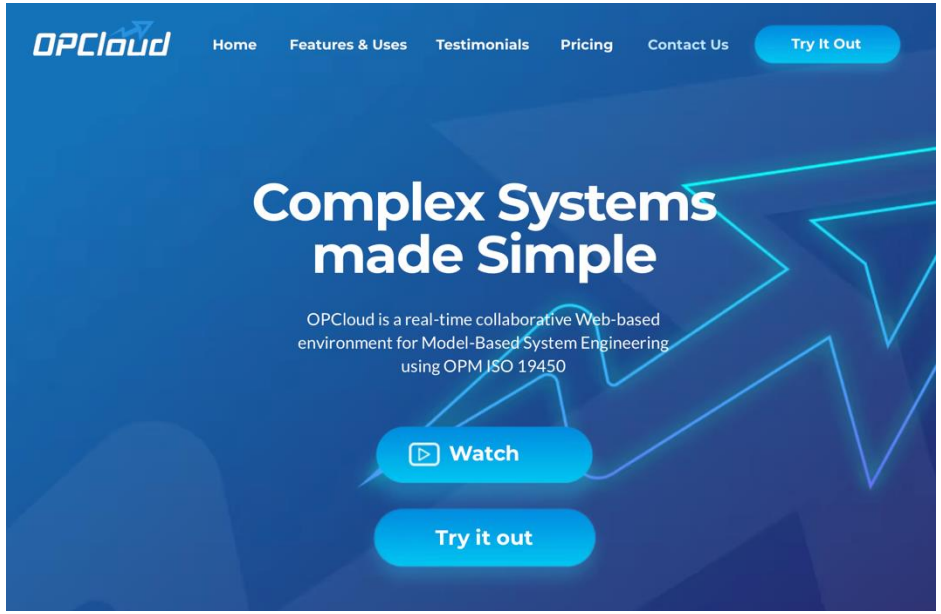
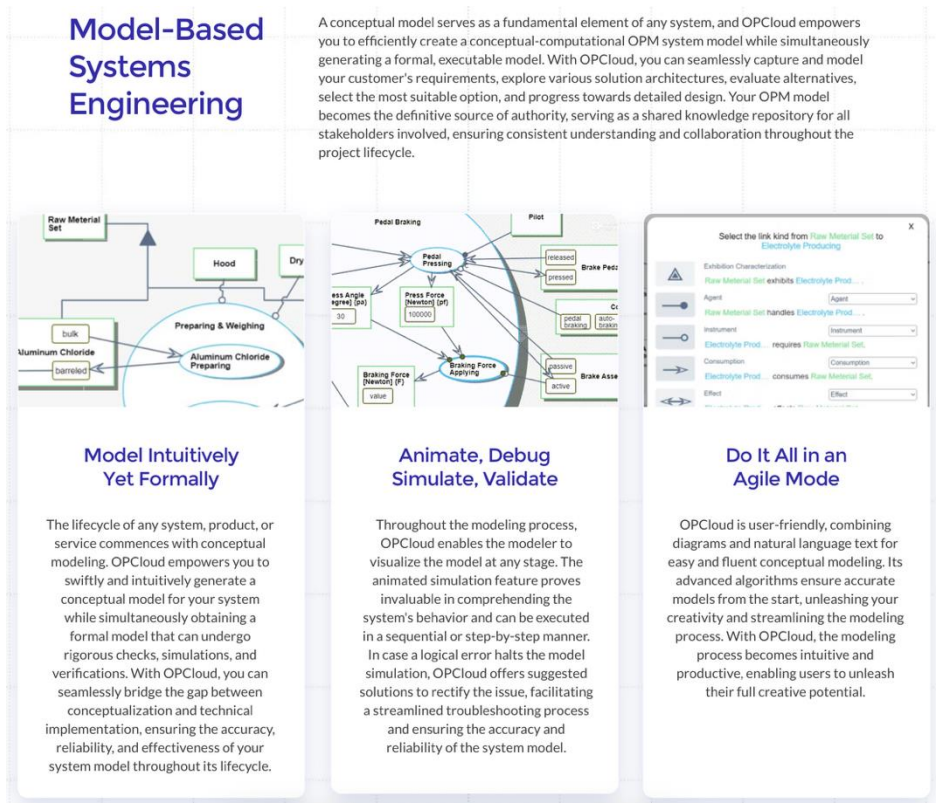
OPM EXTENDED

WEEK	CLASS ACTIVITY	REF	INDIVIDUAL	W	GROUP	W
1 28/Jul	Course Structure and Initial Definitions Systems Engineering Review	[illegible]	IA-01 - Reading and Conceptual Questions (10)	10%		0%
2 04/Aug	Classical Systems Engineering Diagrams (IDEF-0/N2/eFFBD/DFD)	[4] *papers	IA-02	0%	GA-02 - Prepare a representation of your system using classical Diagrams	50%
3 11/Aug	Transition from Legacy to MBSE MBSE Methodologies MBSE Languages	[5] [7] *papers	IA-03 - Reading and Conceptual Questions (10)	10%		0%
4 18/Aug	OPM - Basic	[6]	IA-04 - Exercises	10%		0%
5 25/Aug	OPM - Extended	[6]	IA-05 - Exercises	10%		0%
6 01/Sep	OPM - Group Presentation		IA-06	0%	G6 - Prepare a presentation of your system using OPM	50%
7 08/Sep	SysML Introduction (bdd/ibd)	[7]	IA-07 - Exercises	10%		0%
8 15/Sep	P1 - Conceptual Questions and Case	[1] [2] [3] [4] [6]	IA-08 - Questions and a mini-case	50%	GA-08 -	
				100%		100%

Resources for this lecture

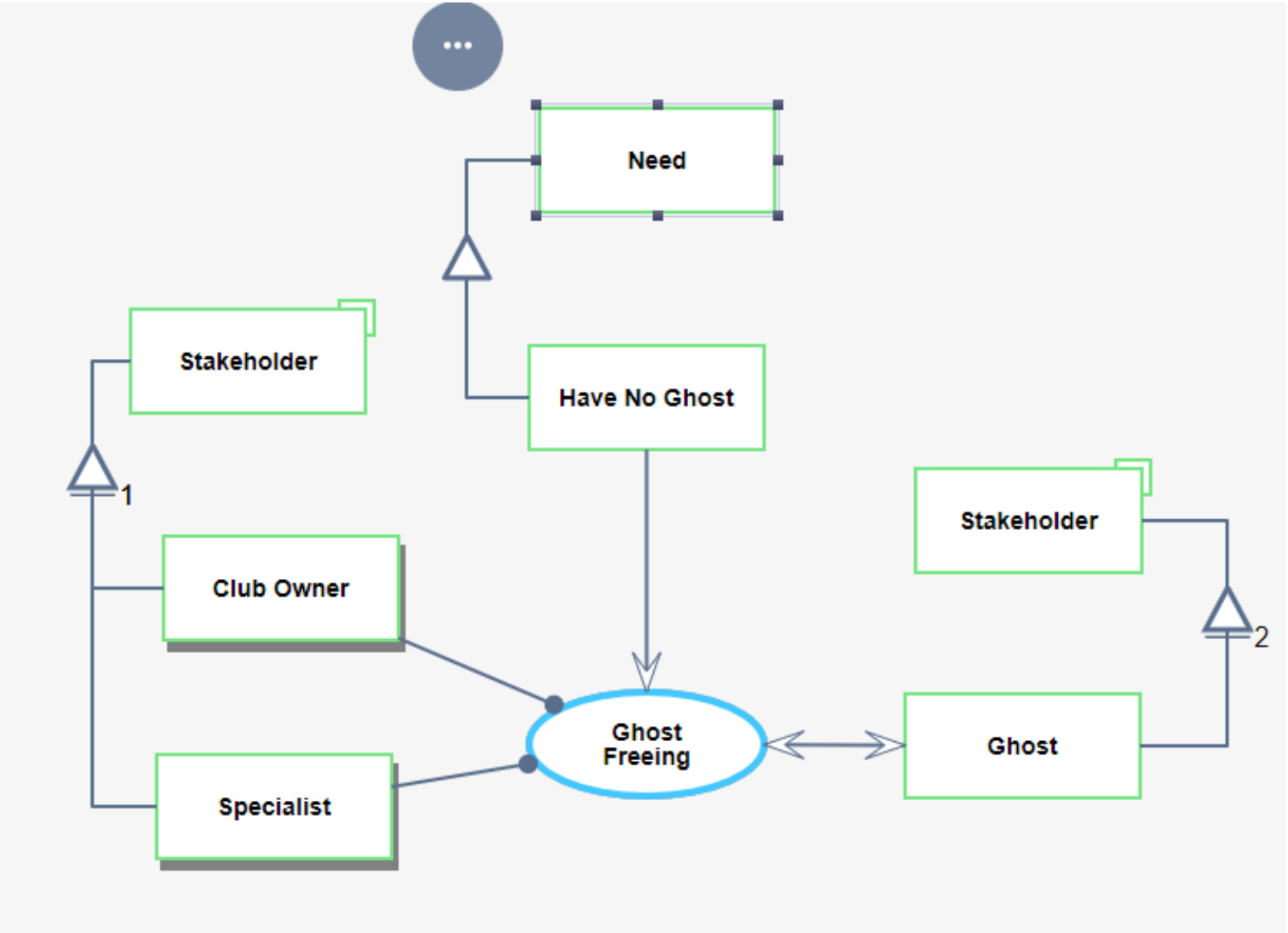
- OPCloud
- **Logged account:**
  - https://opcloud.systems/
  - Connect w/ Google SSO using your **@ga account**
- **Not logged**
  - It **does not save** it, but works similarly
  - https://www.opcloud.tech





Some Examples

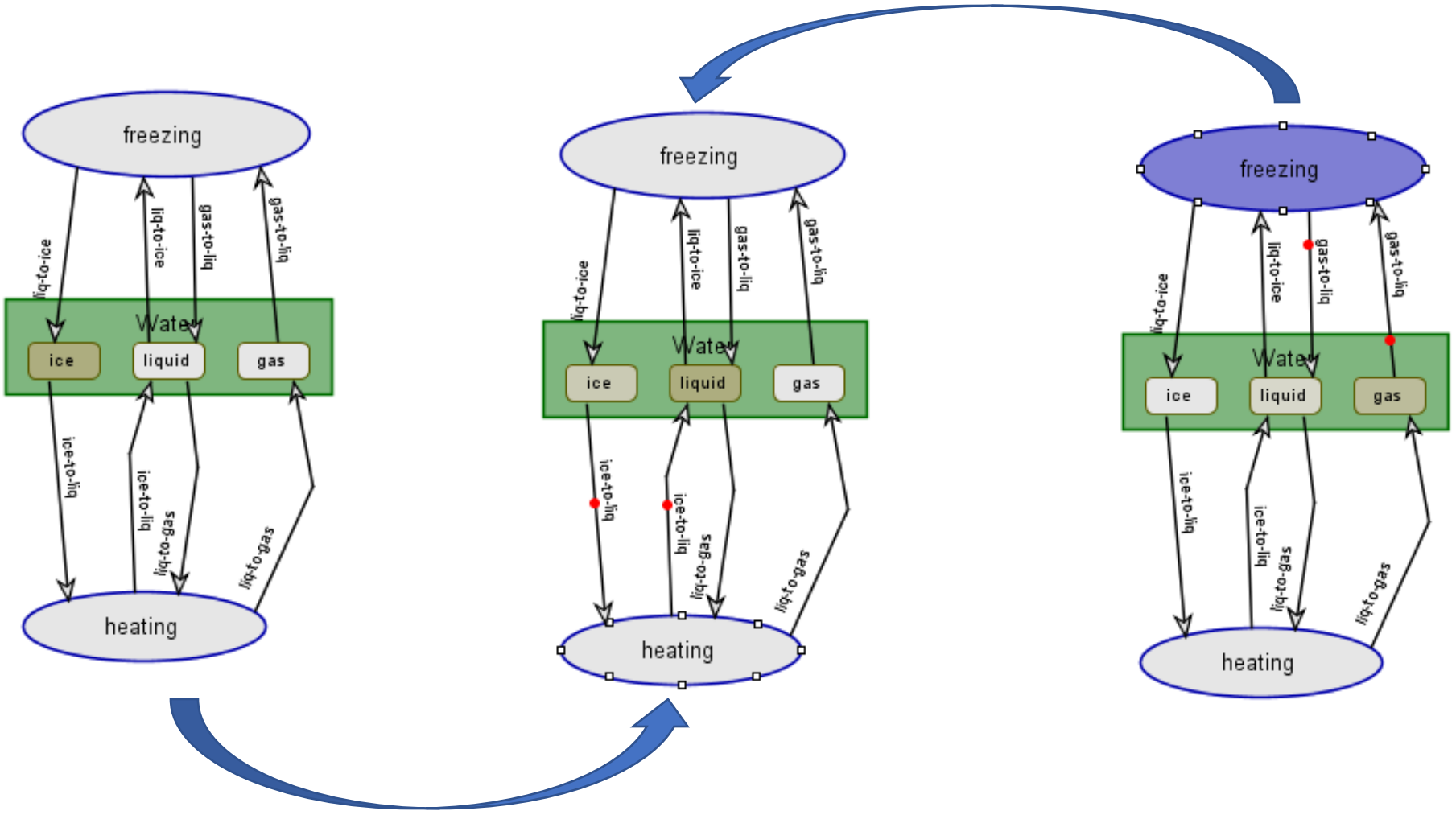
Starting Simple



What is the fundamental need?

be free of ghosts

Simple Example – states of the water



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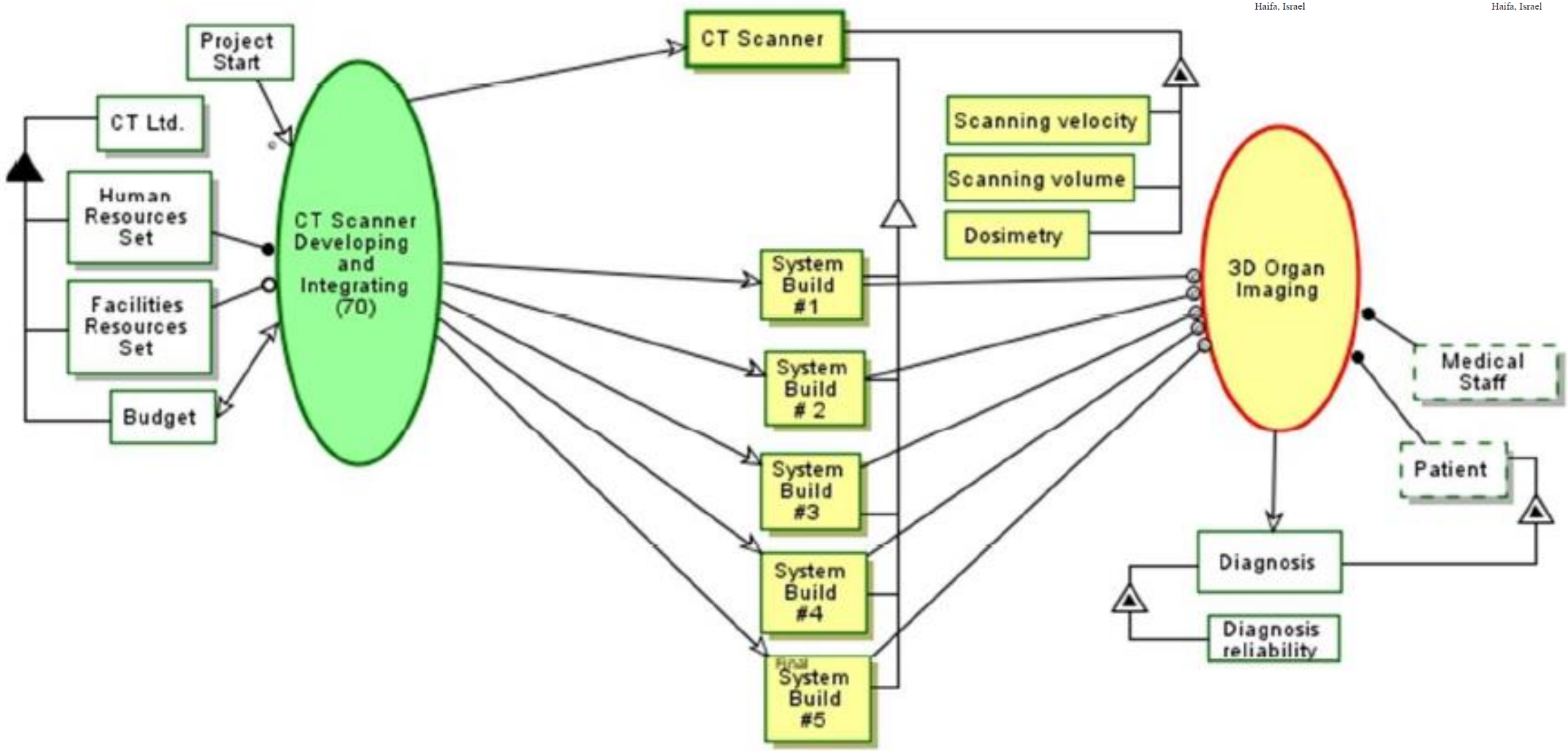

Figure A2. SD1 - CT scanner Project-Product Lifecycle Management in-zoomed (2)

Model-Based Protocol Engineering: Specifying Kerberos with Object-Process Methodology

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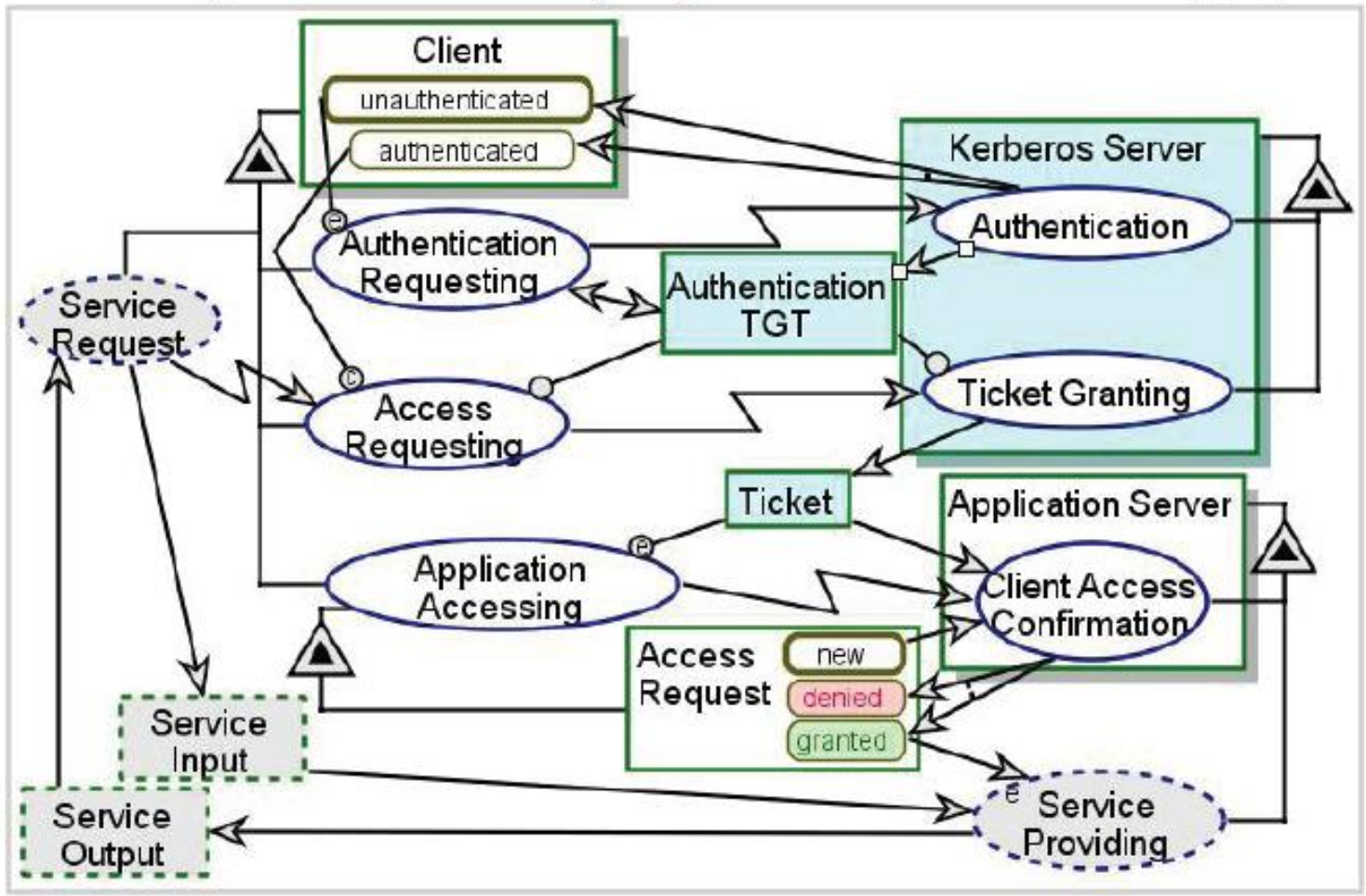


Fig. 6. Top-Level OPM Diagram of the Kerberos Authentication Protocol

A client computer attempting to connect to a server is required to provide proof of its authenticity, verifying its identity and access to the server. In order to be authenticated, the client must contact the Kerberos 3rd party service and receive a ticket indicating that it is who it says it is. A simple diagram of Kerberos is shown in Fig. 3 [9].

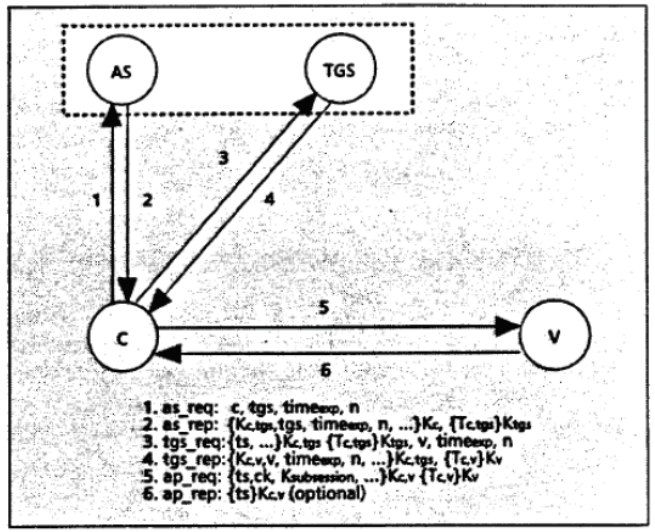
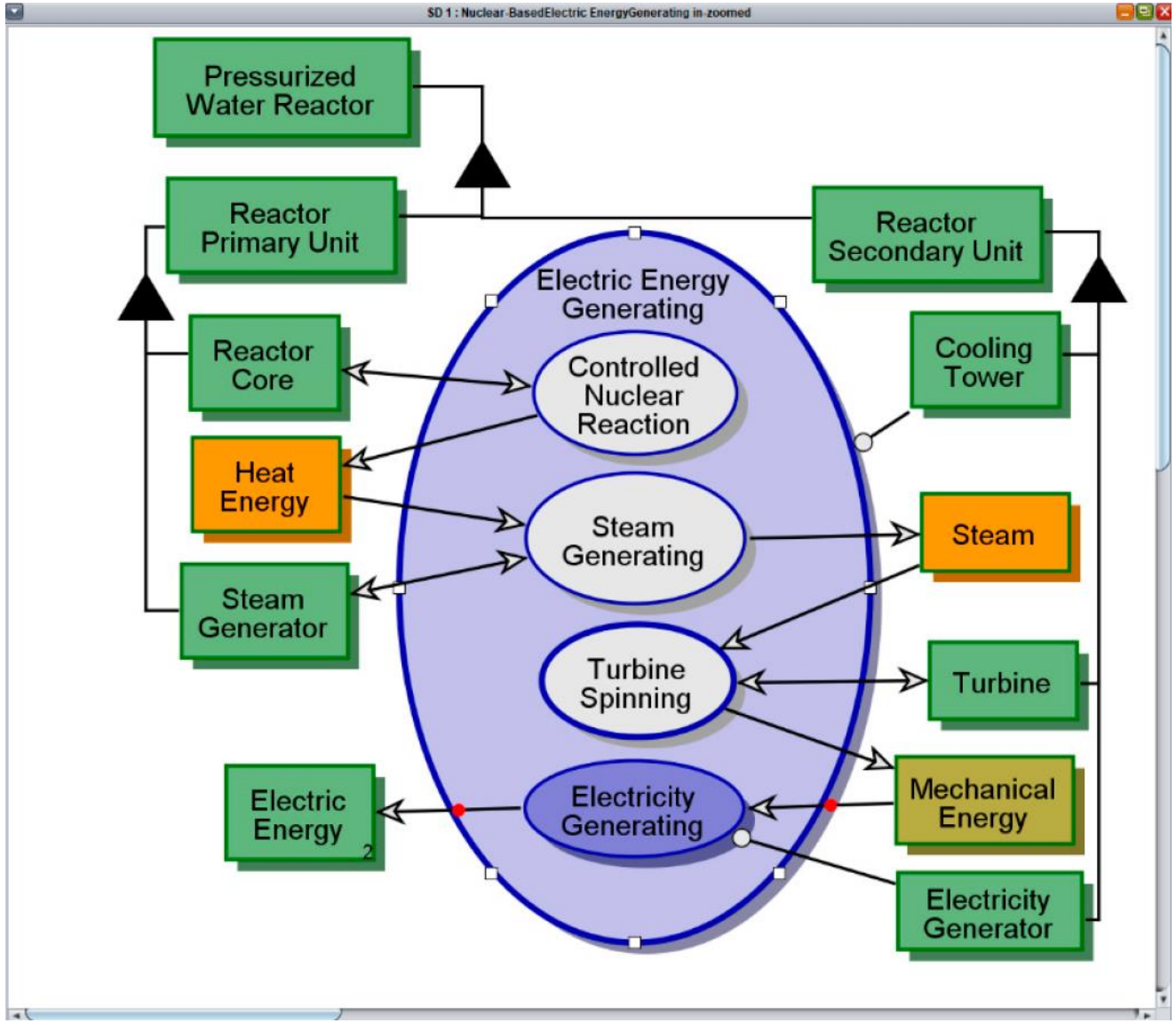


Fig. 3. Simplified View of Kerberos Authentication Flow [9]

Article

Minding the Cyber-Physical Gap: Model-Based Analysis and Mitigation of Systemic Perception-Induced Failure

Yaniv Mordecai [1,2,*] and Dov Dori [3,4]



Complexity

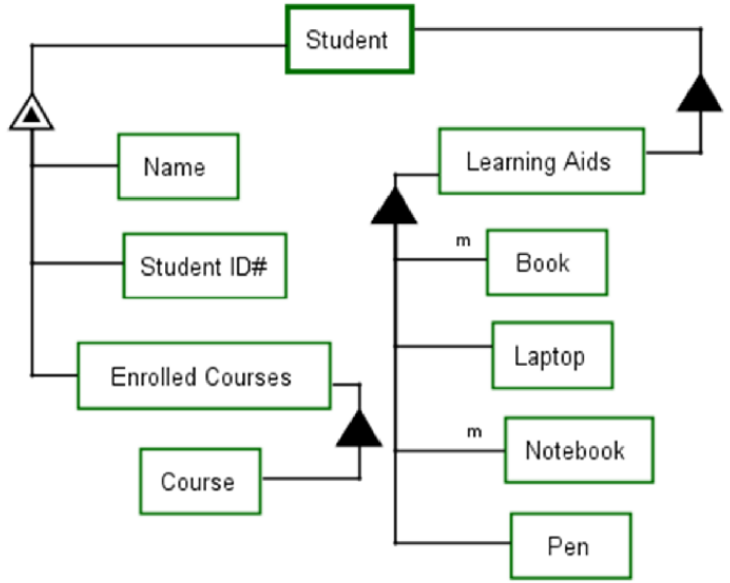

COMPLEXITY
Even Vader does not know what are those buttons for.
VERY DEMOTIVATIONAL .com

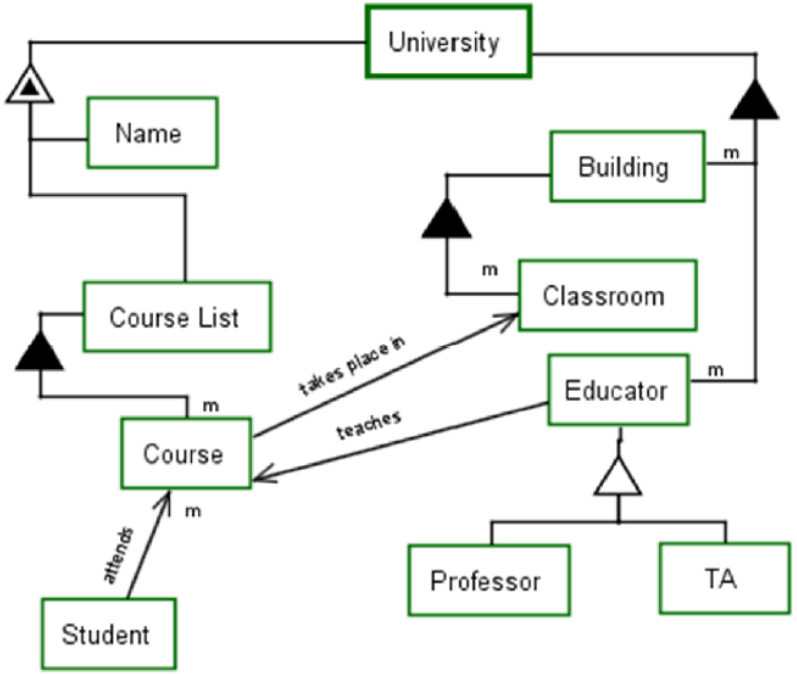
Managing Complexity

- OPM helps manage the system's complexity with three refinement mechanisms:
  - In-Zooming/Out-Zooming: primary used to model **process** flow.
  - Un-Folding/Folding: primary used to model **object** structure.
  - State Expression/Suppression: show only the **states** of an **object** that are relevant in the current context of the model.

Unfolding

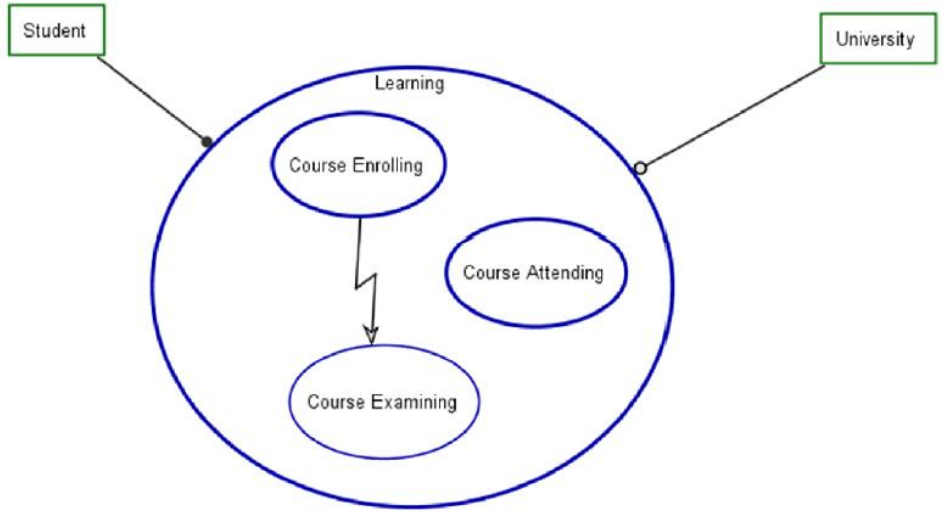
- Creates a new diagram with the unfolded object at the top.
- The unfolded object can now be refined by adding its parts and attributes.
- The attributes and parts can be further refined in the same diagram or with further unfolding

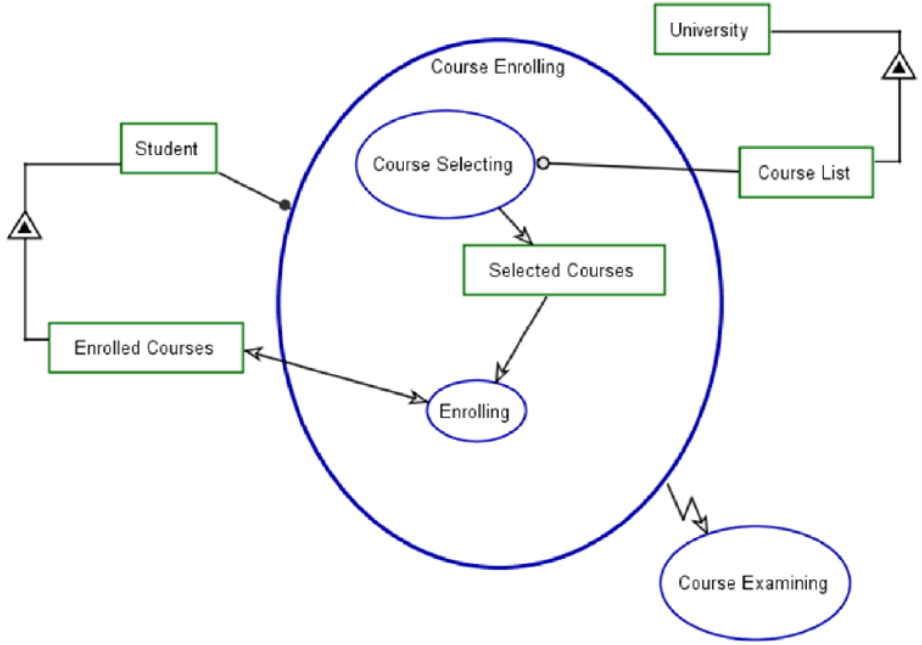




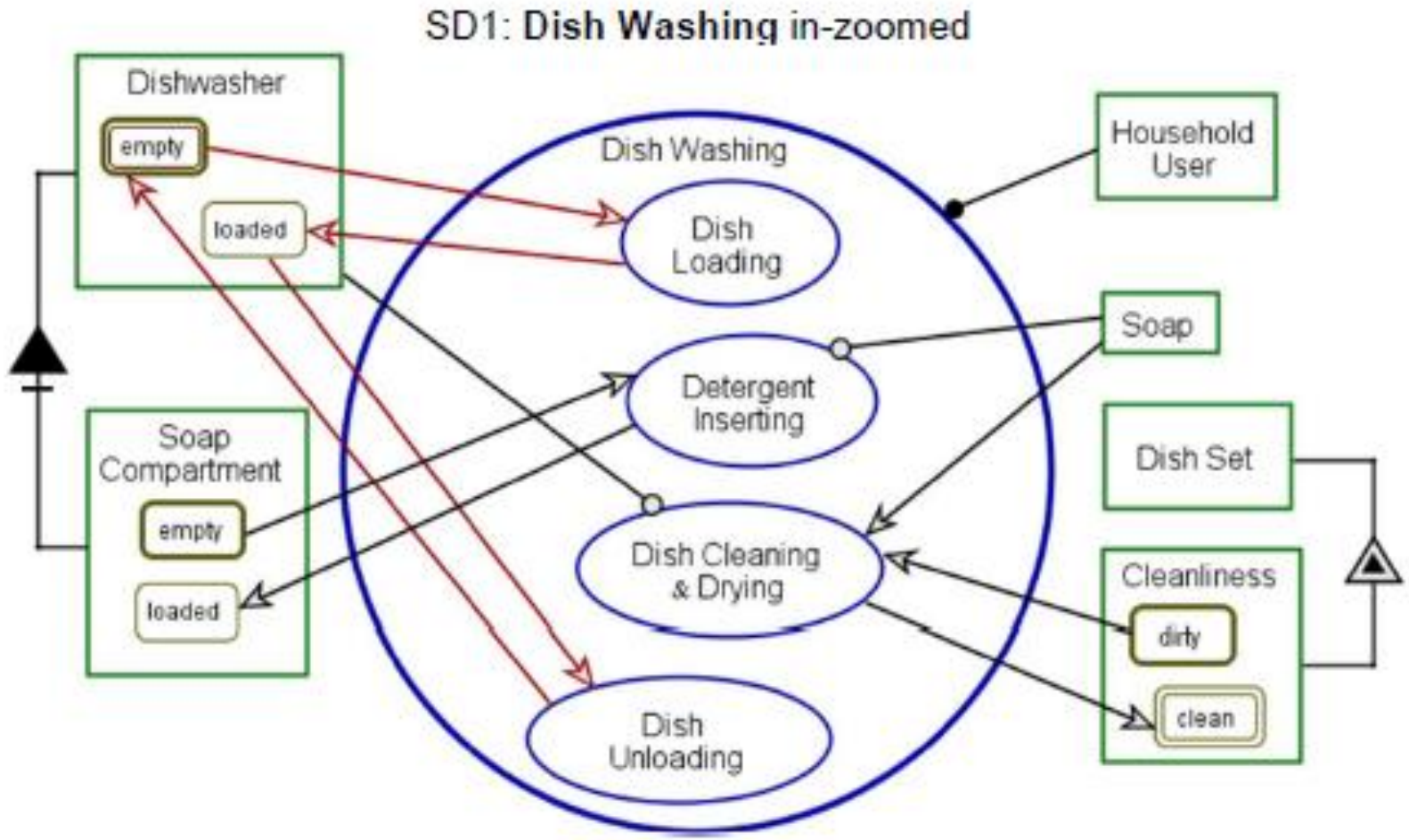
In-Zooming

- Creates a new diagram with the in-zoomed process centered and enlarged.
- The in-zoomed can now be refined by displaying the internal processes that compose it.
- The objects that are linked to the process can also be refined and connected to the processes that compose the in-zoomed process.
- The inner processes can be refined further by inzooming or unfolding.





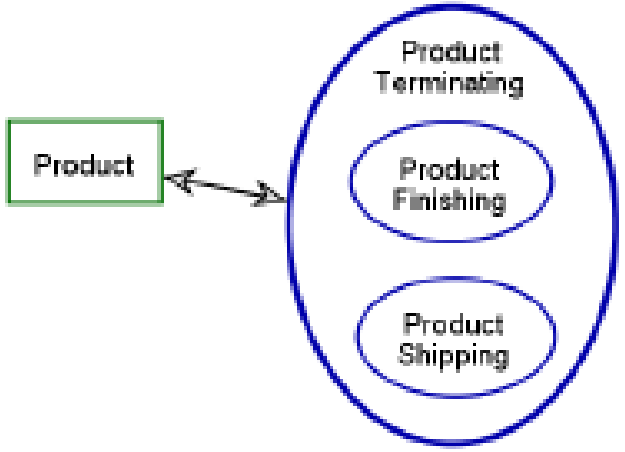

SD: Dish Washing System
Dishwasher
Household User
Dish Washing
Soap
Dish Set


SD1: Dish Washing in-zoomed
Dishwasher
empty
loaded
Soap Compartment
empty
loaded
Dish Washing
Dish Loading
Detergent Inserting
Dish Cleaning & Drying
Dish Unloading
Household User
Soap
Dish Set
Cleanliness
dirty
clean

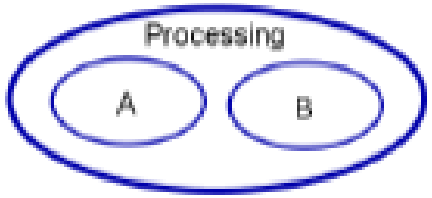
Execution Order

- An in-zoomed process can contain many subprocesses.
- When the flow of information in the model does not state otherwise, the processes inside an in-zoomed process are executed from top to bottom.
  - Upon subprocess completion within the context of an in-zoomed process, the subprocess immediately invokes the one(s) below it.

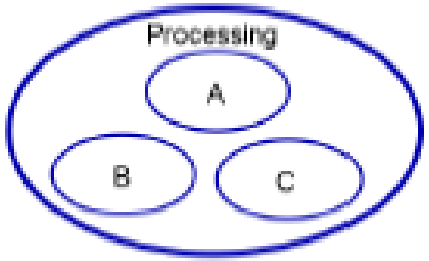
  - Top: Subprocesses A and B initiate in parallel as soon as Processing starts.
  - Bottom: Subprocesses B and C initiate in parallel as soon as subprocess A ends.



Product Terminating zooms into **Product Finishing** and **Product Shipping**, in that sequence.



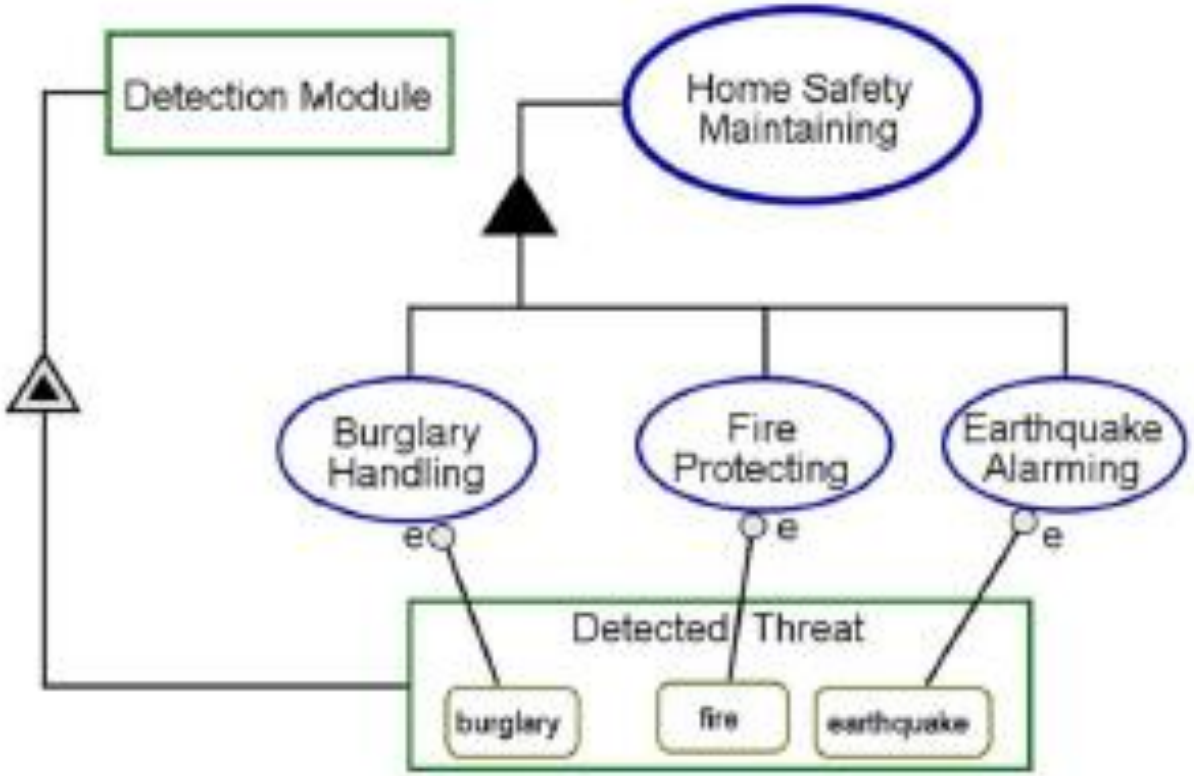
Processing zooms into parallel **A** and **B**.



Processing zooms into **A** and parallel **B** and **C**, in that sequence.

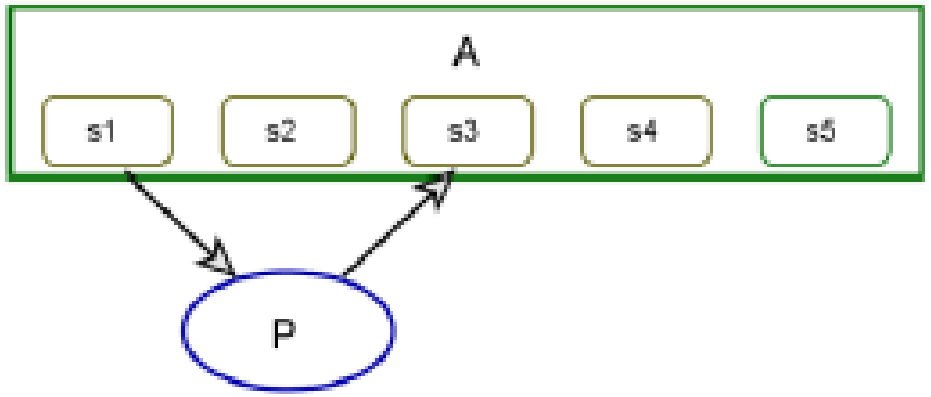
Asynchronous

The modelling of asynchronous process refinement shall use the aggregation-participation fundamental structural link either through in-diagram aggregation unfolding or as a new-diagram aggregation unfolding of the process.

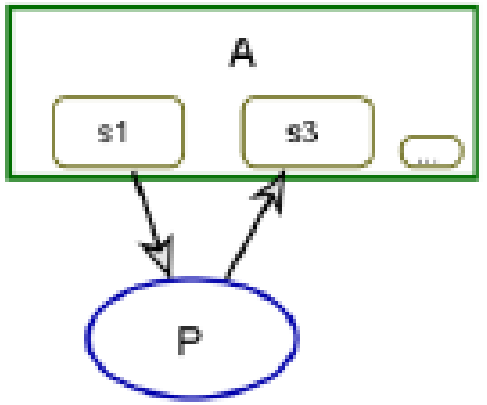


Home Safety Maintaining consists of **Burglary Handling**, **Fire Protecting**, and **Earthquake Alarming**.
Detection Module exhibits **Detection Treat**.
Detection Treat can be **burglary**, **fire**, or **earthquake**.
Burglary Detected Threat initiates **Burglary Handling**, which requires **burglary Detected Threat**.
Fire Detected Threat initiates **Fire Protecting**, which requires **fire Detected Threat**.
Earthquake Detected Threat initiates **Earthquake Alarming**, which requires **earthquake Detected Threat**

State Suppressing



A can be **s1**, **s2**, **s3**, **s4**, or **s5**.
P changes A from **s1** to **s3**.



A can be **s1**, **s3**, or other states.
P changes A from **s1** to **s3**.

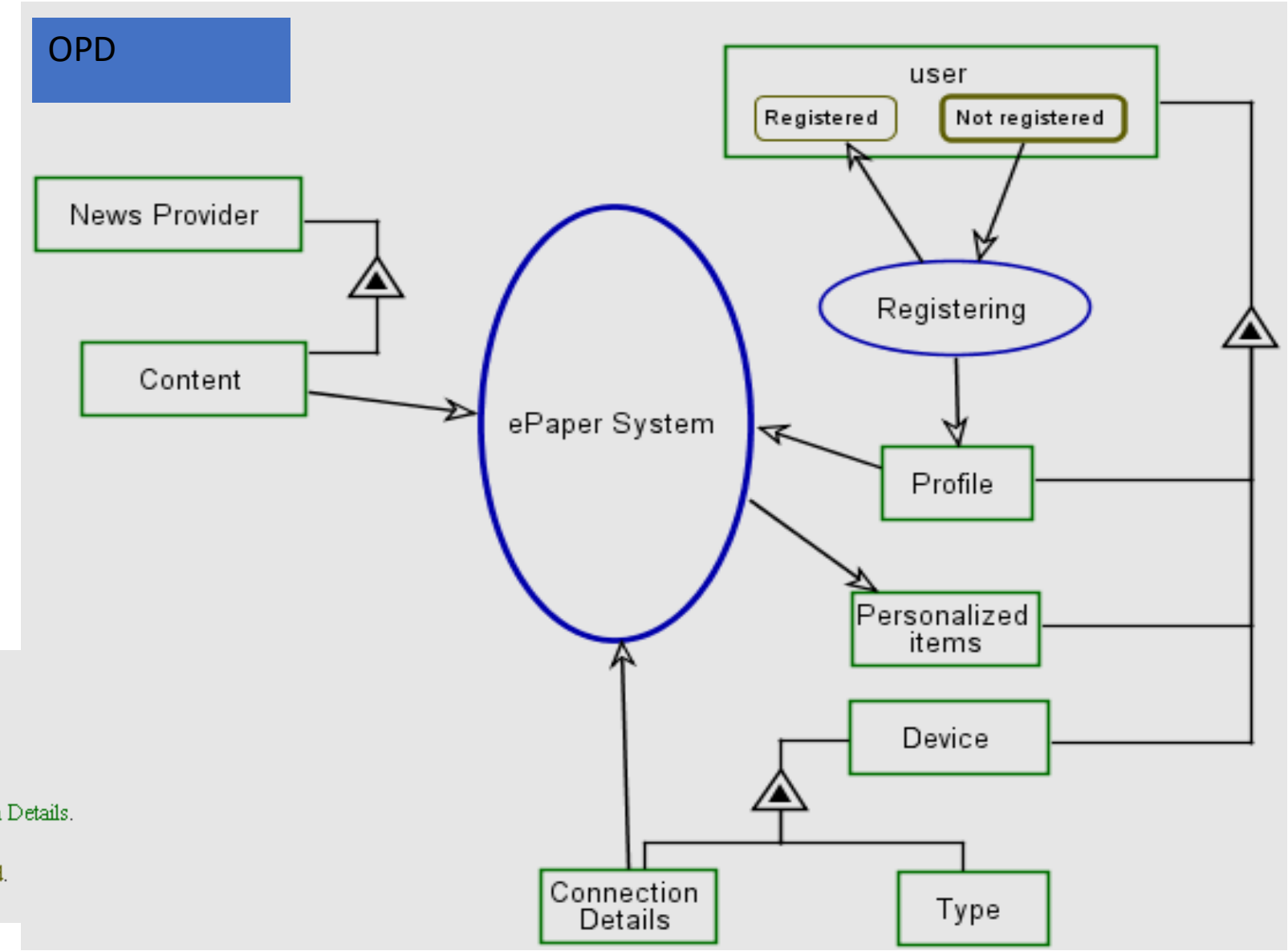
Case Study: Epaper Project

- Aggregating news content from several providers
- Content management
- Building subscribers profiles
  - Initial profile (content-based)
  - Collaborative filtering
- Sending news items that matching the user's profile

OPM model

- SD: High level view

OPD



OPL

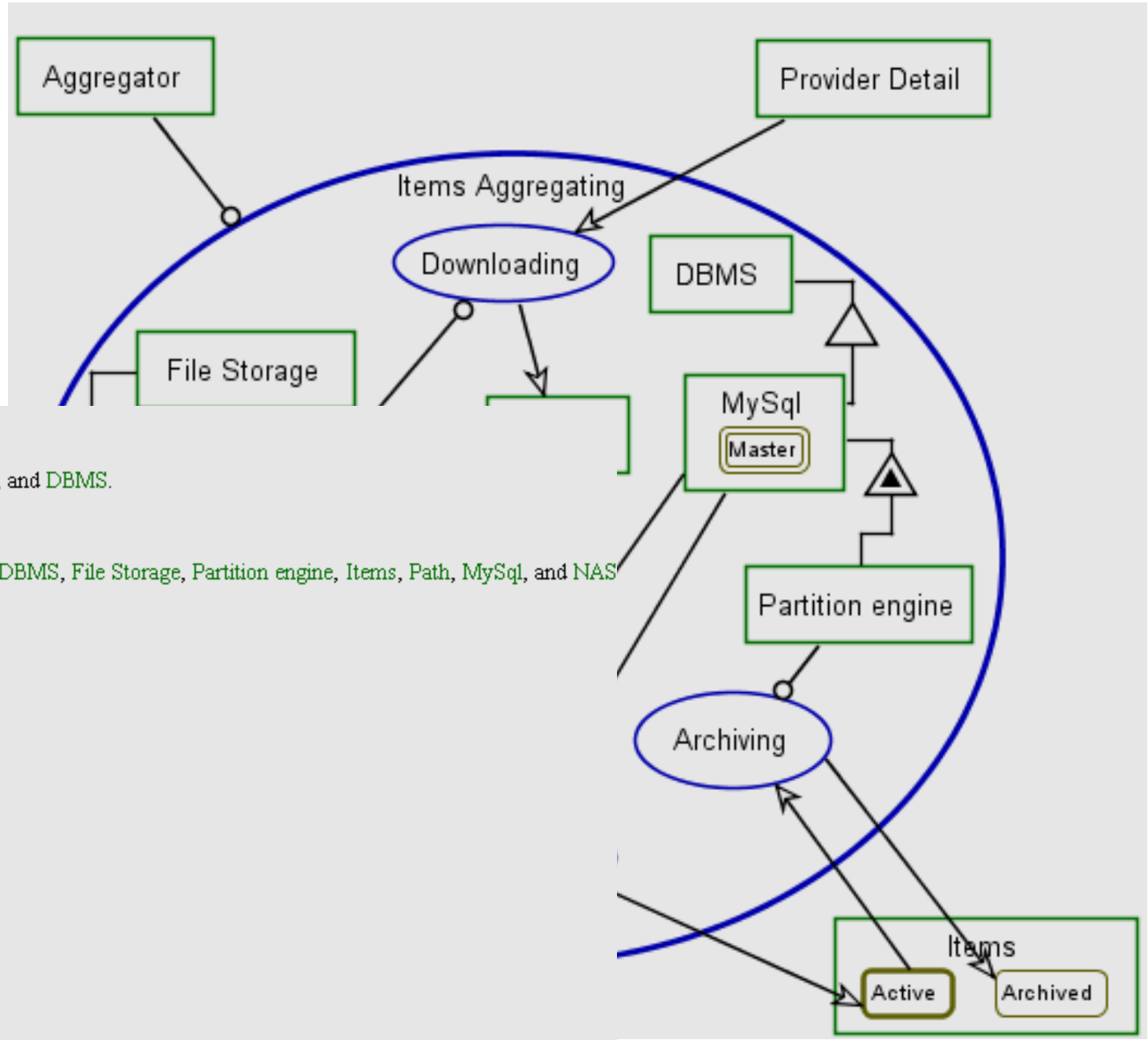
user can be Registered or Not registered.
Not registered is initial.
user exhibits Profile, Personalized items, and Device.
Device exhibits Connection Details and Type.
News Provider exhibits Content.
ePaper System consumes Content, Profile, and Connection Details.
ePaper System yields Personalized items.
Registering changes user from Not registered to Registered.
Registering yields Profile.

OPM Model cont.

- SD1.1 (Zooming-In)

Case Study cont.

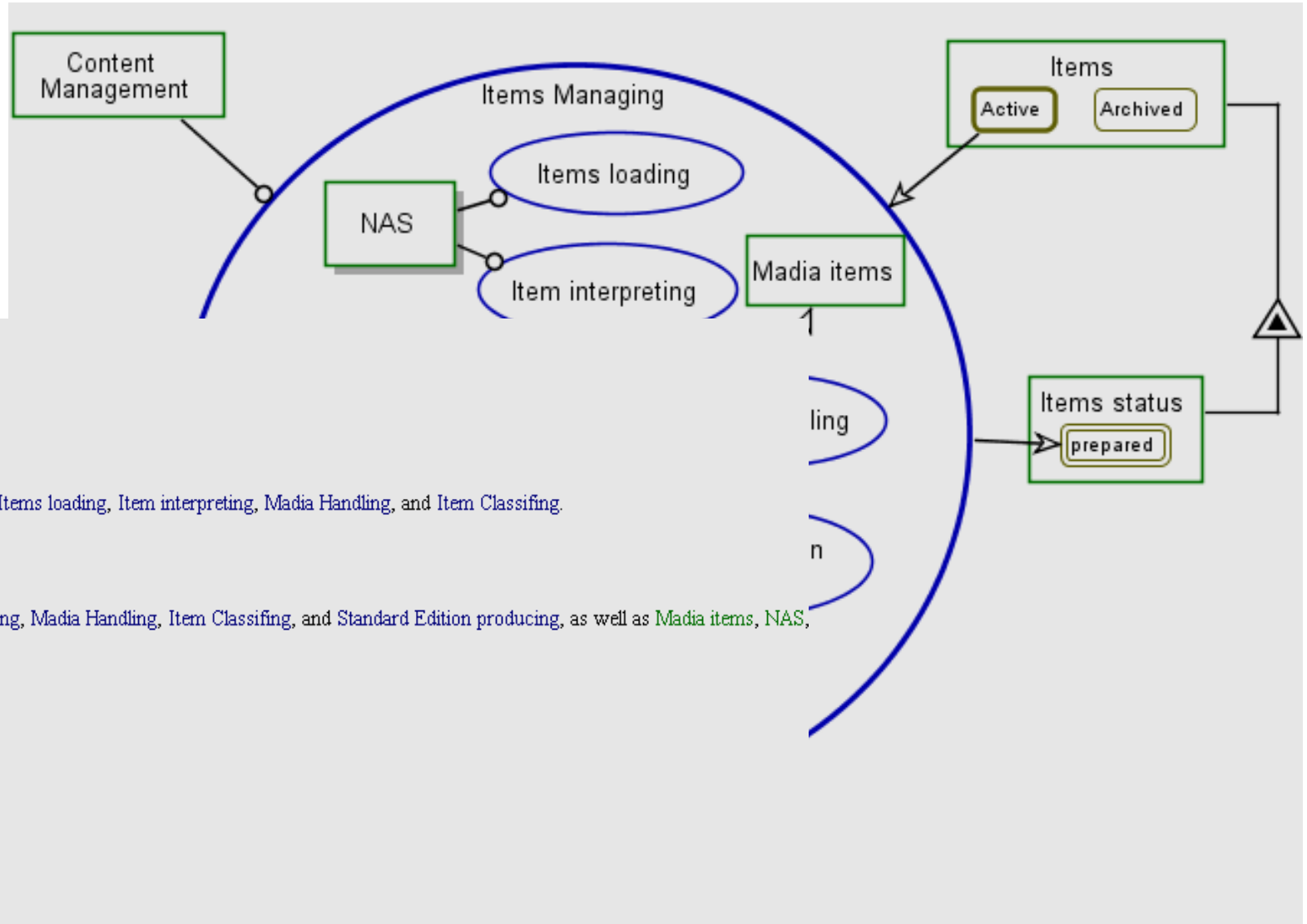
- SD1.1 :Item aggregating



Items can be Active or Archived.
Active is initial.
Items Aggregating exhibits NAS, MySql, Path, Items, Partition engine, File Storage, and DBMS.
Items Aggregating consists of Downloading, Organizing, and Archiving.
Items Aggregating requires Aggregator.
Items Aggregating zooms into Downloading, Archiving, and Organizing, as well as DBMS, File Storage, Partition engine, Items, Path, MySql, and NAS.
Items exhibits Path.
Items stores in NAS.
MySql is a DBMS.
MySql is Master.
Master is final.
MySql exhibits Partition engine.
MySql holds Path.
NAS is a File Storage.
Downloading requires NAS.
Downloading consumes Provider Detail.
Downloading yields Items.
Archiving requires Partition engine.
Archiving changes Items from Active to Archived.
Organizing requires MySql and NAS.
Organizing yields Active Items.

Case Study cont.

- Item Managing (SD1.1)

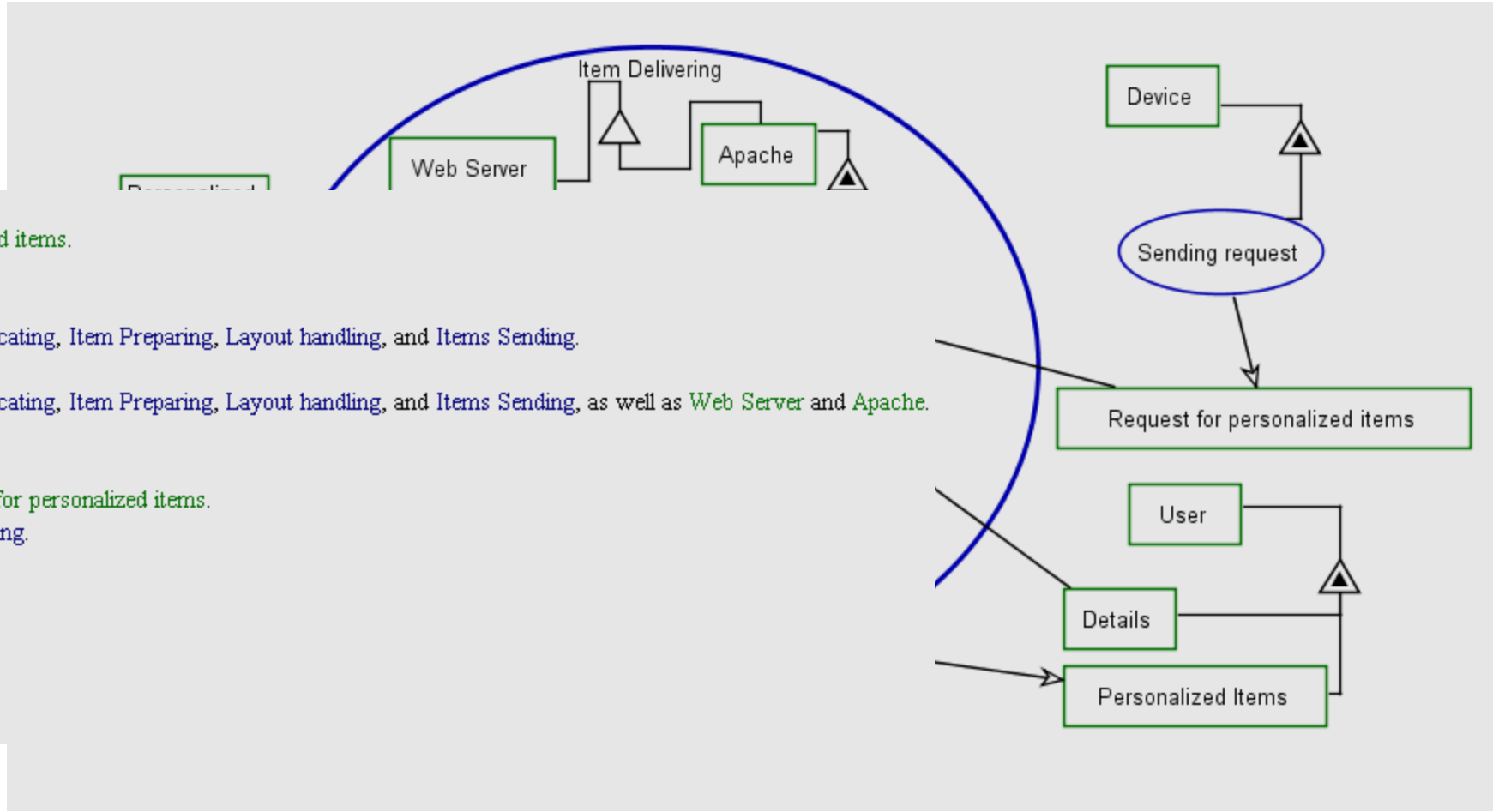


Items can be Active or Archived.
Active is initial.
Items exhibits Items status.
Items status is prepared.
prepared is final.
Items Managing exhibits MySQL, NAS, and Madia items.
Items Managing consists of Similarity Computing, Standard Edition producing, Items loading, Item interpreting, Madia Handling, and Item Classifing.
Items Managing requires Content Management.
Items Managing consumes Active Items.
Items Managing yields prepared Items status.
Items Managing zooms into Items loading, Item interpreting, Similarity Computing, Madia Handling, Item Classifing, and Standard Edition producing, as well as Madia items, NAS, MySQL.
NAS is physical.
MySQL is physical.
MySQL is Master.
Master is final.
Items loading requires NAS.
Item interpreting requires NAS.
Similarity Computing requires MySQL.
Madia Handling affects Madia items.
Item Classifing requires MySQL.
Standard Edition producing requires MySQL.

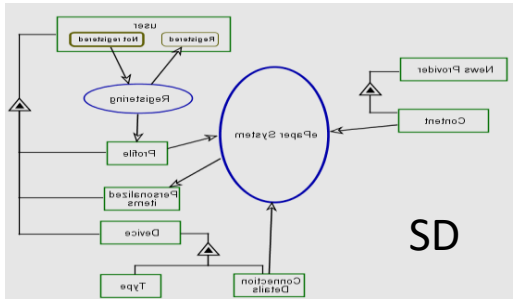
Case Study cont.

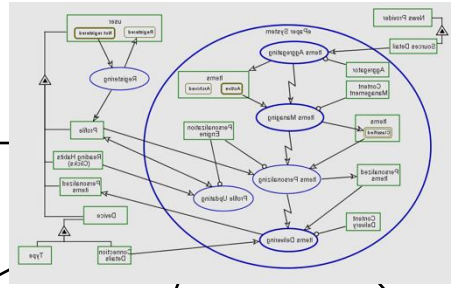
- Item Delivering (SD1.1)

Device exhibits Sending request.
Sending request yields Request for personalized items.
User exhibits Details and Personalized Items.
Item Delivering exhibits Web Server and Apache.
Item Delivering consists of Request Handling, Authenticating, Item Preparing, Layout handling, and Items Sending.
Item Delivering requires Content Delivery.
Item Delivering zooms into Request Handling, Authenticating, Item Preparing, Layout handling, and Items Sending, as well as Web Server and Apache.
Apache is a Web Server.
Apache exhibits Request Handling.
Request Handling consumes Request for personalized items.
Request Handling invokes Authenticating.
Authenticating consumes Details.
Authenticating invokes Item Preparing.
Item Preparing consumes Personalized Items.
Item Preparing invokes Layout handling.
Layout handling invokes Items Sending.
Items Sending yields Personalized Items.

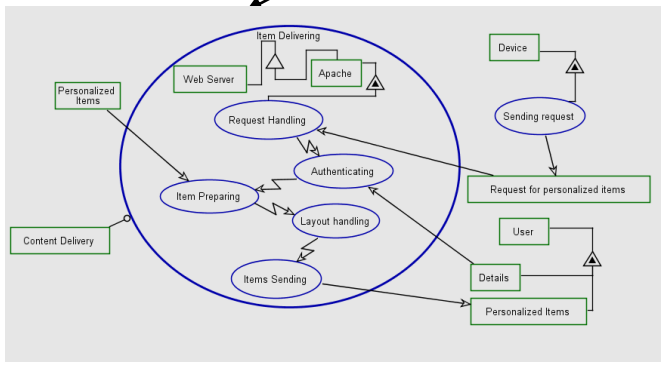


OPM map

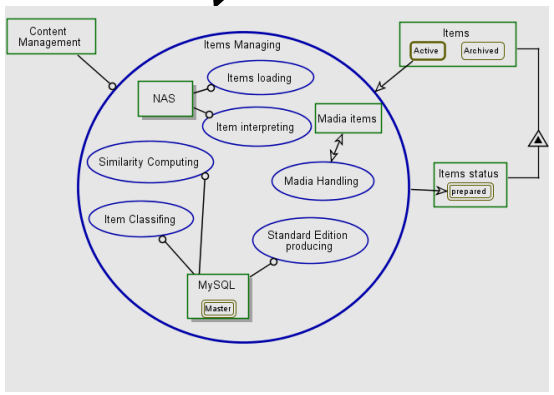




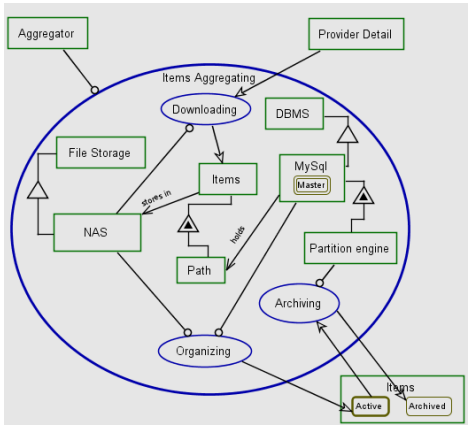
SD1.3



SD1.2



SD1.1

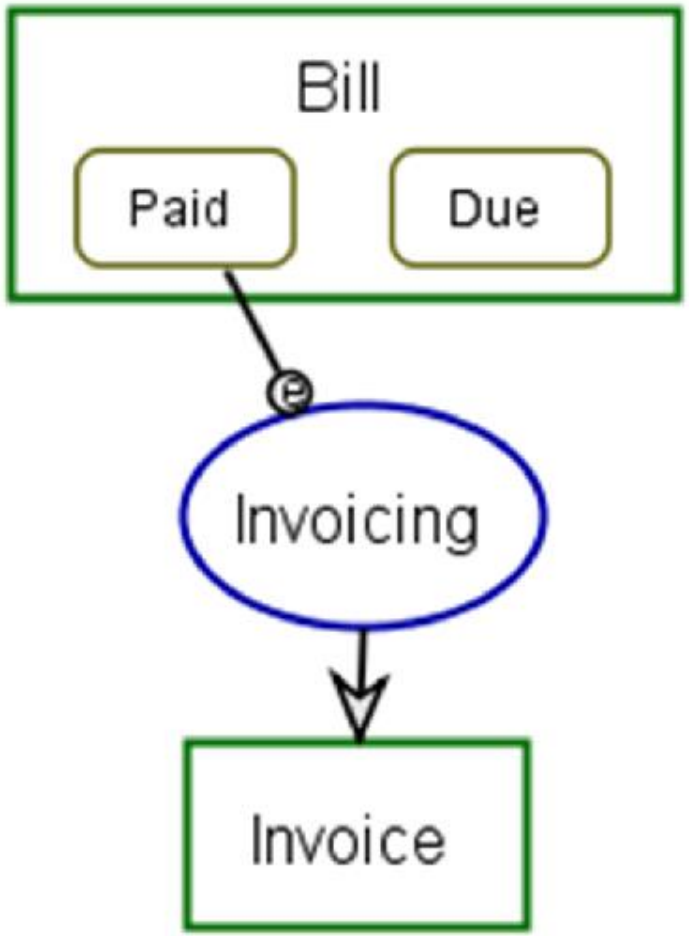


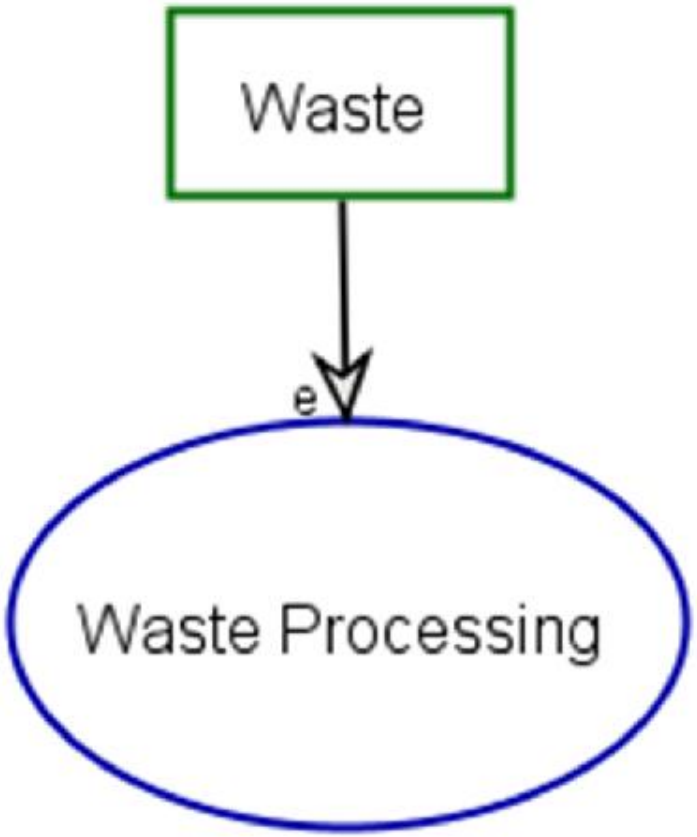
Conditions & Events

Advanced Procedural Links

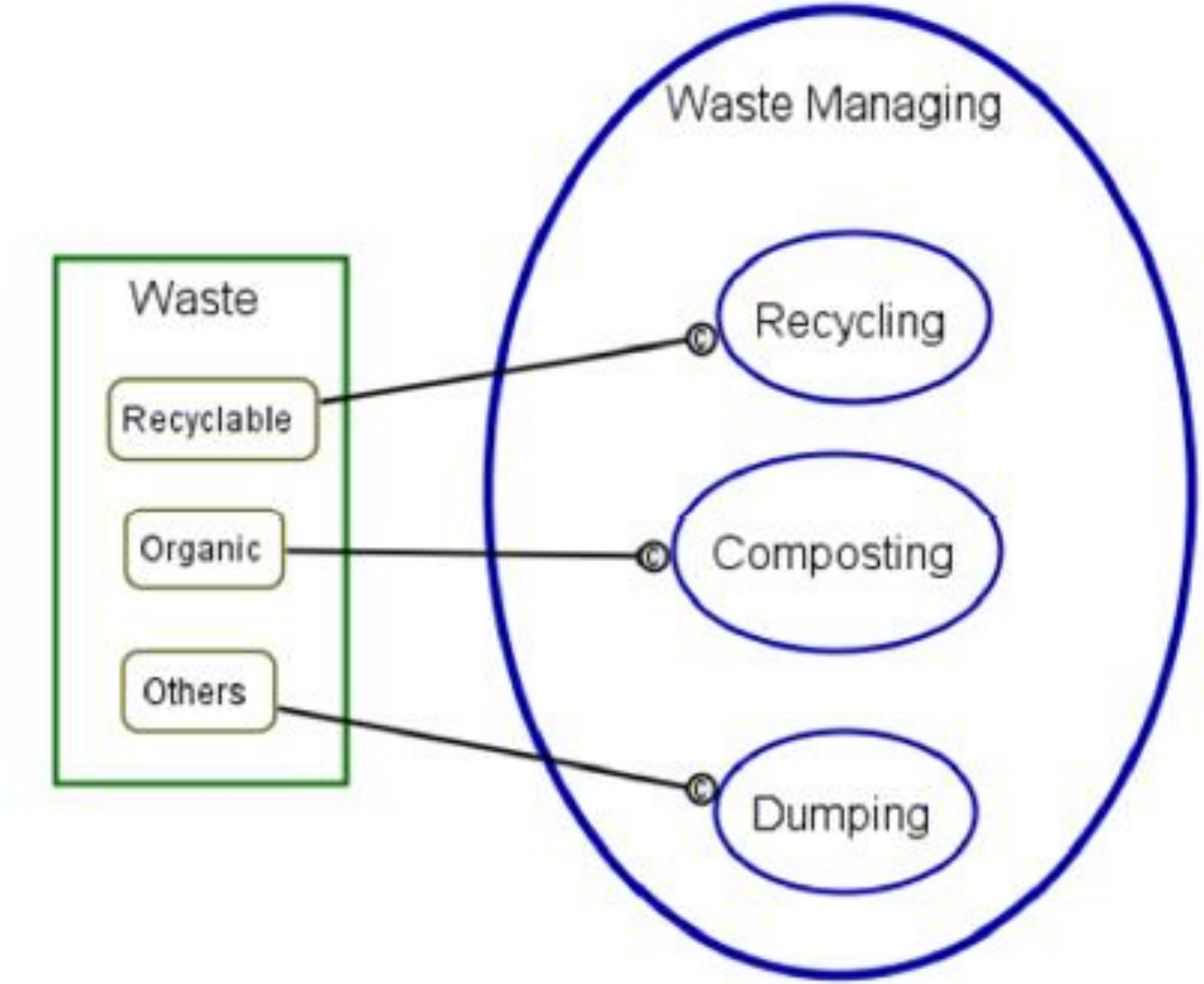
- **Event links**: triggers process activation if the event is satisfied. They are **used when agents are not controlling the process**. Two kinds of event links:
  - **Instrument event link**: the process is triggered if the **instrument object exists** (or is in a specific state).
  - **Consumption event link**: the process is triggered if the **consumed object exists** (or is in a specific state). The object is then consumed.
- **Condition link**: conditions the execution of a process to the **existence of an object or to the object being in a specific state**. If the condition is not matched, the process is skipped.

Event Link

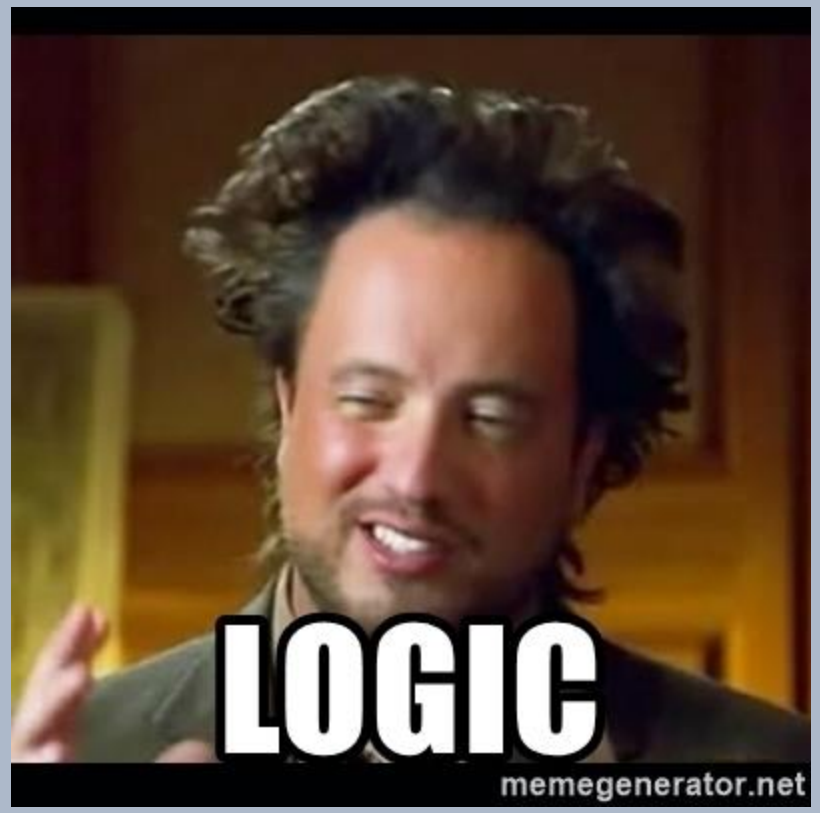




Conditional Link



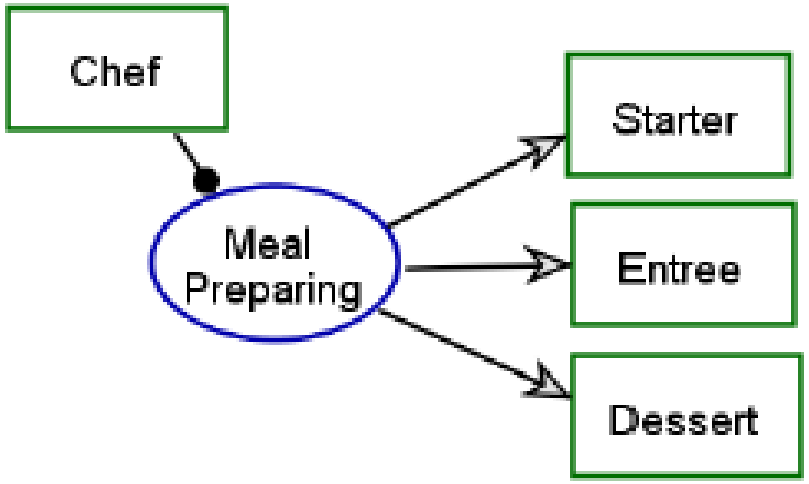
Logical operations



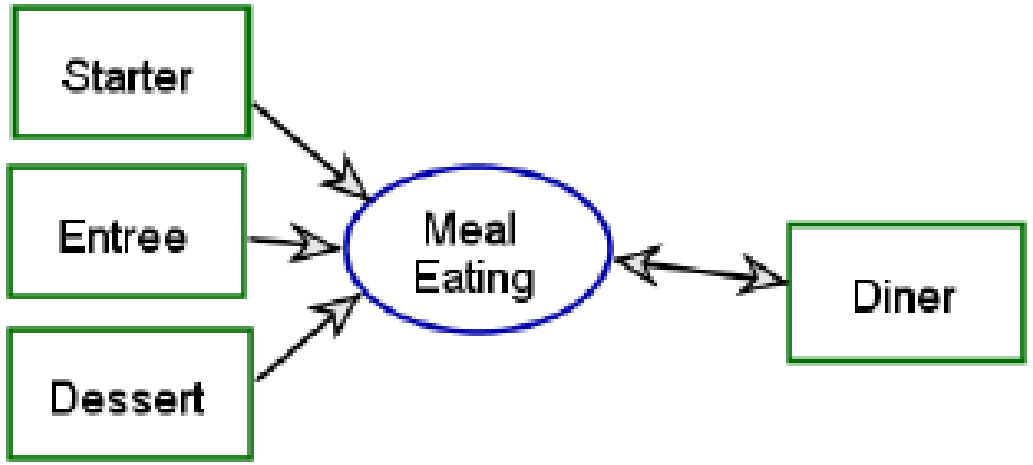
AND, XOR, and OR

- A group of two or more procedural links of the same kind that originate from, or arrive at, the same process shall have the semantics of logical **AND**.
- A group of two or more procedural links of the same kind that **originate from a common point**, or arrive at a common point, on the same object or process shall be a link fan. A link fan shall follow the semantics of either a **XOR or an OR** operator.
  - The **XOR operator** shall mean that **exactly one** of the things at the divergent link end of the link fan exists.
  - The **OR operator** shall mean that **at least one** of the two or more things at the divergent end of the link fan exists.

AND

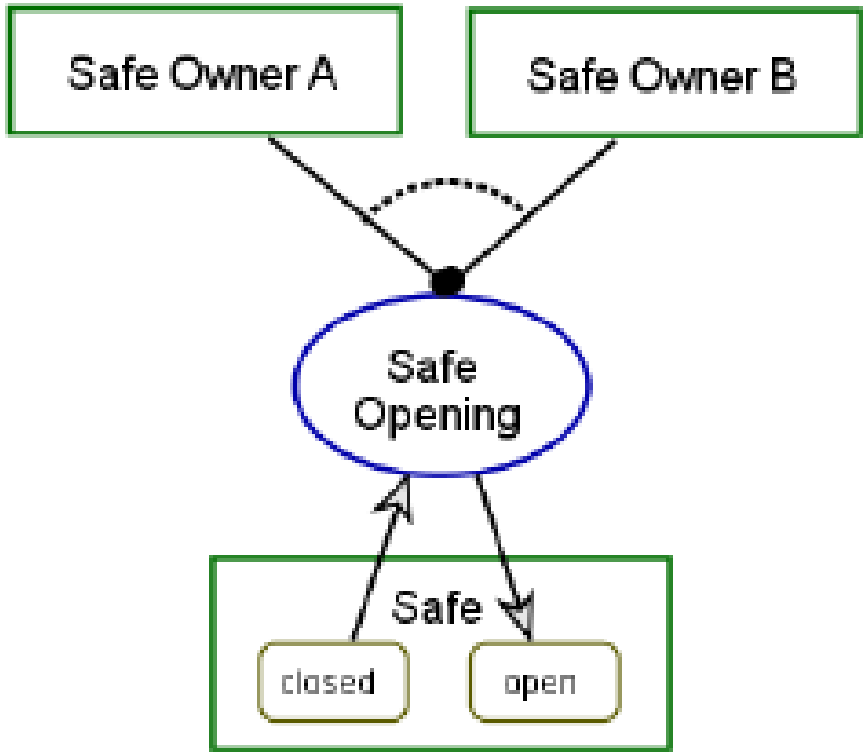


Chef handles **Meal Preparing**.
Meal Preparing yields **Starter**, **Entree**, and **Dessert**.

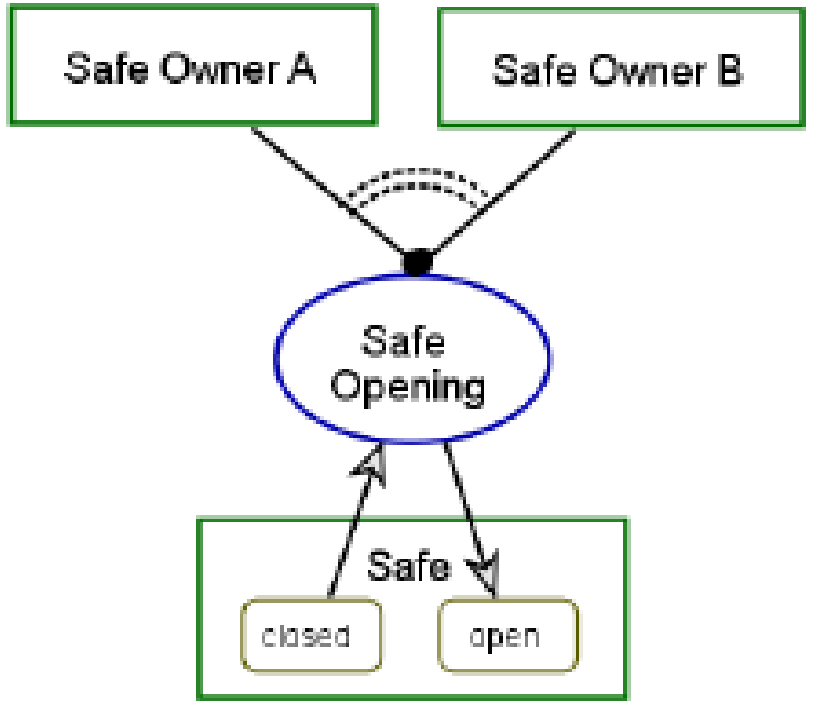


Meal Eating affects **Diner**.
Meal Eating consumes **Dessert**, **Entree**, and **Starter**.

XOR / OR

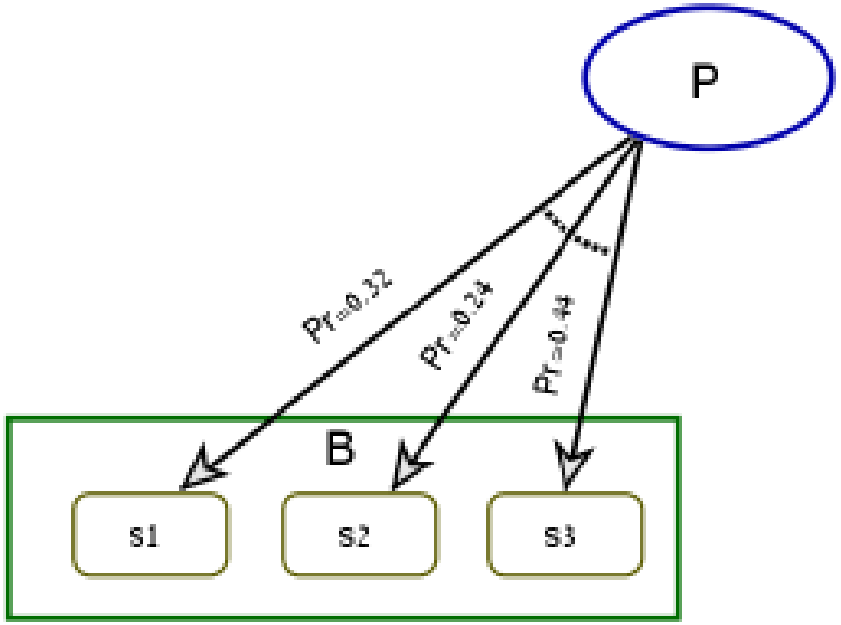


Exactly one of **Safe Owner A** and **Safe Owner B** handles **Safe Opening.**



At least one of **Safe Owner A** and **Safe Owner B** handles **Safe Opening.**

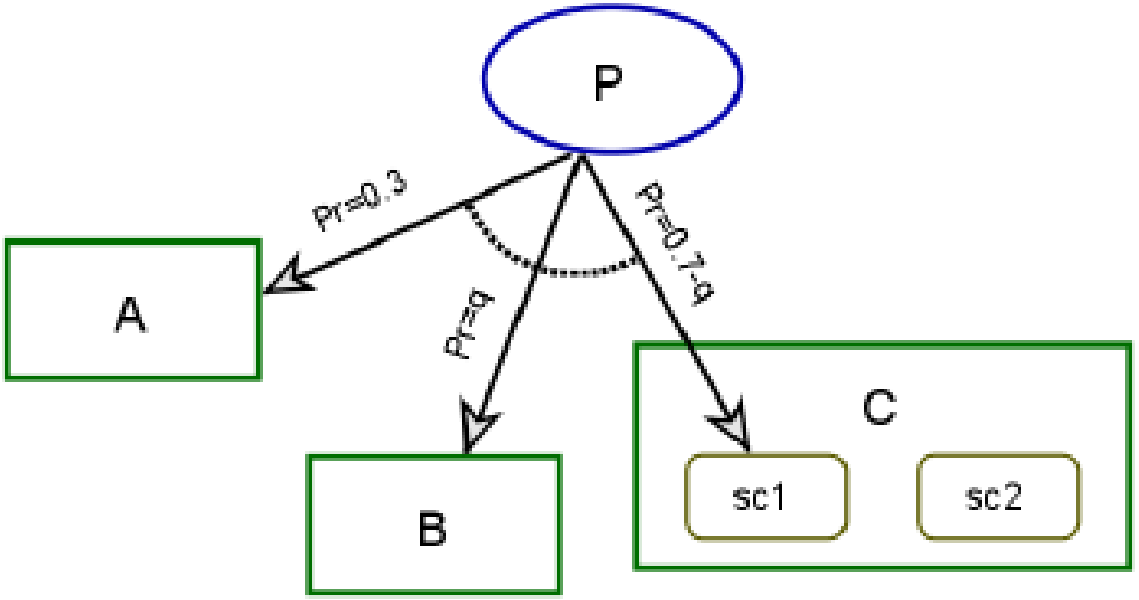
Add probabilistic chances



P yields **s1** B with probability **0.32**, **s2** B with probability **0.24**, or **s3** B with probability **0.44**.

The analogous deterministic case:

P yields exactly one of **s1** B, **s2** B, or **s3** B.

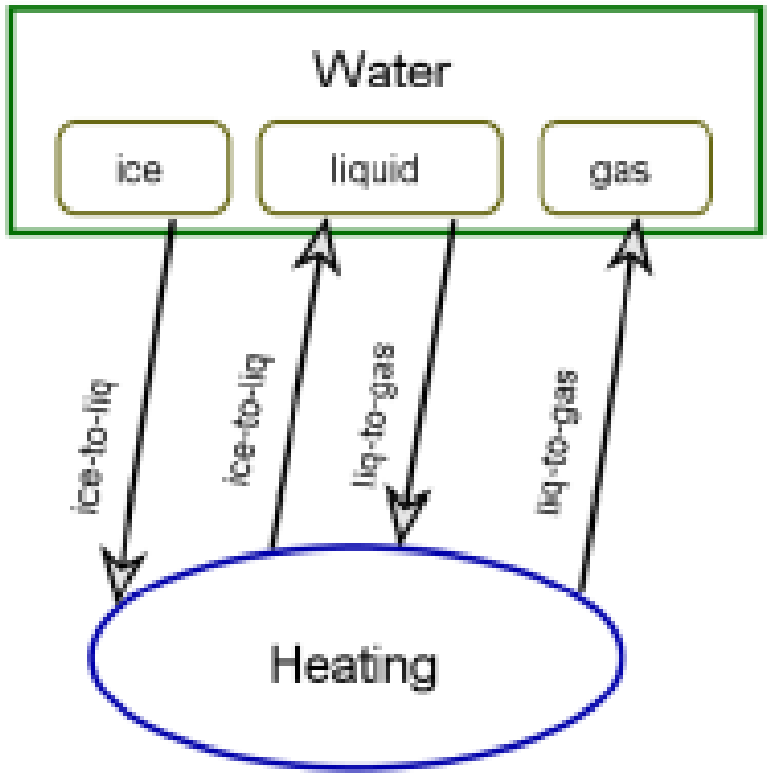


P yields **A** with probability **0.3**, **B** with probability **q**, or **sc1** C with probability **0.7-q**.

The analogous deterministic case:

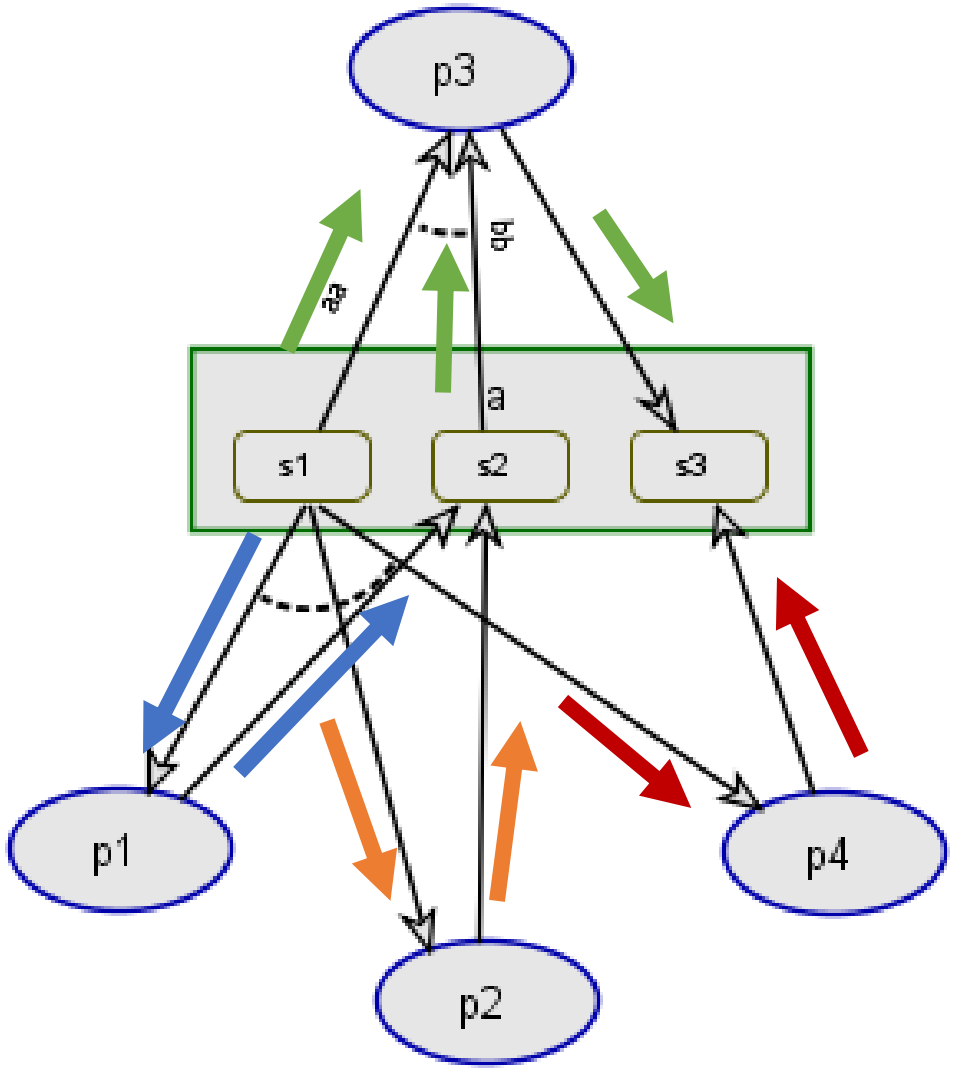
P yields exactly one of **A**, **B**, or **sc1** C.

Path labels



Following path **carnivore**, **Food Preparing** consumes **Meat.**
Following path **herbivore**, **Food Preparing** consumes Cucumber and Tomato.
Following path **carnivore**, **Food Preparing** yields **Stew** and **Steak.**
Following path **herbivore**, **Food Preparing** yields **Salad.**

Simple Example – Logics



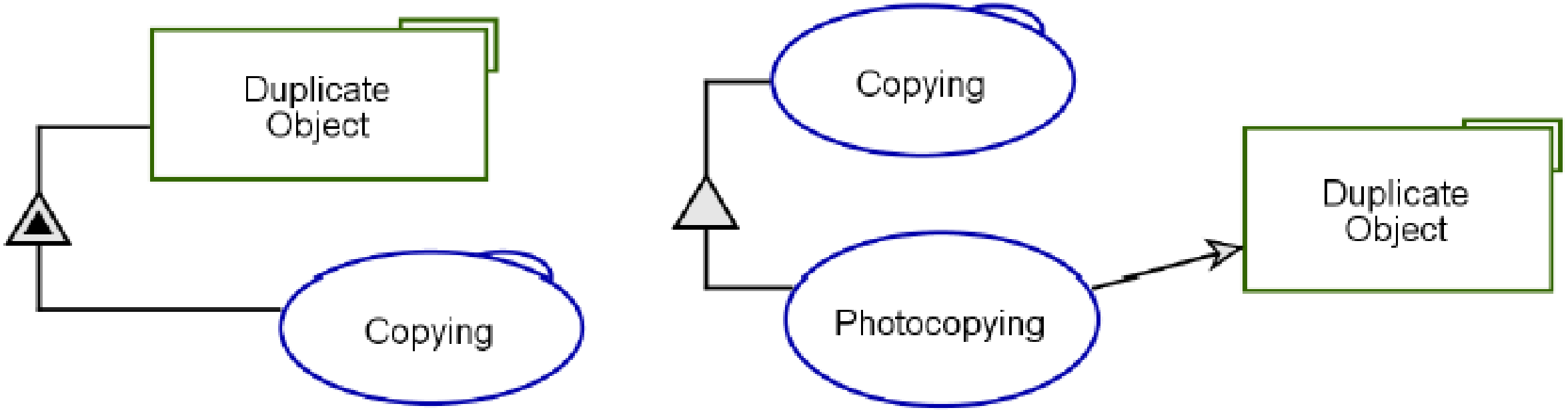
p1 changes a from s1 to s2.

p2 changes a from s1 to s2.

Following path aa, p3 consumes s1 a.
Following path bb, p3 consumes s2 a.
p3 yields s3 a.

p4 changes a from s1 to s3.

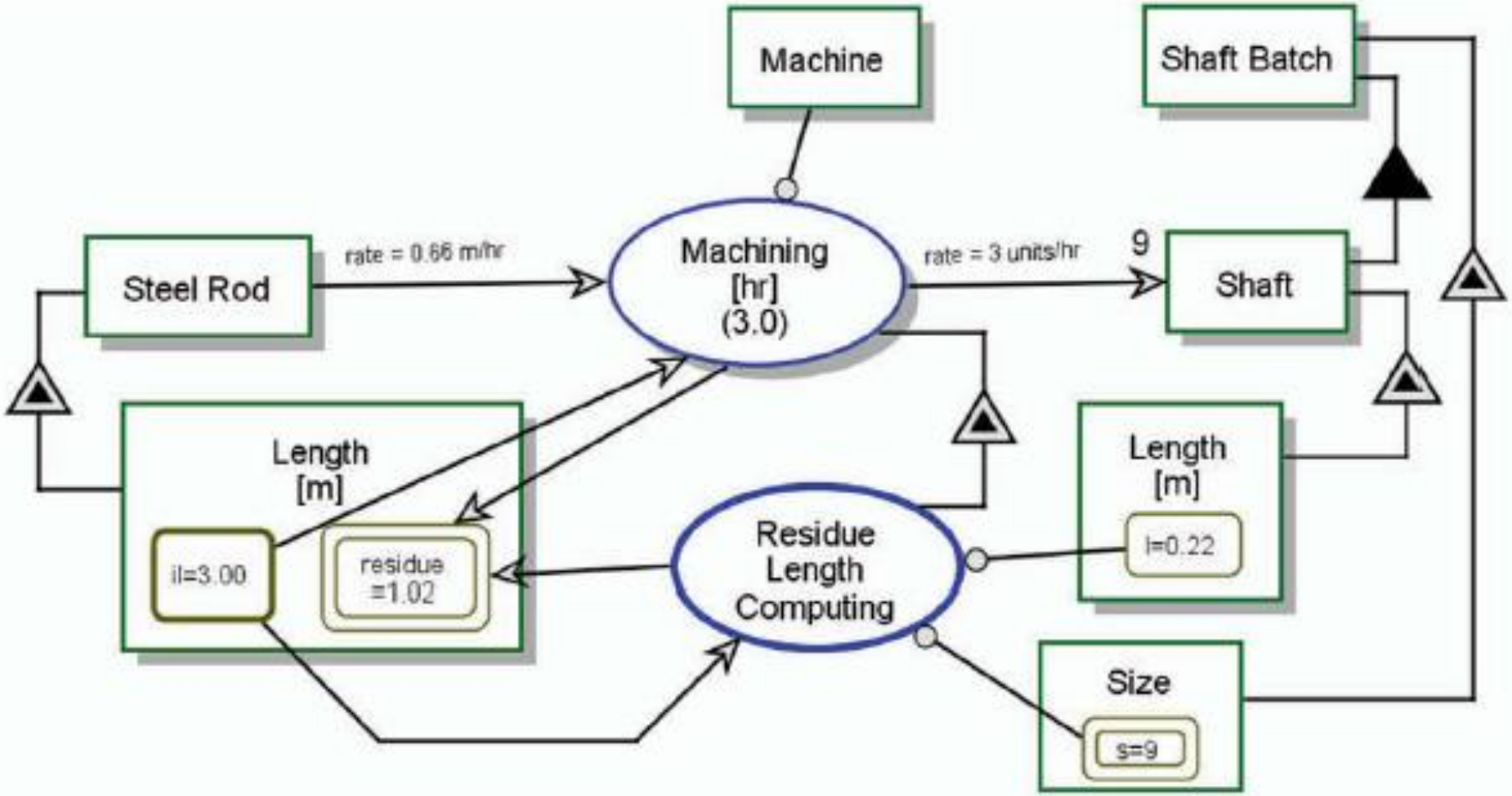
Multiple copies



Timing

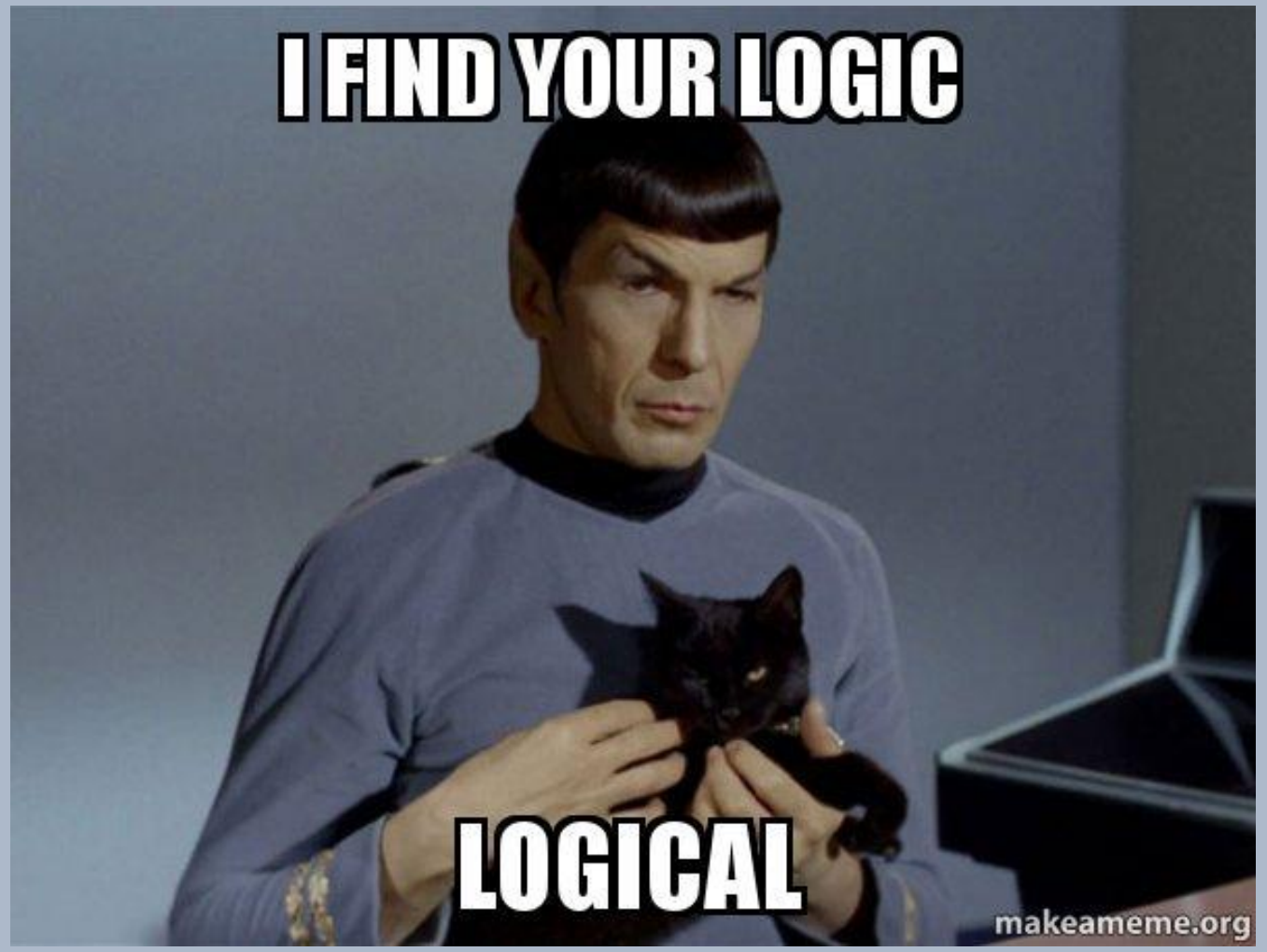
- A process may have a **Duration** attribute with a value that expresses units of time. **Duration** may specialize into **Minimal Duration**, **Expected Duration**, and **Maximal Duration.**
  - The **overtime exception link** shall connect the source process with an overtime handling destination process to specify that if at runtime, performance of the source process instance exceeds its **Maximal Duration** value, then an event initiates the destination process.
  - The **undertime exception link** shall connect the source process with an undertime handling destination process to specify that if at runtime, performance of the source process instance takes less than its **Minimal Duration** value, then an event initiates the destination process.

Calculations

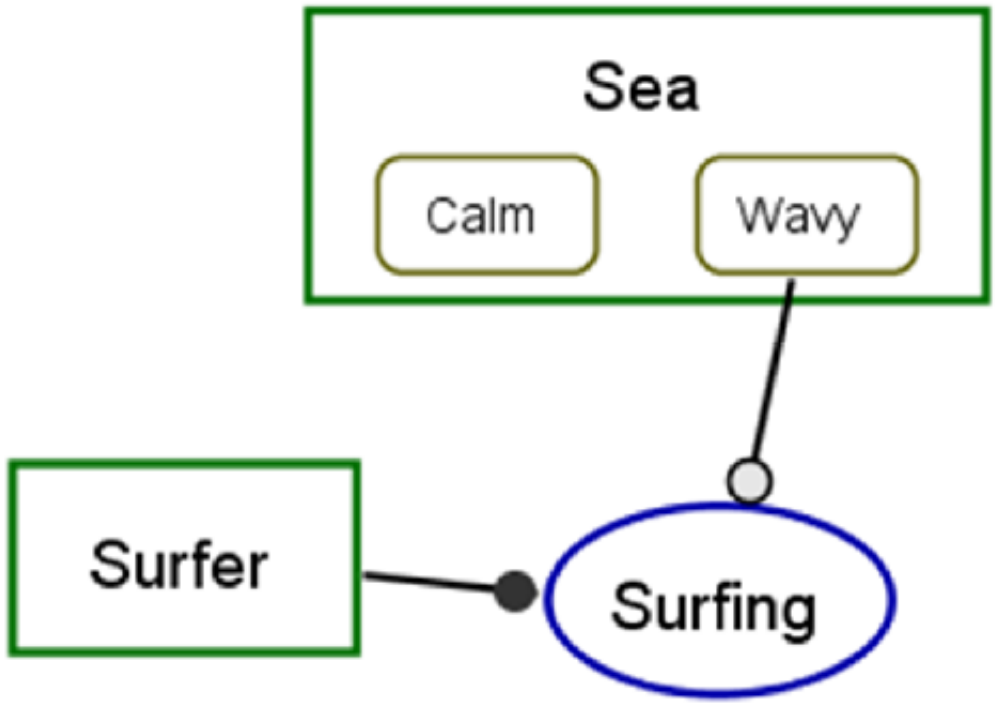


Residue Length Computing requires the value **l=0.22** m of **Length** of **Shaft** and the value of **Size s=9** of **Shaft Batch.**
Residue Length Computing changes the value of **Length** of **Steel Rod** from **il=3.00** m to **residue=1.02.**

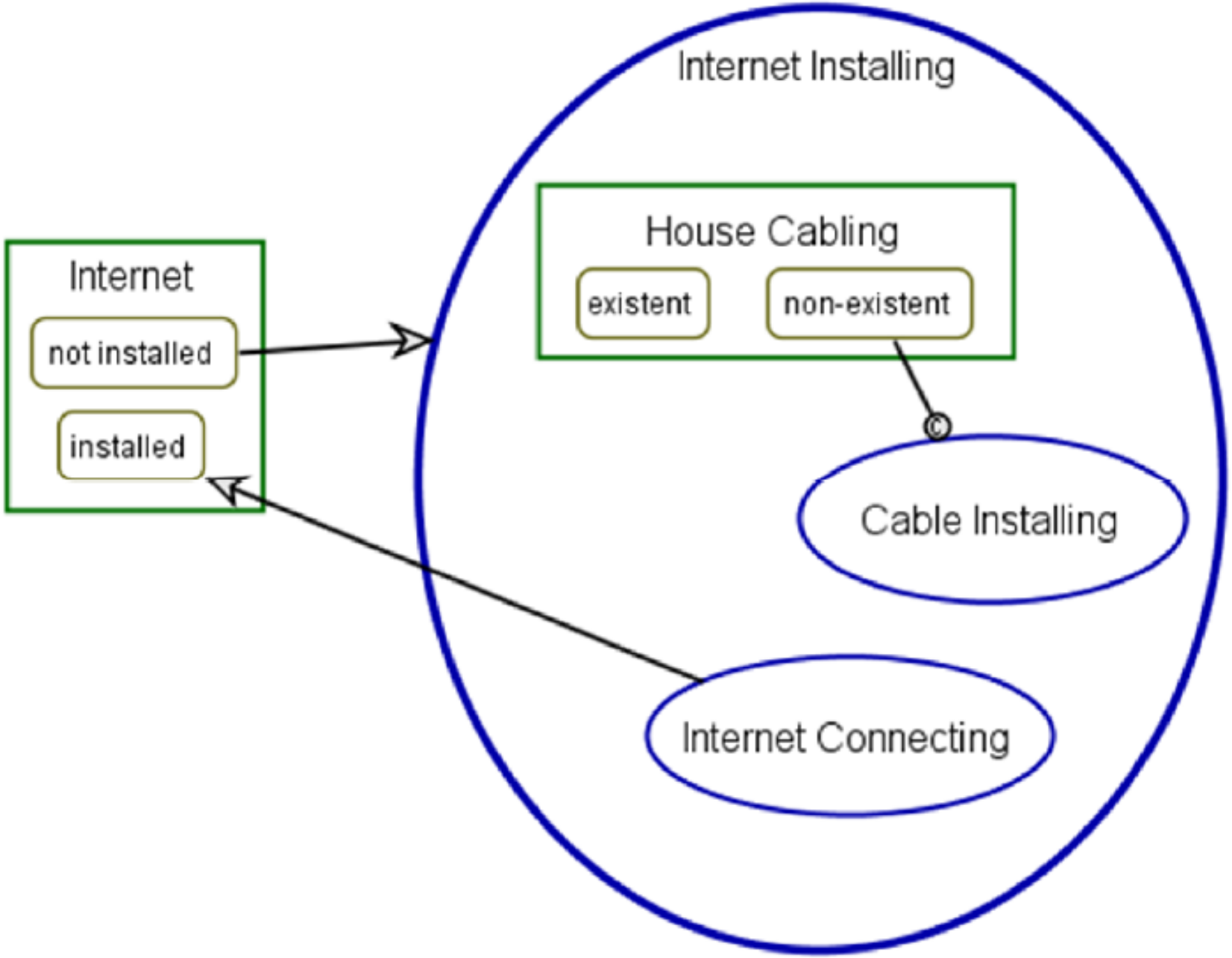
Common logical structures



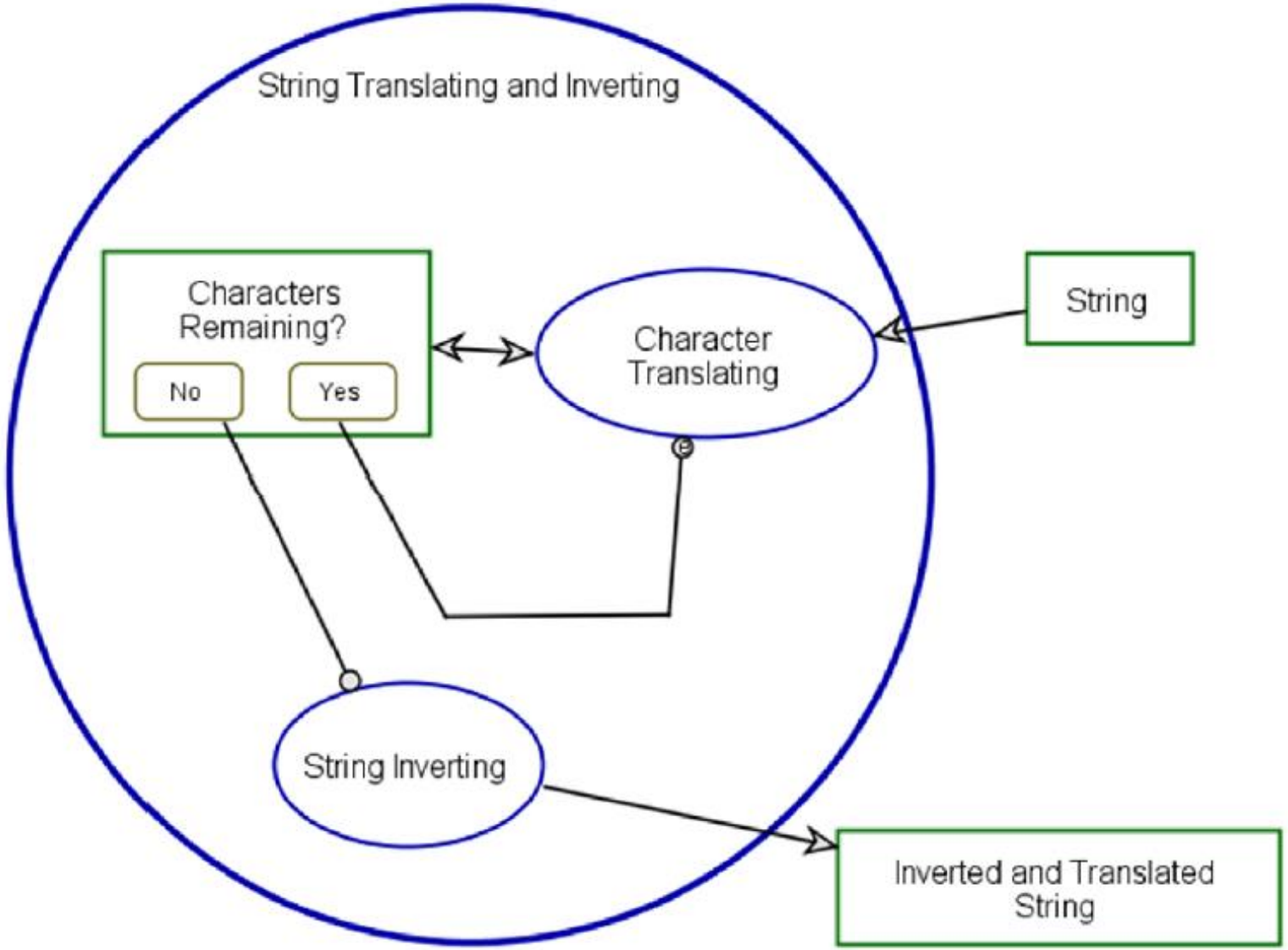
Wait until



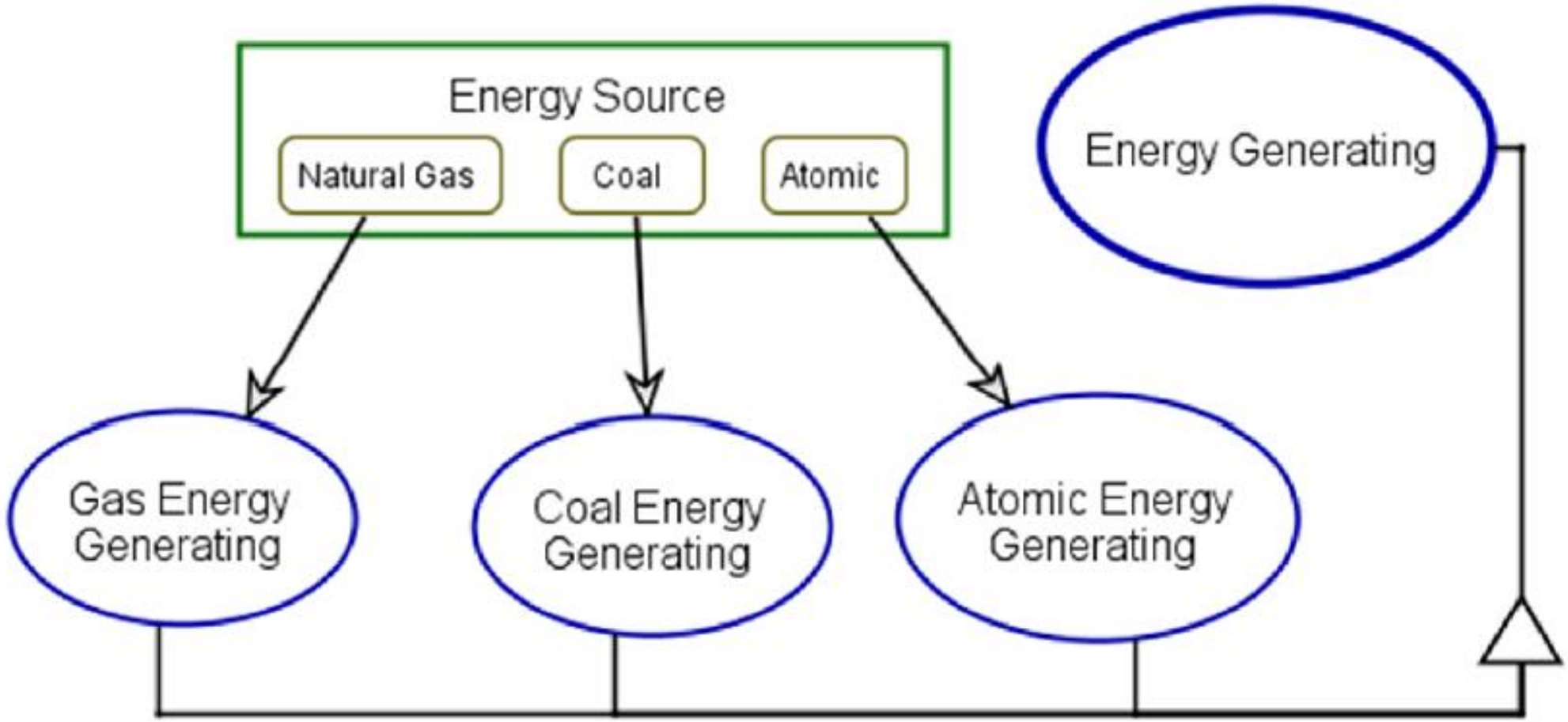
Do If


Internet Installing
House Cabling
existent
non-existent
Internet
not installed
installed
Cable Installing
Internet Connecting

Do while


String Translating and Inverting
Characters Remaining?
No
Yes
Character Translating
String
String Inverting
Inverted and Translated String

Case


Energy Source
Natural Gas
Coal
Atomic
Energy Generating
Gas Energy Generating
Coal Energy Generating
Atomic Energy Generating

12 OPM Principles

- **1. The Function-as-a-Seed** – Modelling a system starts by defining, naming, and depicting the function of the system, which is also its top-level process.

- **2. The Model Fact Representation** – An OPM model fact needs to appear in at least one OPD in order for it to be represented in the model.

- **3. The Timeline** – The timeline wihin an in-zoomed process is directed by default from the top of the in-zoomed process elipse to its bottom

- **4. The Minimal Conceptual Modelling Language** – A symbol system – a language – that can conceptually model a given system using ontology with fewer diagram kinds and fewer symbosl and relations among them is prefeable over a larger ontology with mode diagram kinds and more symbols and relations among them.

- **5. The Thing Importance** – The importance of a thing T in an OPM Model is directly related to the highest OPD in the OPD hierarchy where T appears.

- **6. The Object Transformation by Process** – In a complete OPM Model, each process must be connected to at least one object that the process transforms or one state of the object that the process transforms.

- **7. The Procedural Link Uniqueness** – At any level of detail, na object and a process can be connected with at most one procedural link, which uniquely determines the role of the object with respect to the process.

- **8. The Singular Name** – A name of an OPM thing must be singular. Plural has to be converted to singular by adding the world “Set” for inanimate things or “Group” for humans.

- **9. The Graphics-Text Equivalence** – Any model fact expressed graphically in an OPD is also expressed textually in the corresponding OPL paragraph.

- **10. The Thing Name Uniqueness** – Different things in na OPM Model which are not features must have different names. Features are distinguishable by appending to them the reserved word “of” and the name of their exhibitor.

- **11. The Detail Hierarchy** – Whenever an OPD becames hard to comprehend due to an excessive amount of details, a new, descendant OPD shall be created.

- **12. The Skip Semantics Precedence** – Skip semantics takes precedence over wait semantics.

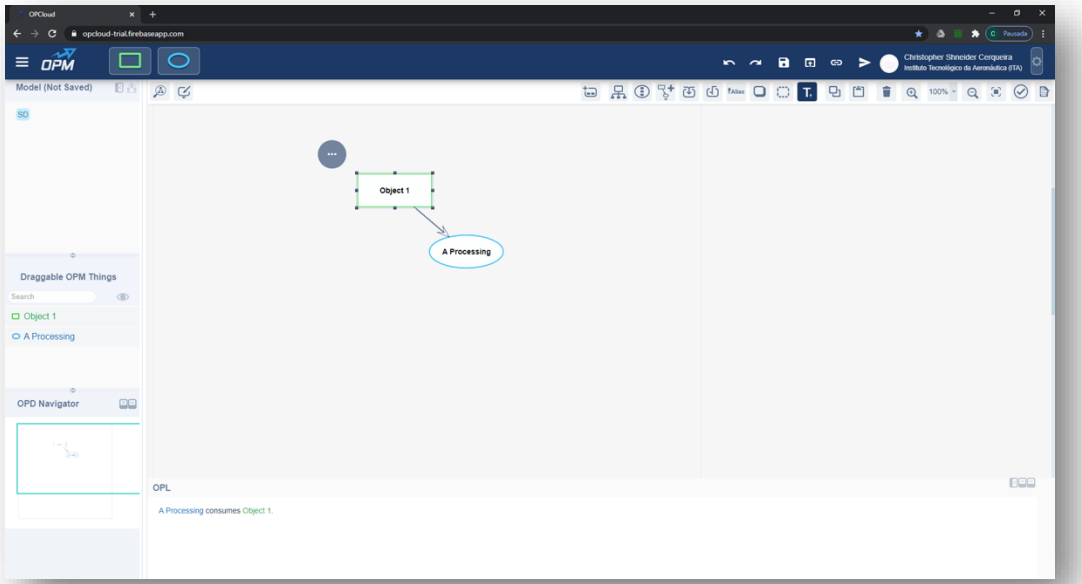
Final Remarks

Some thoughts

- OPM is **simple and powerful to talk with stakeholders** and create the first architectures
- OPM uses **one diagram type** to handle structure and behavior
  - the language vocabulary has only a **couple of symbols** and **semantics to mimic common sketching**.
- OPM allows simple-formal modelling and enables to **control the complexity**.
- OPM is the only MBSE that **simulates CONCEPTS**.
- As it is an ISO, it is **worth a try**.
- OPM **lacks transformational tools** to other domains and an open metamodel (EMF).

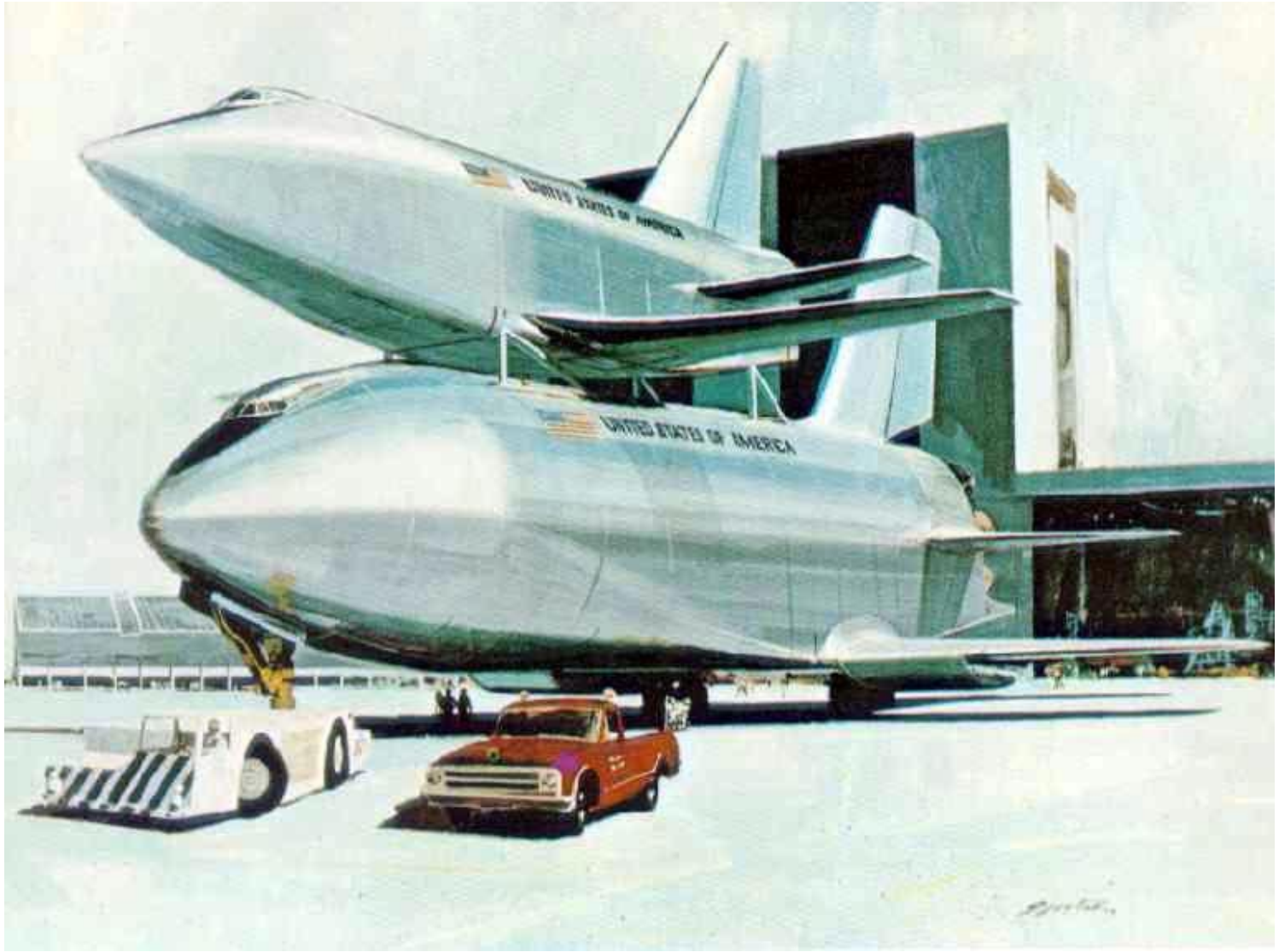
OPM is growing

- OPM main tool is the OPCloud (“web” based)
- It has been highly improved from the OPCat used through the course.
  - Usability is better
  - Allows dynamic behavior
  - IoT connectable through MQTT
  - Socket connection
  - Stereotypes
  - Styling
  - Timing



CONOPS FUNDAMENTALS

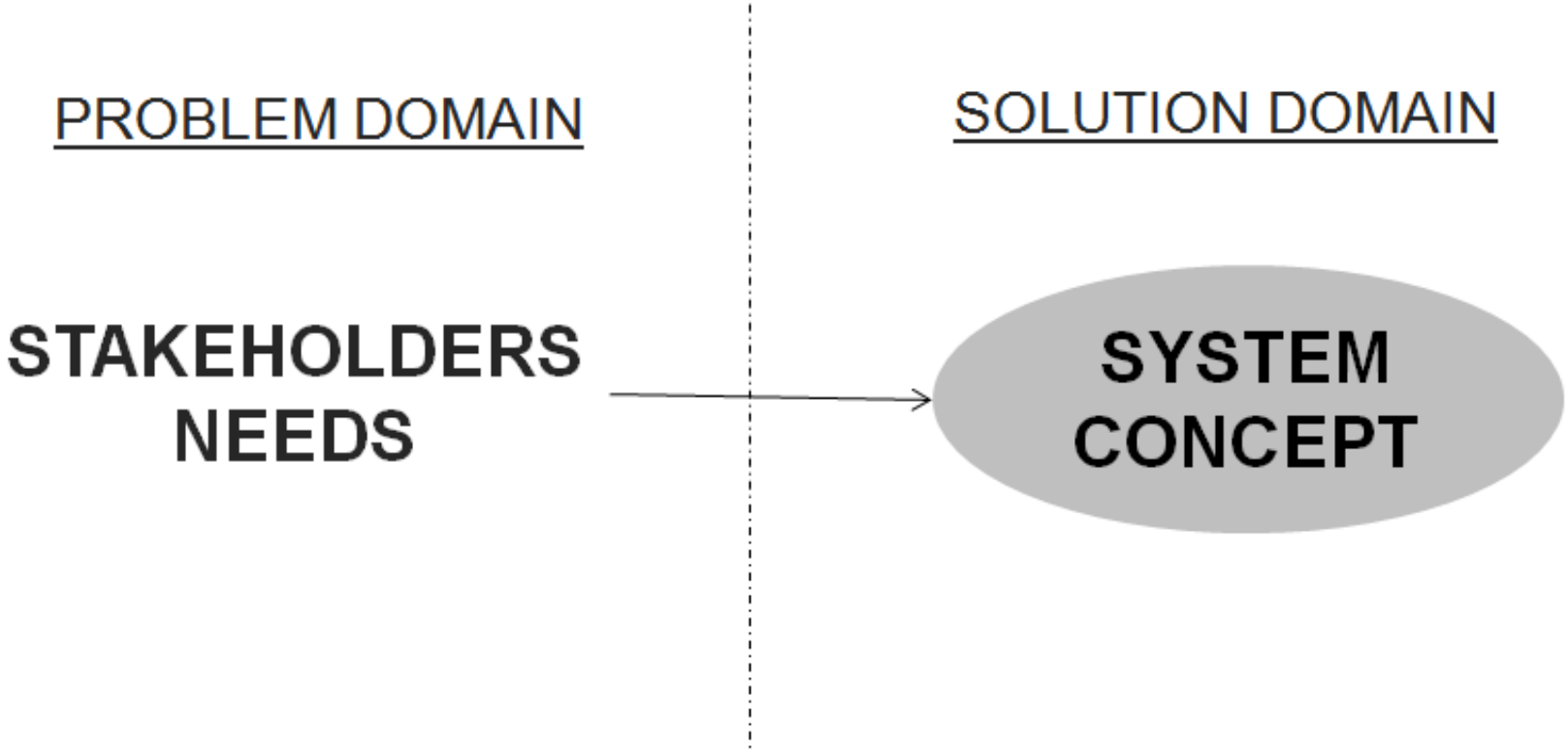
Concept Review



“Early in the system development activity, a system is conceptual in nature”.

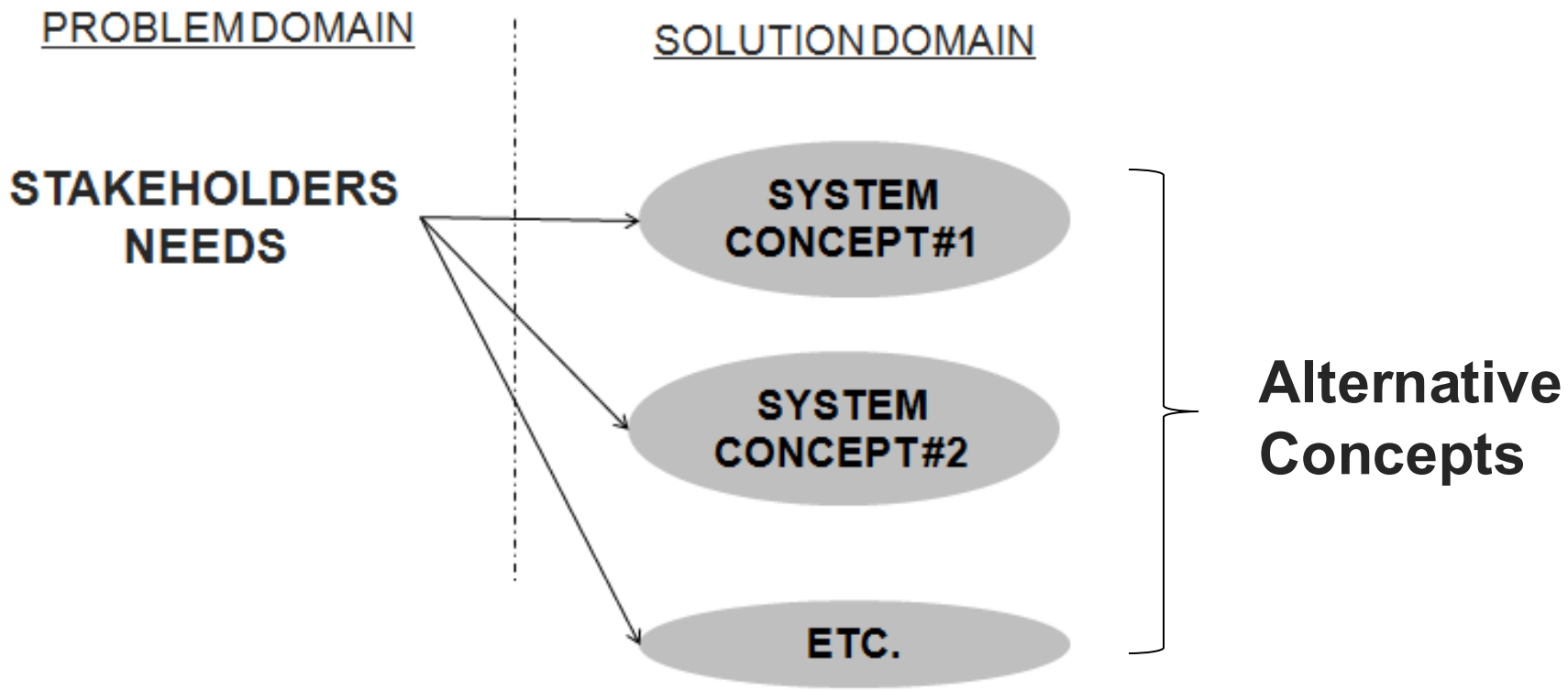
Concept Definition Phase

- The conceptual design provides a description of the proposed system that fulfills the stakeholders needs.



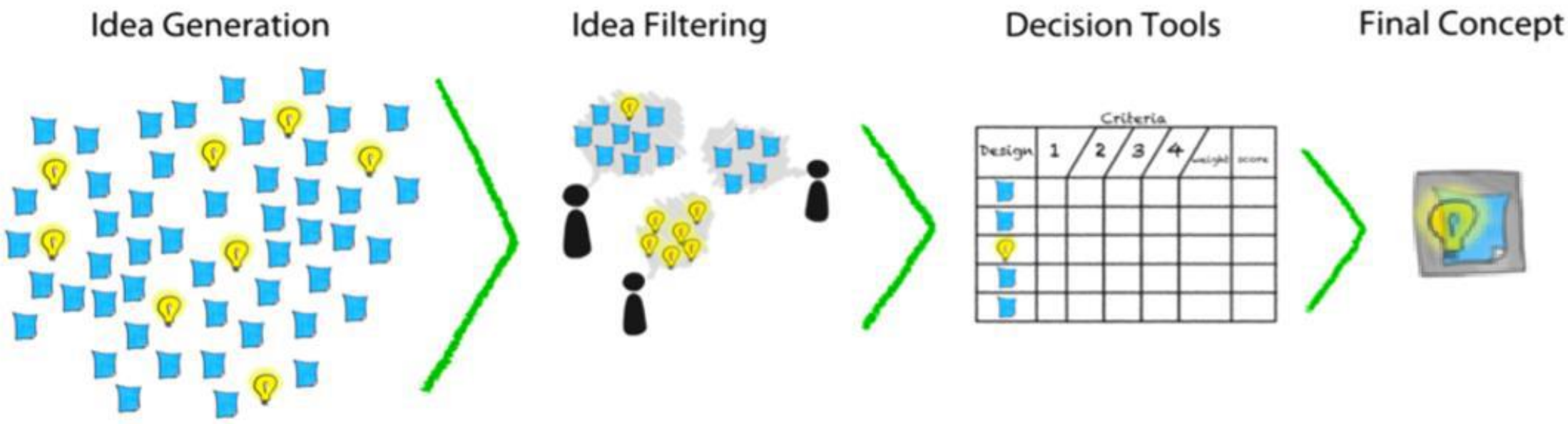
Alternative Concepts

- During the concept stage, alternate concepts are created to determine the best approach to meet stakeholder needs.

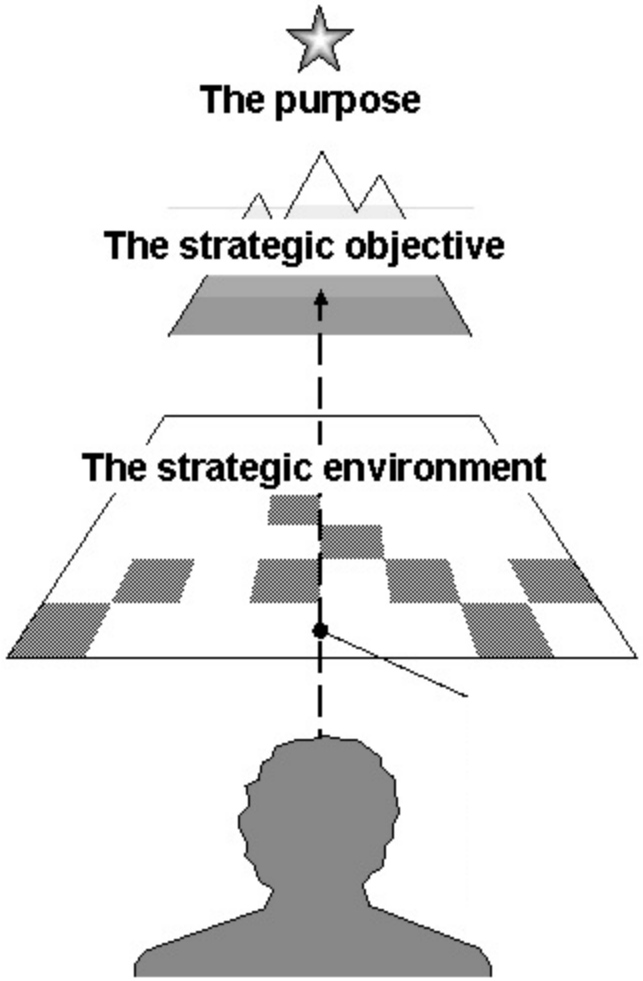


Feasible solution

- Concept design explores the feasibility of a system and guarantees that there is at least one solution that fulfils the operational need at “minimum cost”.

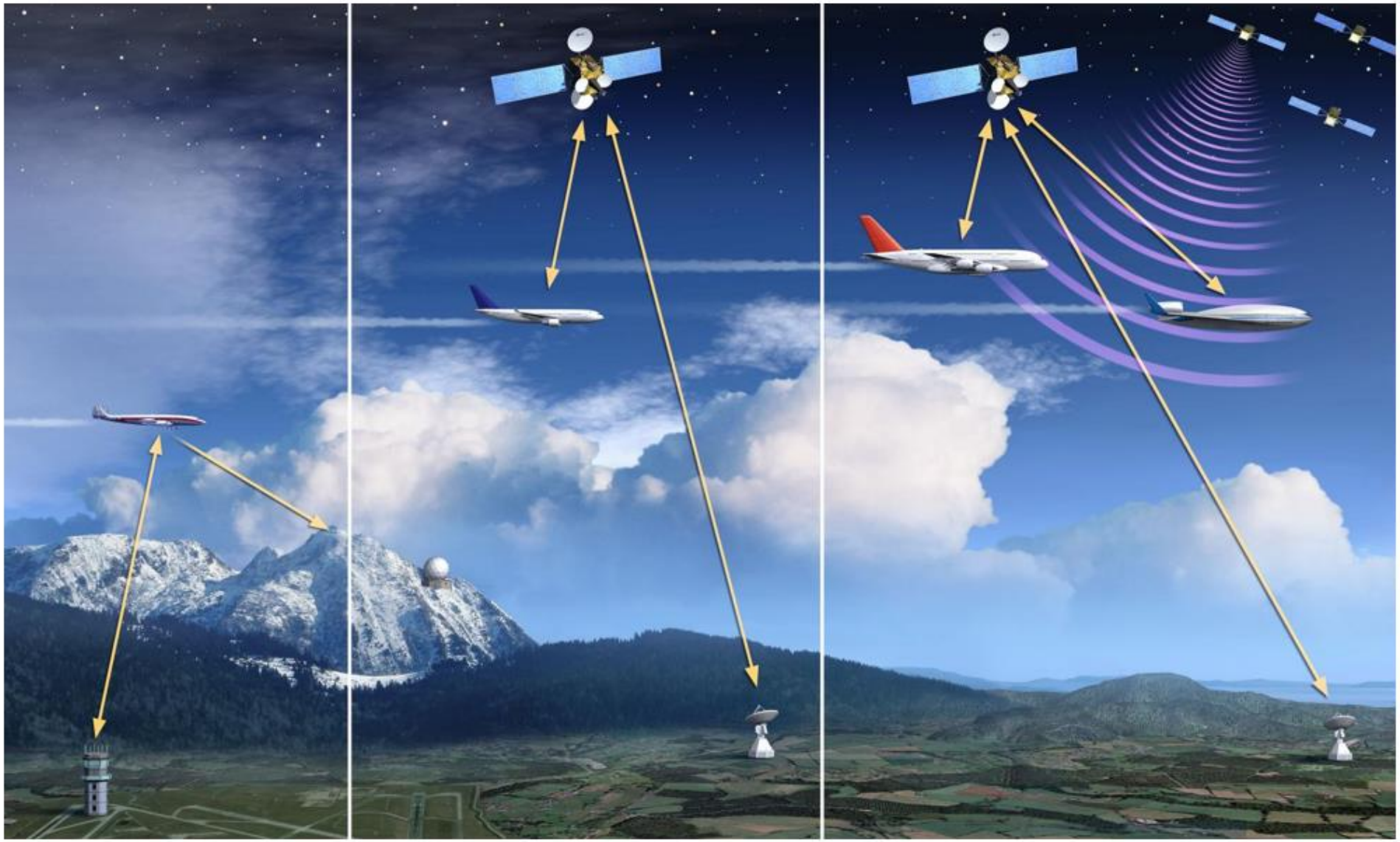


Scenarios Methodology



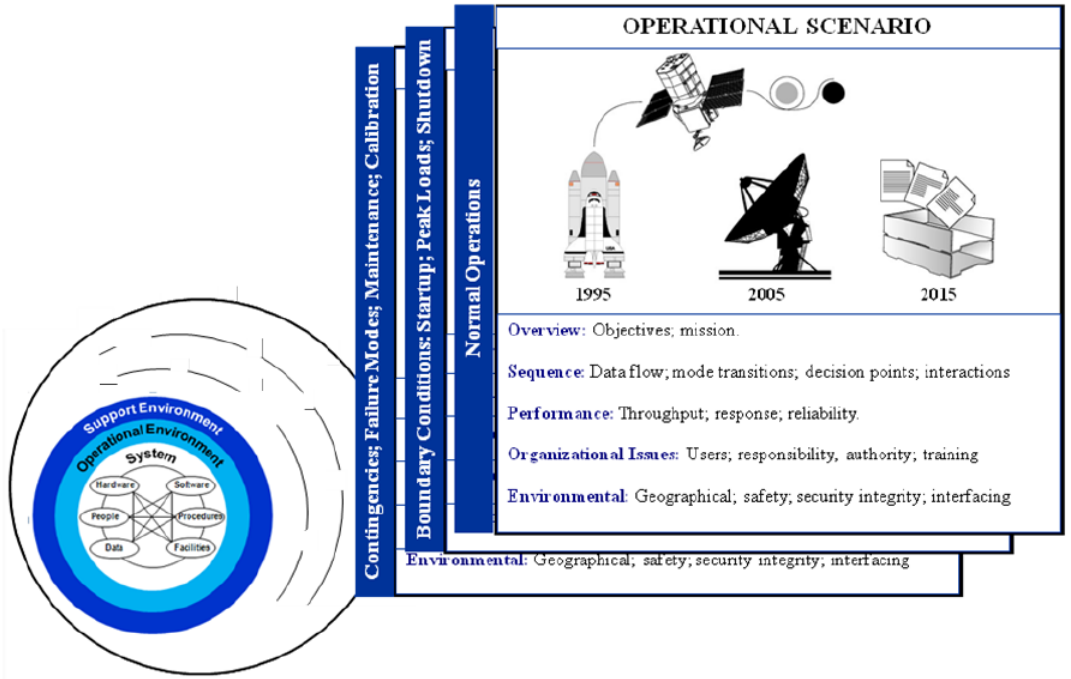
- Scenarios serves as a methodology for designing, planning and decision making.
  - The exercise makes people think in a creative way
  - Reduce the chances of overlooking important factors
  - Enhances communications within and between organizations.

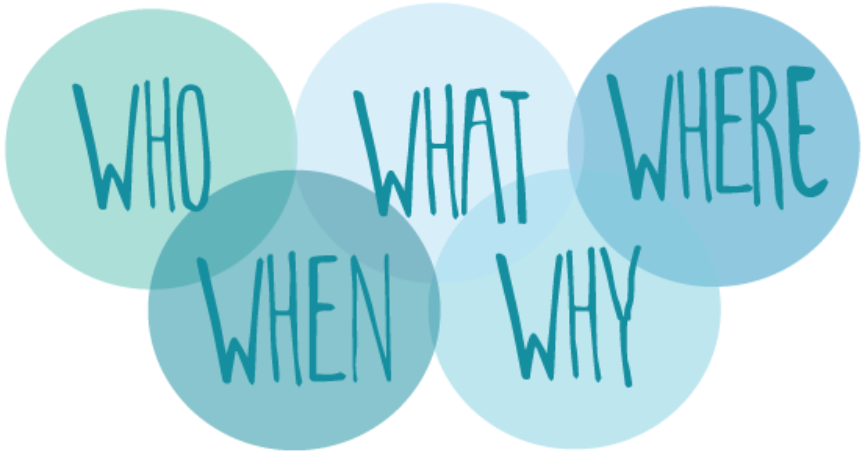
Operational Scenarios are stories which describe the expected utilization of the future system



Operational Scenarios

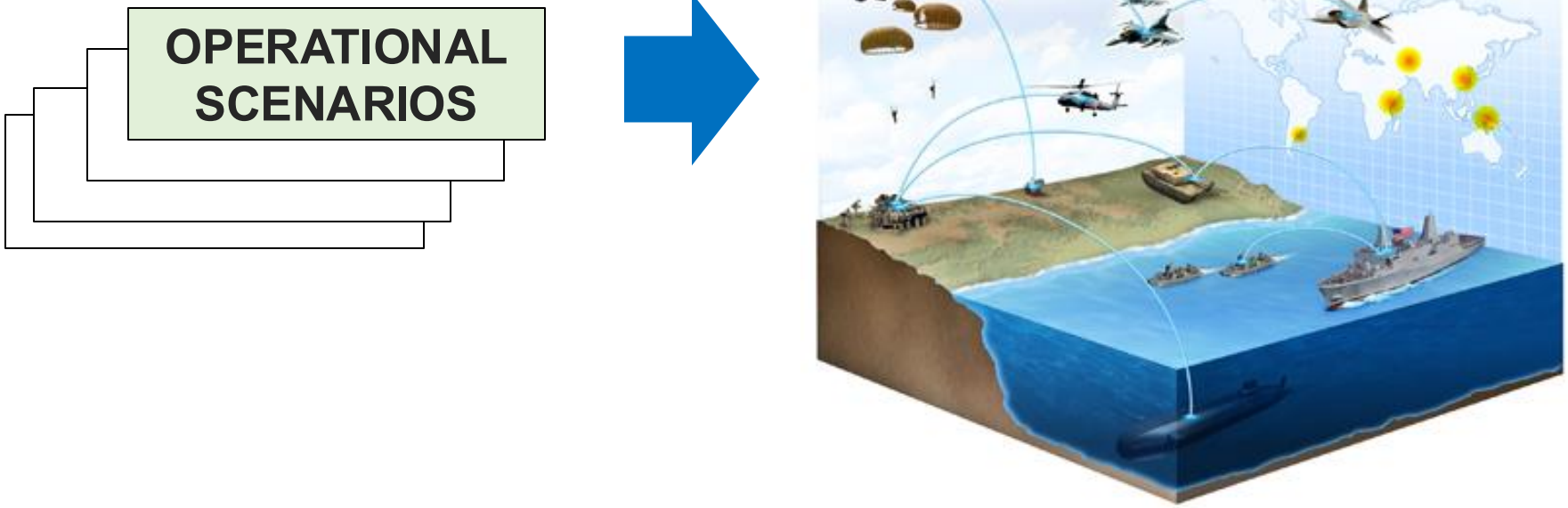
- A useful scenario is one which describes how a system is to be operated and maintained during a specific time, mission phase, operational mode, or critical sequence of activities.
- It enables one to establish the Who, What, Where, When and Why for the system.





Operational Scenarios

- Operational scenarios will be input to operational concept



Operational Concept

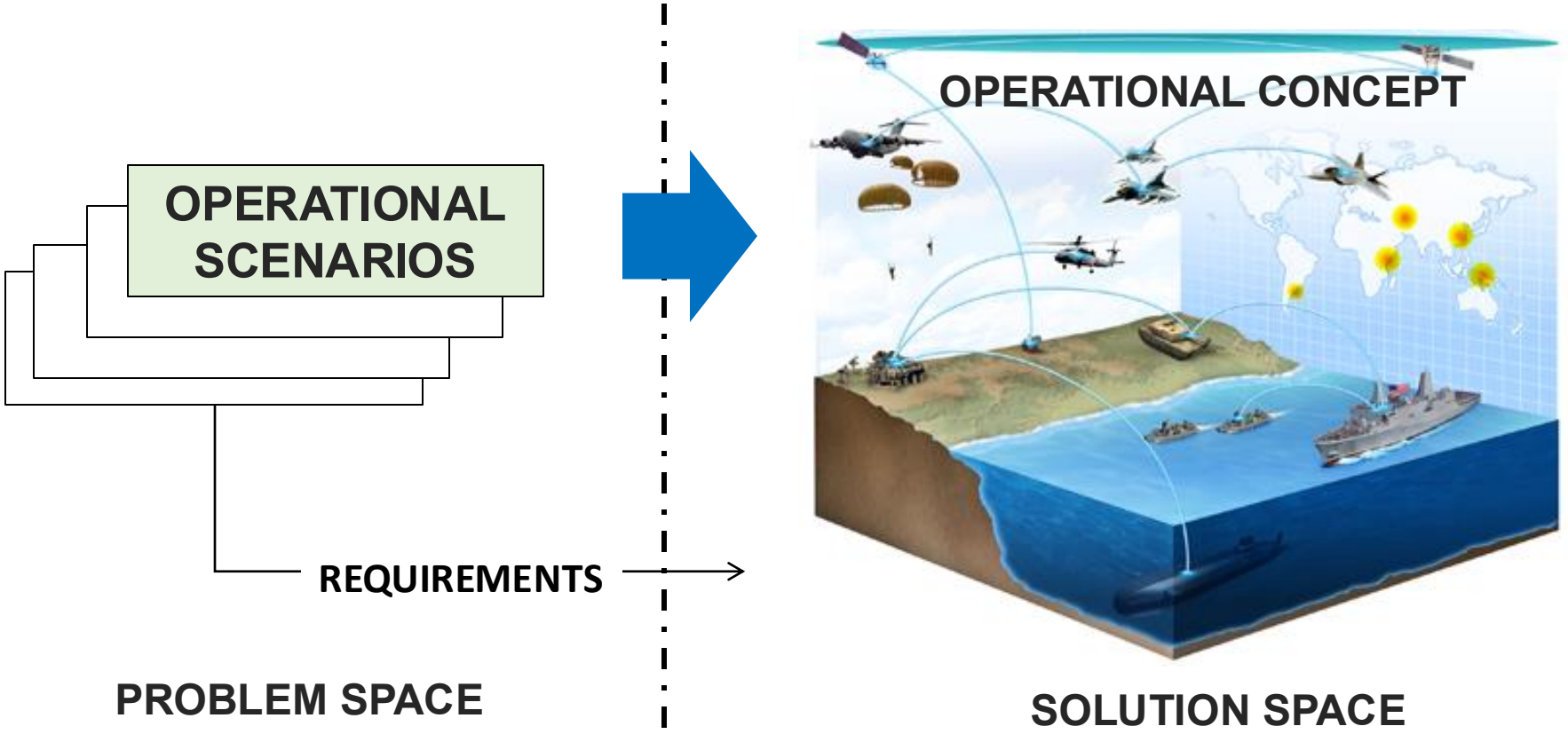
- An abstract model created by an organization to
  - Describe the likely operation of a future or existing system in the terminology of its users
  - Describe the operational needs, desires, visions, and expectations of the user without being overly technical or formal.
- An Operational Concept generally evolves from a (abstract) concept and is a description of how a set of capabilities may be employed to achieve desired objectives or end state.

Goals of an Operational Concept

- To provide a clear vision of the intended use and the resulting benefits of the system;
- To provide a document which can be understood and utilized to facilitate a clear understanding of the system context and the users; and
- To provide the basis for system development and validation.

Operational Concept

- Operational concept implements the required capabilities addressed by the operational scenarios



Using the OPM Model to do a MBSE CONOPs

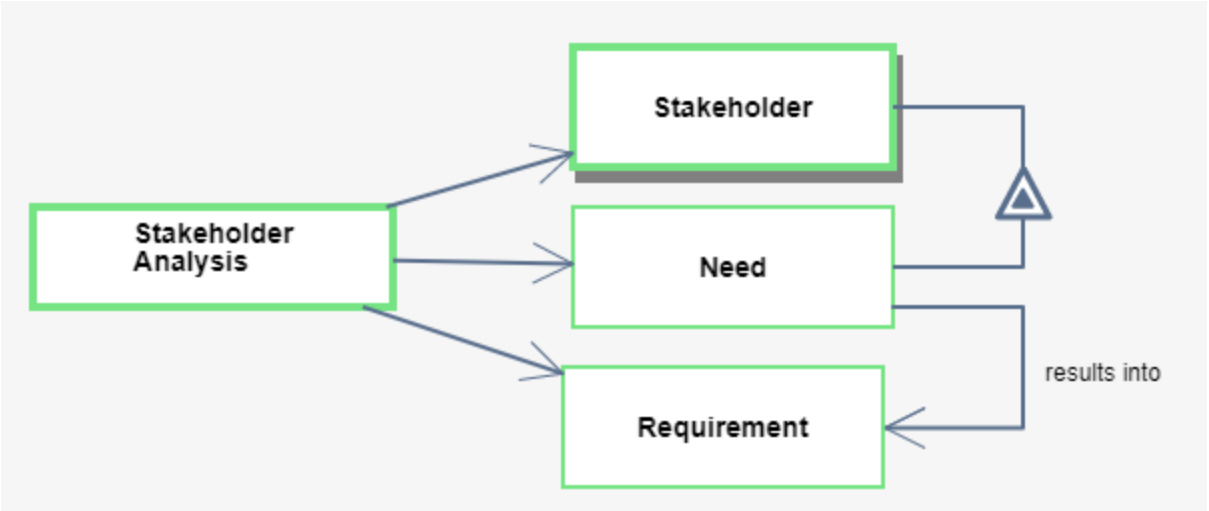
2h30 – Ghost Catching CONOPS

- STATEMENT OF NEED: (Ghost Catching) A ghost appeared at a party; we need to have a clear way of stopping and capturing in future occurrences. This must be handled by an external trained staff, that should promptly arrive in next events, so that they can work effectively and provide good service.

[01] Organize the Process

- **Stakeholder Analysis**: Identify who are involved and their intents / needs / requirements.
- **Operational Scenario**: Map some required capabilities options that accomplish the needs
- **Concept of Operation**: Candidate Conceptual Arquitectures that optimally answer the stakeholders' needs

[02a] Elements of Stakeholder Analysis *Metamodel*



Stakeholder is physical.

Stakeholder exhibits Need.

Need results into Requirement.

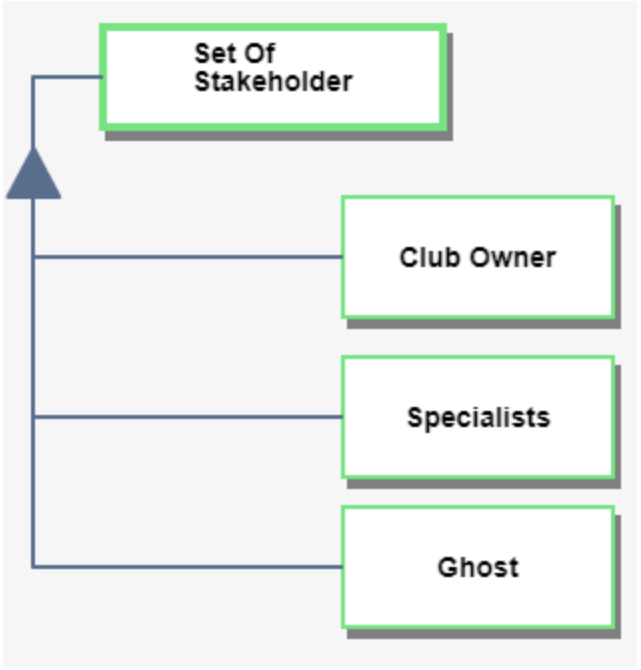
Stakeholder Analysis relates to Requirement.

Stakeholder Analysis relates to Stakeholder.

Stakeholder Analysis relates to Need.

[02b] Elements of Stakeholder Analysis *Model*

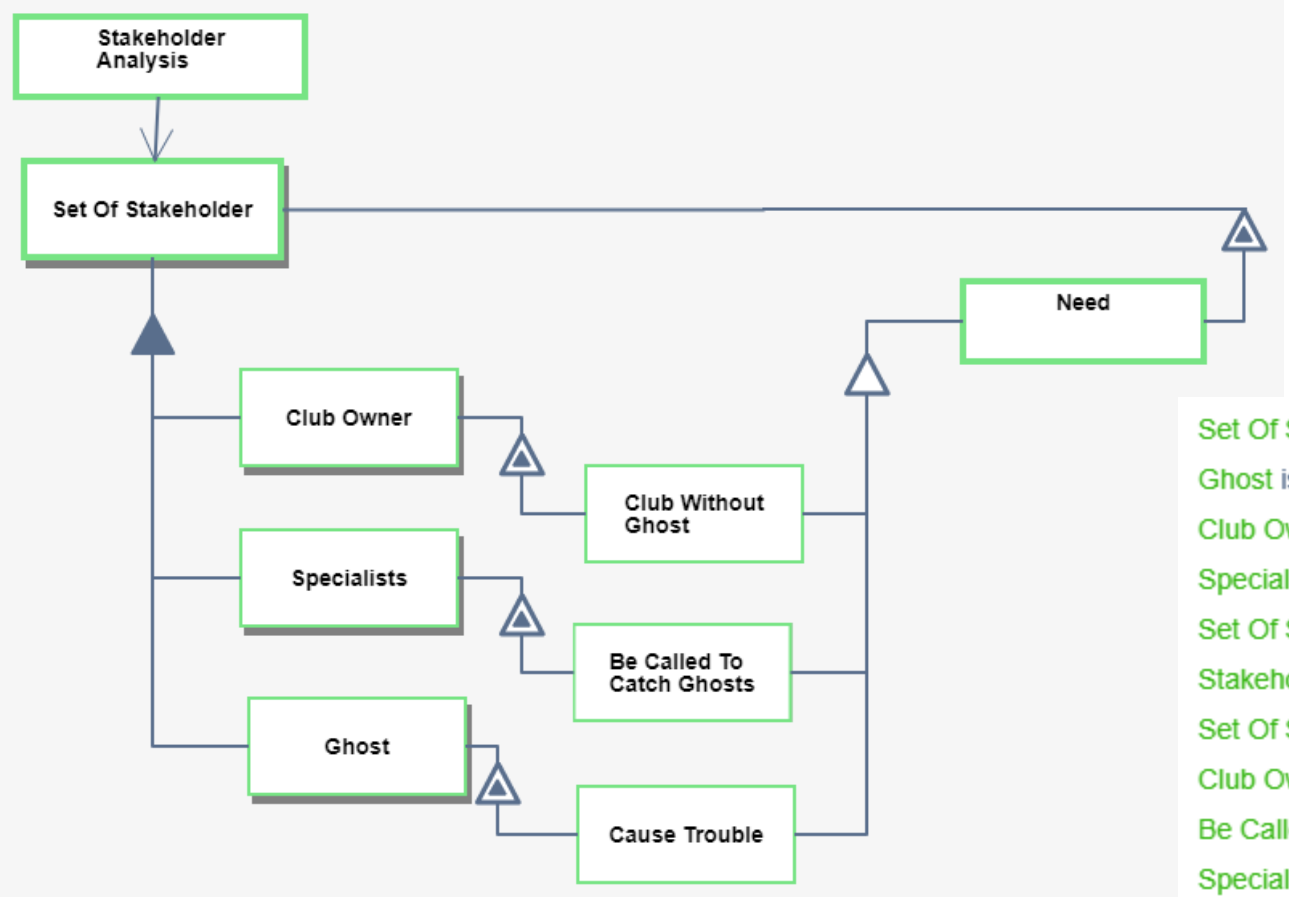
- One approach is: elicit the possible stakeholders first
- Zoom-in of the Set of Stakeholder



Set Of Stakeholder is physical.
Club Owner is physical.
Specialists is physical.
Ghost is physical.
Set Of Stakeholder consists of Club Owner, Ghost, and Specialists.

[02c] Elements of Stakeholder Analysis *Model*

- Get each stakeholder desired emergence: needs



Set Of Stakeholder is physical.

Ghost is physical.

Club Owner is physical.

Specialists is physical.

Set Of Stakeholder exhibits Need.

Stakeholder Analysis relates to Set Of Stakeholder.

Set Of Stakeholder consists of Club Owner, Ghost, and Specialists.

Club Owner exhibits Club Without Ghost.

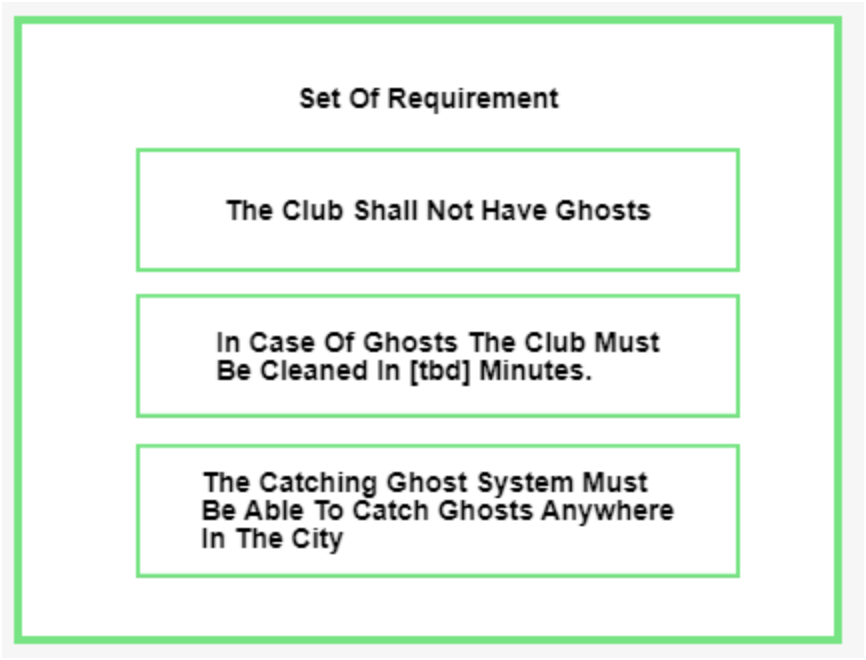
Be Called To Catch Ghosts><b>, Cause Trouble, and Club Without Ghost are Need.

Specialists exhibits Be Called To Catch Ghosts.

Ghost exhibits Cause Trouble.

[02d] Elements of Stakeholder Analysis *Model*

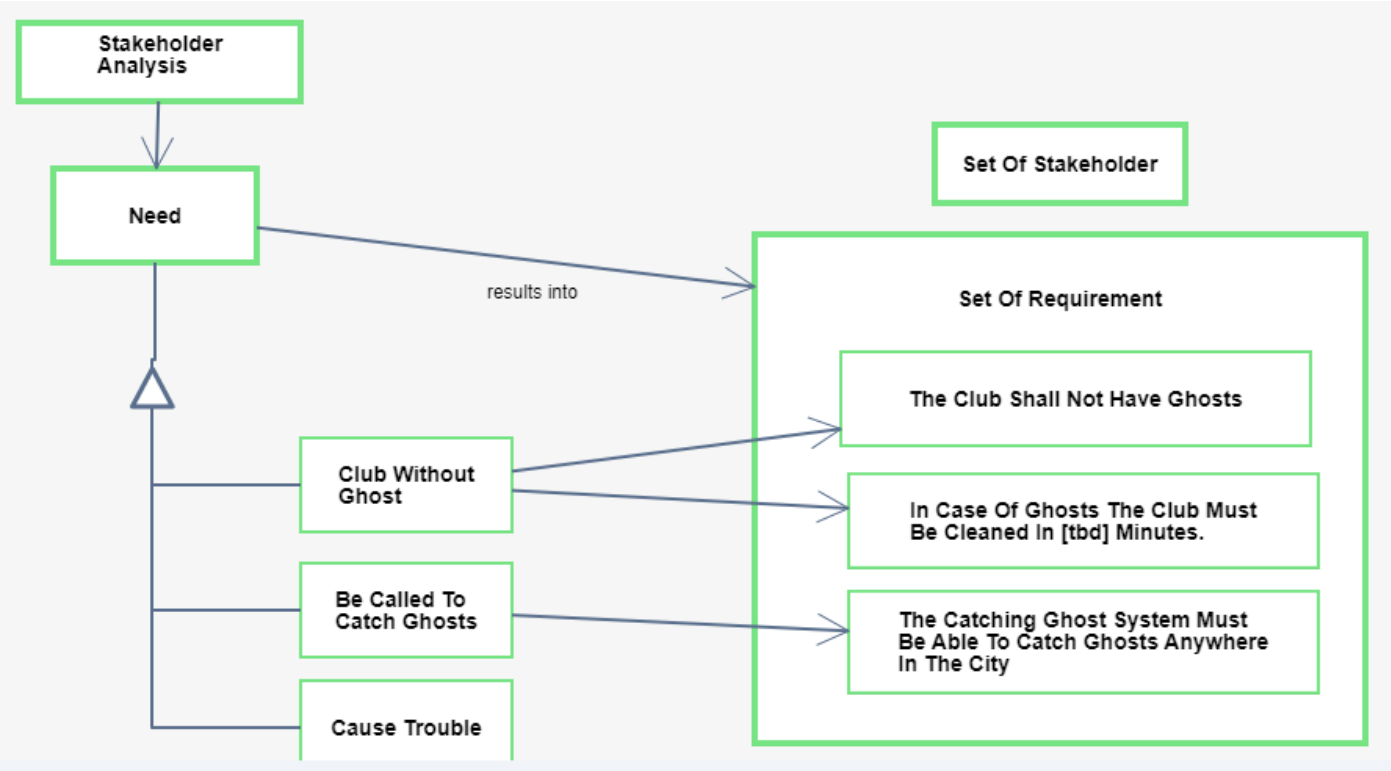
- Start writing some mission/stk requirements



Set Of Requirement from SD2 zooms in SD2.3 into The Club Shall Not Have Ghosts, In Case Of Ghosts The Club Must Be Cleaned In Minutes., and The Catching Ghost System Must Be Able To Catch Ghosts Anywhere In The City, in that vertical sequence.

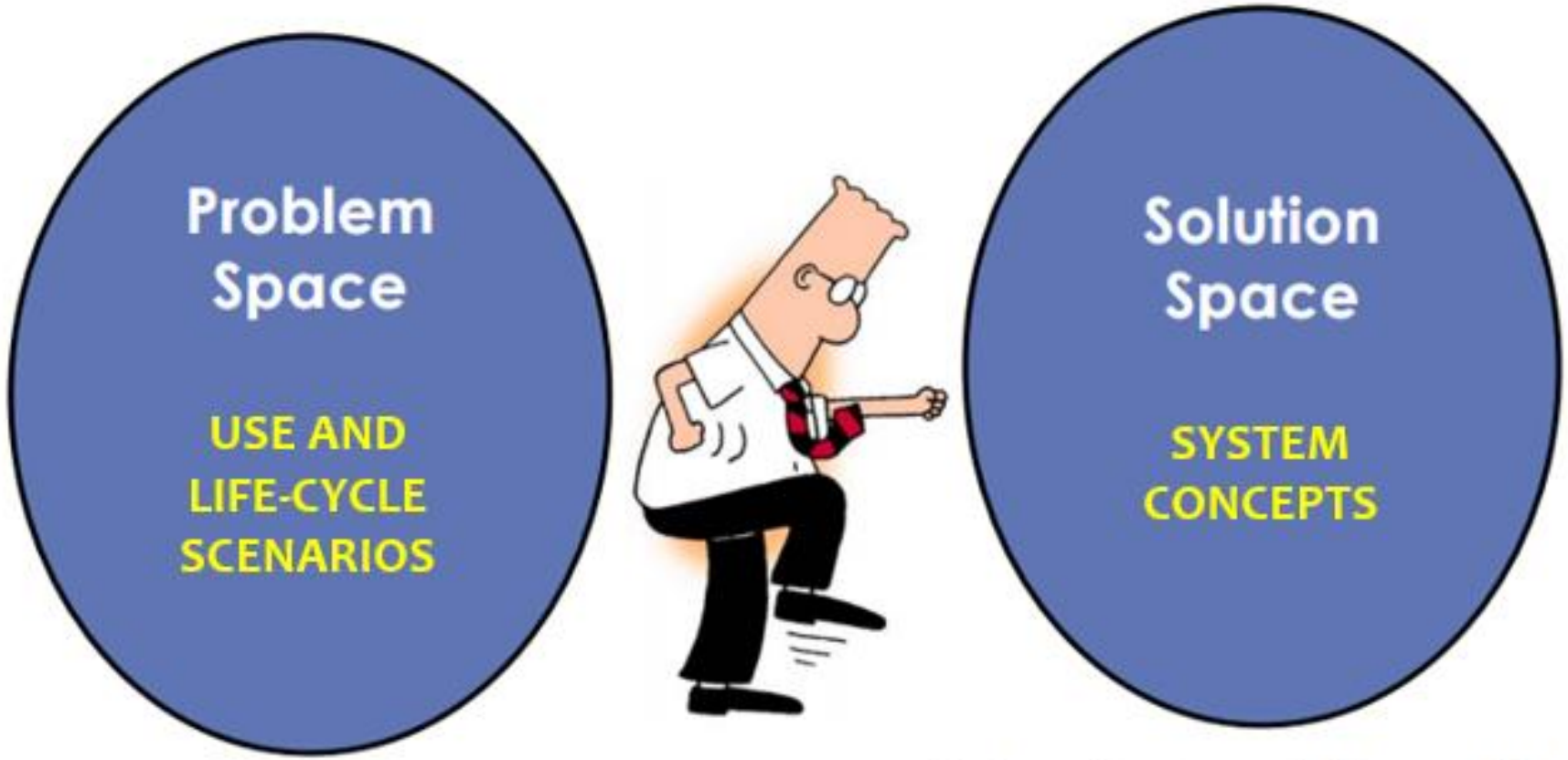
[02e] Elements of Stakeholder Analysis *Model*

- Tie the requirements with the needs



Set Of Requirement from SD2 zooms in SD2.3 into The Club Shall Not Have Ghosts, In Case Of Ghosts The Club Must Be Cleaned In Minutes., and The Catching Ghost System Must Be Able To Catch Ghosts Anywhere In The City, in that vertical sequence.
Need results into Set Of Requirement.
Stakeholder Analysis relates to Need.
Be Called To Catch Ghosts><b>, Cause Trouble, and Club Without Ghost are Need.
Club Without Ghost relates to The Club Shall Not Have Ghosts.
Be Called To Catch Ghosts relates to The Catching Ghost System Must Be Able To Catch Ghosts Anywhere In The City.
Club Without Ghost relates to In Case Of Ghosts The Club Must Be Cleaned In Minutes..

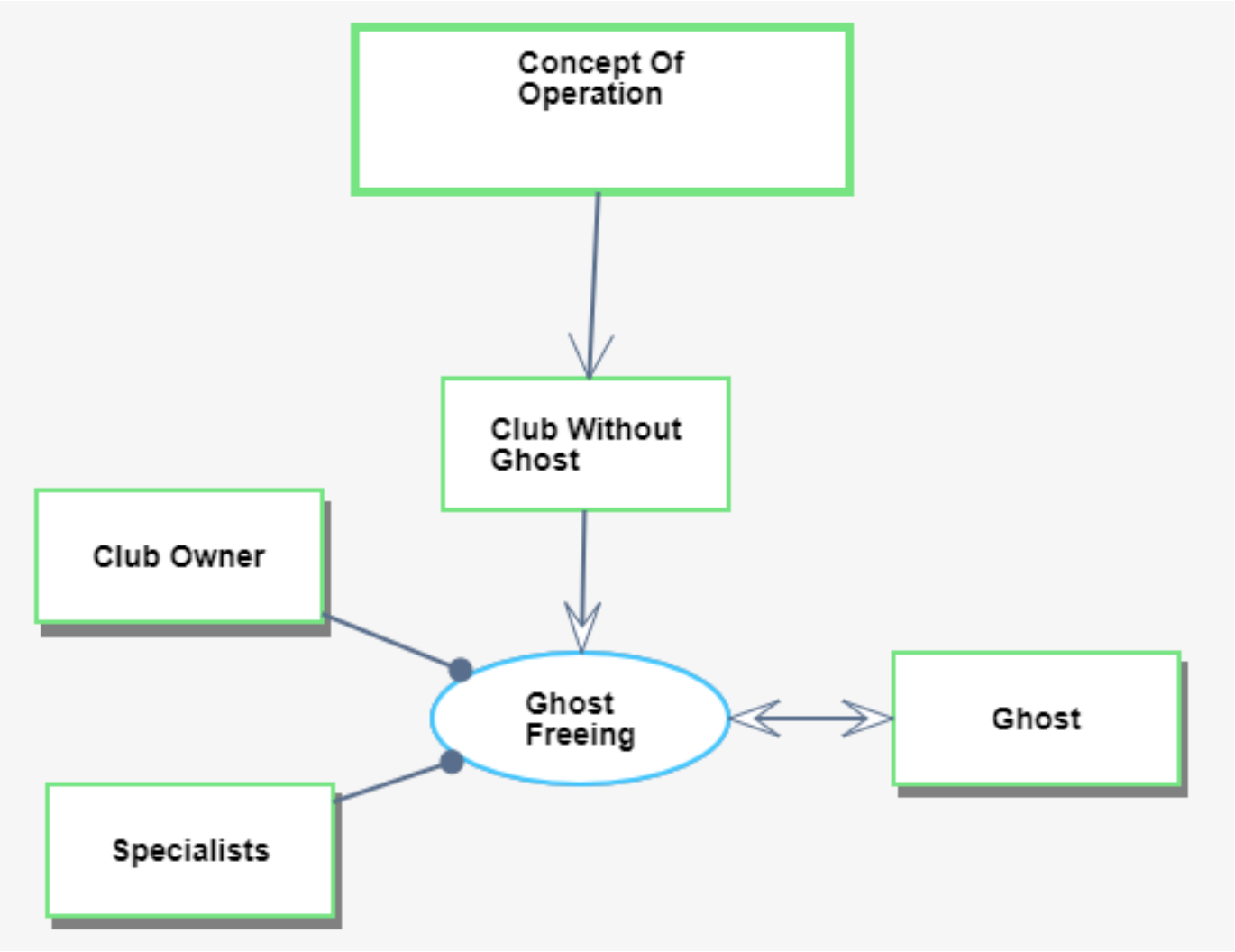
From Problem to Solution



It is **all about needs**

It is all about **the offerings that satisfy needs**

First Level CONOPS



Concept Of Operation relates to Club Without Ghost.

Club Owner is physical.

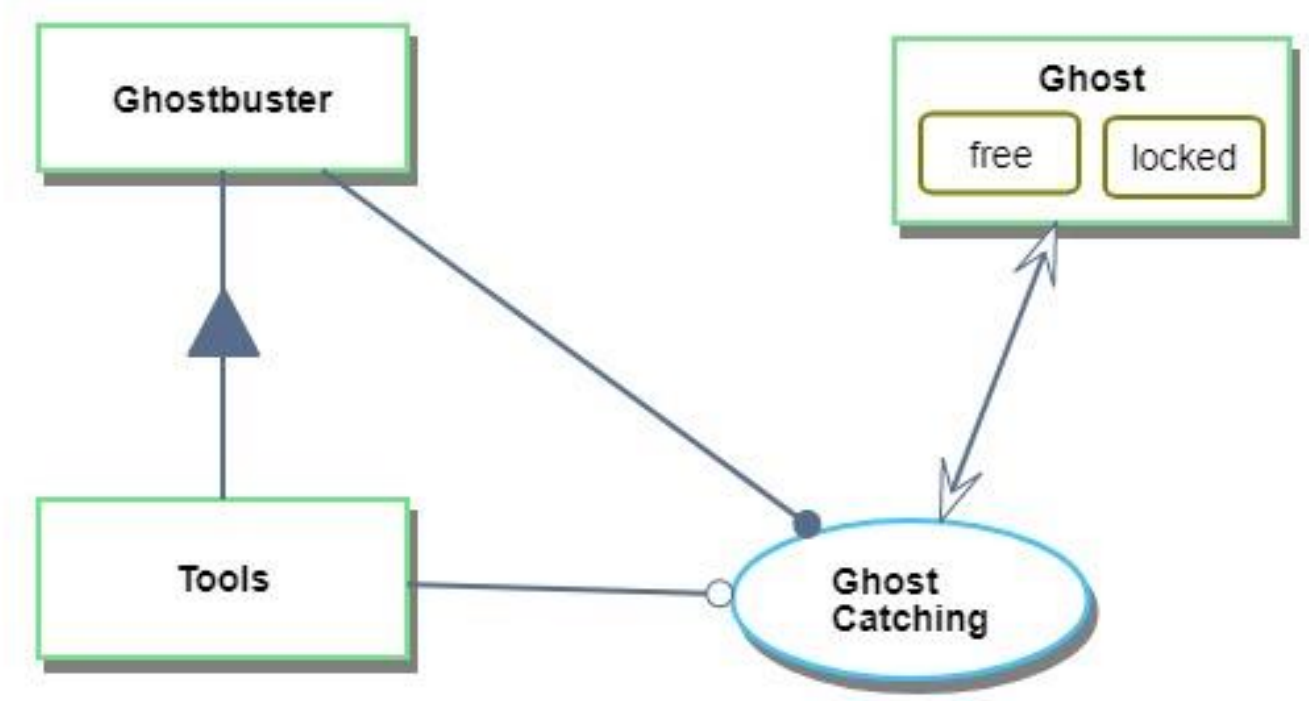
Ghost is physical.

Specialists is physical.

Club Owner and Specialists handle Ghost Freeing.

Ghost Freeing affects Ghost.

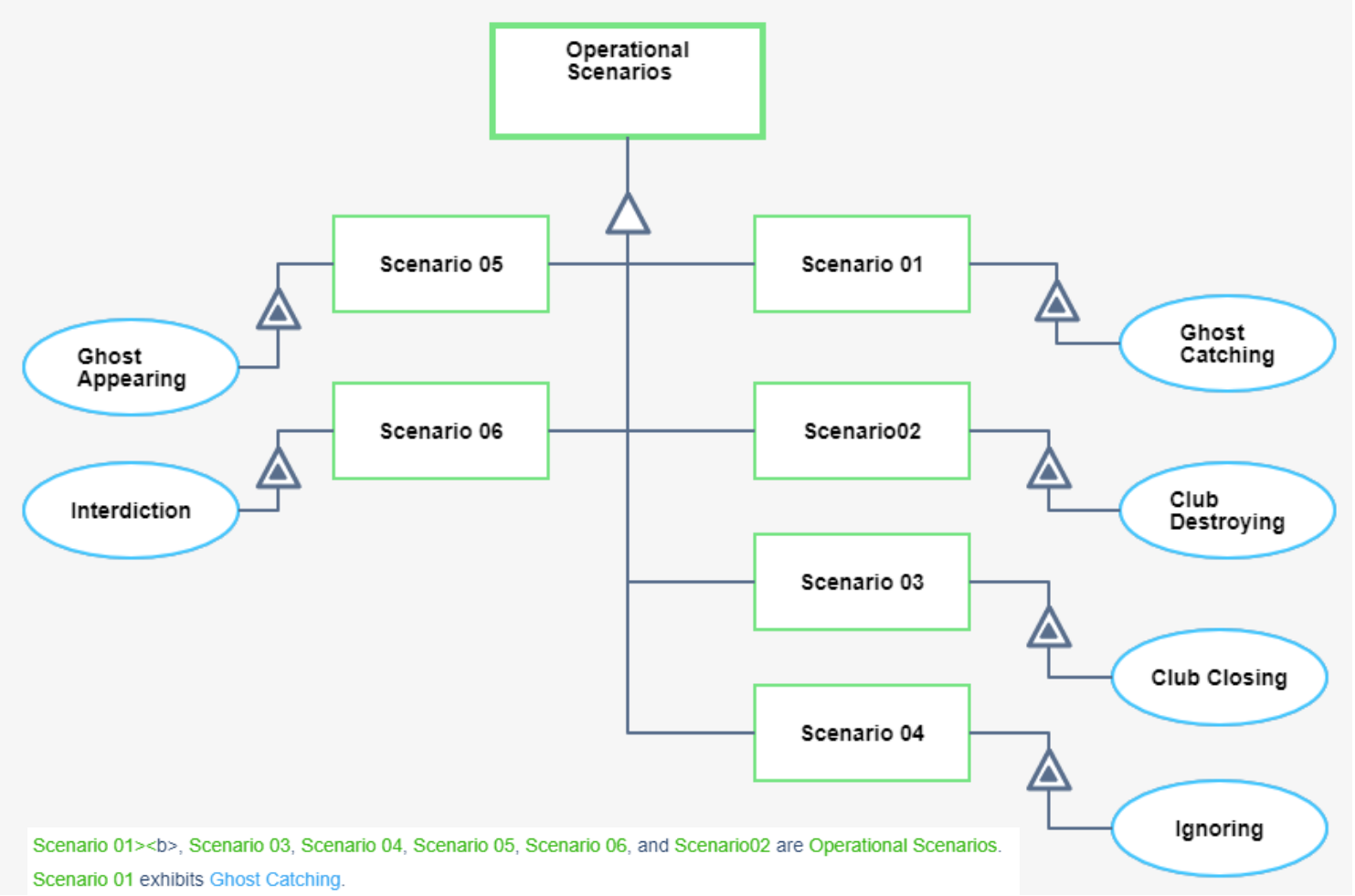
Ghost Freeing consumes Club Without Ghost.



Ghostbuster is physical and systemic.
Ghost is physical and systemic.
Ghost can be free or **locked**.
Tools is physical and systemic.
Ghostbuster consists of Tools.
Ghost Catching is physical and systemic.
Ghostbuster handles Ghost Catching.
Ghost Catching requires Tools.
Ghost Catching affects Ghost.

Ghost Catching

[3] Organizating possible scenarios



Scenario 01><b>, Scenario 03, Scenario 04, Scenario 05, Scenario 06, and Scenario02 are Operational Scenarios.

Scenario 01 exhibits Ghost Catching.

Scenario02 exhibits Club Destroying.

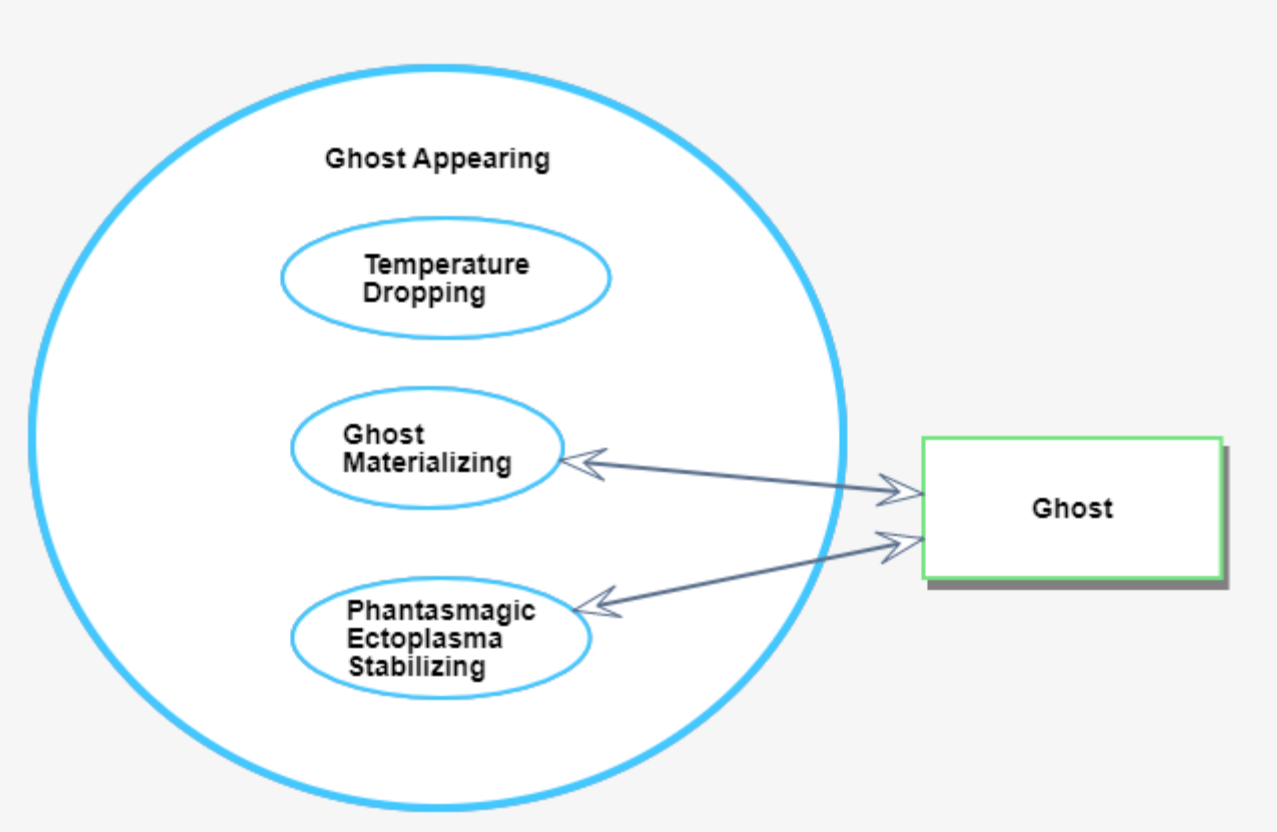
Scenario 03 exhibits Club Closing.

Scenario 04 exhibits Ignoring.

Scenario 05 exhibits Ghost Appearing.

Scenario 06 exhibits Interdiction.

[3] Scenario 05: Ghost Appearing



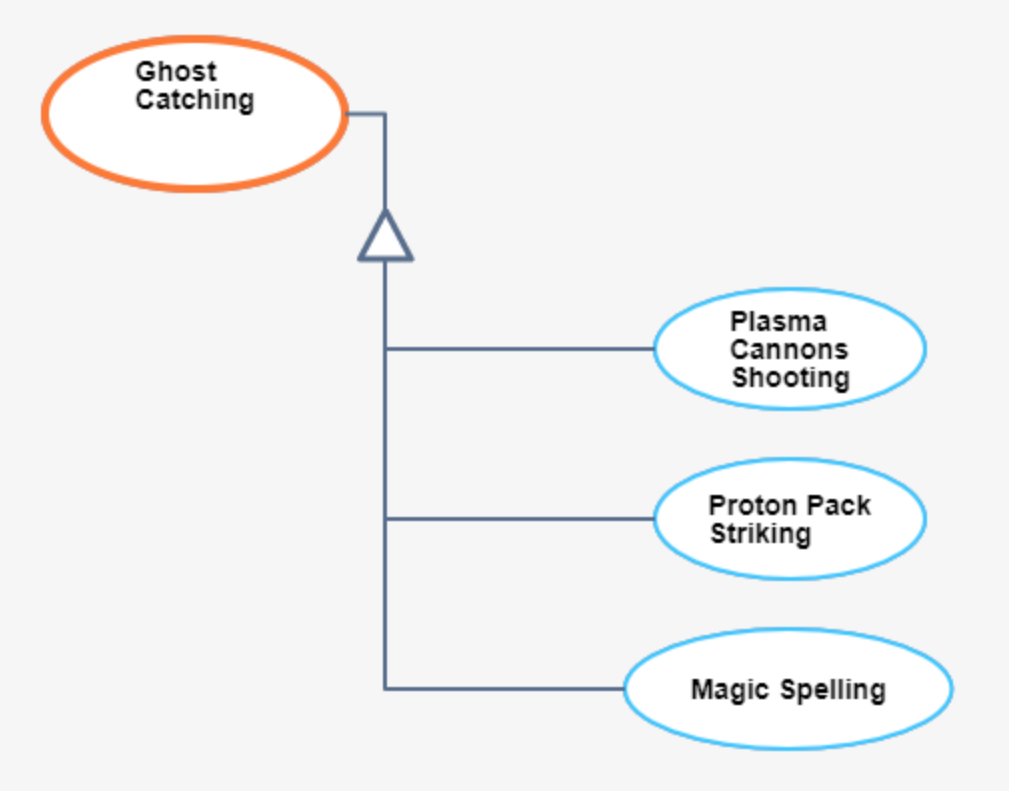
Ghost Appearing from SD1 zooms in SD1.1 into Temperature Dropping, Ghost Materializing, and Phantasmagic Ectoplasma Stabilizing, which occur in that time sequence.

Ghost is physical.

Ghost Materializing affects Ghost.

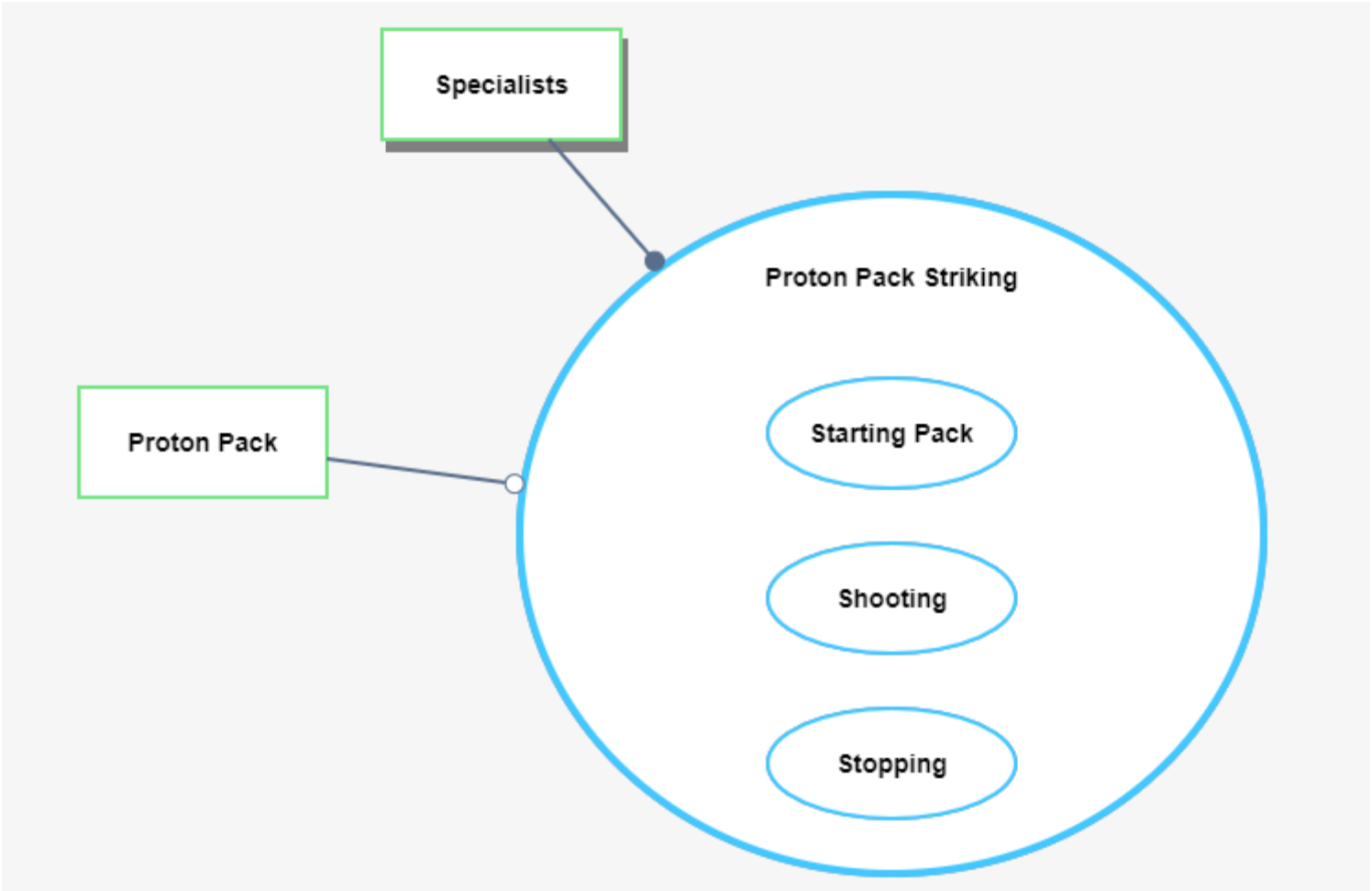
Phantasmagic Ectoplasma Stabilizing affects Ghost.

[3] Refining Scenario Options



Magic Spelling><b>, Plasma Cannons Shooting, and Proton Pack Striking are Ghost Catching.

[3] Proton Pack Striking Study

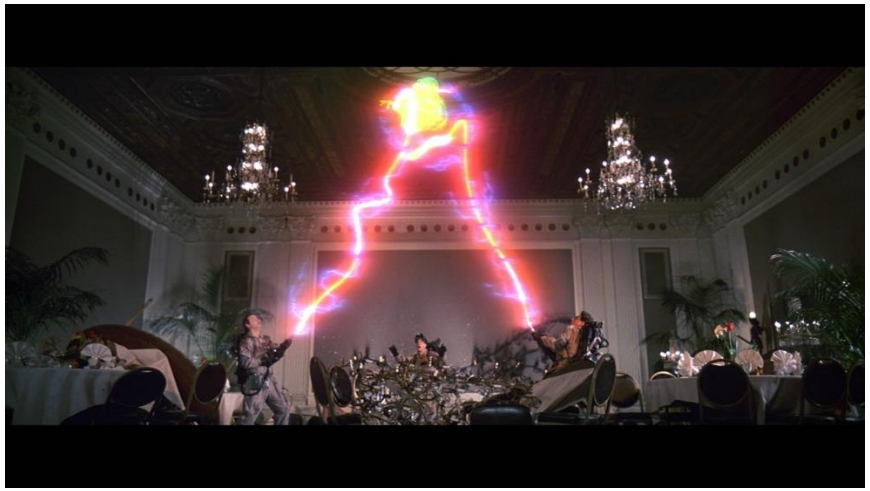


Proton Pack Striking from SD1.2 zooms in SD1.2.1 into Starting Pack, Shooting, and Stopping, which occur in that time sequence.

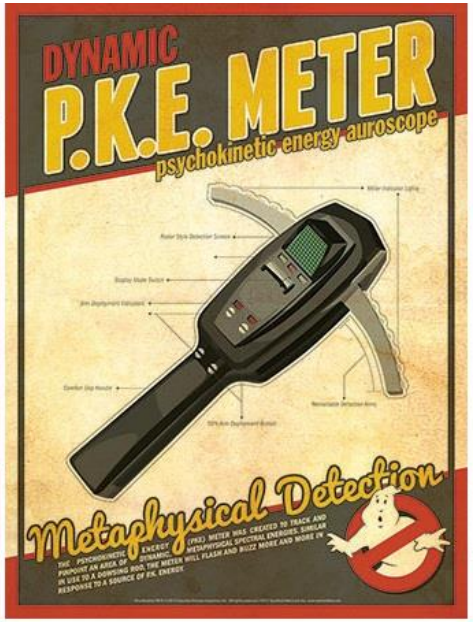
Specialists is physical.

Specialists handles Proton Pack Striking.

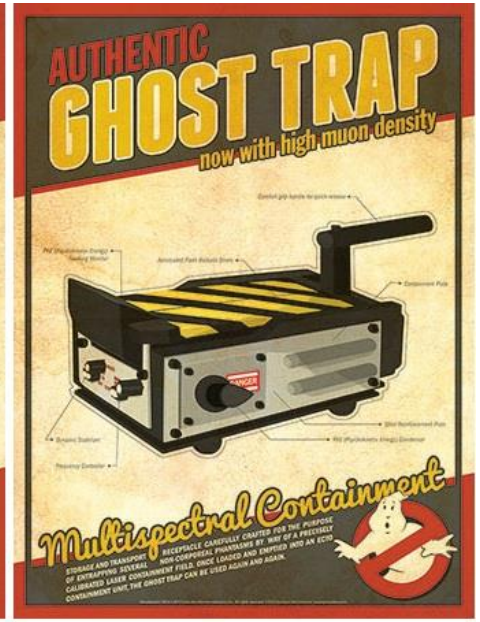
Proton Pack Striking requires Proton Pack.




FUTURISTIC
ECTO-1 LAB
upgraded mobile headquarters
Expedited Transportation


DYNAMIC
P.K.E. METER
psychokinetic energy auroscope
Metaphysical Detection

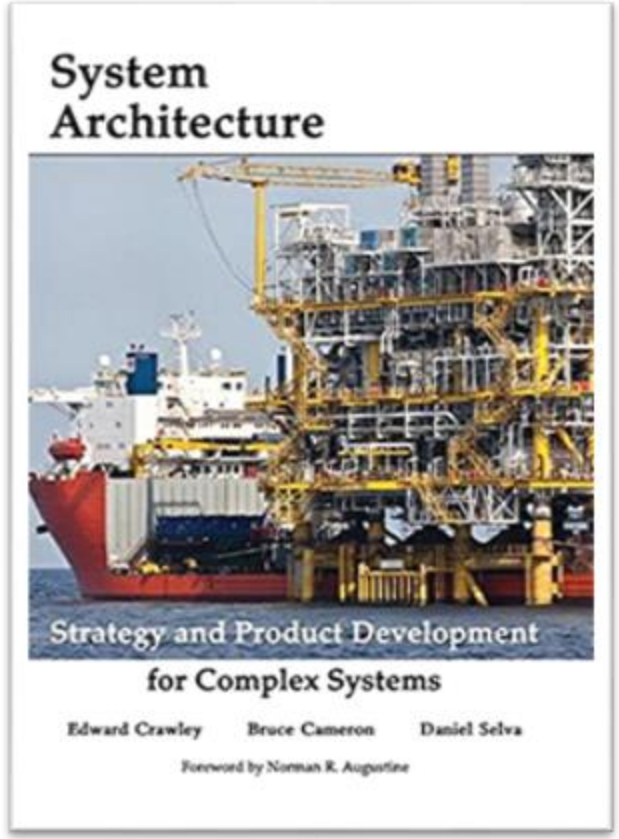

PORTABLE
PROTON PACK
particle accelerator
Spectral Entanglement


AUTHENTIC
GHOST TRAP
now with high muon density
Multispectral Containment

SYSTEMS ARCHITECTURE USING OPM

context

- **Systems Engineering** engineer systems that will **deliver a value** to the stakeholders.
- The value comes with a **form** (**architecture elements and properties**) and with **functions** (**actions and events**)
- **Complex Systems** have **multiple functions**.
- The Systems Engineers must **identify** and **organize** those functions, managing the complexity.



System duality

- As a matter of definition, systems are composed of a set of entities *and their relationships.* These relationships can have two characters: they can be functional relationships or formal relationships.
- Functional relationships are relationships between entities that do something; they involve operations, transfers, or exchanges of something between the entities. We sometimes call functional relationships *interactions* to emphasize their dynamic nature.
- Formal relationships are relationships among the entities that exist or could exist stably for some period of time. We sometimes call formal relationships *structure* to emphasize their static nature.

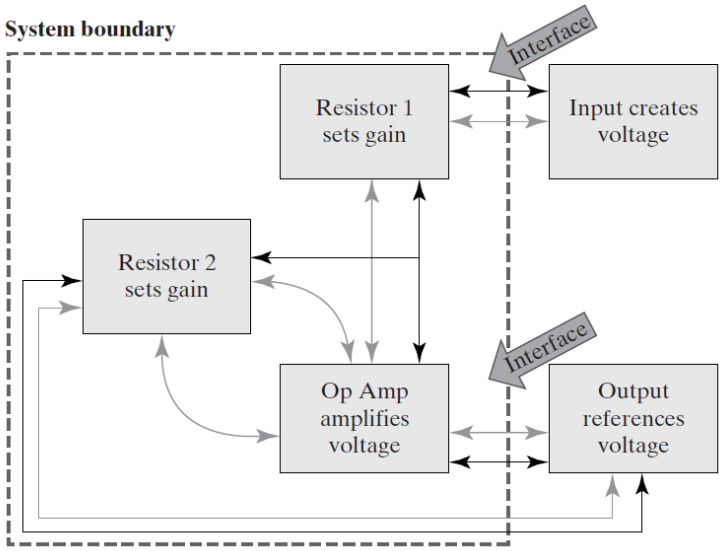
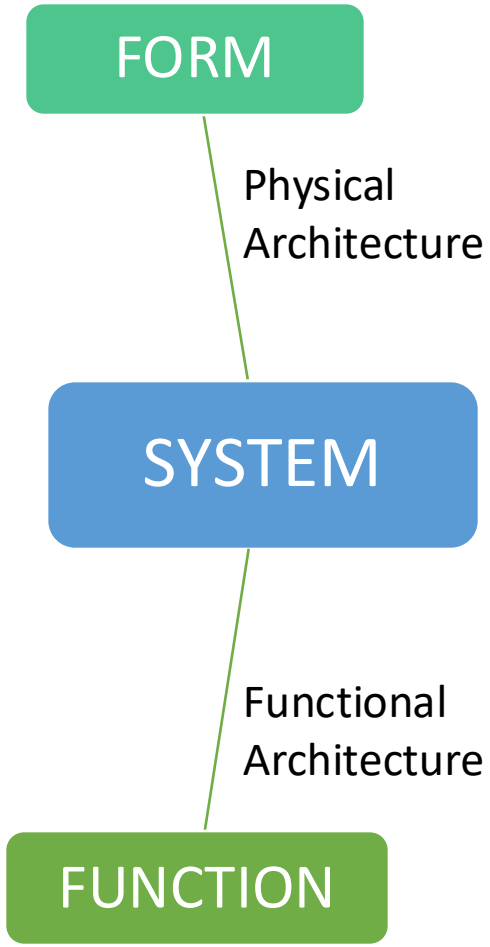


FIGURE 2.11 Formal structure and functional interaction for the amplifier circuit.



In general, a functional relationship usually requires a **formal relationship**.

The formal relationship is the instrument of the **functional relationship**.

The heart cannot exchange blood with the lung without a connection.

Distinguish form from function

- It is surprisingly difficult to separate form from function. In common speech, **we refer to form with function words**.
- Try describing a paper coffee **cup**, a **pencil**, or a **spiral notebook** without any reference to function. *If you used the words "handle," "eraser," and "binding," you were using words rooted in a function.*
- **To stay entirely in the form domain, we might use "flat cardboard half-circle," "rubber cylinder," and "metal spiral."**

PHILOSOPHY

- **Form is what has been or is eventually *implemented.***
- **Form is about existence**.
- **Form is what the system *is***. It is the concrete and often visible manifestation of the system.

- Form is the physical or informational embodiment of a system that exists or has the **potential for stable, unconditional existence, for some period, and is instrumental in the execution of function**. Form includes the entities of form and the formal relationships among the entities. Form exists prior to the execution of function.
- Form is a product/system attribute.

- System architecture is the **embodiment of a *concept***, the **allocation of physical/informational *function* to the elements of *form***, and the **definition of *relationships* among the elements** and with the **surrounding *context***.

OPM FUNCTION

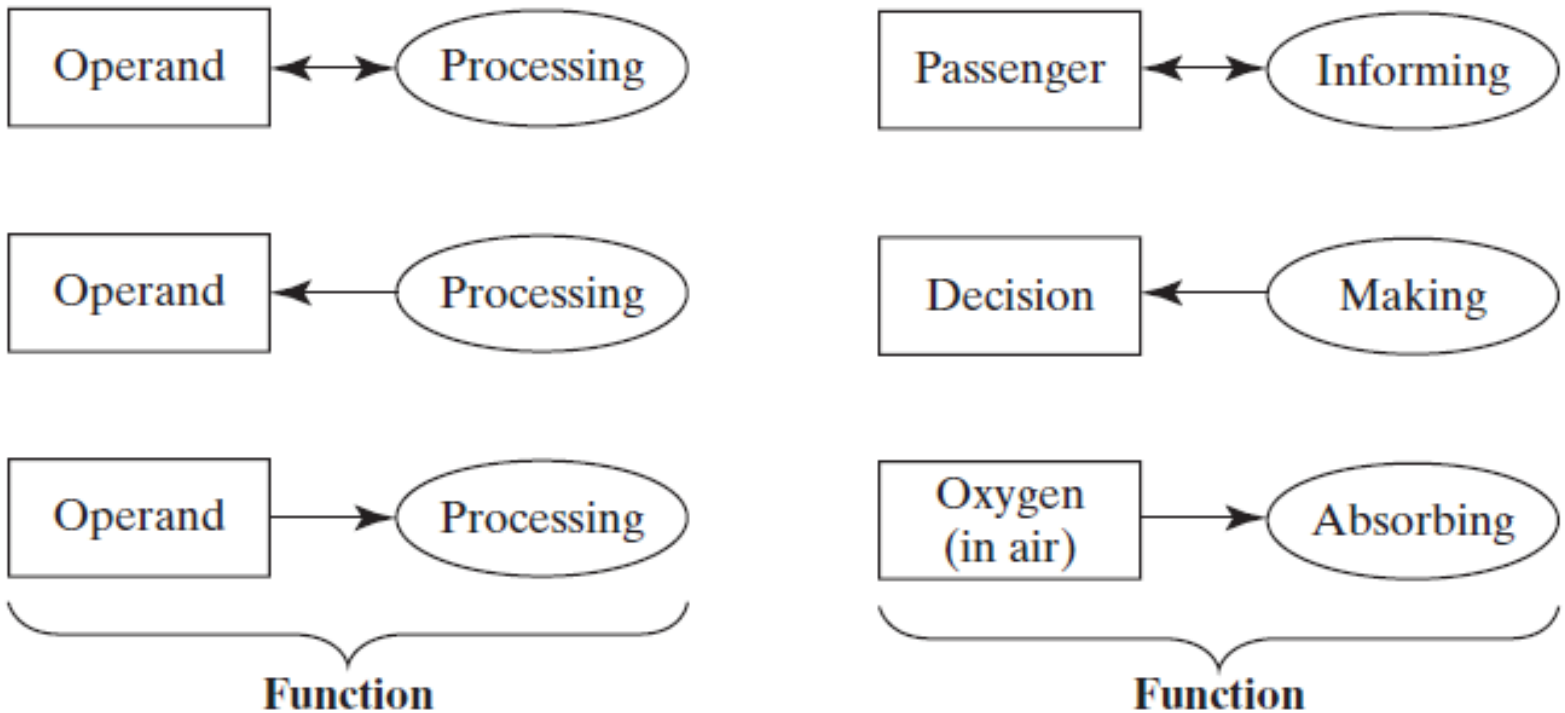
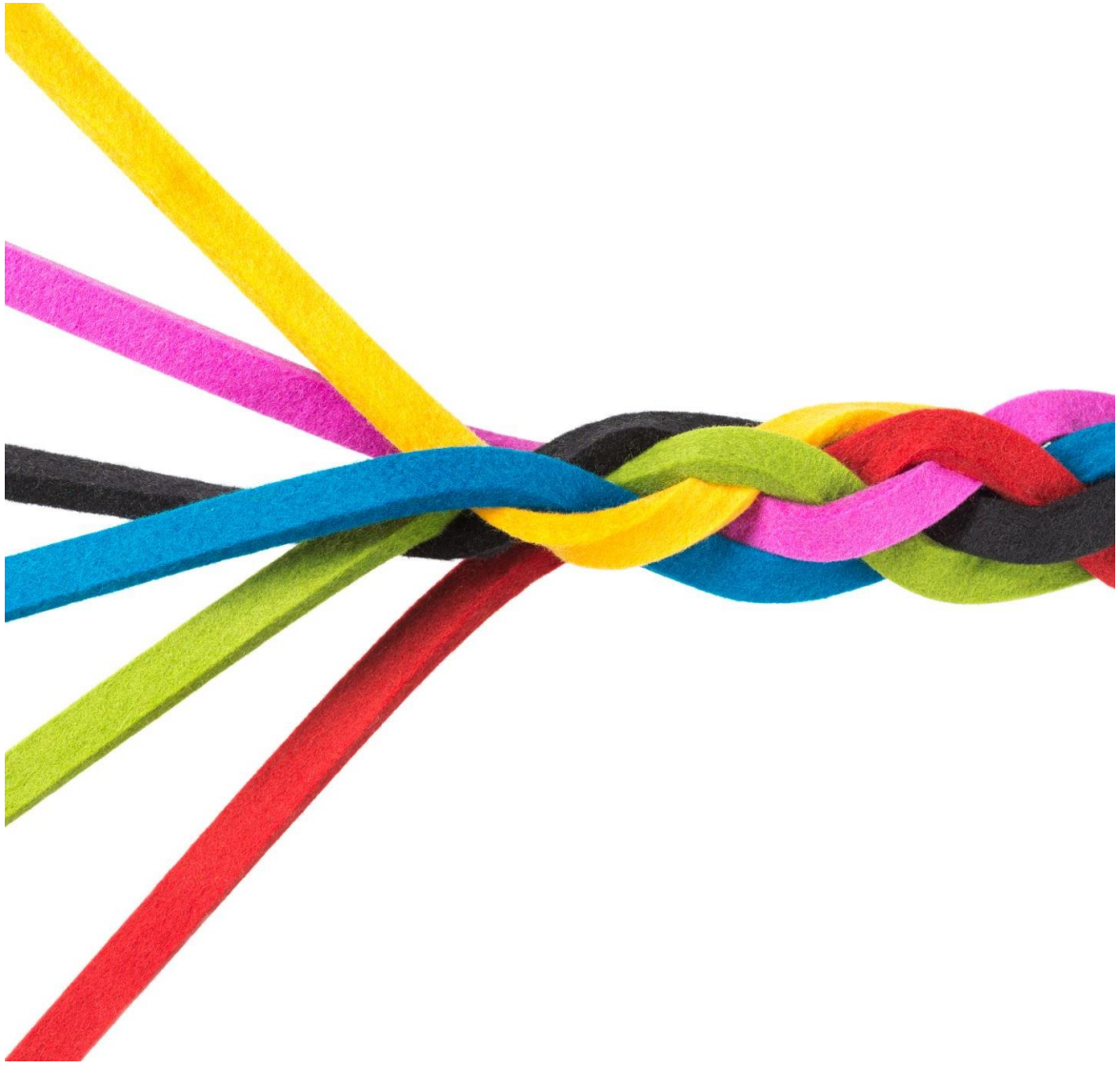


FIGURE 5.2 OPM diagram of process + operand yielding function. From top to bottom, these represent the process affecting the operand, consuming the operand, and producing the operand.

FORM AND FUNCTION



- **Form**, a system attribute consisting of elements and **structure**.
- **Function**, a system attribute consisting of entities of function and **interactions through operands**.
- System Architecture, the combination of form and function.

OPM FUNCTION + FORM

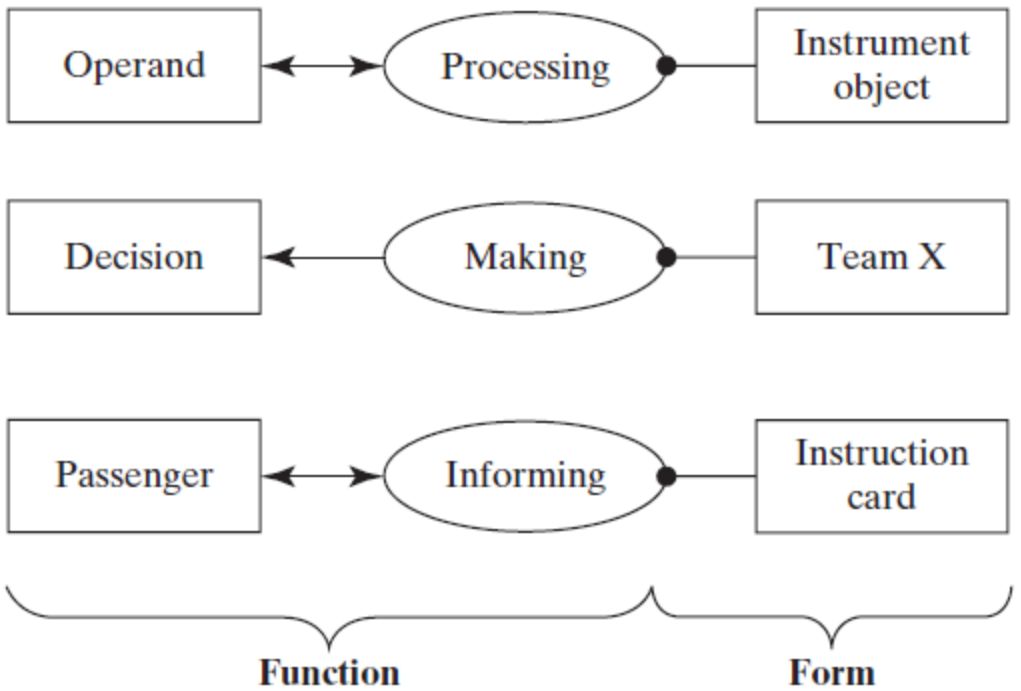


FIGURE 5.3 OPM representation of the canonical system architecture: The function as a process and an operand that the process affects, and the form as an instrument object.

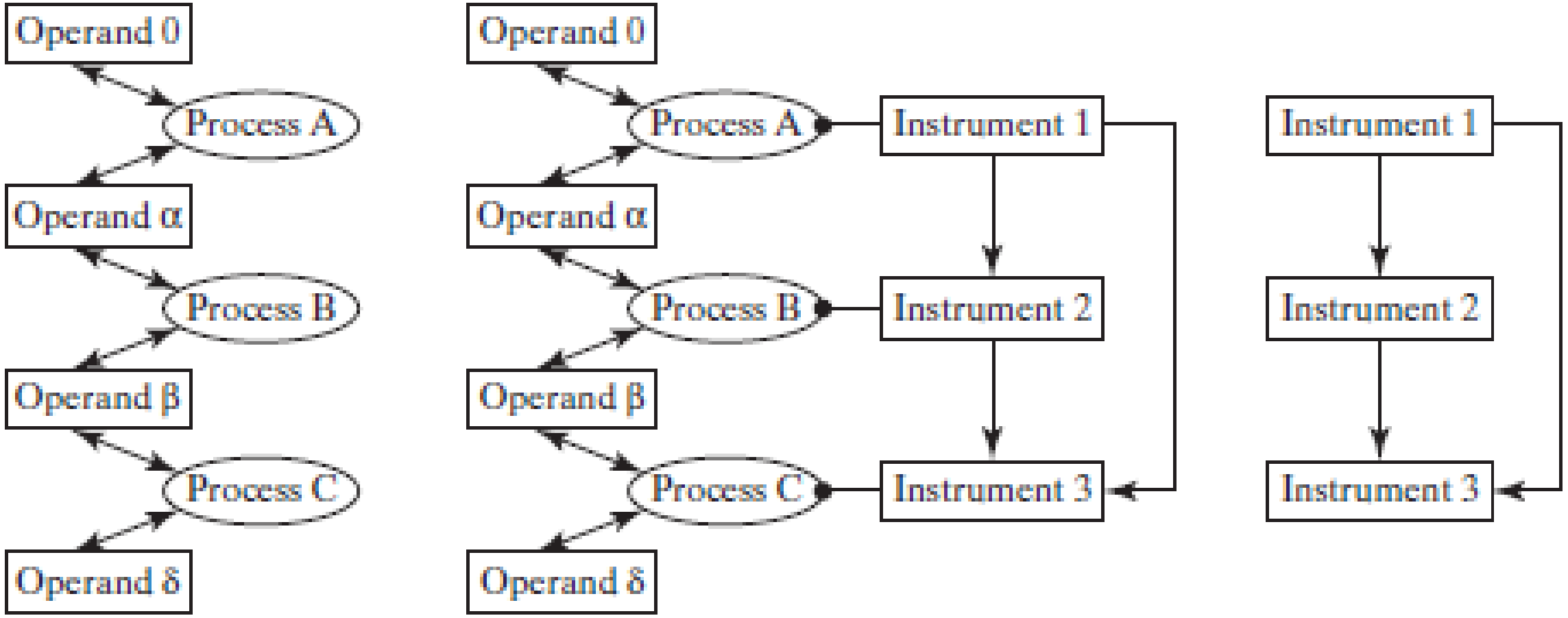


FIGURE 6.1 System architecture as the combination of functional architecture and elements and structure of form.

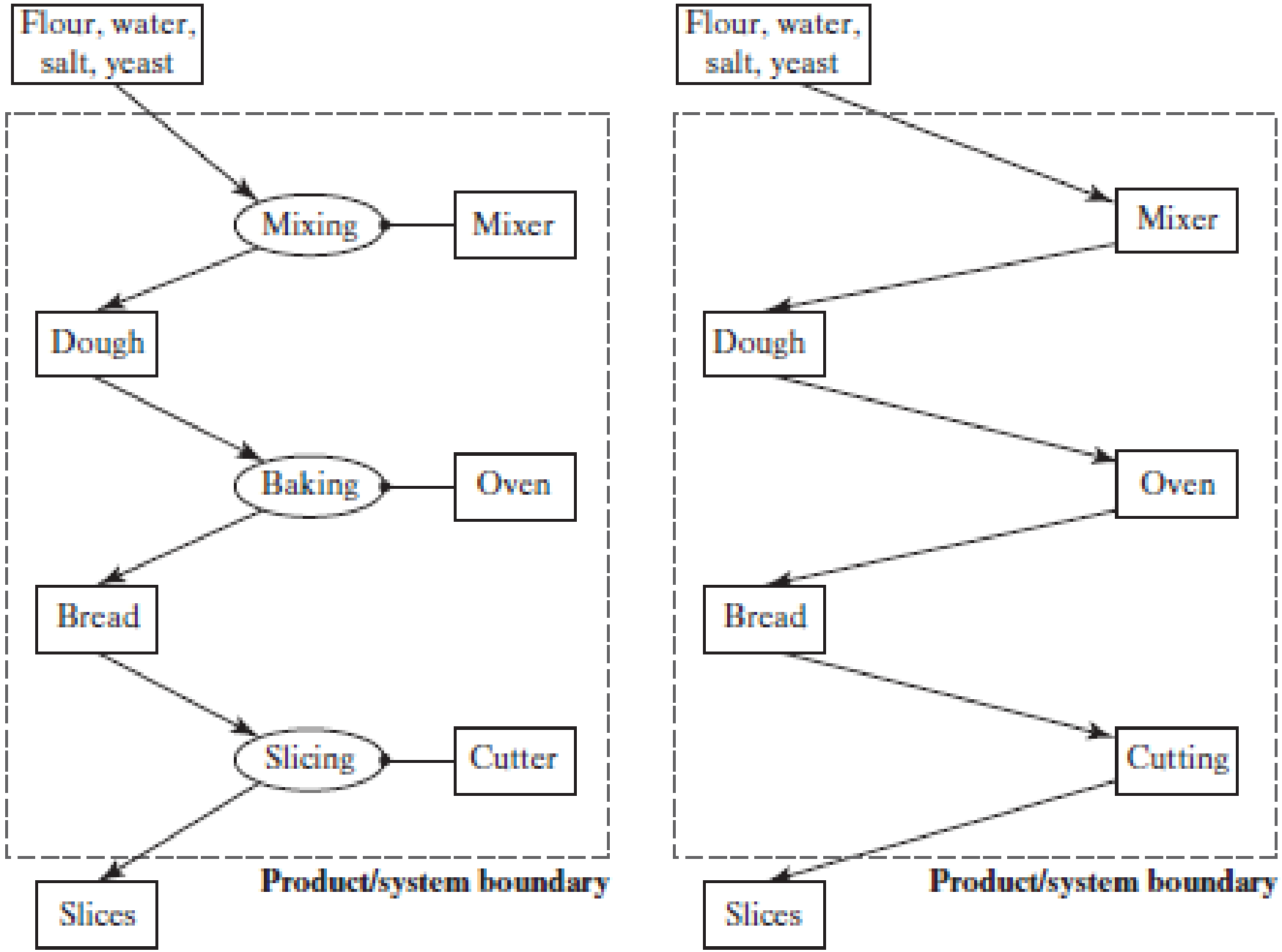
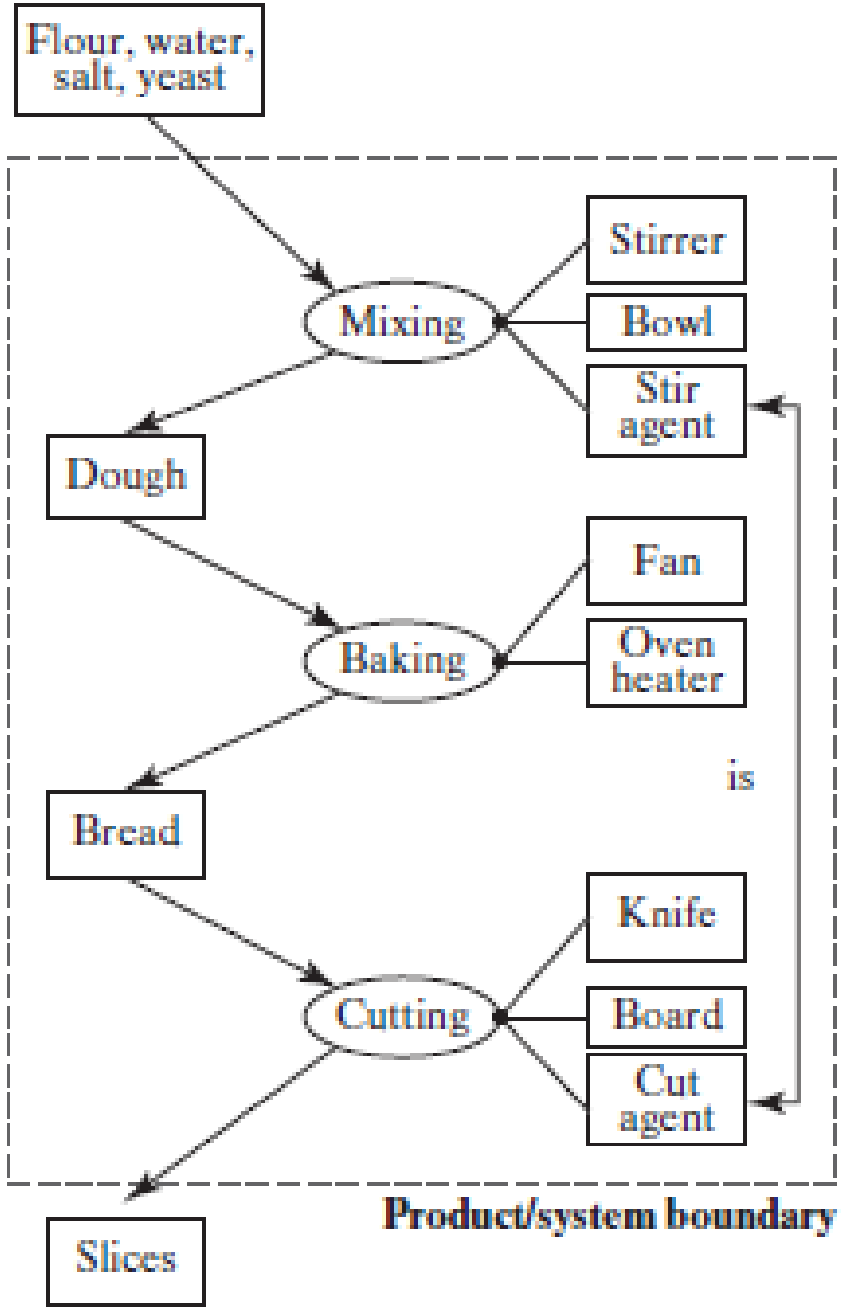


FIGURE 6.3 Simple system architecture of sliced bread making.



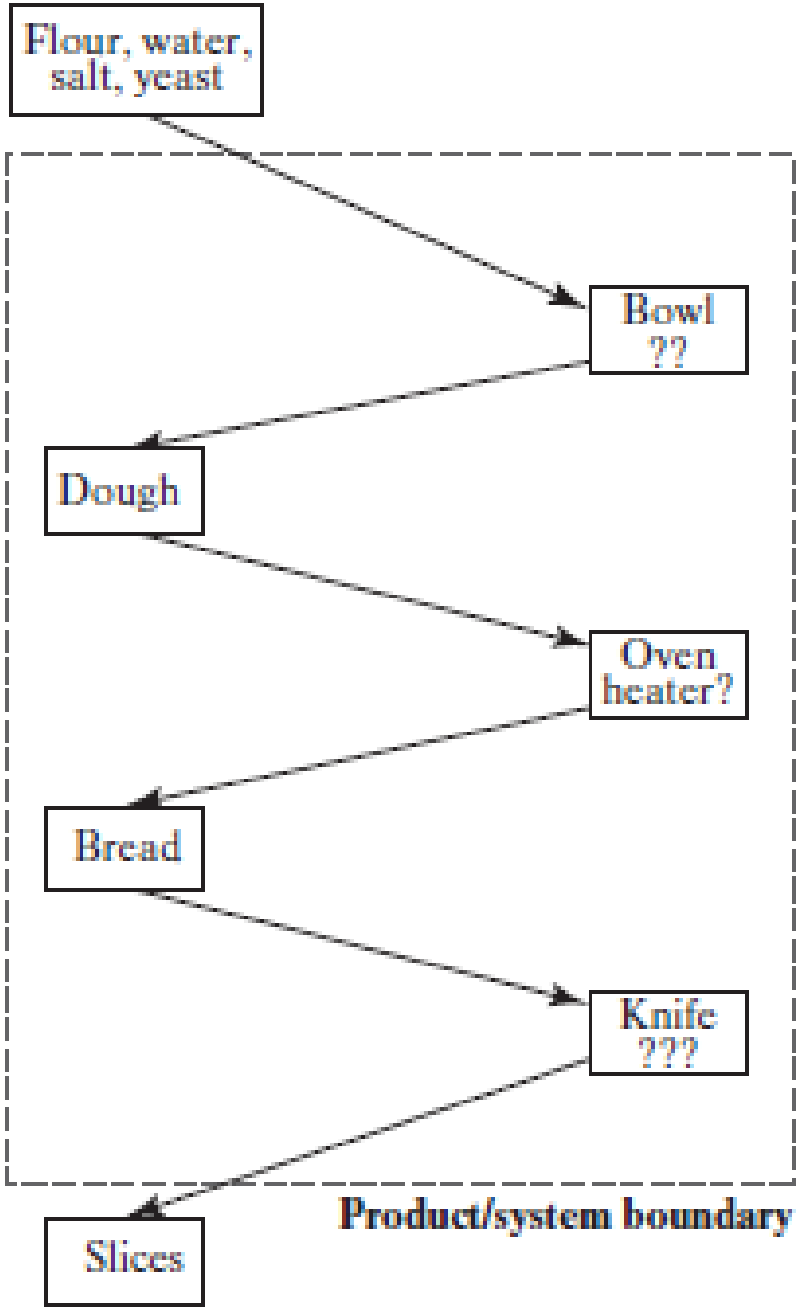


FIGURE 6.4 A not-so-simple system architecture of sliced bread making.

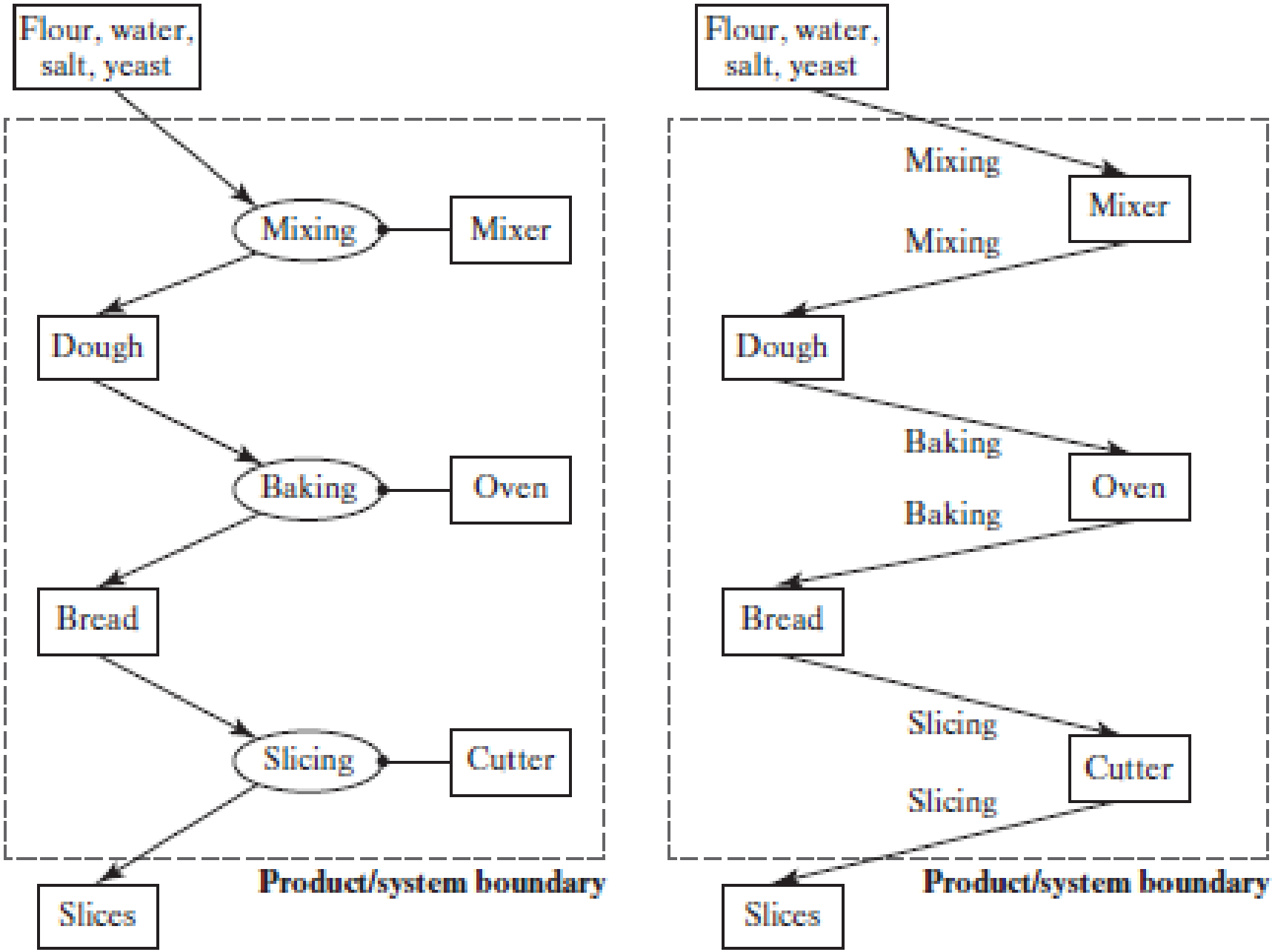


FIGURE 6.16 Projection onto the objects of making sliced bread.

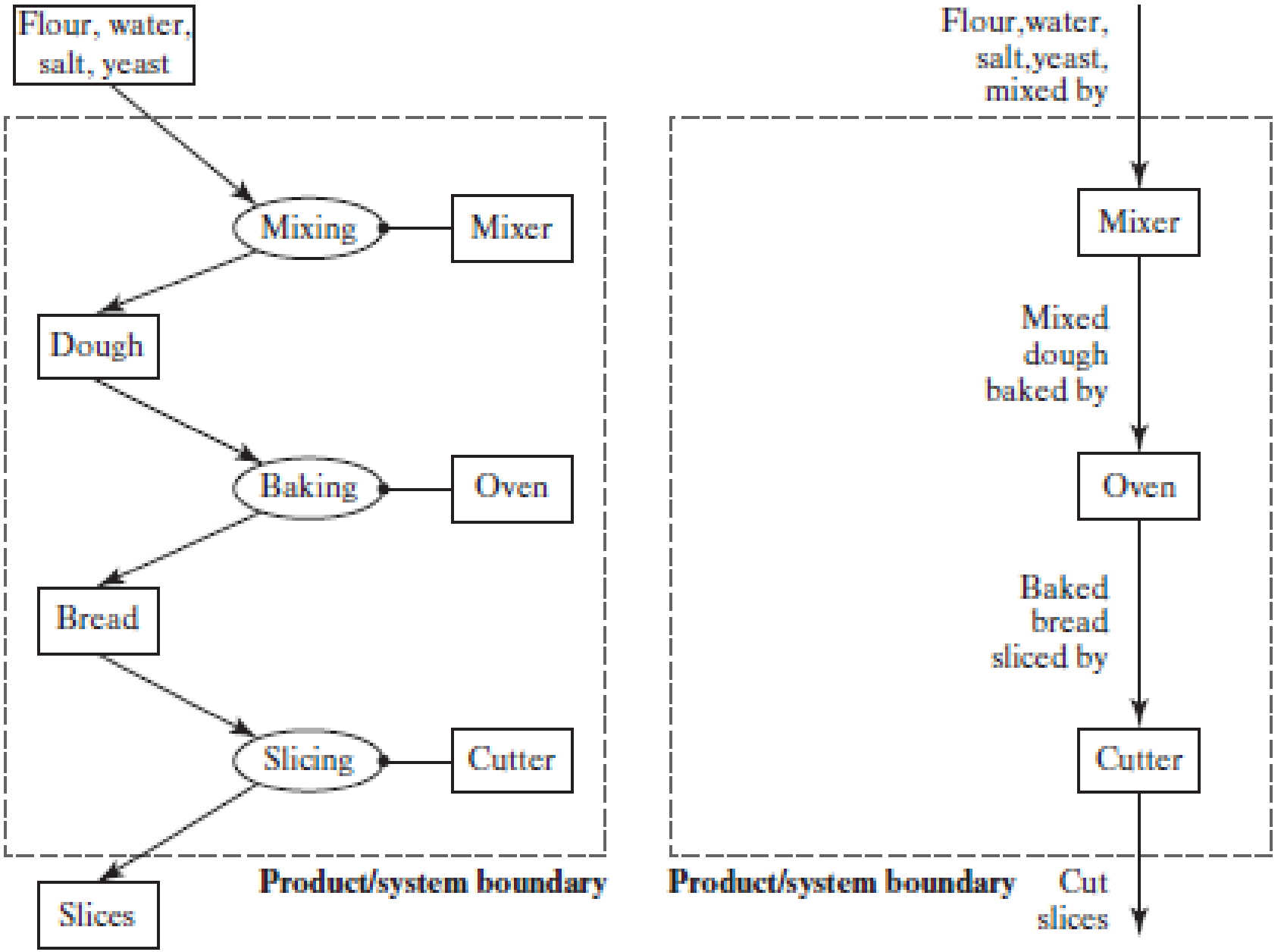
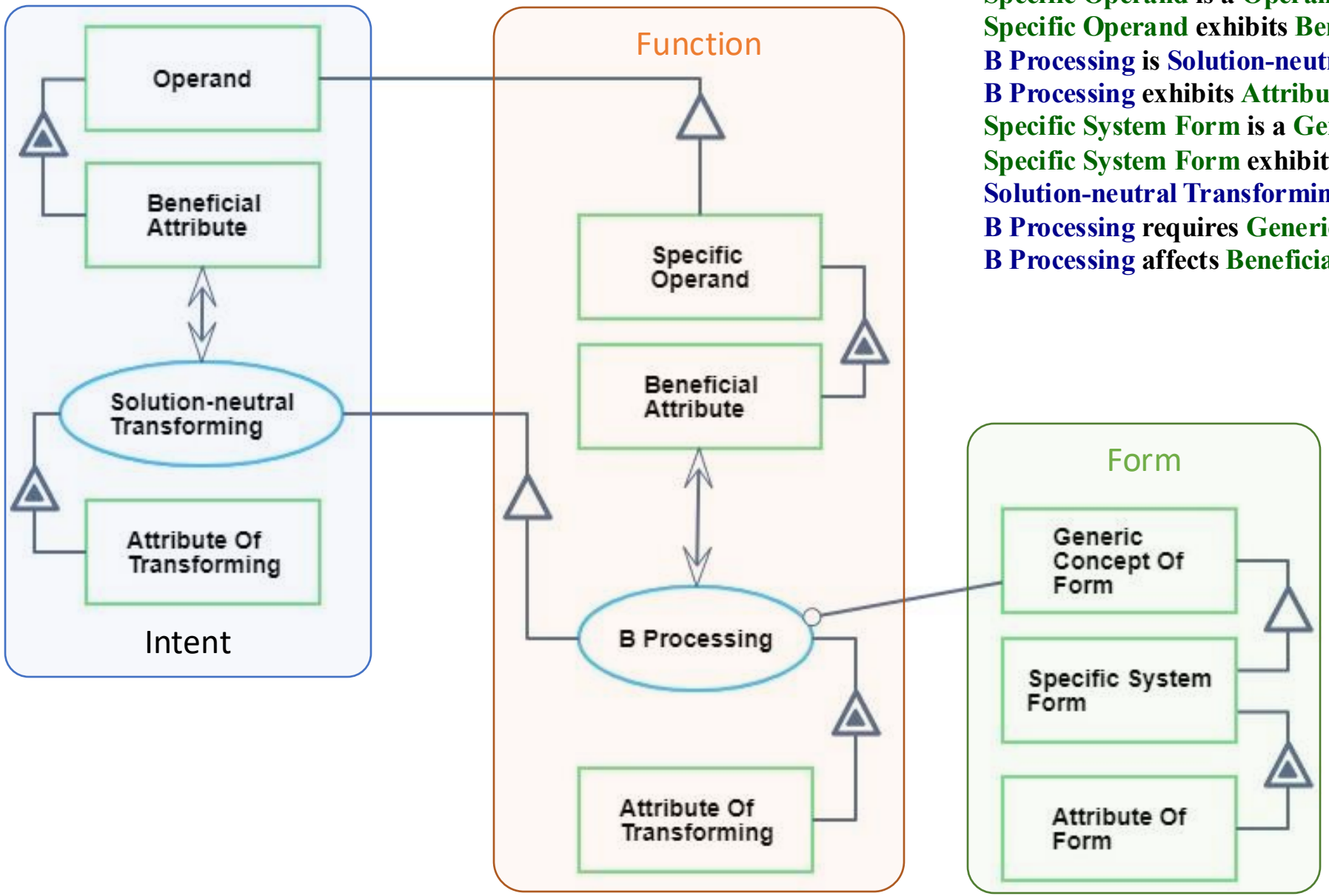


FIGURE 6.19 Projection onto the form of making sliced bread. (Compare with Figure 6.16.)

Neutral Solution



Operand exhibits Beneficial Attribute.
Solution-neutral Transforming exhibits Attribute Of Transforming.
Specific Operand is a Operand.
Specific Operand exhibits Beneficial Attribute.
B Processing is Solution-neutral Transforming.
B Processing exhibits Attribute Of Transforming.
Specific System Form is a Generic Concept Of Form.
Specific System Form exhibits Attribute Of Form.
Solution-neutral Transforming affects Beneficial Attribute.
B Processing requires Generic Concept Of Form.
B Processing affects Beneficial Attribute.

Removing a wine bottle cork

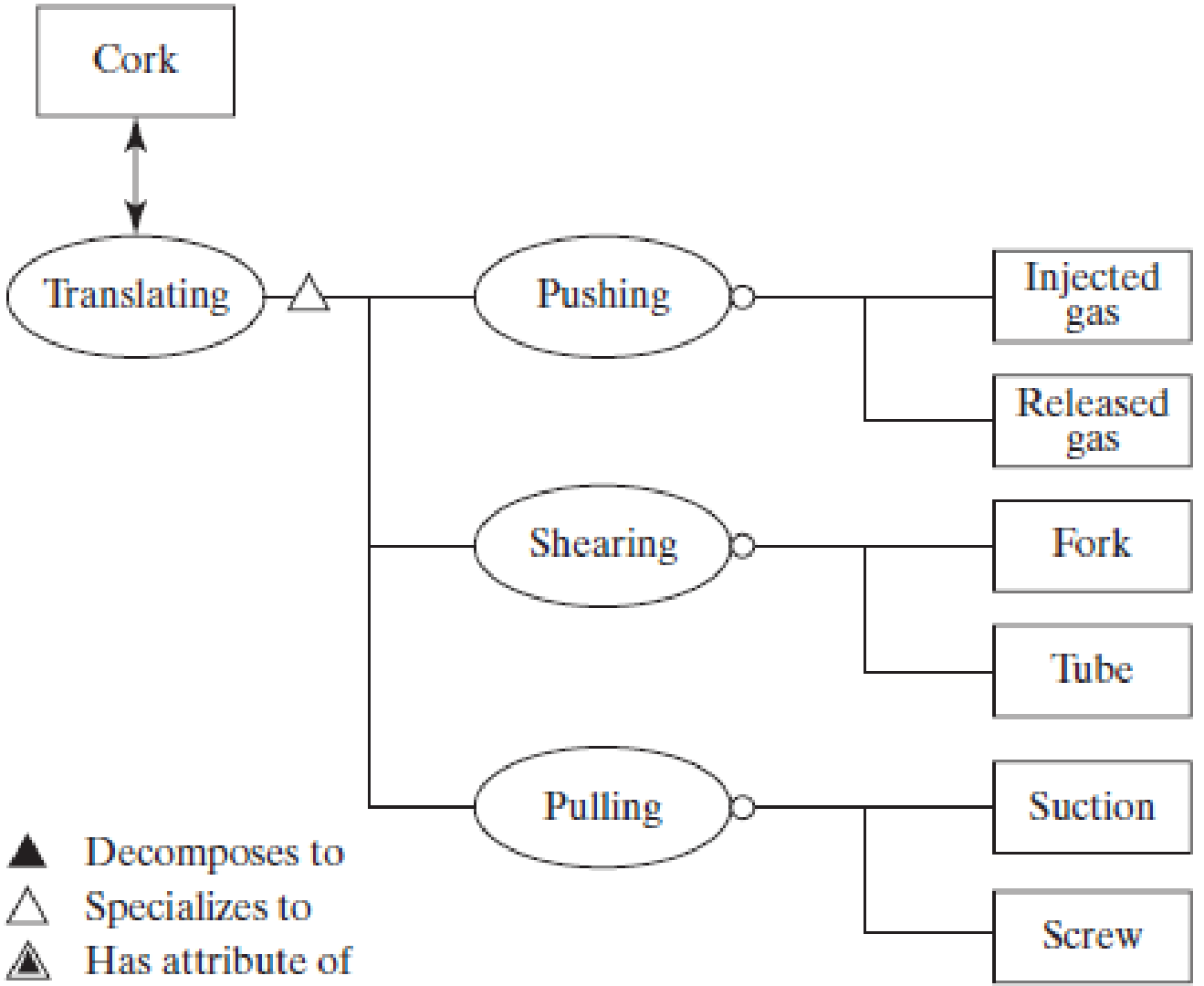


FIGURE 7.1 Concepts for removing a wine bottle cork.

Selectable options template

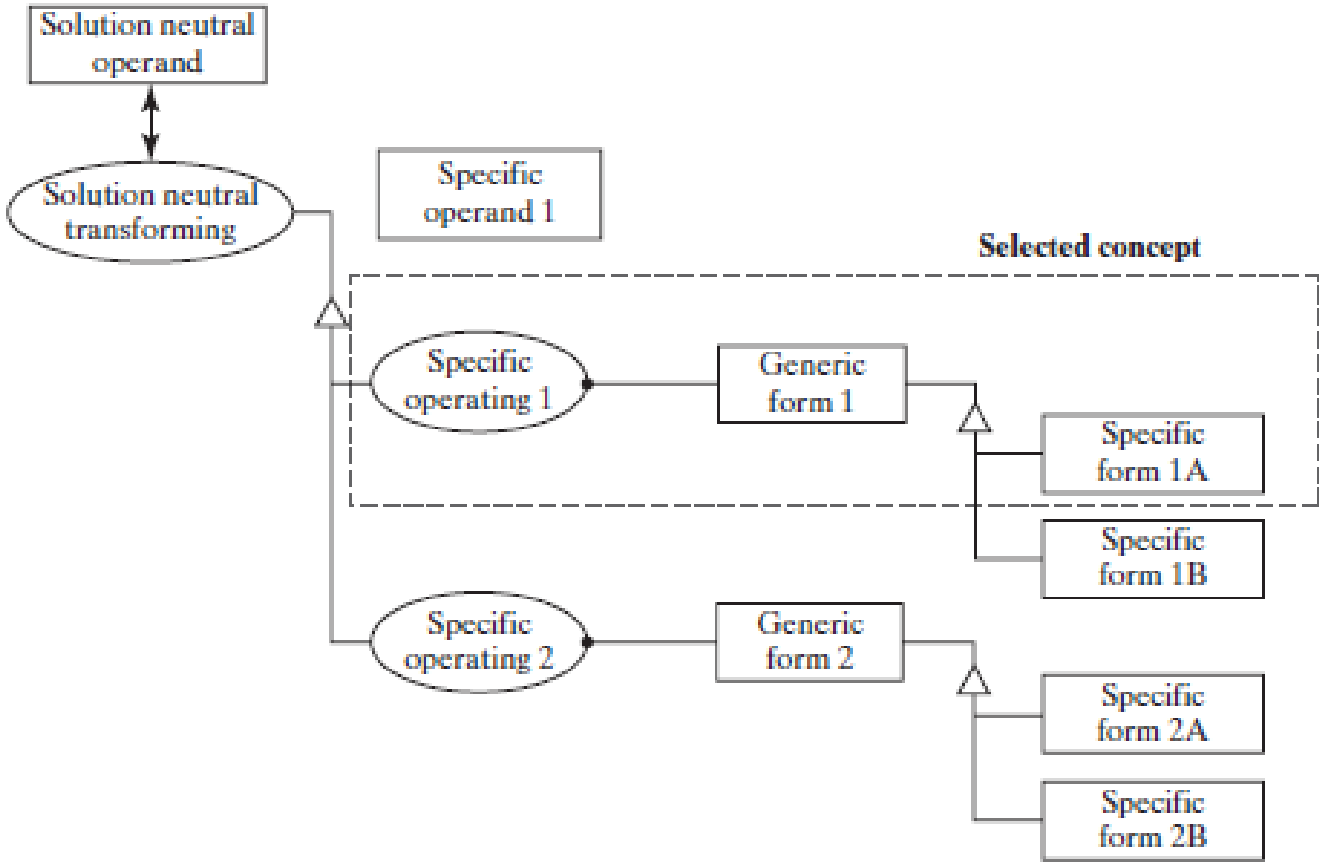


FIGURE 7.5 Tree showing the options among concepts, with different specific operating and specific instruments of form, but all with the same specific operand 1.

Transportation service options

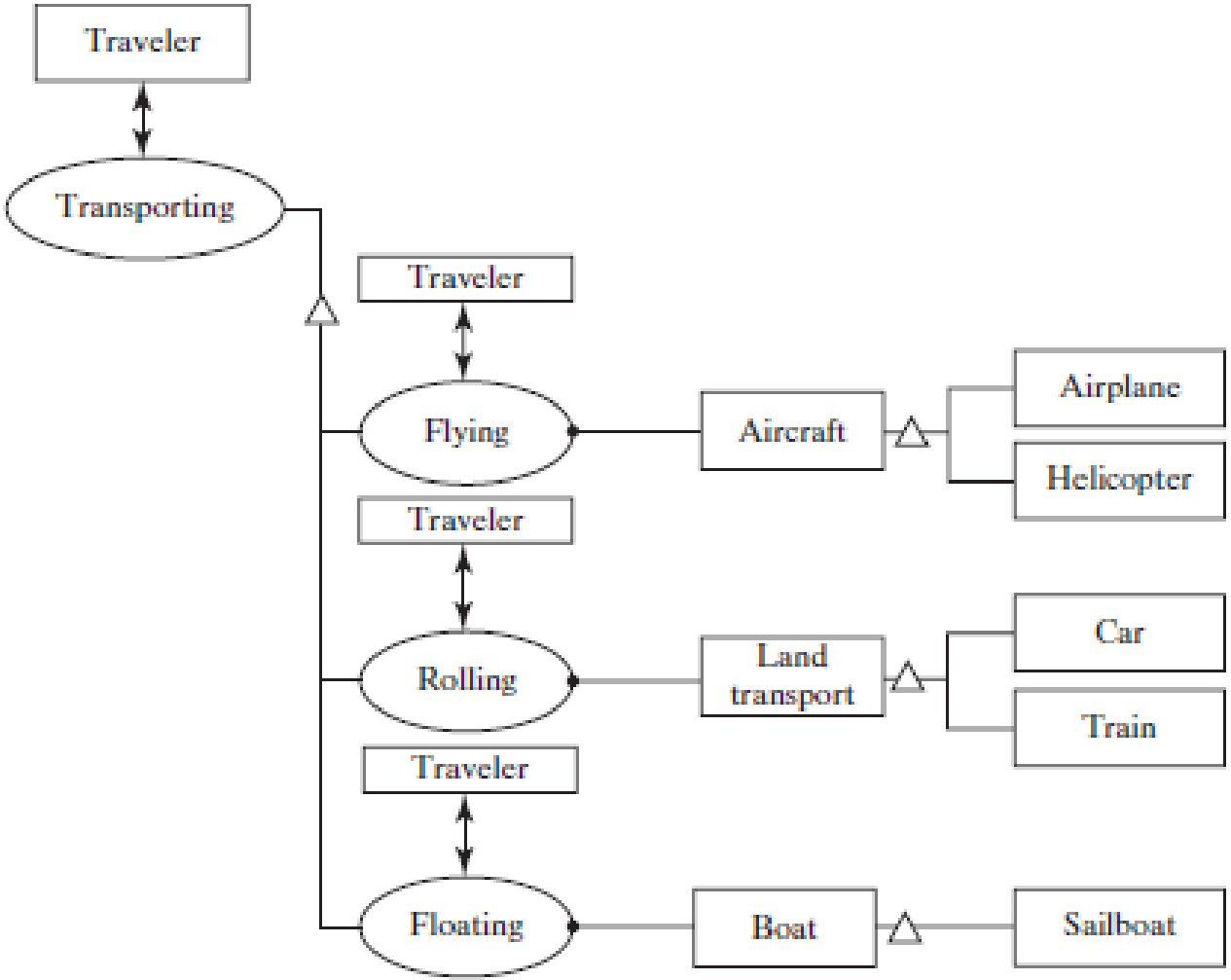


FIGURE 7.8 Solution-neutral function and solution-specific concept options for "transportation service" system.

Linking function

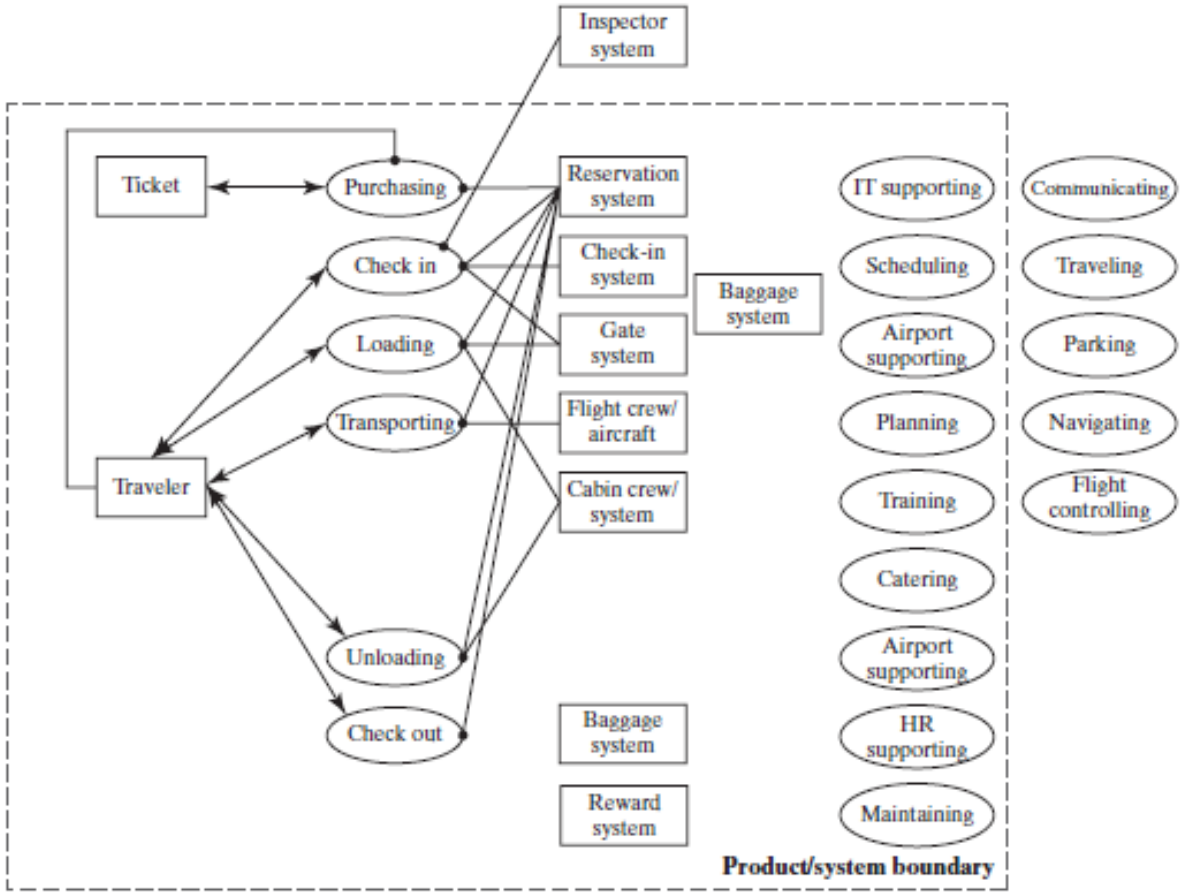


FIGURE 8.1 Partial architecture of the primary value delivery of the air transportation service.

TABLE 8.4 | A DSM array showing the coupling through operands of the processes of the air transportation service with suggested Level 1 clustering. Matrix entries show the number of operands linking the row, column processes.

		Reservation					Ticket			Passenger							Checked Bags					Carry Bags				Secondary				
		linking	learning	reserving	purchasing	amending	changing	issuing	crediting	arriving at airport	inspecting	embarking	transporting	disembarking	evacuating	departing airport	checking	loading	shipping	unloading	collecting	examining	storing	conveying	collecting	alerting	informing	entertaining	nourishing
Cluster 1	linking	2	2	2	2	2	2	1	1	1	1	1	0	1	1	1	2	0	0	0	1	1	1	0	1	1	1	1	1
	learning	2	3	3	2	3	2	1	1	1	1	1	0	1	1	1	2	0	0	0	1	1	1	0	1	1	1	1	1
	reserving	2	3	4	3	4	3	2	2	1	2	1	0	1	1	1	3	1	0	1	2	2	1	0	1	1	1	1	1
	purchasing	2	2	3	4	4	4	3	2	1	2	1	0	1	1	1	3	1	0	1	2	2	1	0	1	1	1	1	1
	amending	2	3	4	4	5	4	3	2	1	2	1	0	1	1	1	3	1	0	1	2	2	1	0	1	1	1	1	1
Cluster 2	changing	2	2	3	4	4	5	4	2	1	2	2	0	2	2	1	3	1	0	1	2	2	2	0	1	2	1	2	2
	issuing	1	1	2	3	3	4	4	2	0	1	1	0	1	1	0	2	1	0	1	1	1	1	0	0	1	0	1	1
	crediting	1	1	2	2	2	2	2	2	0	1	0	0	0	0	0	2	1	0	1	1	1	0	0	0	0	0	0	0
Cluster 3	arriving at airport	1	1	1	1	1	1	0	0	4	1	3	1	3	2	4	1	1	1	1	2	1	2	1	2	1	1	1	1
	inspecting	1	1	2	2	2	2	1	1	1	3	1	0	1	1	1	2	1	0	1	2	2	1	0	1	1	1	1	1
	embarking	1	1	1	1	1	2	1	0	3	1	4	1	4	3	3	1	0	0	0	1	1	3	1	2	2	1	2	2
	transporting	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	disembarking	1	1	1	1	1	2	1	0	3	1	4	1	4	3	3	1	0	0	0	1	1	3	1	2	2	1	2	2
	evacuating	1	1	1	1	1	2	1	0	2	1	3	1	3	3	2	1	0	0	0	1	1	2	0	1	2	1	2	2
	departing airport	1	1	1	1	1	1	0	0	4	1	3	1	3	2	4	1	1	1	1	2	1	2	1	2	1	1	1	1
Cluster 4	checking	2	2	3	3	3	3	2	2	1	2	1	0	1	1	1	4	1	0	1	3	2	1	0	1	1	1	1	1
	loading	0	0	1	1	1	1	1	1	1	1	0	0	0	0	1	1	2	1	2	2	1	0	0	0	0	0	0	0
	shipping	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0
	unloading	0	0	1	1	1	1	1	1	1	1	0	0	0	0	1	1	2	1	2	2	1	0	0	0	0	0	0	0
	collecting	1	1	2	2	2	2	1	1	2	2	1	0	1	1	2	3	2	1	2	4	2	1	0	1	1	1	1	1
Cluster 5	examining	1	1	2	2	2	2	1	1	1	2	1	0	1	1	1	2	1	0	1	2	3	1	0	1	1	1	1	1
	storing	1	1	1	1	1	2	1	0	2	1	3	0	3	2	2	1	0	0	0	1	1	3	1	2	2	1	2	2
	conveying	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	0	0	0	0	0	1	1	1	0	0	0	0
	collecting	1	1	1	1	1	1	0	0	2	1	2	0	2	1	2	1	0	0	0	1	1	2	1	2	1	1	1	1
Cluster 6	alerting	1	1	1	1	1	2	1	0	1	1	2	0	2	2	1	1	0	0	0	1	1	2	0	1	3	1	2	2
	informing	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	0	0	0	1	1	1	0	1	1	2	1	1
	entertaining	1	1	1	1	1	2	1	0	1	1	2	0	2	2	1	1	0	0	0	1	1	2	0	1	2	1	3	2
	nourishing	1	1	1	1	1	2	1	0	1	1	2	0	2	2	1	1	0	0	0	1	1	2	0	1	2	1	2	3

Blue Origin ss Virgin Galacts

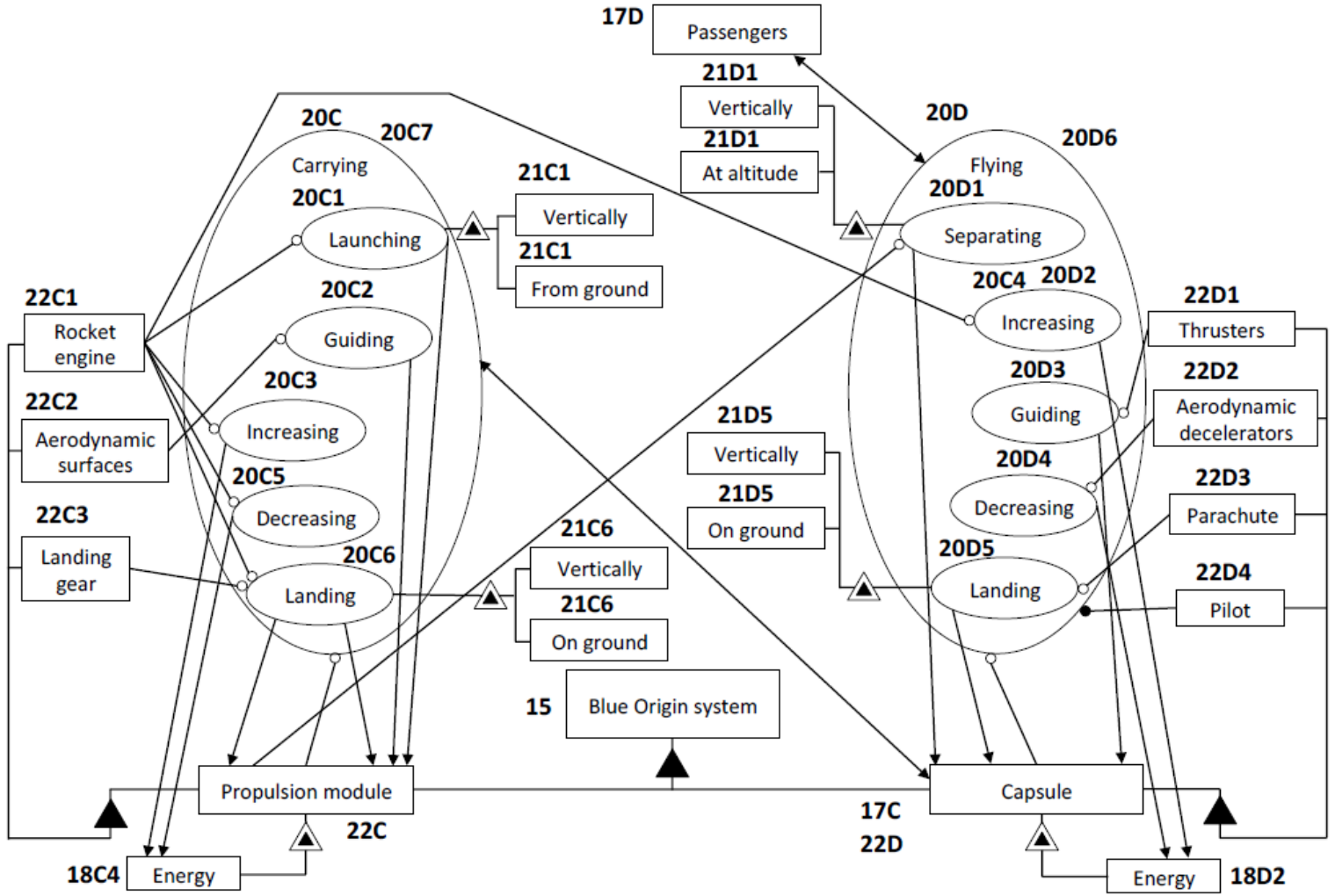


Fig. 16. OPM representation of the integrated concept (fourth assertion) at the second level decomposition for Blue Origin's "Propulsion module" and "Capsule"

Fig. 21. Concept of Operations (fifth assertion) for Blue Origin system

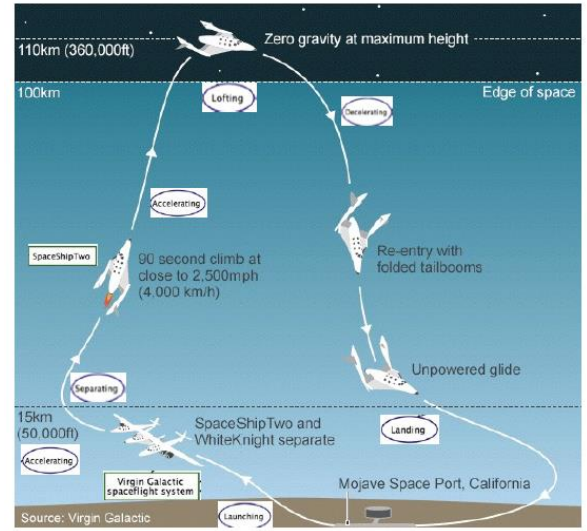


Fig. 20. Concept of Operations (fifth assertion) for Virgin Galactic system