Modeling Requirements

Critical Embedded Systems

Dr. Ákos Horváth

Prepared by
Budapest University of Technology and Economics
Faculty of Electrical Engineering and Informatics
Dept. of Measurement and Information Systems

Overview

- Modeling Textual Requirements
- Modeling Requirements with Use Cases
- Modeling Flow Based Behavior with Activities

Modeling Textual Requirements

Context of the Modeling Aspect

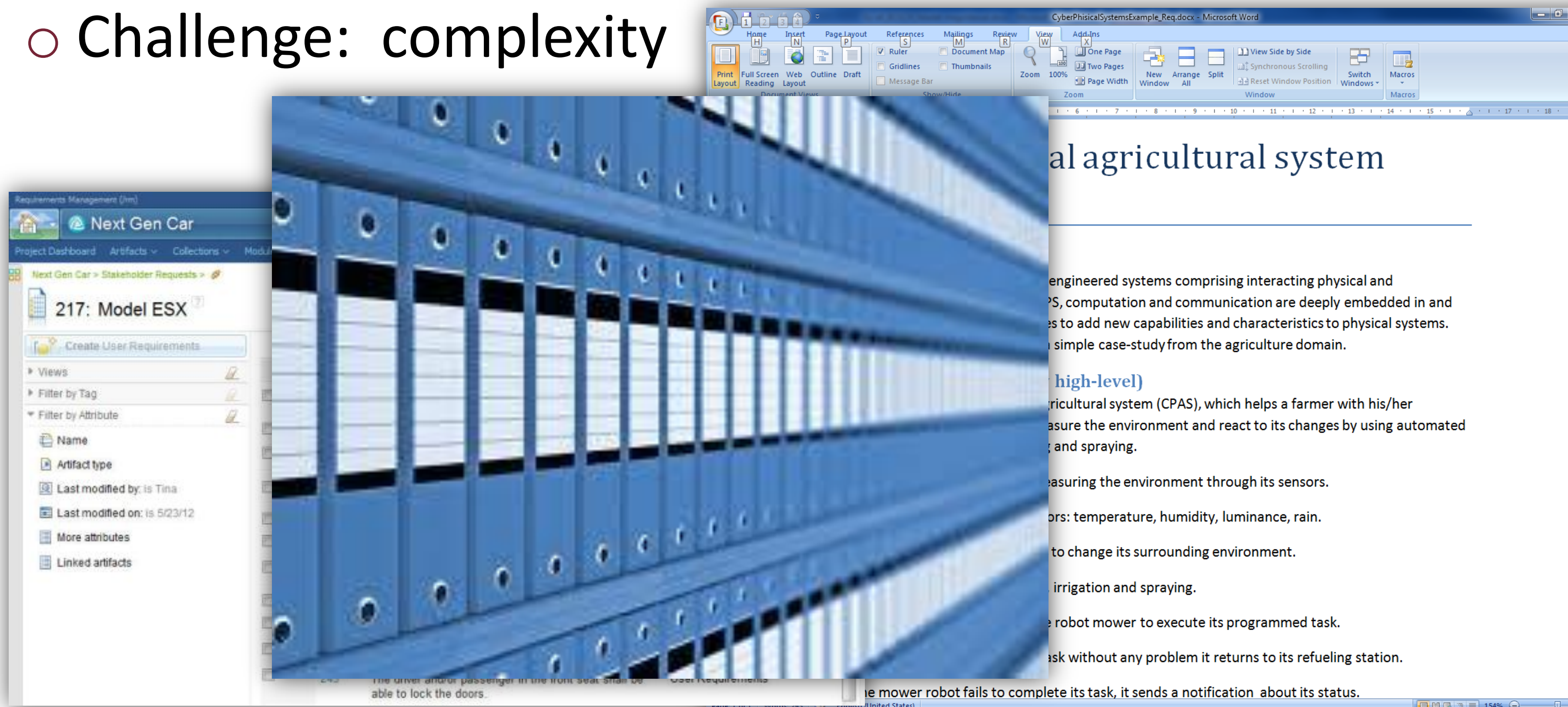
Sample Requirements (Cyber-physical Agricultural System)

Modeling Elements & Notation

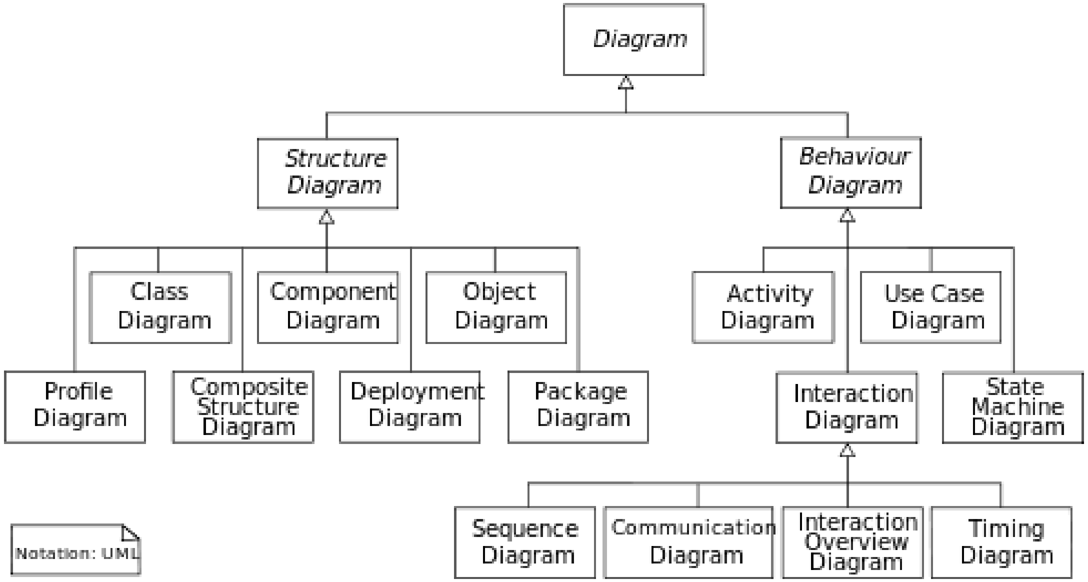
Summary

Roots & Relations

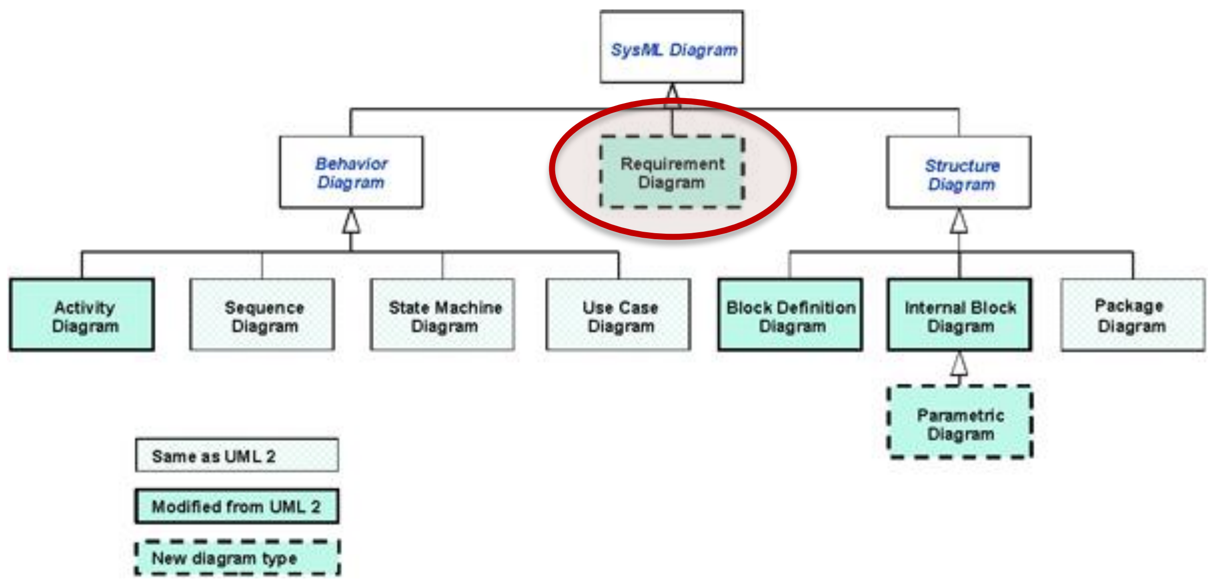
- Document based system development
  - Formulated requirements textually (e.g. in Word)
  - Handled by Req. management tools (e.g. DOORS)
  - Challenge: complexity



Requirements Diagram

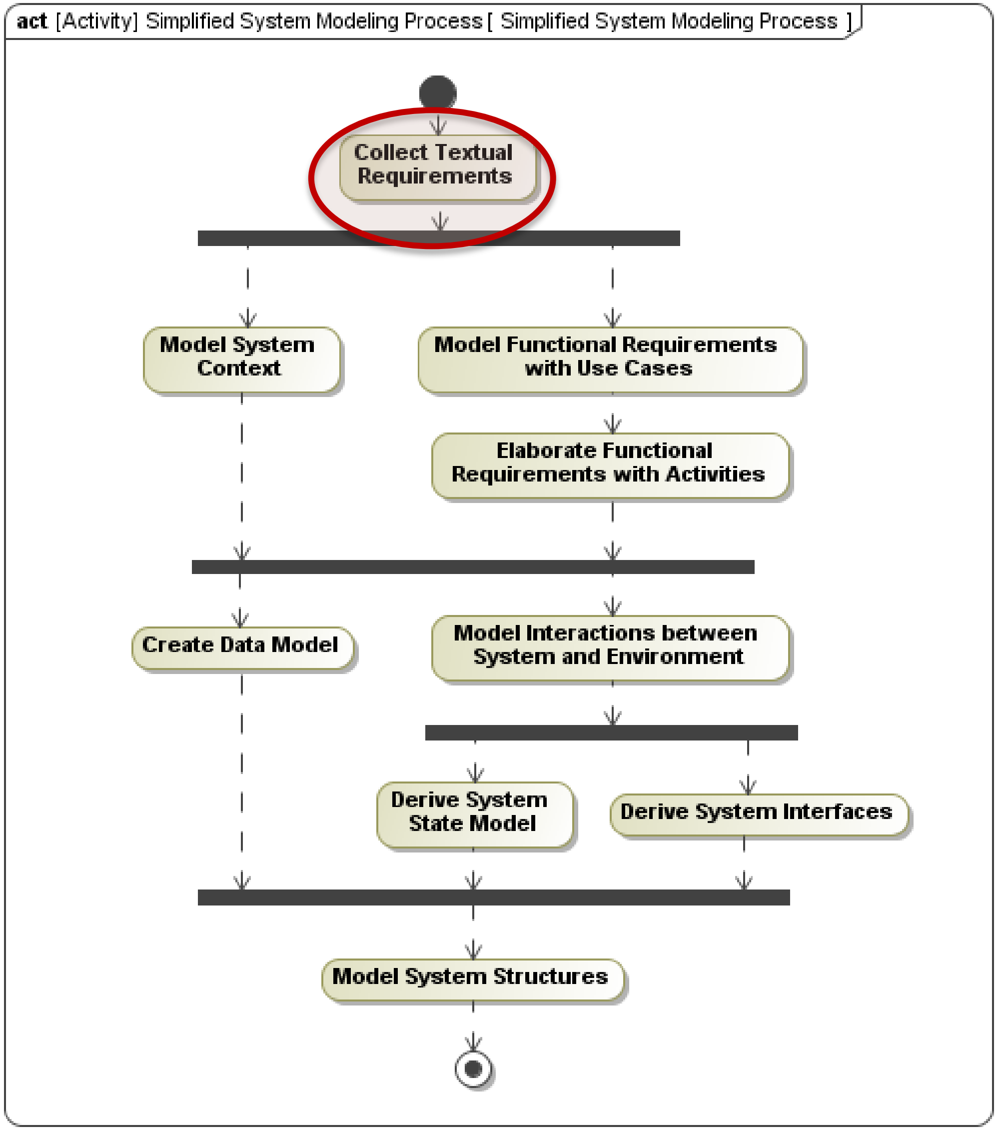


UNIFIED MODELING LANGUAGE



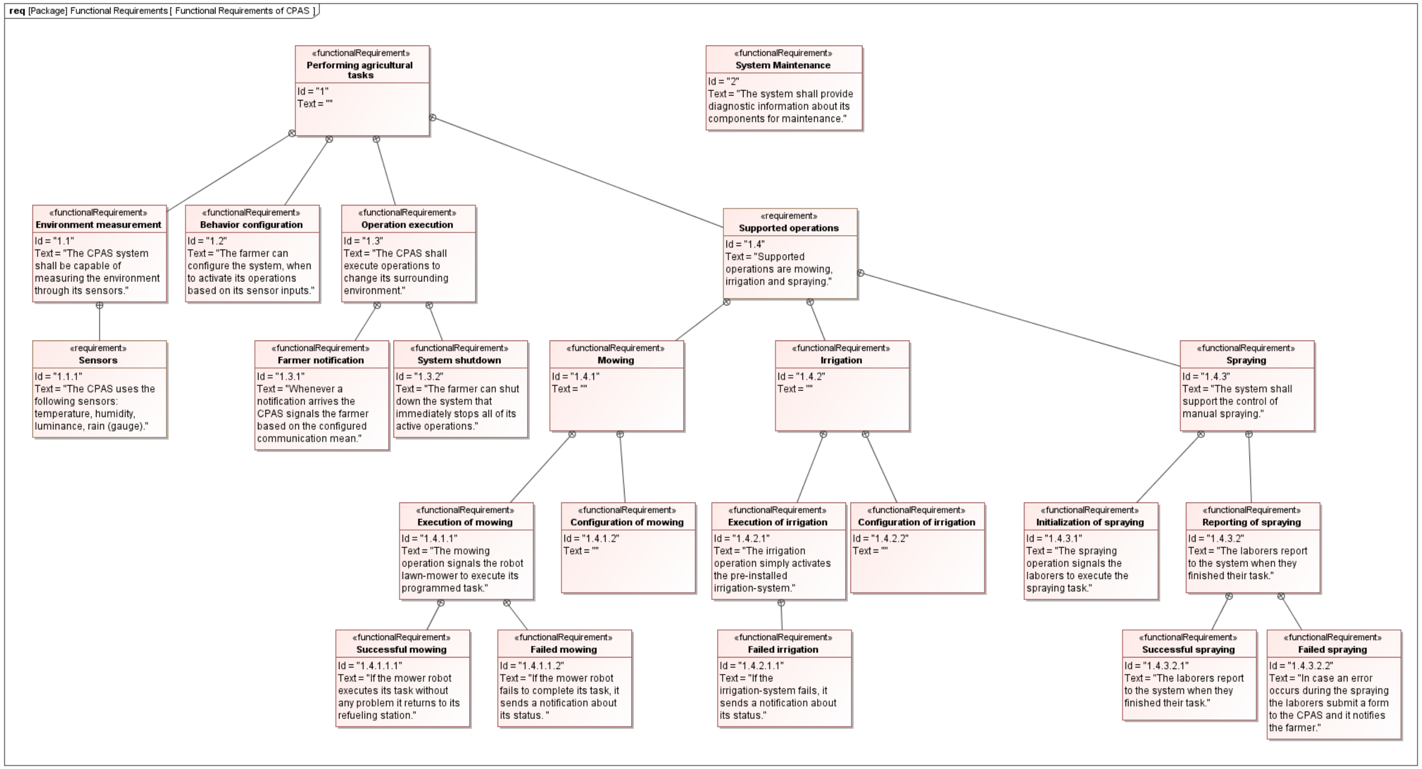
OMG SYSTEMS MODELING LANGUAGE

System Modeling Process



Modeling Aspect

What are the main requirements formulated textually and what are their hierarchy?



Objectives

- Provides linkage between traditional textual and model based requirements specifications
- Helps establishing relations between requirements
  - Containment hierarchy
  - Derivation
  - Reusing between projects
- Provides traceability of requirements

Modeling Textual Requirements

Context of the Modeling Aspect

Sample Requirements (Cyber-physical Agricultural System)

Modeling Elements & Notation

Summary

Cyber-physical system

- American terminology
  - Novel buzz-word for embedded system
  - In EU it is ~ „Internet of things”

„ Cyber-Physical Systems (CPS) are engineered systems comprising interacting physical and computational components. In CPS, computation and communication are deeply embedded in and interacting with physical processes to add new capabilities and characteristics to physical systems.”

- E.g., acoustic sniper detection system

Example requirements

Design a simple Cyber-physical agricultural system (CPAS), which helps a farmer with his/her everyday life using sensors to measure the environment and react to its changes by using automated operations like irrigation, mowing and spraying.

Requirements

- The CPAS system is capable of measuring the environment through its sensors.
- The CPAS uses the following sensors: temperature, humidity, luminance, rain.
- The CPAS can execute operations to change its surrounding environment.
- These operations can be mowing, irrigation and spraying.
- The mowing operation signals the robot mower to execute its programmed task.
- If the mower robot executes its task without any problem it returns to its refueling station.
- If the mower robot fails to complete its task, it sends a notification about its status

Example requirements (con't)

- The irrigation operation simply activates the pre-installed irrigation-system.
- If the irrigation-system fails, it sends a notification about its status.
- Whenever a notification arrives the CPAS signals the farmer based on the configured communication mean.
- The spraying operation signals the laborers to execute the spraying task.
- The laborers report to the CPAS when they finished their task.
- In case an error occurs during the spraying the laborers submit a form to the CPAS and it notifies the farmer.
- The farmer can configure the system, when to activate its operations based on its sensor inputs.
- The farmer can shut down the CPAS system that immediately stops all of its active operations.
- The system shall provide diagnostic information about its components for maintenance.

Modeling Textual Requirements

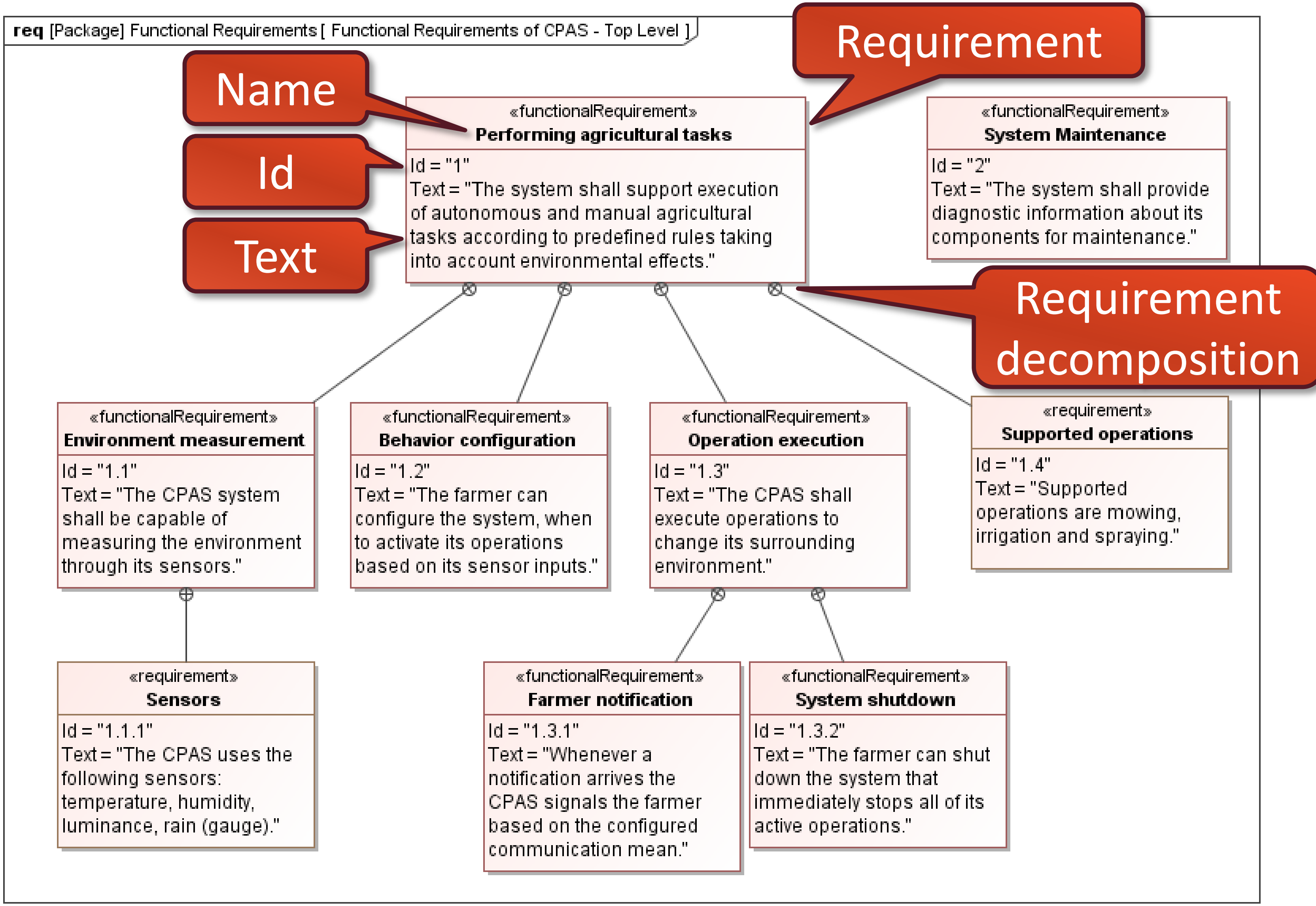
Context of the Modeling Aspect

Sample Requirements (Cyber-physical Agricultural System)

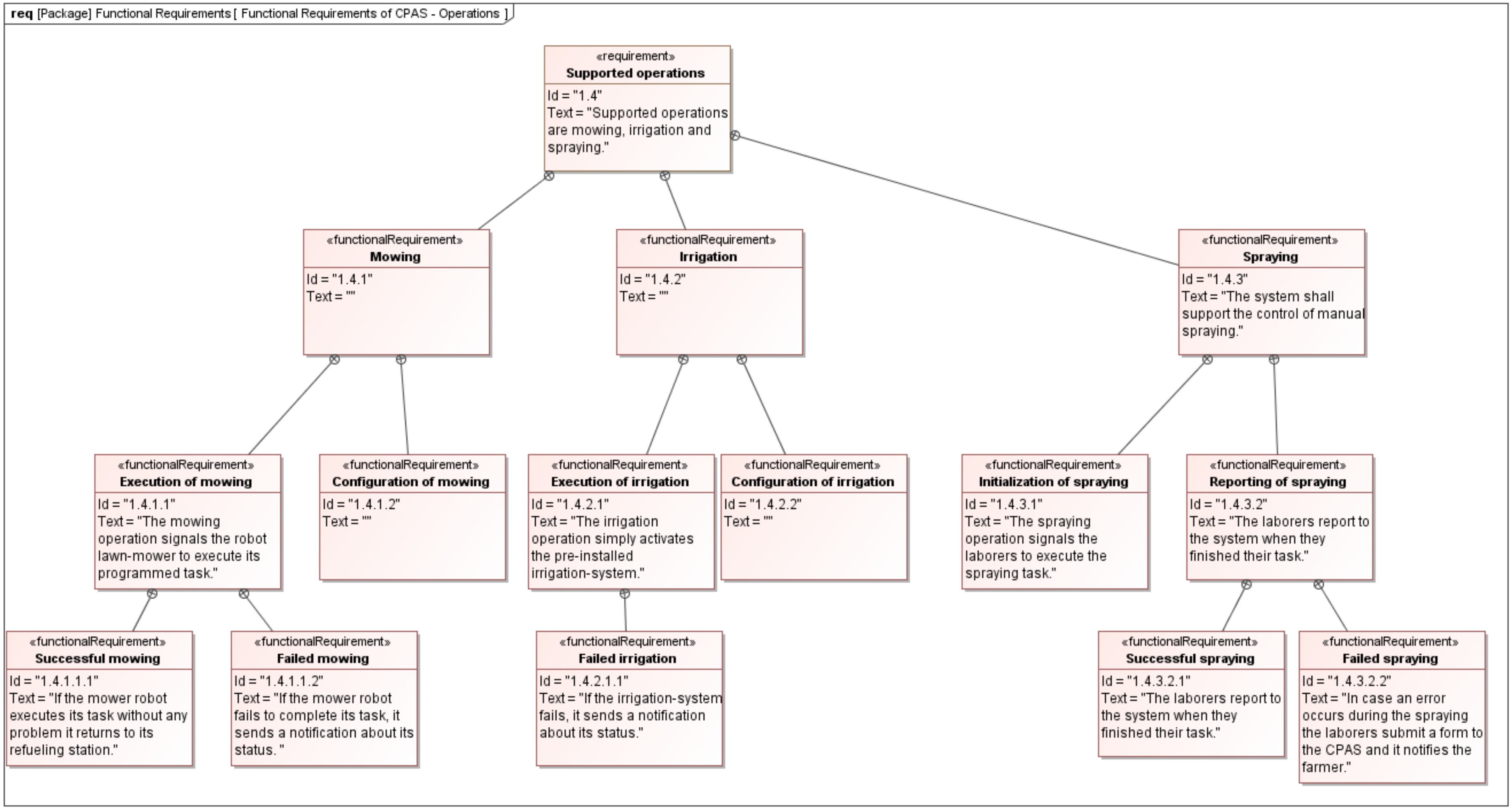
Modeling Elements & Notation

Summary

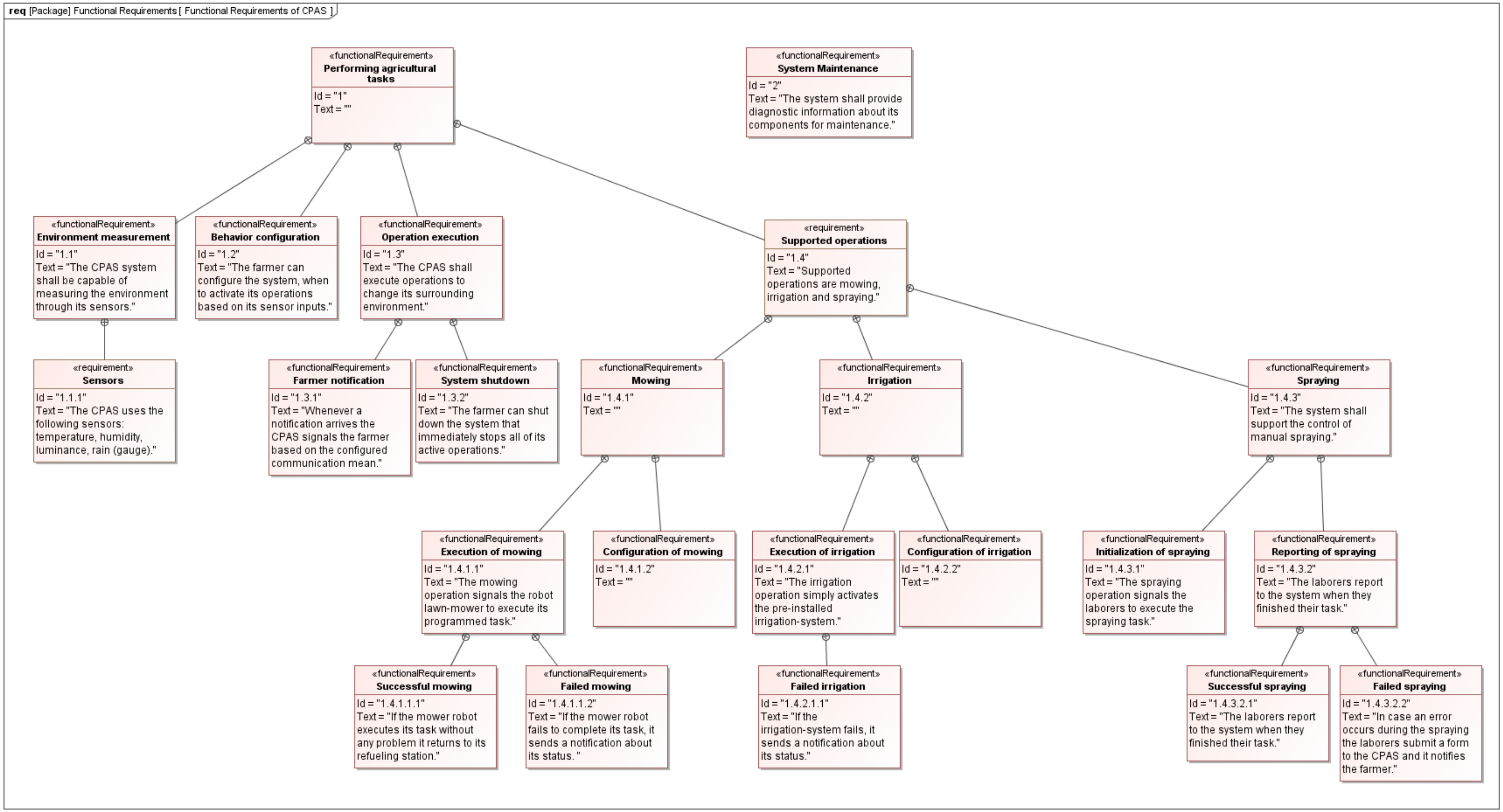
Example – Top Level Requirements



Example – Further Decomposed



Example – Full Hierarchy



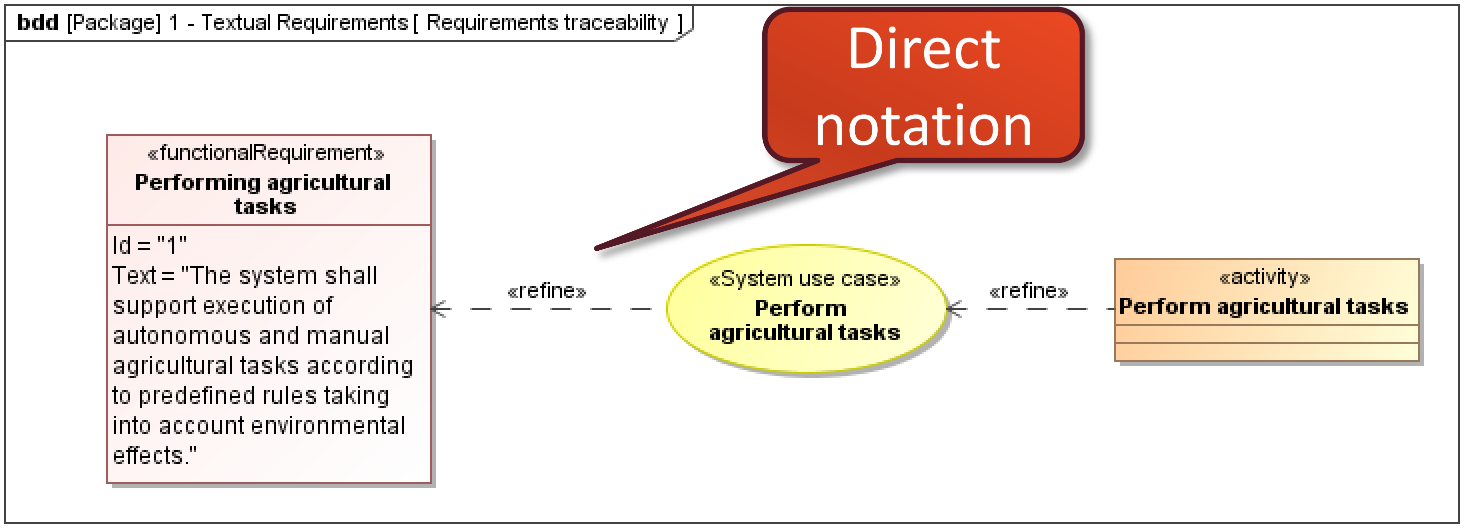
Requirements Table

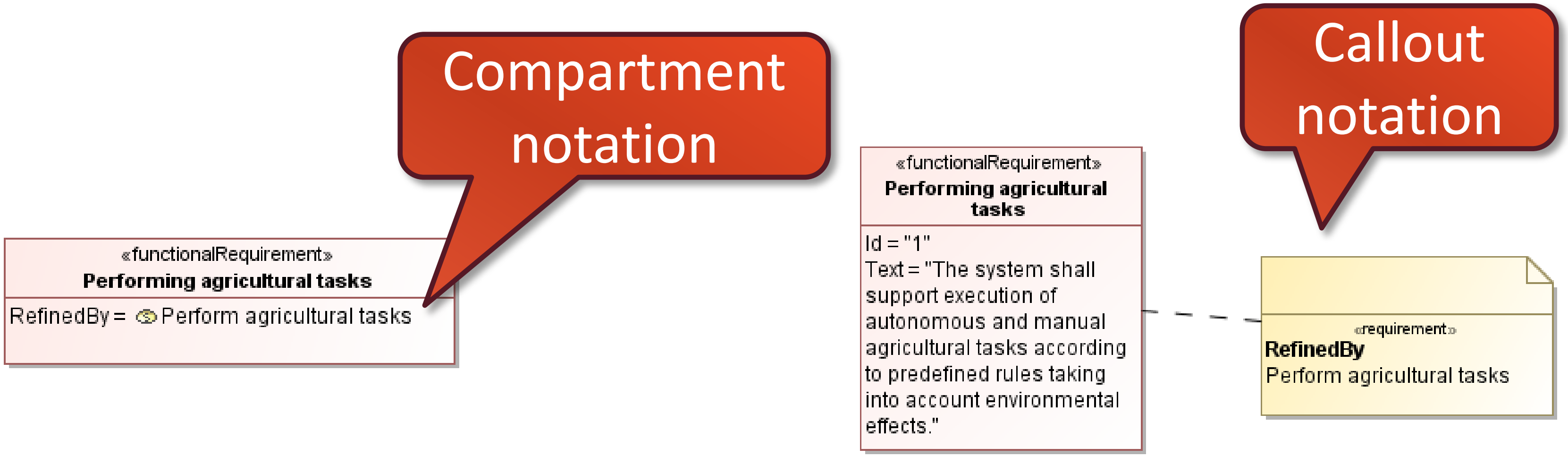
#	Id	Name	Text
1	1	Performing agricultural tasks	
2	1.1	Environment measurement	The CPAS system shall be capable of measuring the environment through its sensors.
3	1.1.1	Sensors	The CPAS uses the following sensors: temperature, humidity, luminance, rain (gauge).
4	1.2	Behavior configuration	The farmer can configure the system, when to activate its operations based on its sensor inputs.
5	1.3	Operation execution	The CPAS shall execute operations to change its surrounding environment.
6	1.3.1	Farmer notification	Whenever a notification arrives the CPAS signals the farmer based on the configured communication mean.
7	1.3.2	System shutdown	The farmer can shut down the system that immediately stops all of its active operations.
8	1.4	Supported operations	Supported operations are mowing, irrigation and spraying.
9	1.4.1	Mowing	
10	1.4.1.1	Execution of mowing	The mowing operation signals the robot lawn-mower to execute its programmed task.
11	1.4.1....	Successful mowing	If the mower robot executes its task without any problem it returns to its refueling station.
12	1.4.1....	Failed mowing	If the mower robot fails to complete its task, it sends a notification about its status.
13	1.4.1.2	Configuration of mowing	
14	1.4.2	Irrigation	
15	1.4.2.1	Execution of irrigation	The irrigation operation simply activates the pre-installed irrigation-system.
16	1.4.2....	Failed irrigation	If the irrigation-system fails, it sends a notification about its status.
17	1.4.2.2	Configuration of irrigation	
18	1.4.3	Spraying	The system shall support the control of manual spraying.
19	1.4.3.1	Initialization of spraying	The spraying operation signals the laborers to execute the spraying task.
20	1.4.3.2	Reporting of spraying	The laborers report to the system when they finished their task.
21	1.4.3....	Successful spraying	The laborers report to the system when they finished their task.
22	1.4.3....	Failed spraying	In case an error occurs during the spraying the laborers submit a form to the CPAS and it notifies the farmer.
23	2	System Maintenance	The system shall provide diagnostic information about its components for maintenance.

Requirements Trace Relations

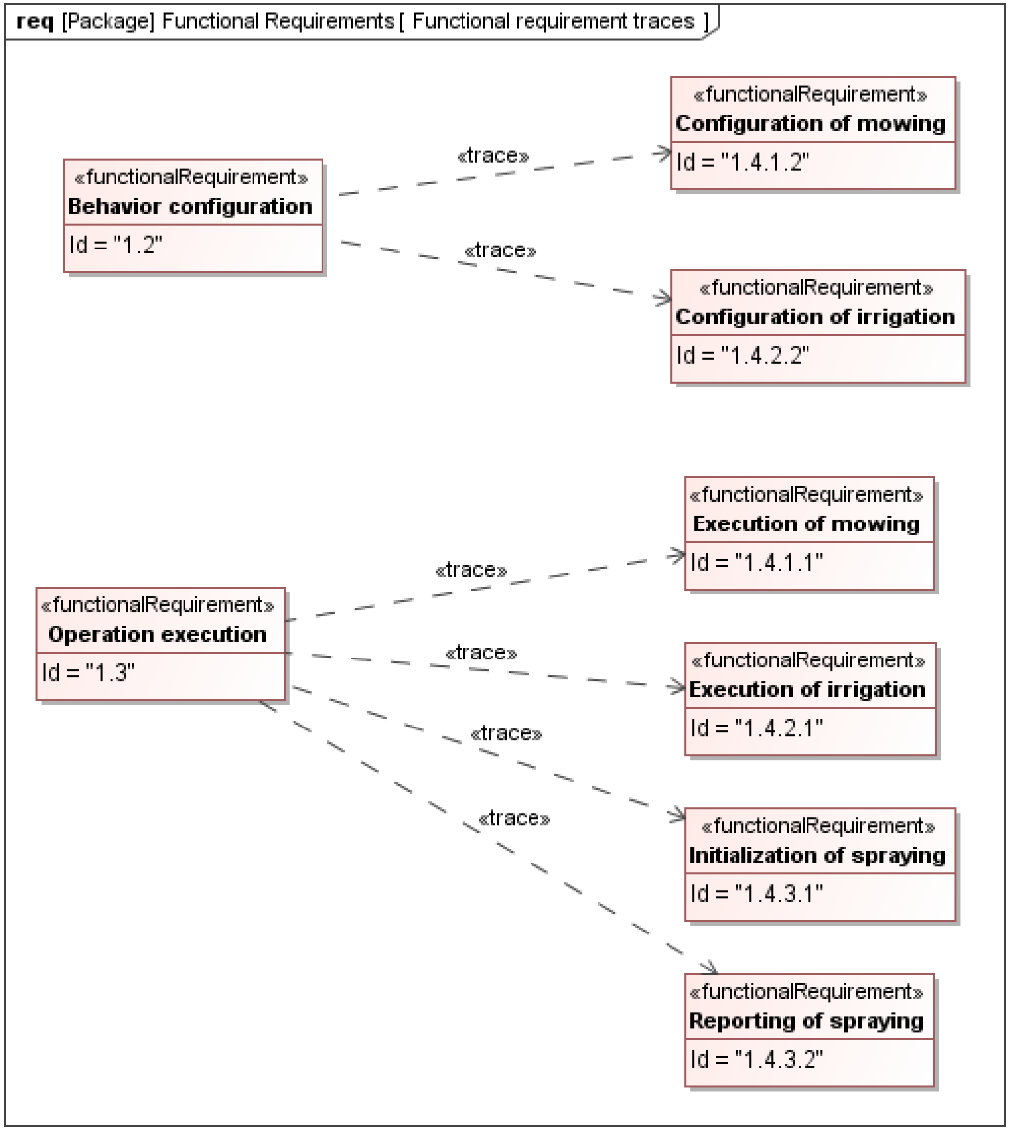
- **Refine**
  - Depicts a model element that clarifies a requirement
  - Typically a use case or a behavior
- **Satisfy**
  - Depicts a design or implementation model element that satisfies the requirement
- **Verify**
  - Used to depict a test case that is used to verify a requirement
- **Derive**
  - Used when a requirement is derived from another requirement based on analysis
  - Typically at the next level of the system hierarchy
- **Copy**
  - Supports reuse by copying requirements to other namespaces
  - Master-slave relation between requirements
- **Trace**
  - General trace relationship
  - Between requirement and any other model element

Example refine relationship





Example trace relationships



Requirements Relations in Table

#	Id	Name	Text	Traced To
1	1	Performing agricultural tasks		
2	1.1	Environment measurement	The CPAS system shall be capable of measuring the environment through its sensors.	
3	1.1.1	Sensors	The CPAS uses the following sensors: temperature, humidity, luminance, rain (gauge).	
4	1.2	Behavior configuration	The farmer can configure the system, when to activate its operations based on its sensor inputs.	1.4.2.2 Configuration of irrigation 1.4.1.2 Configuration of mowing
5	1.3	Operation execution	The CPAS shall execute operations to change its surrounding environment.	1.4.2.1 Execution of irrigation 1.4.3.1 Initialization of spraying 1.4.3.2 Reporting of spraying 1.4.1.1 Execution of mowing
6	1.3.1	Farmer notification	Whenever a notification arrives the CPAS signals the farmer based on the configured communication mean.	
7	1.3.2	System shutdown	The farmer can shut down the system that immediately stops all of its active operations.	30 Shutdown speed
8	1.4	Supported operations	Supported operations are mowing, irrigation and spraying.	
9	1.4.1	Mowing		
10	1.4.1.1	Execution of mowing	The mowing operation signals the robot lawn-mower to execute its programmed task.	
11	1.4.1....	Successful mowing	If the mower robot executes its task without any problem it returns to its refueling station.	
12	1.4.1....	Failed mowing	If the mower robot fails to complete its task, it sends a notification about its status.	
13	1.4.1.2	Configuration of mowing		
14	1.4.2	Irrigation		
15	1.4.2.1	Execution of irrigation	The irrigation operation simply activates the pre-installed irrigation-system.	
16	1.4.2....	Failed irrigation	If the irrigation-system fails, it sends a notification about its status.	
17	1.4.2.2	Configuration of irrigation		
18	1.4.3	Spraying	The system shall support the control of manual spraying.	
19	1.4.3.1	Initialization of spraying	The spraying operation signals the laborers to execute the spraying task.	

Modeling Textual Requirements

Context of the Modeling Aspect

Sample Requirements (Cyber-physical Agricultural System)

Modeling Elements & Notation

Summary

Summary

- Goal
  - Bridge the gap between textual requirements and requirement and design models
    - Handles textual req.s as model elements
    - Provides support for requirements traceability
- Modeling aspect
  - *What are the main requirements formulated textually and what are their hierarchy?*
- Relation of requirements to other aspects
  - Refined by model elements (e.g. use case, activity)
  - Satisfied by blocks
  - Verified by test cases

Modeling Requirements with Use Cases

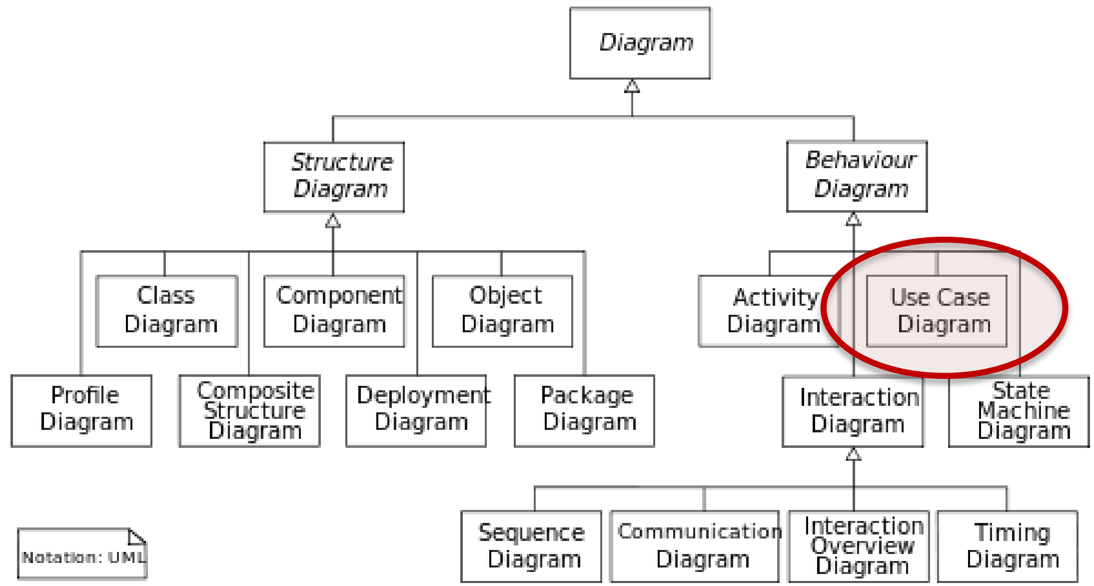
Context of the Modeling Aspect

Elements of Use Case Diagrams by Example

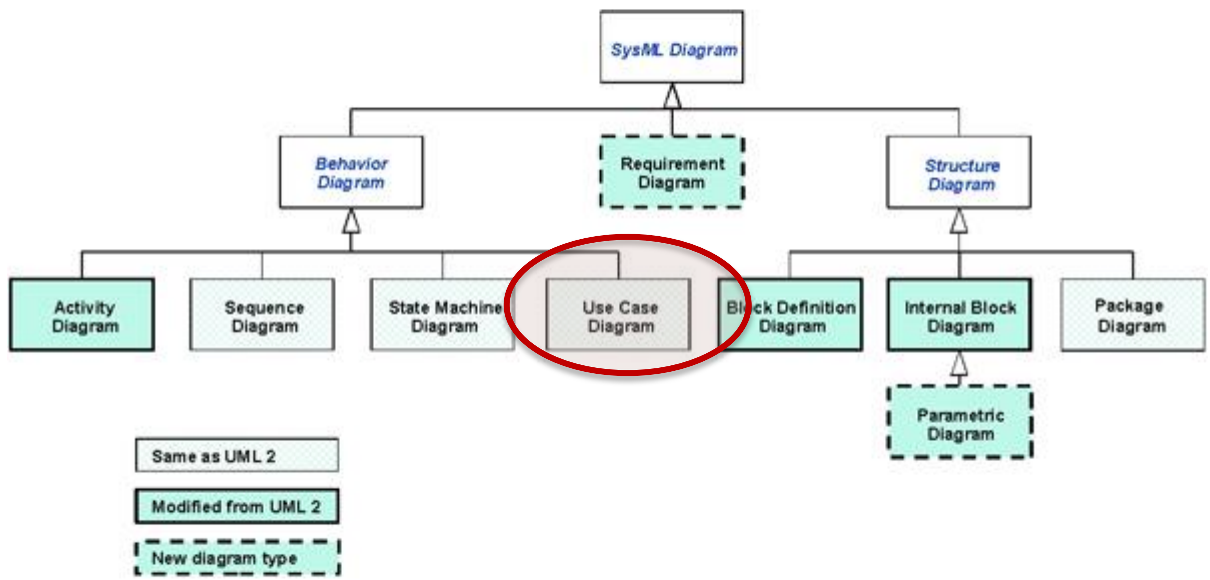
Relations between UC elements

Summary

Use Case Diagrams

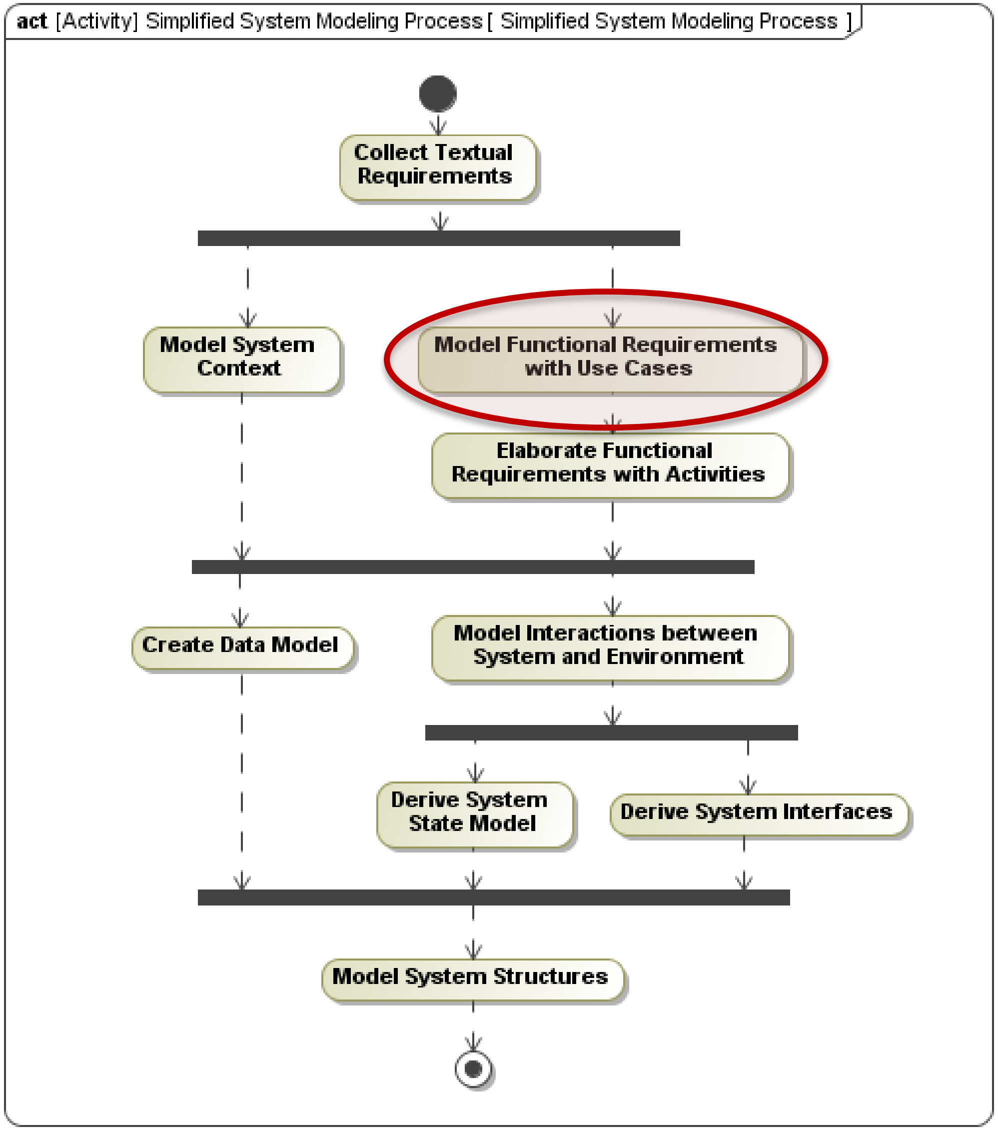


UNIFIED MODELING LANGUAGE



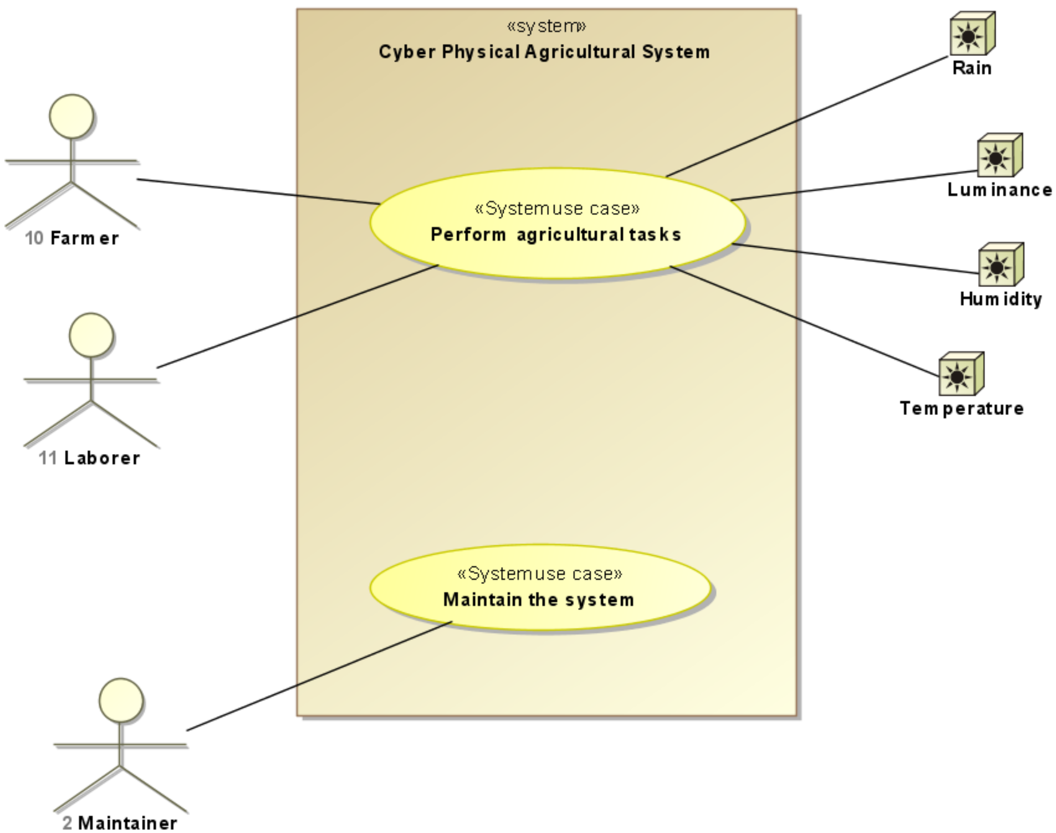
OMG SYSTEMS MODELING LANGUAGE

System Modeling Process



Modeling Aspect

Who will use the system and for what?



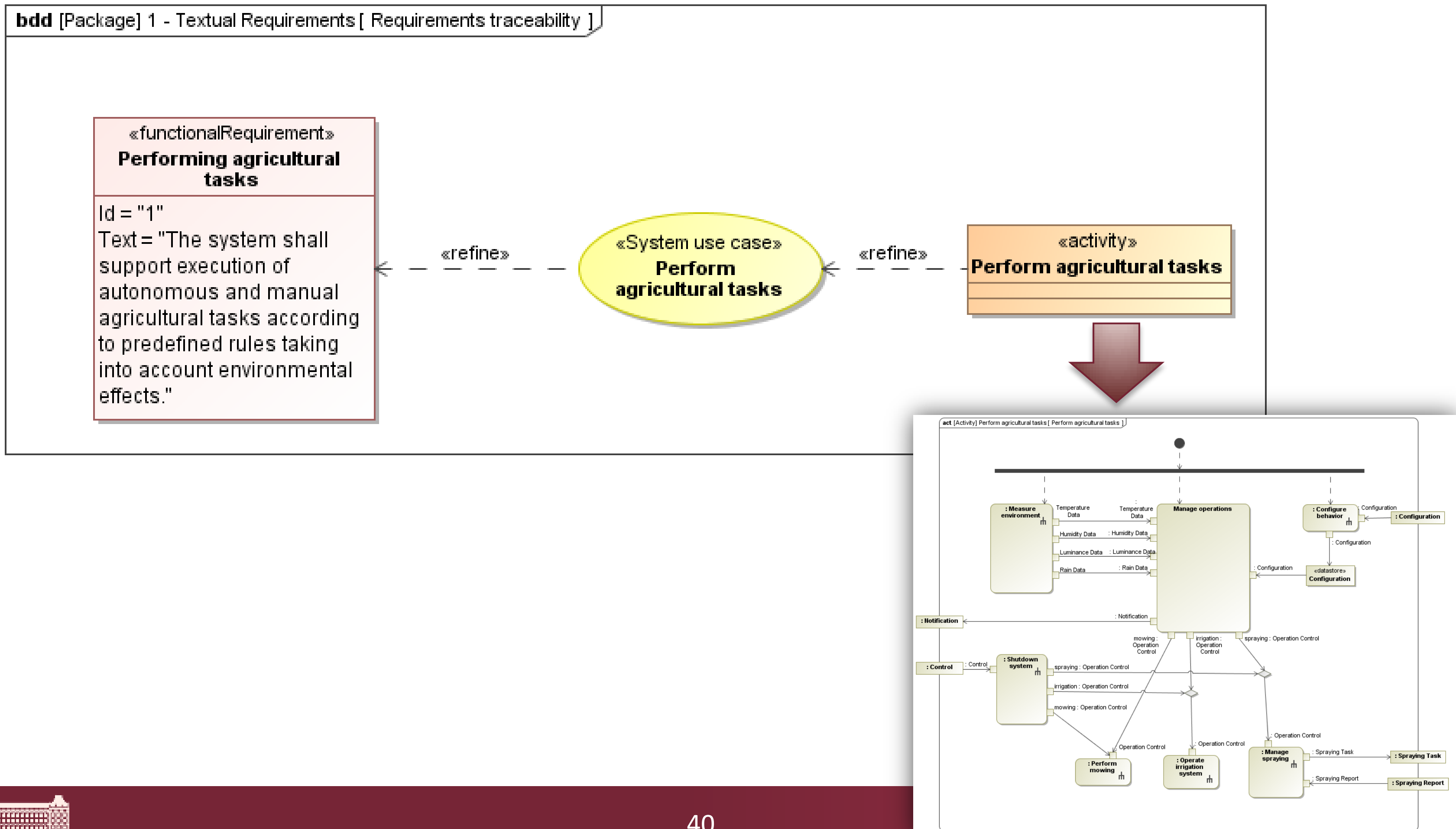
Definition of Use Cases

- **Use cases (használati eset)** capture the functional requirements of a system
- UCs describe
  - the typical interactions
  - between the *users* of a *system* and
  - **the system itself,**
  - by providing a narrative of how a system is used
- A set of scenarios tied together by a common user goal
- Its definition comes from
  - Either directly from the written requirement
    → **Verb + Noun (Unique)!**
  - Based on the Requirement diagram + System context definition
    → **refinement**

M. Fowler: UML Distilled.
3rd Edition. Addison-Wesley

Relations to other aspects

- Refines textual requirements
- Can be further refined by behaviors (e.g. activity)



Modeling Requirements with Use Cases

Context of the Modeling Aspect

Elements of Use Case Diagrams by Example

Relations between UC elements

Summary

Example requirements

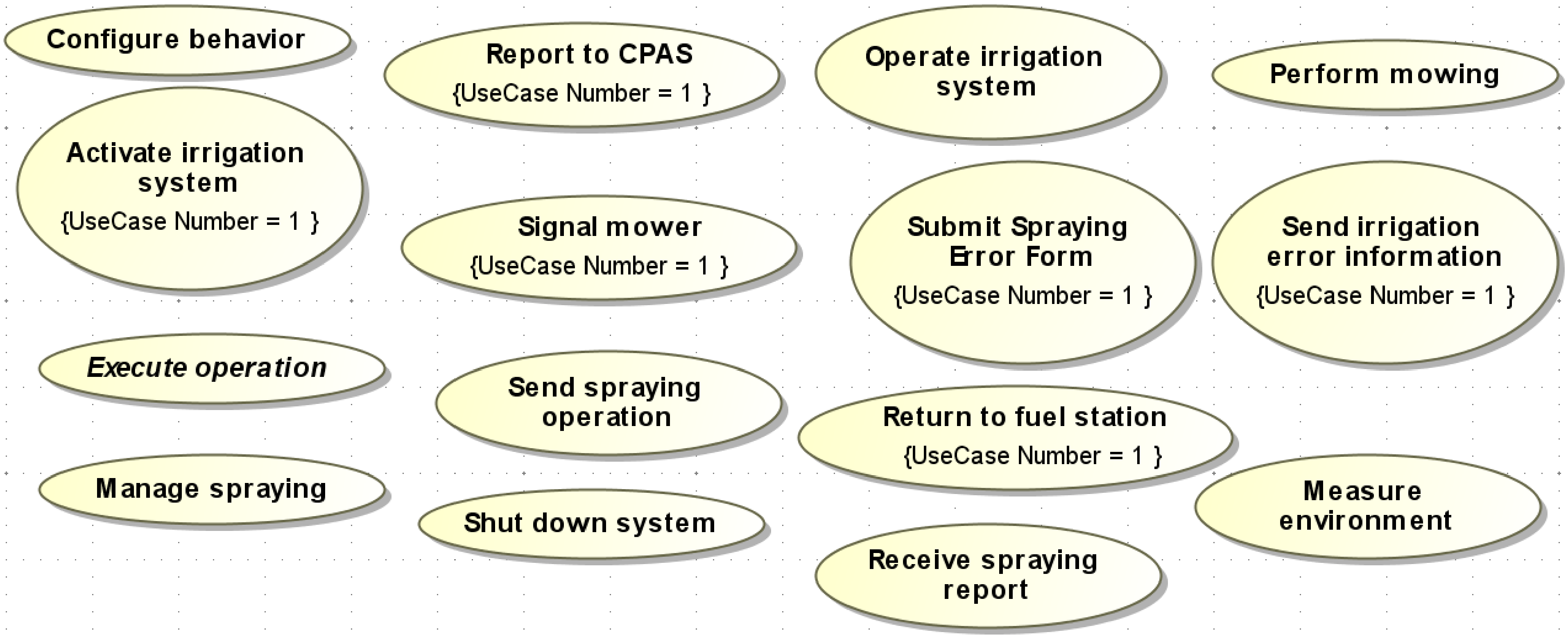
- Design a simple Cyber-physical agricultural system (CPAS), which helps a farmer with his/her everyday life using sensors to measure the environment and react to its changes by using automated operations like irrigation, mowing and spraying.

- Requirements
  - The CPAS system is capable of measuring the environment through its sensors.
  - The CPAS uses the following sensors: temperature, humidity, luminance, rain.
  - The CPAS can execute operations to change its surrounding environment.
  - These operations can be mowing, irrigation and spraying.
  - The mowing operation signals the robot mower to execute its programmed task.
  - If the mower robot executes its task without any problem it returns to its refueling station.
  - If the mower robot fails to complete its task, it sends a notification about its status

Example requirements (con't)

- Requirements
  - The irrigation operation simply activates the pre-installed irrigation-system.
  - If the irrigation-system fails, it sends a notification about its status.
  - Whenever a notification arrives the CPAS signals the farmer based on the configured communication mean.
  - The spraying operation signals the laborers to execute the spraying task.
  - The laborers report to the CPAS when they finished their task.
  - In case an error occurs during the spraying the laborers submit a form to the CPAS and it notifies the farmer.
  - The farmer can configure the system, when to activate its operations based on its sensor inputs.
  - The farmer can shut down the CPAS system that immediately stops all of its active operations.
  - The system shall provide diagnostic information about its components for maintenance.

Initial set of Activities

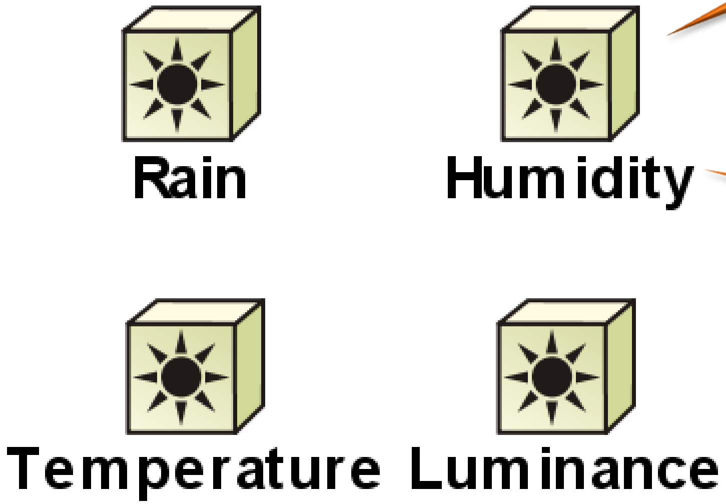


Definition of Actors

- **Actor (aktor)** is a **role** that a user plays with respect to the system.
  - *Primary actor*: calls the system to deliver a service
  - *Secondary actor*: the system communicates with them while carrying out the service
- Relationship of UCs and Actors
  - A single actor may perform many use cases;
  - A use case may have several actors performing it.
- One person may act as more than one actor,
  - Example: The farmer may also act as a laborer who performs the spraying
- An actor is outside the boundary of the system
- Its definition comes from
  - Directly from the written requirements
  - Based on the System context definition

(Initial) Collection of Primary Actors

(Initial) Collection of Secondary Actors



Customized representation

Could use the UML actor visualization instead!

Modeling Requirements with Use Cases

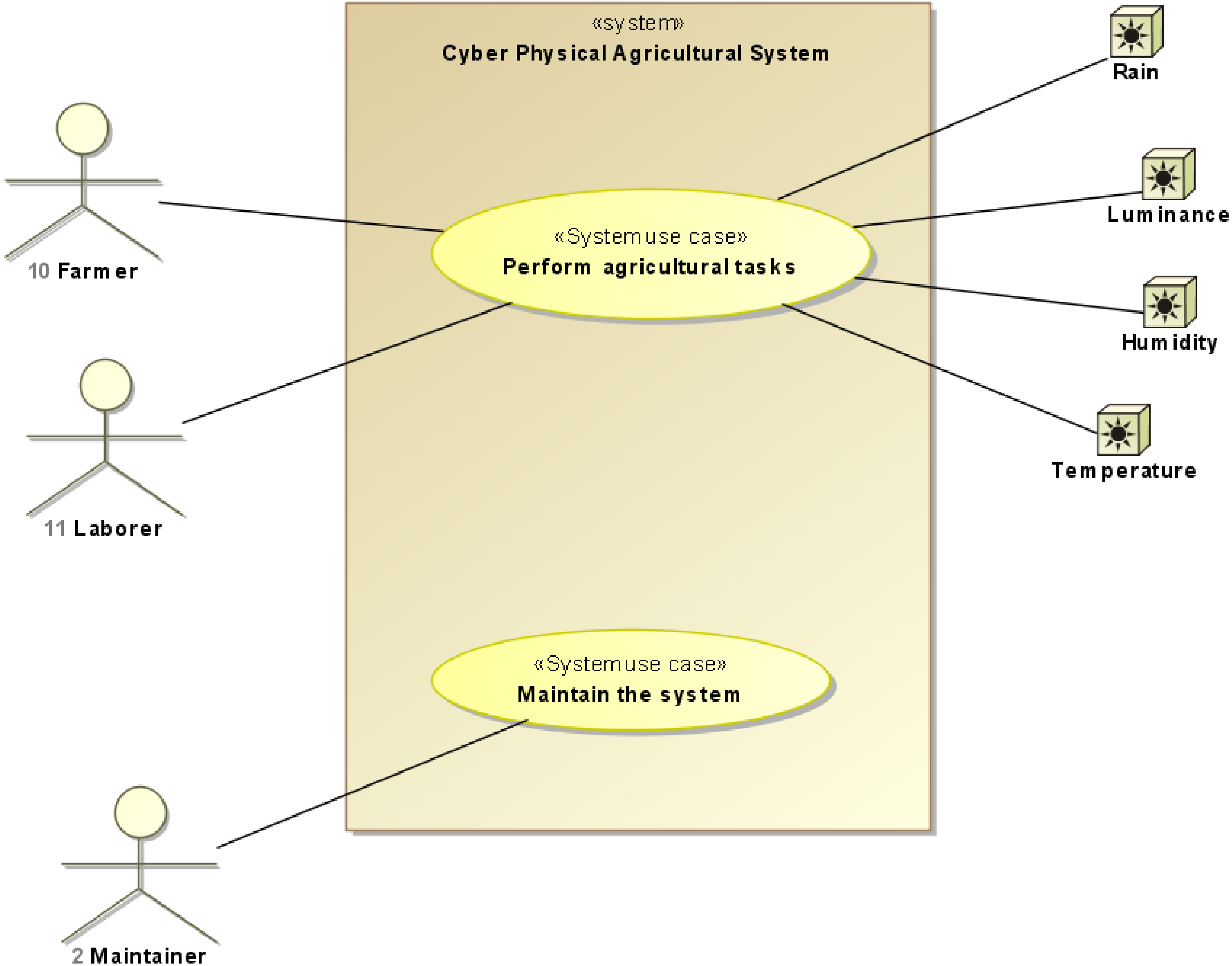
Context of the Modeling Aspect

Elements of Use Case Diagrams by Example

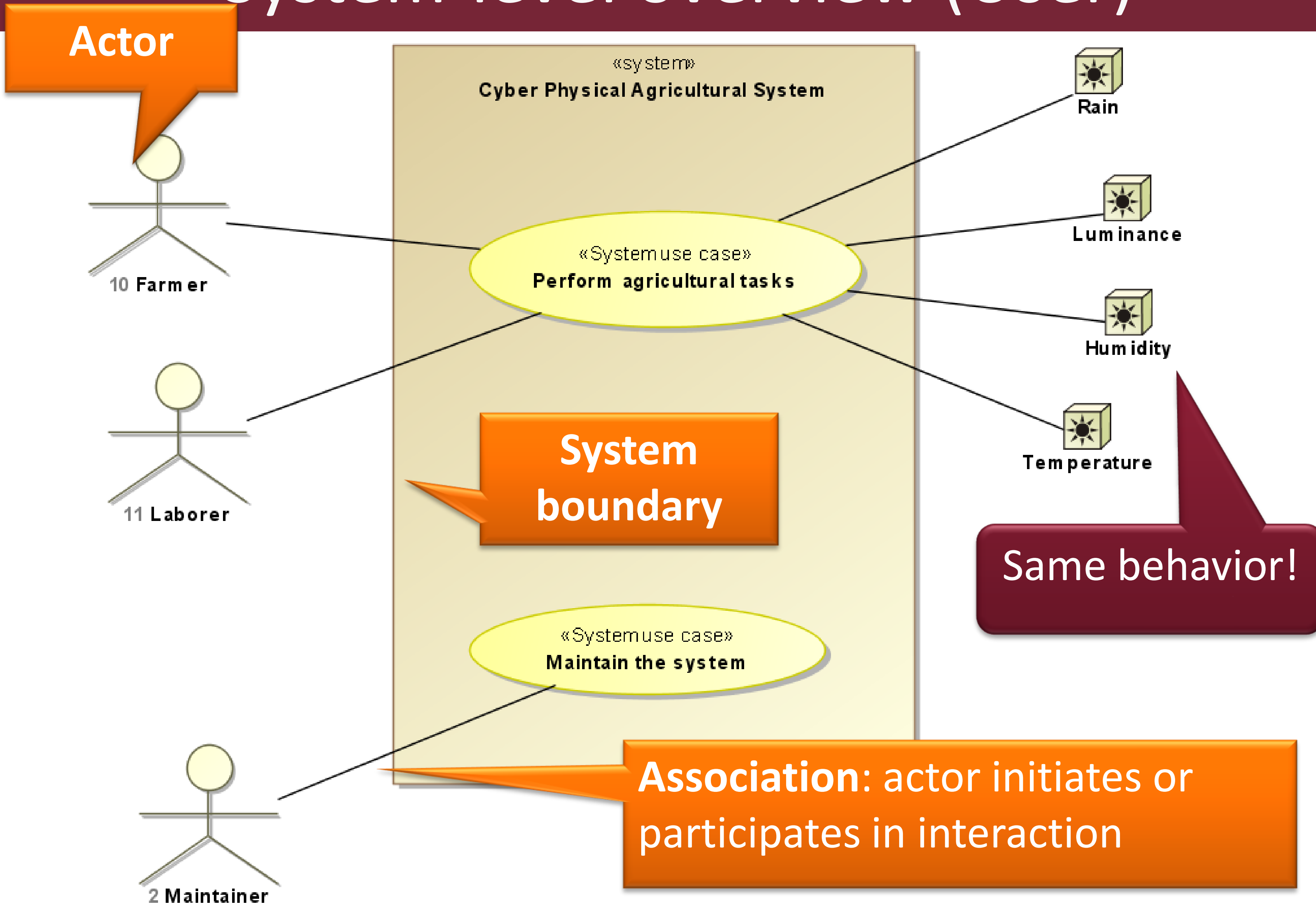
Relations between UC elements

Summary

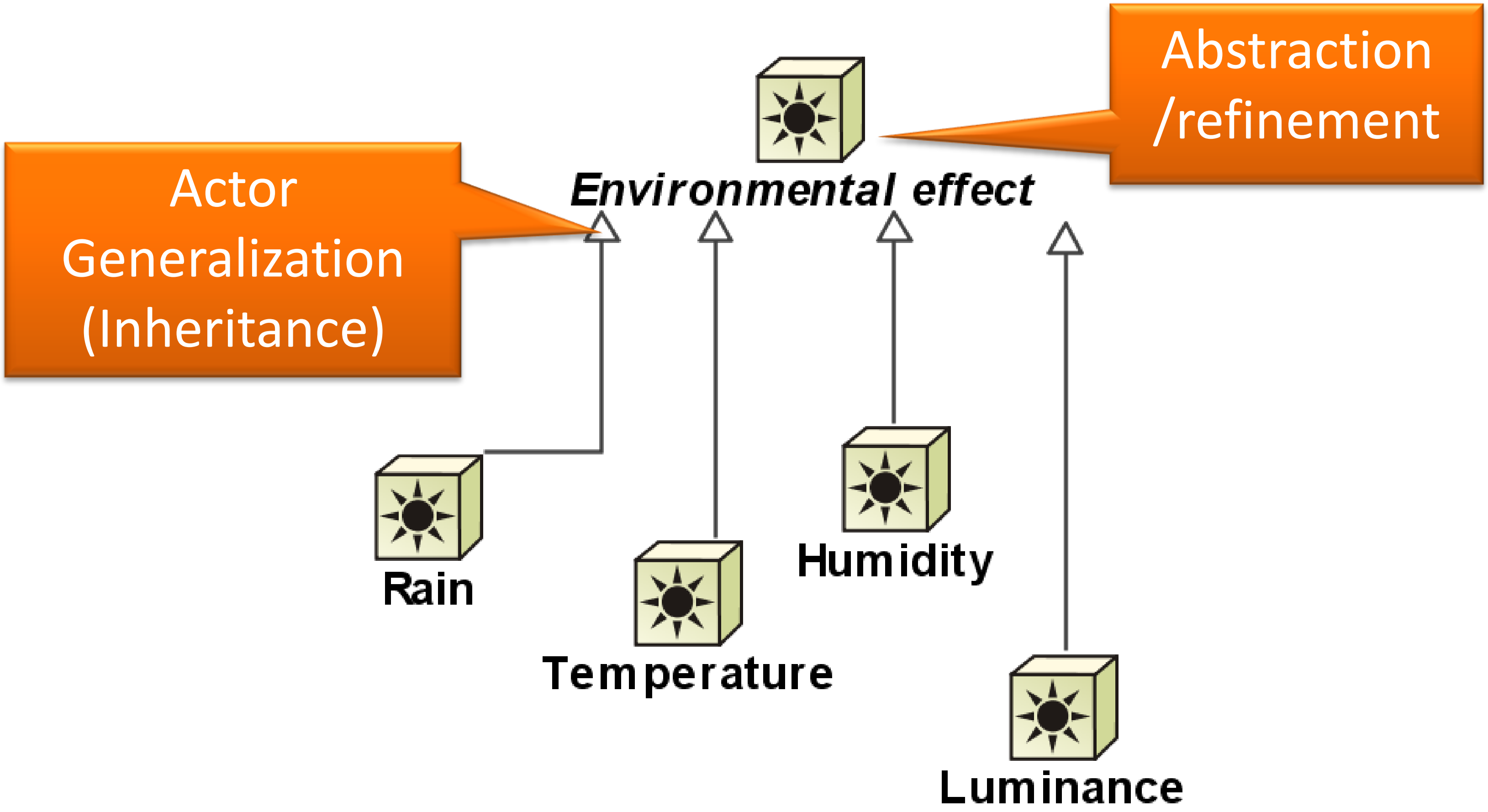
System-level overview (User)



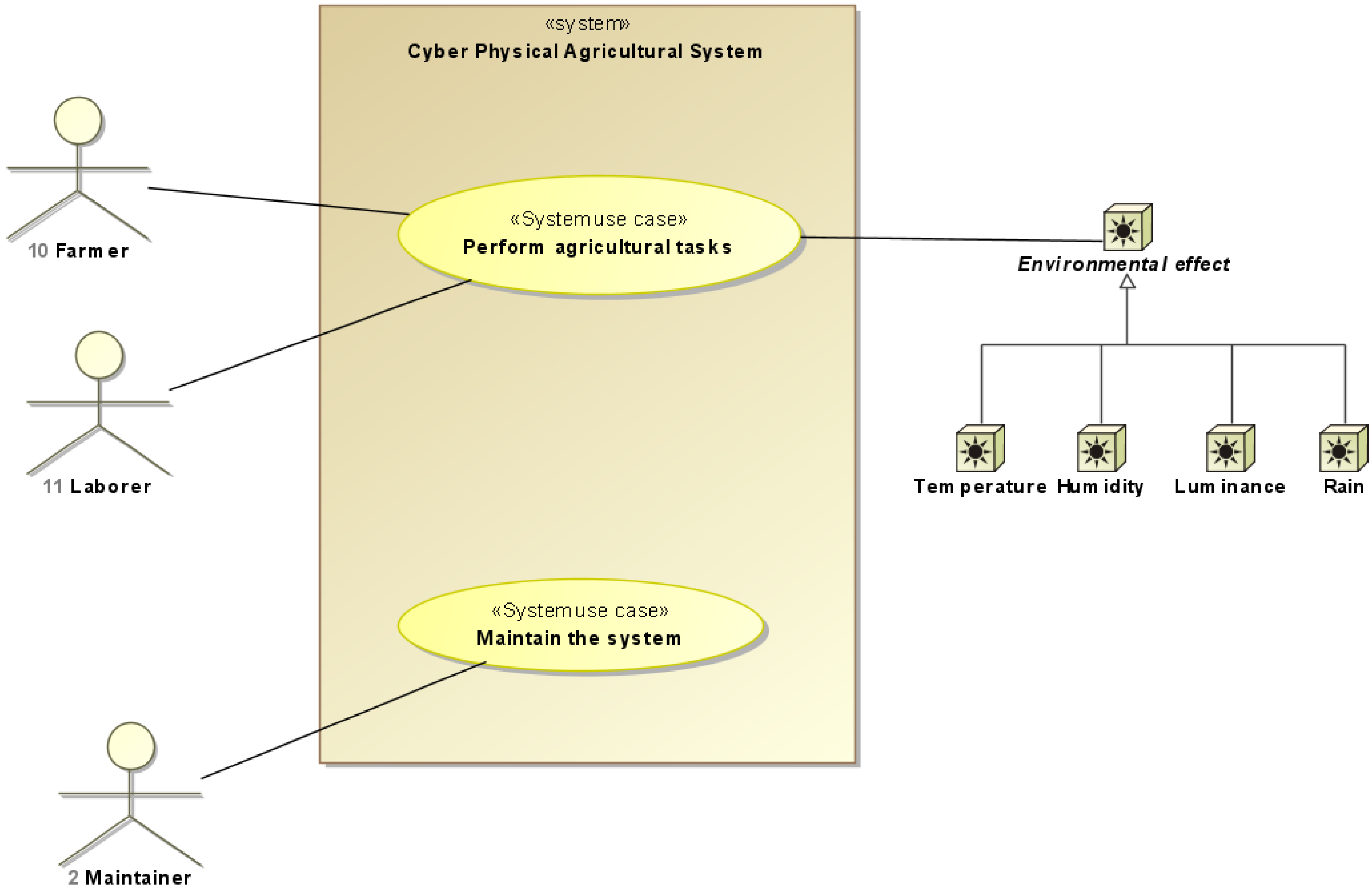
System-level overview (User)



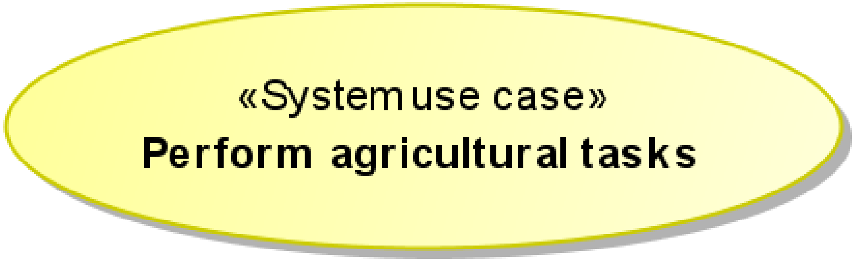
Generalization of Actors (abstraction)



System-level overview (User)



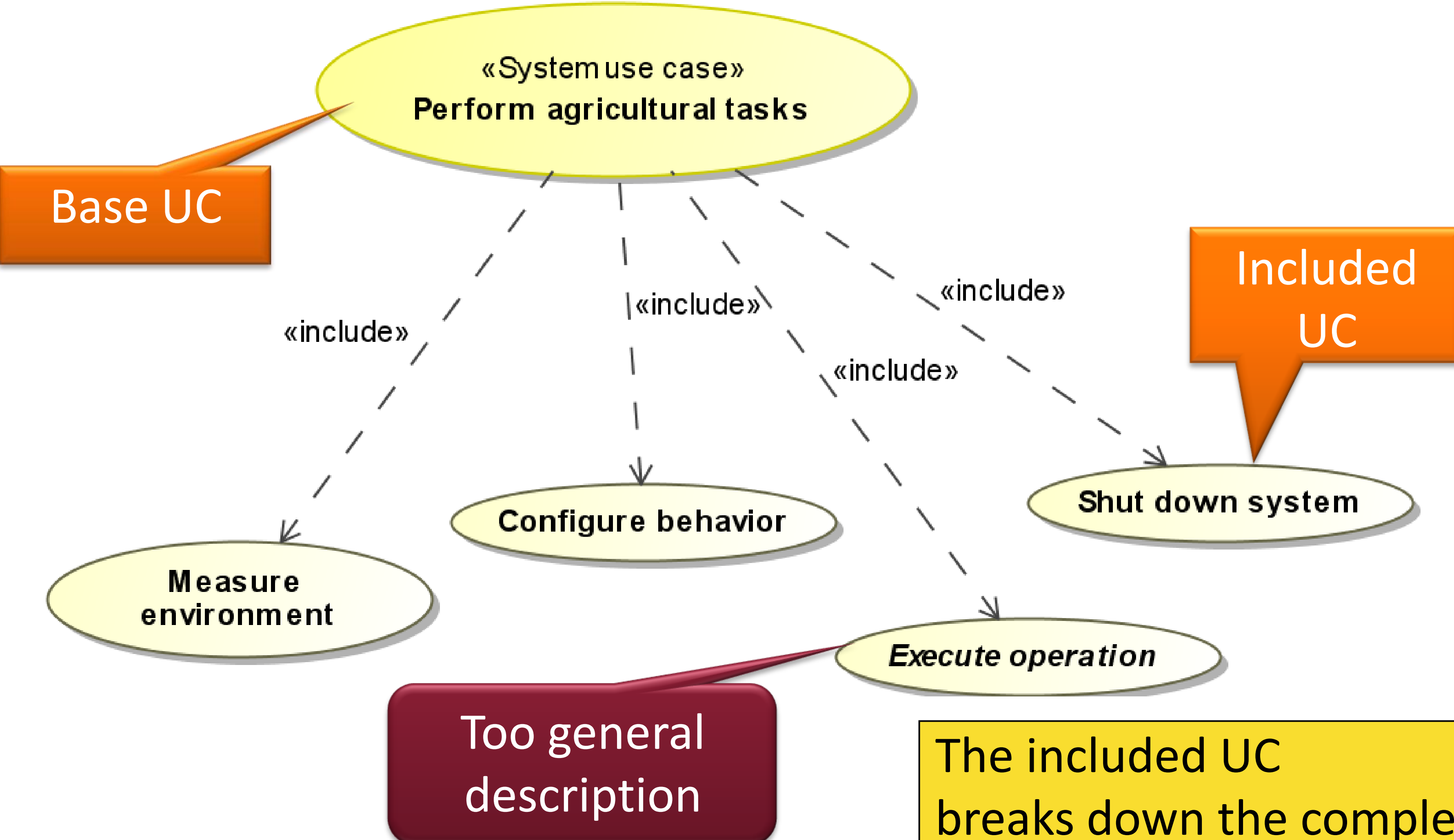
How to handle complex functionality?



Perform agr. tasks =

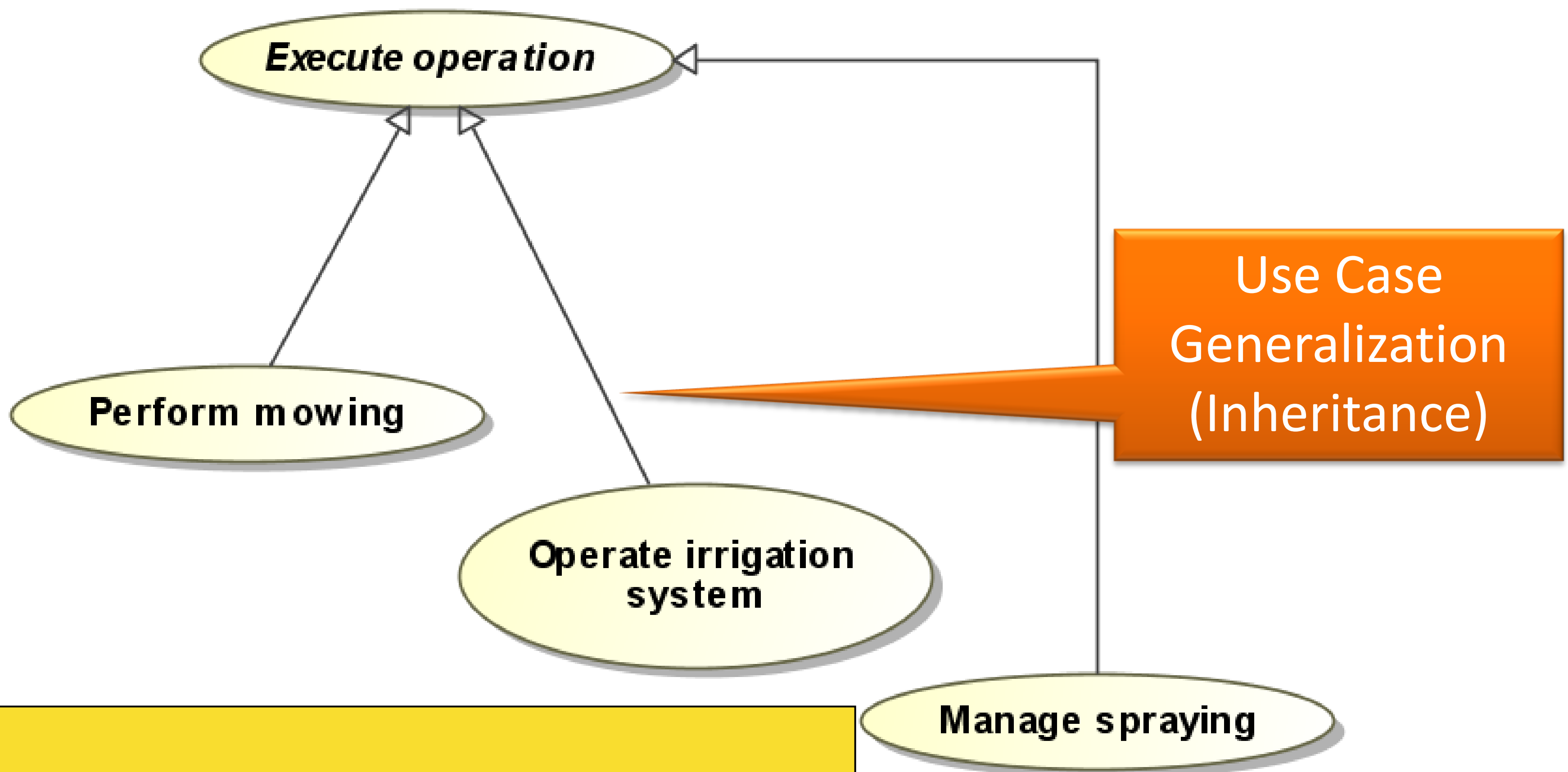
- Measure the environment
- Configure the system
- Execute agr. operations
- Shut down the system

Refinement with include relation



The included UC breaks down the complex core functionality into more elementary steps

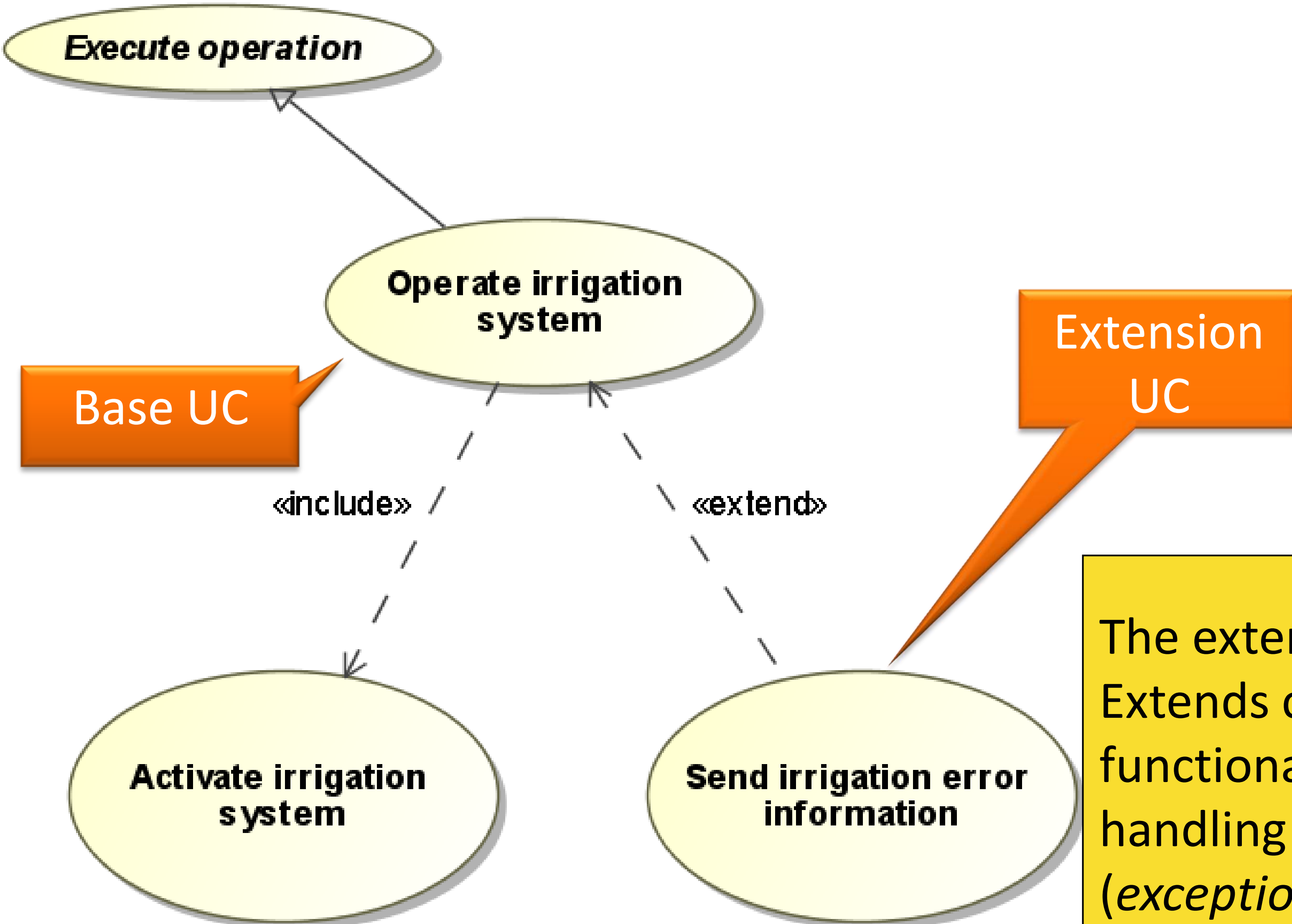
Generalization of UCs



What happens if

- the irrigation operation fails?

Extend relationship



The extension UC Extends core functionality by handling unusual (*exceptional*) situation

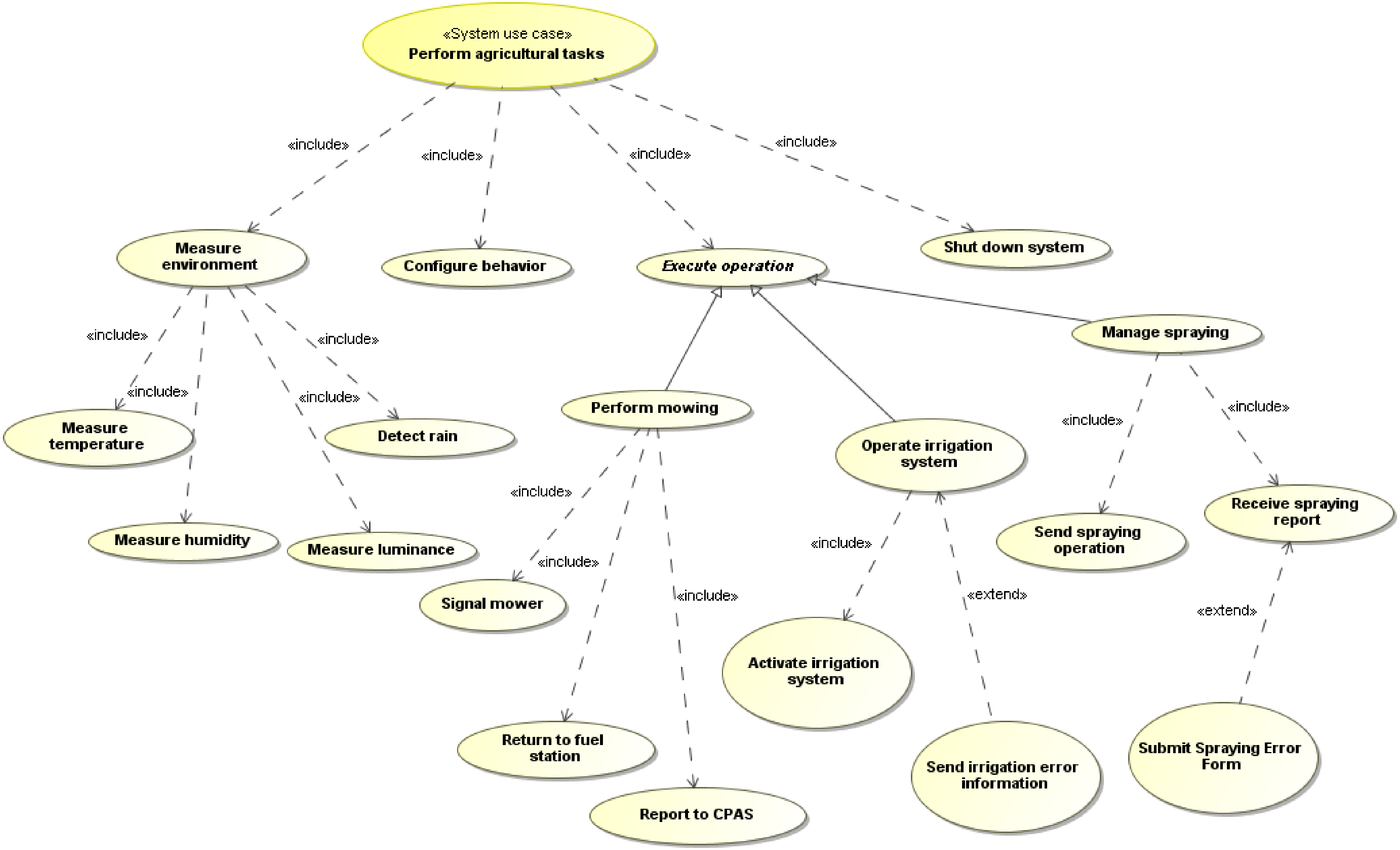
Summary: UC Relations

- **Association**
  - actor – use case
  - the actor initiates (or participates in) the use of the system
- **Extend**
  - use case – use case
  - a UC may be extended by another UC (typically solutions for exceptional situations)

Summary: UC Relations

- **Generalization**
  - actor – actor
  - use case – use case
  - a UC or actor is more general / specific than another UC or actor
- **Include**
  - use case – use case
  - a complex step is divided into elementary steps
  - a functionality is used in multiple UCs

Example: Complete 'Perform agr. task' UC refinement



Modeling Requirements with Use Cases

Context of the Modeling Aspect

Elements of Use Case Diagrams by Example

Relations between UC elements

Summary

Summary

- Goal
  - Identify top level functional requirements
  - Identify involved actors
- Modeling Aspect
  - *Who will use the system and for what?*
- Relations to other aspects
  - Refines textual requirements
  - Can be refined by other behaviors (e.g. activity)

Modeling Flow Based Behavior with Activities

<u>Context of the Modeling Aspect</u>

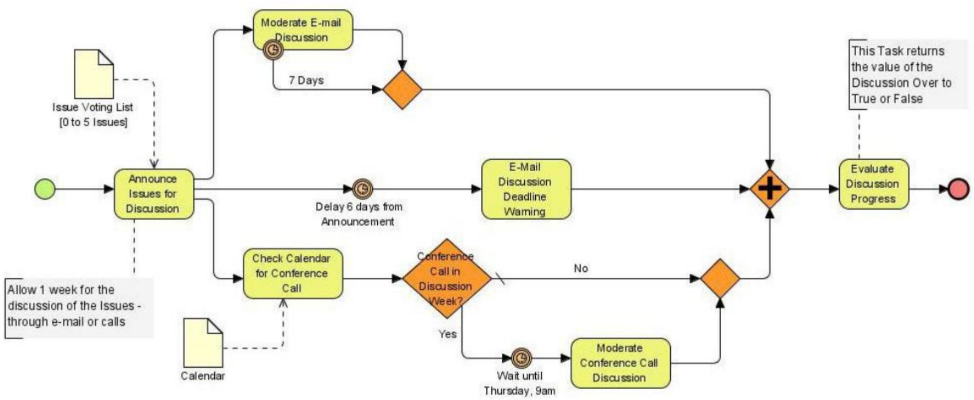
Modeling Elements & Notation

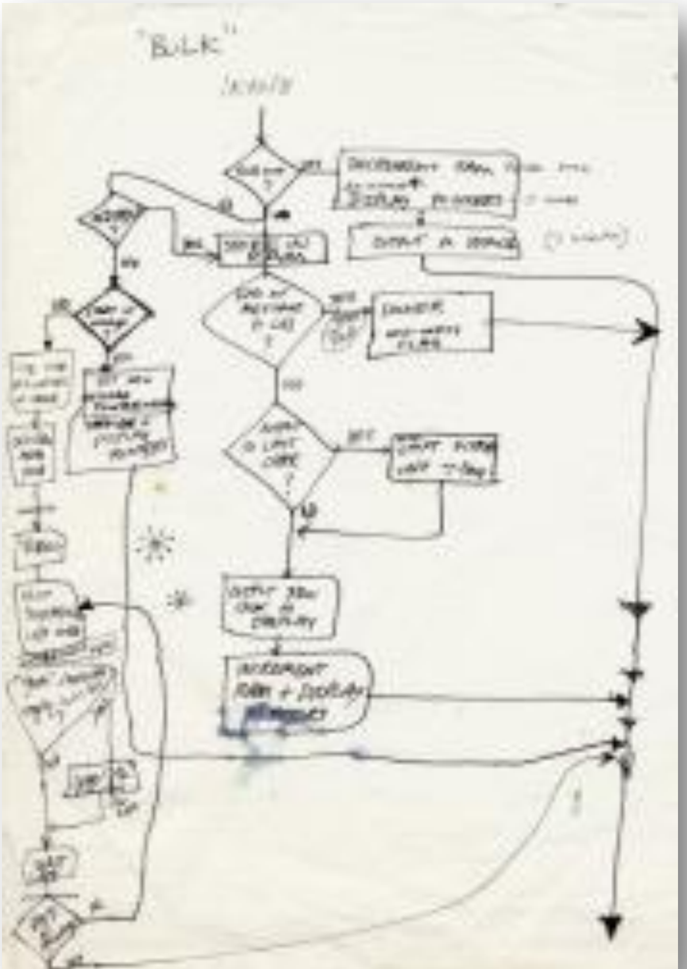
Semantics of the Model

Summary

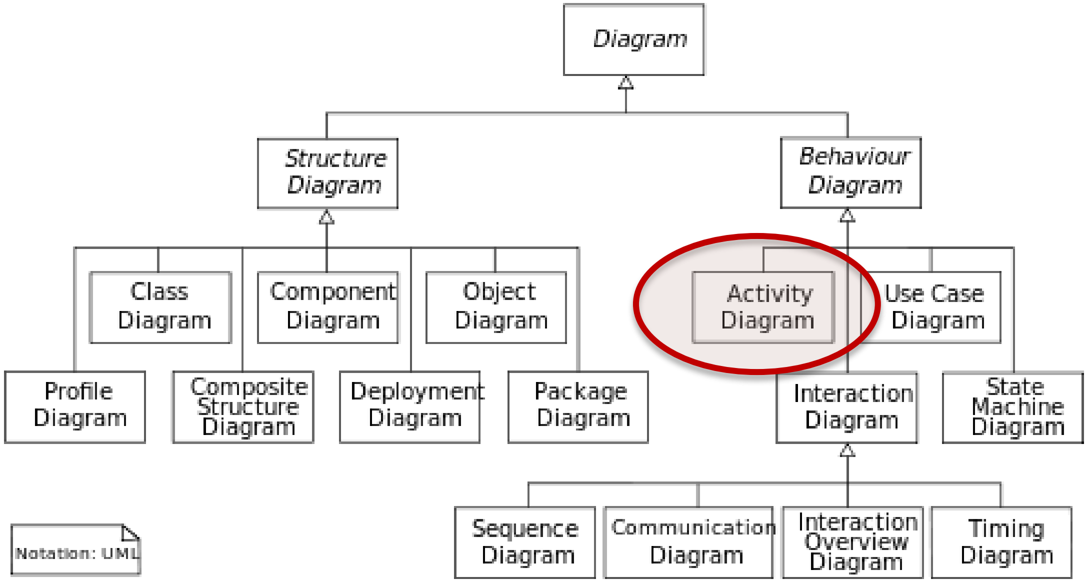
Roots & Relations

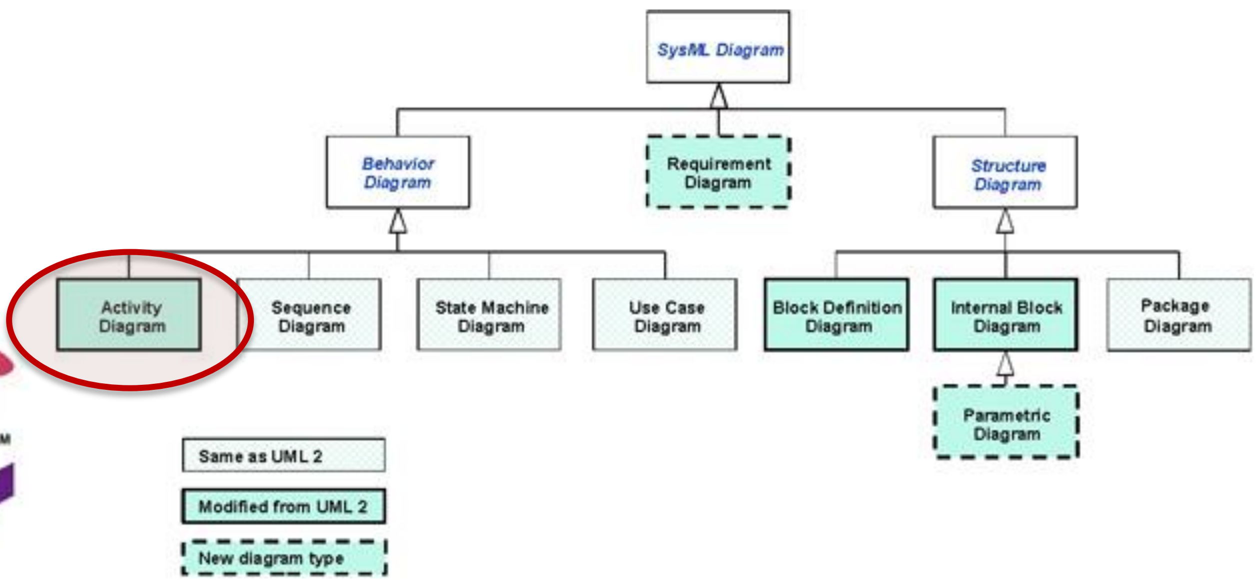
- Flow-sheets and flow-charts are used everywhere...
  - Brainstorming
  - Computer algorithms
  - Business processes



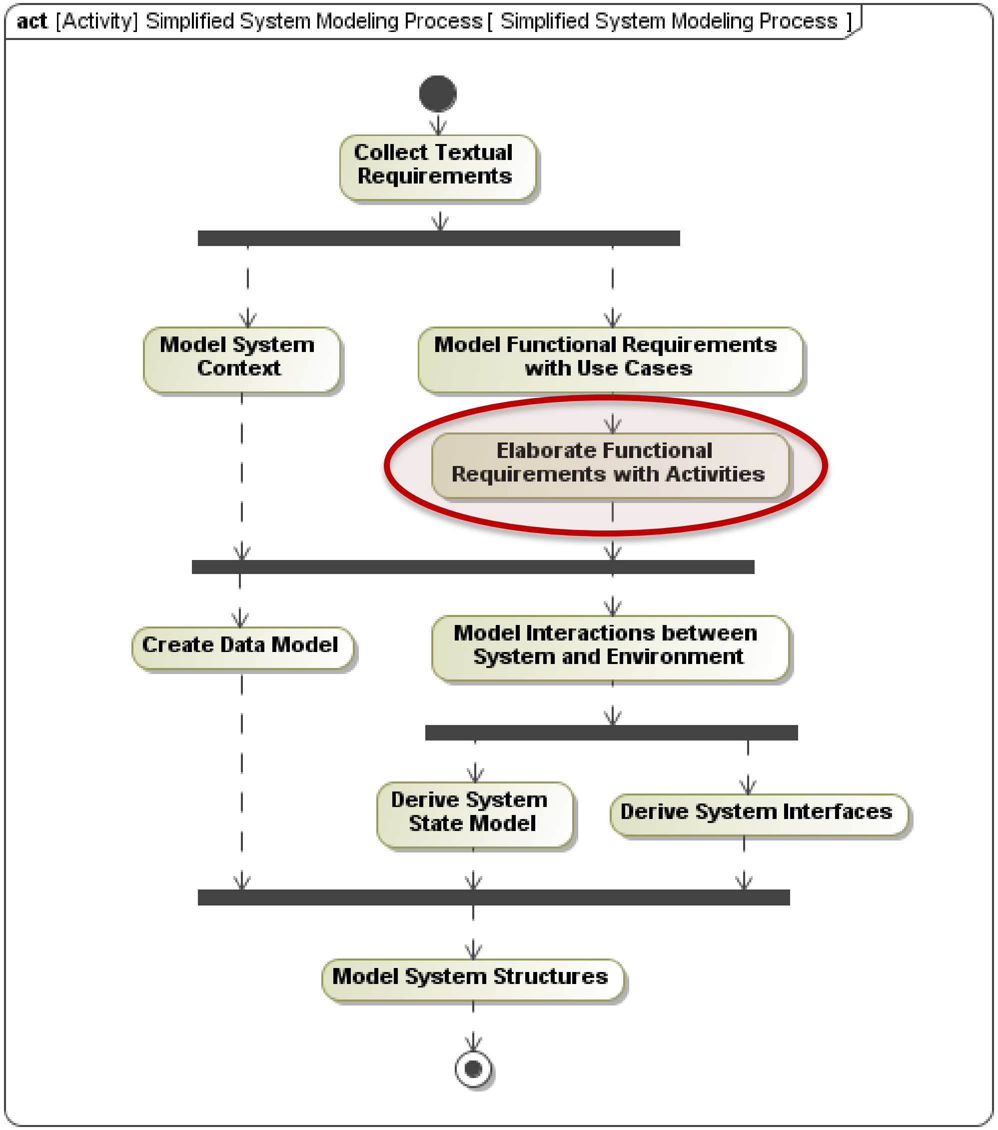


Activity Diagram





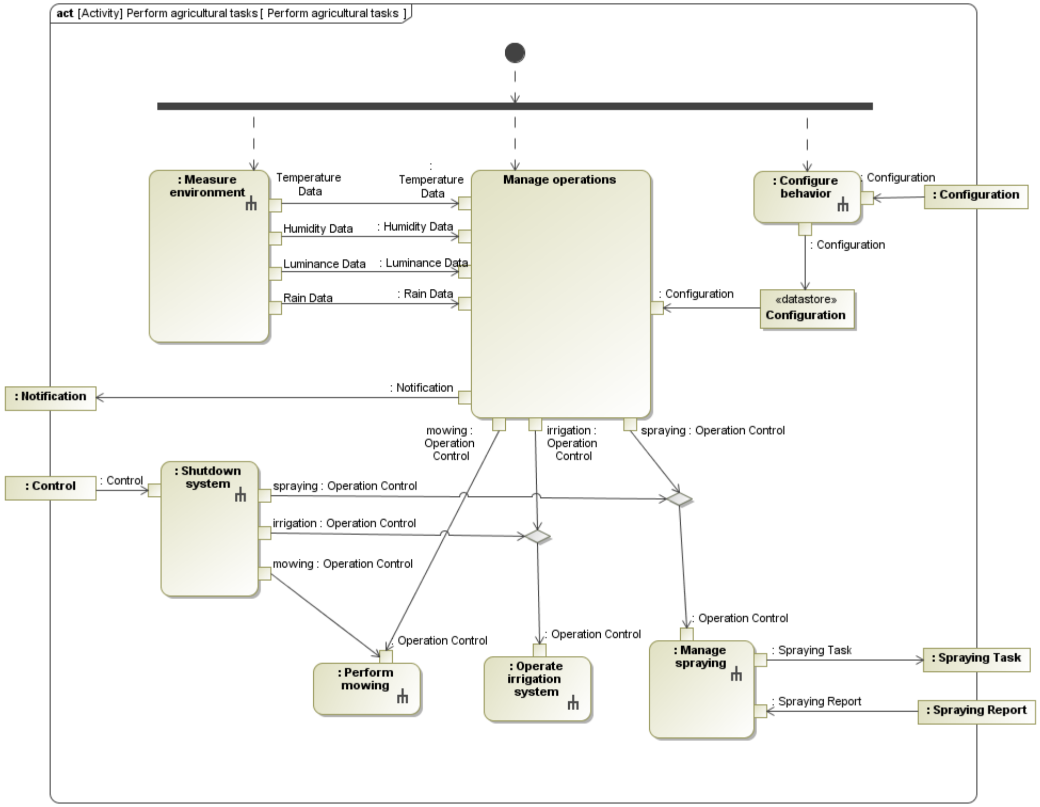
System Modeling Process



Modeling Aspect

What are the steps in a process?

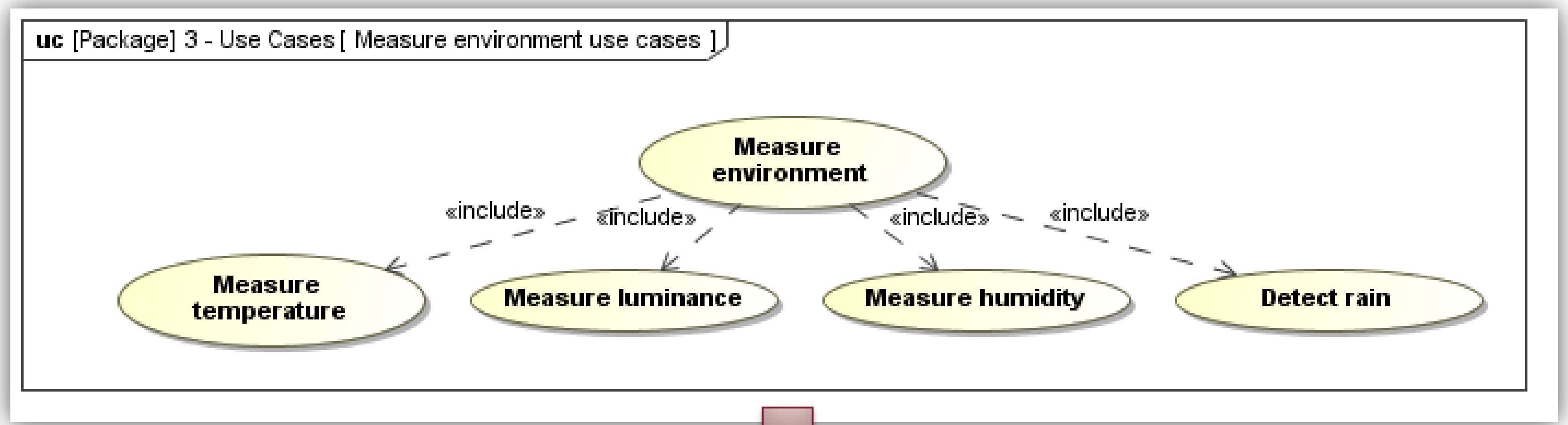
What data flows in the process?

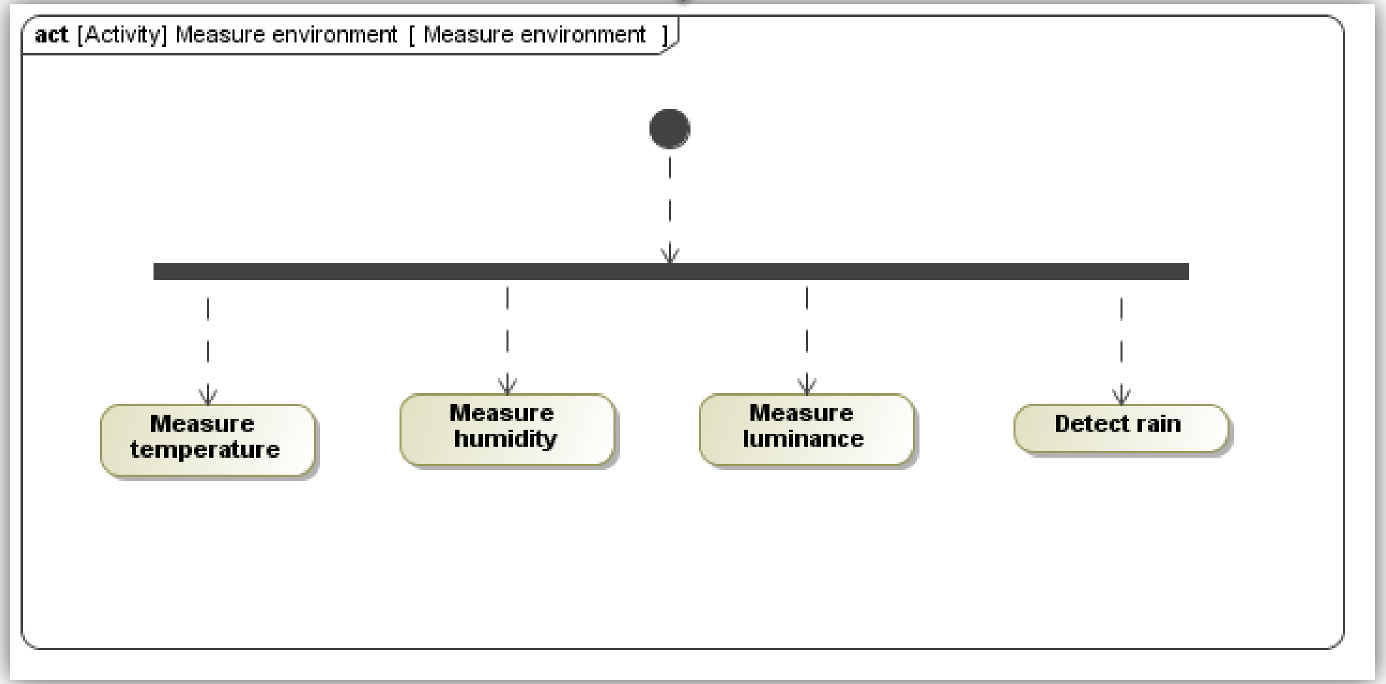


Objectives

- Modeling behavior that specifies the *transformation of inputs to outputs* through a sequence of actions
- Combined modeling of *control flow* and *data flow* in a process or workflow
- Supporting the definition of *high level processes*
  - Elaboration of use cases, i.e. helps to define functional requirements that system components or actors will perform
  - Providing *functional decomposition* of the system
- Supporting the definition of *low level activities*
  - Elaboration of behavior executed at given ‘points’ of the system (e.g. reaction to an event)

Elaborates use cases





Modeling Flow Based Behavior with Activities

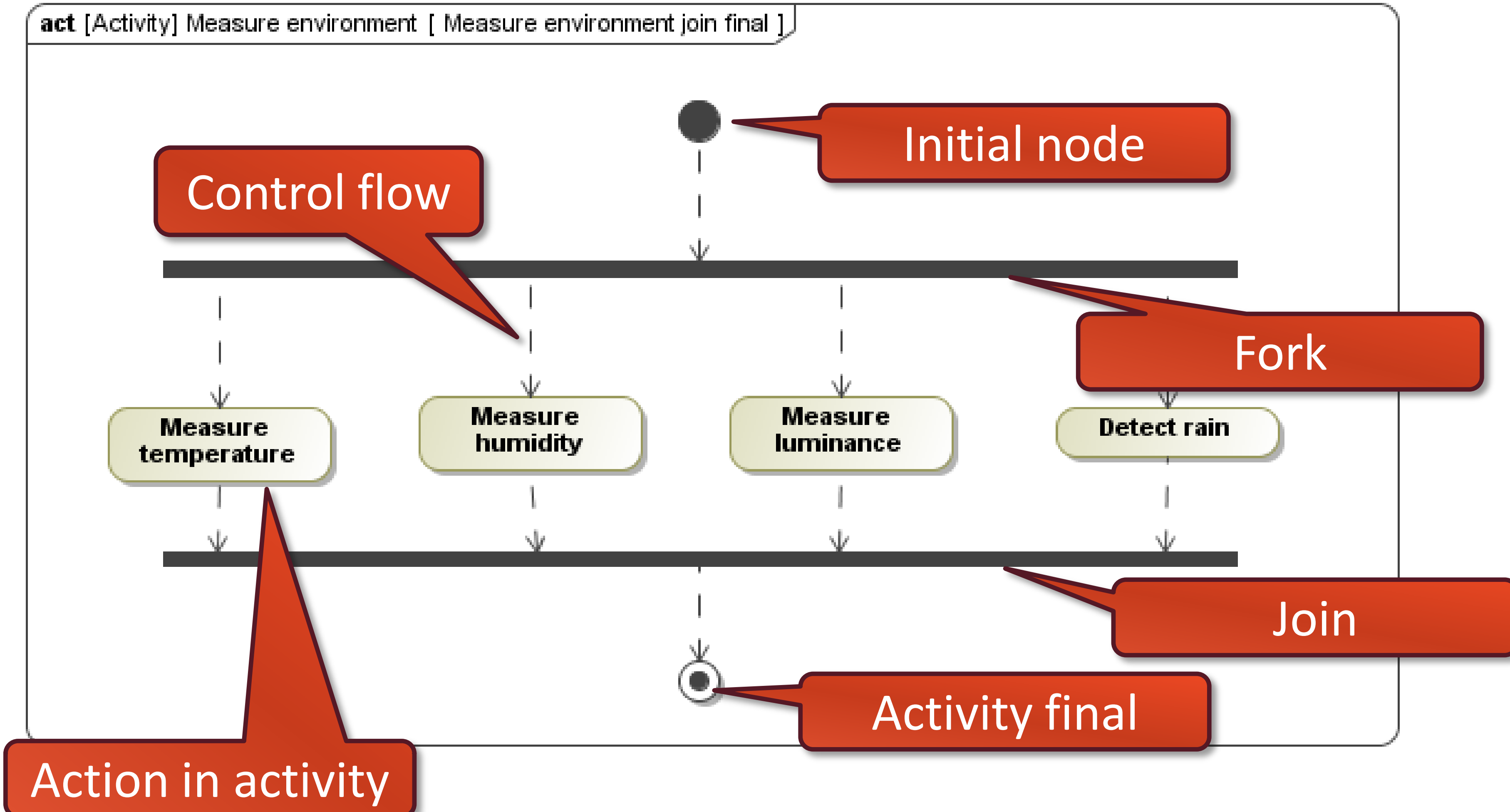
Context of the Modeling Aspect

Modeling Elements & Notation

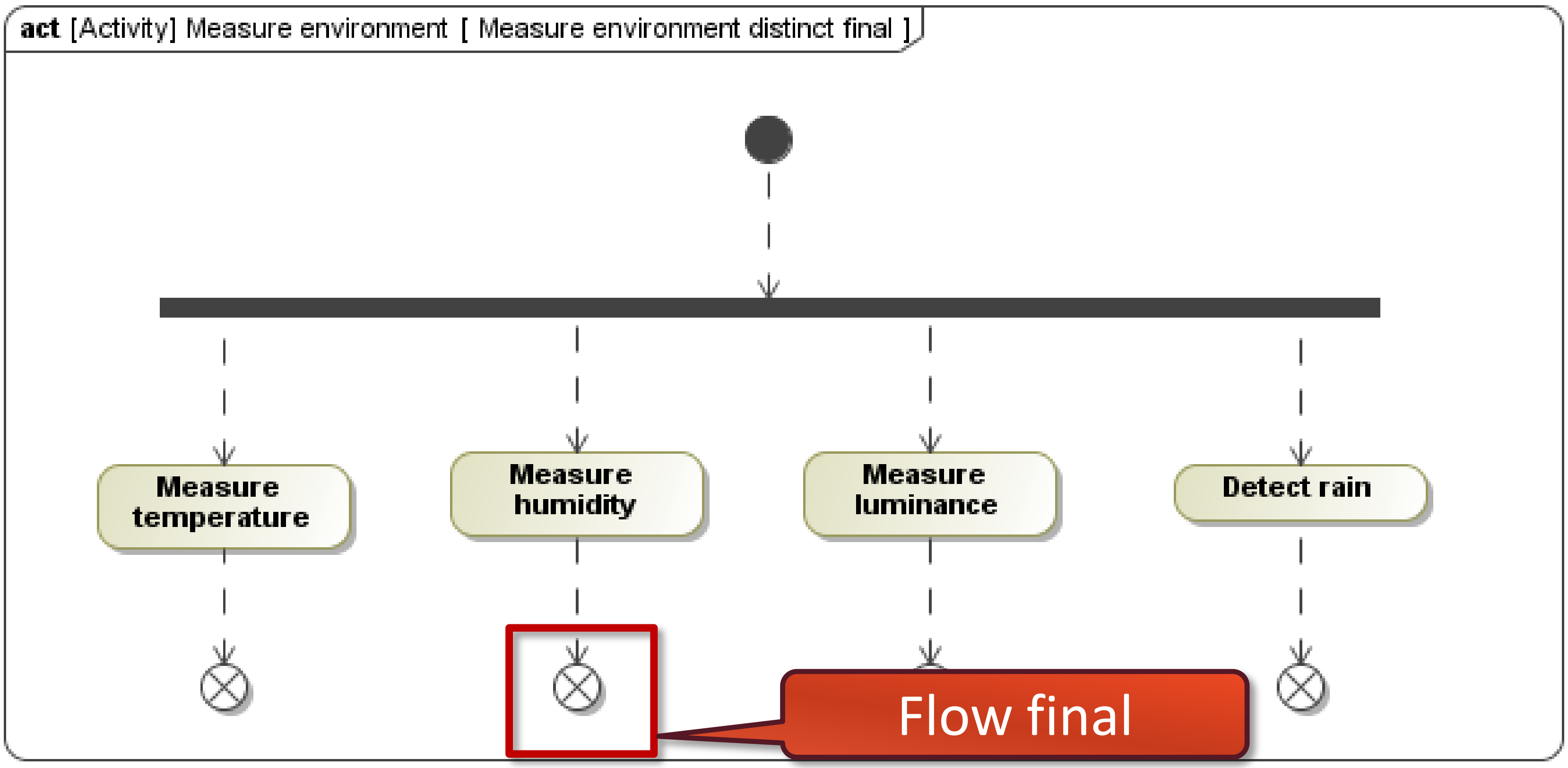
Semantics of the Model

Summary

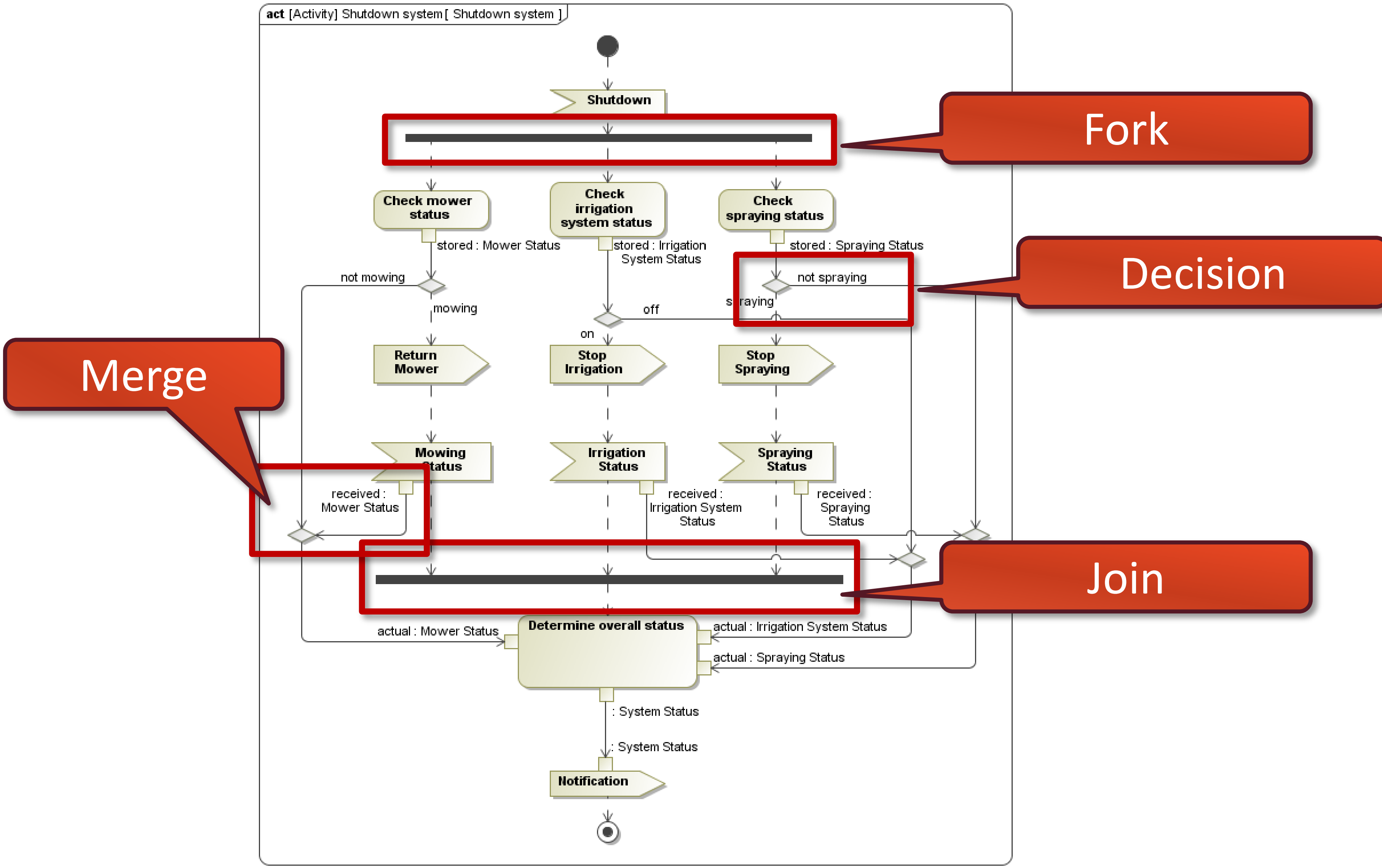
Control flow



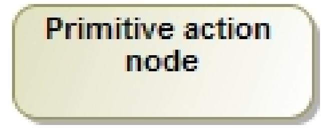
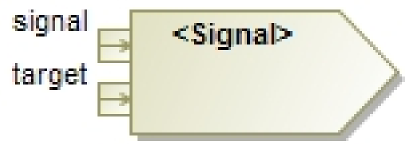
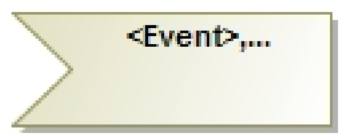
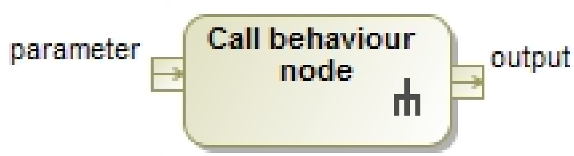
Control flow with flow final



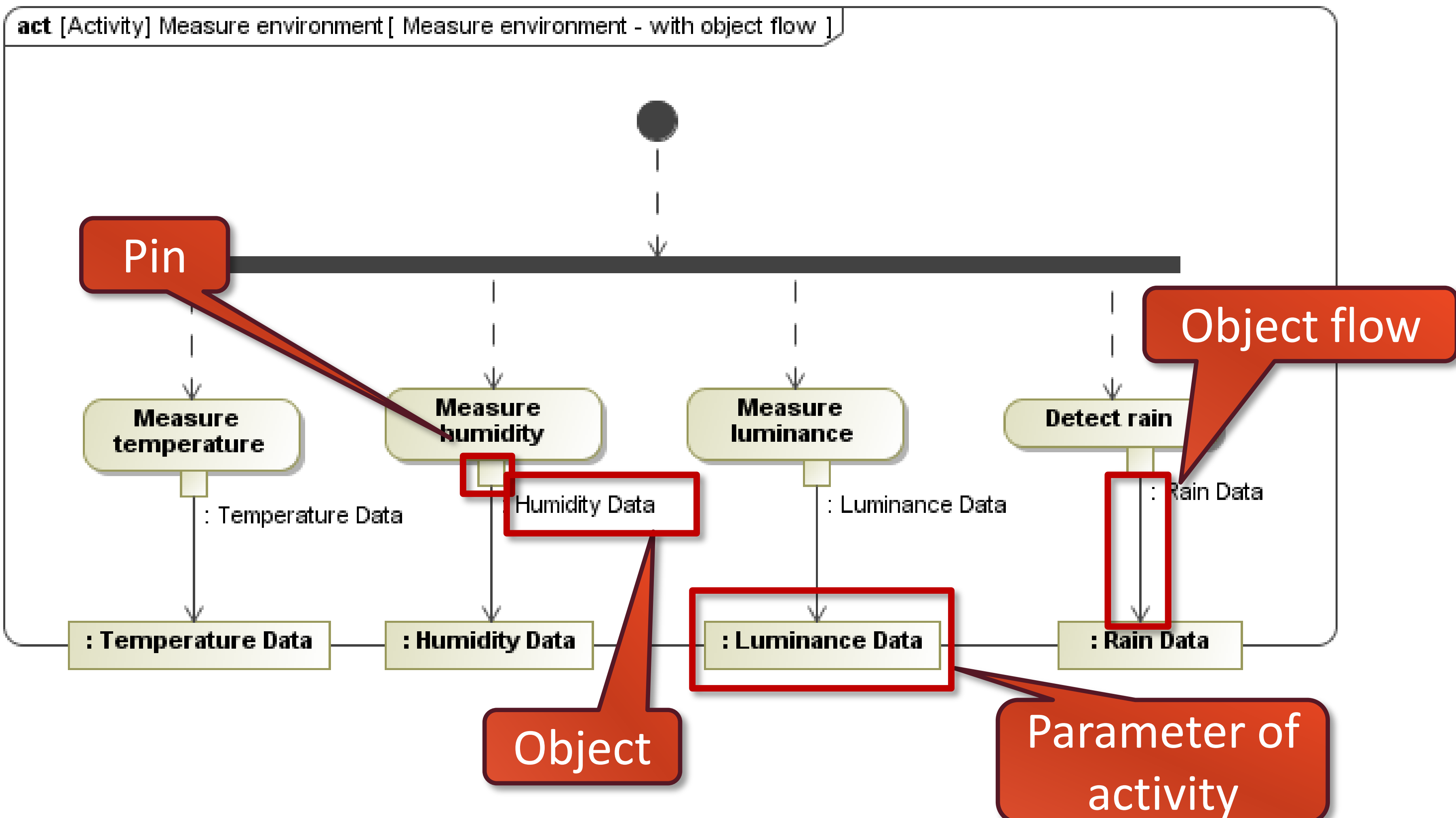
Fork, join, decision, merge



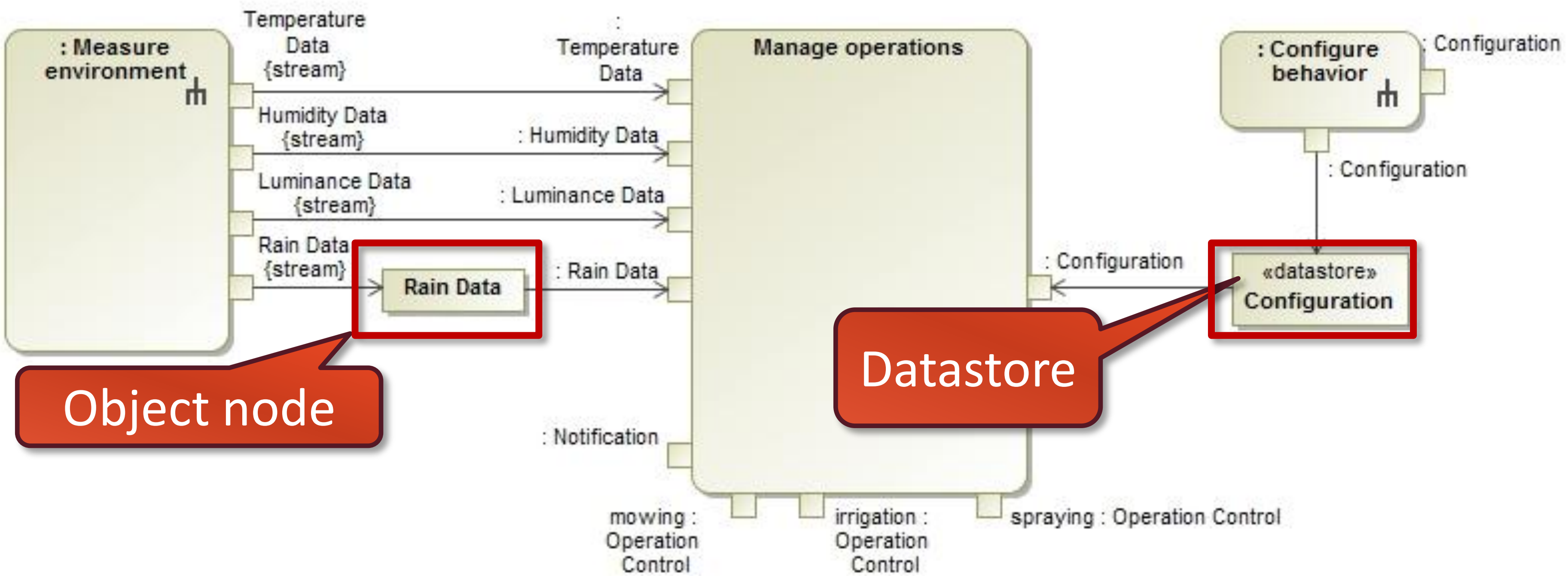
Action types

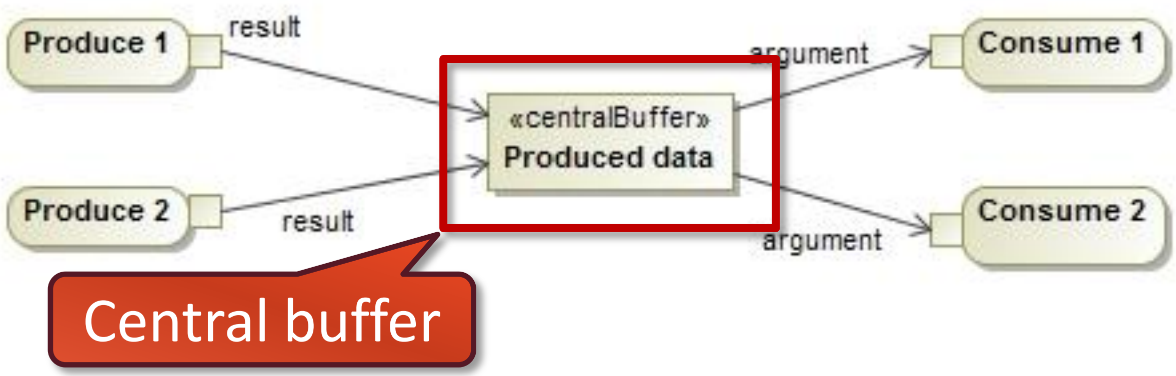
Primitive action node		Primitive actions include object access, update and manipulation actions.
Send signal node		Send signal data to target.
Accept event node		Accept events, typically has output pins for received data.
Accept time event node		Time event corresponds to an expiration of an (implicit) timer.
Call behavior node		Call other behavior (e.g. another activity).

Combined control and data flow

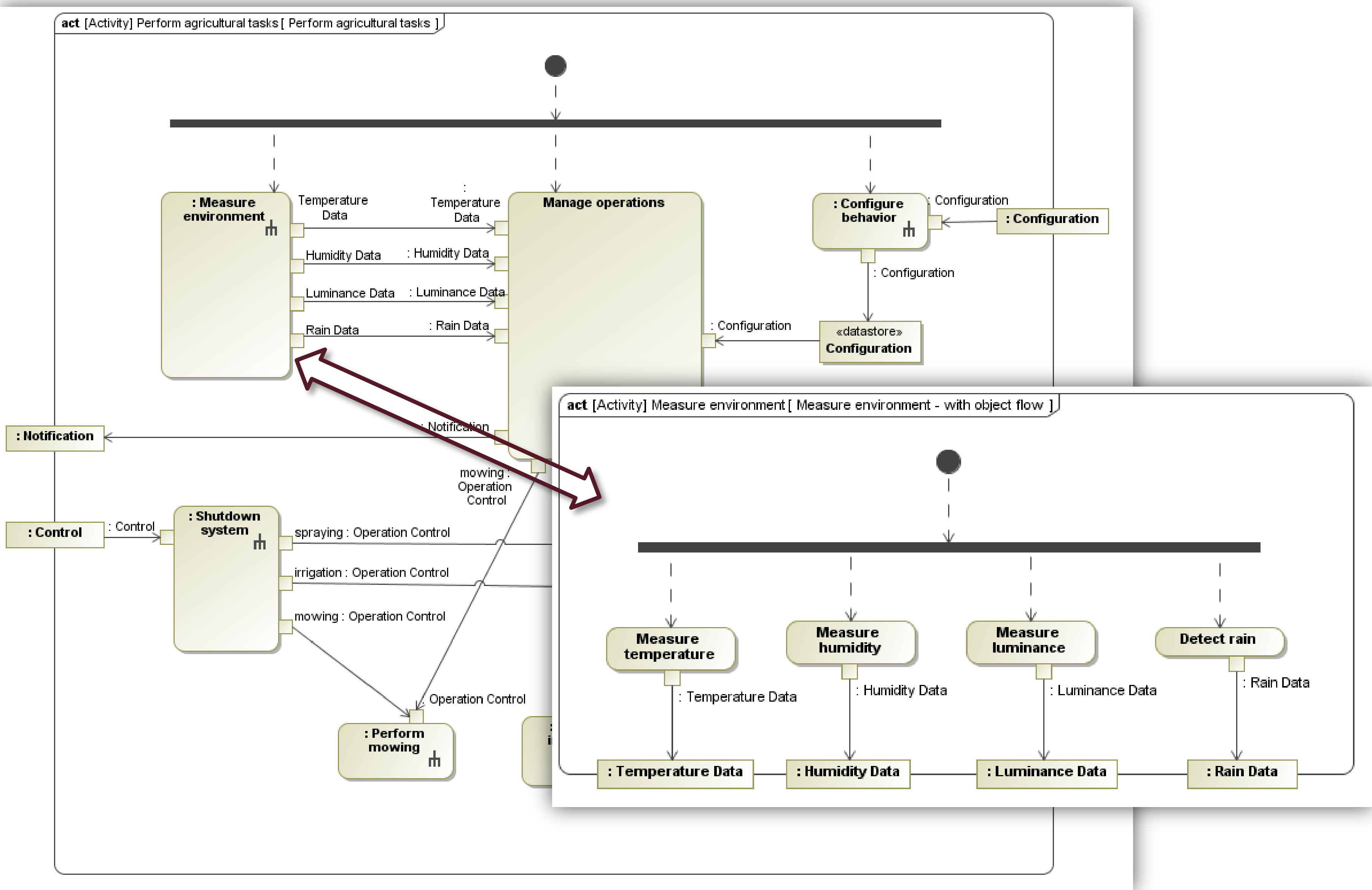


Object nodes

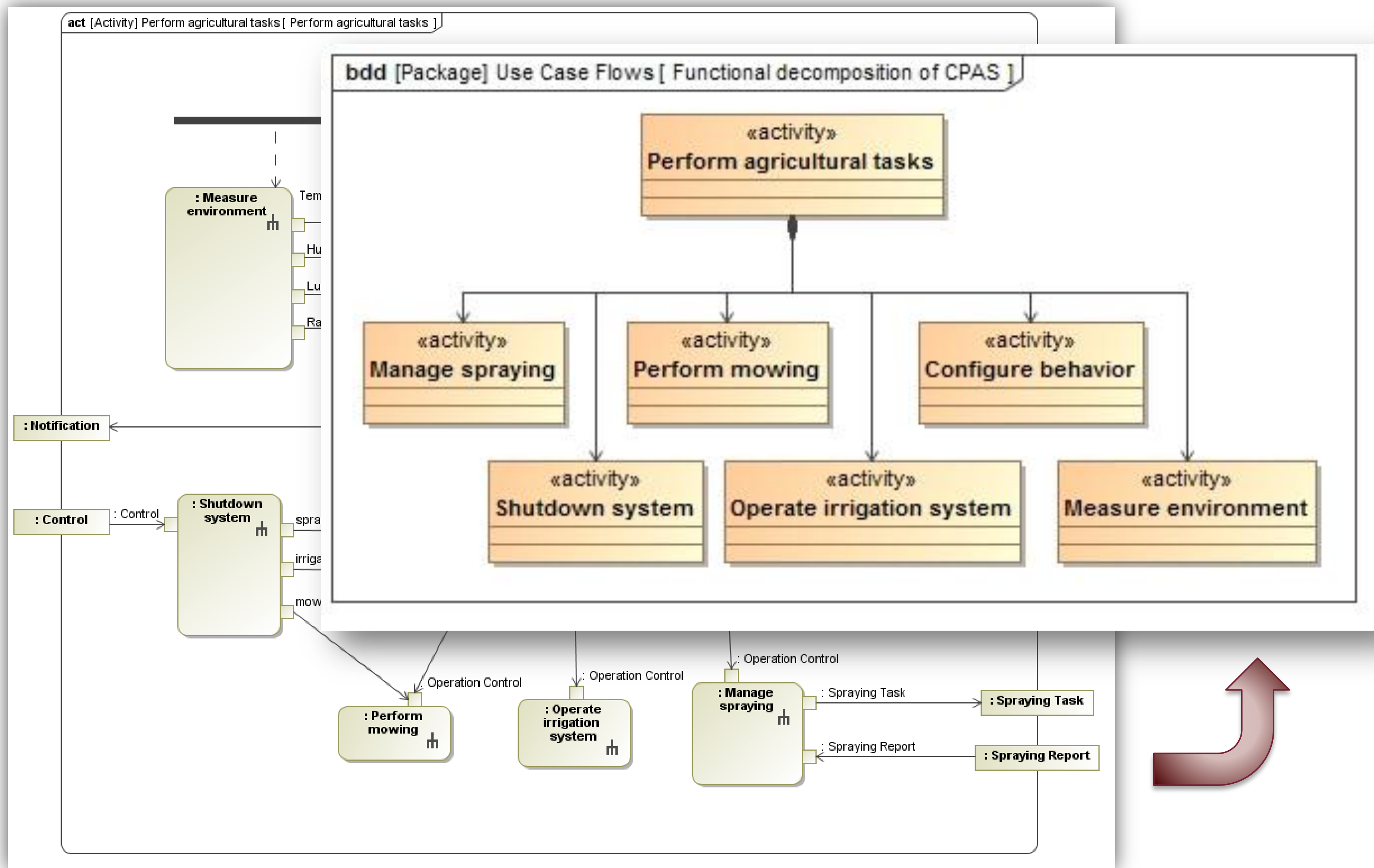




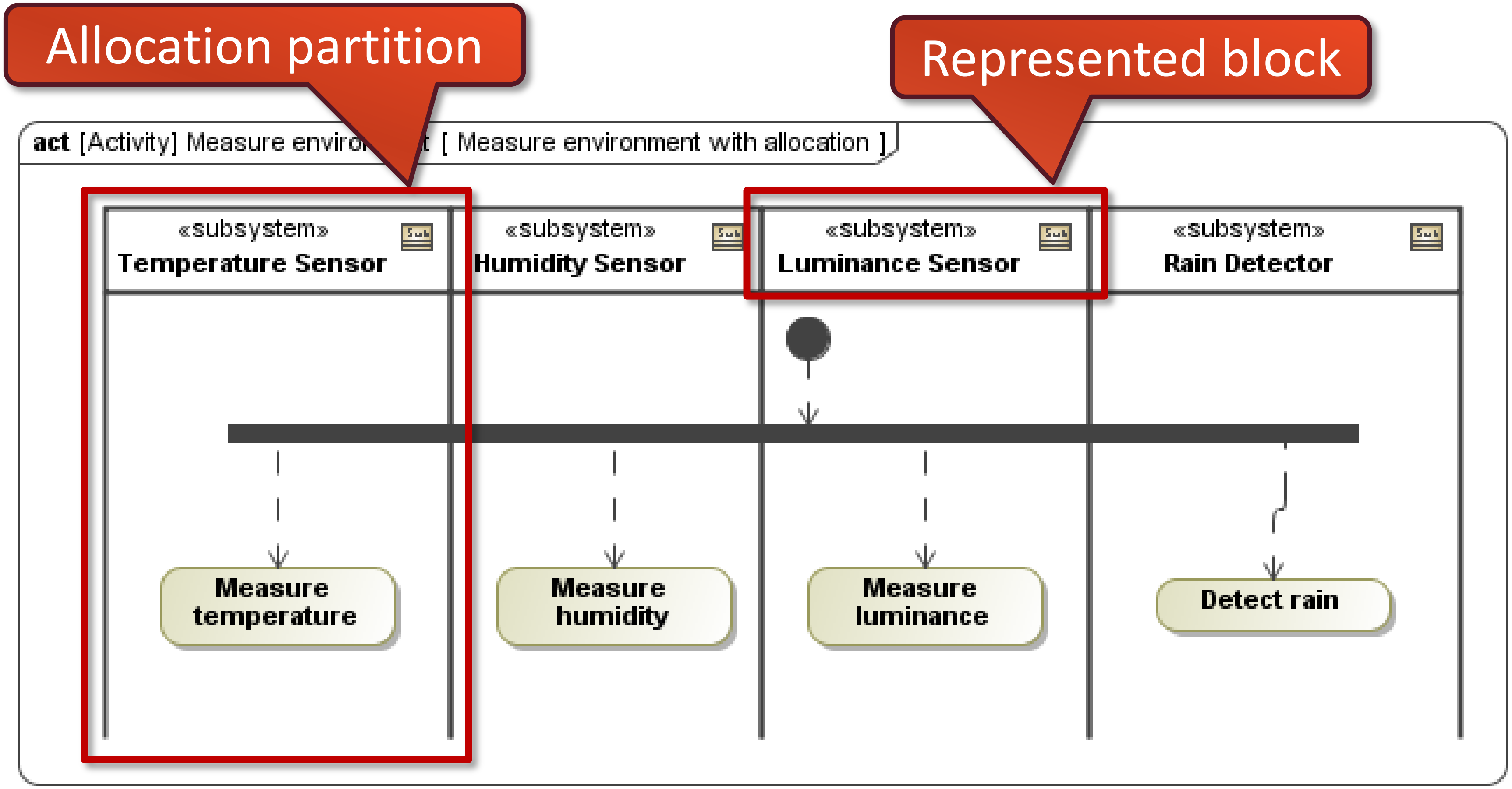
Activity decomposition



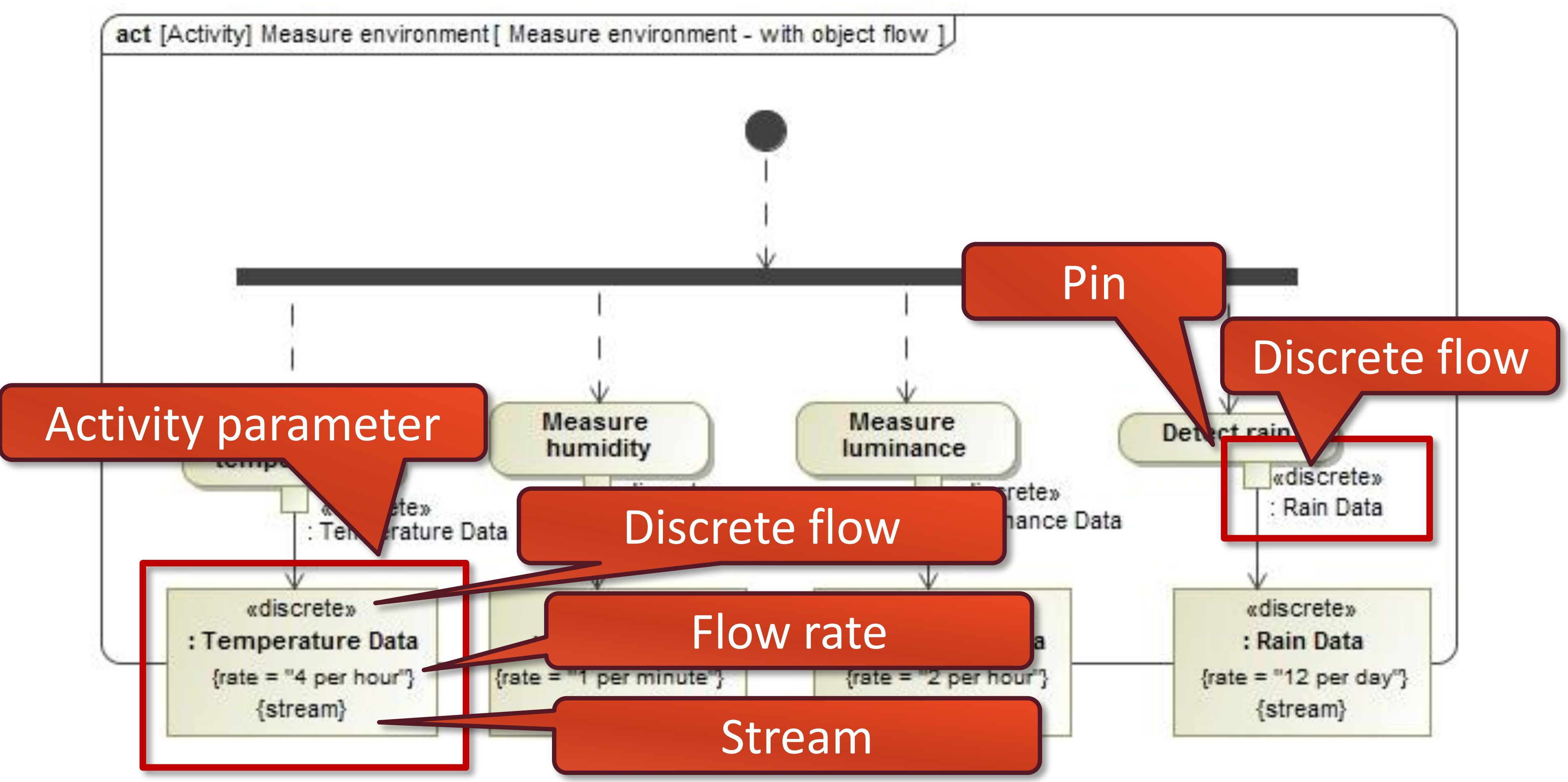
Activity Hierarchy (Functional Decomposition)



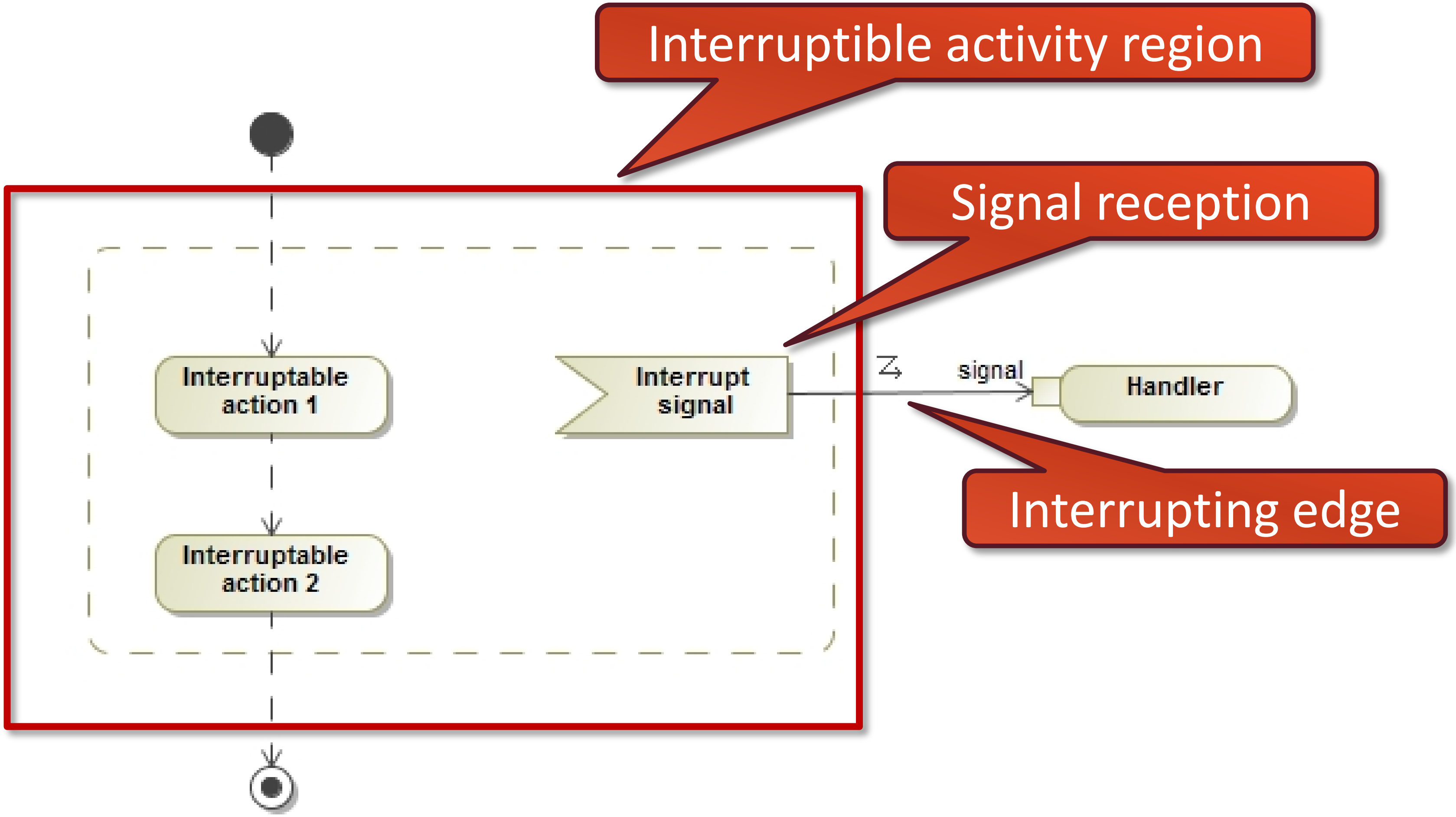
Allocating actions



Modelling Streams (SysML)



Interruptible Activity Region



Modeling Flow Based Behavior with Activities

Context of the Modeling Aspect

Modeling Elements & Notation

Semantics of the Model

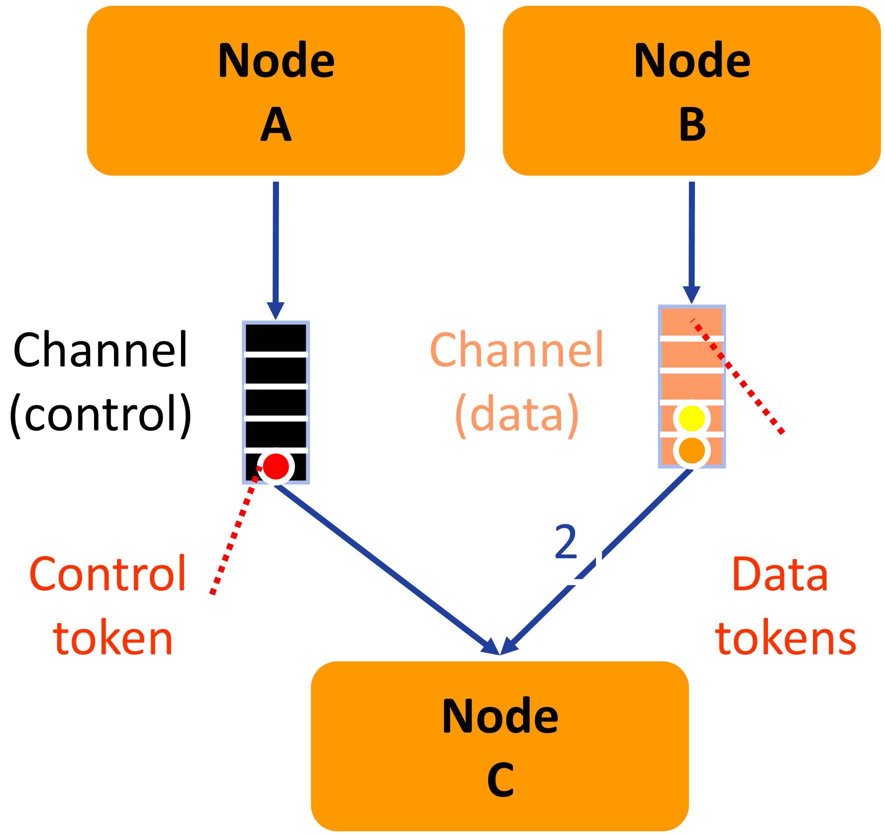
Summary

Data flow and Control flow

- Combined control and data flow model
  - semantics ≈ dataflow networks
- Data Flow: data token
  - Object node ⇒ Action node
    - An object node is a channel / queue
    - An object may be linked to multiple action nodes
    - Output actions are competing for the data token (i.e. the object)
  - Type conformance: object type < input type of action
- Control flow: control token
  (ordering constraint between two actions)
  - All predecessor actions should be terminated prior to starting the current action
  - The current action should terminate prior to starting any of the successor actions

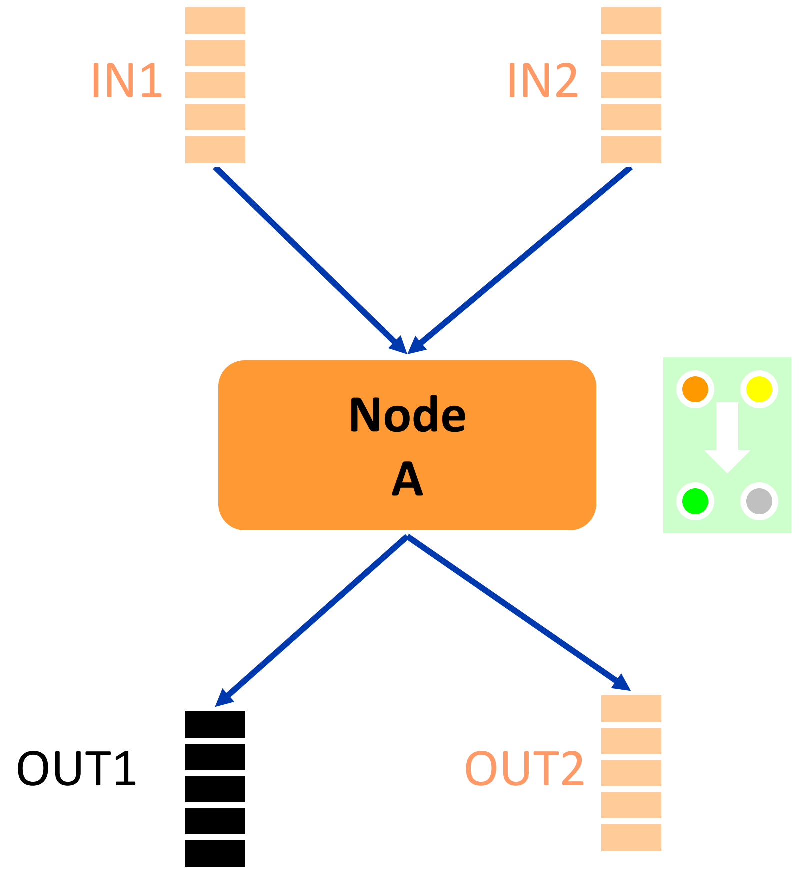
Semantics: Dataflow Networks

- Tokens:
  - control + several data
- Channel: object node
  - Stores the tokens
- Node: action node
  - Processing tokens
- Edges:
  - Flow of tokens
  - weights: how many tokens are in the flow at a time?
- Firing rule:
  - Behaviour of a node



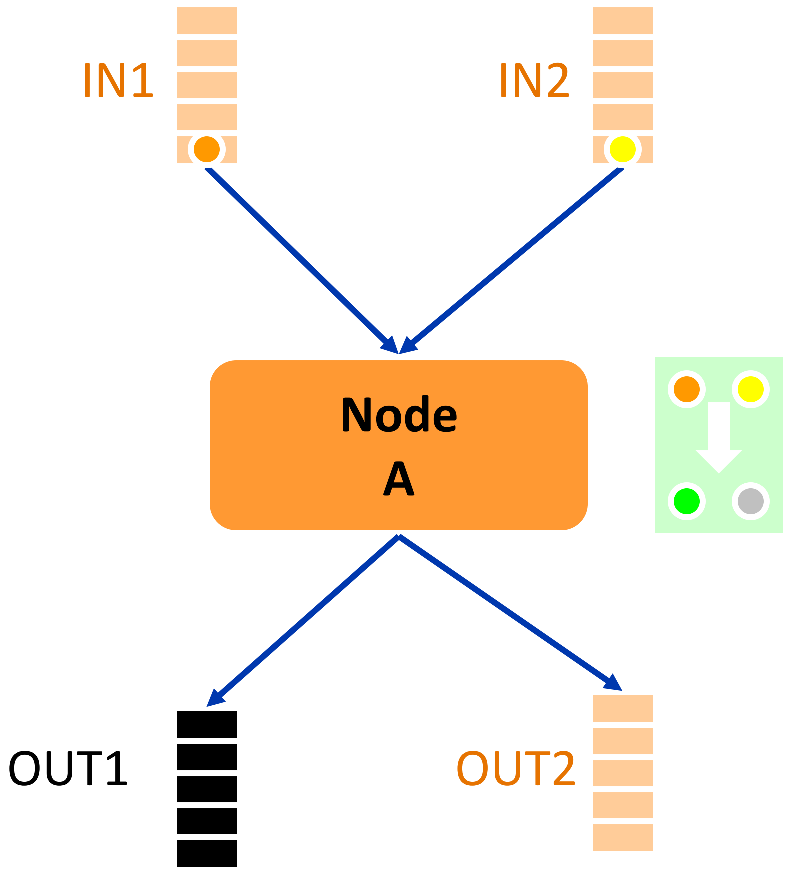
Semantics: Dataflow Networks

- Firing rule (cont.):
  - precondition:
    - input tokens + current state
  - postcondition
    - output tokens + new state



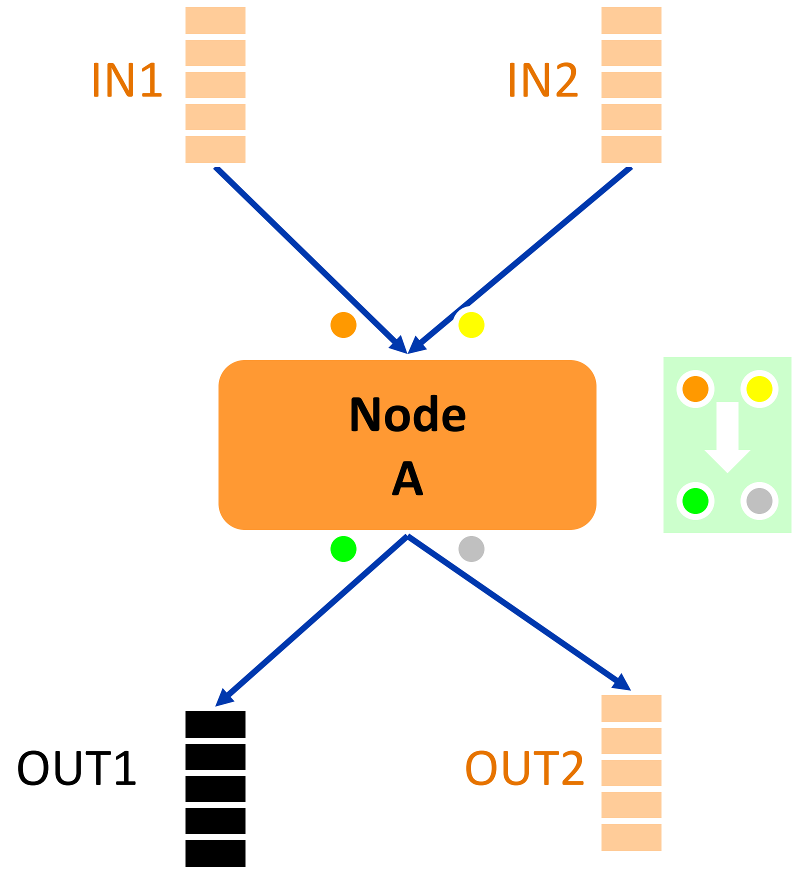
Semantics: Dataflow Networks

- Firing rule (cont.):
  - precondition:
    - input tokens + current state
  - postcondition:
    - output tokens + new state
- Execution of a firing:
  - Is there token on all inputs with
    - Right amount?
    - Right type?



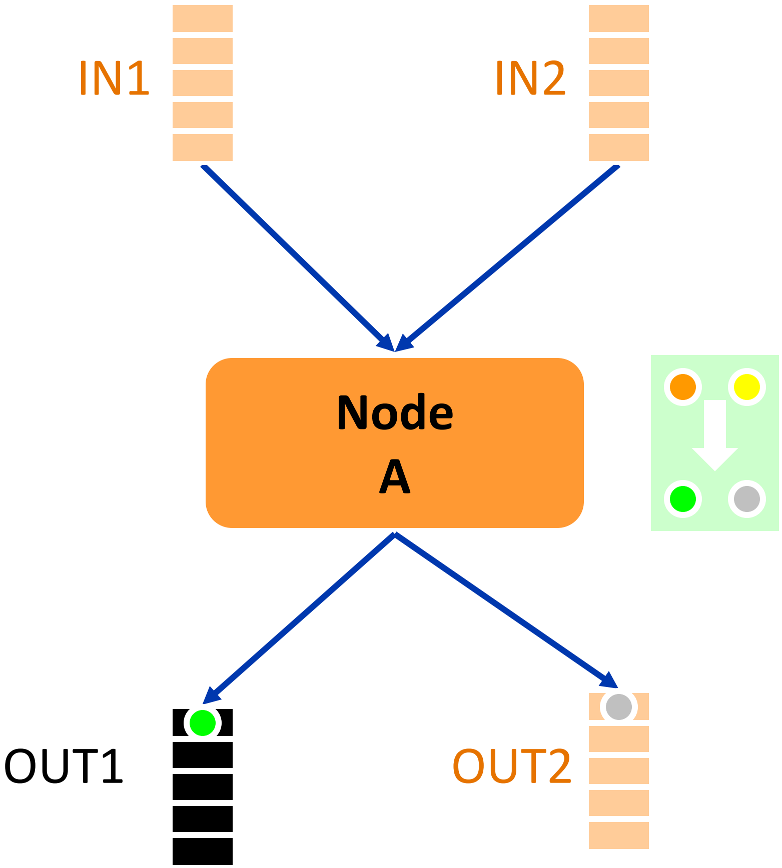
Semantics: Dataflow Networks

- Firing rule (cont.):
  - precondition:
    - input tokens + current state
  - postcondition
    - output tokens + new state
- Execution of a firing:
  - Is there token on all inputs with
    - Right amount?
    - Right type?
  - Execution of action

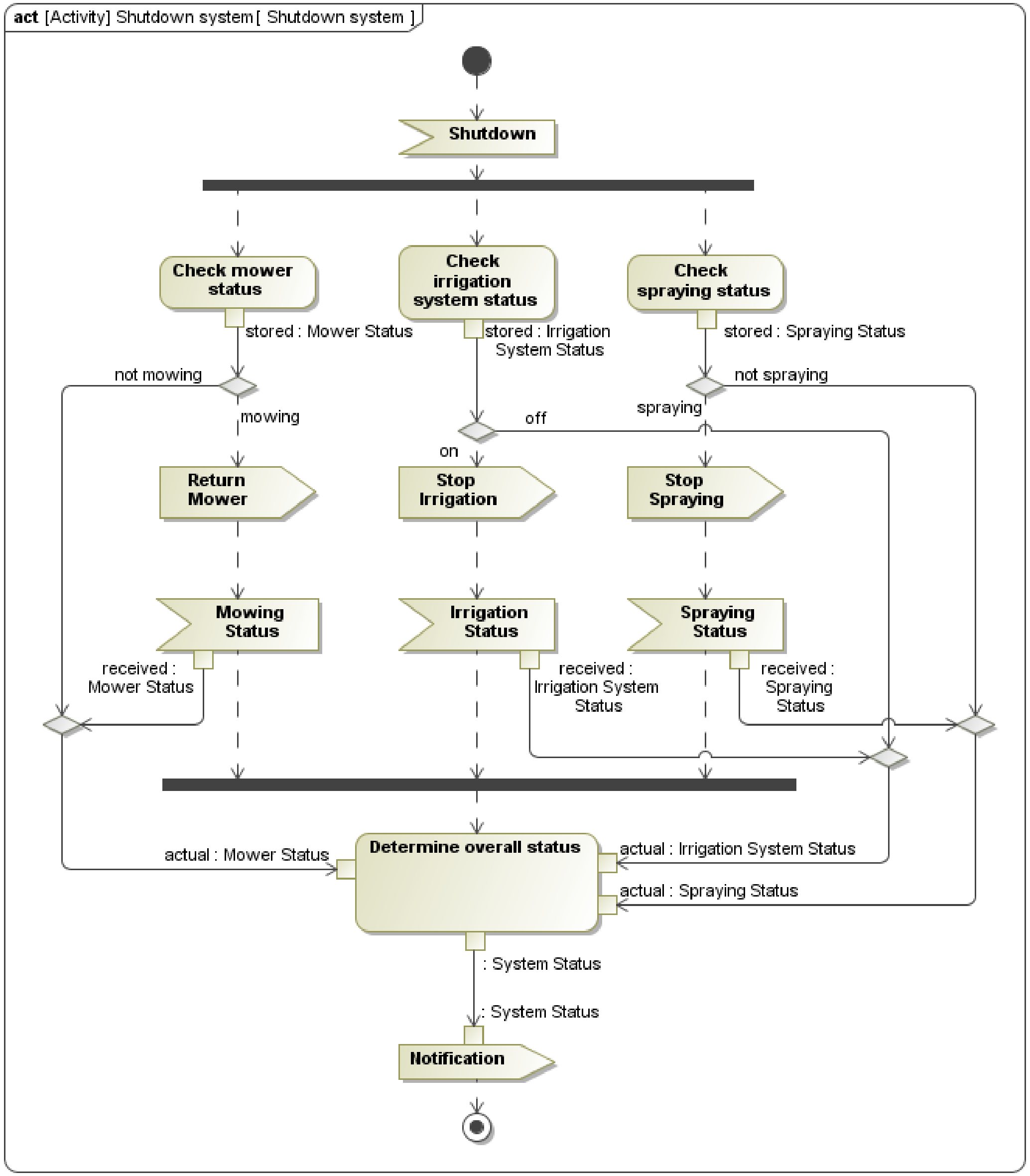


Semantics: Dataflow Networks

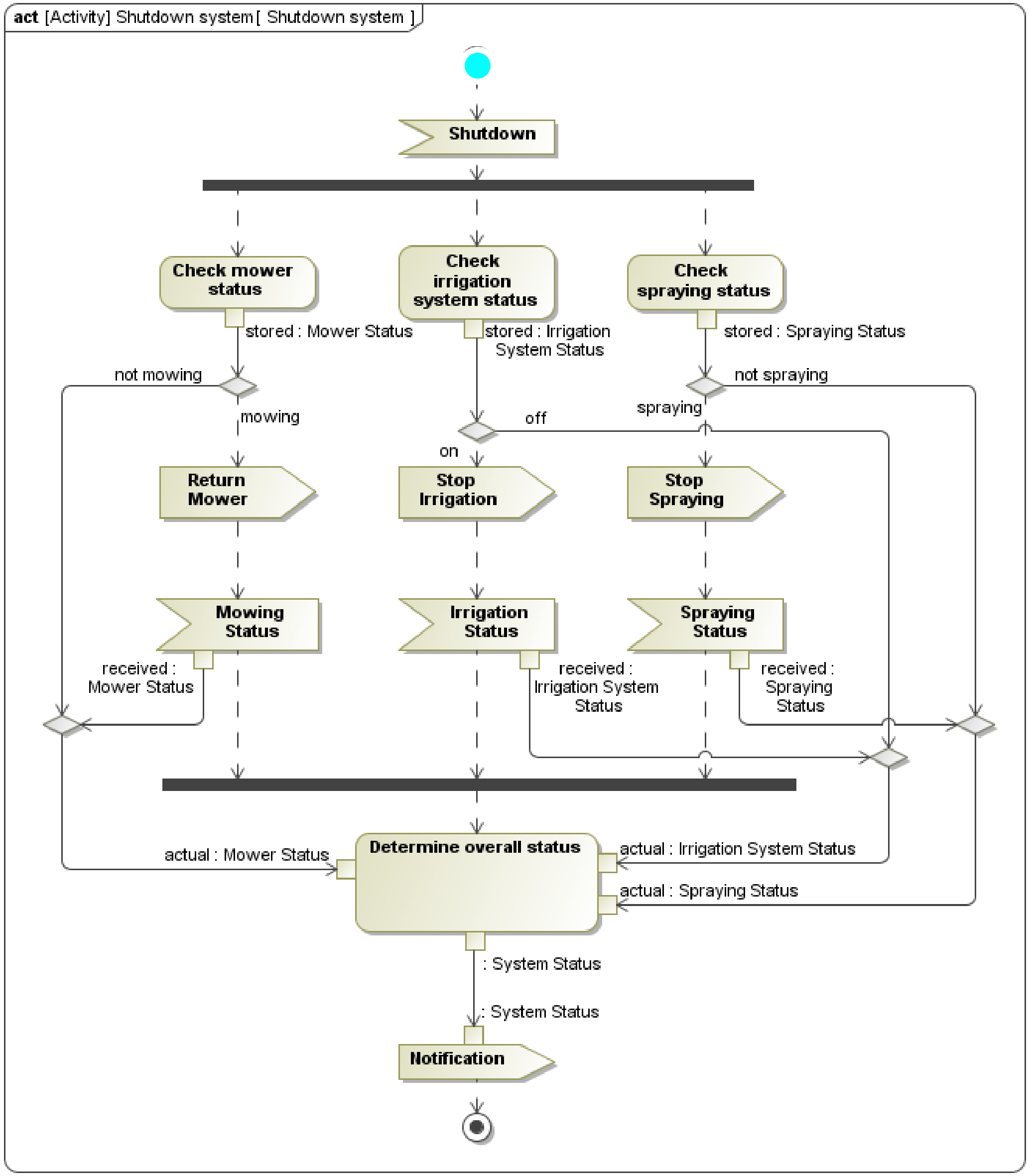
- Firing rule (cont.):
  - precondition:
    - input tokens + current state
  - postcondition
    - output tokens + new state
- Execution of a firing:
  - Is there token on all inputs with
    - Right amount?
    - Right type?
  - Execution of action
  - Sending the output tokens



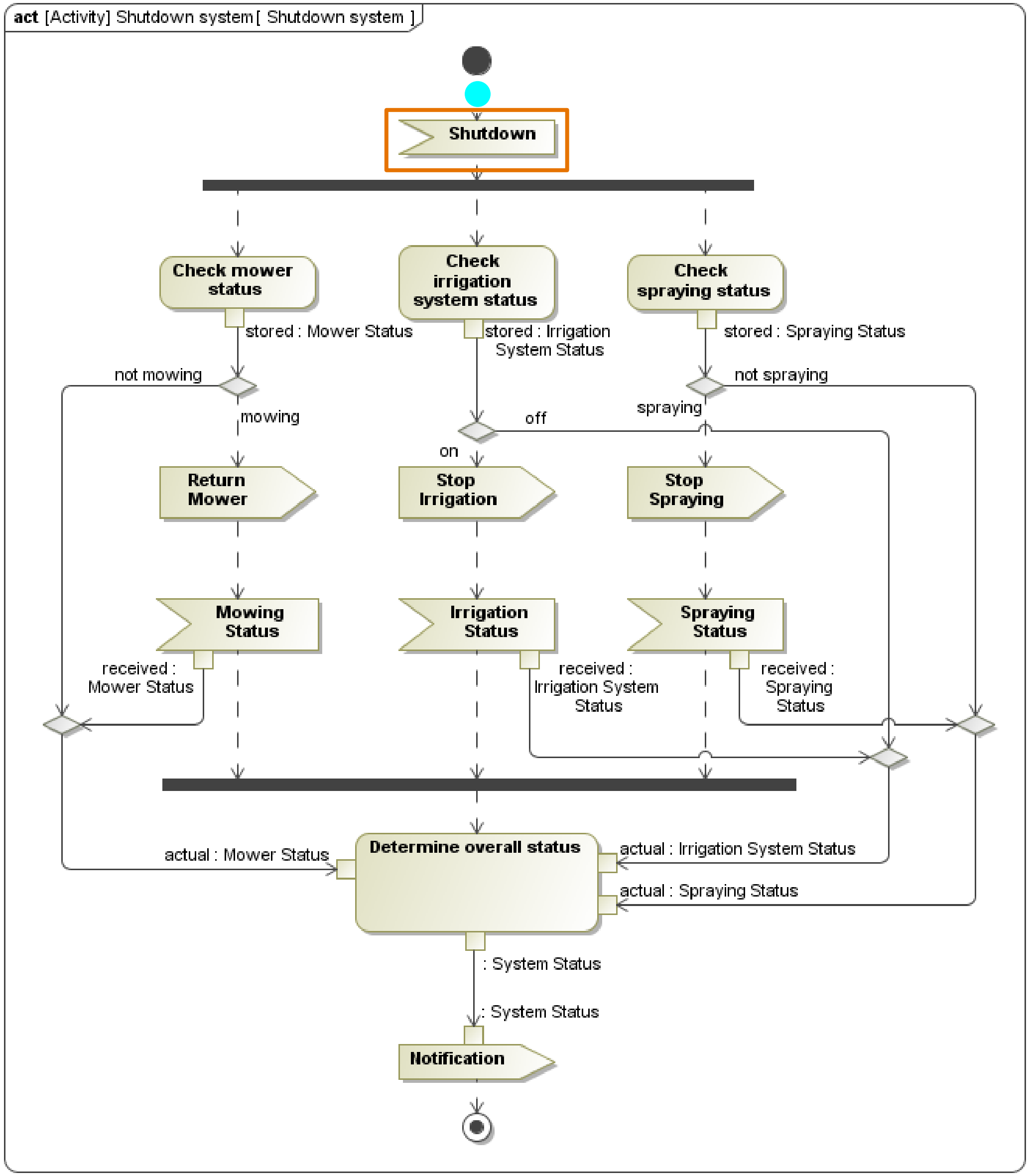
Example: Shutdown system



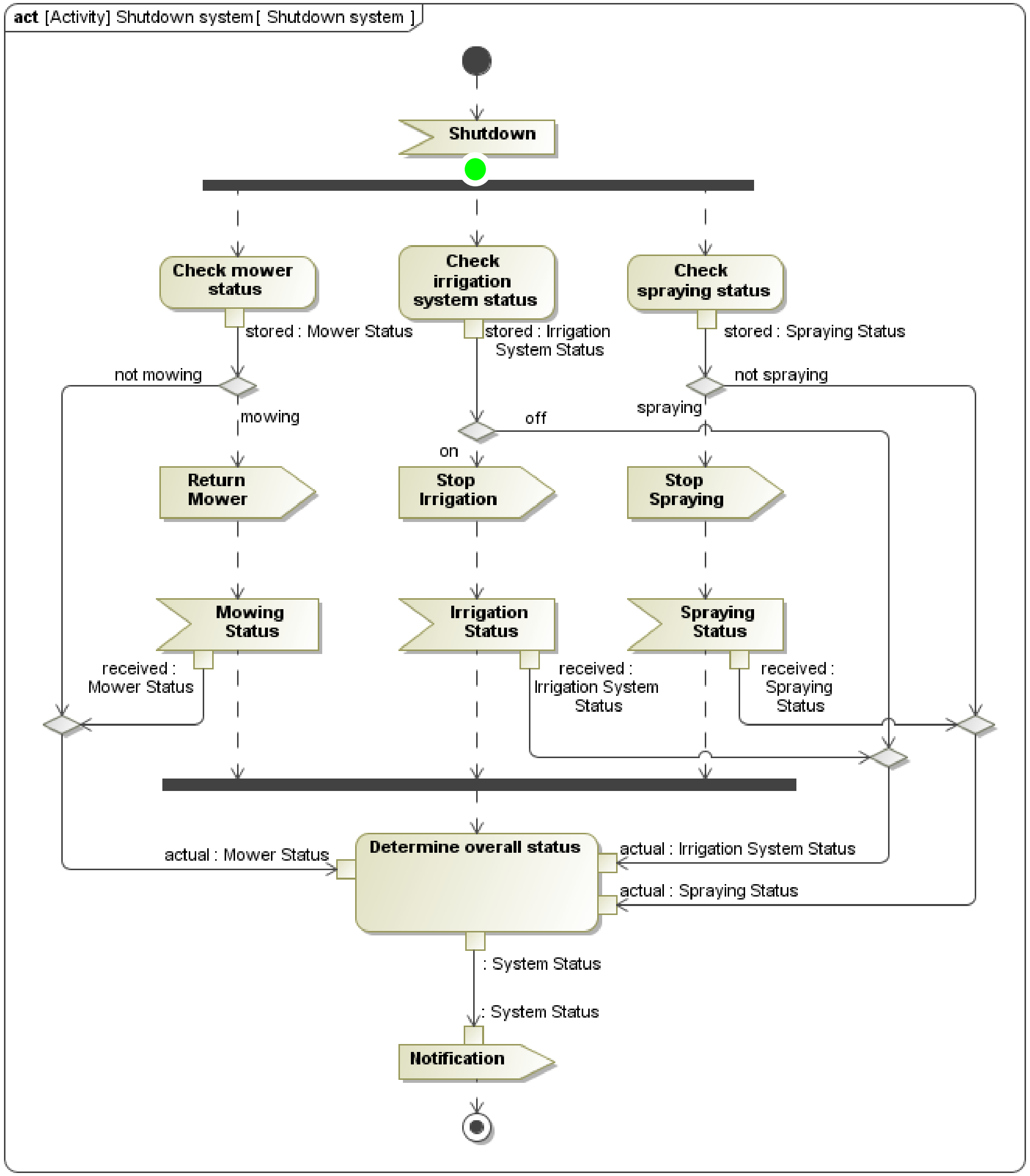
Example: Shutdown system



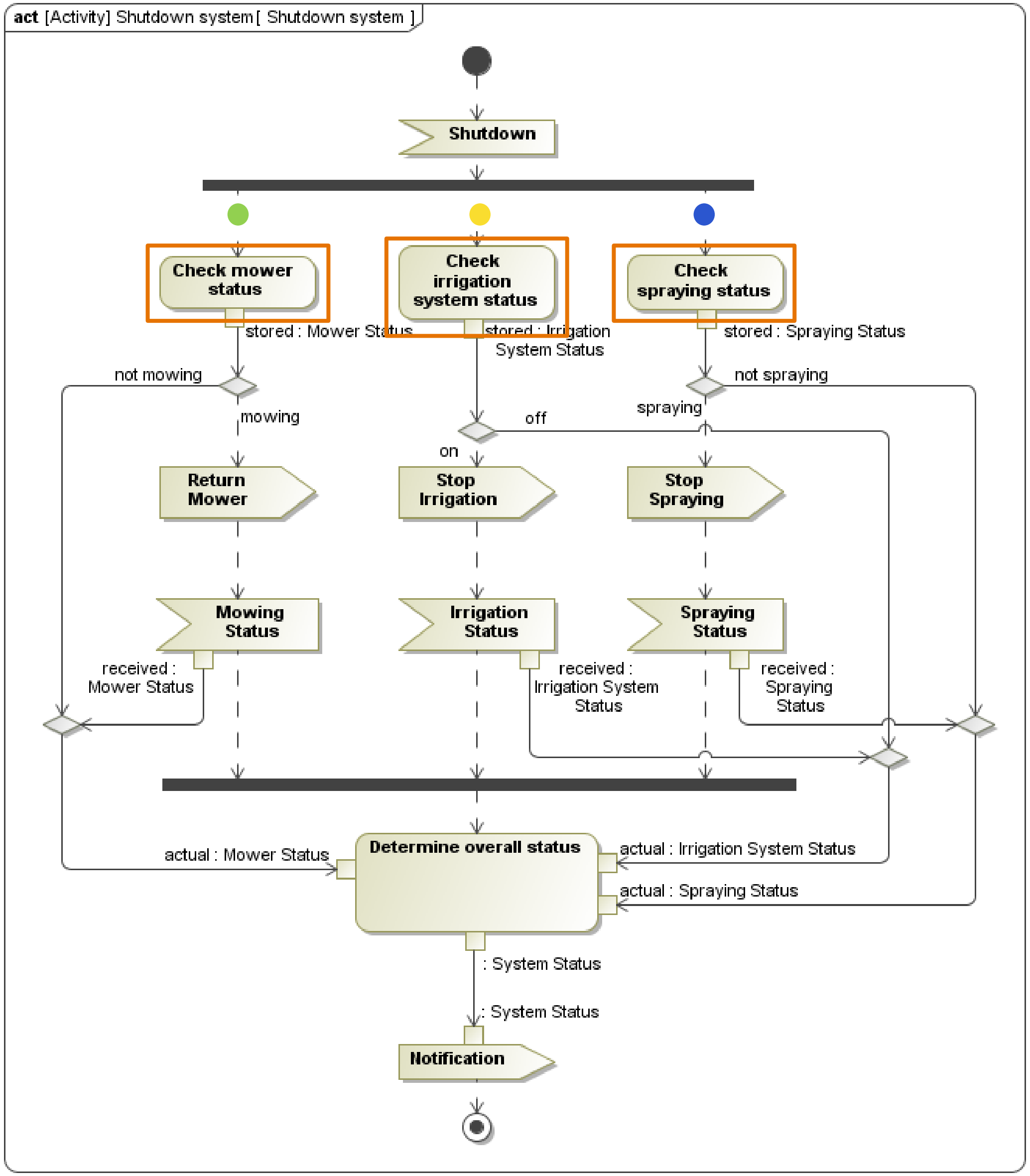
Example: Shutdown system



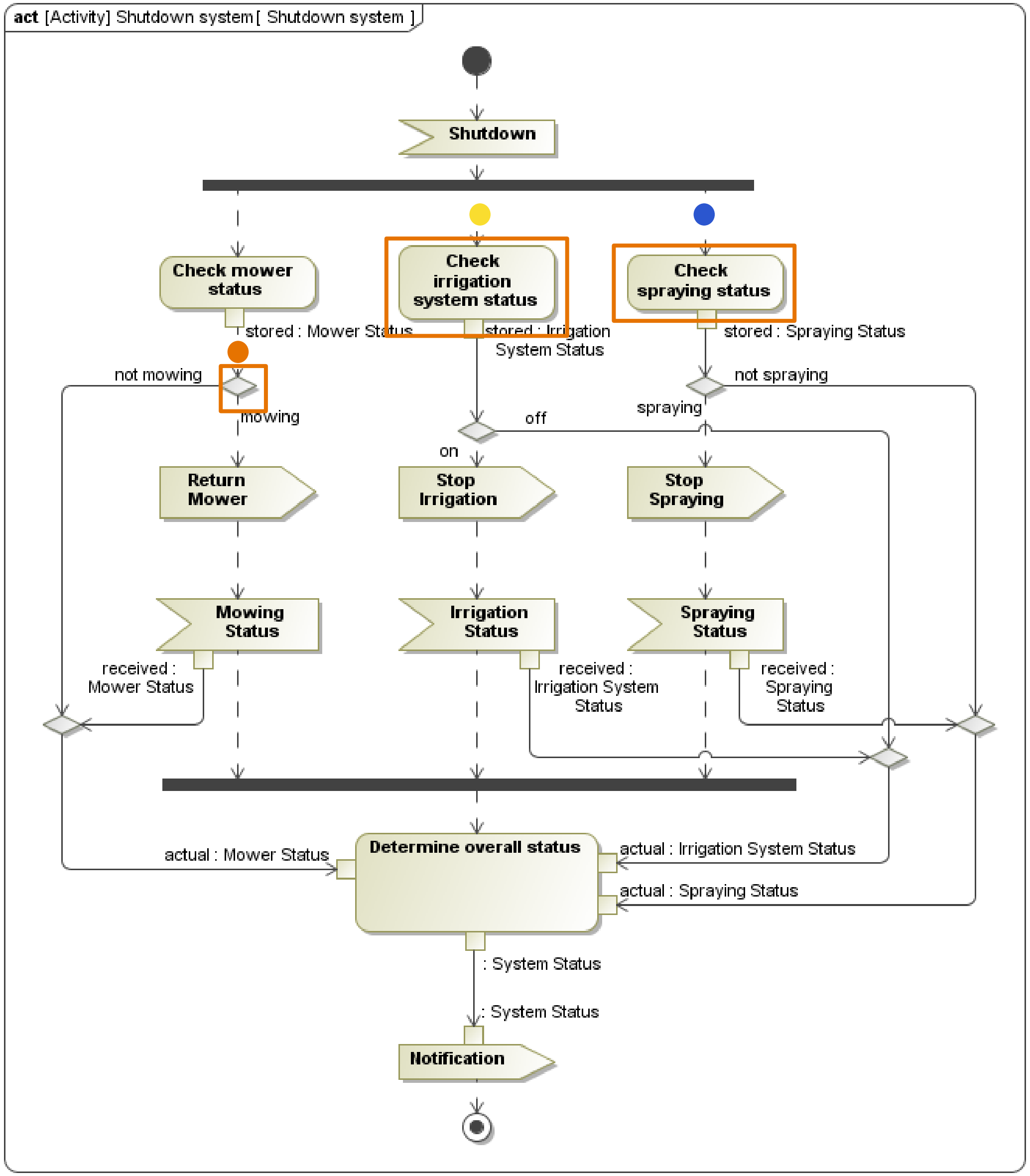
Example: Shutdown system



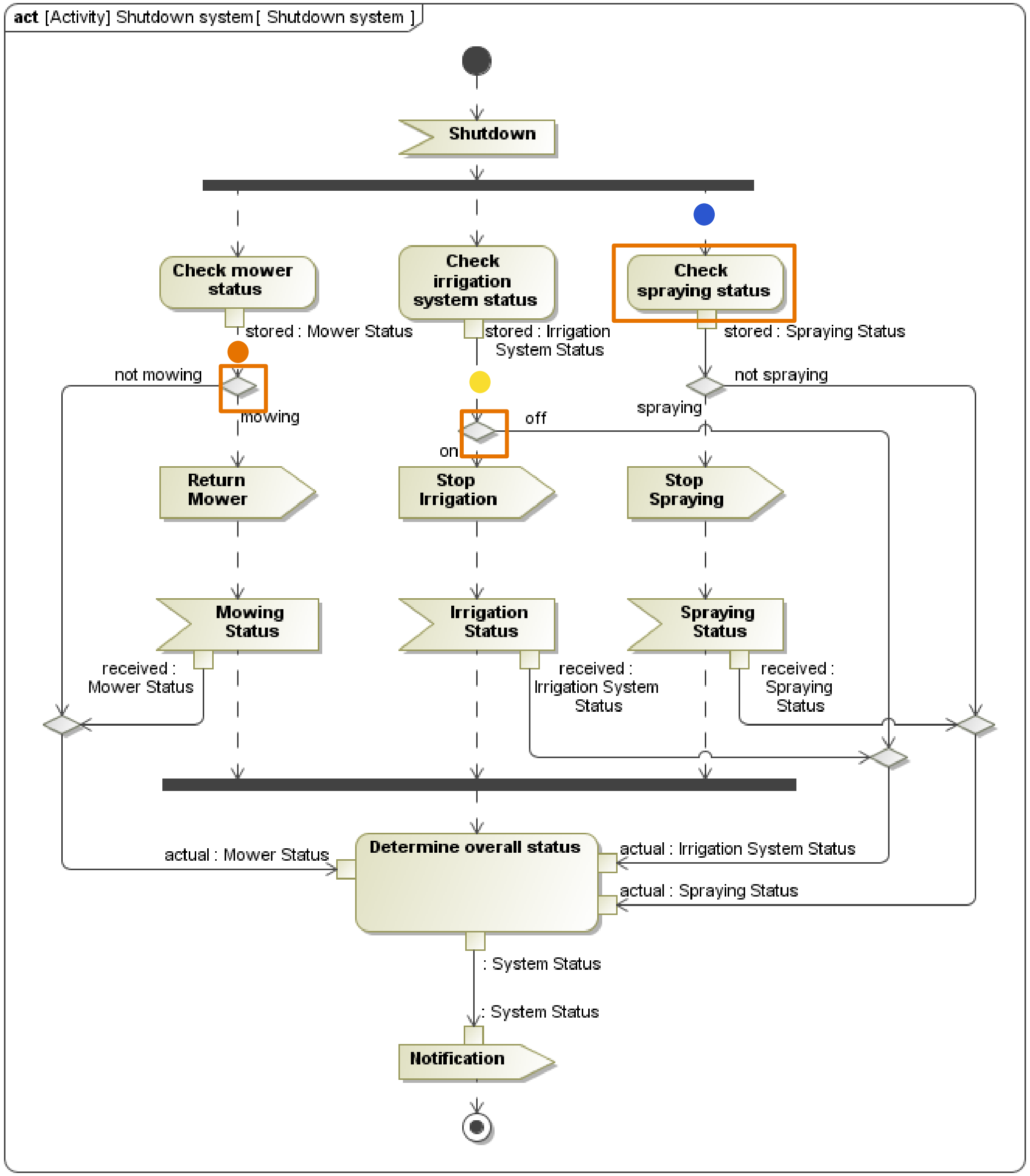
Example: Shutdown system



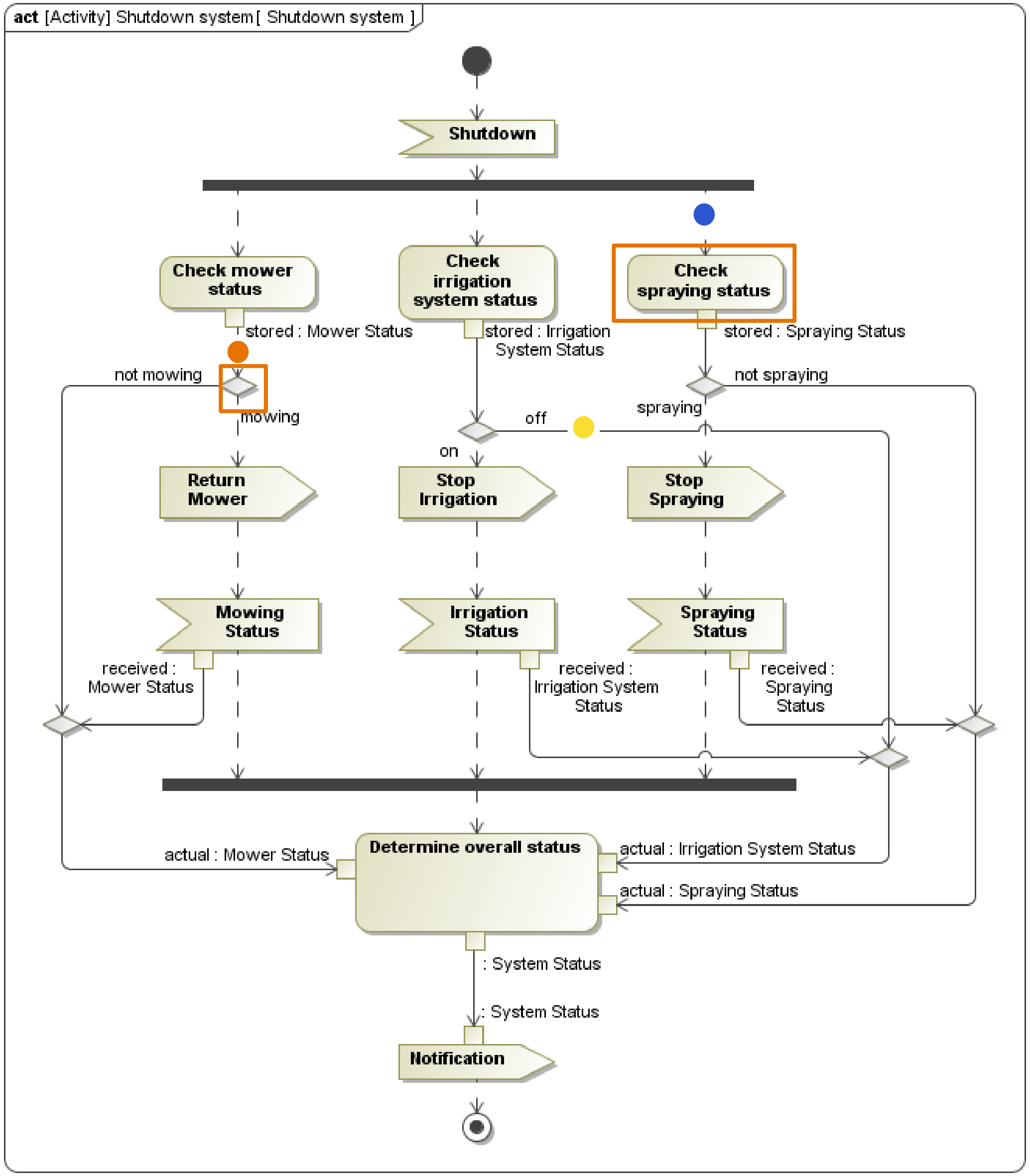
Example: Shutdown system



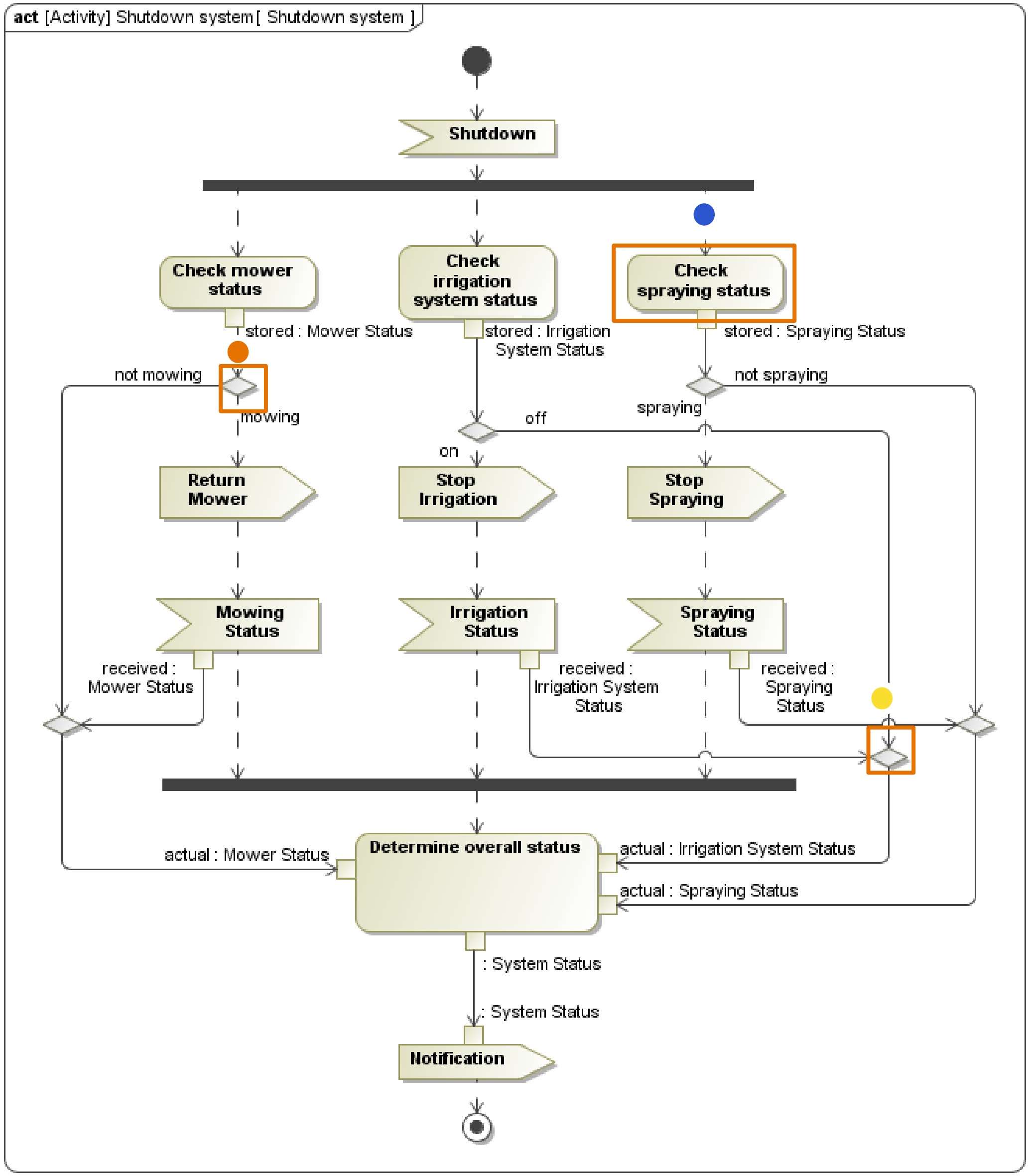
Example: Shutdown system



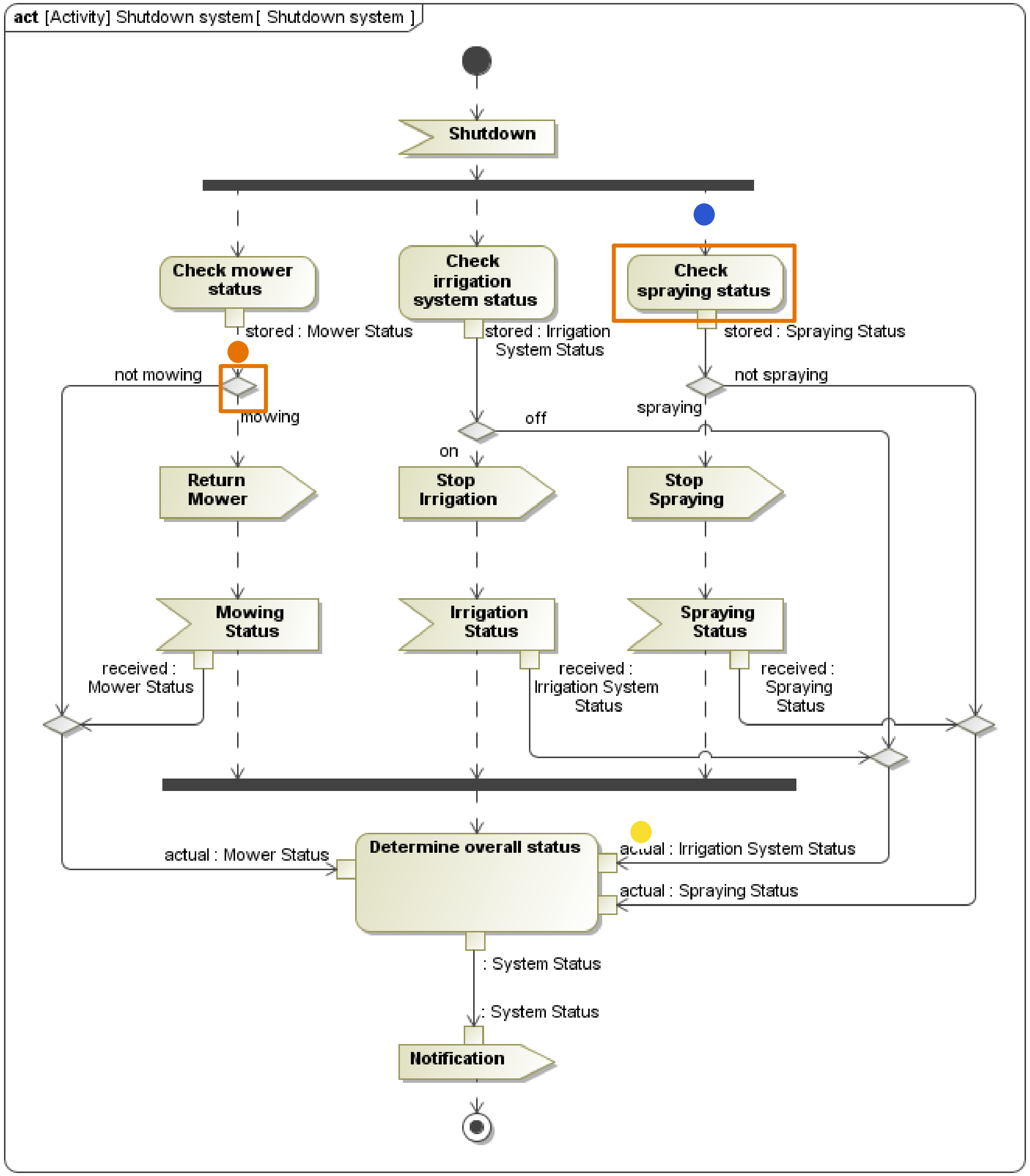
Example: Shutdown system



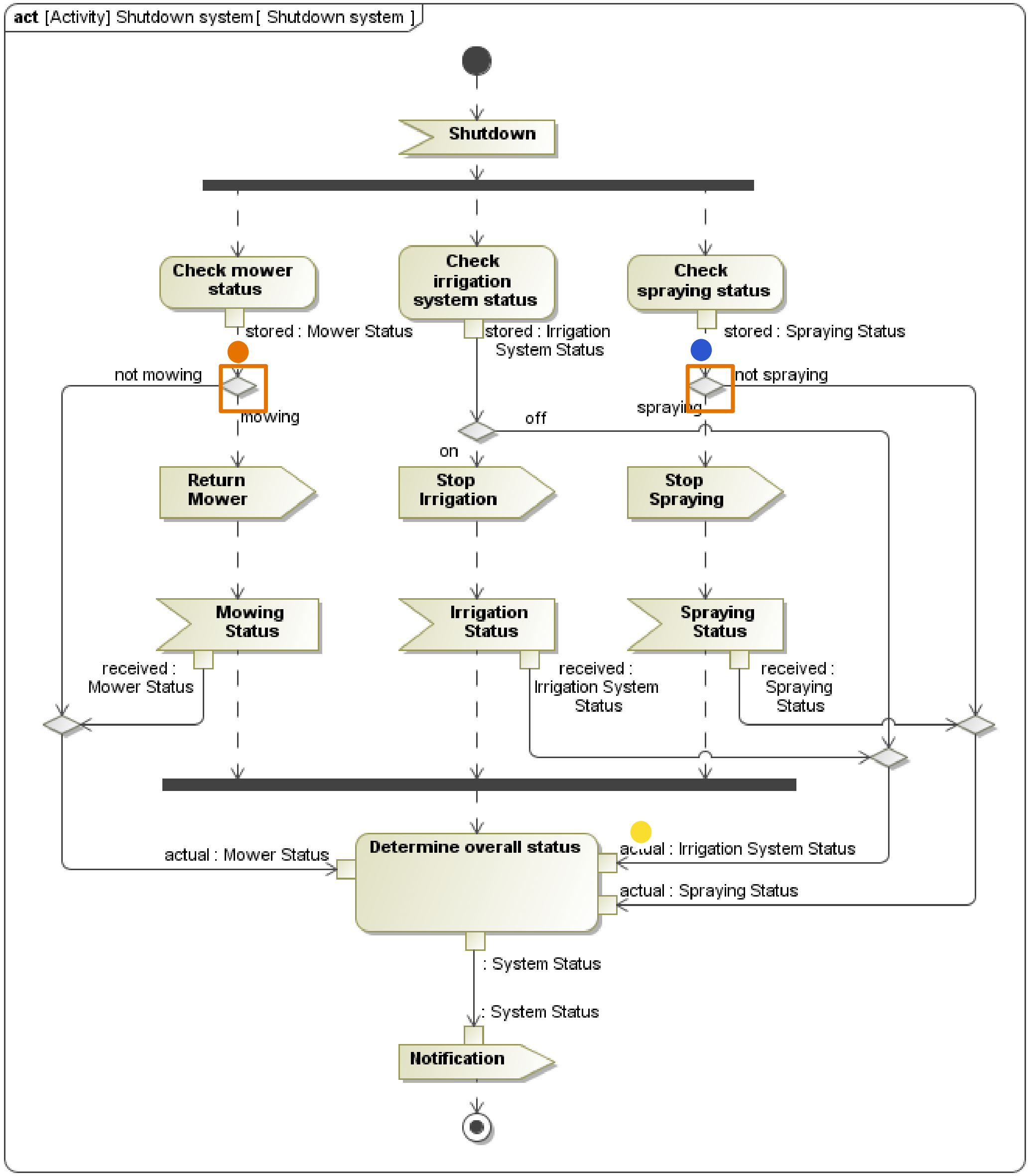
Example: Shutdown system



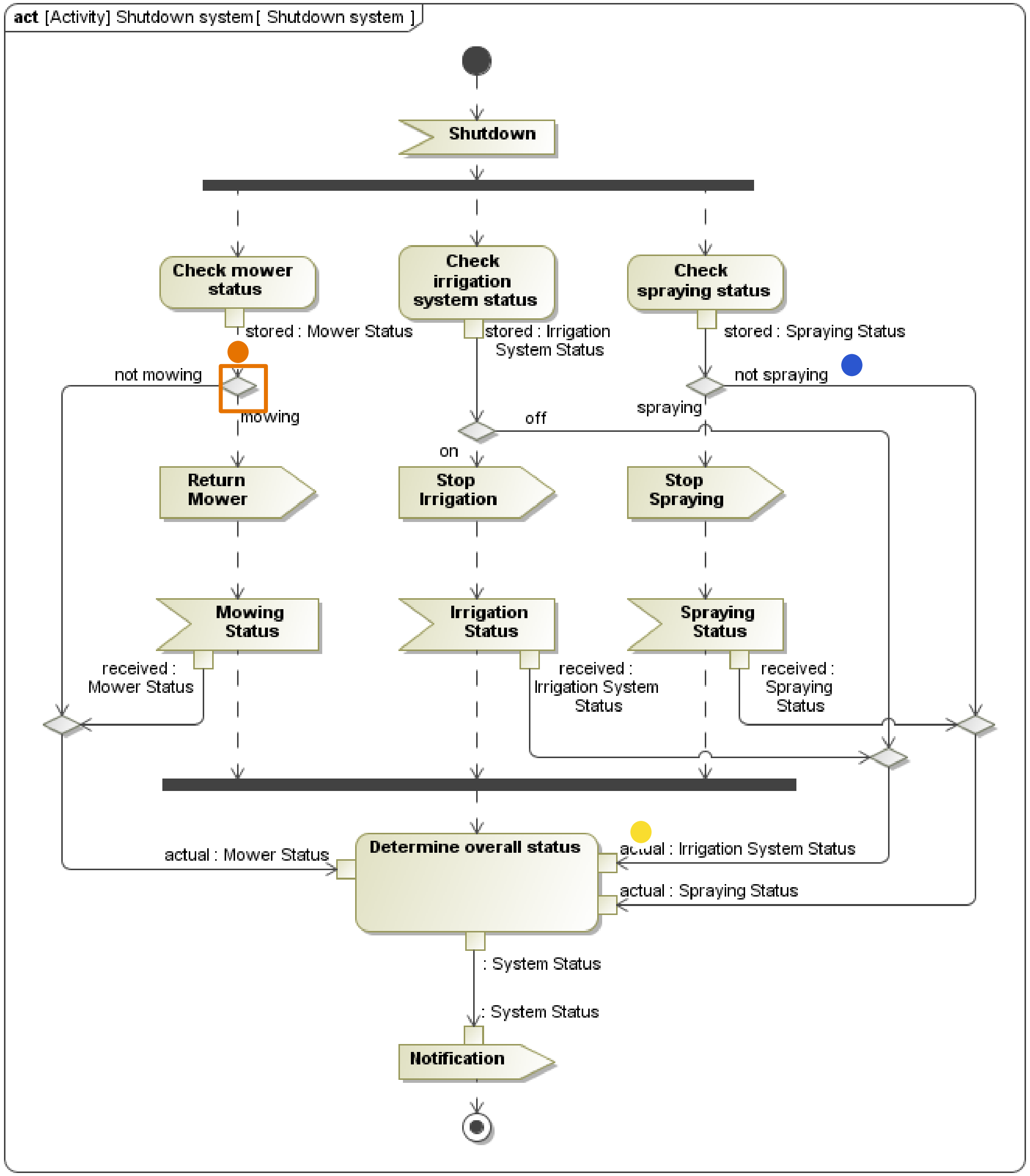
Example: Shutdown system



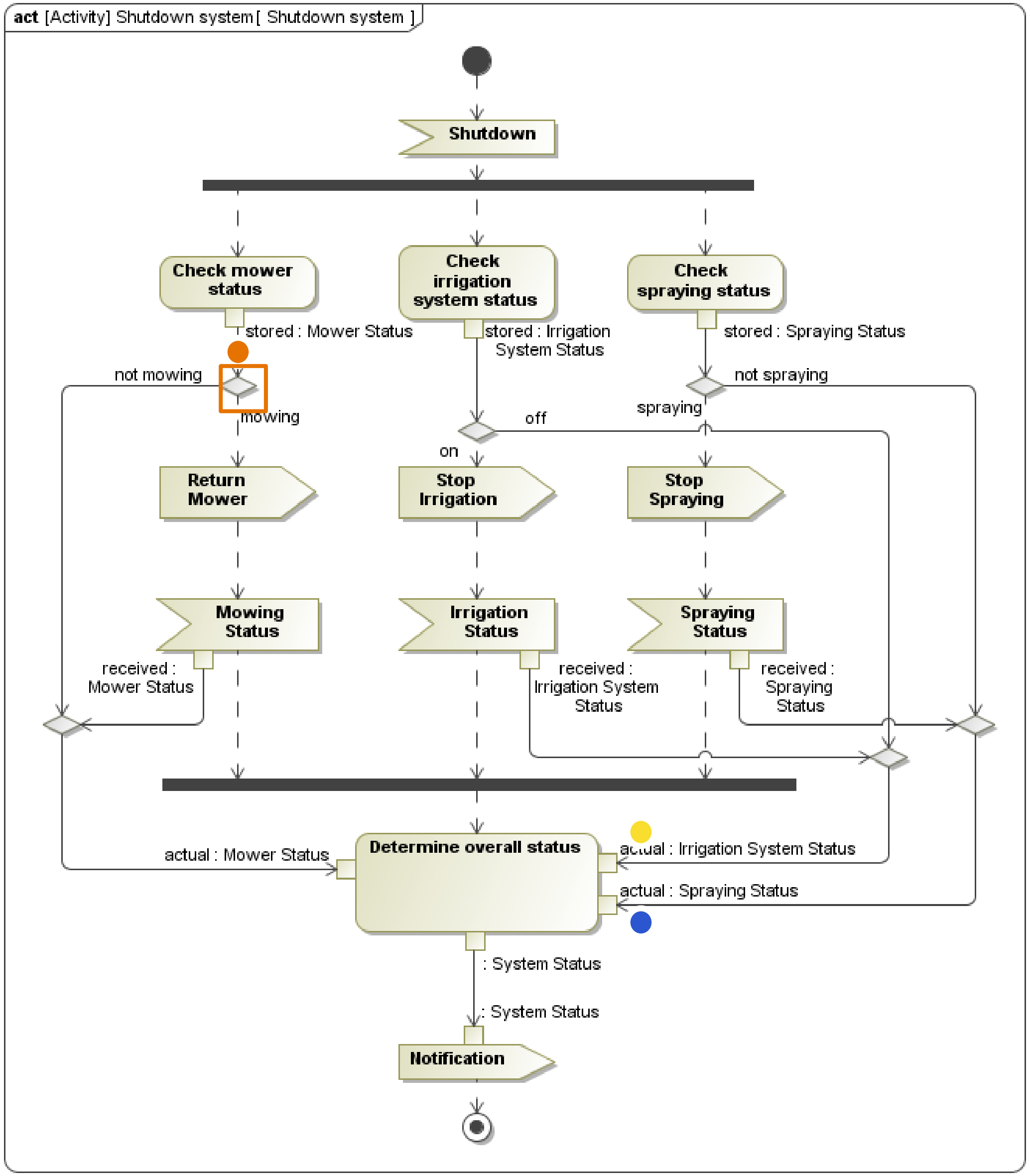
Example: Shutdown system



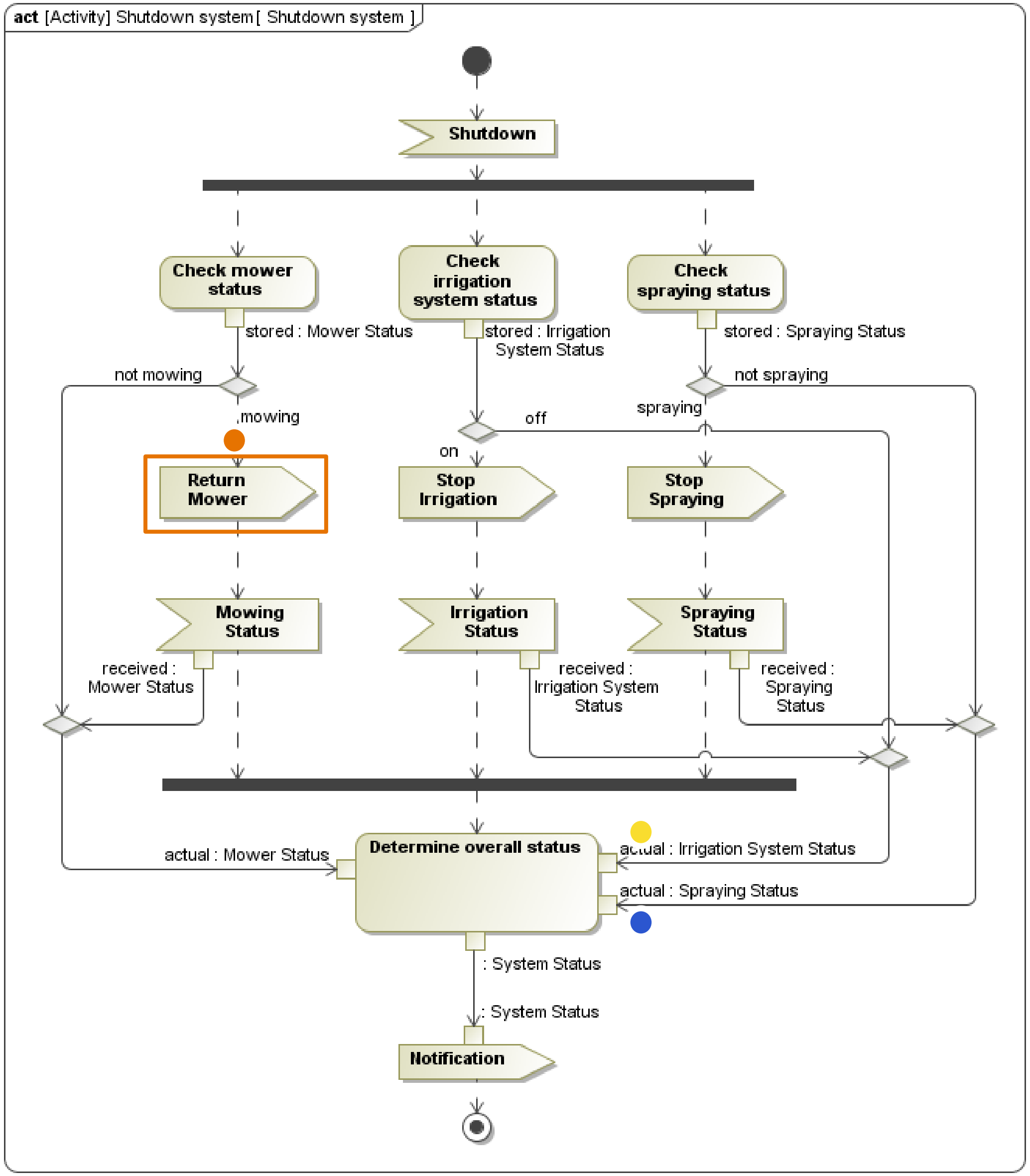
Example: Shutdown system



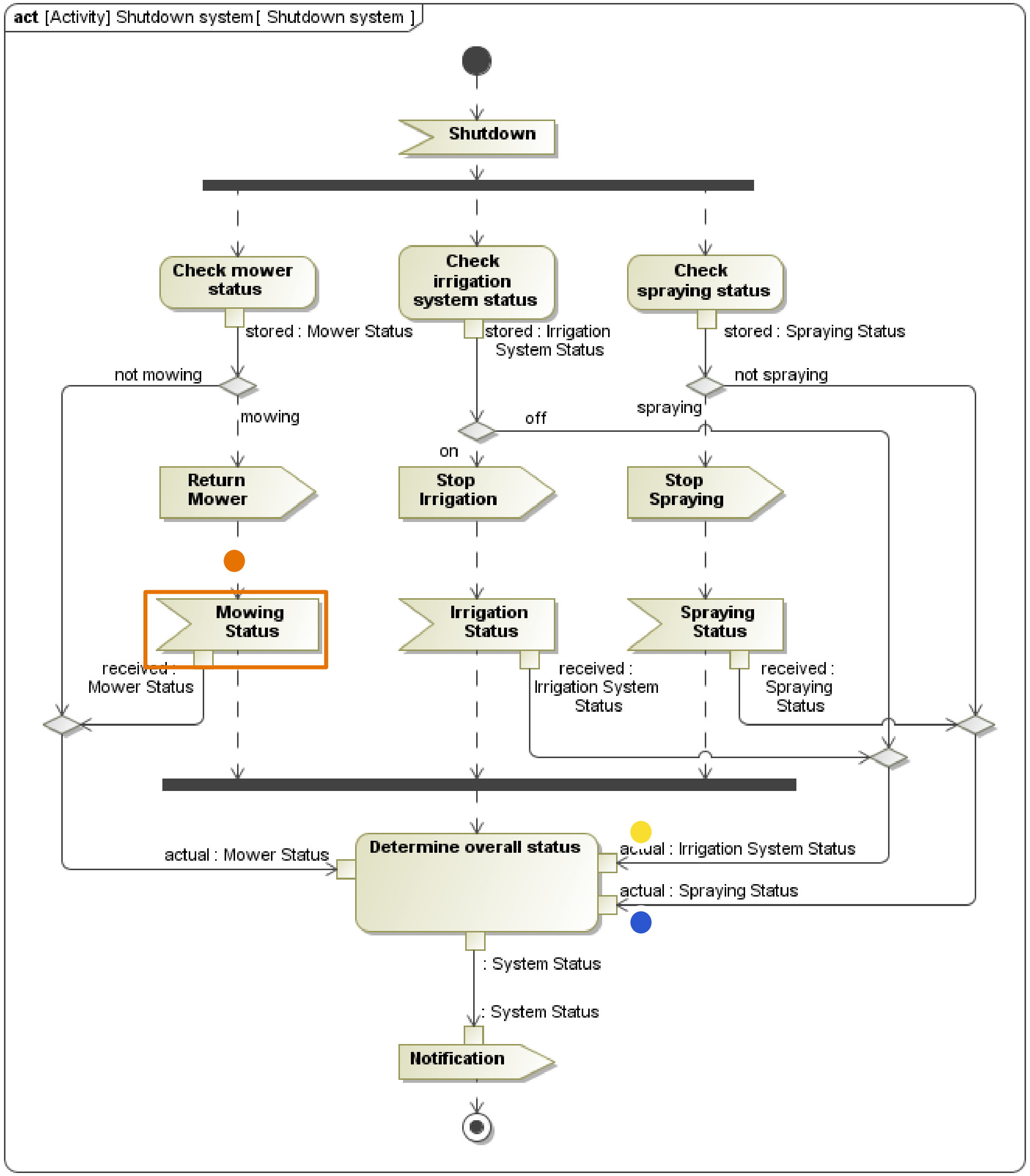
Example: Shutdown system



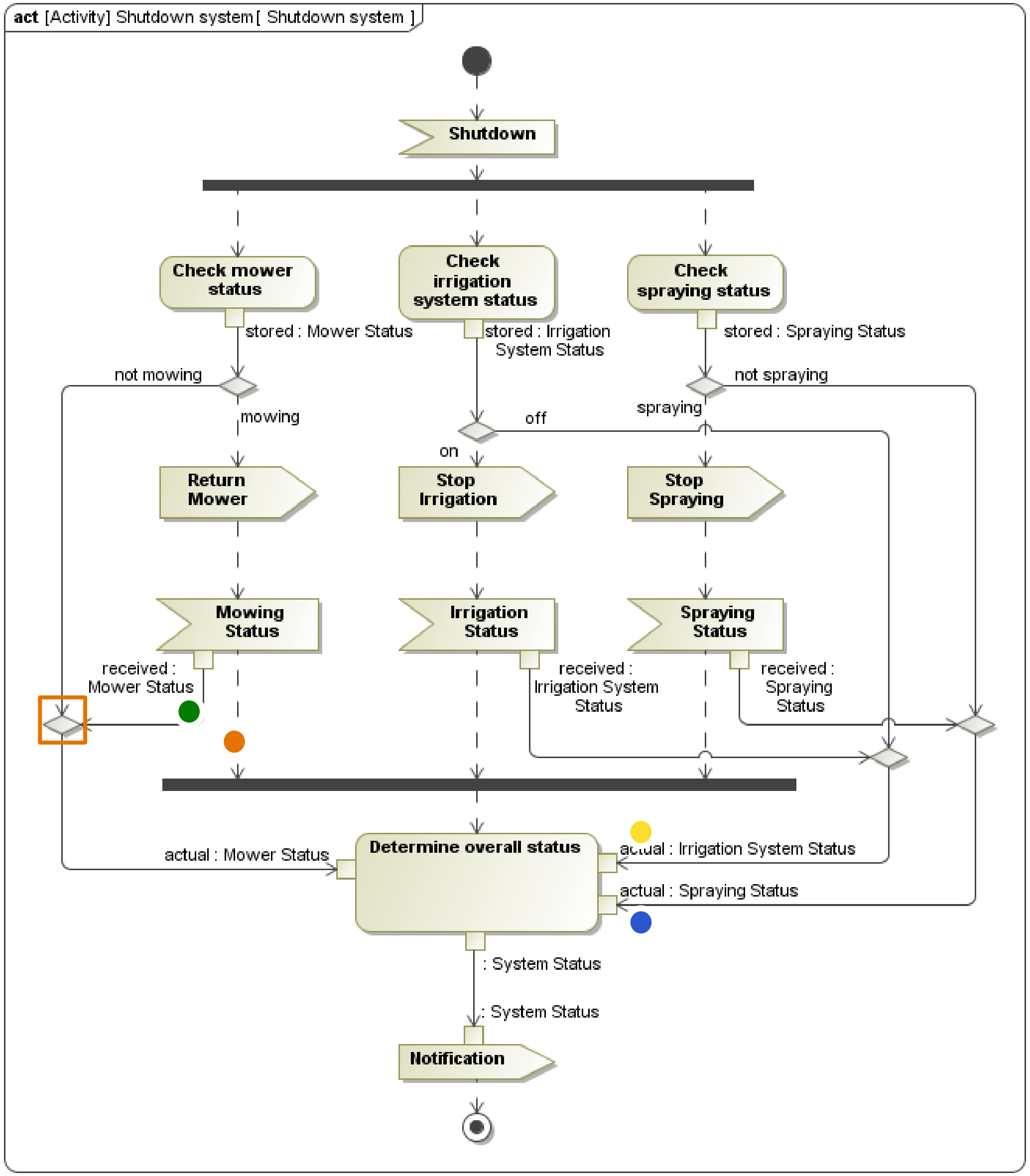
Example: Shutdown system



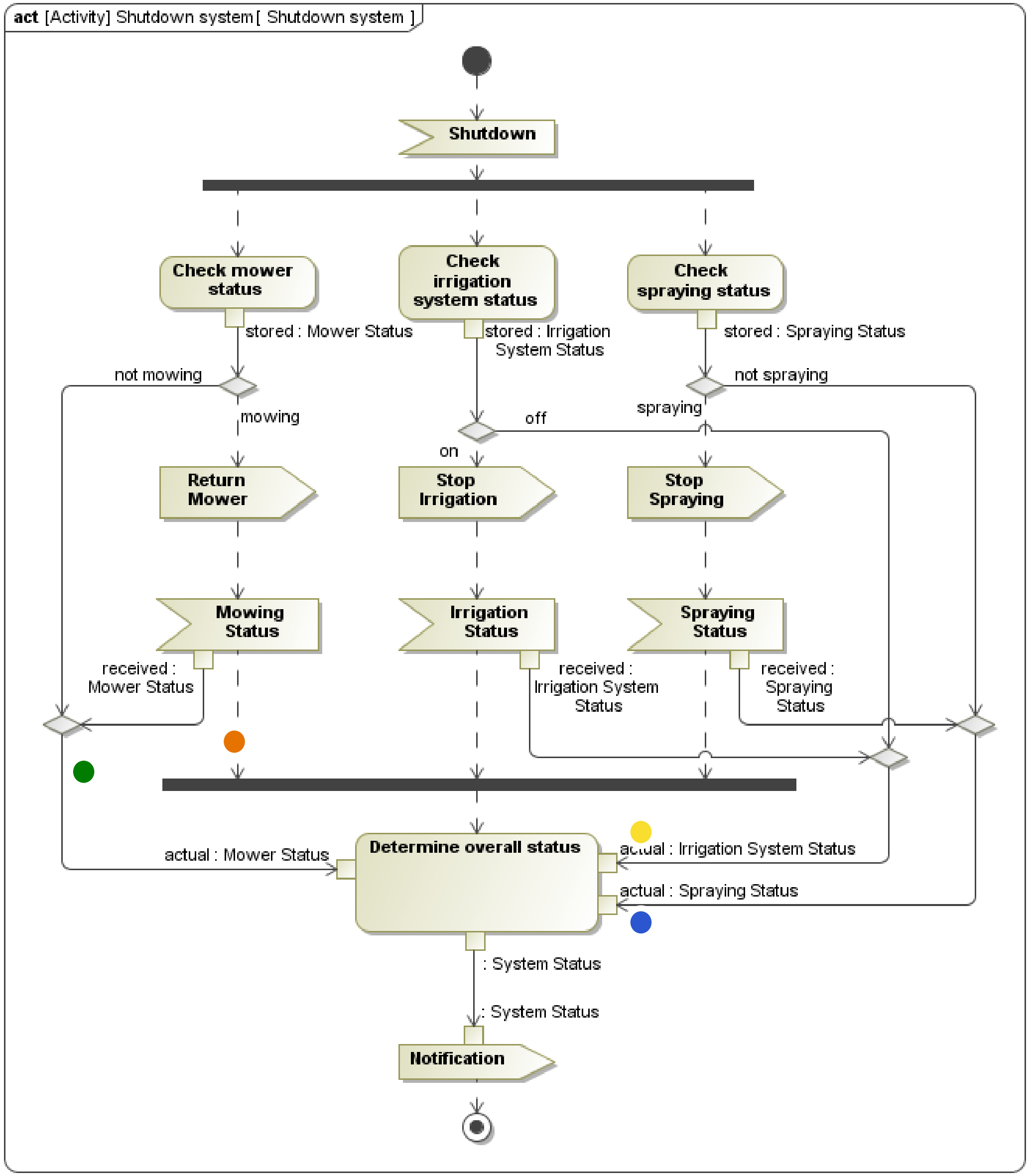
Example: Shutdown system



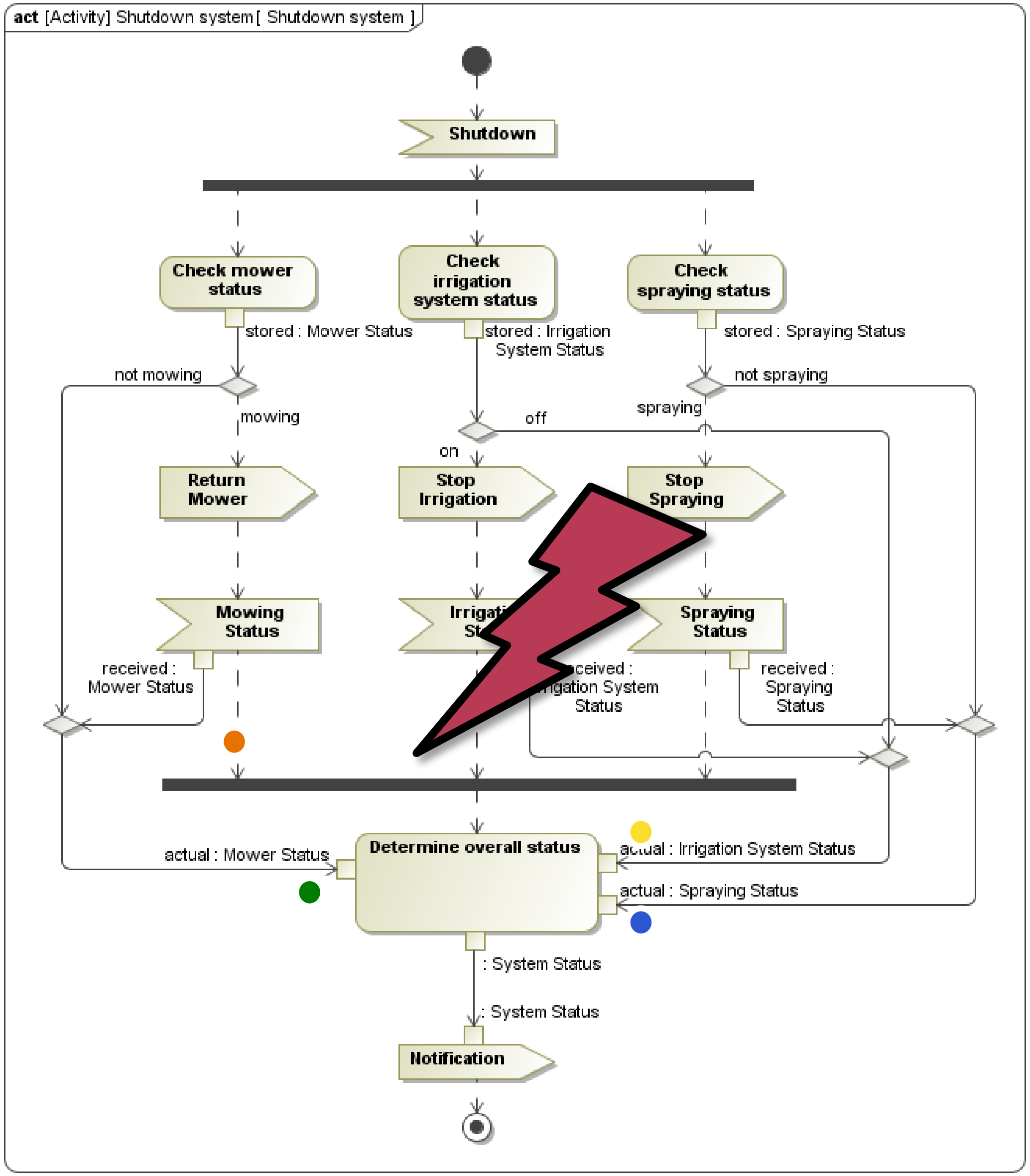
Example: Shutdown system



Example: Shutdown system



Example: Shutdown system



Modeling Flow Based Behavior with Activities

Context of the Modeling Aspect

Modeling Elements & Notation

Semantics of the Model

Summary

Summary

- Goal
  - Model transformation of input to output in processes
  - Combined modeling of control and data flow
- Modeling aspect
  - *What are the steps in a process?*
  - *What data flows in the process?*
- Relations to other aspects
  - Refines requirements, use cases and interactions
  - Allocates activities to blocks
  - Defines behavior of blocks, operations or in state machines