MARTE and Model transformation

Ansgar Radermacher / Asma Smaoui
ansgar.radermacher@cea.fr

Acknowledgments – contains material from my CEA colleagues
Shuai Li, Jérémie Tatibouët, François Terrier, Sébastien Gérard

Agenda

1. UML MARTE
    1. **Motivation, history, packages**
    2. Selected packages
    3. Example
    4. Schedulability analysis
2. Model transformation
    1. Principles
    2. Languages

MARTE

- Complex system modeling
  - UML as base modeling language (for OO software architectures)
  - SysML for system engineering concerns
  - Requirements, mathematical expressions, continuous behavior, etc…
  - Good industrial acceptance level
- What about concerns of real-time embedded systems (RTES)?
  - Embedded: autonomous system with limited resources & performance properties/constraints like energy consumption and resource contention
  - Real-time: data processing correctness also depends on time

MARTE

Need a language for
Modeling and **A**nalysis of **R**eal-**T**ime **E**mbedded systems

MARTE

What is MARTE?

- A modeling language for the RTES domain, based on several industrial systems and standards
- Implemented as a UML profile
- Standardized by the Object Management Group (who also standardizes UML among other things…)

Why MARTE?

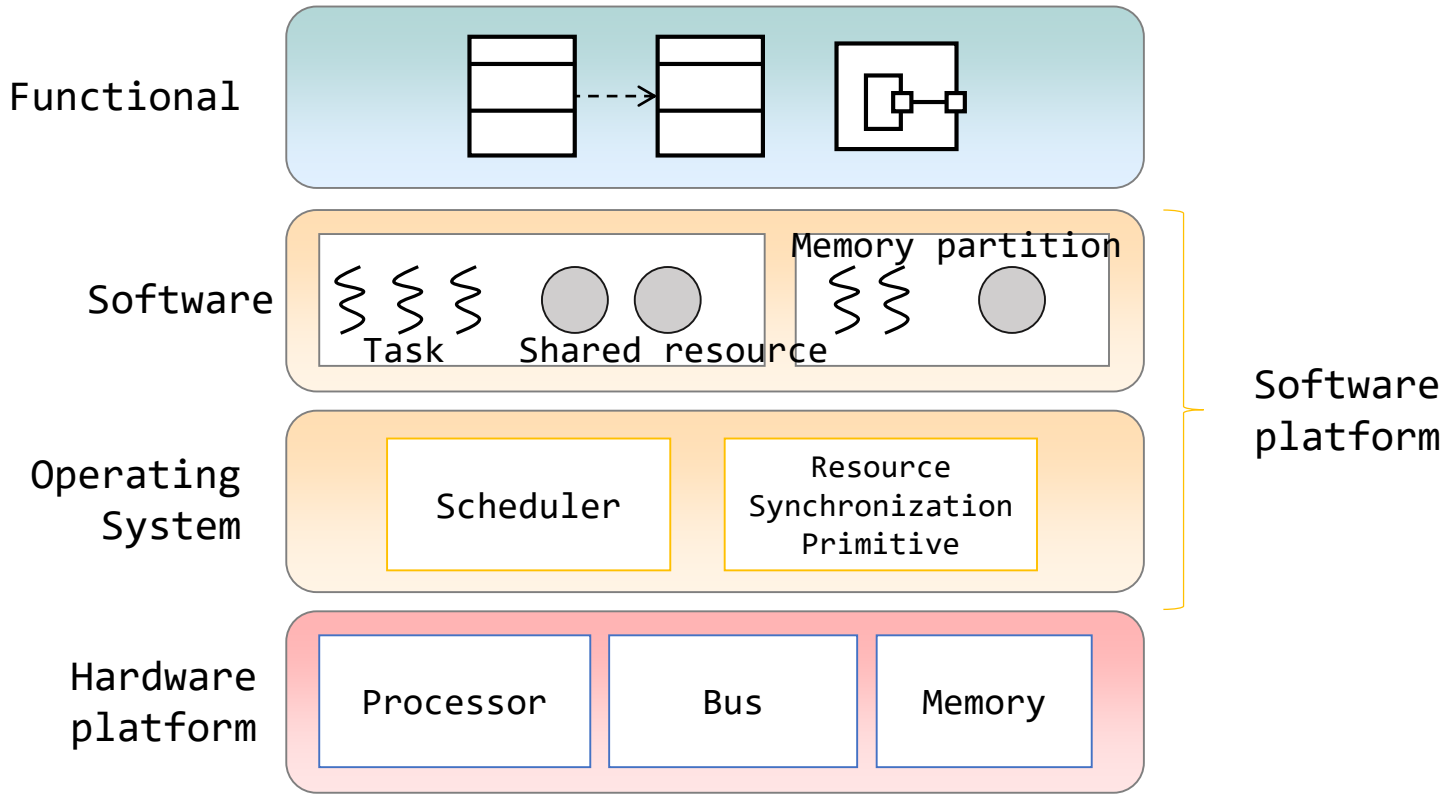
- Remember why UML was proposed:
  - Too many languages and tools for software design
    ⇨ interoperability not guaranteed, engineering expertise difficult to manage
  - UML unifies all these languages around a standard language that shares many software concerns
- Same situation for RTES:
  - Too many languages and tools for RTES design
    ⇨ interoperability not guaranteed, engineering expertise difficult to manage
  - Same problems as software design, so same pattern to solve the problem!
  - A standard language for RTES is hard to propose since this domain is very heterogeneous

Real-time Embedded System

- Embedded system
  - Computing system composed of hardware and software
  - … with a specific mission while using limited resources (e.g. processing, memory, battery).
  - Embedded within larger system. Interaction with execution environment
- Real-time system
  - Computing system composed of hardware and software,
  - Computing is subject to time constraints – take some input some data, then launch some behavior or produces some output **within a time limit**.
  - Produced data must not only be correct (functional correctness) but also arrive in time (temporal correctness). Time constraints impose deadlines

Real-time Embedded System

A RTES can be characterized by its architecture



This is a simplified view of the RTES architecture from the viewpoint of a real-time software engineer!

Real-time Embedded System – Terminology

- Function – a sequence of instructions to be executed. The system executes functions to accomplish its mission. Functions may be encapsulated.

- Functional architecture – specifies the functions, their eventual encapsulation, the data types they handle, and their data dependencies through interfaces.

Real-time Embedded System – Terminology

- Task – a unit executing a set of instructions
  - task release = release a job of the task
  - Once released, instructions are executed on a processor and are either for computing or synchronization with other tasks.
- Priority – indicates its order of importance for scheduling.
- Worst Case Execution Time, WCET – longest possible time to execute a task on a specific processor.
- Worst Case Response Time, WCRT – longest possible response time from release to completion of any of its jobs.
- Deadline - the longest allowed response time.

Real-time Embedded System – Terminology

- Shared Resource – accessed by several tasks in a mutual exclusive manner to enforce data consistency.
  - The shared resource is protected by some primitive.
  - A task that wants to access a shared resource may be blocked by another task that has access to the shared resource.
- Memory Partition – a list of memory locations. A task can read from and write to the memory locations to which it is allocated.

Real-time Embedded System – RTOS

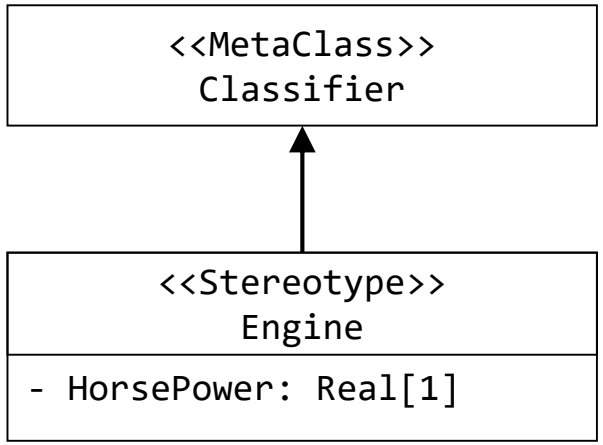
- Scheduler – part of RTOS
  - Selects which task **has access to the hardware processors at a given time**.
  - **Scheduling** = method by which tasks are given access to resources, noticeably computing resources, with the goal of respecting time constraints
  - Implements a **scheduling policy**. A policy (or scheduling algorithm) describes how tasks are given access to resources, like computing resources
- Resource Synchronization Primitive
  - OS handles the protection of shared resources
  - Tasks call synchronization primitives when they want to access the shared resources
  - May have a consequence on task scheduling

Real-time Embedded System – Hardware

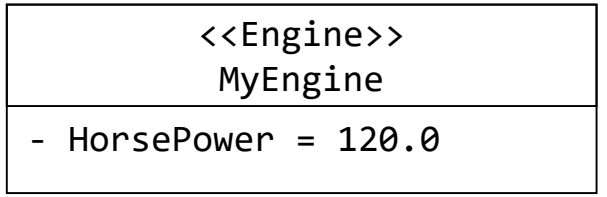
- The hardware platform has processors for the execution of the software. The system may be characterized according to the number of processors and how they interact:
  - Uniprocessor – only one processor core
  - Multiprocessor - several processor cores that share a common memory. The cores are connected by buses that are optimized for this kind of architecture.
  - Distribute – several processors that have their own memory. The processors are connected by buses forming networks.
  - Buses connecting processors may schedule messages with a scheduling policy. For example messages may have a fixed priority if transiting on some bus. Thus messages are scheduled on buses while tasks are scheduled on processors.

Modeling with MARTE

- MARTE is a UML profile for the RTES domain
- Modeling with MARTE depends on the development method, i.e. there is no unique way to model with MARTE, as long as the specification is respected

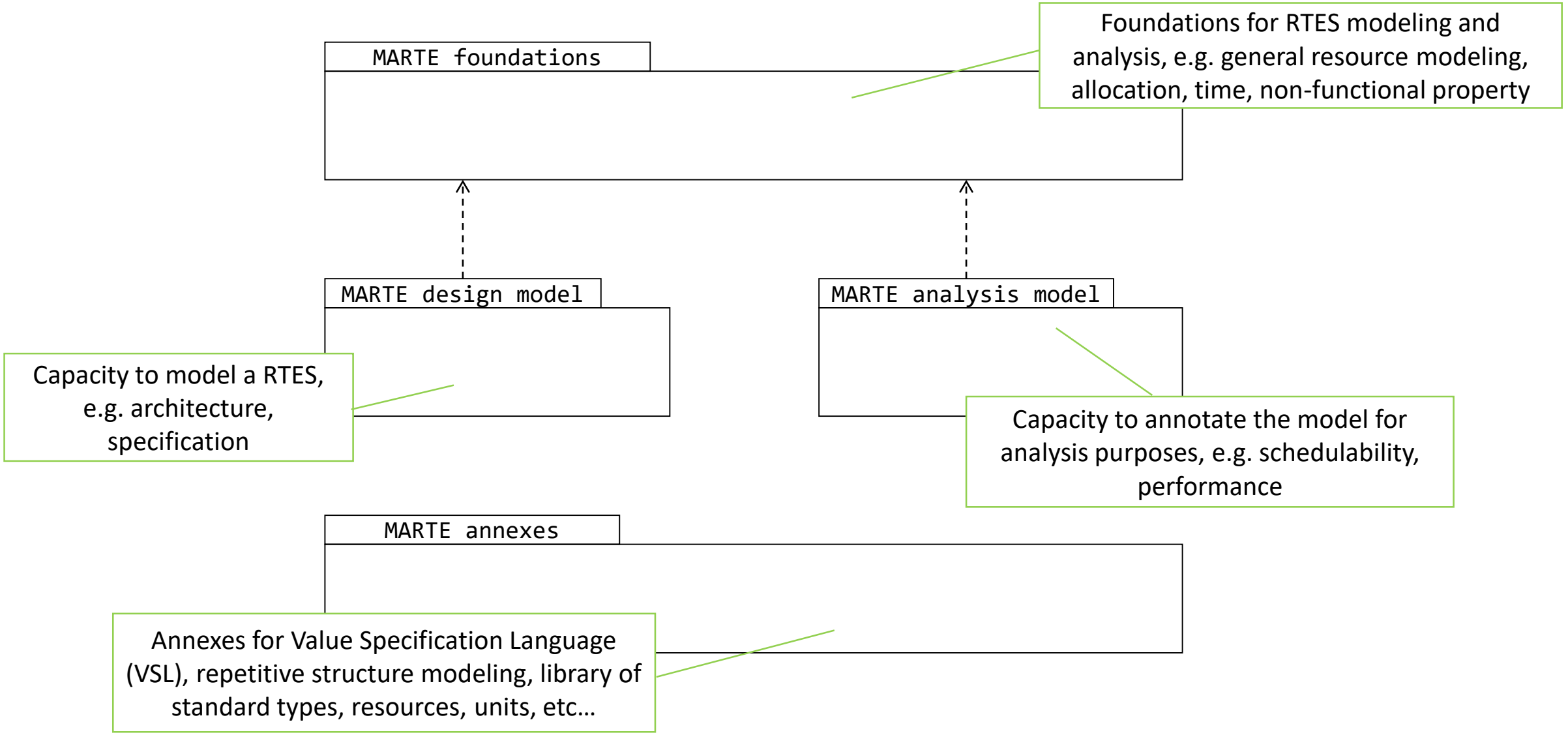


Profile definition

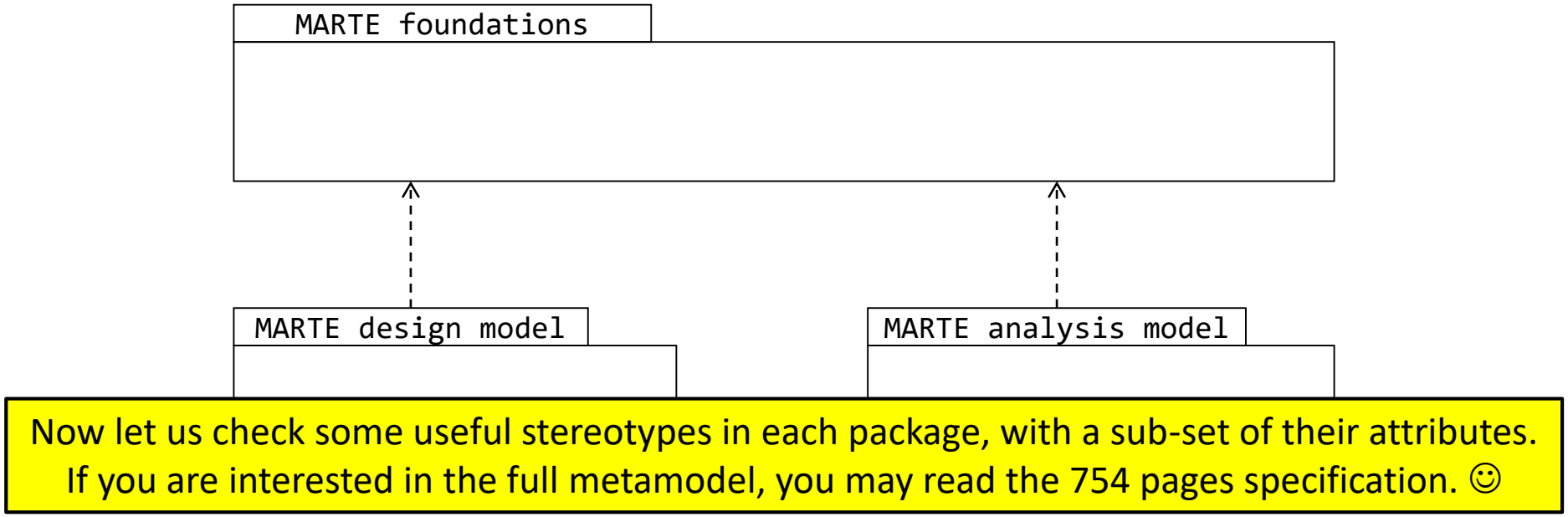


Profile usage

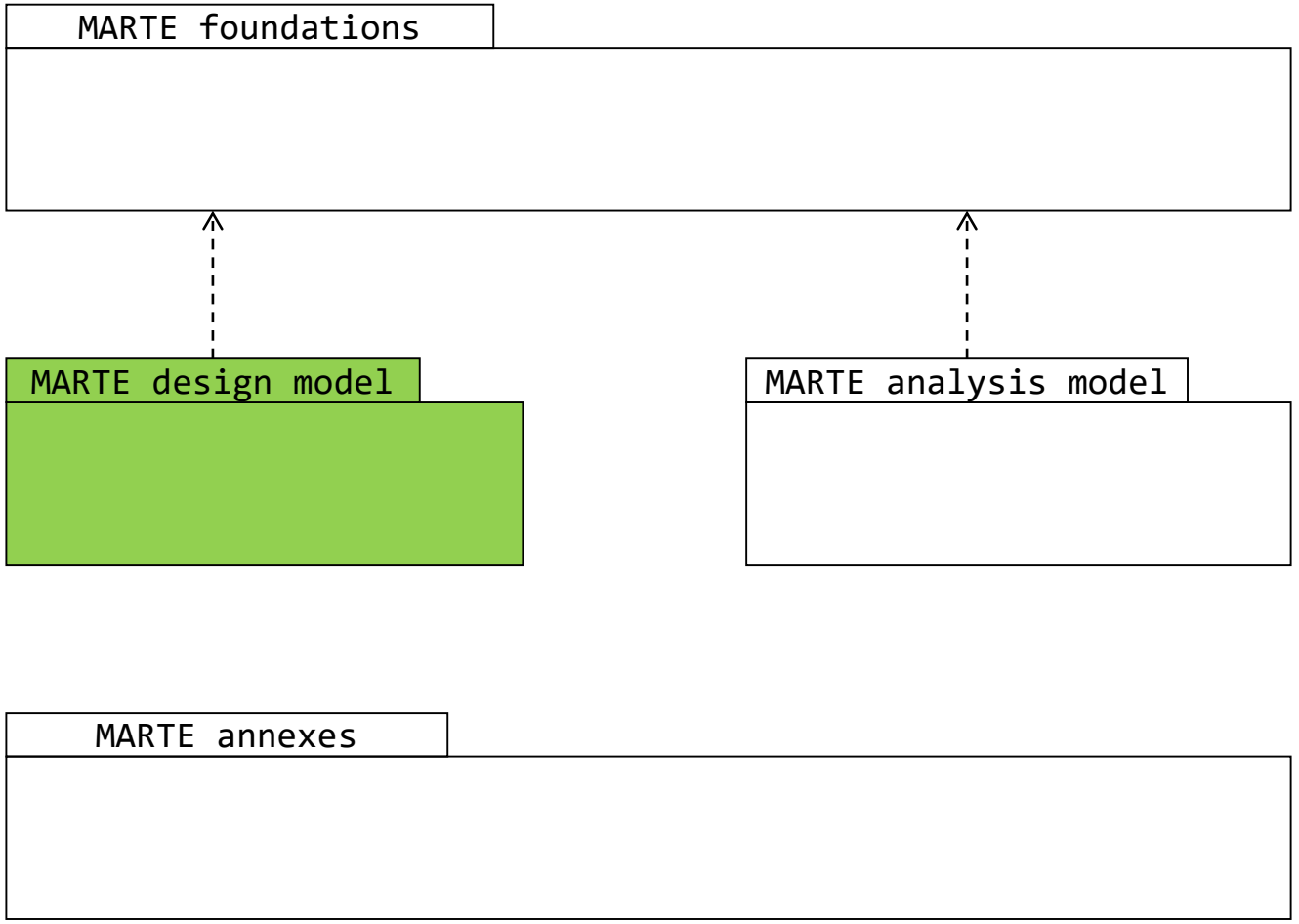
Modeling with MARTE – packages



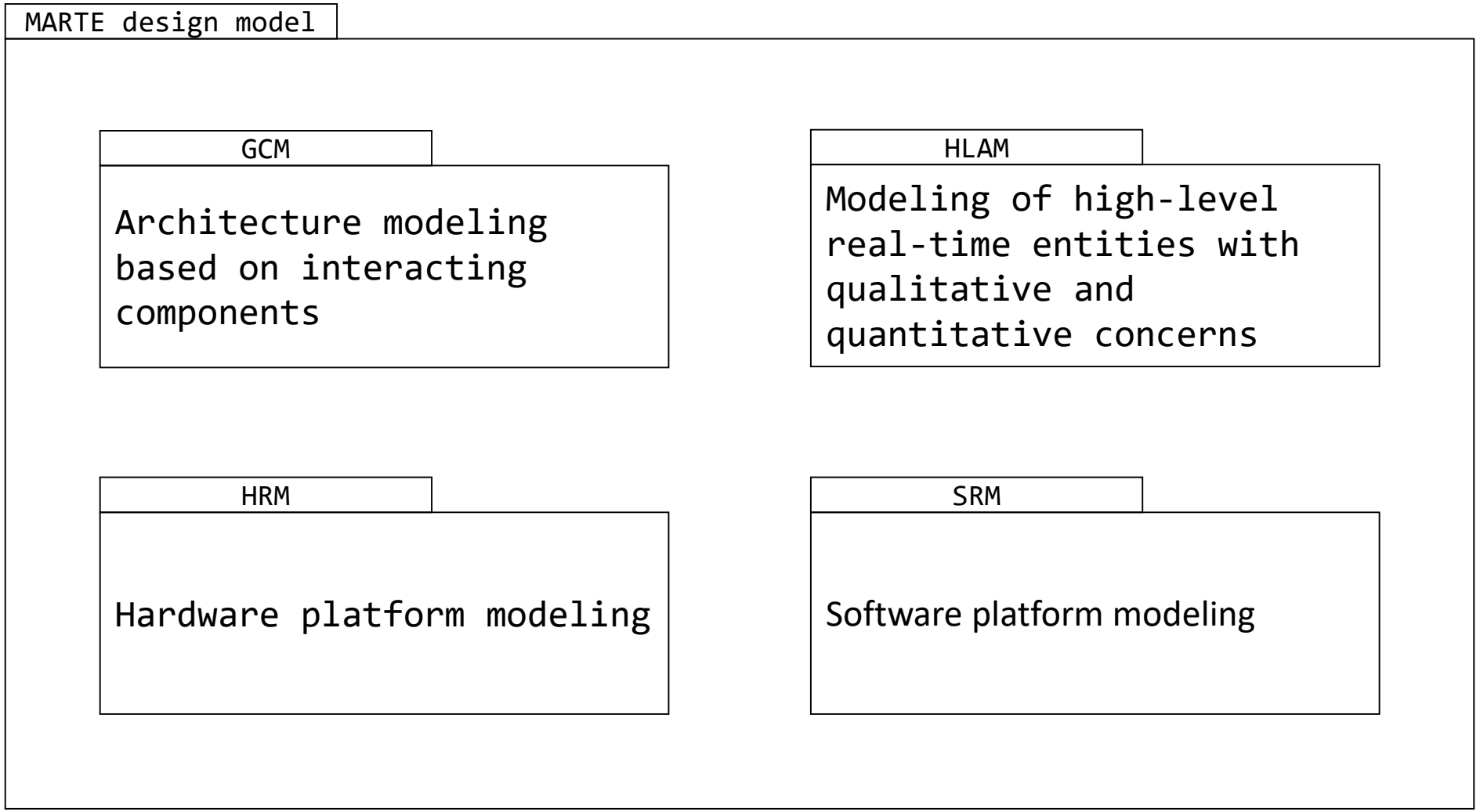
Modeling with MARTE – packages



Modeling with MARTE – packages



Modeling with MARTE – packages



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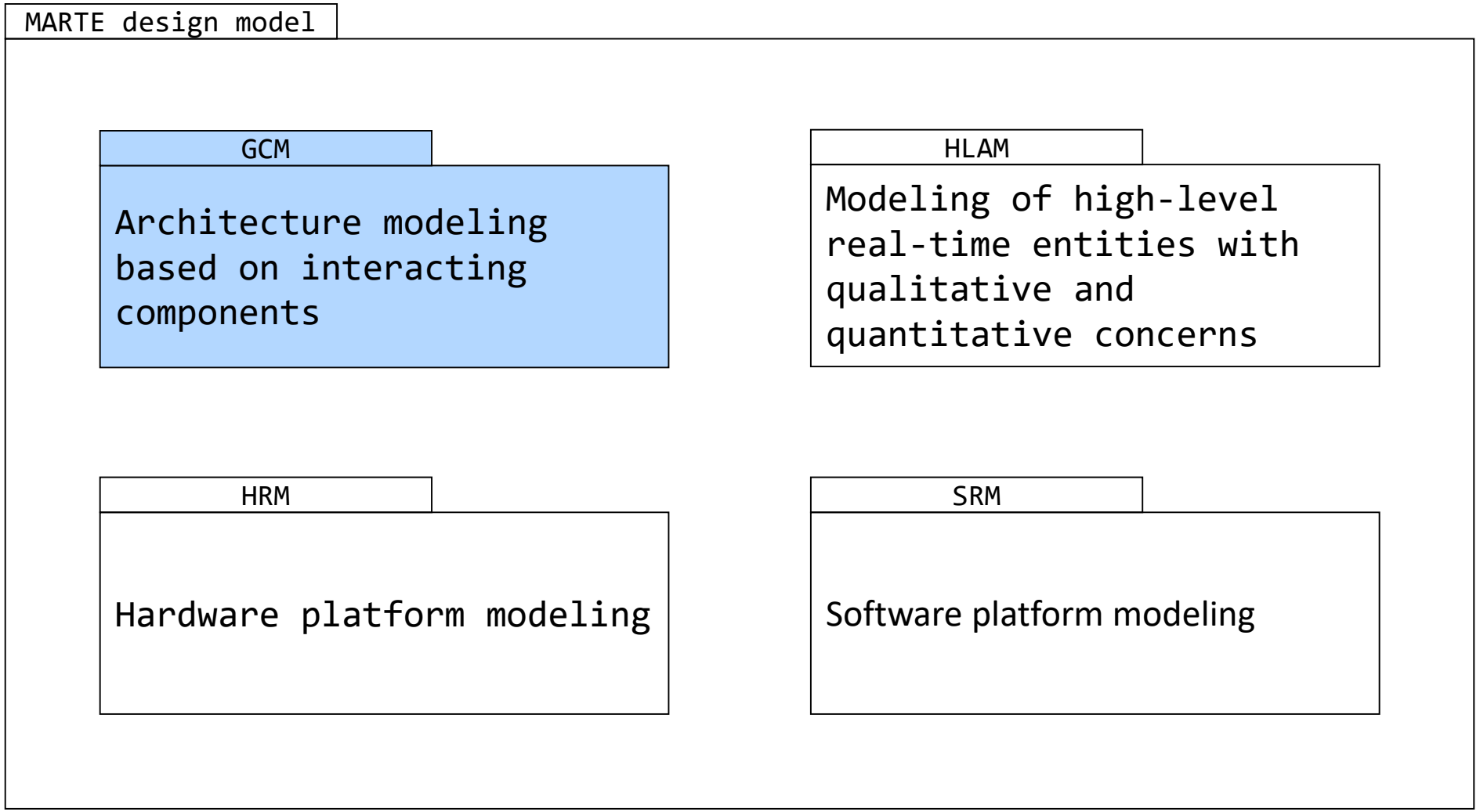
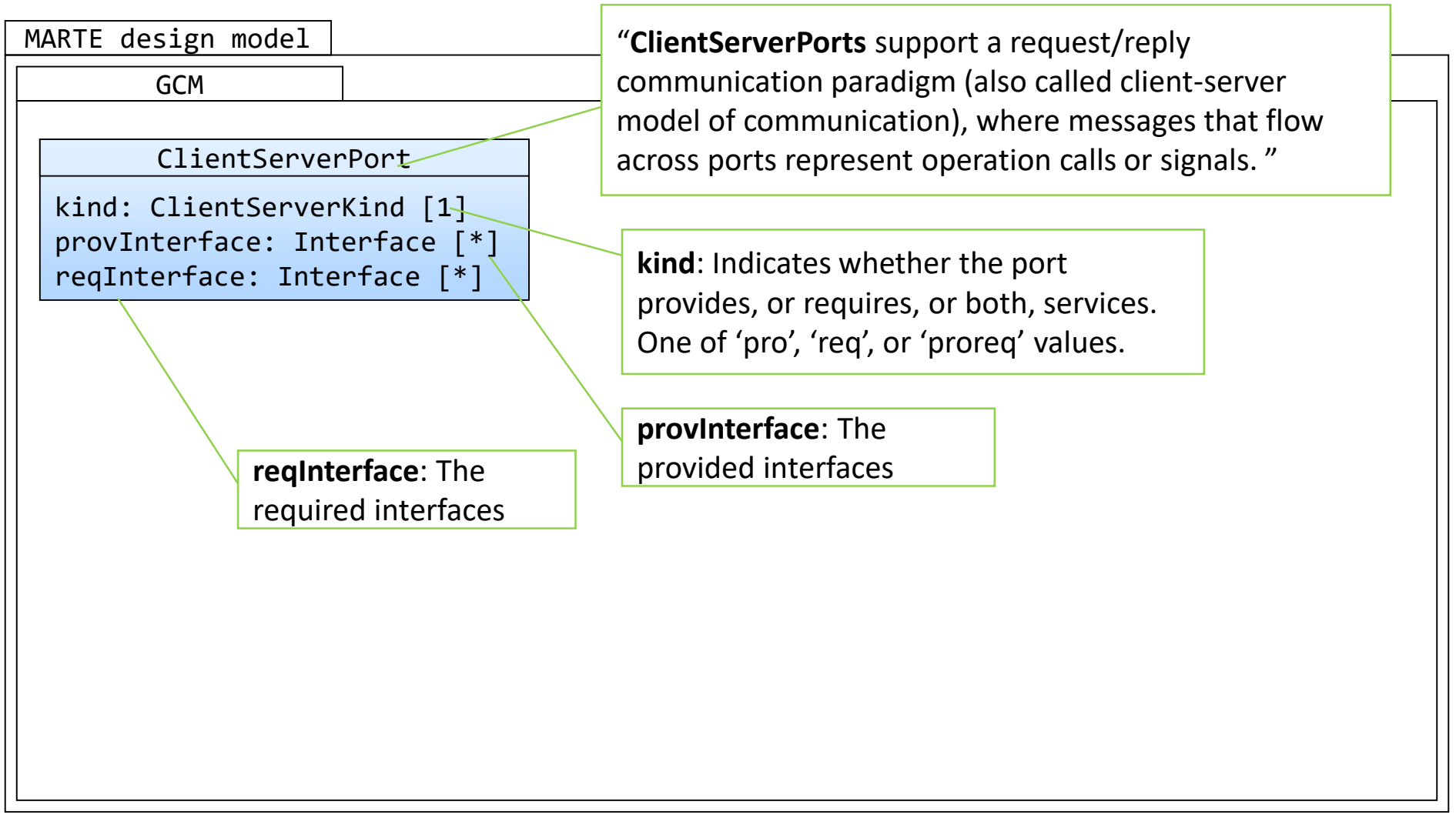
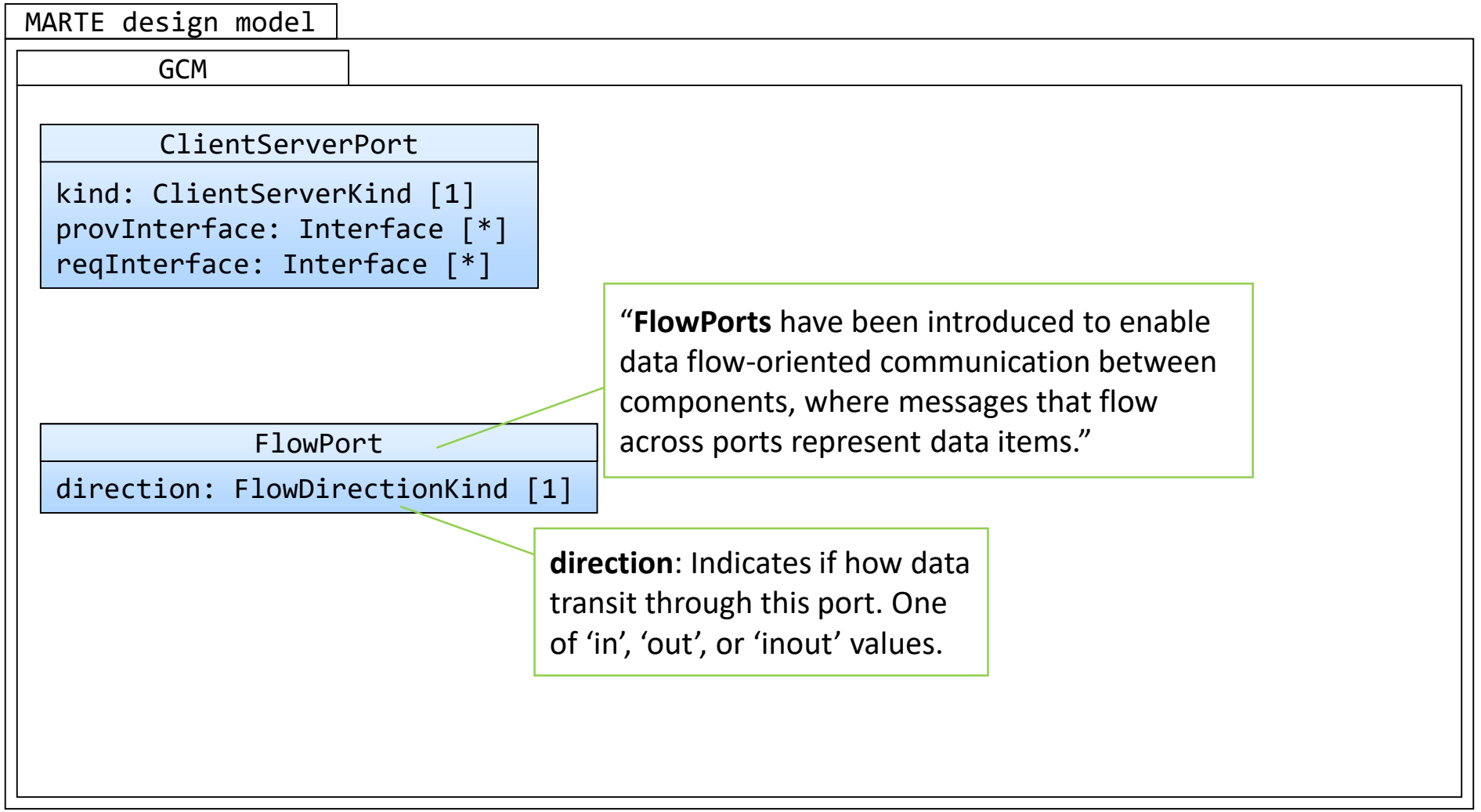
Modeling with MARTE – GCM



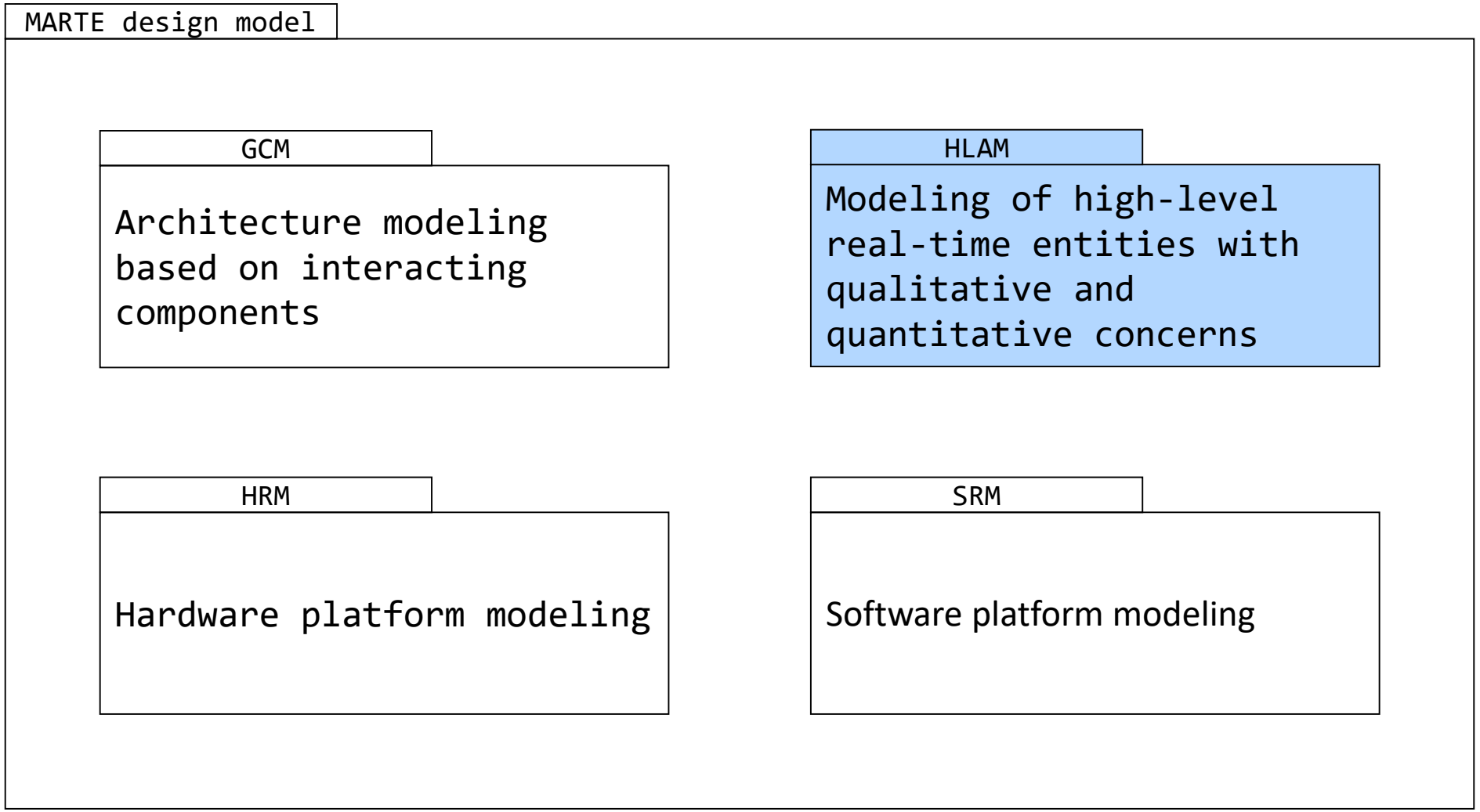
Modeling with MARTE – ClientServerPort



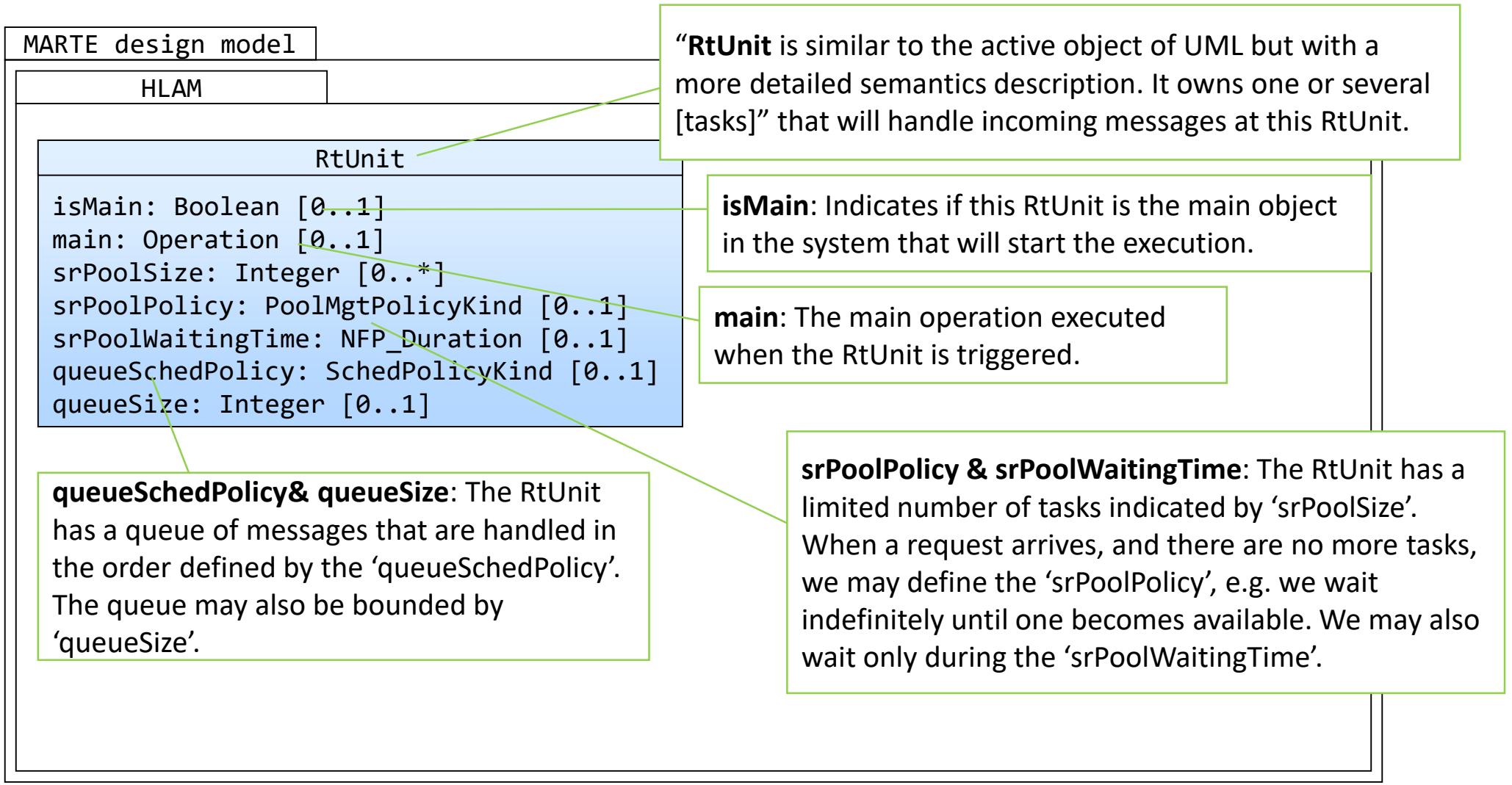
Modeling with MARTE – packages



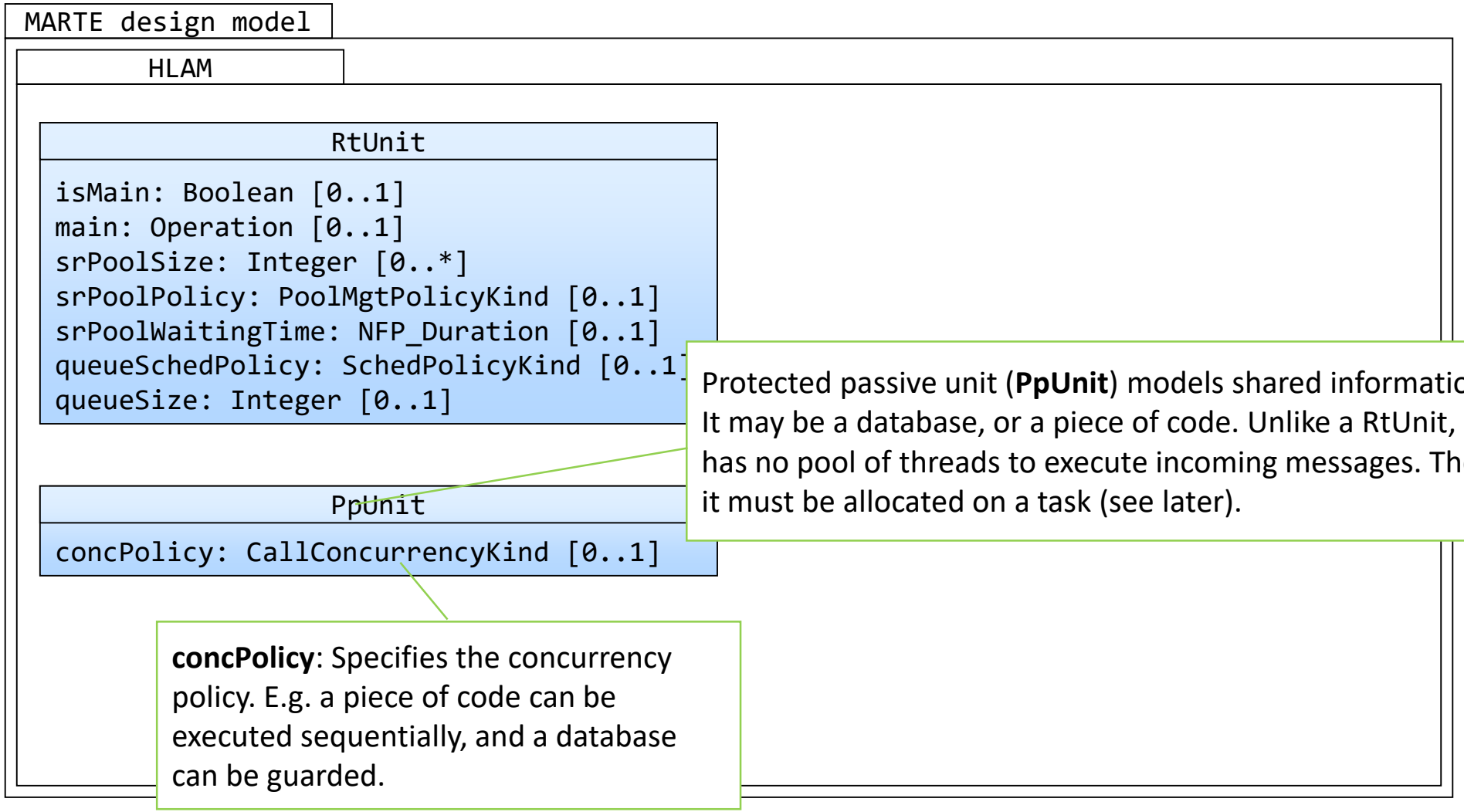
Modeling with MARTE – packages



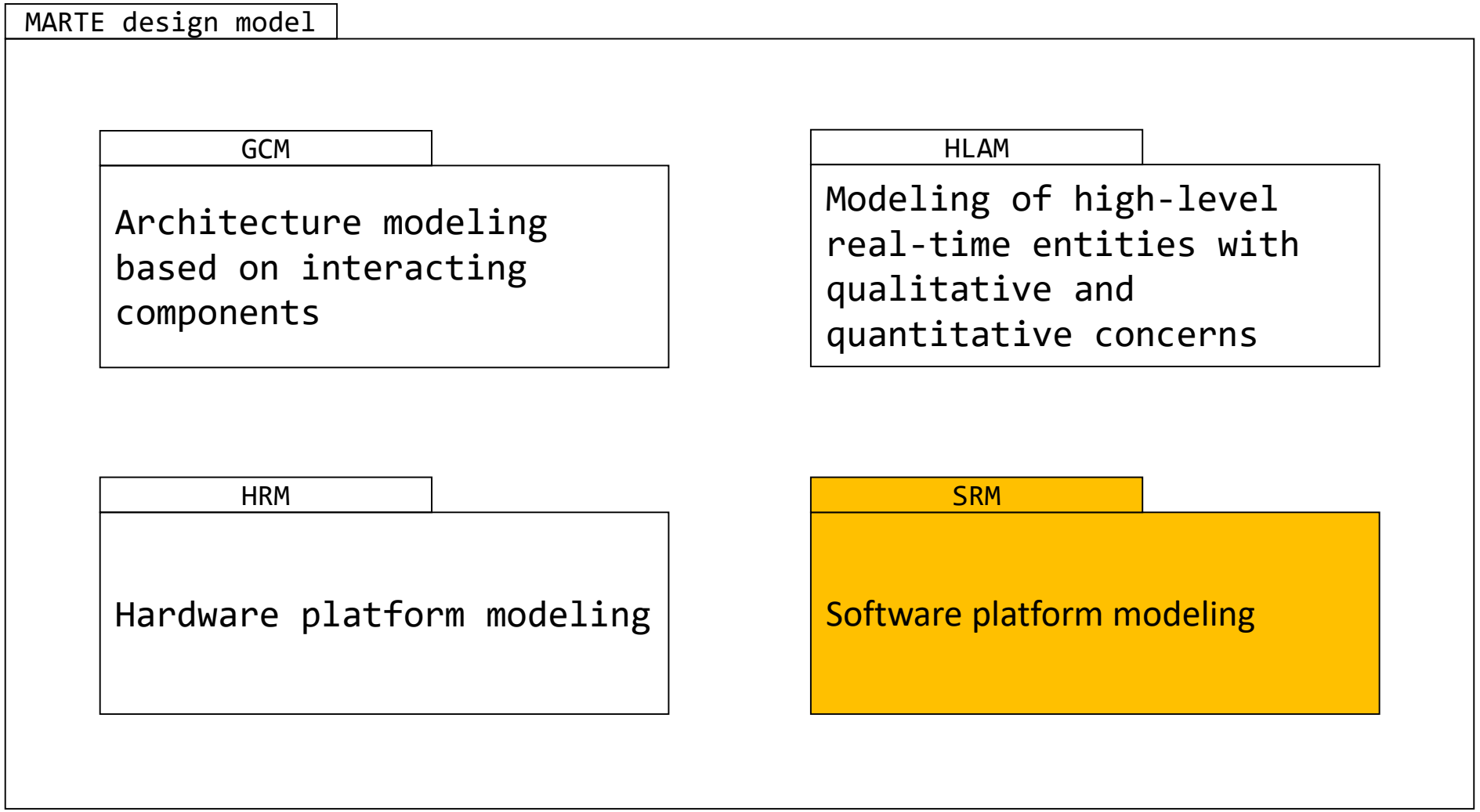
Modeling with MARTE – RtUnit



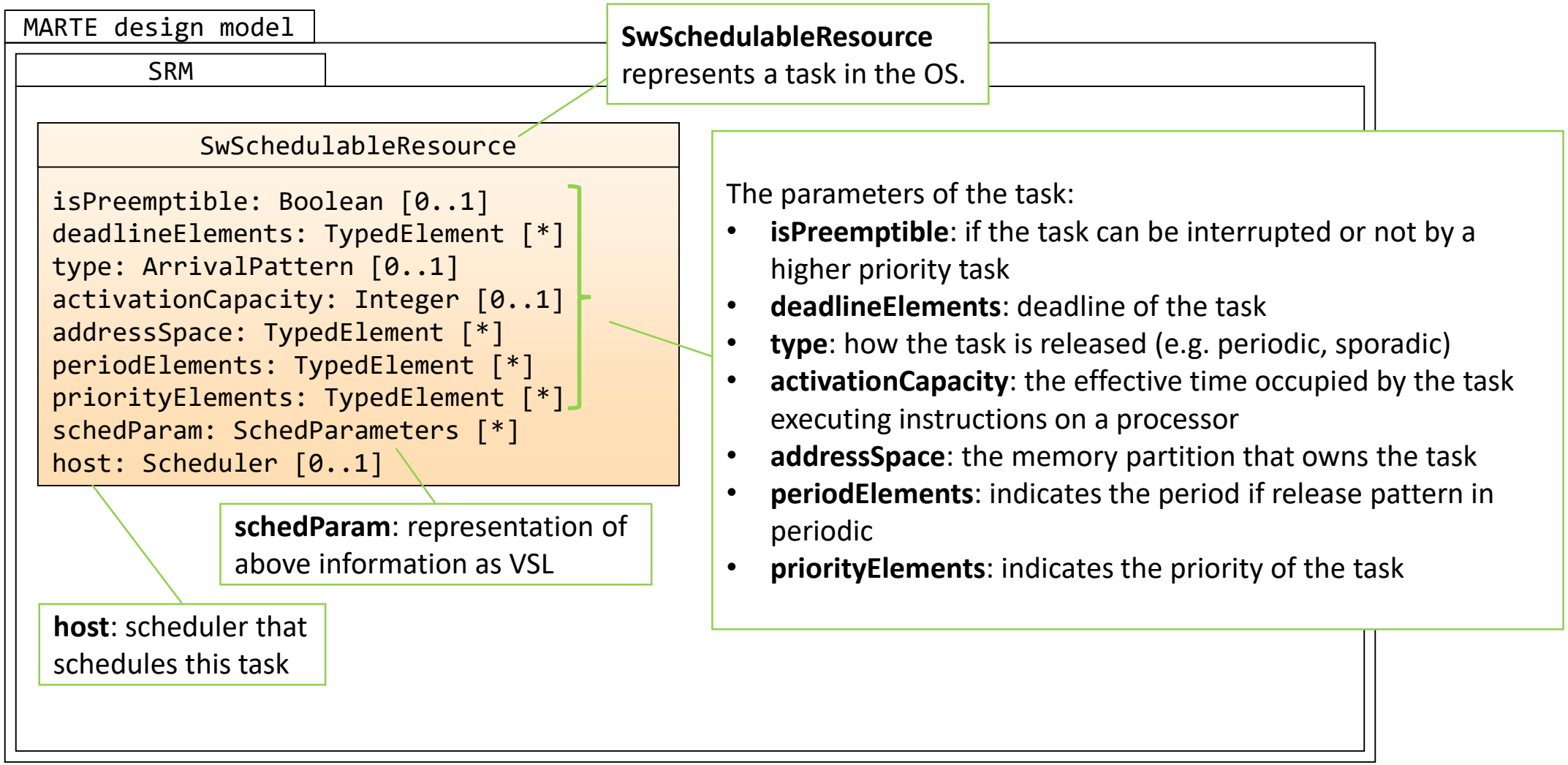
Modeling with MARTE – PpUnit



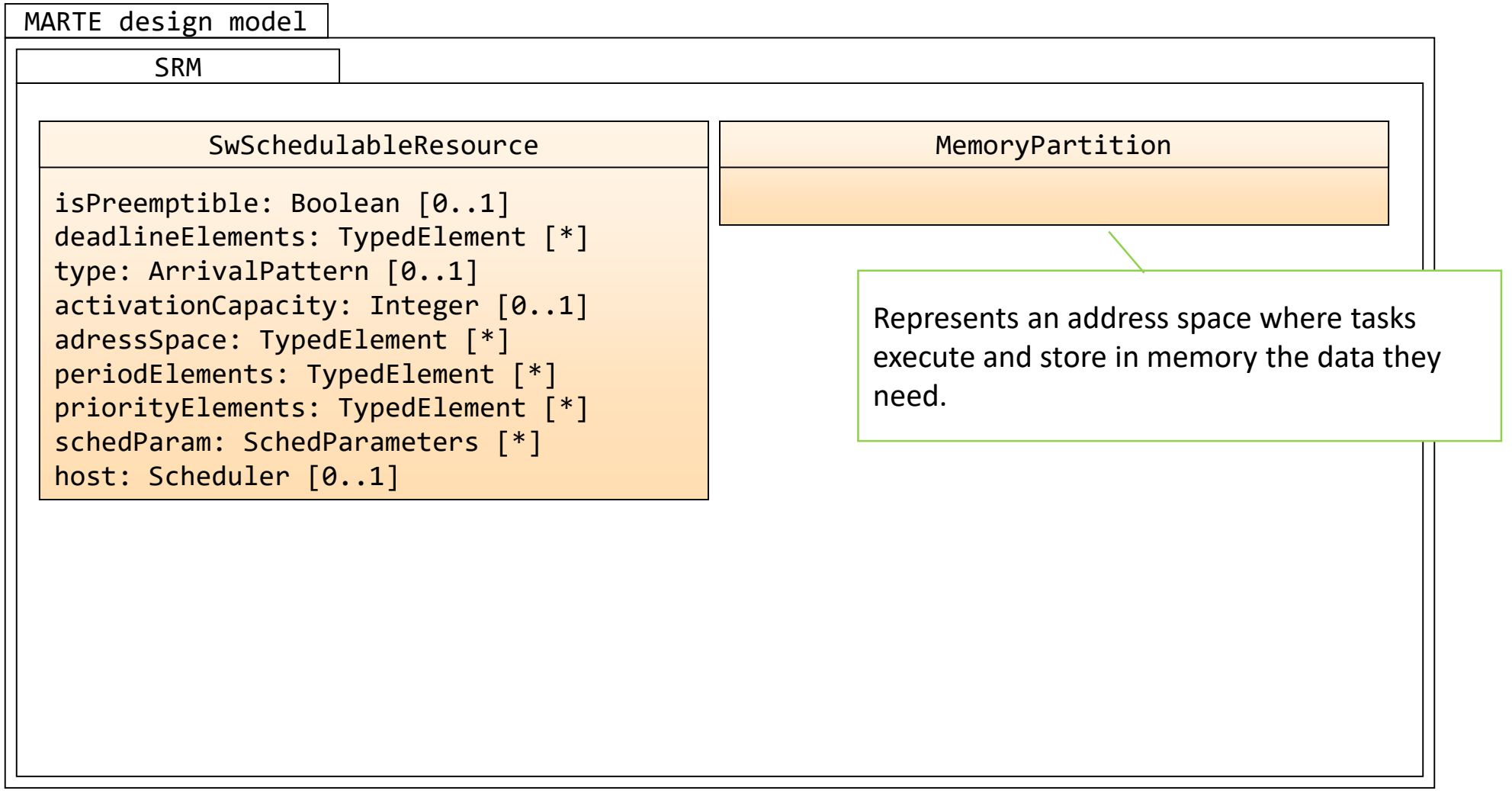
Modeling with MARTE – SRM package



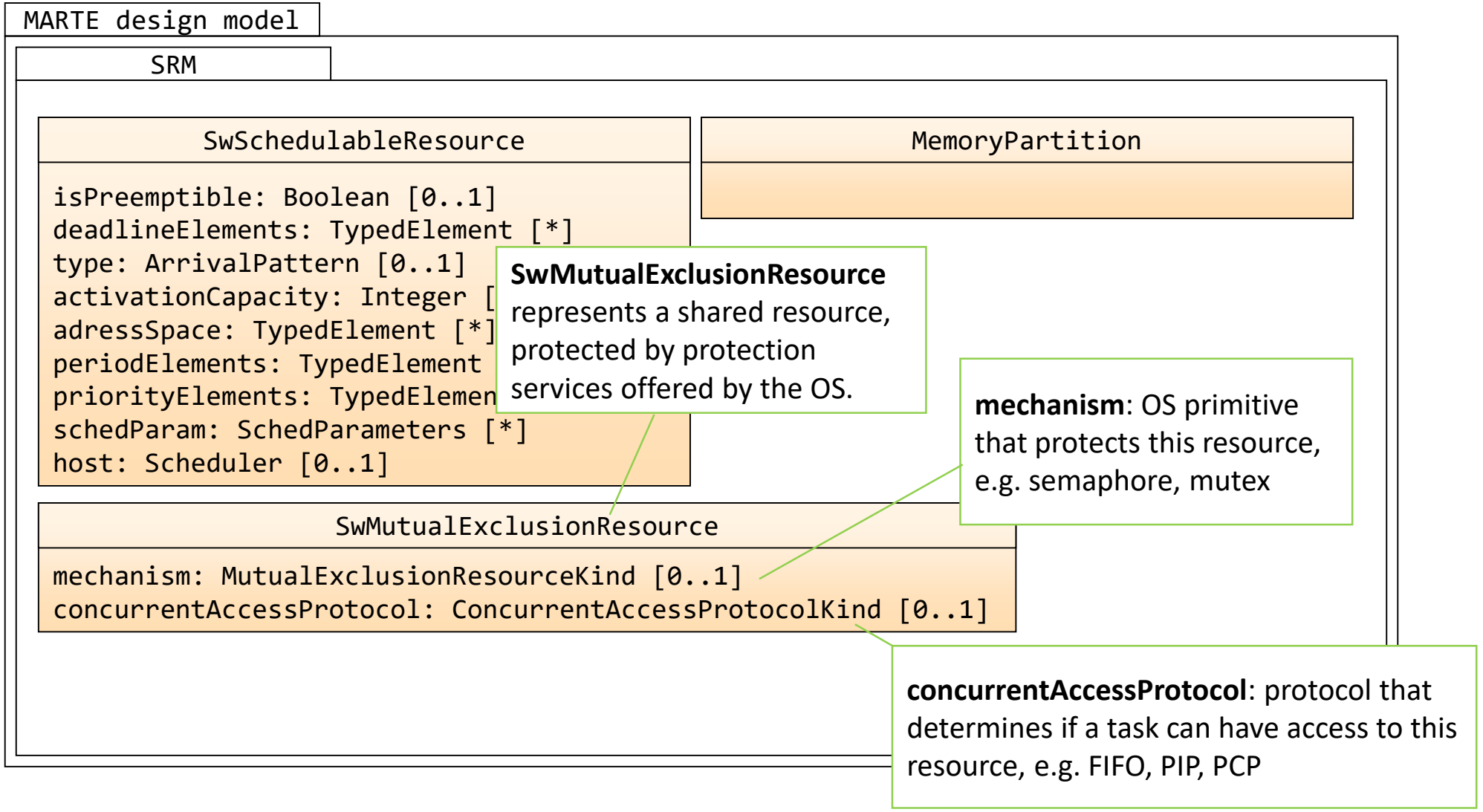
Modeling with MARTE – SwSchedulableResource



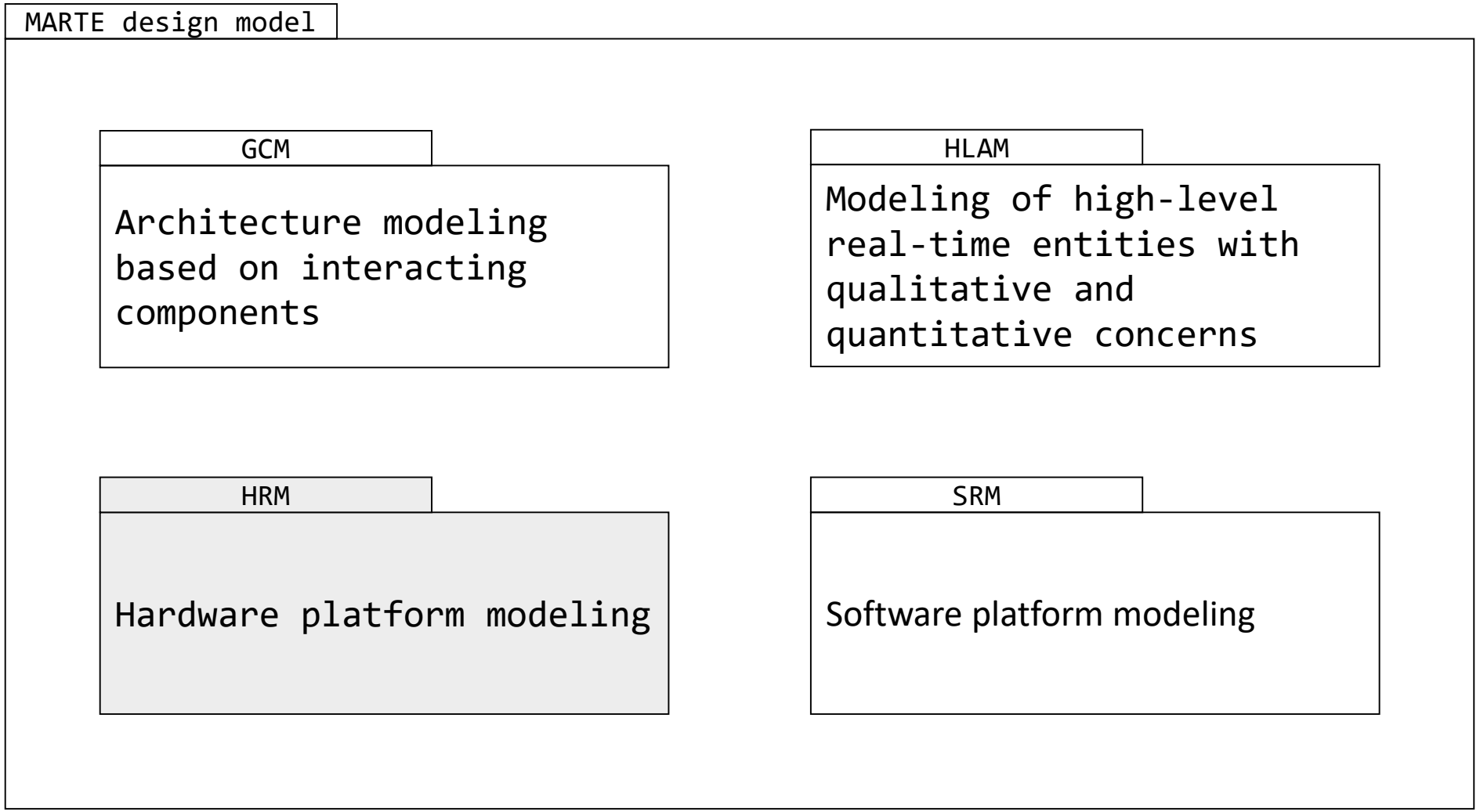
Modeling with MARTE – MemoryPartition



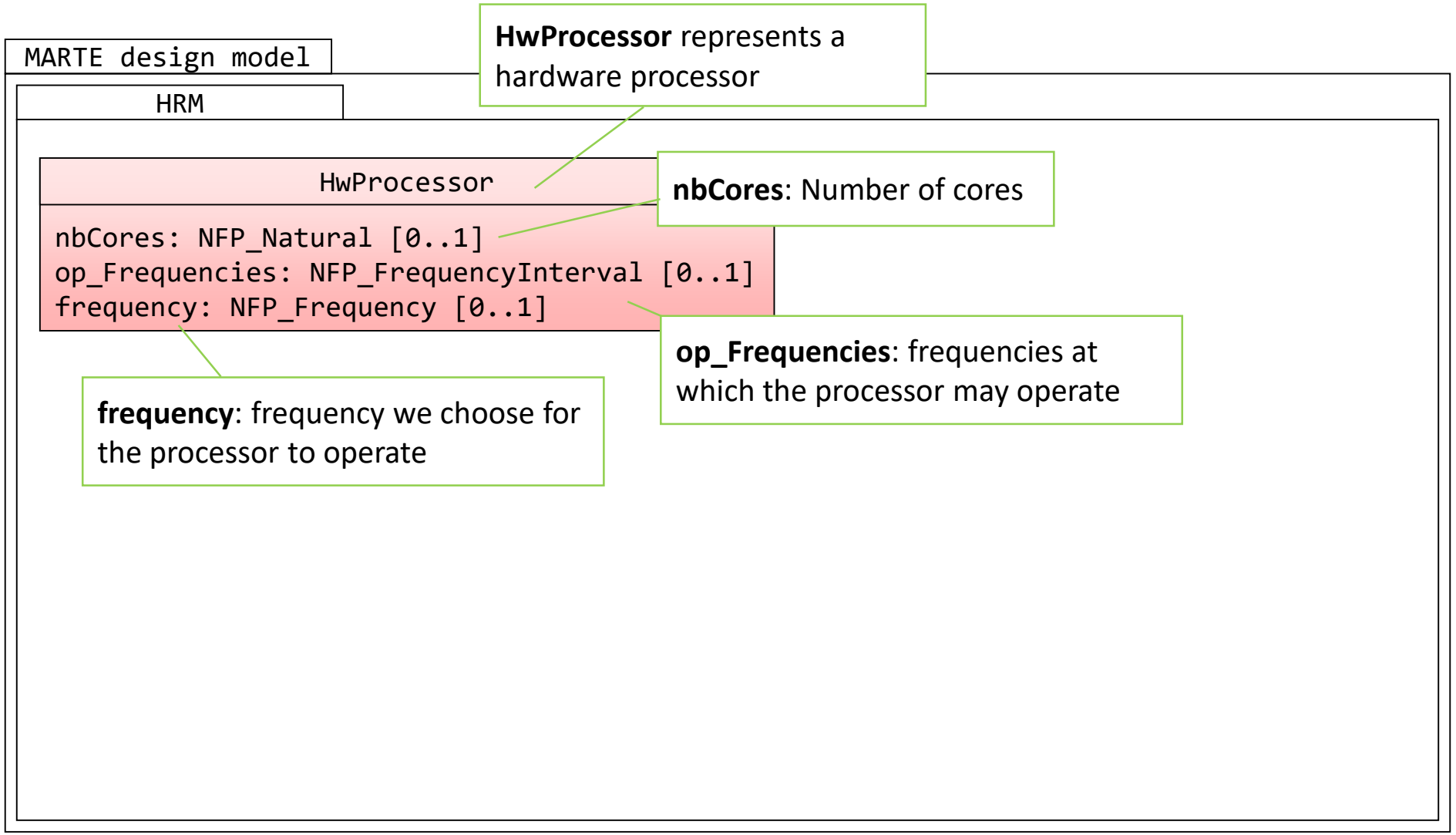
Modeling with MARTE - SwMutualExclusionResource



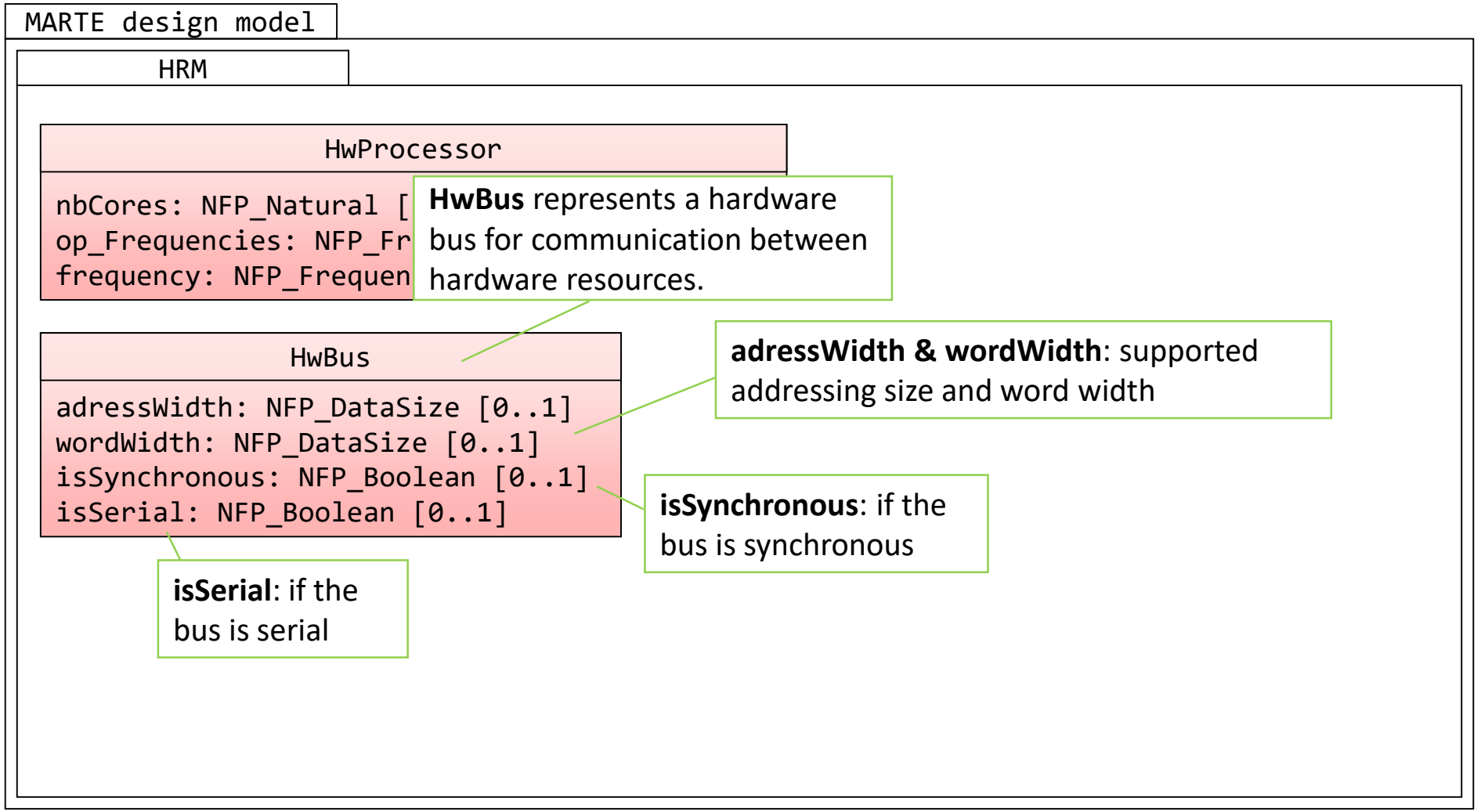
Modeling with MARTE – HRM package



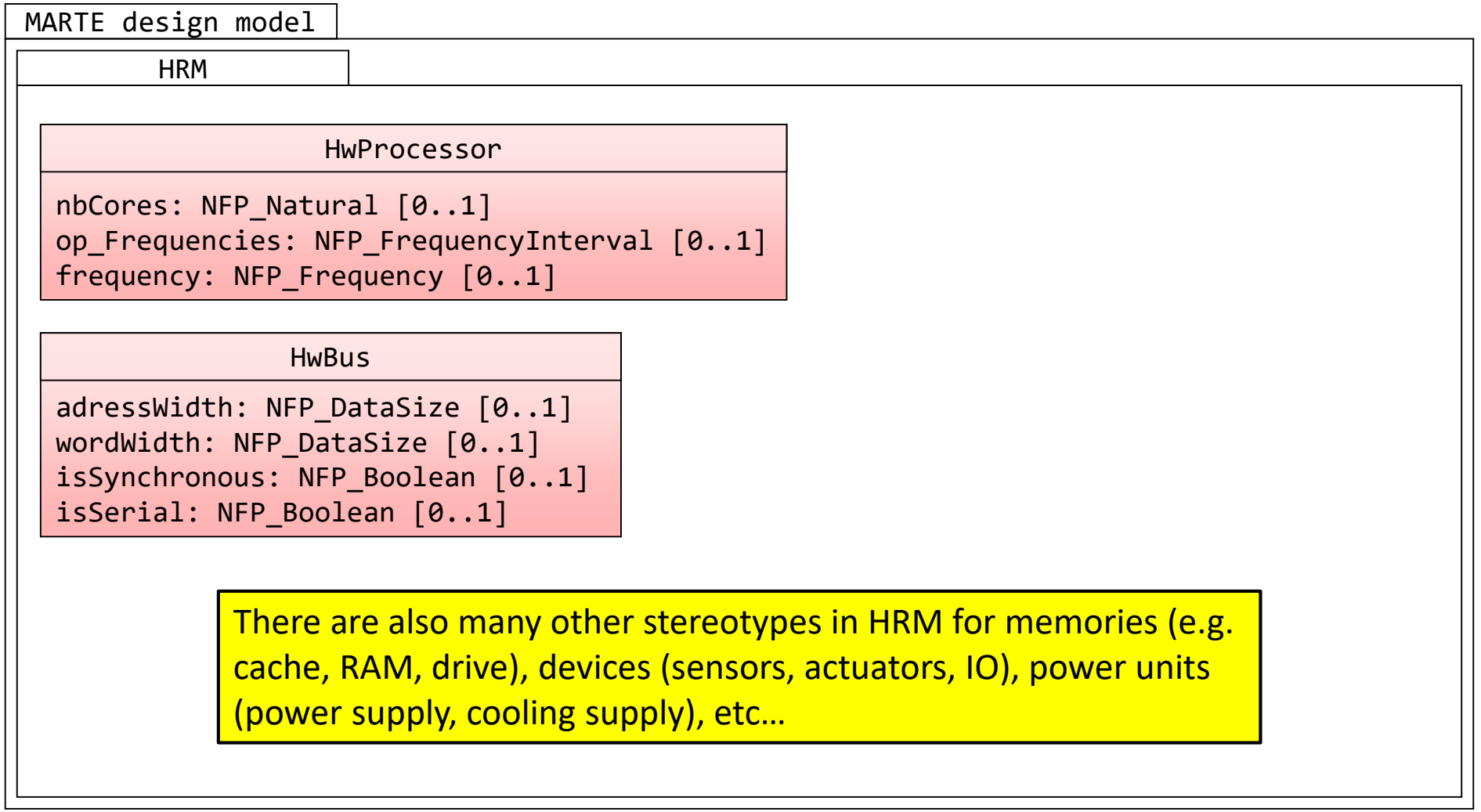
Modeling with MARTE – HwProcessor



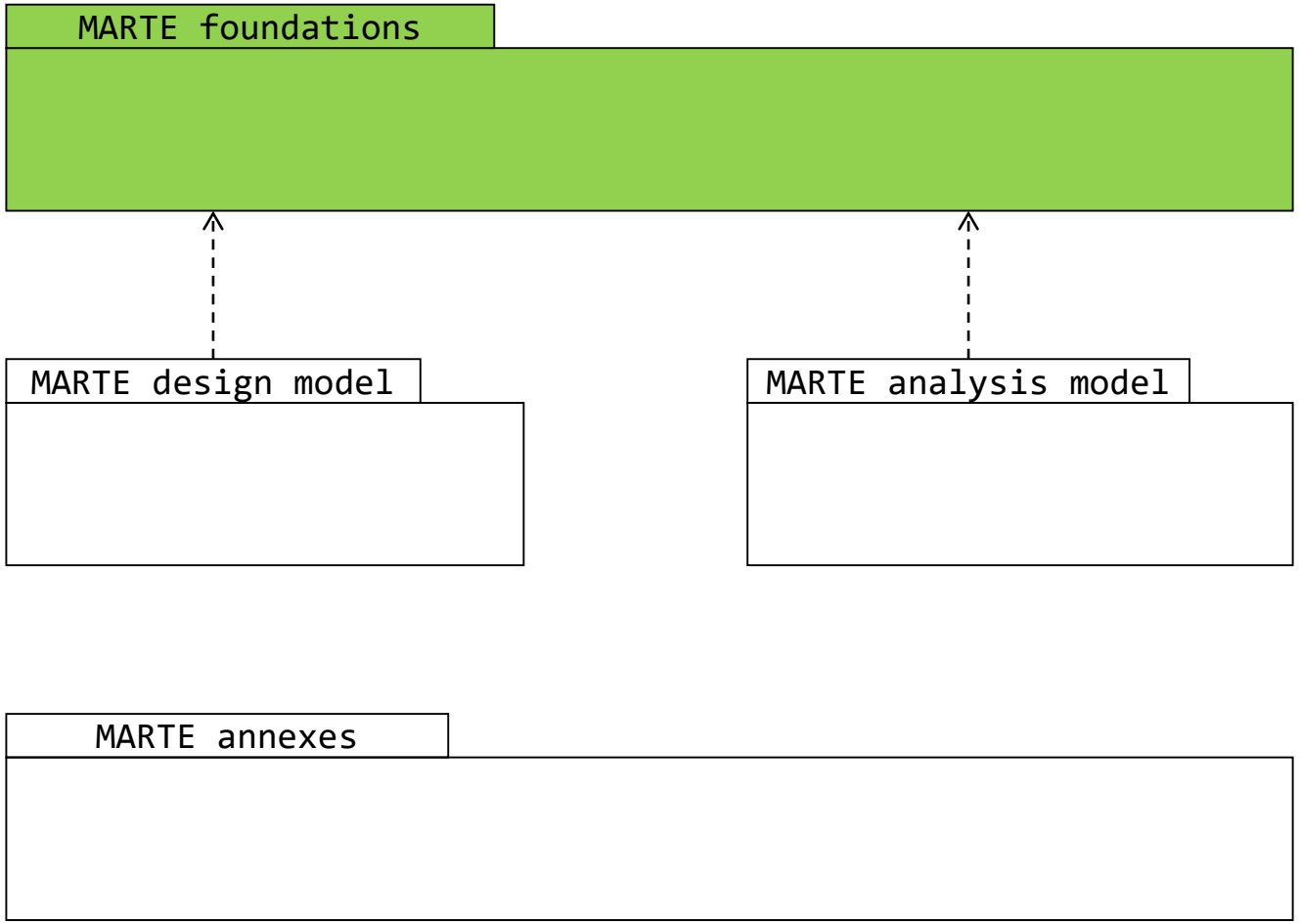
Modeling with MARTE – HwBus



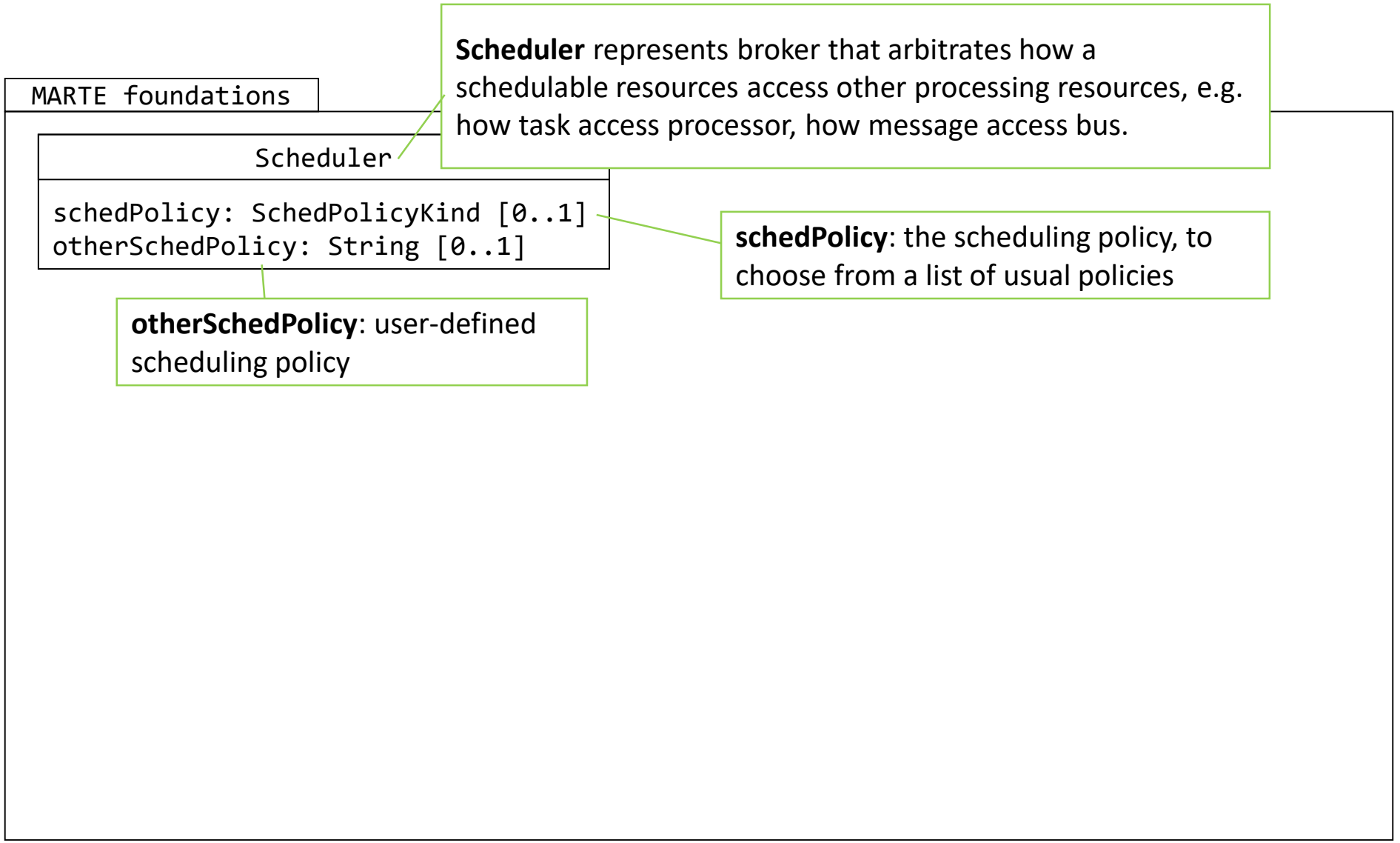
Modeling with MARTE – Further HRM stereotypes



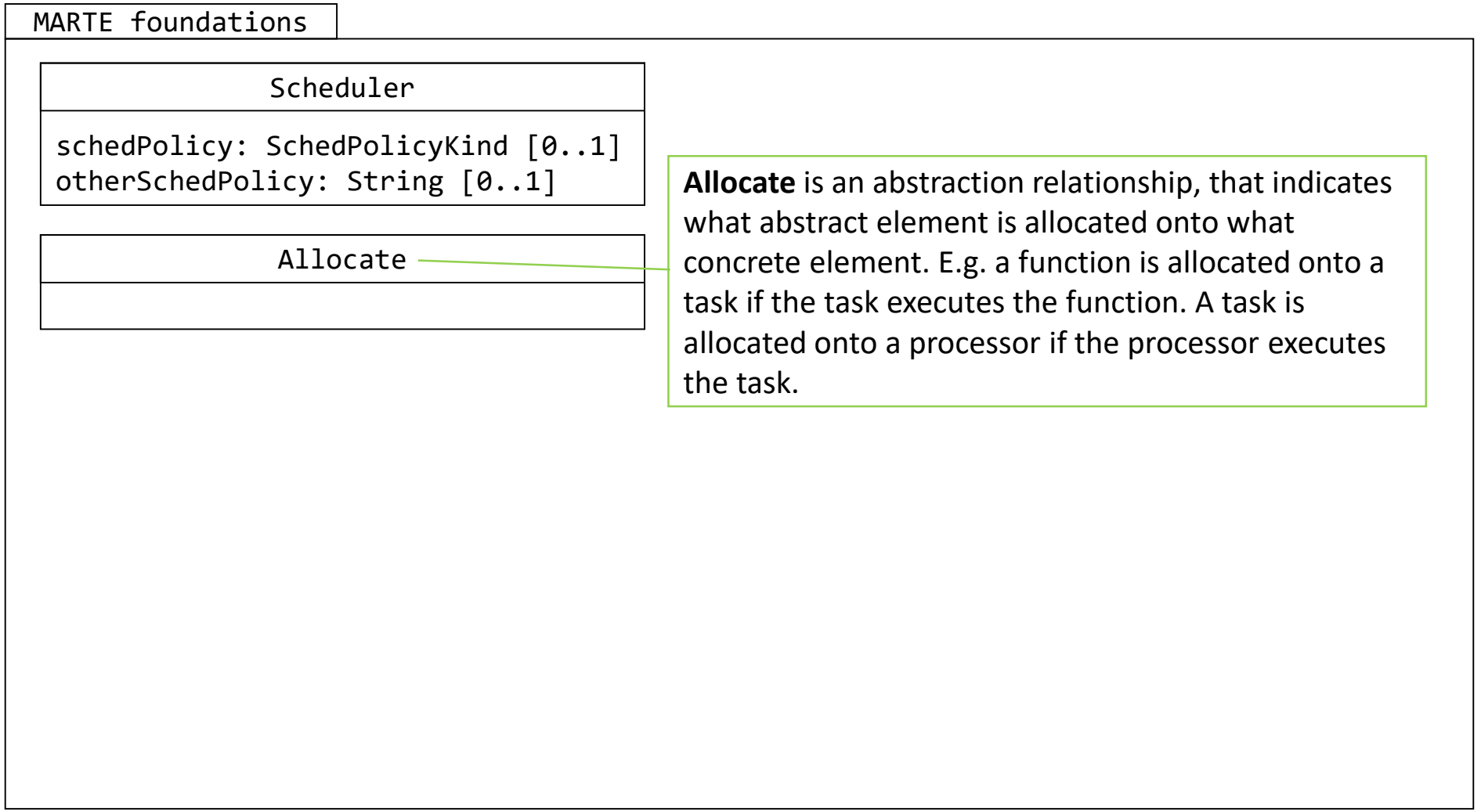
MARTE packages – Foundations



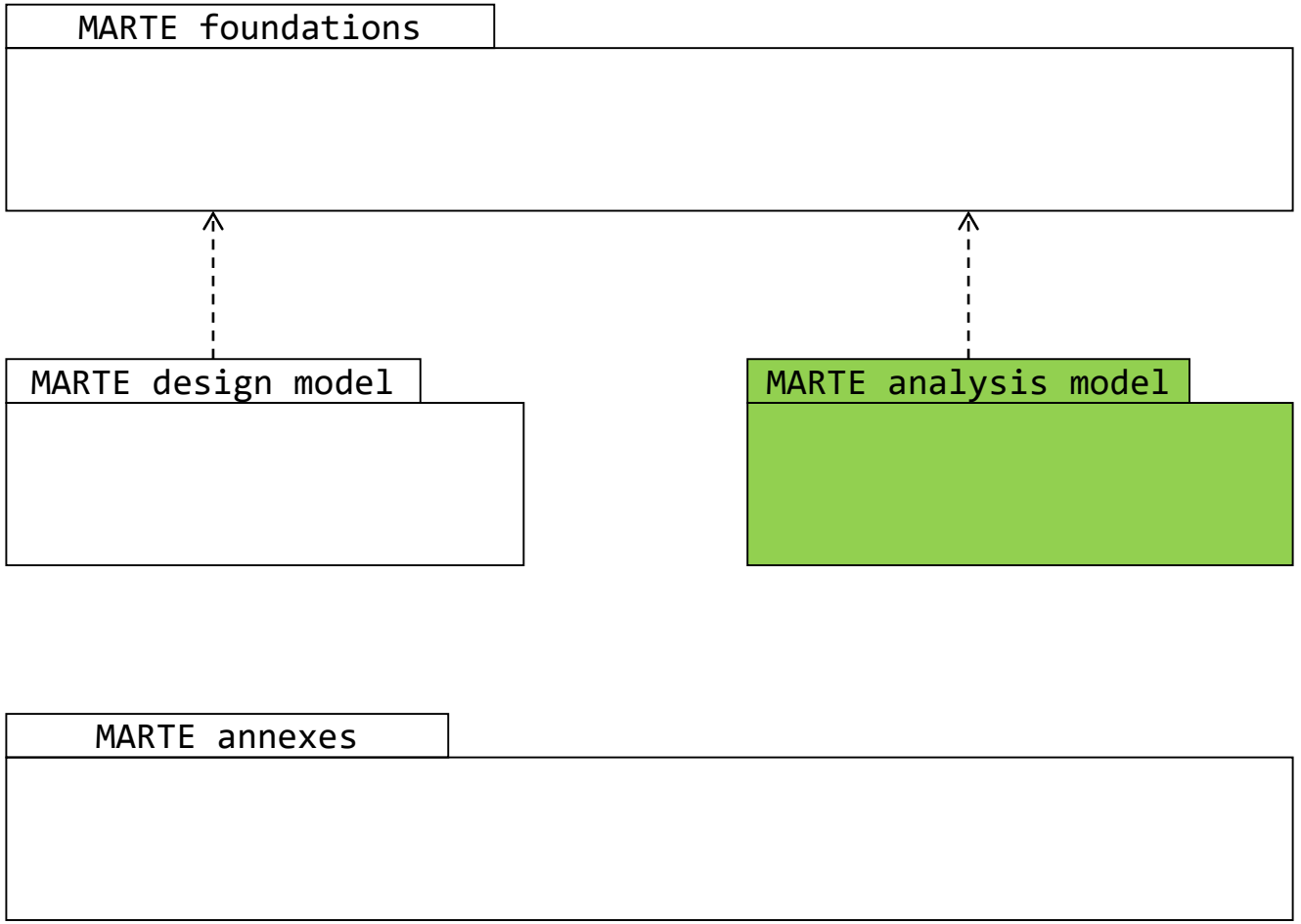
Modeling with MARTE – foundations



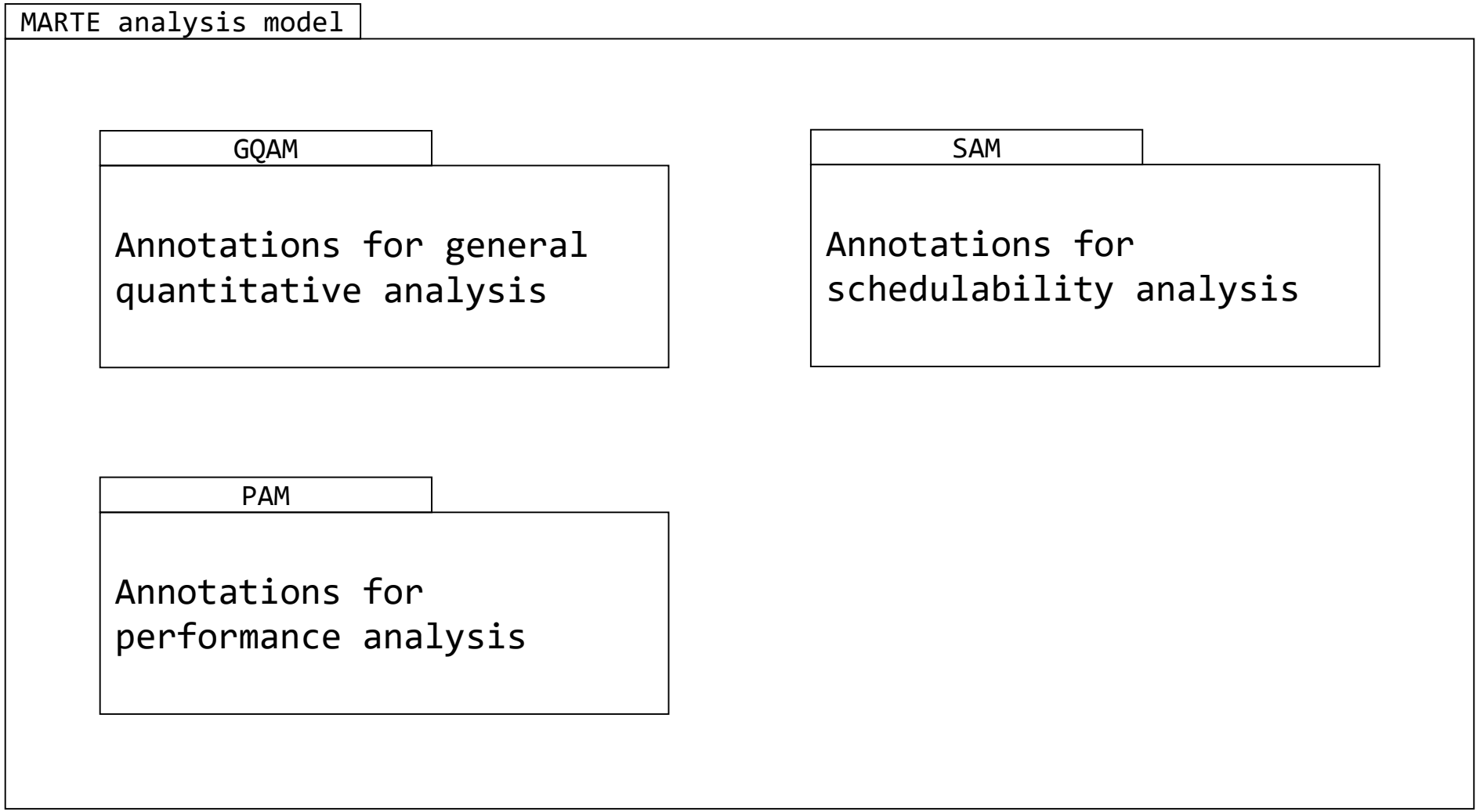
Modeling with MARTE – Allocate



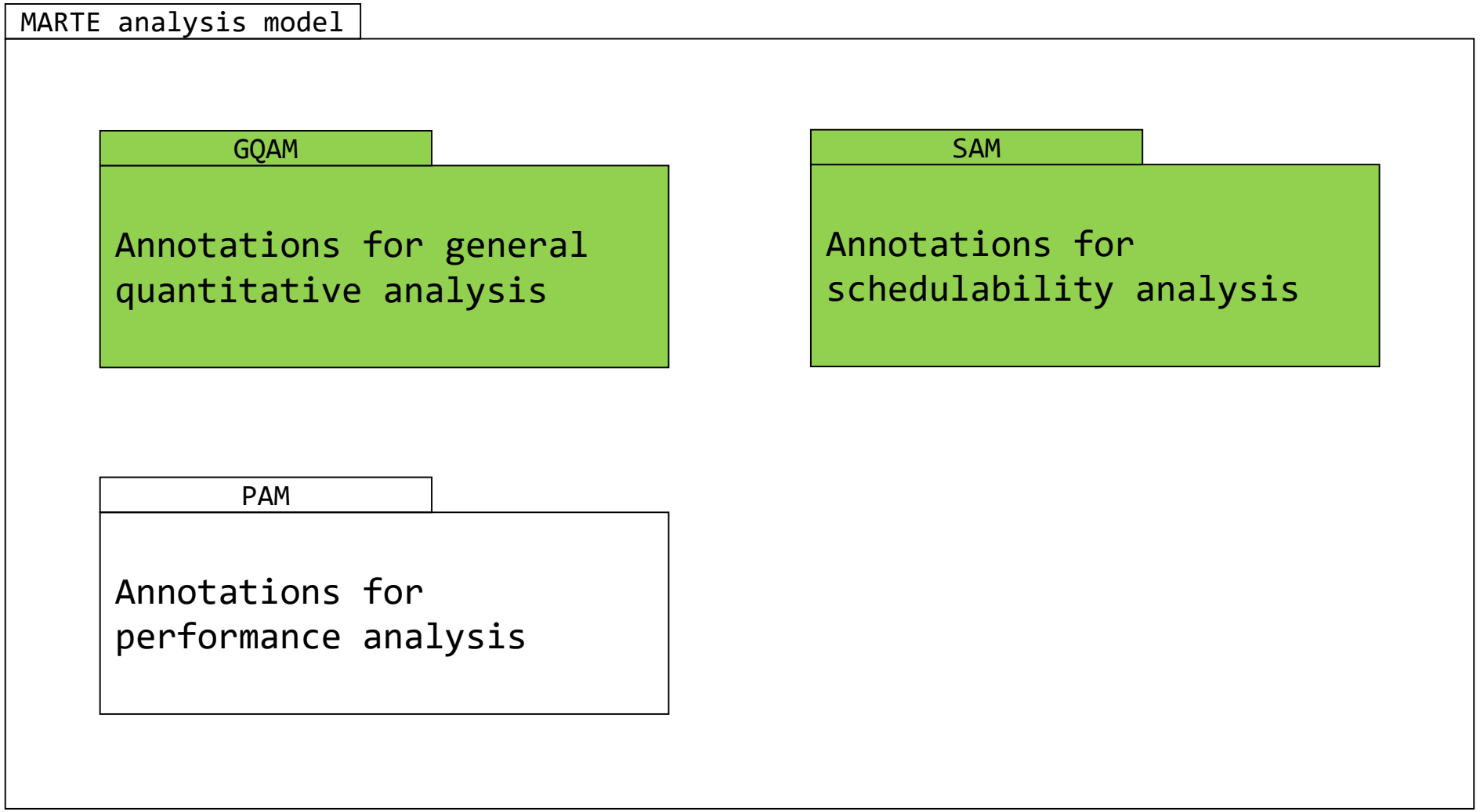
Modeling with MARTE – packages



Modeling with MARTE – Analysis model



MARTE packages – GQAM & SAM



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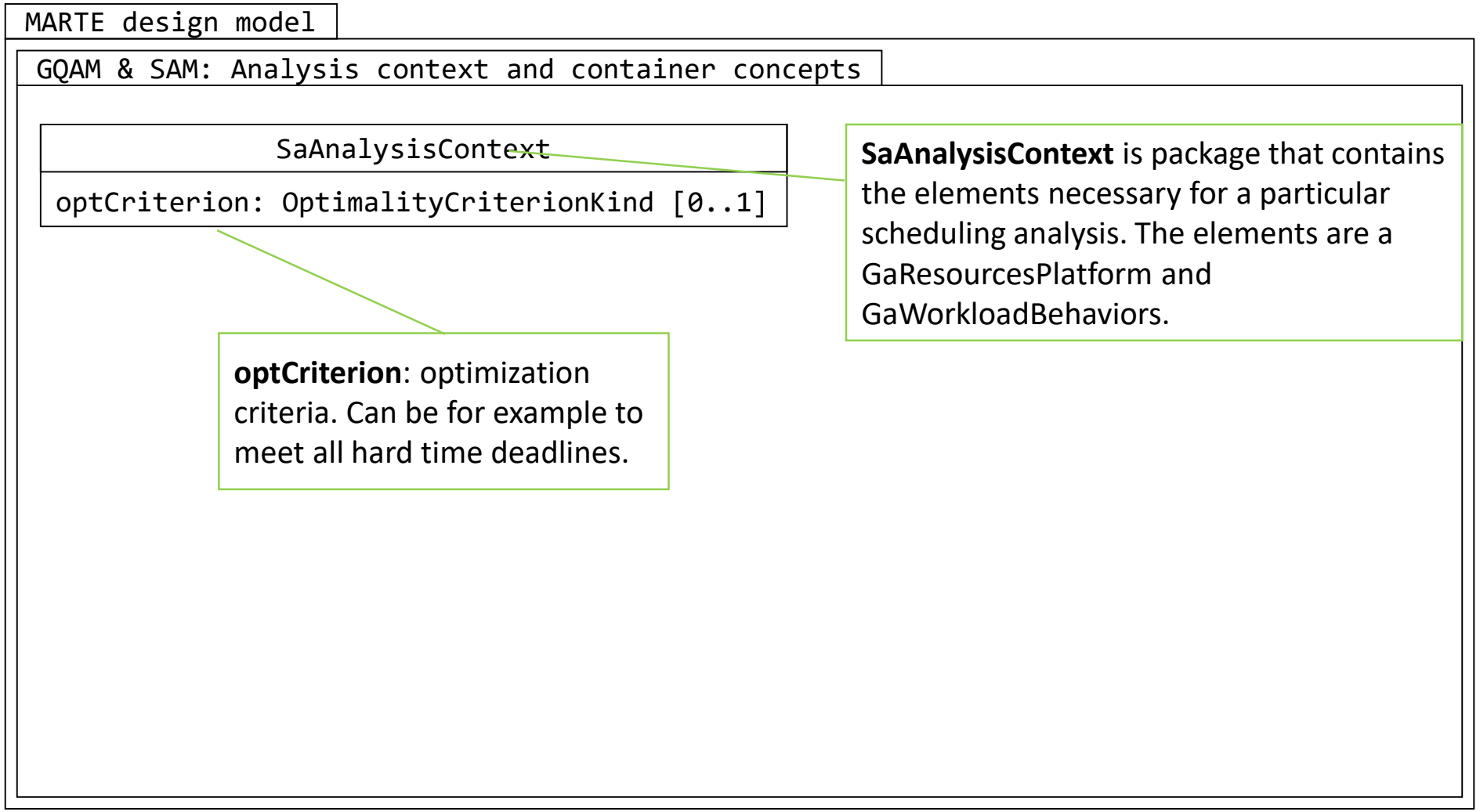

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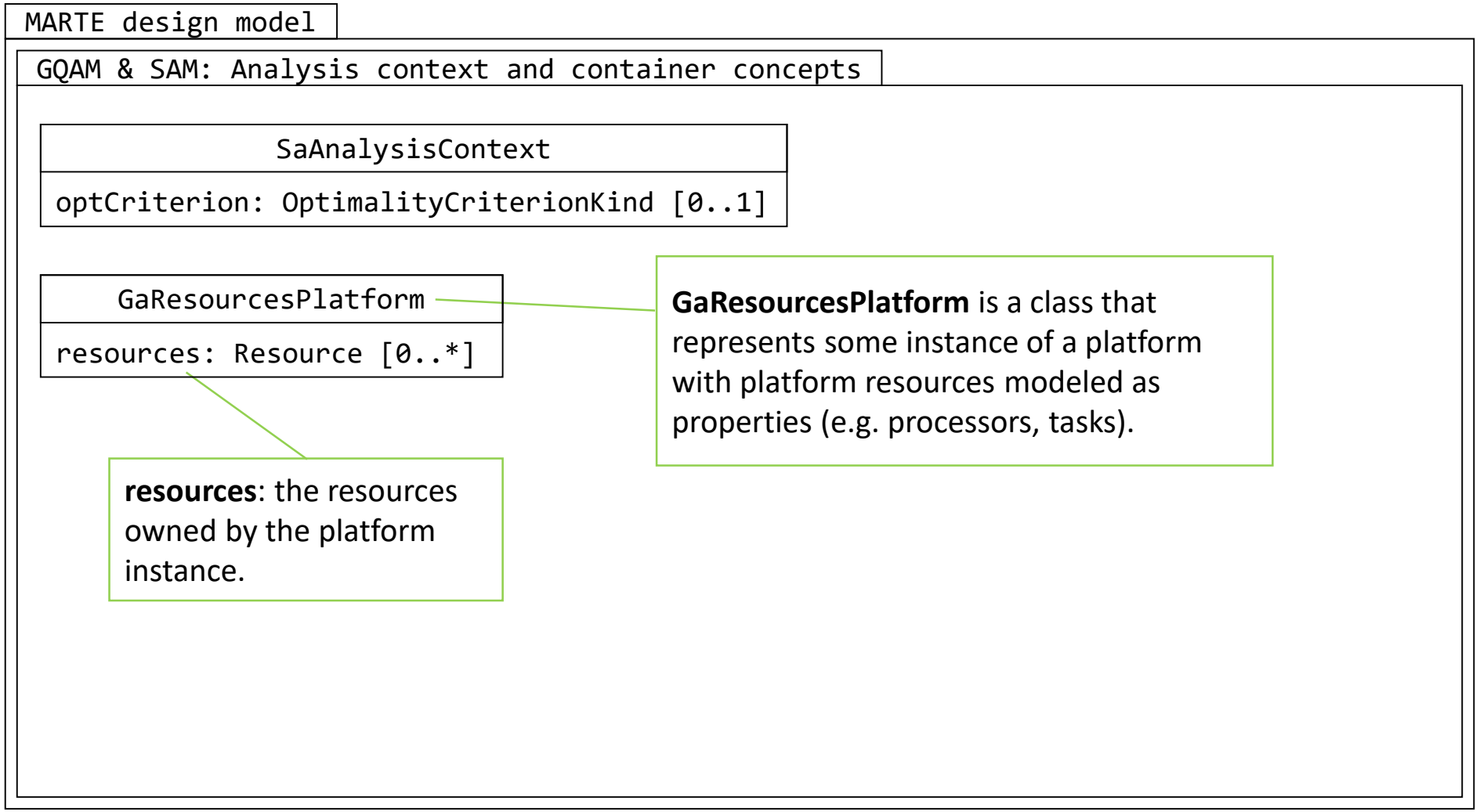

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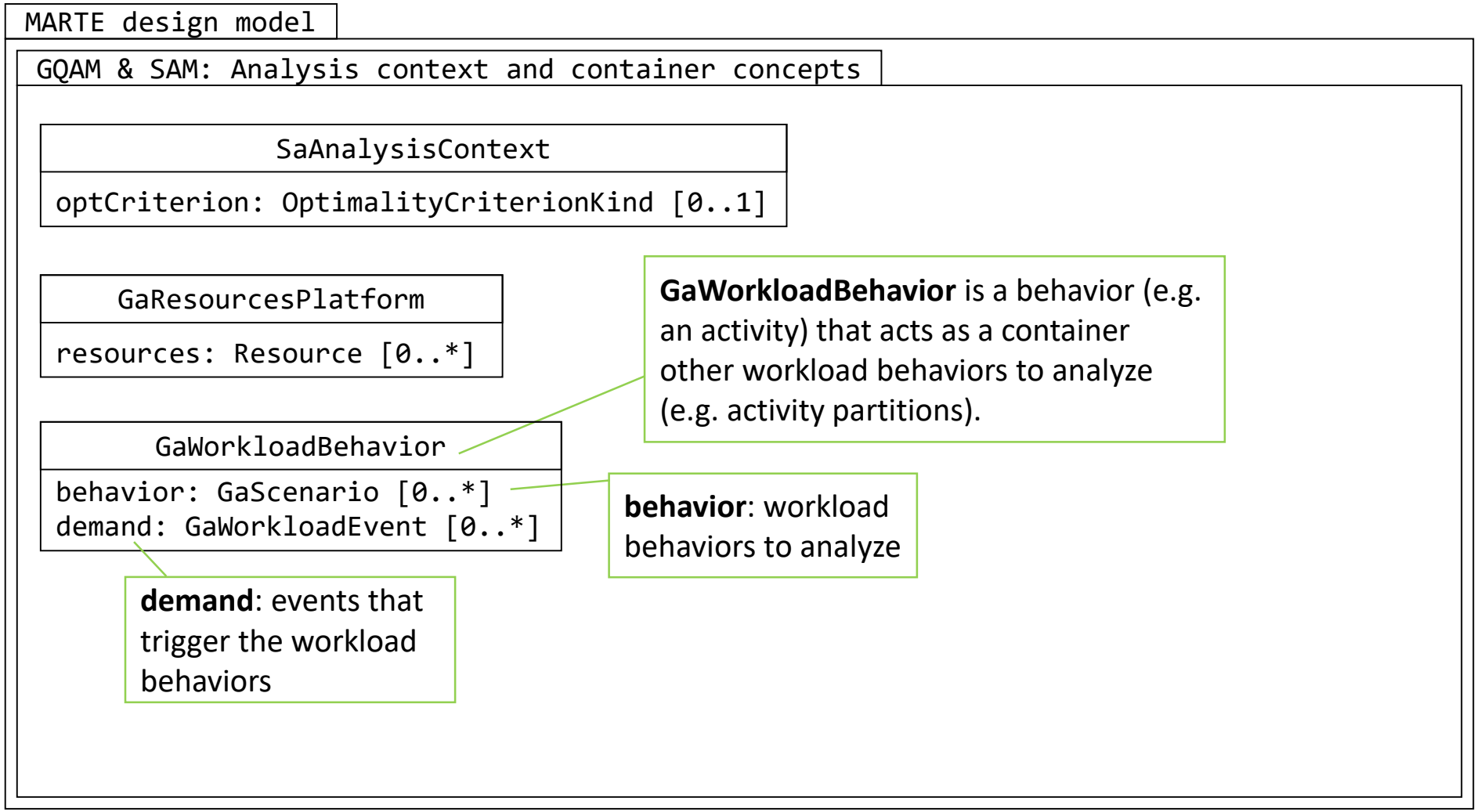

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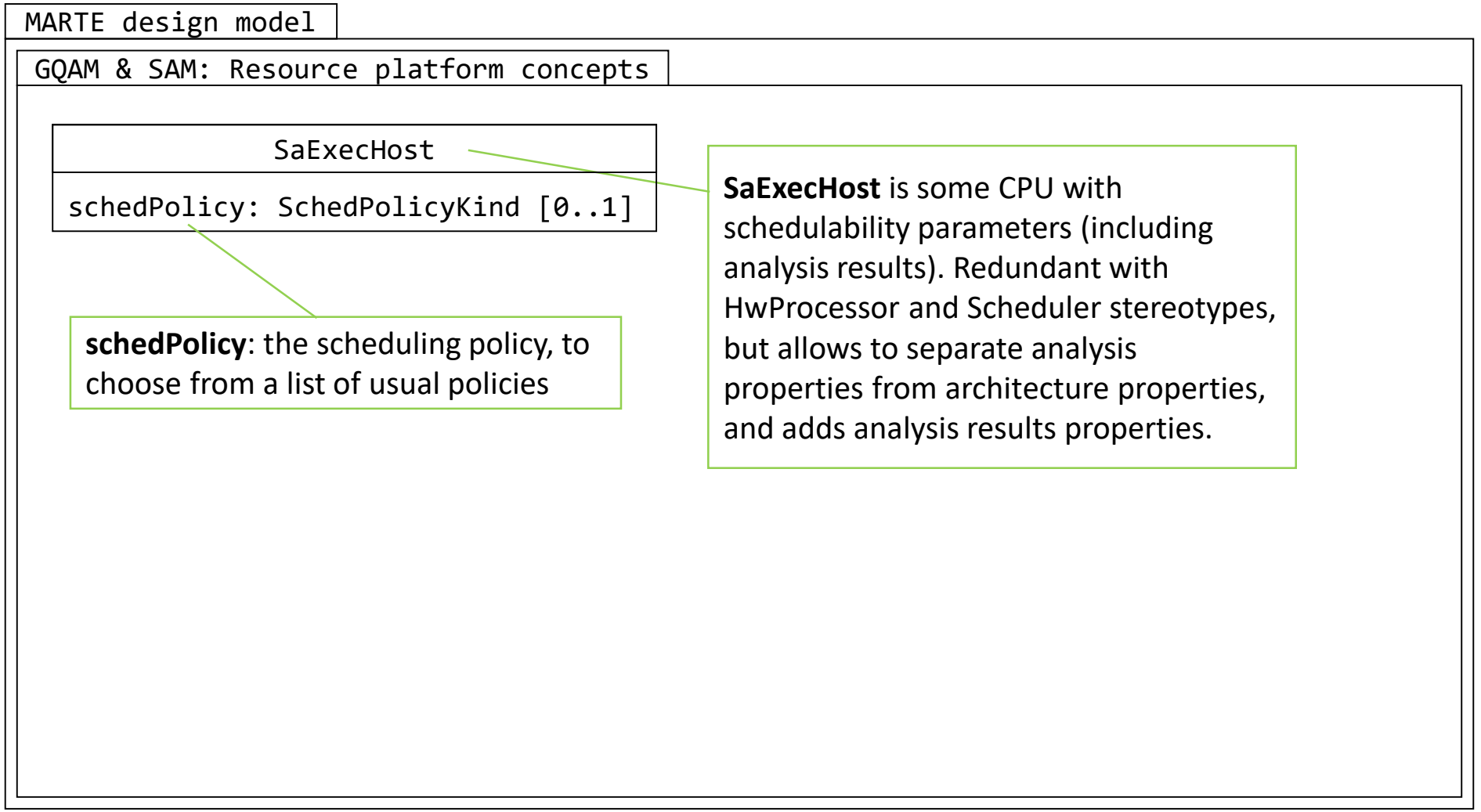

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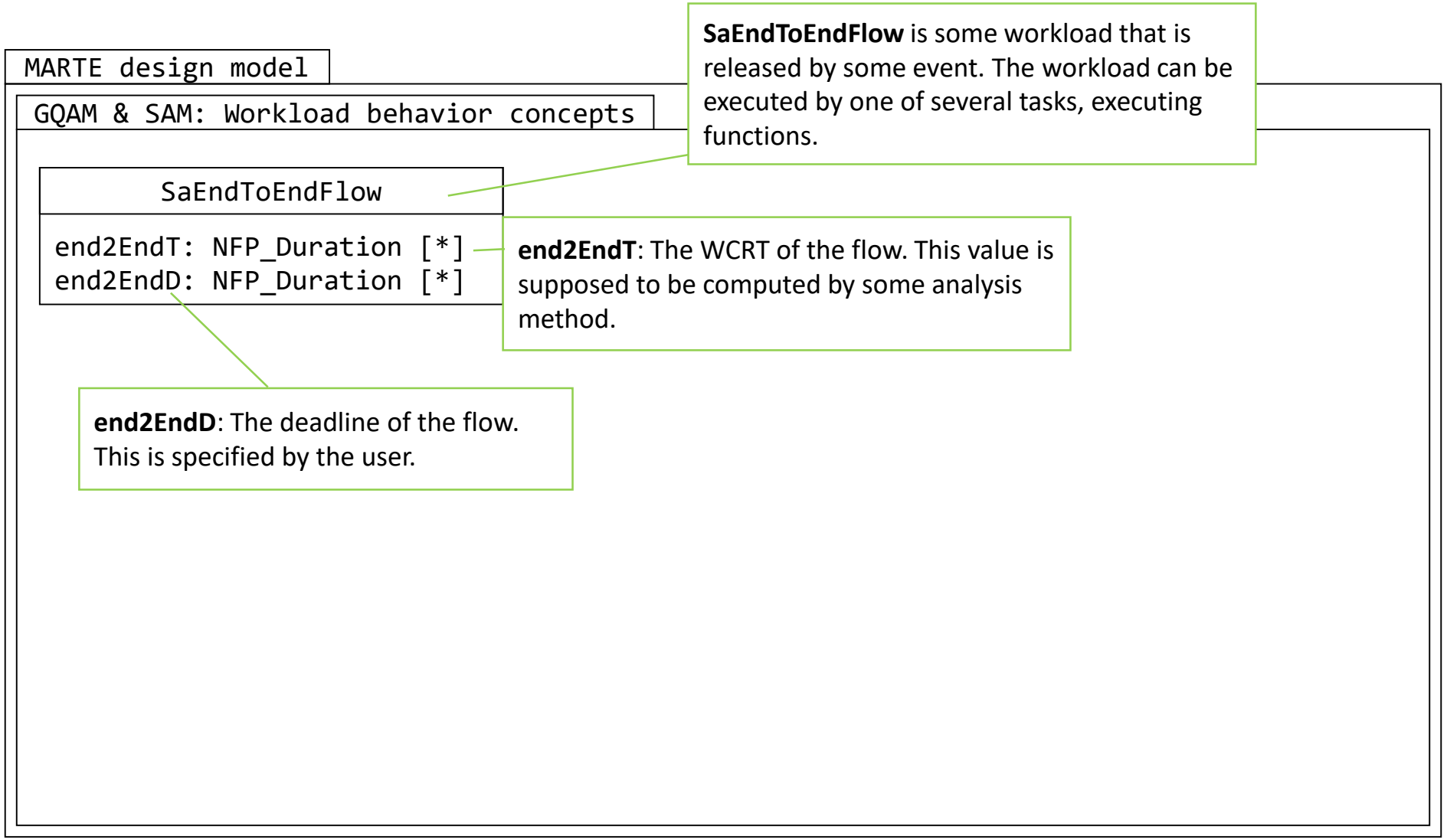

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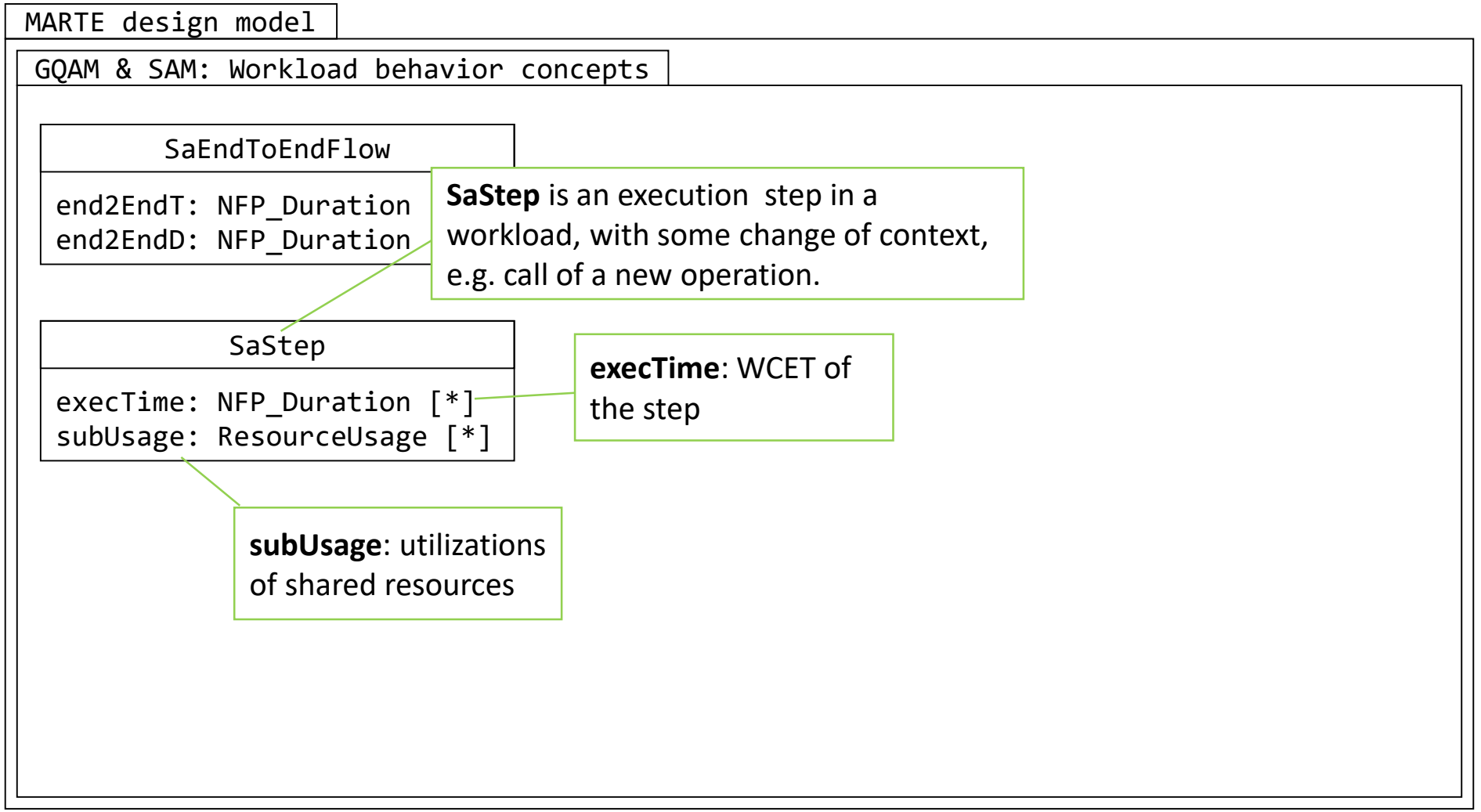

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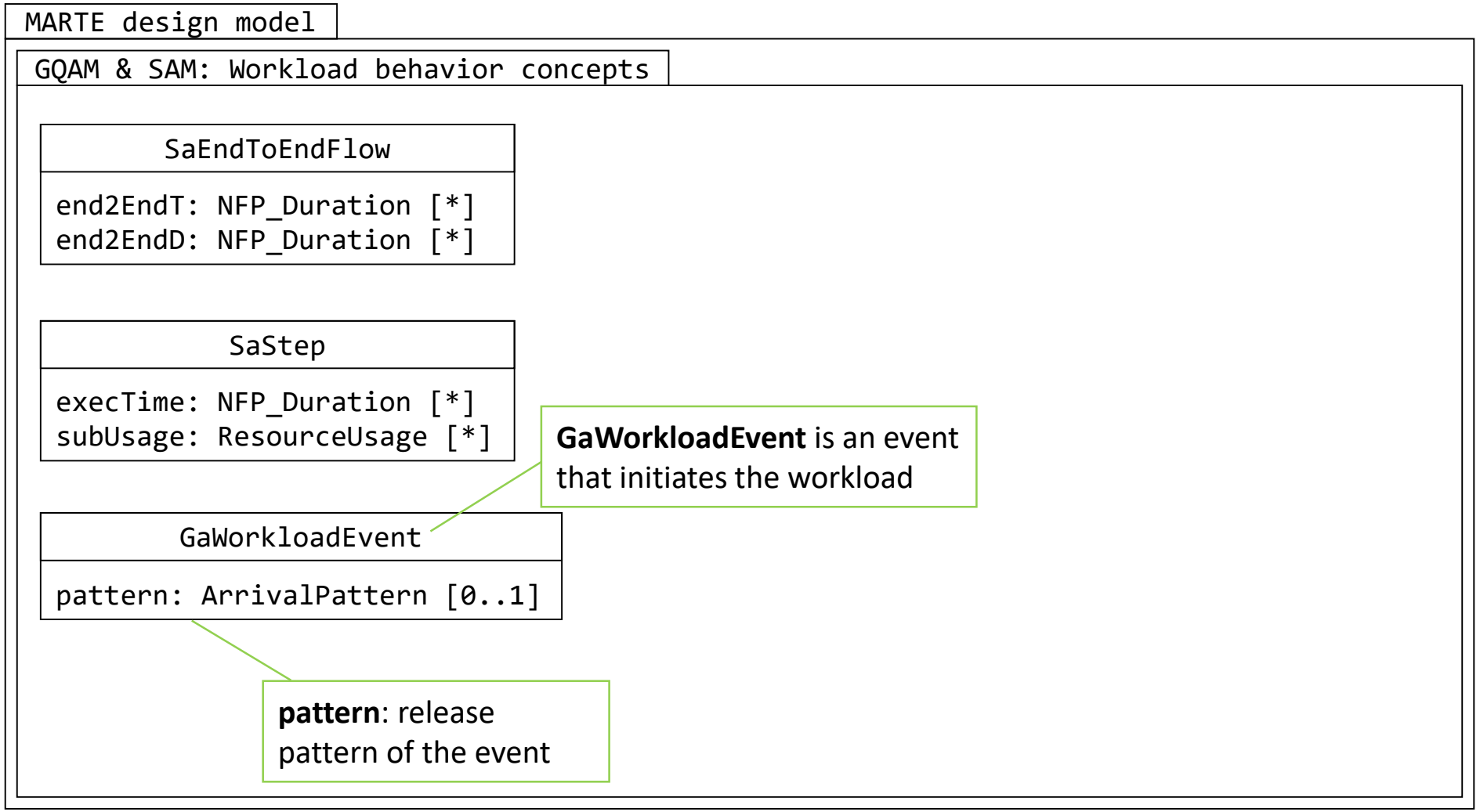

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    1. Motivation, history, packages
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    3. **Example**
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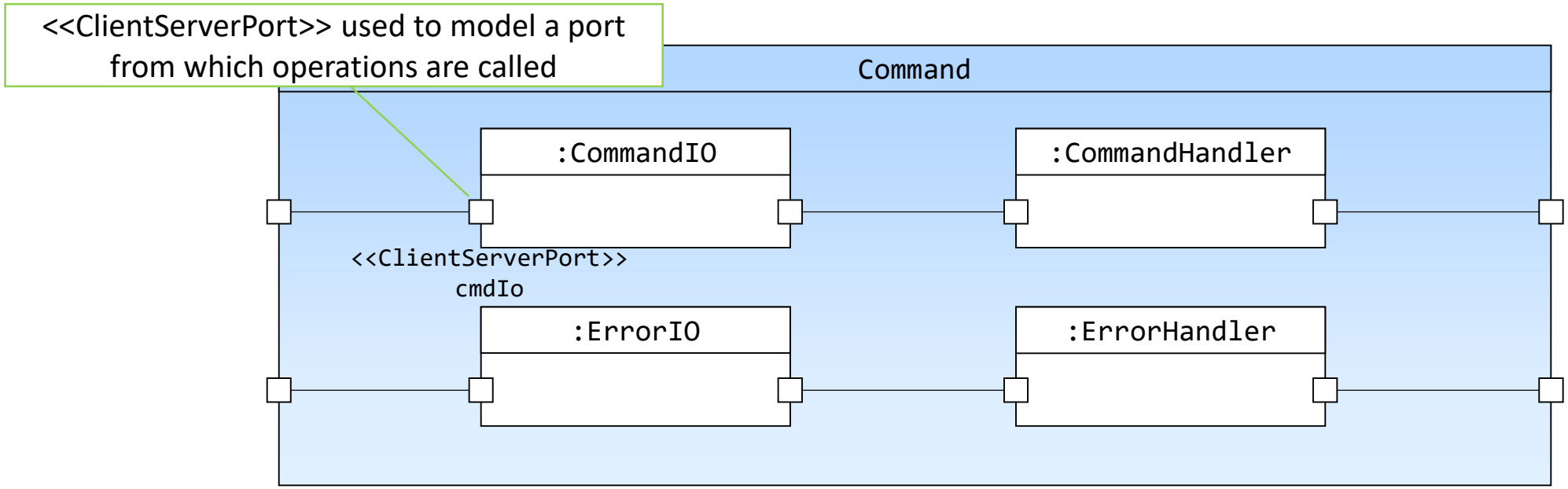
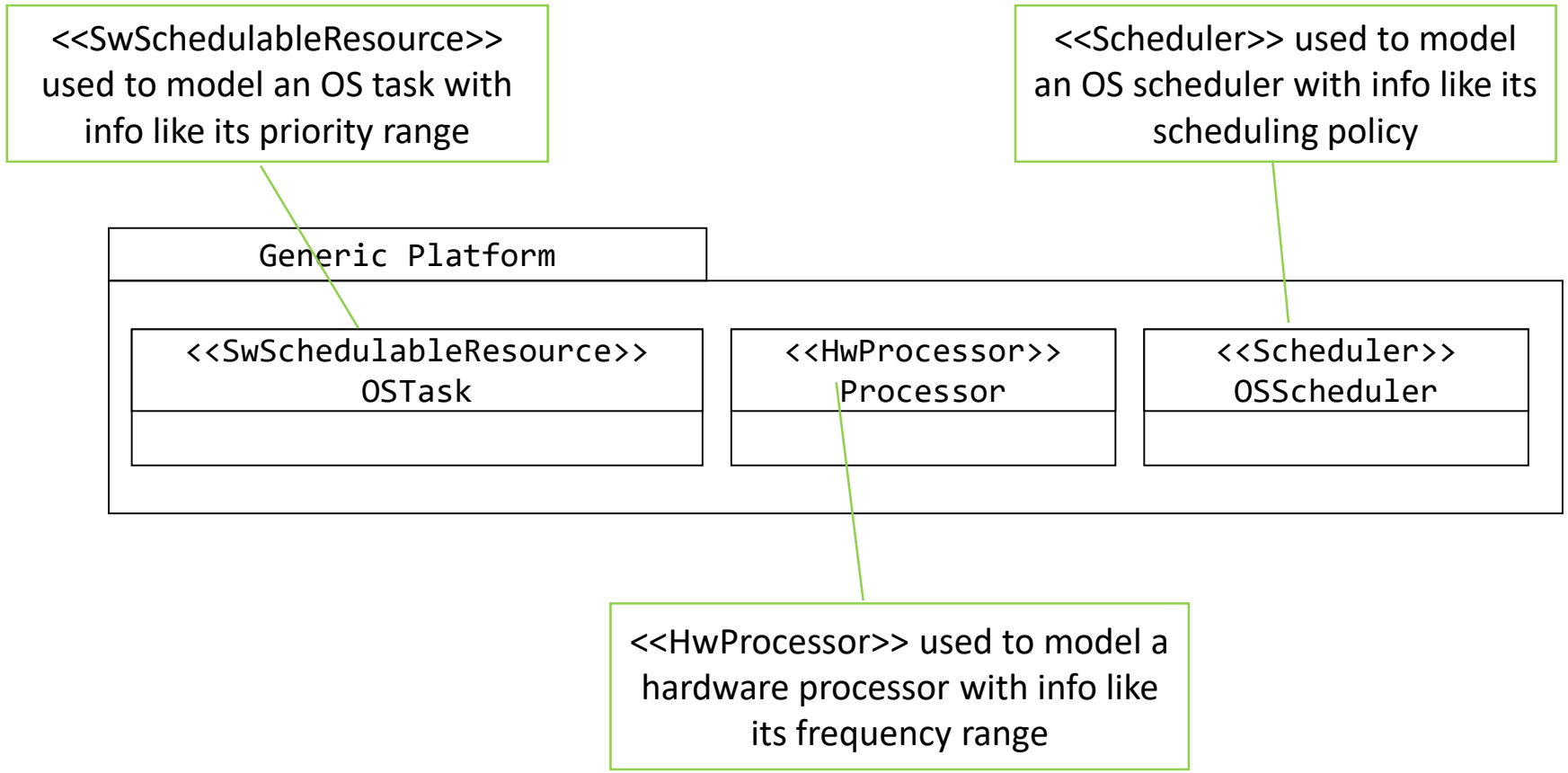
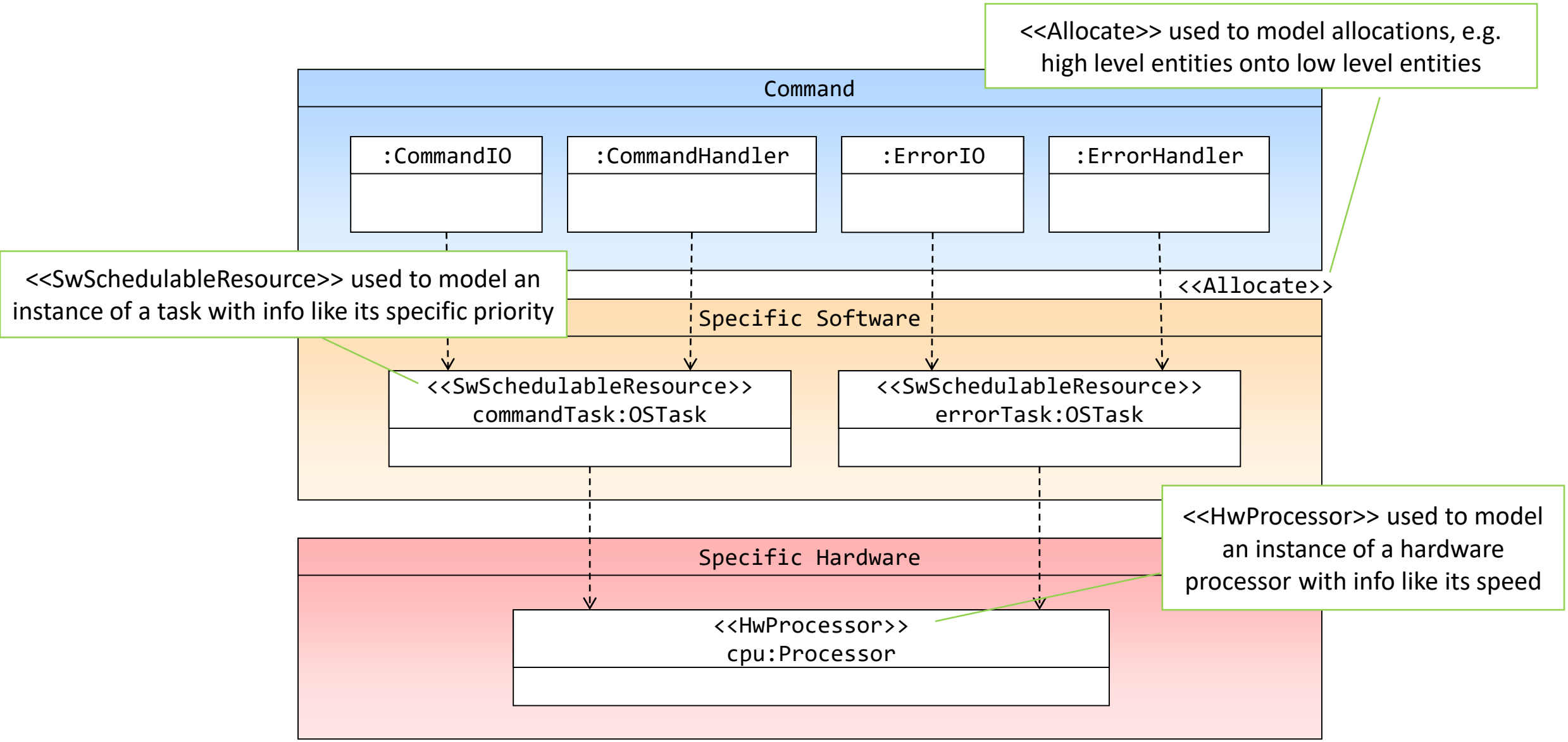
Modeling with MARTE – Functional Example



Modeling with MARTE – Platform model example



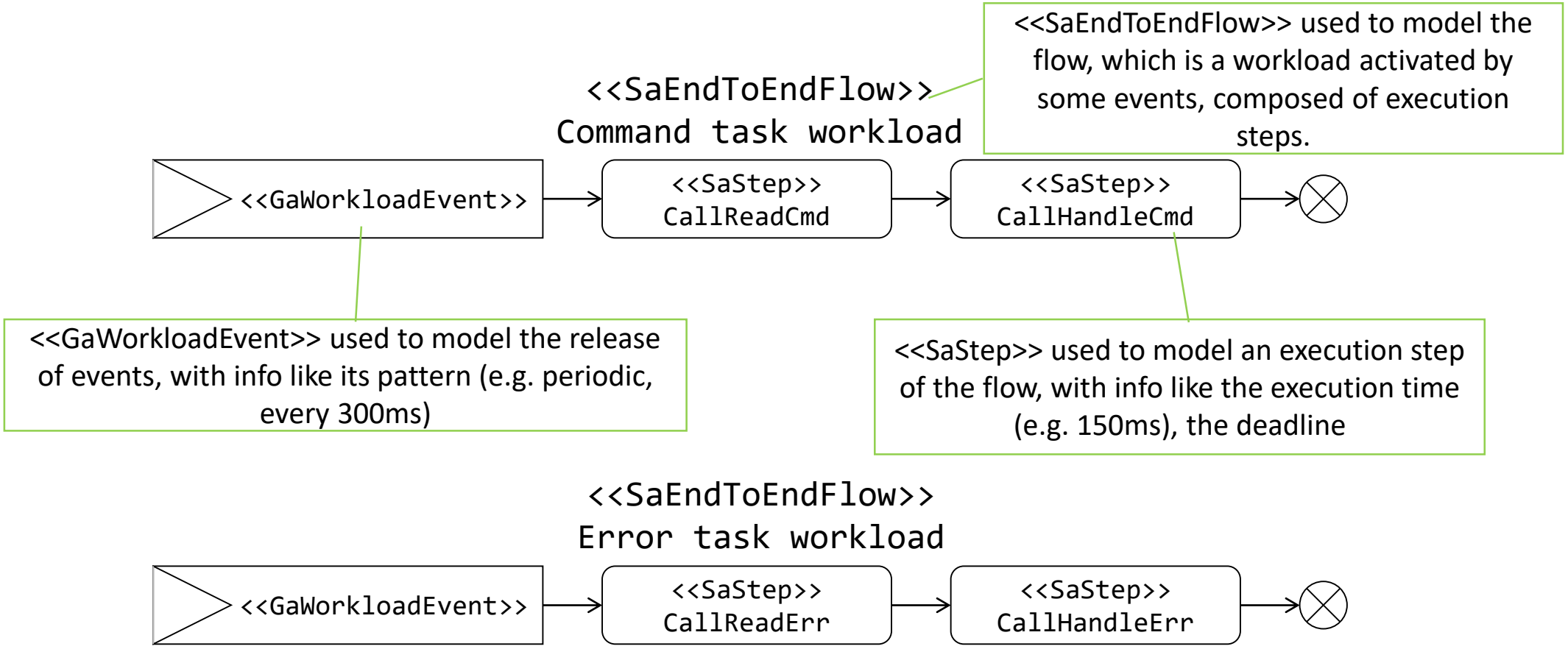
Modeling with MARTE – allocation model example



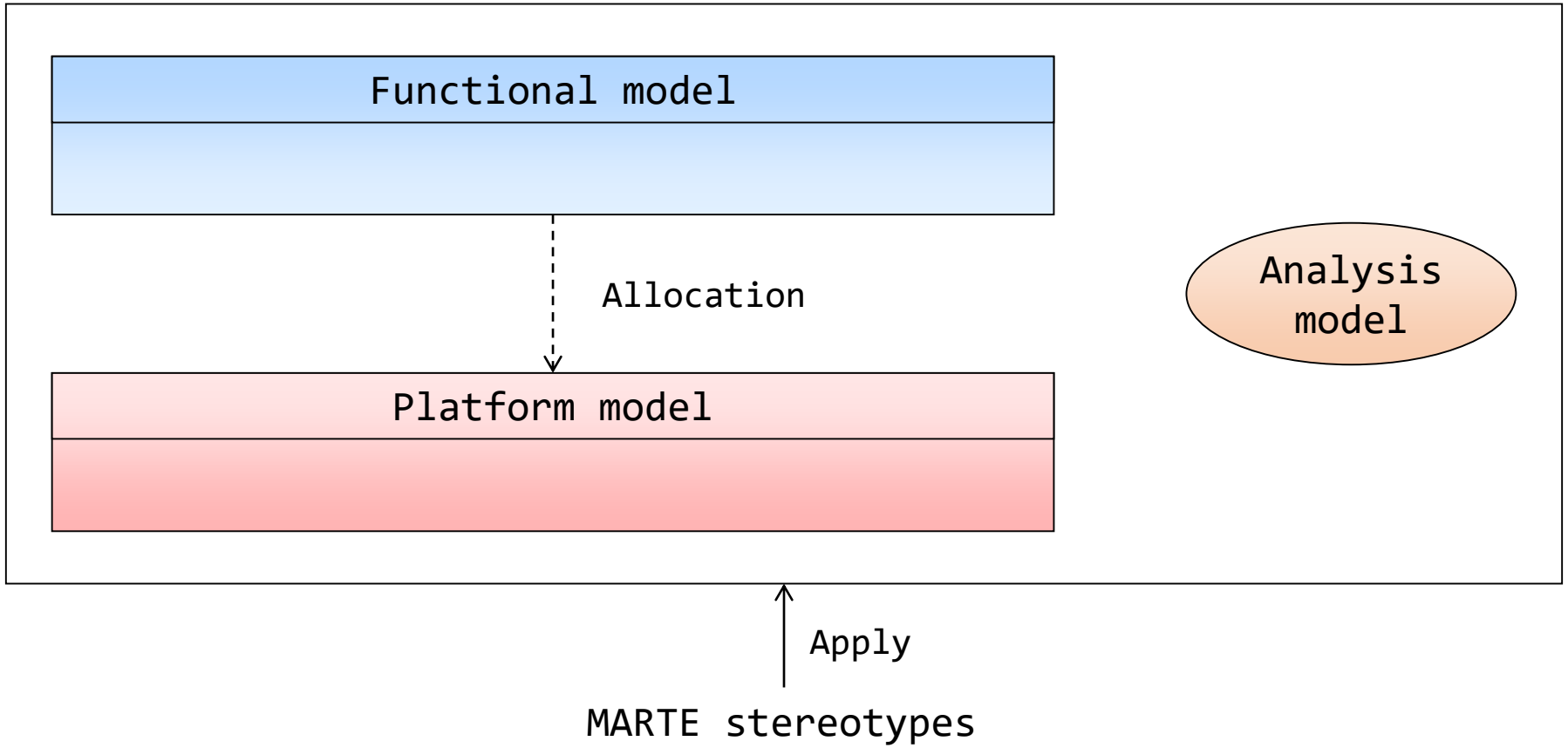
Small exercise

- Install MARTE via update site (Help->Install New Software)
  https://download.eclipse.org/modeling/mdt/papyrus/components/marte/
- Create a new Model, apply the registered MARTE HRM (sub-)profile
- Create a composite structure diagram
- Add a part “processor”, apply «HwProcessor» stereotype,
  set some properties (frequency, architecture)

Performance analysis model example: end-to-end flow of tasks (behavior)



Modeling with MARTE – allocation summary



Agenda

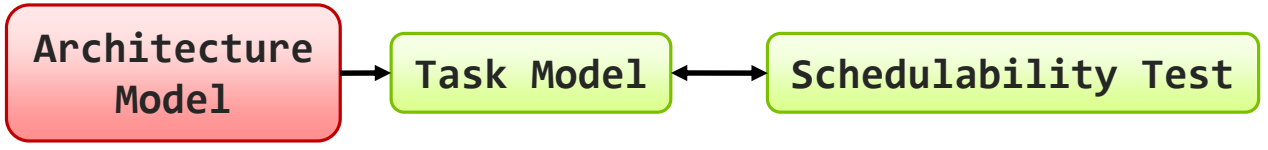
1. UML MARTE
    1. Motivation, history, packages
    2. Selected packages
    3. Example
    4. **Schedulability analysis**
2. Model transformation
    1. Principles
    2. Languages

MARTE in Practice: Tasks scheduling in RTES

- RTES are (usually) implemented as a multi-tasking system; tasks are concurrent and must be scheduled
- Recap, scheduling – method that gives tasks access to processors, i.e. according to a scheduling policy; performed by a scheduler in the OS

Schedulability analysis

- Verify that tasks meet their time constraints, when running on limited computing resources, according to a scheduling policy



$$R_i^n = C_i + \sum_{j \in hp(i)} C_j \left\lceil \frac{R_i^{n-1}}{T_j} \right\rceil \leq D_i$$

Execution Time

Response Time

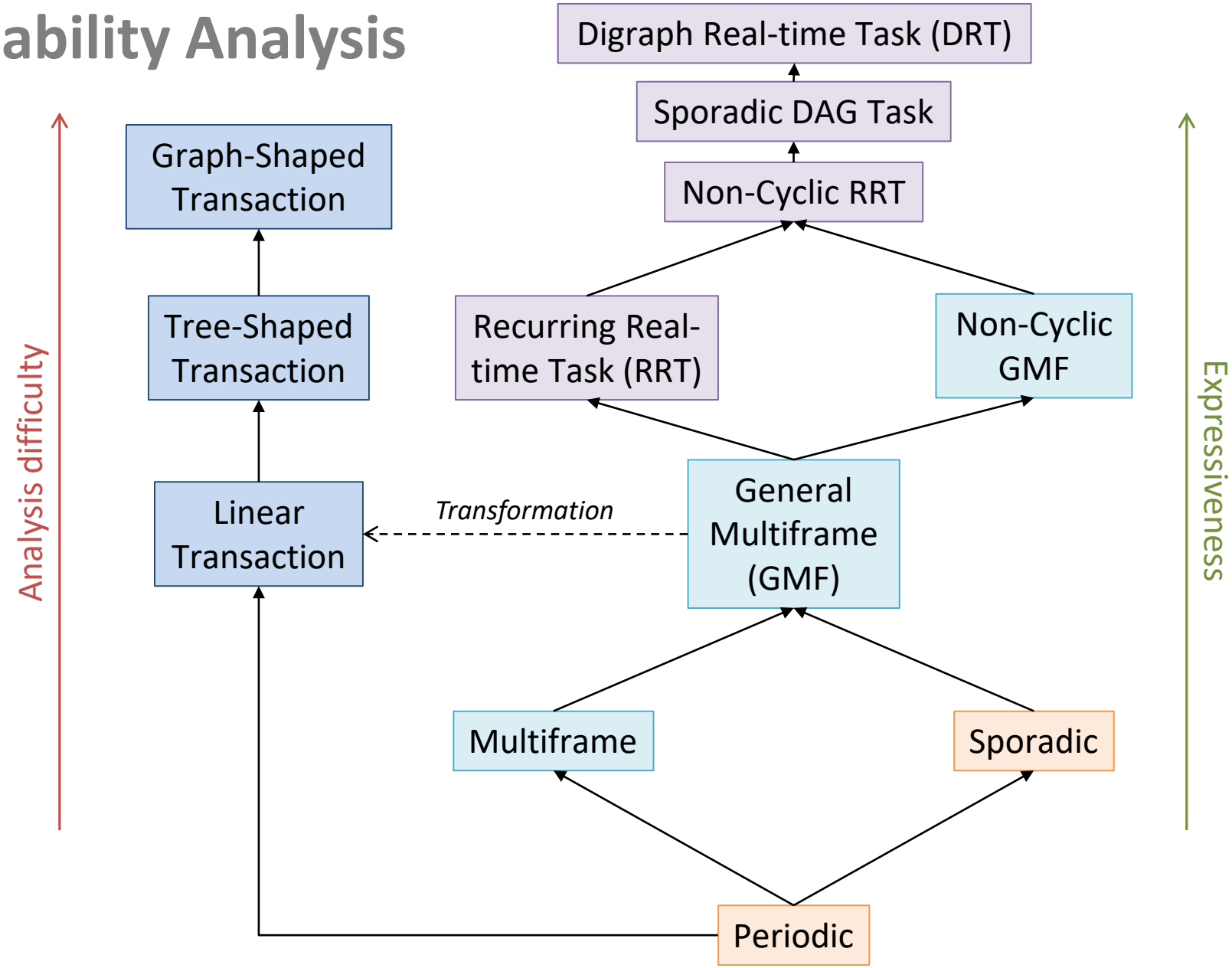
Interference

Deadline

Joseph and Pandya (1986)

MARTE in Practice – Schedulability Analysis

Task models



MARTE in Practice: Schedulability Analysis

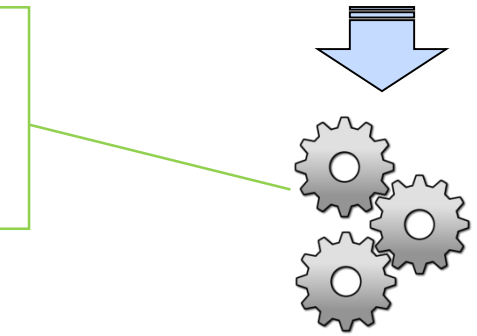
- Periodic task model
  - Periodic task denoted by τ_i with parameters:
  - C_i is the WCET
  - D_i is the deadline
  - T_i is the period
  - $prio(\tau\_i)$ is the priority
  - Suitable for uniprocessor systems
  - Suitable for tasks that share resources
  - Not suitable for task with precedence dependencies (i.e. task 2 waits for the end of task 1 before it can execute)

MARTE in Practice – Schedulability Analysis

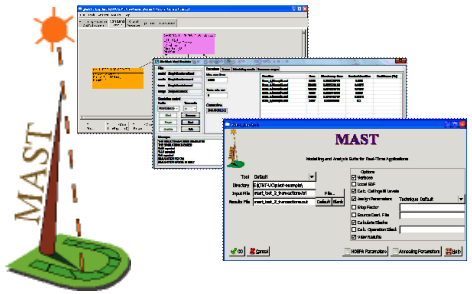
MARTE

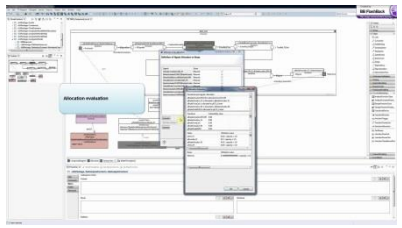
Annotate your model for schedulability analysis

Transform unique MARTE model to suitable task model (implemented in analysis tools)

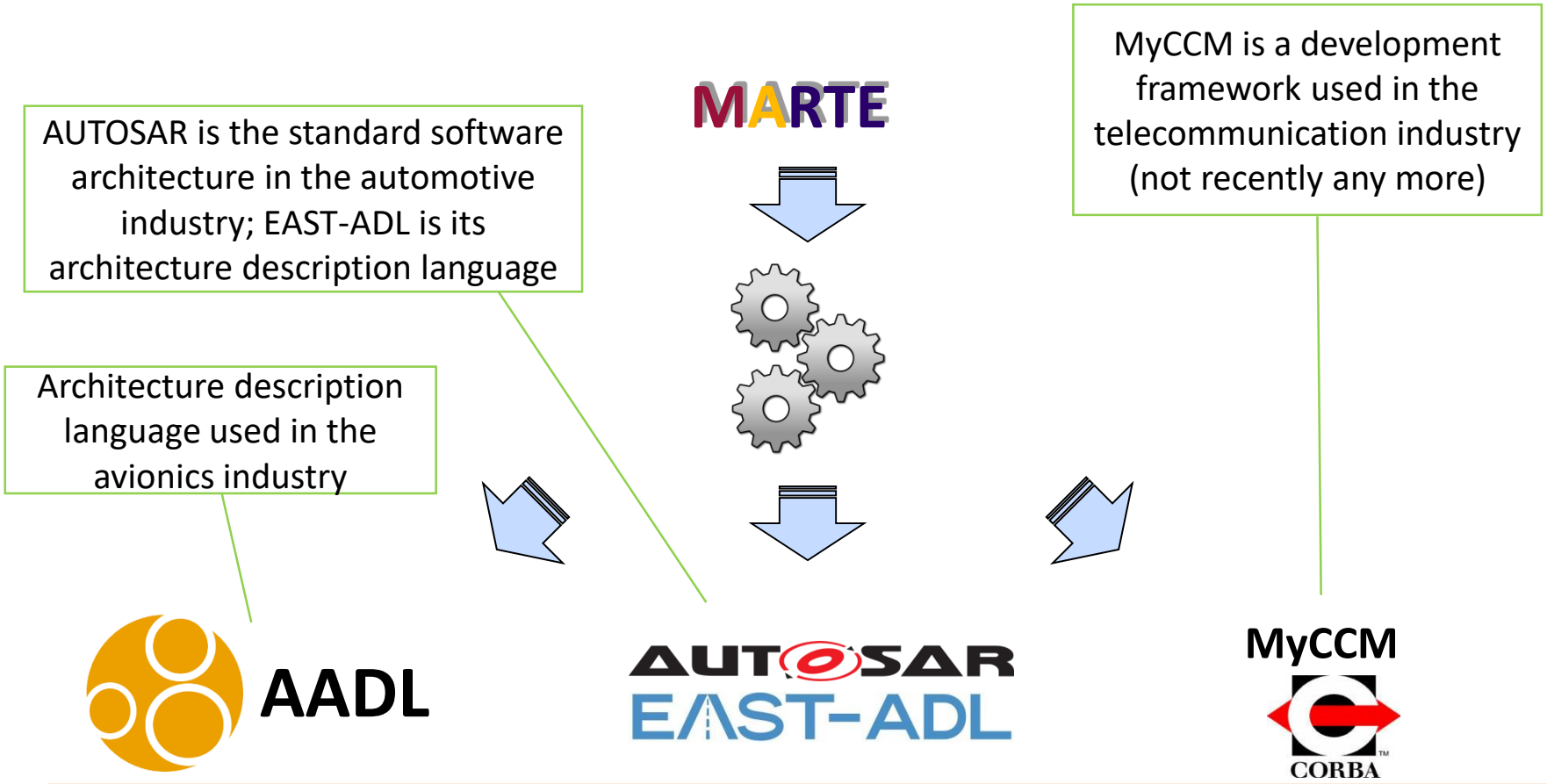


Cheddar, MAST, and PyCPA (SW Designer) are examples of open-source schedulability analysis tools





MARTE (industrial) support



Modeling with MARTE depends on the development method, i.e. there is no unique way to model with MARTE, as long as the specification is respected (semantic and syntax)

MARTE support

Industrials

- Alcatel
- Lockheed Martin
- THALES
- Orange

Academics

- Carleton University
- CEA LIST
- ESEO
- ENSIETA
- INRIA
- INSA Lyon
- Software Engineering Institute (CMU)
- Universidad de Cantabria

Modeling tool vendors

- Atego
- IBM
- Mentor Graphical Corporation
- Softeam
- Tri-Pacific Software
- No Magic
- MathWorks

MARTE – Summary and conclusions

- MARTE proposed as a standard modeling language for RTES domain, based on several industrial systems and standards
- MARTE implemented as a UML profile
- MARTE allows to model RTES domain-specific information contrary to a generic software modeling language like UML
- MARTE models analyzed through model transformation to analysis tool models; MARTE models can also be transformed to several industrial standard models
- MARTE supported by modeling tool vendors, academics and industrials
- Further reading: B. Selic, S. Gérard, “Modeling and Analysis of Real-Time and Embedded Systems with UML and MARTE: Developing Cyber-Physical Systems”, 1st edition, Burlington US-MA: Morgan Kaufmann, 2013

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Model Transformations

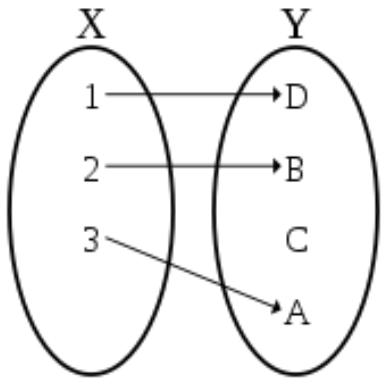
- Goal – transform one model into another
- Why?
  - Manual editing
  - Refactor your model (as IDEs do for code)
  - (automatically) obtain a model that is build for a specific purpose
    - Analysis
    - Model checking
    - Code generation
- Different kind of transformations
  - Do source and target comply with same MM?
  - Specific variant - Model to text
  - Bijective? (import reverse transformation?)

Model Transformations

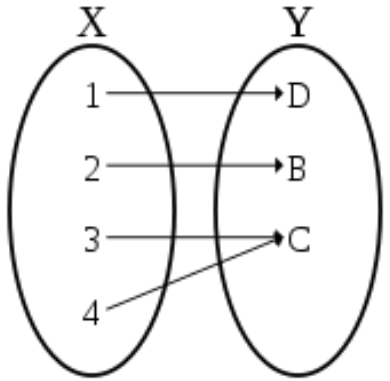
- Different kind of transformations
  - Do source and target comply with same MM?
  - Specific variant - Model to text

- Mathematical properties
  - Injective? – map distinct elements of source to distinct elements of target model
  - Surjective? – for each element in the target model, there is an associated element in the source model
  - Bijective? – injective and surjective

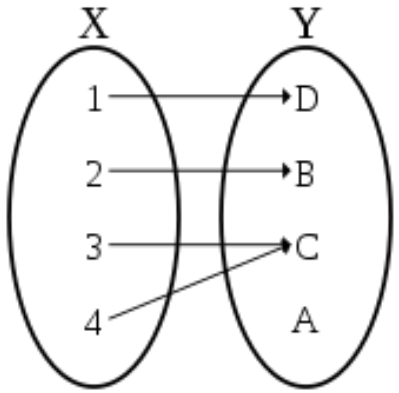
Mathematical properties



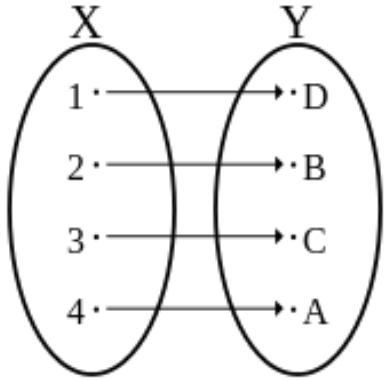
Injective, but not surjective



Non injective, but surjective



Non injective, non surjective



Bijective

Source: wikipedia

Practical implications?

- For a bijective transformation, there is an associated **reverse transformation** without **loss of information**
- Would enable **round-trip engineering**, e.g.

  model => code => modified code => model´

- Might need additional annotations (e.g. special comments)
- Not useful, if differences in abstraction level are too high

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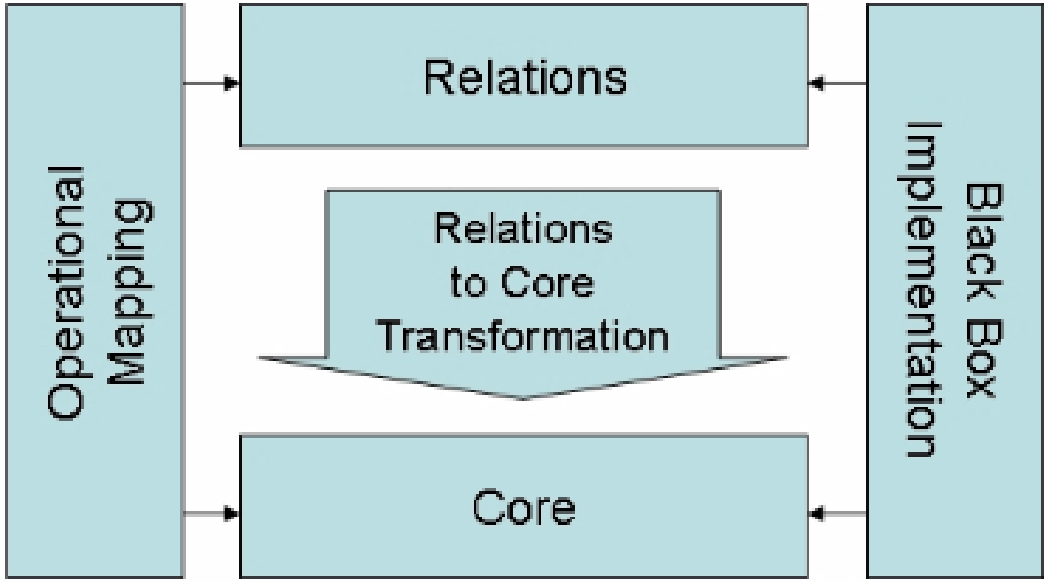
Model transformation implementations

- General purpose programming language, e.g. Java
  - Use UML2 (modeling language) API to access model, remove, add or change model elements programmatically
  - Papyrus SW designer follows this approach, supported by a lazy model copier
  - Advantage: known language, debugging environment
  - Disadvantage: less adapted to task

- Use a dedicated model transformation language
  - QVT (Query/View/Transformation), OMG
  - ATL (ATLAS Transformation Language), INRIA, maintained by OBEO
  - For M2T: Acceleo and xtend (we will see these languages later)

QVT (Query/View/Transformation)

- OMG standard
- Set of three languages for model transformation
  - **Operational** – imperative language for **unidirectional** transformations.
  - **Relations** – declarative language for **bidirectional** model transformations
  - **Core** – infrastructure language for the first two, but currently not implemented like this

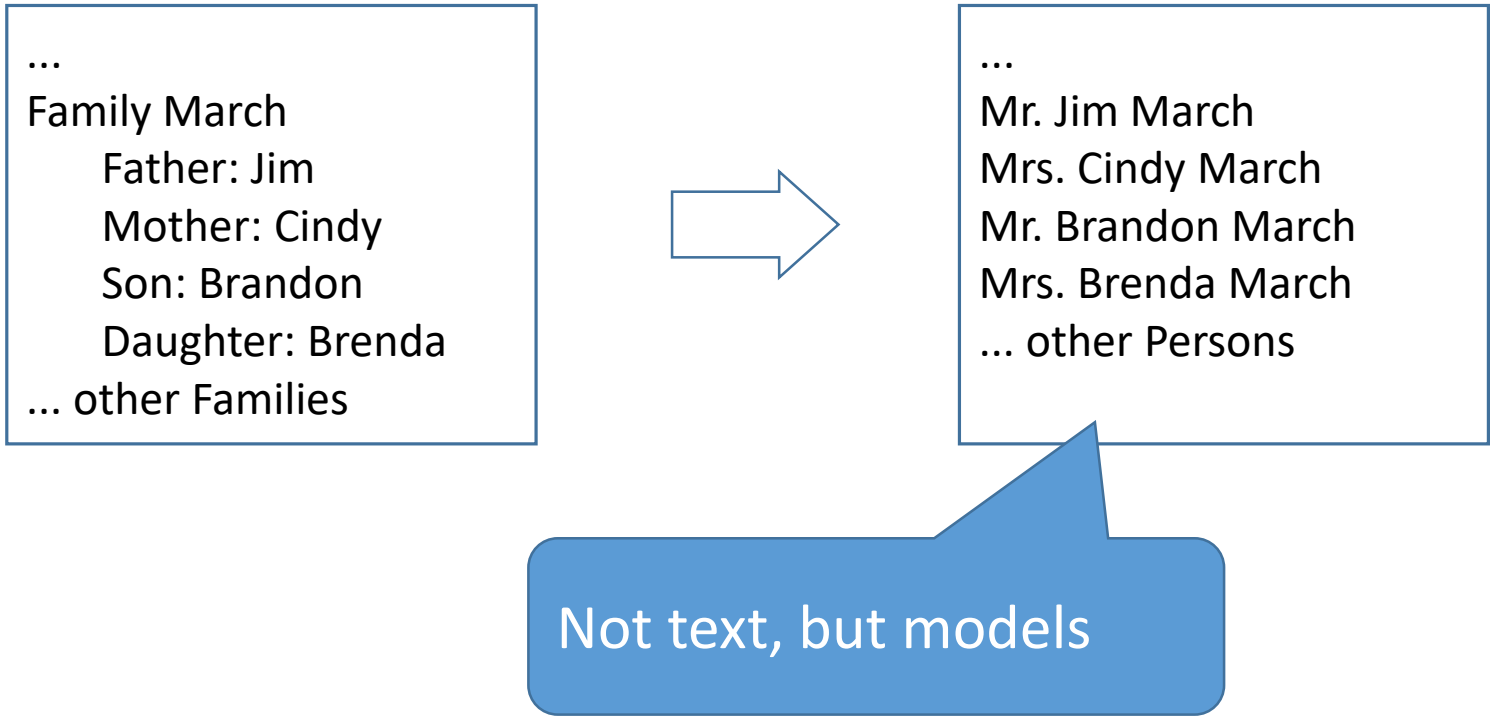


History

- 2002: OMG issued a Request for proposal (RFP) on MOF Query/View/Transformation
  - Seek a standard compatible with the Model Driven Architecture (MDA) recommendation suite (UML, MOF, OCL, etc.).
  - Several replies, evolution towards common proposal,
- 2005: first version was submitted and approved
- 2011: QVT Version 1.1
- 2016: QVT Version 1.3

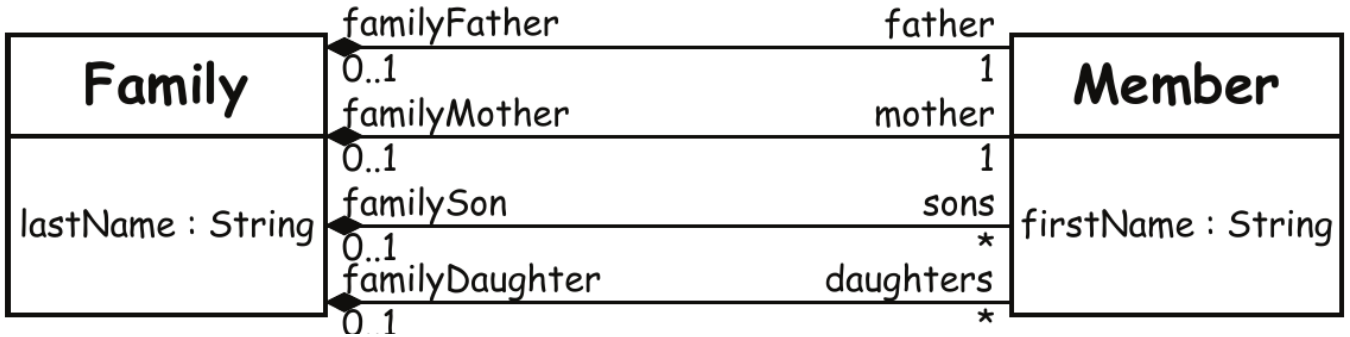
ATL

- Originally developed by INRIA, maintained by OBEO, less used today
- Example (courtesy of Freddy Allilaire, Frédéric Jouault – INRIA)

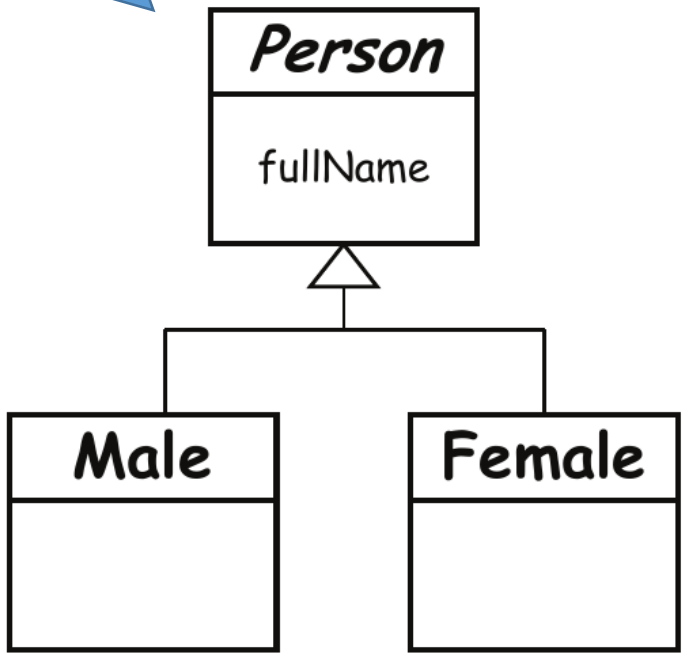


Source and target meta-models

Source meta-model



Target meta-model

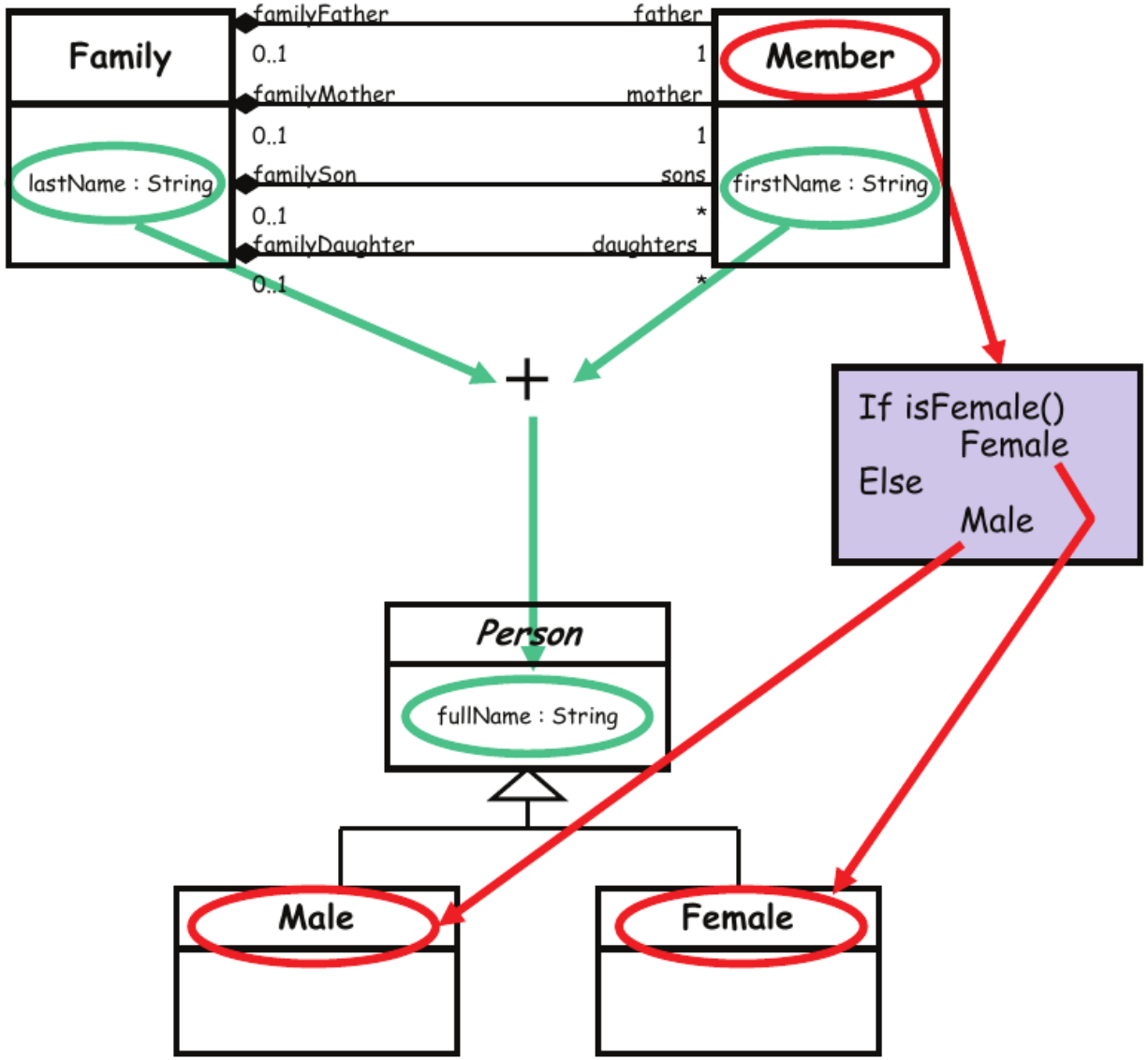


Bijective transformation?

Transformation rules

```
rule Member2Male {
    from
        s : Families!Member (not s.isFemale())
    to
        t : Persons!Male (
            fullName <- s.firstName + ' ' + s.familyName
        )
}

rule Member2Female {
    from
        s : Families!Member (s.isFemale())
    to
        t : Persons!Female (
            fullName <- s.firstName + ' ' + s.familyName
        )
}
```



Merci !

Questions?