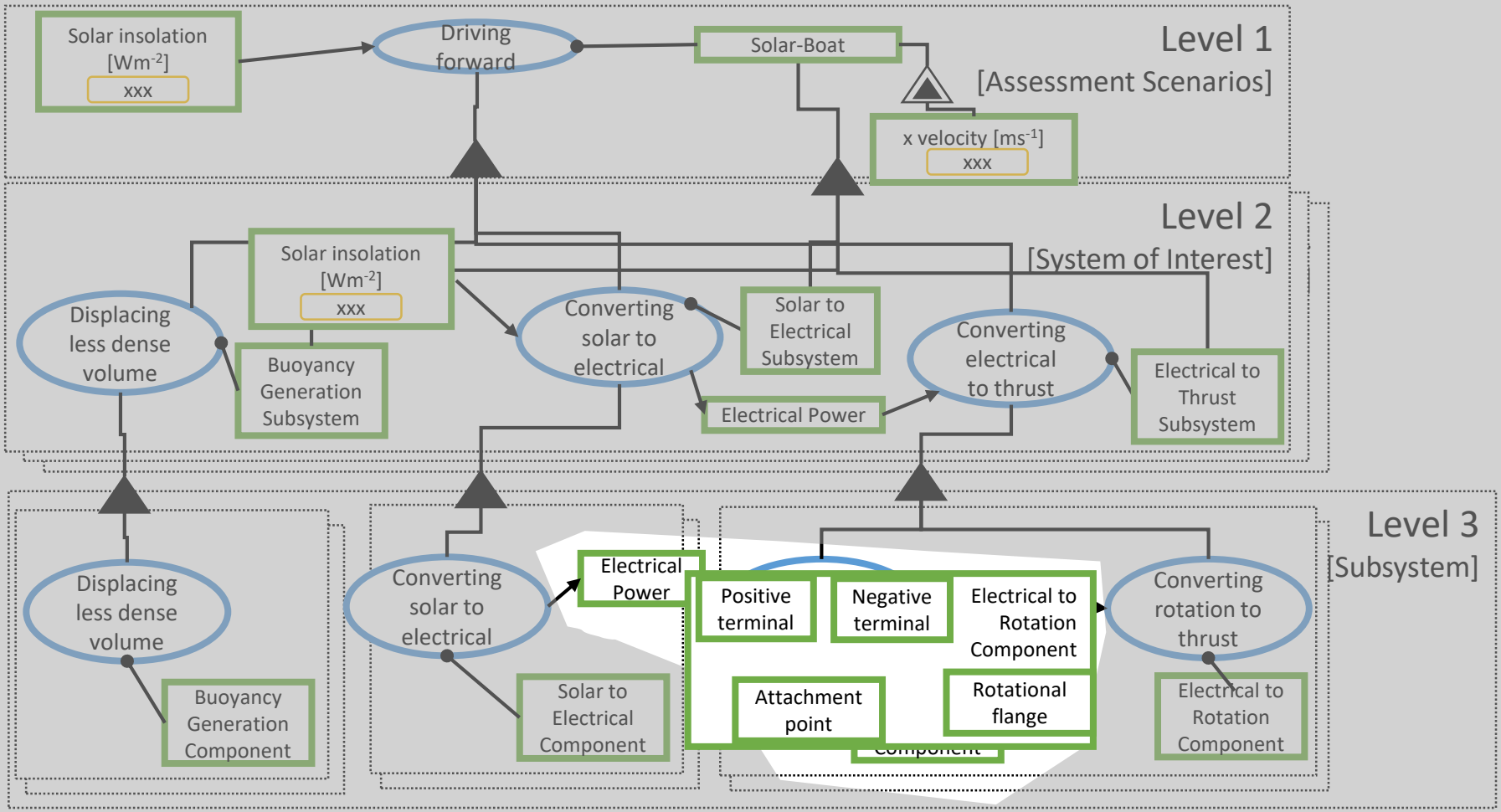

Stage 2: Create Architectures
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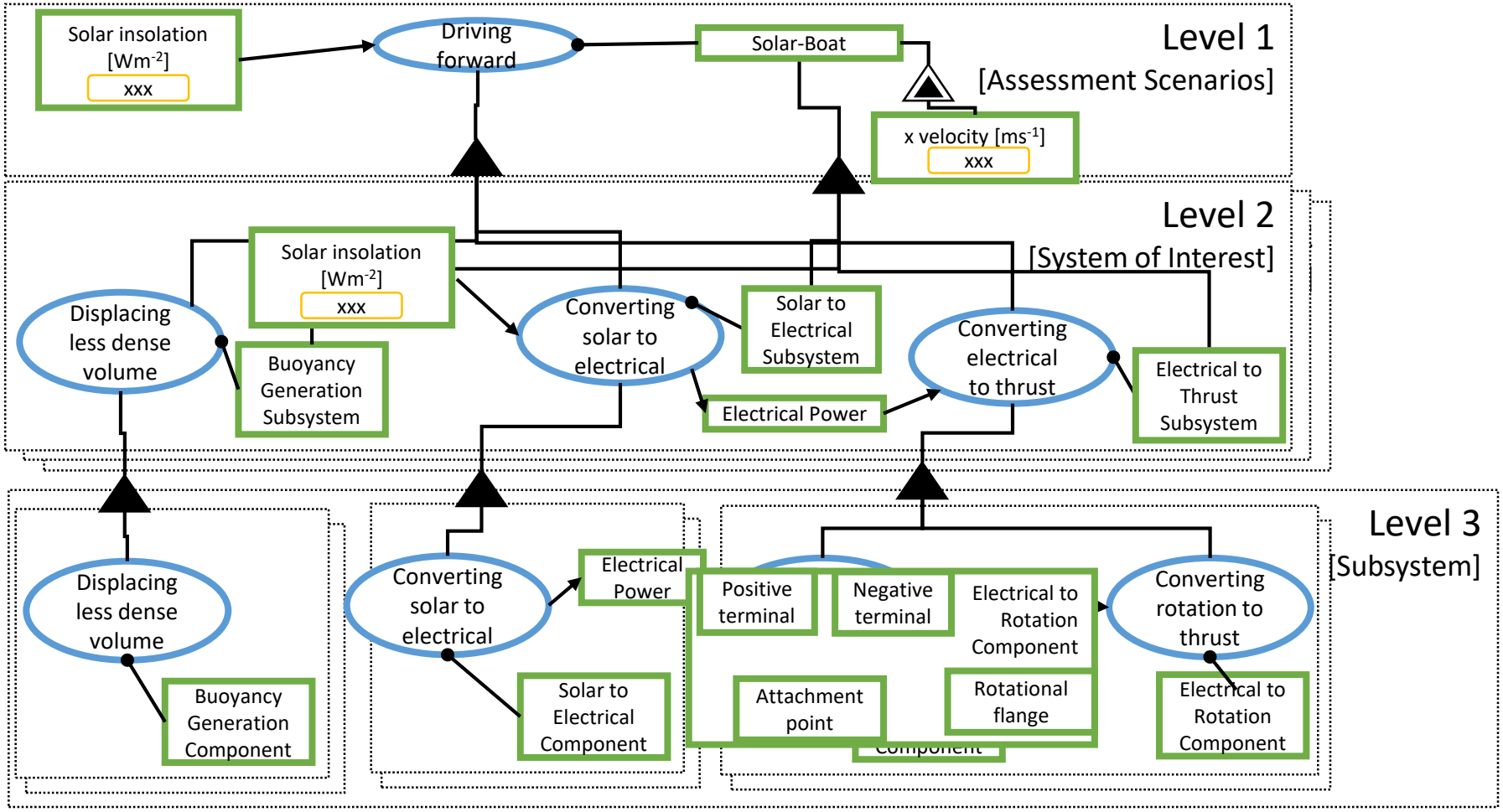
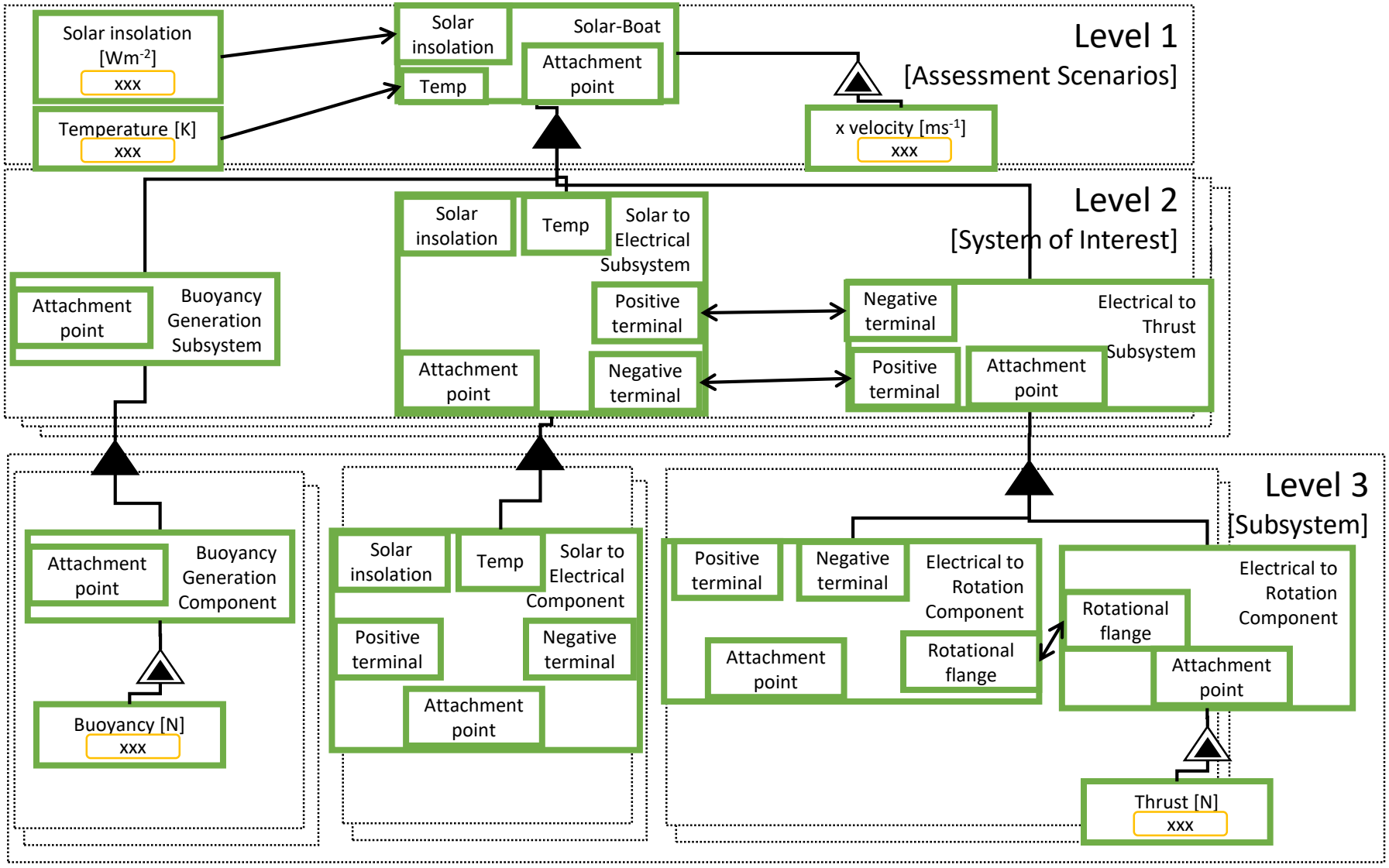
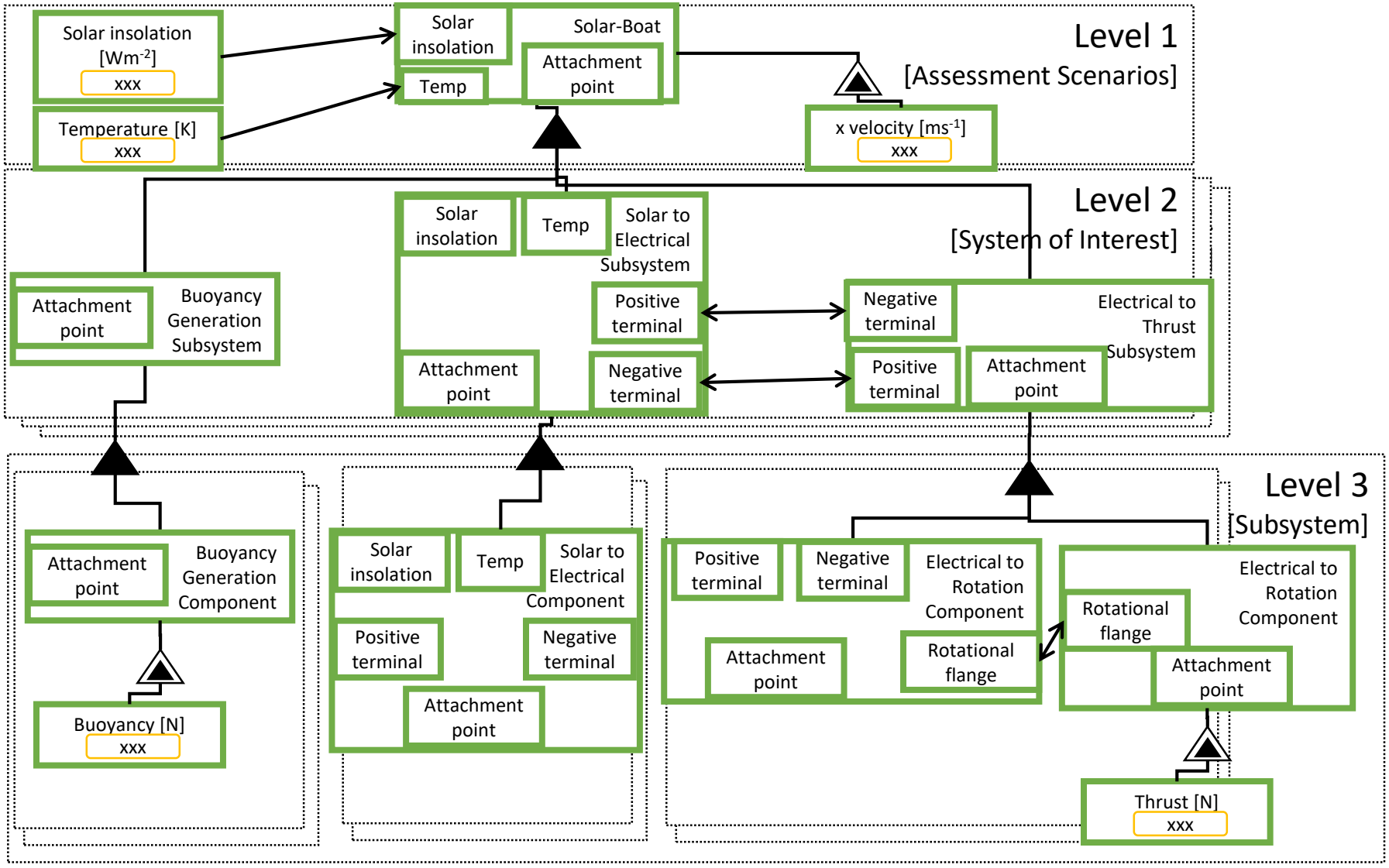


Stage 2: Create Architectures
b. Create a Formal Structure (in OPM)



Stage 2: Create Architectures
c. Create a Formal Structure (in Modelica)



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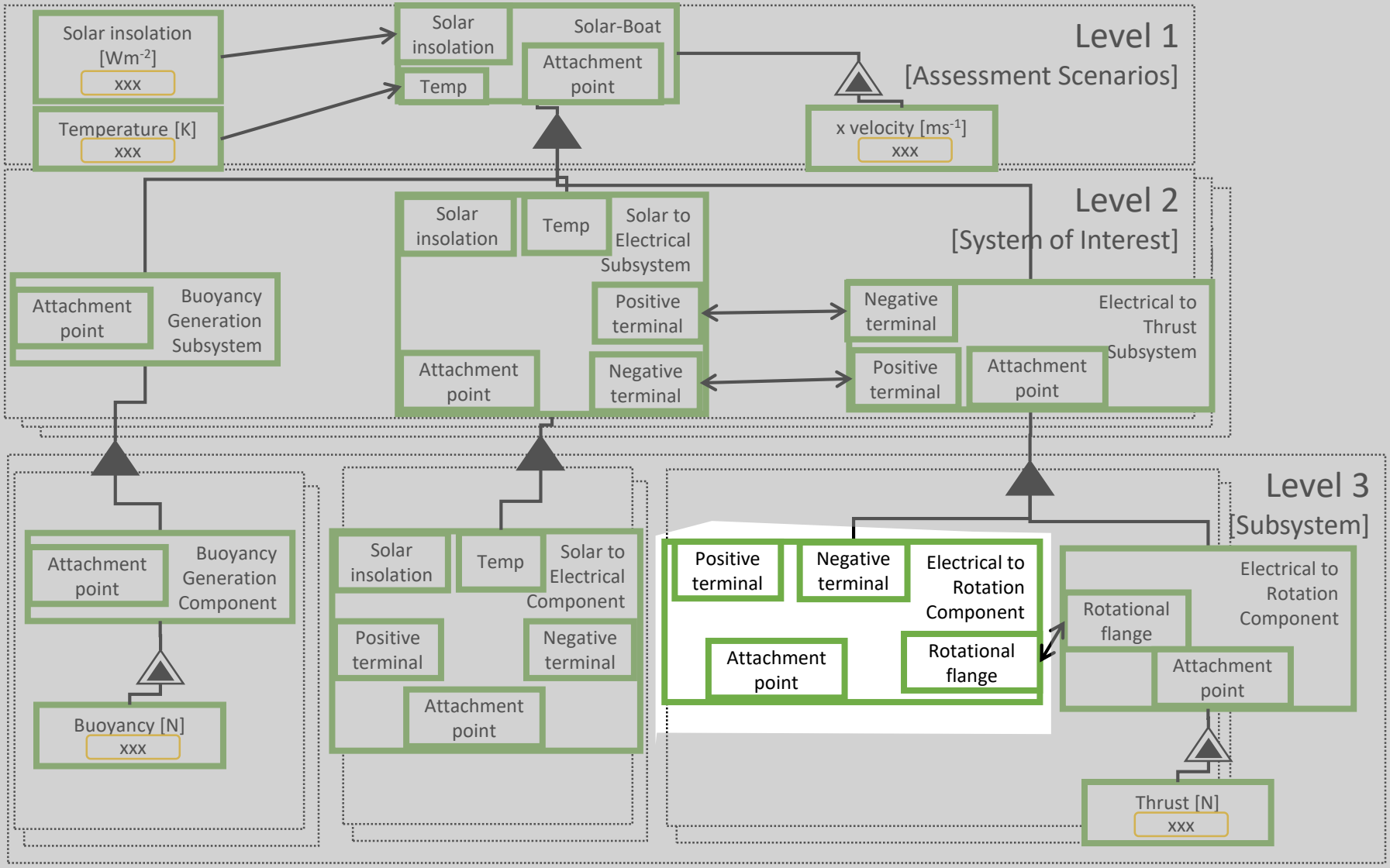
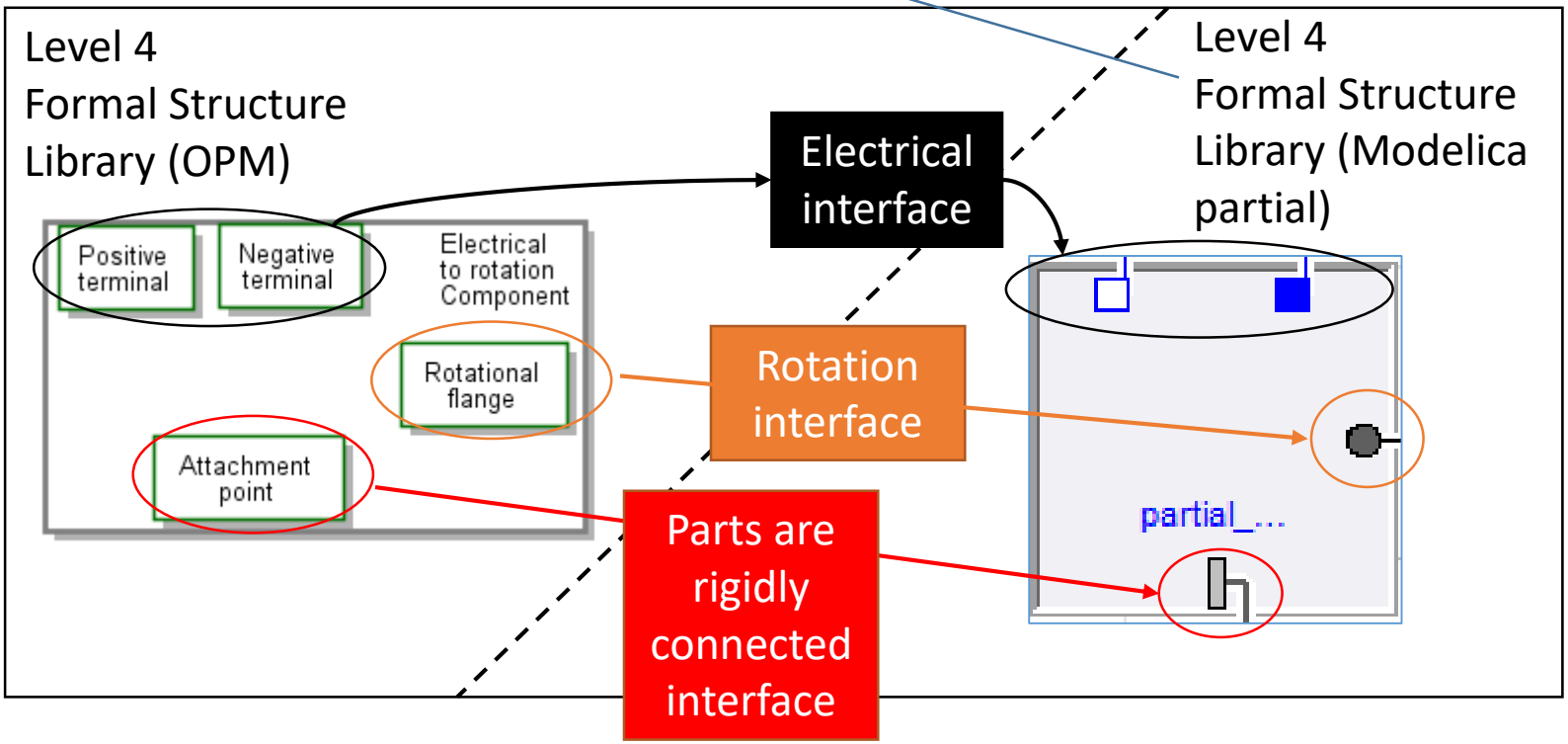


Stage 2: Create Architectures
c. Create a Formal Structure (in Modelica)

Assume there is a library of Level 4 Formal Structures in Modelica.
Enables us to build a model of partial models.
Creating a "skeleton"



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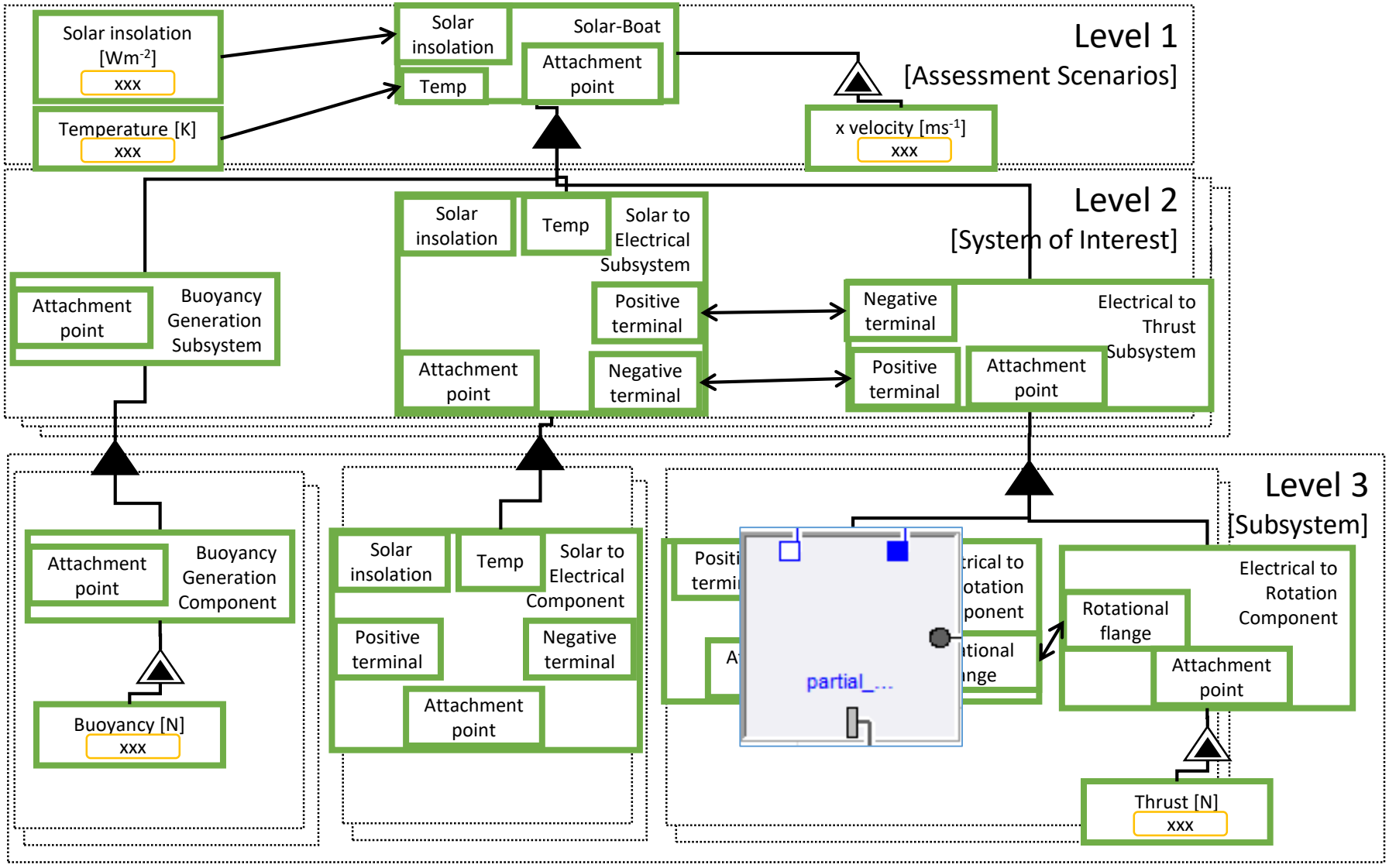

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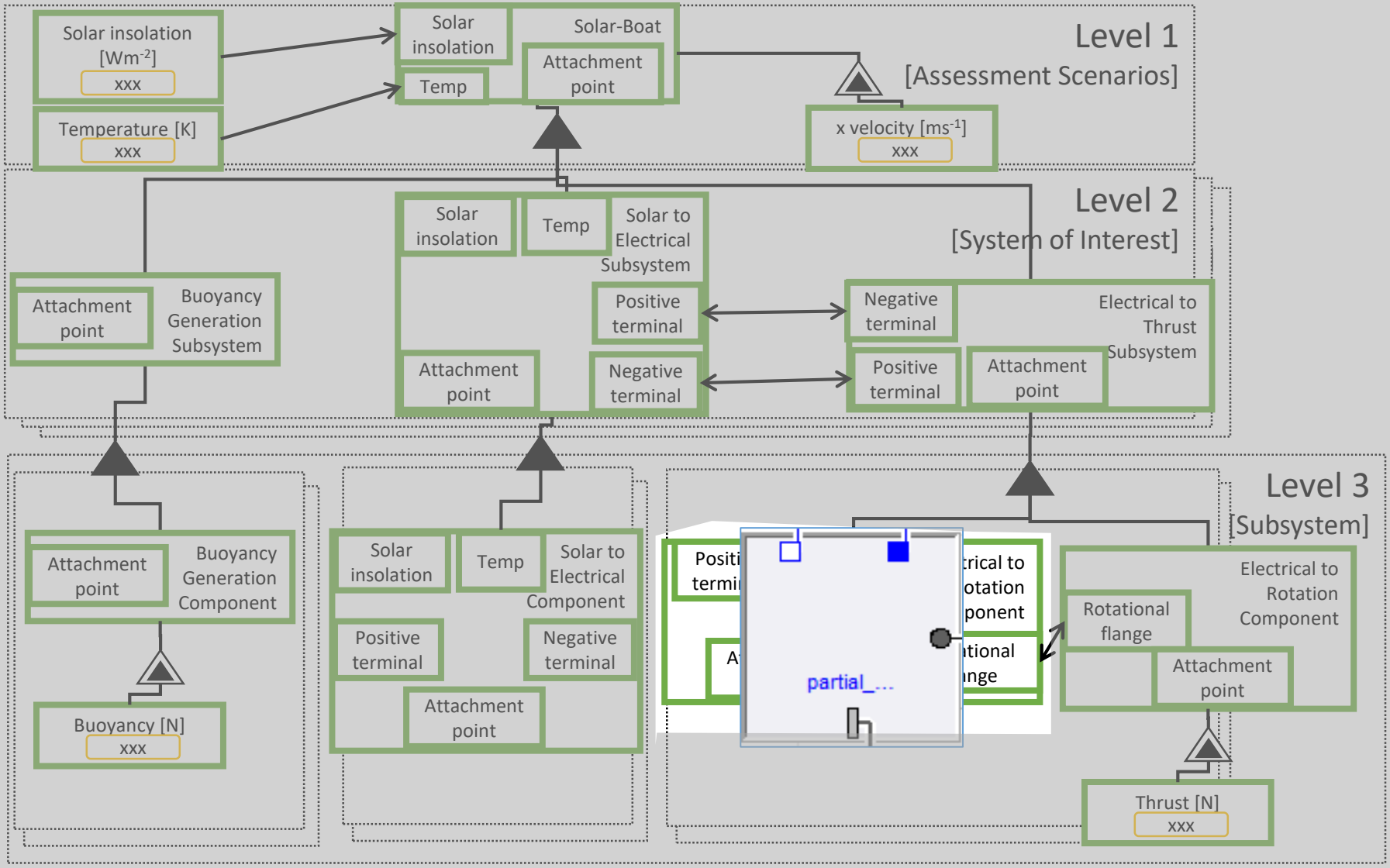

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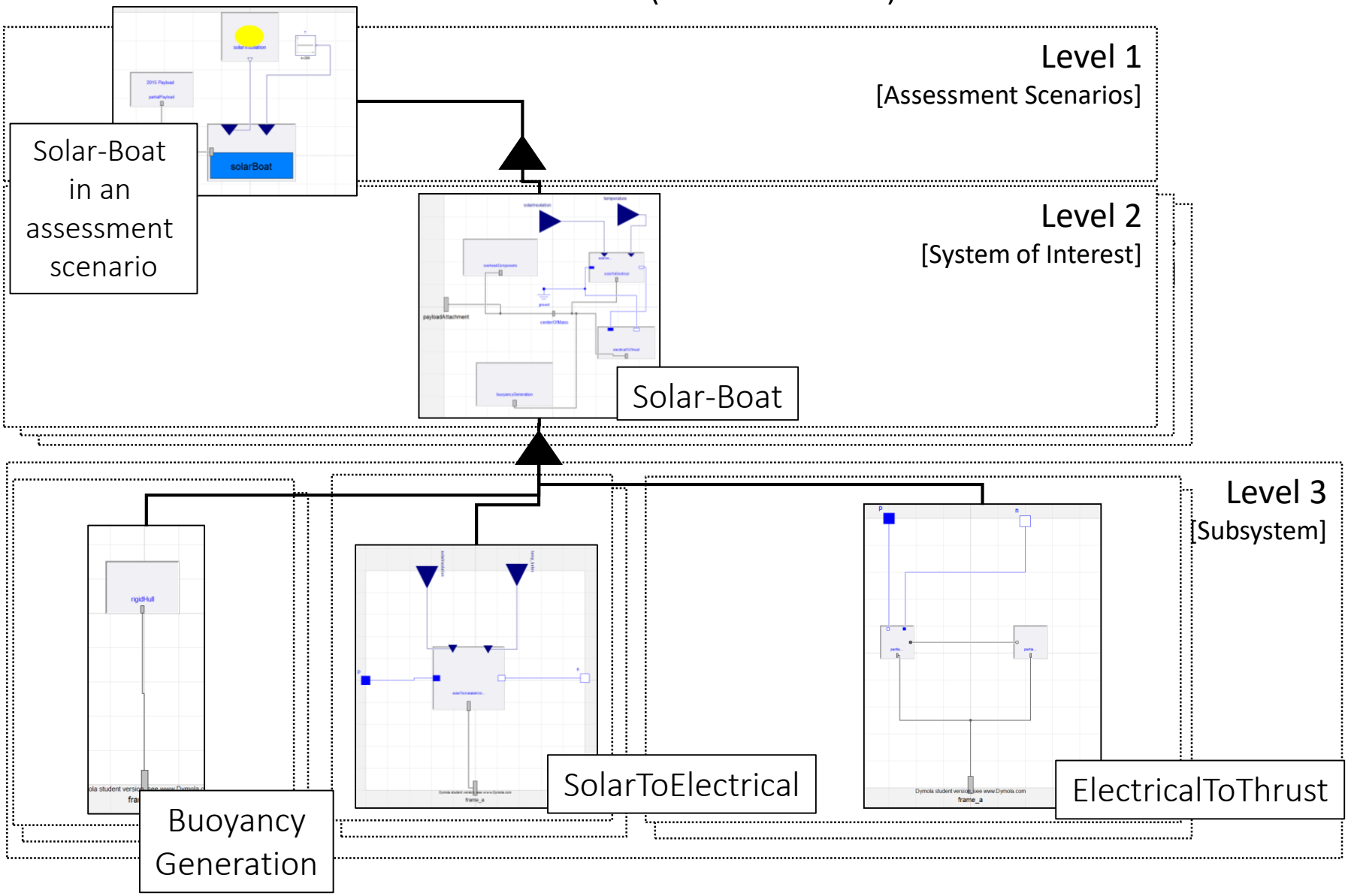
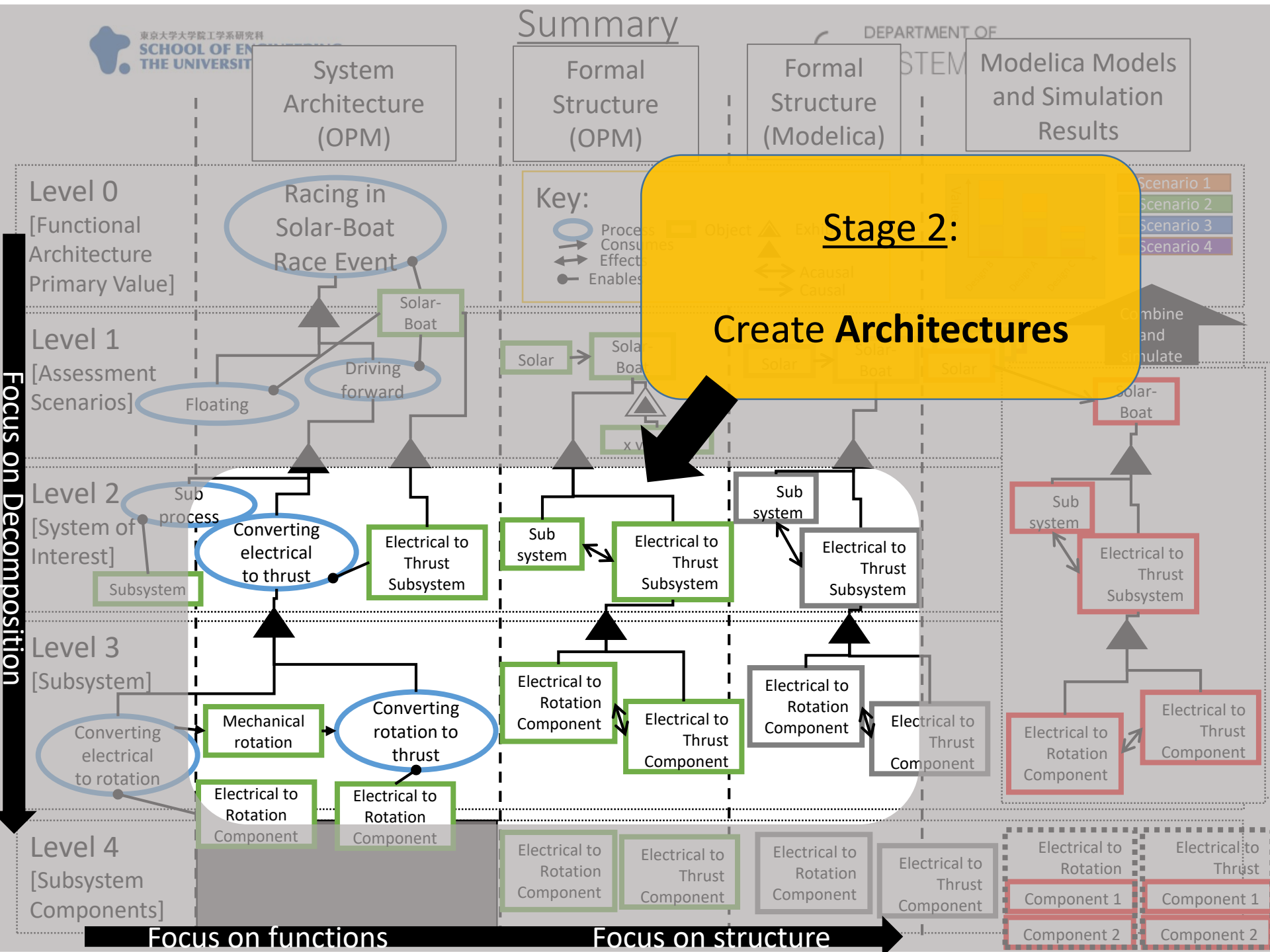
c. Create a Formal Structure (in Modelica)

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Driving forward
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Key:
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Consumes
Effect
Enables
Object
Acausal
Causal
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Stage 2:
Create Architectures
Sub process
Subsystem
Converting electrical to thrust
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Sub system
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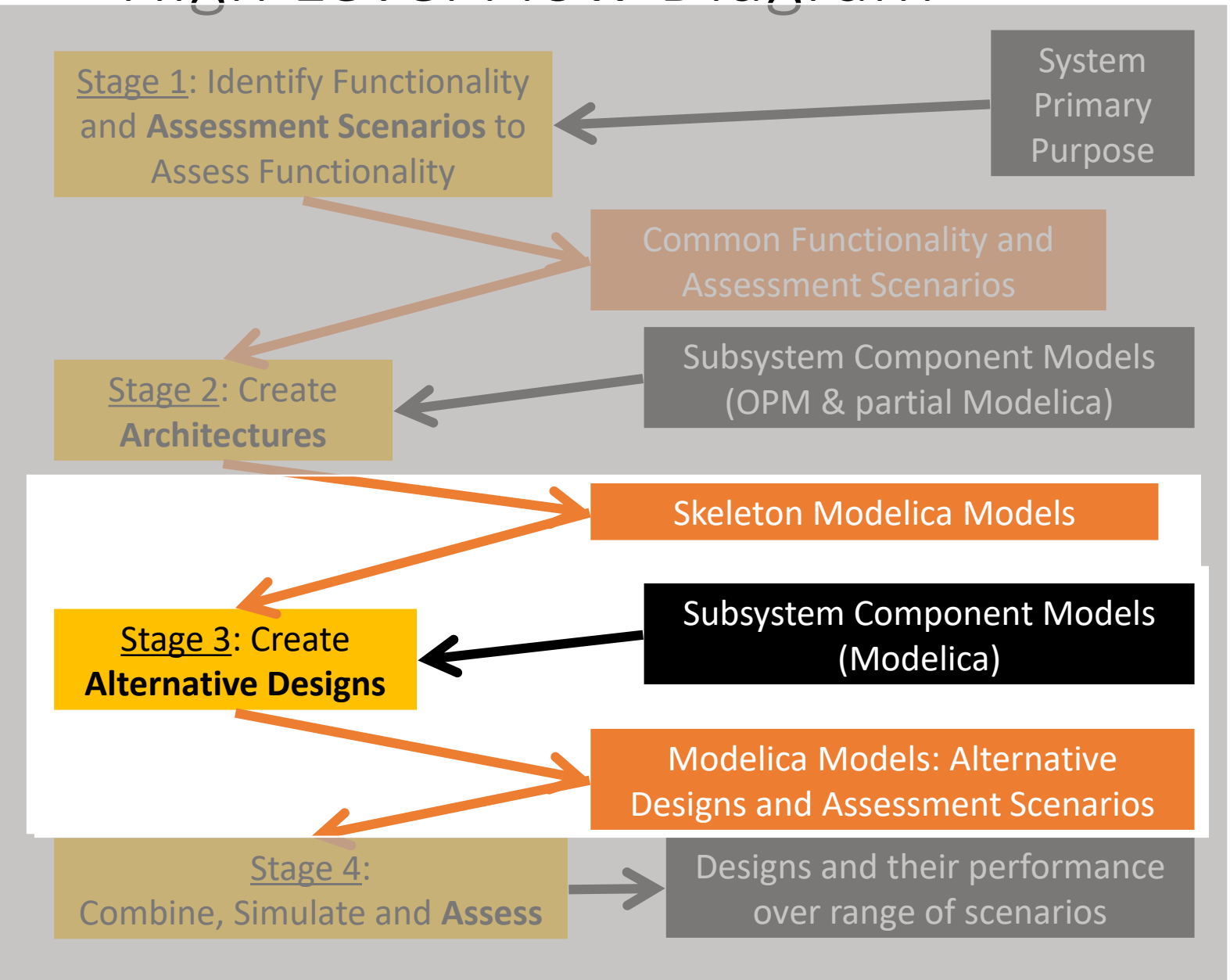
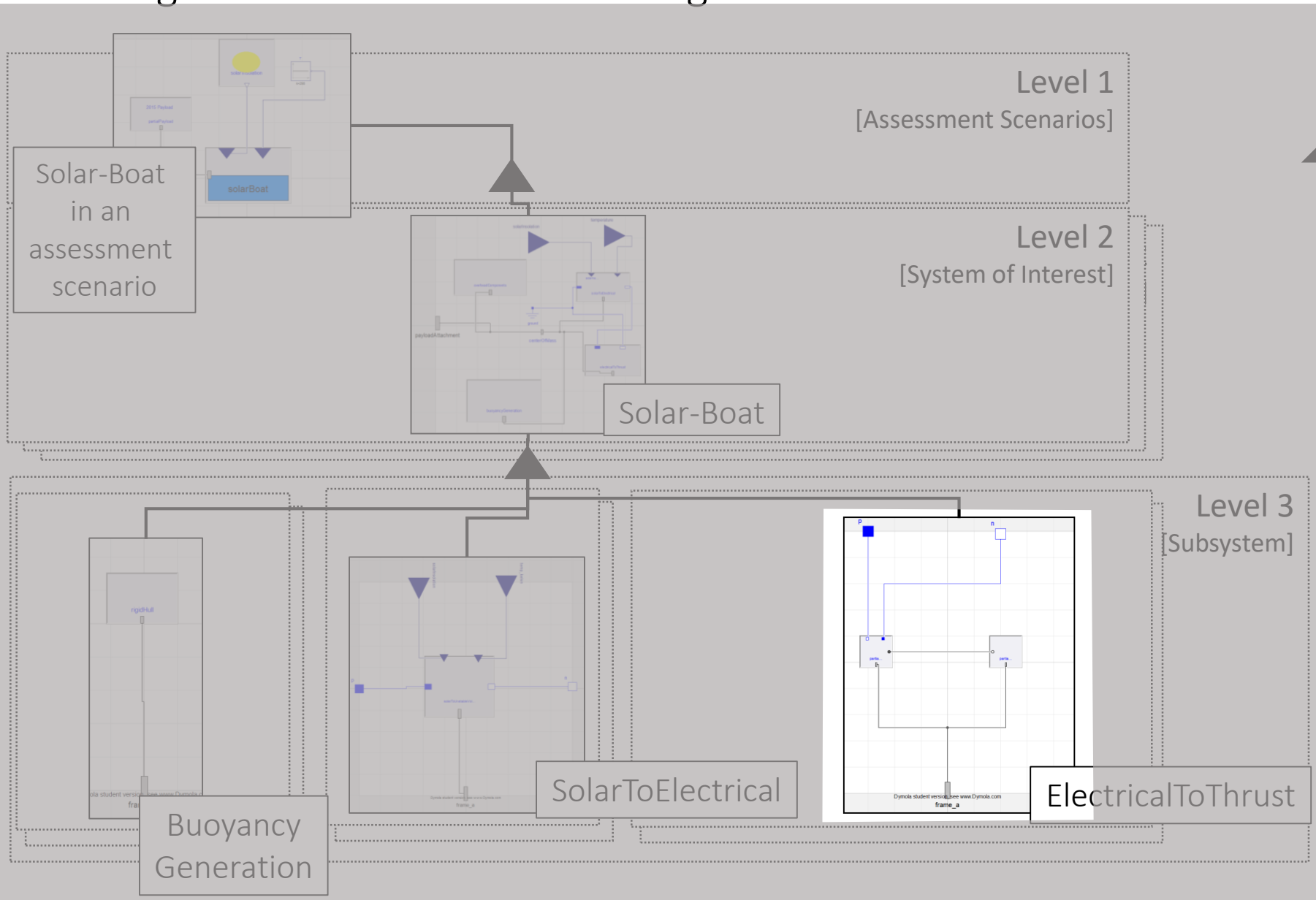
Mechanical rotation
Converting rotation to thrust
Electrical to Rotation Component
Electrical to Thrust Component
Focus on Decomposition
Focus on functions
Focus on structure

High Level Flow Diagram



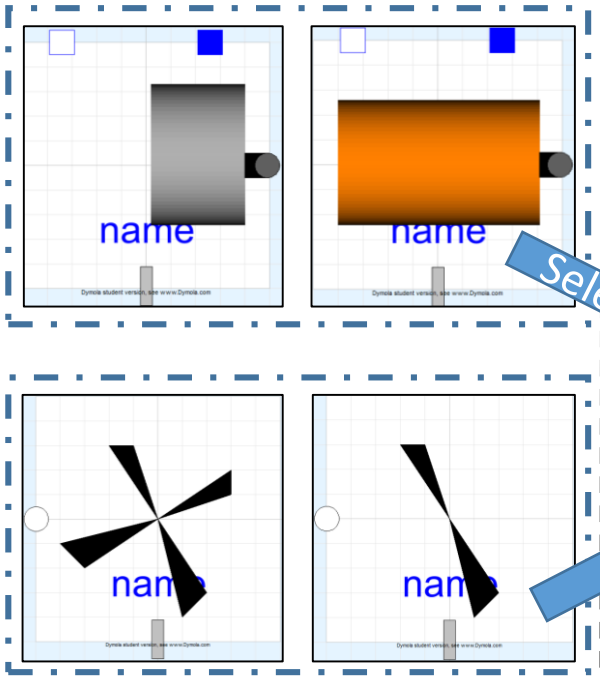
Stage 3: Create Alternative Designs



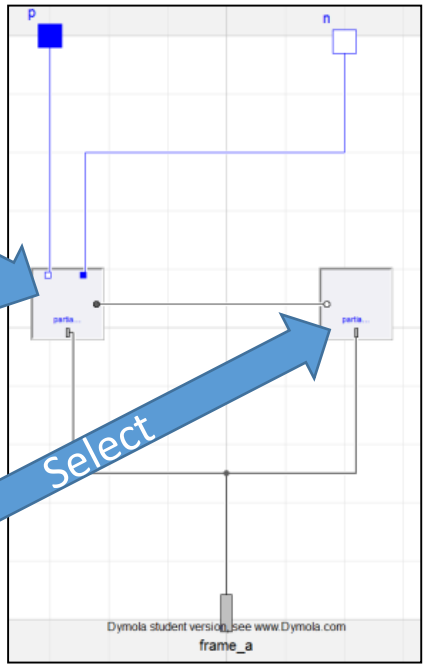
Stage 3: Create Alternative Designs

Assume there is a library of Level 4 Subsystem Components in Modelica.

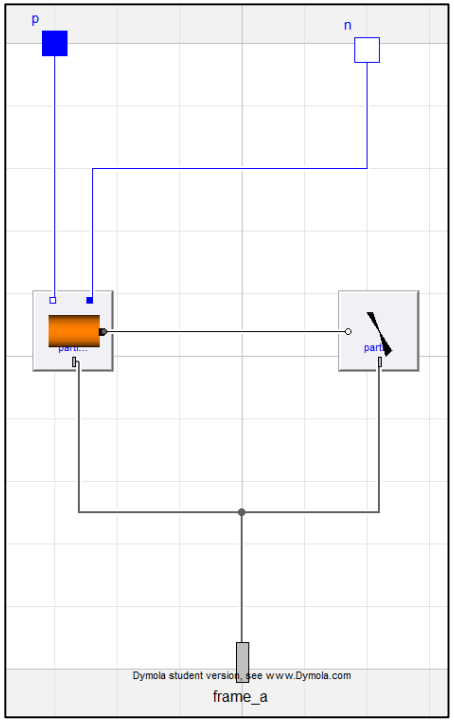
Level 4
Modelica Subsystem
Components Library



Level 3
Subsystem
Formal Structure
Modelica



Level 2
Subsystem
Design



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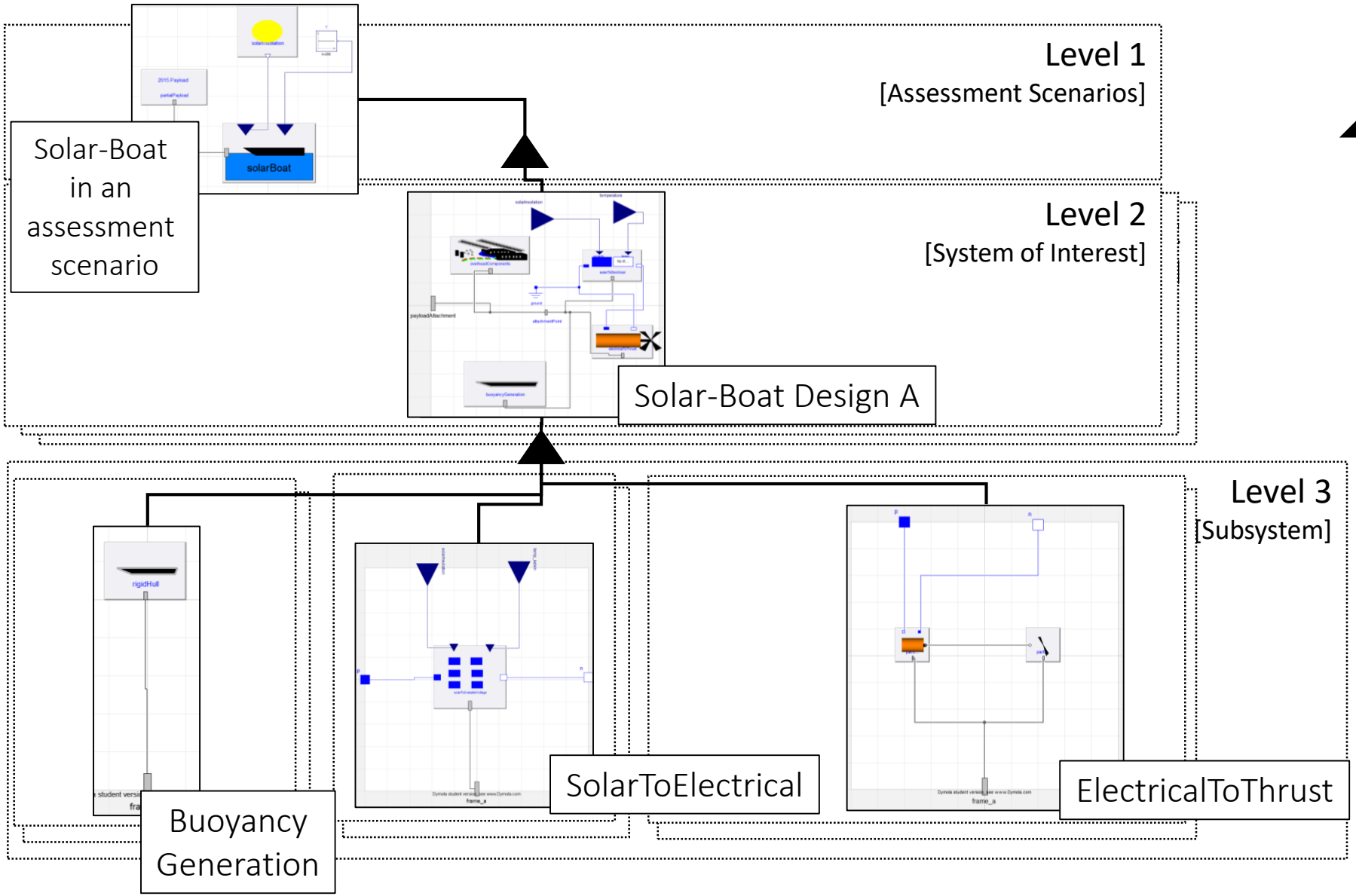

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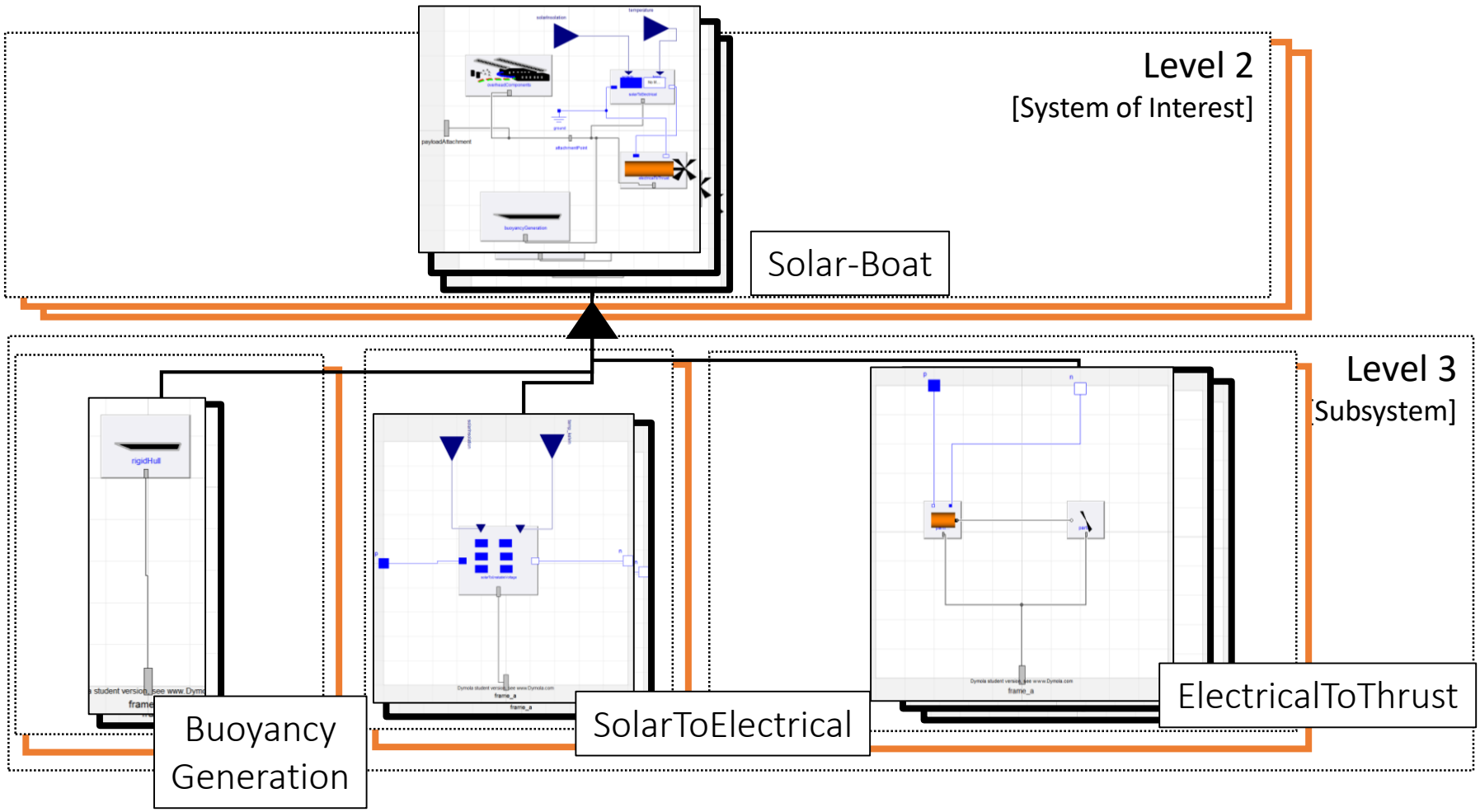
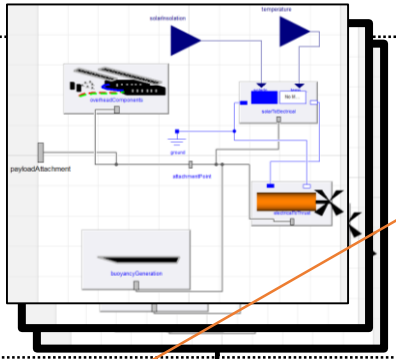


Stage 3: Create Alternative Designs

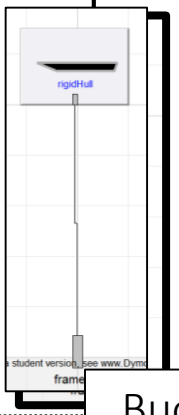
1) Alternatives architectures



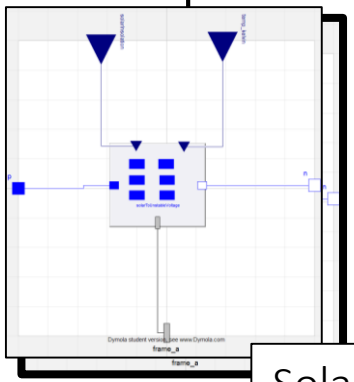
Level 2
[System of Interest]

Solar-Boat

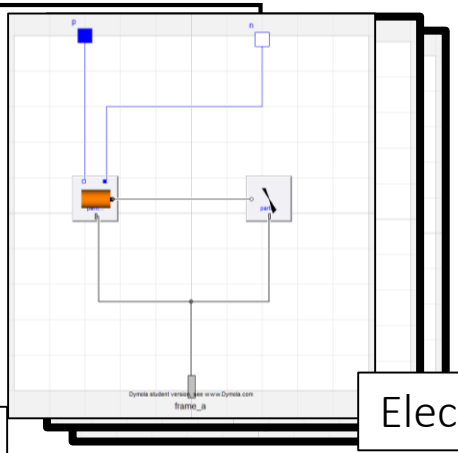
Level 3
[Subsystem]



Buoyancy Generation

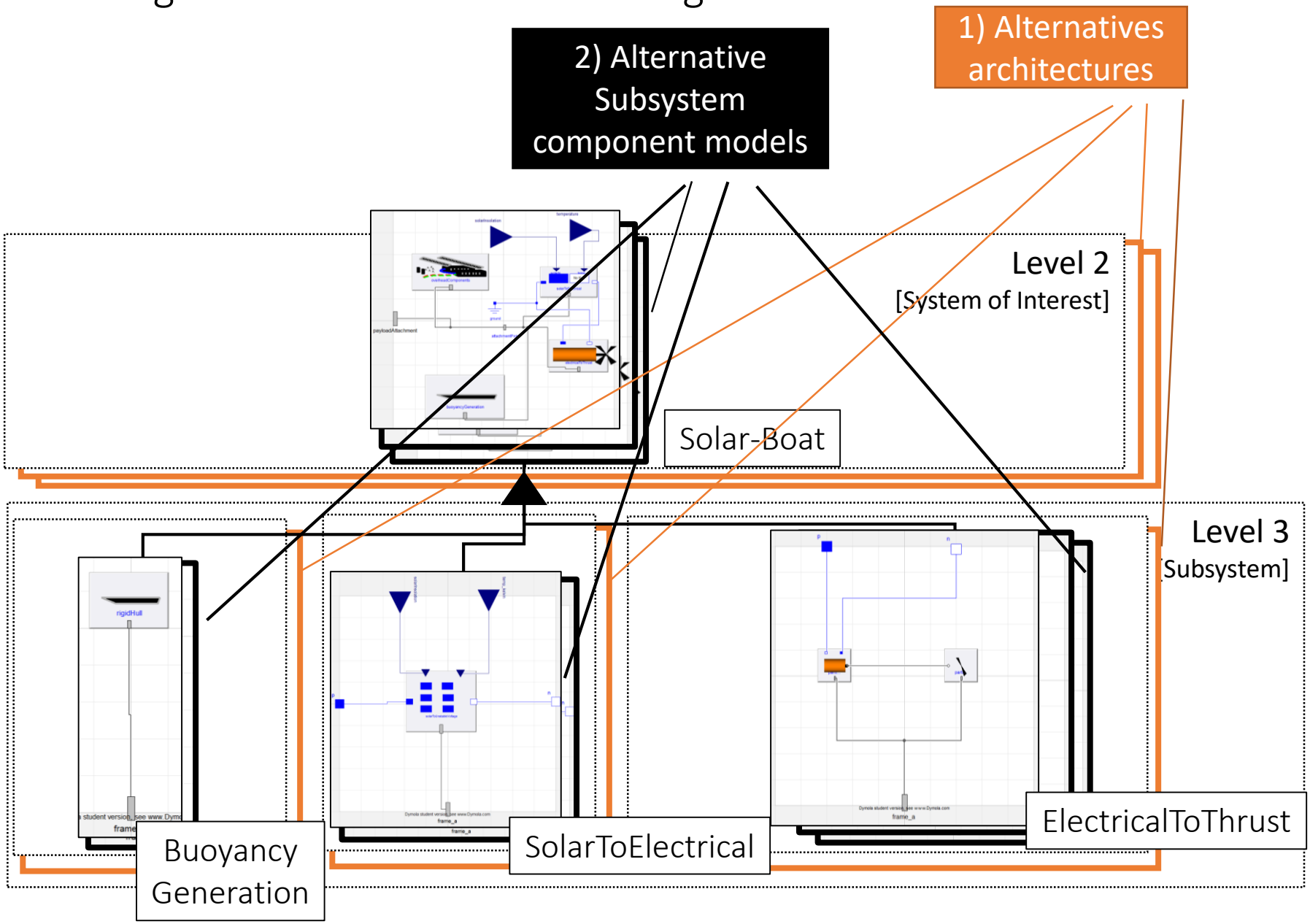


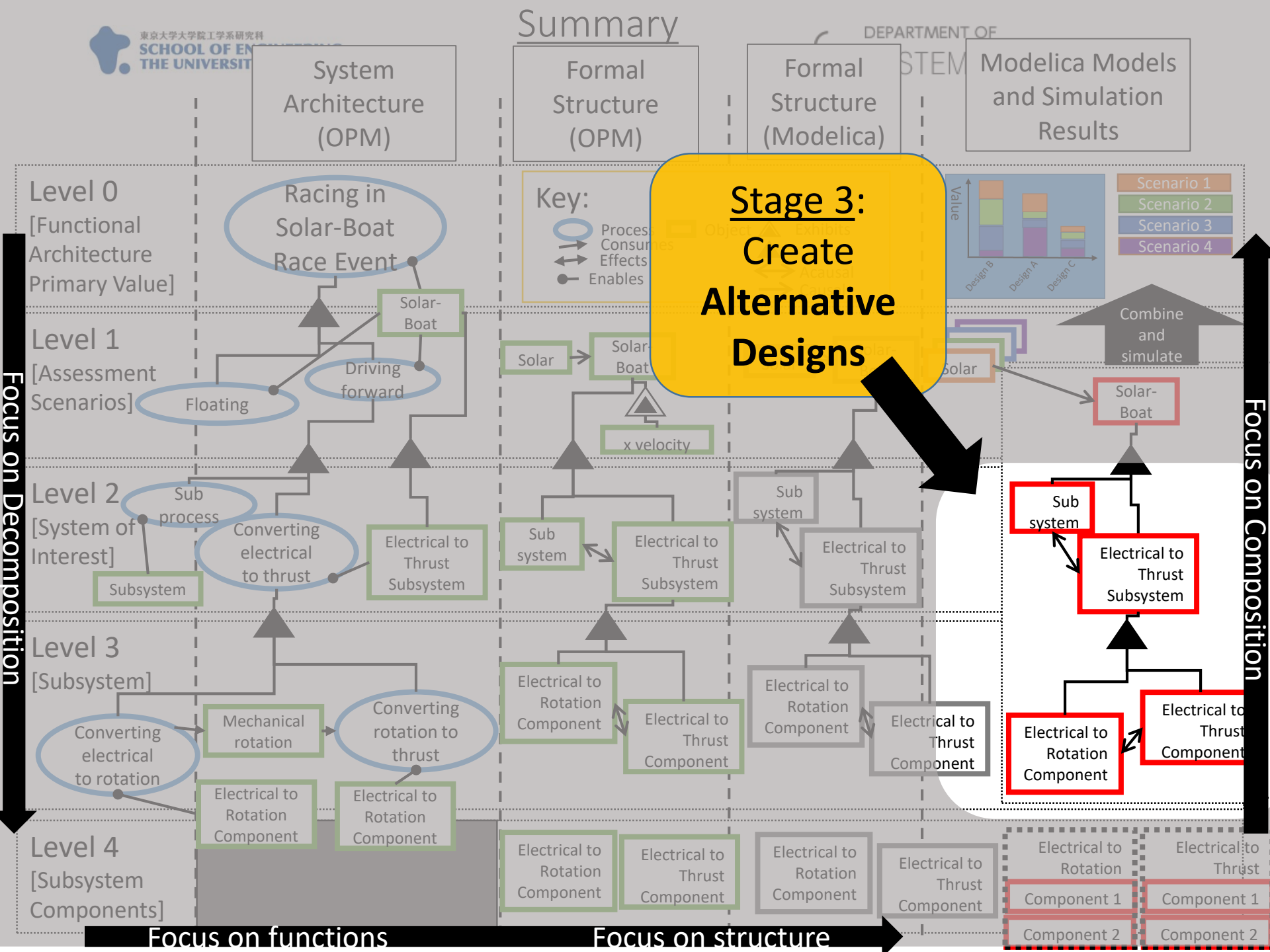
SolarToElectrical



ElectricalToThrust

Stage 3: Create Alternative Designs

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Key:
Enables
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Value
Design B
Design A
Design C
Solar
Solar-Boat
x velocity
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Electrical to Thrust Component
Combine and simulate
Solar
Solar-Boat
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Component 1
Component 2
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Focus on structure

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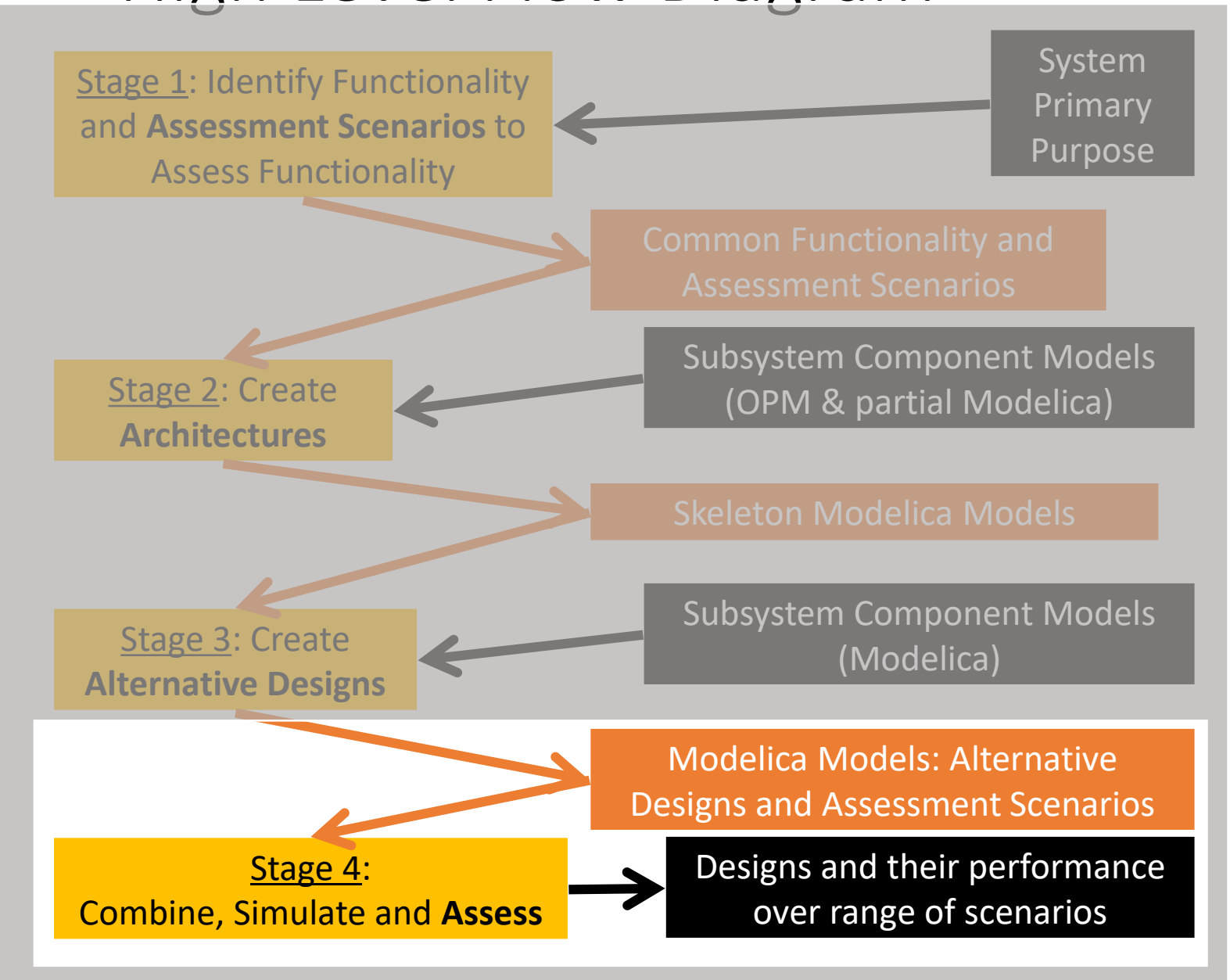

Key:

- Process
- External Input / Output
- Internal Input / Output

Stage 4: Combine, Simulate and Assess

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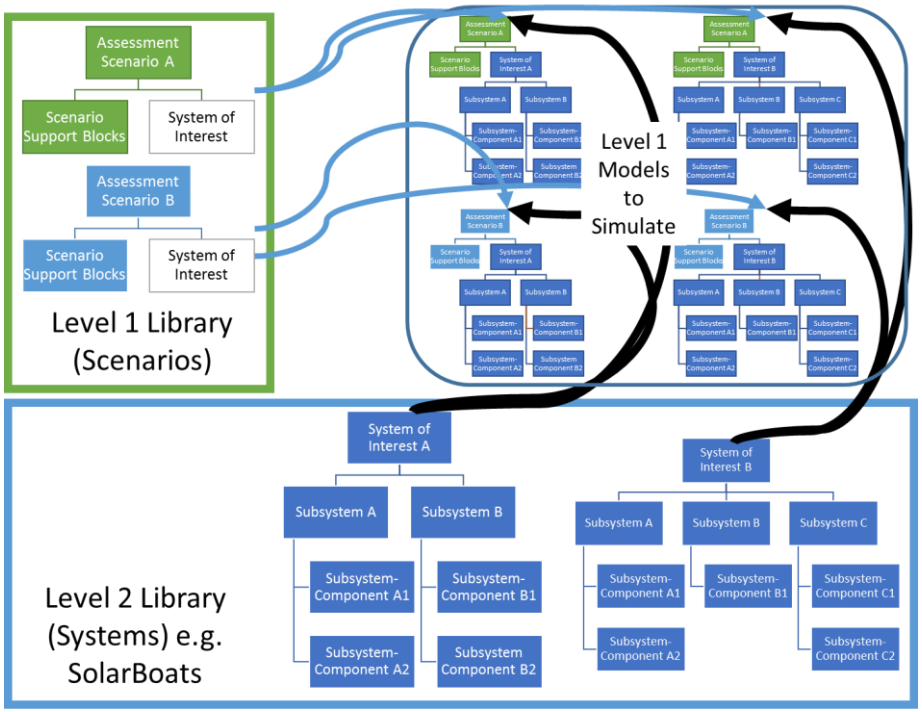

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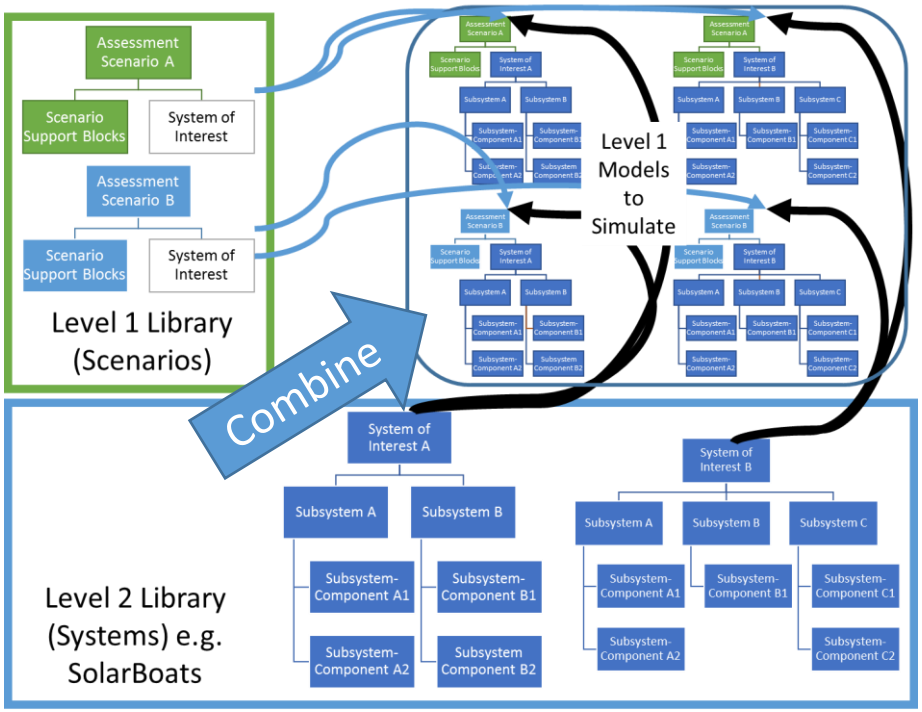

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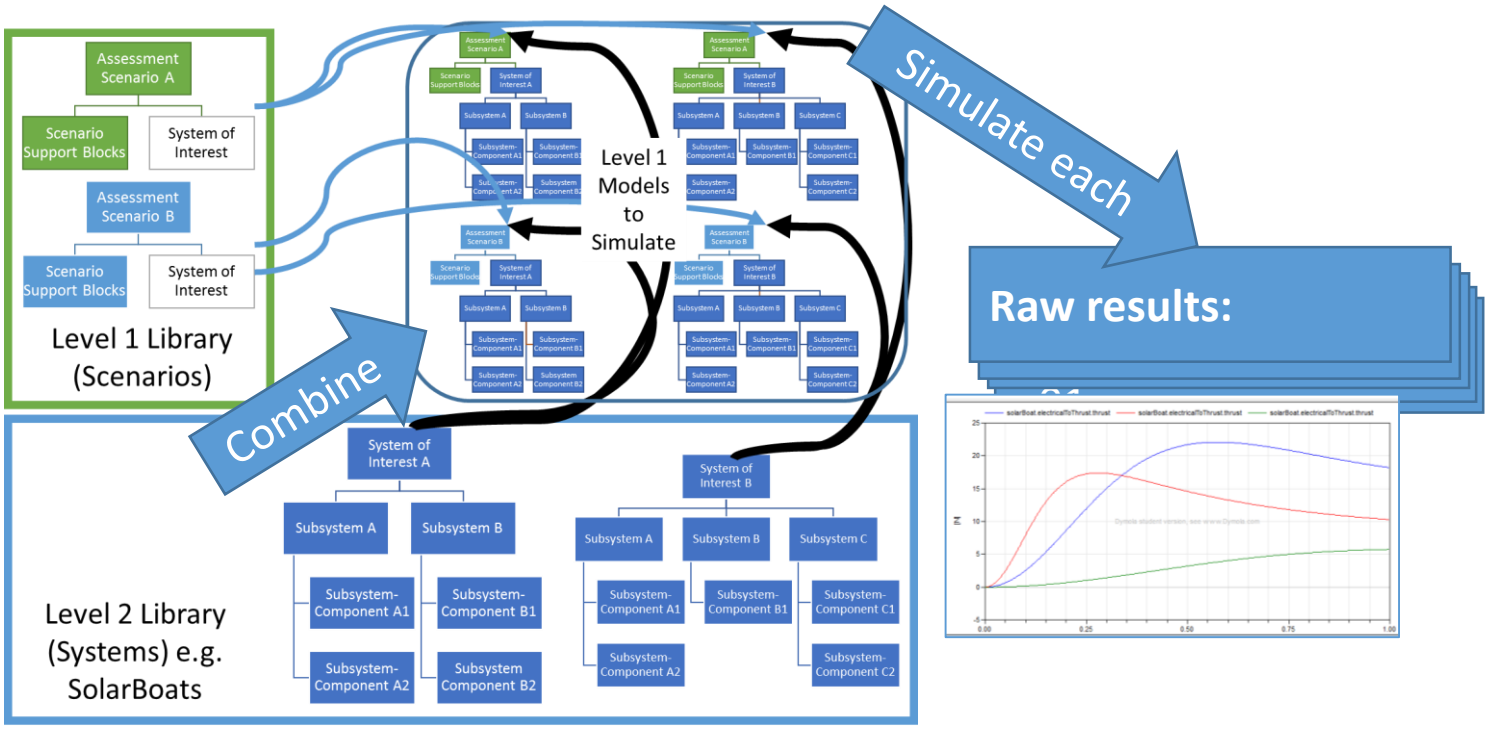

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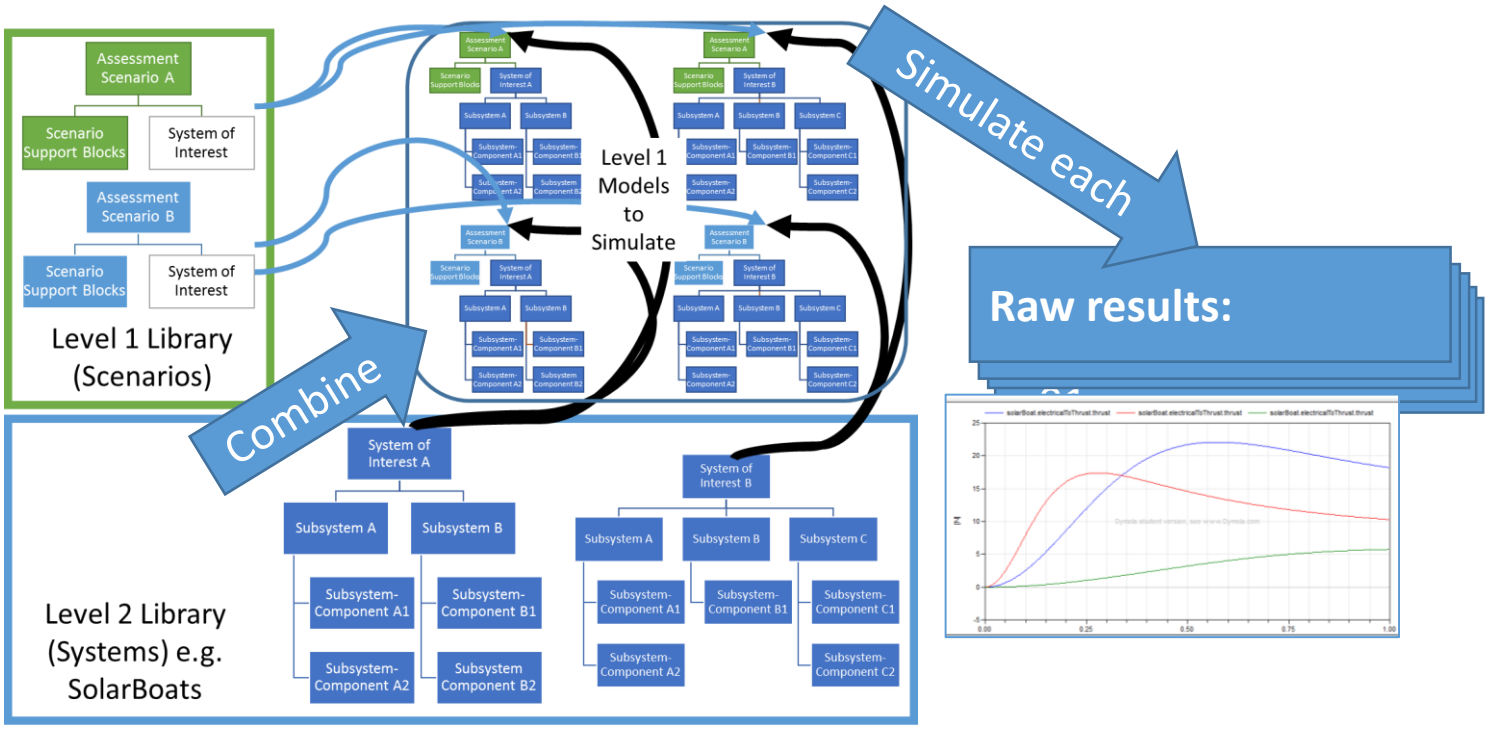

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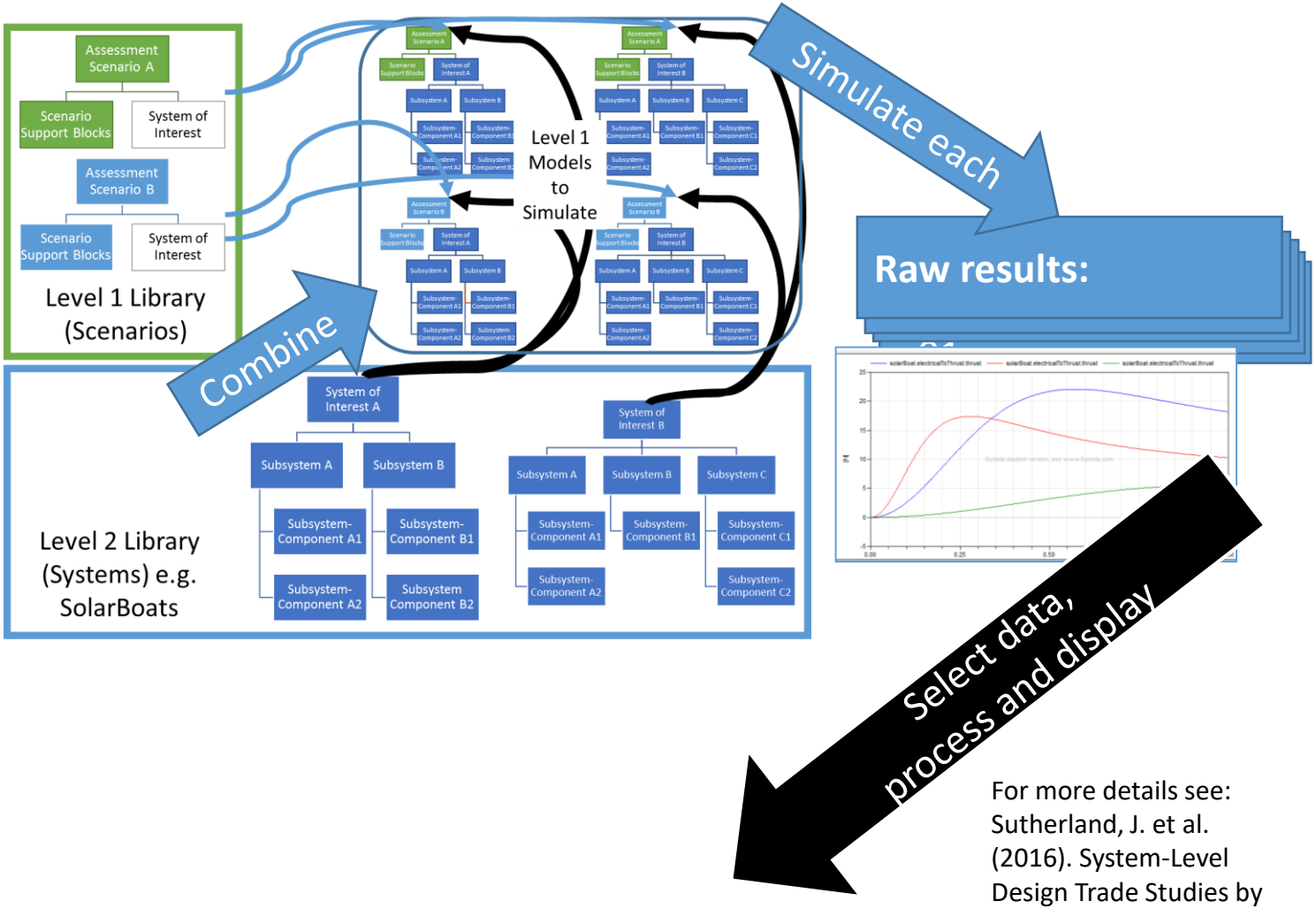

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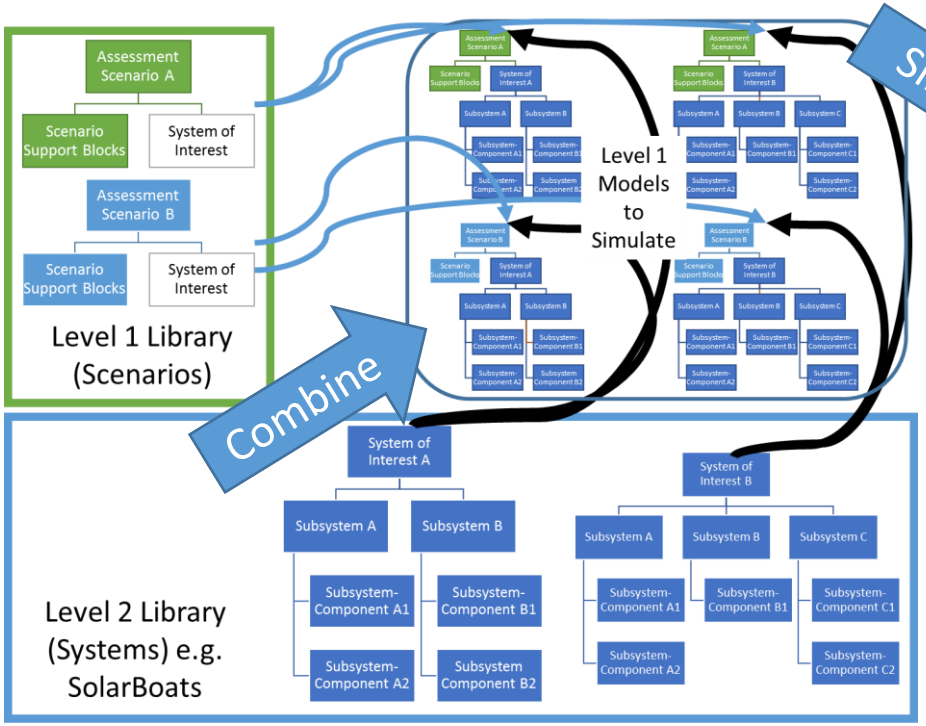
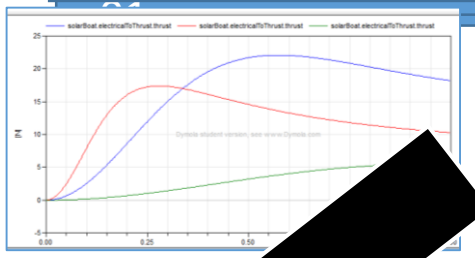
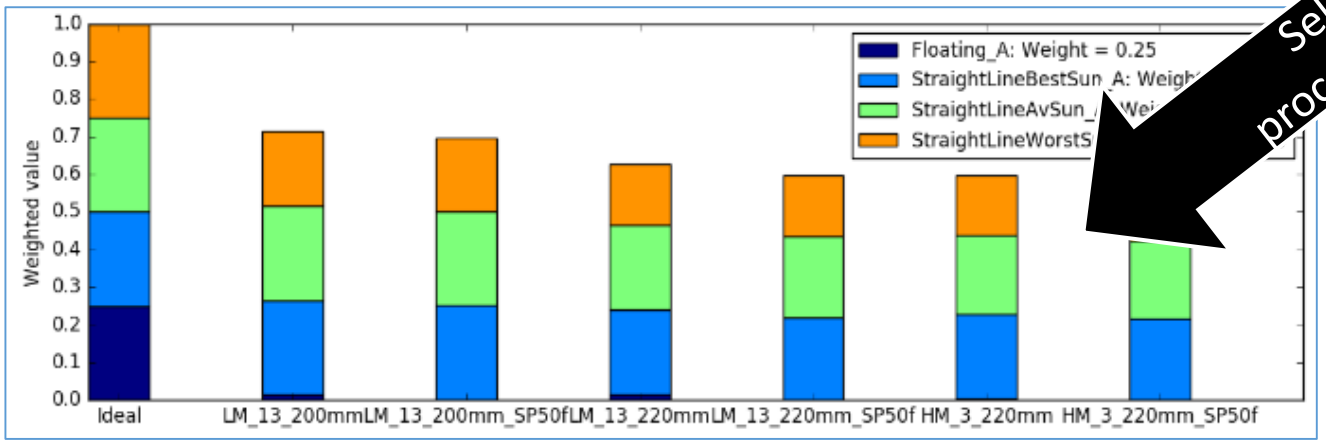




Select data, process and display



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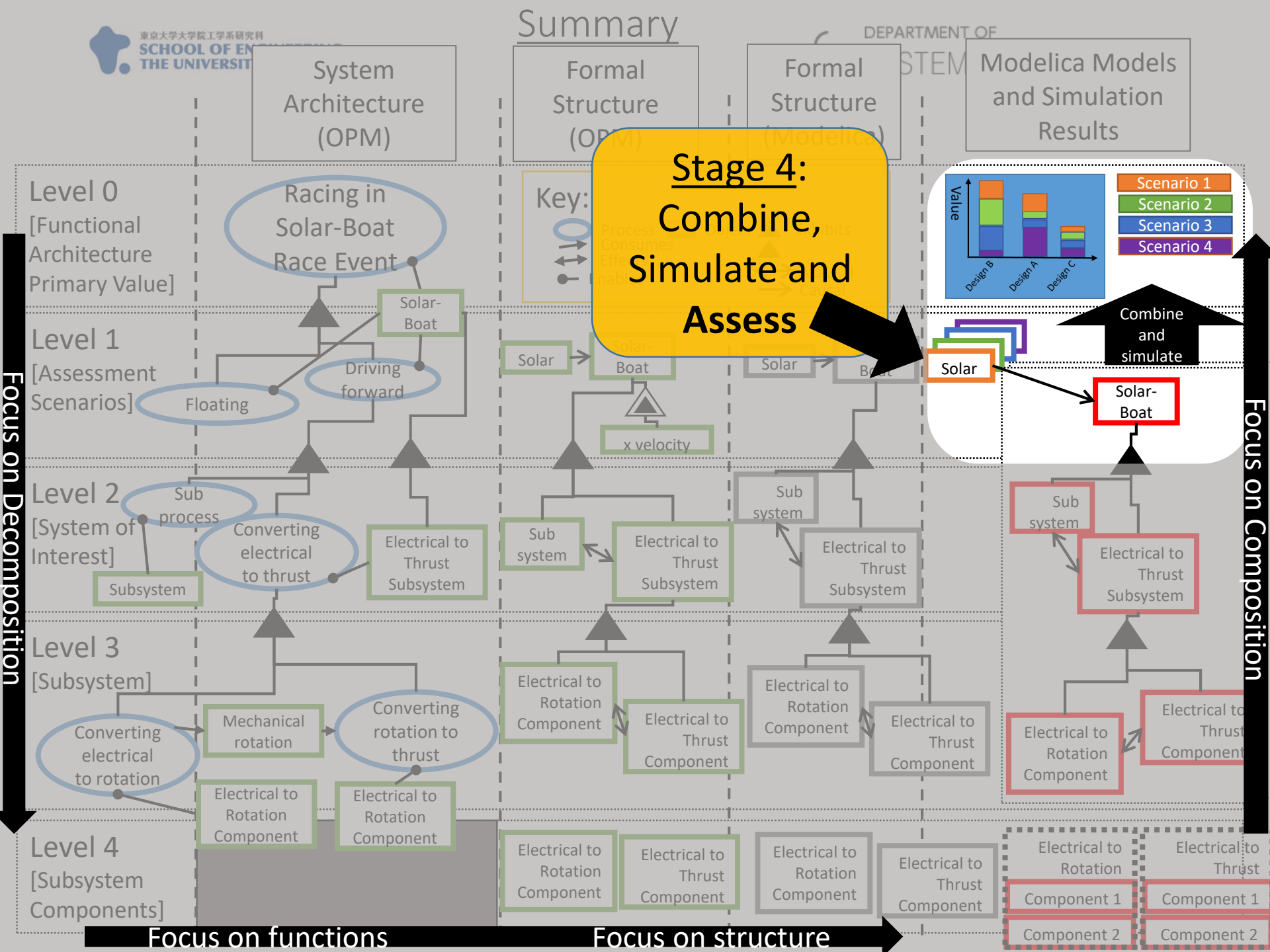
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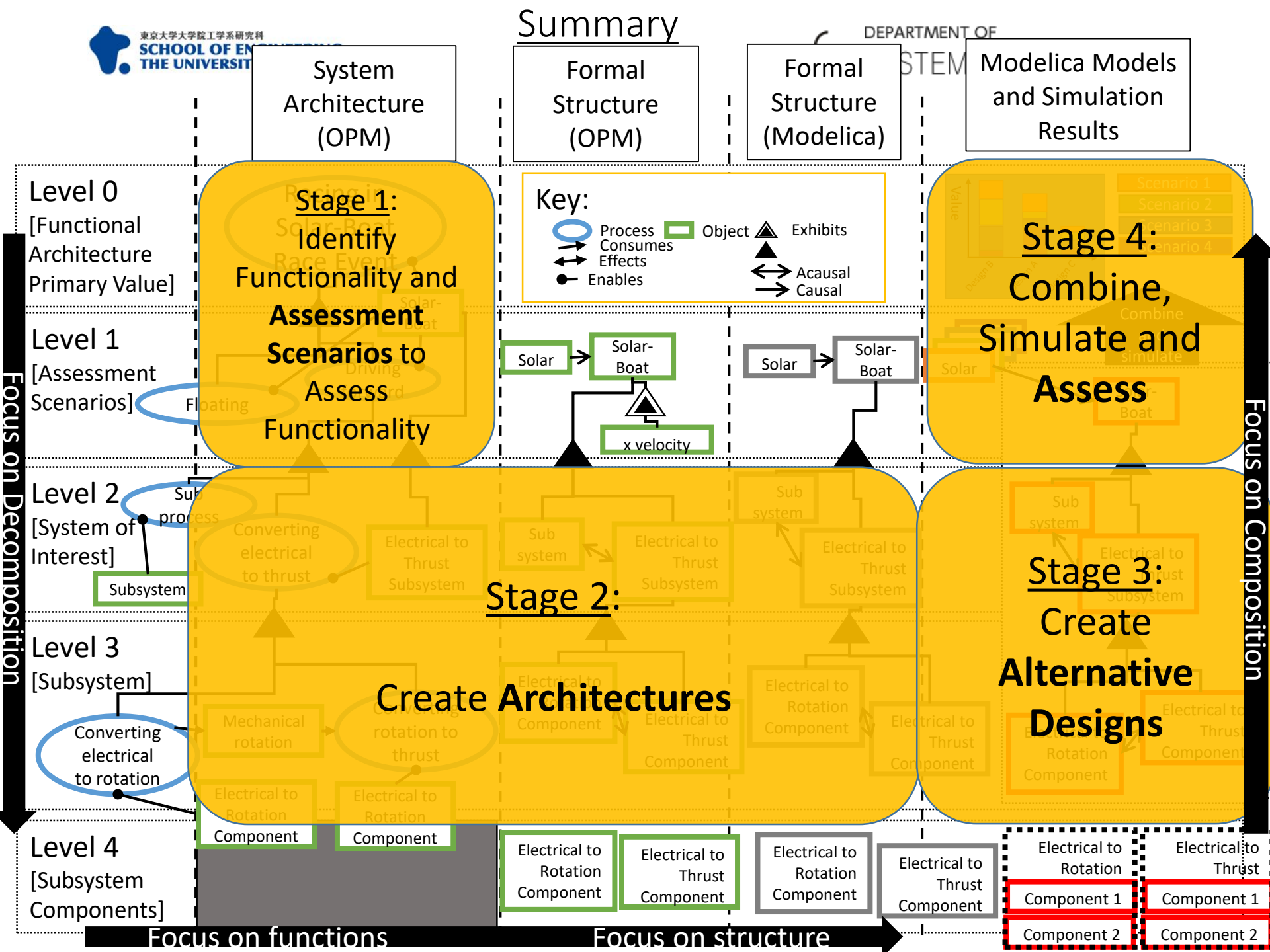
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Presentation Overview

1. Problems to address
2. Proposed solution
3. Proposed solution – Detailed description
4. Discussion

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- Use **OPM** and **Modelica** to **synthesize** new designs and **assess** them

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- As such:
  - Needs demonstration on larger more complex/complicated projects

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Questions?

Stage 2: Create **Architectures**

Stage 3: Create **Alternative Designs**

Stage 4: Combine, Simulate and **Assess**

Focus on Decomposition

Focus on Composition

Focus on functions

Focus on structure

EXTRA Slides

SolarBoat challenge

- Lake Biwa (Japan) competition rules:
  - Max 2m^2 of solar panels
  - Max 20Wh of lead based batteries for power train
  - Complete the 20km course autonomously
  - Possibility to repair boat on route