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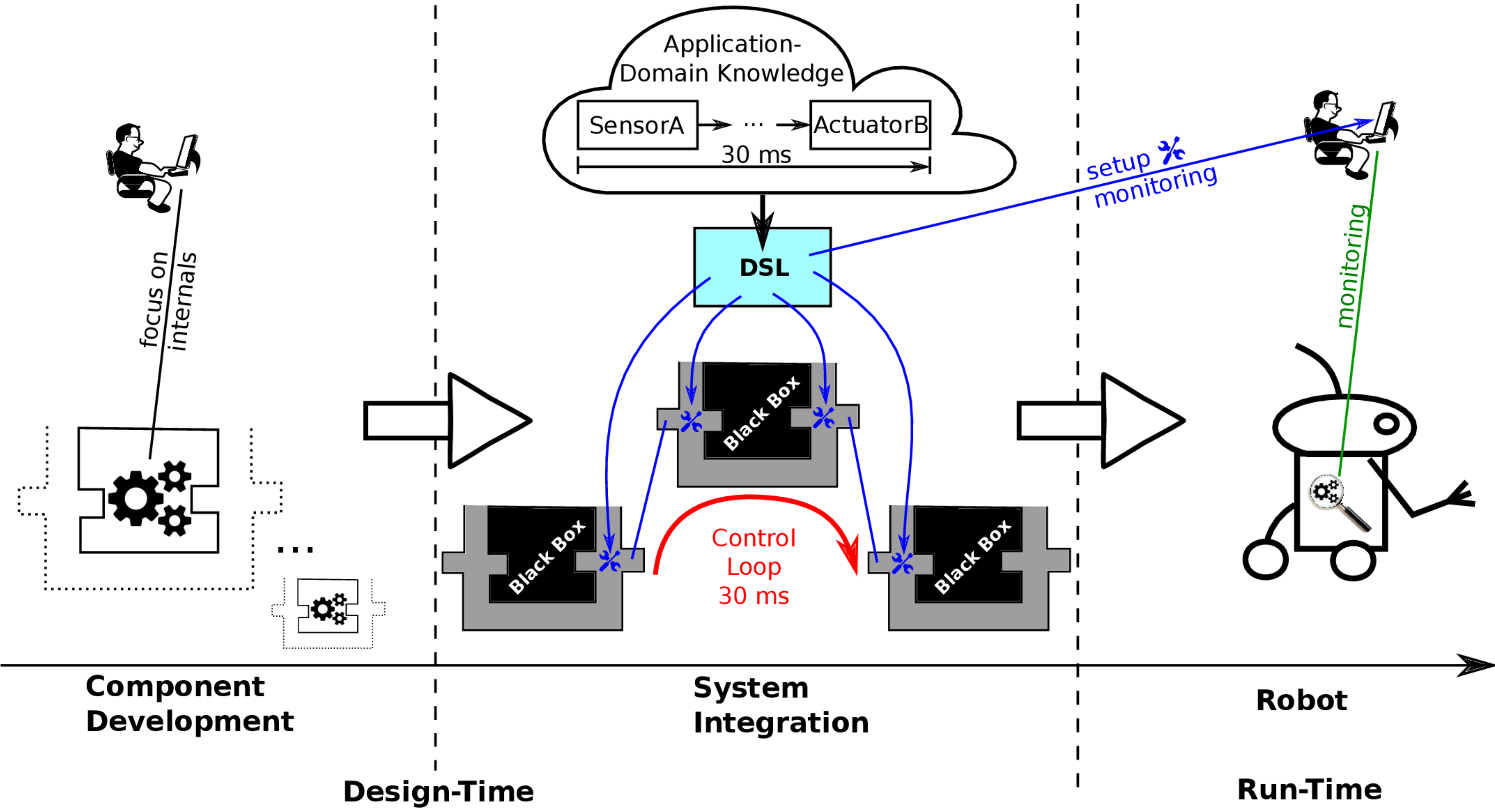
Modeling Non-Functional Application Domain Constraints for Component-Based Robotics Software Systems

DSLRob 2015

Alex Lotz[1], Arne Hamann[2], Ingo Lütkebohle[2],
Dennis Stampfer[1], Matthias Lutz[1] and Christian Schlegel[1]

In bilateral cooperation between the
[1]University of Applied Sciences Ulm and the
[2]Robert Bosch GmbH

Overall approach



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Current Software Engineering Trends for Service-Robotics

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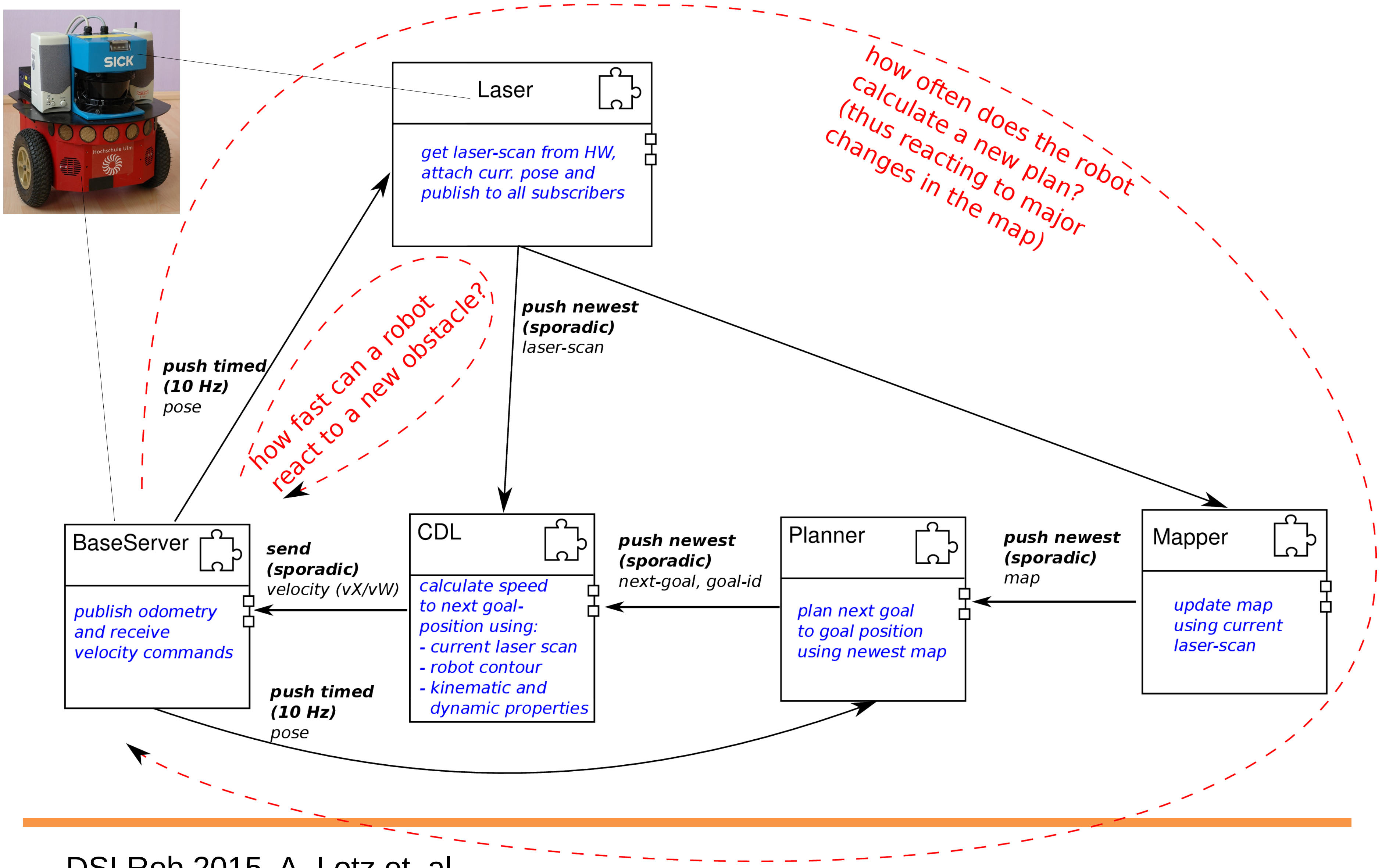
- MDSE applied for Robotics Component Models, e.g.:
  - RobotML (from PROTEUS)
  - OMG RTC (with OpenRTM-aist reference implementation)
  - BRICS Compoment Model (BCM)
  - SmartSoft (and the SmartSoft MDSD Toolchain)
  - etc.
- These approaches already facilitate the development of **functional components** by **robotics experts**
- But: what about non-functional **application-related** aspects such as **responsiveness** and **deterministic behavior**?

Navigation Example


Laser
get laser-scan from HW, attach curr. pose and publish to all subscribers
push newest (sporadic) laser-scan
push timed (10 Hz) pose
how fast can a robot react to a new obstacle?
how often does the robot calculate a new plan? (thus reacting to major changes in the map)
BaseServer
publish odometry and receive velocity commands
send (sporadic) velocity (vX/vW)
CDL
calculate speed to next goal-position using:
- current laser scan
- robot contour
- kinematic and dynamic properties
push newest (sporadic) next-goal, goal-id
Planner
plan next goal to goal position using newest map
push newest (sporadic) map
Mapper
update map using current laser-scan
push timed (10 Hz) pose

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Component's internal view

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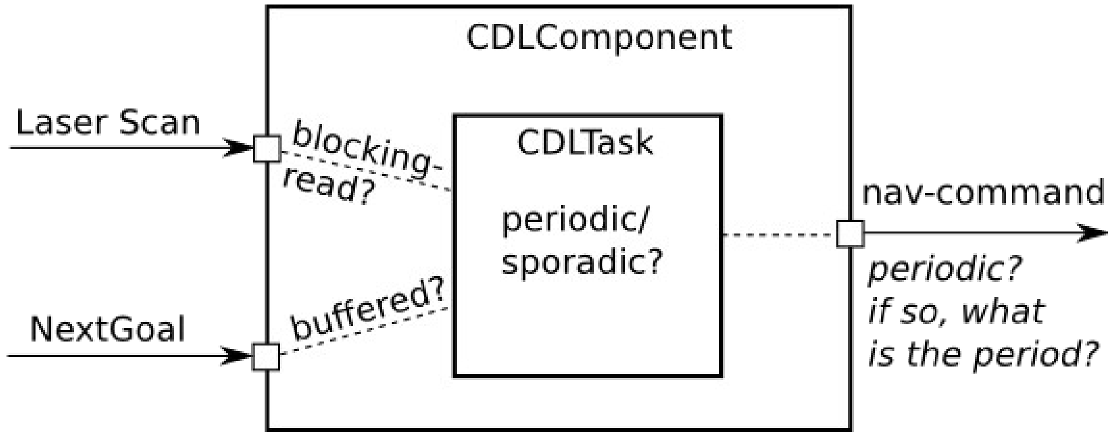
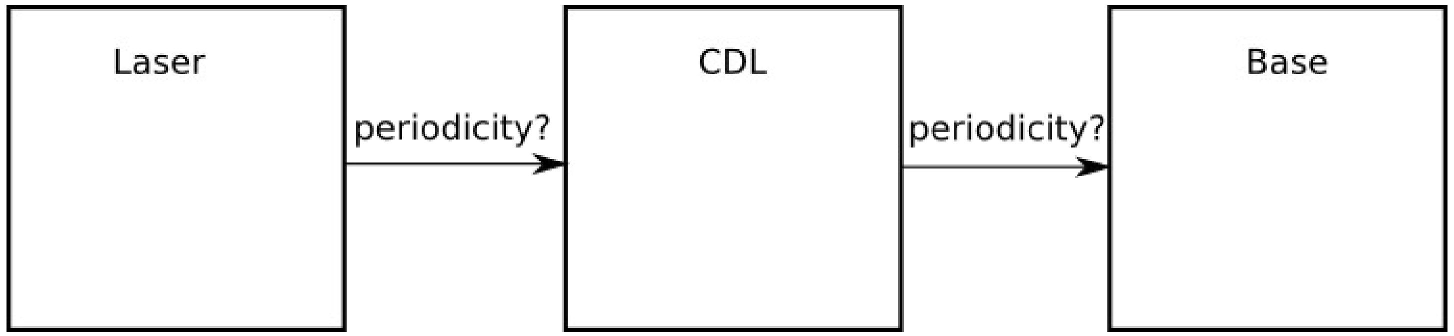


- ***Causality***: is there a certain „in-port“ triggering the execution of the „CDLTask“ and thus influencing the behavior of the „out-port“?
- ***Latency***: how long does it take for a message token to traverse the internal parts of a component (buffers, update-rates, etc.)?
- ***Separation of concerns***: who is actually responsible for designing such issues (i.e. *component developer* or *system integrator*)?

System integration problems before our modeling approach



- ***Causality***: propagation rules for communication behavior in a chain of interconnected components are unknown on model level
- ***Latency and Jitter***: Data aging from source to destination is massively influenced by individual component implementations
- ***Separation of concerns***: system integrators need to investigate and modify components' internal implementations

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Ecore Meta-Model

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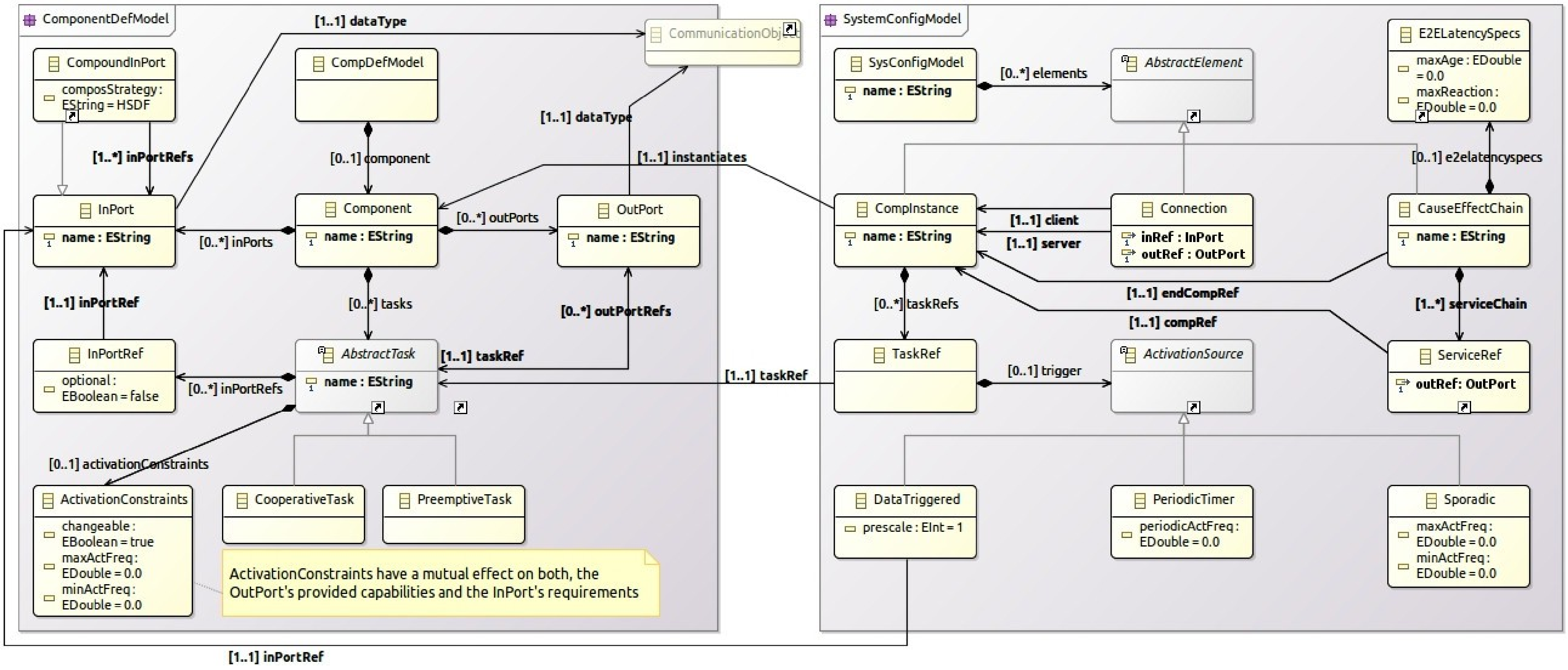

- Ecore meta-model is separated into two packages; one for *component development* (left) and the other for *system configuration* (right)
- Each package can be realized by an individual DSL (either textually or graphically)

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Component-Definition Meta-Model

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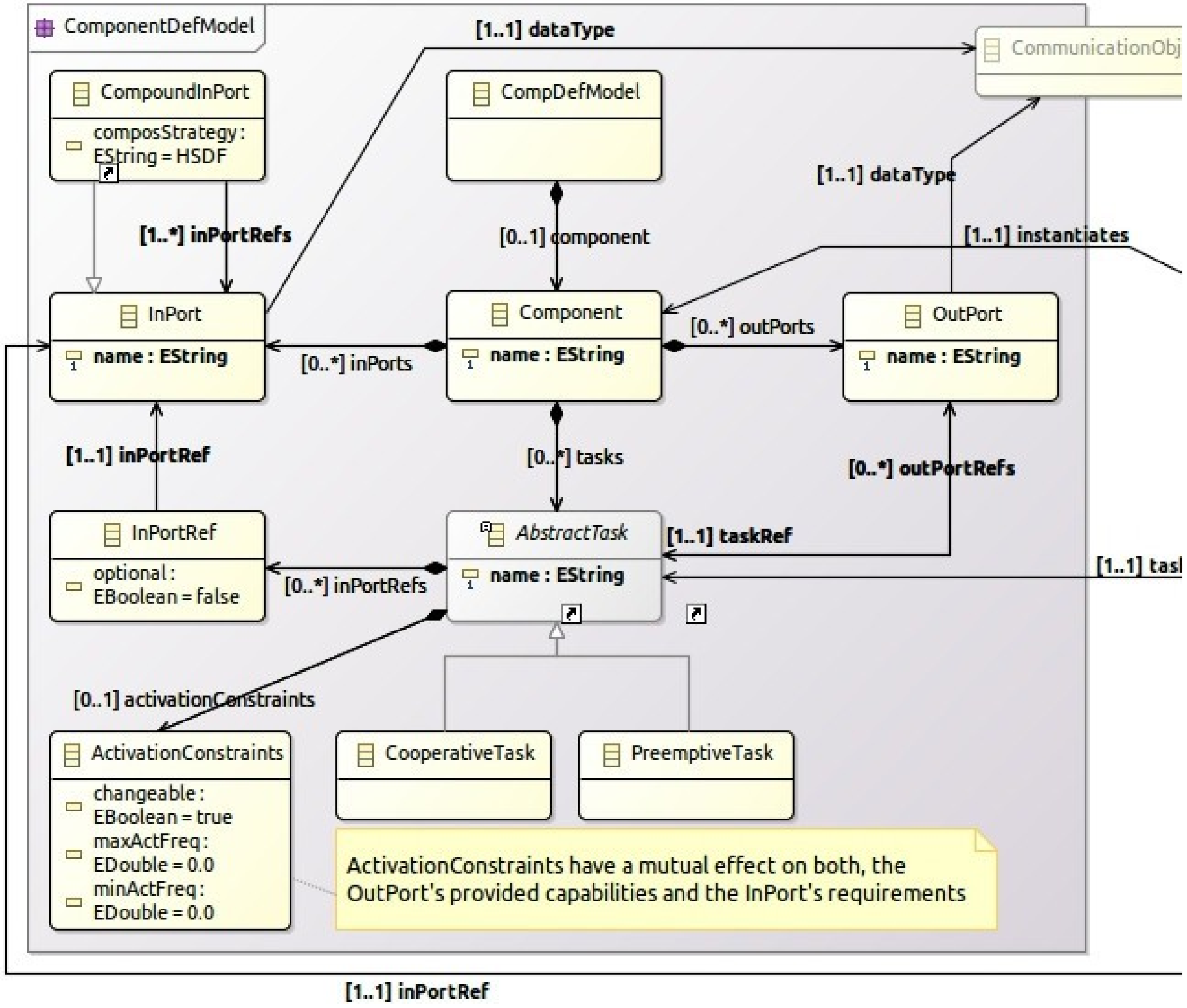

A Component consists of In-/Out-Ports and Tasks

Tasks can use data from several InPorts and can generate data for several OutPorts

Optional ActivationConstraints can define implementation-specific Task execution behavior

If no ActivationConstraints were defined, the Task execution behavior is purposefully left open for later system configuration

ActivationConstraints influence both:

- the required communication behavior for the related InPorts and
- the provided communication behavior for the related OutPorts

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System-Configuration Meta-Model

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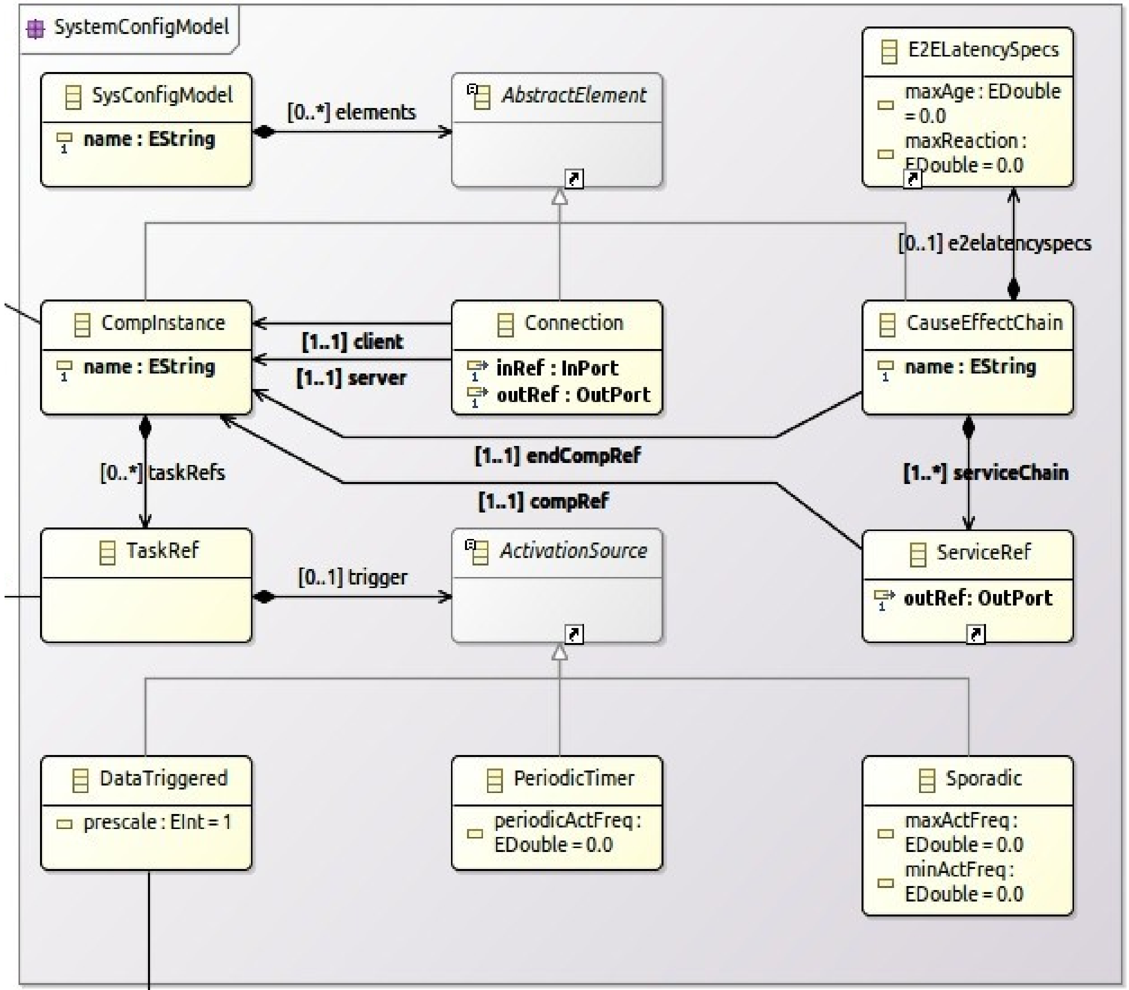
- The main concern here is the definition of component-instances and their initial connections
- In addition, ActivationSources clearly specify the individual Task's execution behavior (i.e. Periodic, Sporadic or DataTriggered)
- Moreover, CauseEffectChains allow to define sensor-to-actuator couplings and assign individual end-to-end latency specifications
- The system configuration model is kept in sync with the referrenced component model definitions
- The system configuration model generates consistent component configurations



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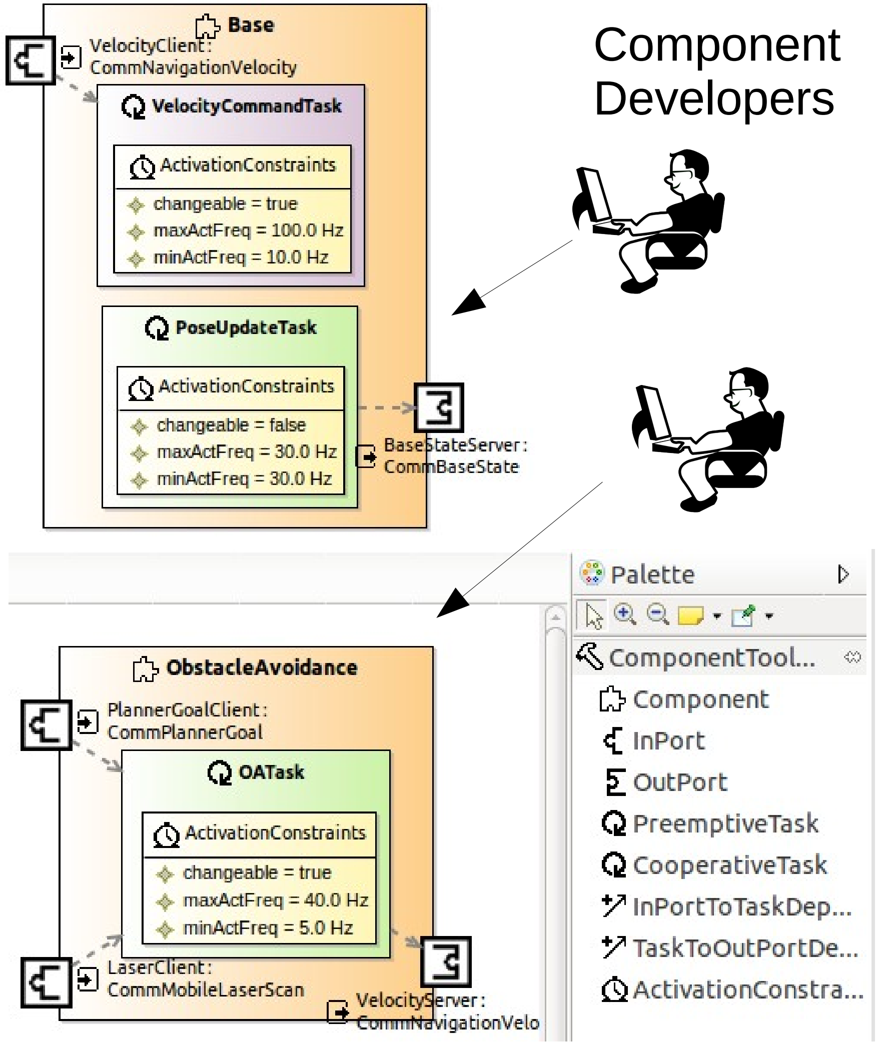
A graphical DSL for Component Definition



- Dashed lines between Tasks and In-/Out-Ports define the functional dependency on input data from several in-ports and/or responsibility to generate data for several out-ports
  - This already allows to fully implement the component without presuming application specific timing requirements
- ActivationConstraints can further specify implementation-specific restrictions (e.g. caused by involved HW drivers or algorythmic needs)
  - These constraints can be either a changeable boundary condition or a strict implementation constraint

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A textual DSL for System Configuration

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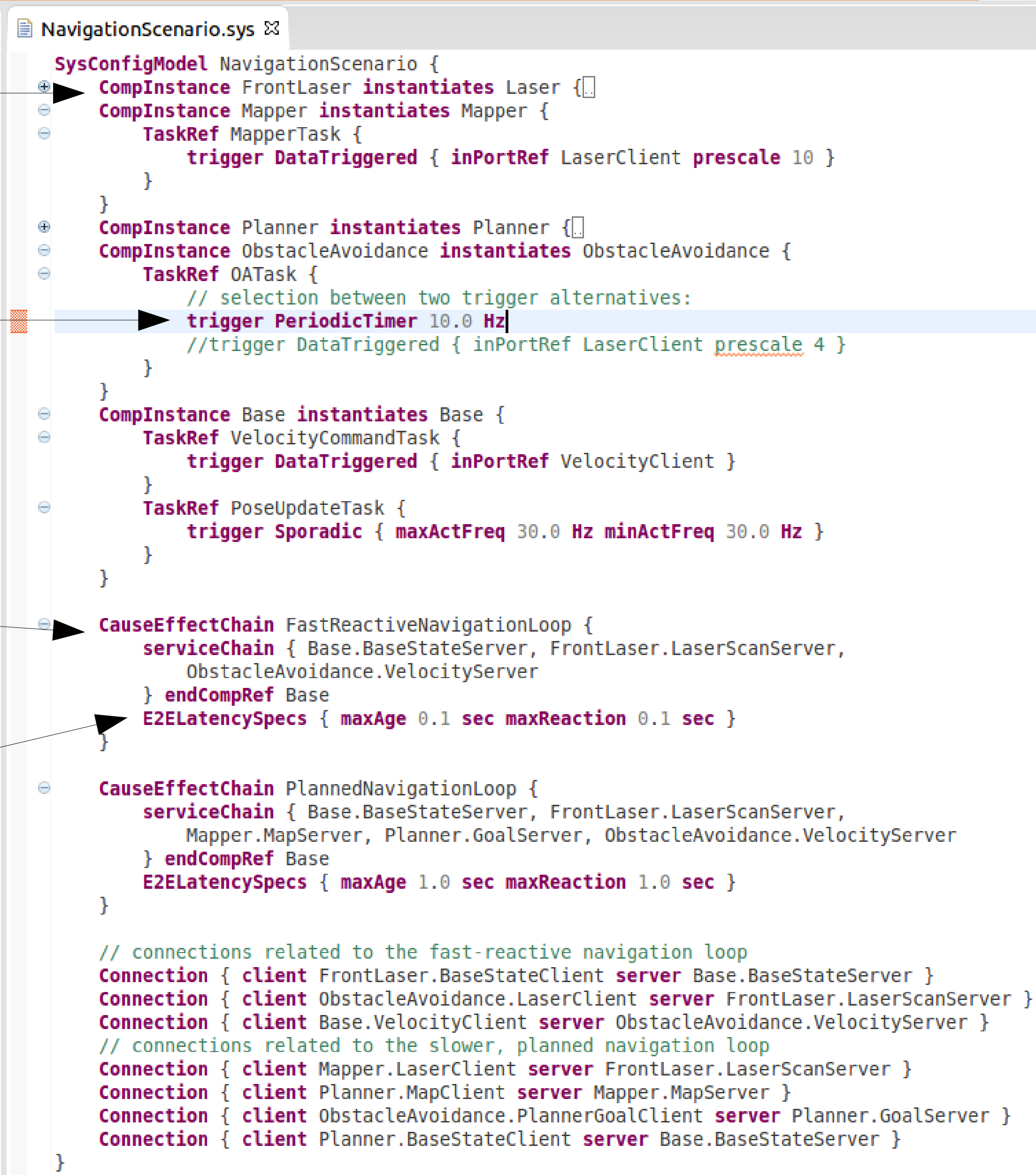
- Sytem Integrator (i.e. the application domain expert) is responsible to instantiate components and to initially connect their ports (see bottom right)
- For each Task in a component-instance an individual ActivationSource is chosen such that potential ActivationConstraints are not violated
- The relevant sensor-to-actuator couplings are defined by CauseEffectChains
  - E2ELatencySpecs further allow to directly annotate application specific end-to-end latency specifications


NavigationScenario.sys

```
SysConfigModel NavigationScenario {
    CompInstance FrontLaser instantiates Laser {
    CompInstance Mapper instantiates Mapper {
        TaskRef MapperTask {
            trigger DataTriggered { inPortRef LaserClient prescale 10 }
        }
    }
    CompInstance Planner instantiates Planner {
    CompInstance ObstacleAvoidance instantiates ObstacleAvoidance {
        TaskRef OATask {
            // selection between two trigger alternatives:
            trigger PeriodicTimer 10.0 Hz
            //trigger DataTriggered { inPortRef LaserClient prescale 4 }
        }
    }
    CompInstance Base instantiates Base {
        TaskRef VelocityCommandTask {
            trigger DataTriggered { inPortRef VelocityClient }
        }
        TaskRef PoseUpdateTask {
            trigger Sporadic { maxActFreq 30.0 Hz minActFreq 30.0 Hz }
        }
    }

    CauseEffectChain FastReactiveNavigationLoop {
        serviceChain { Base.BaseStateServer, FrontLaser.LaserScanServer,
            ObstacleAvoidance.VelocityServer
        } endCompRef Base
        E2ELatencySpecs { maxAge 0.1 sec maxReaction 0.1 sec }
    }

    CauseEffectChain PlannedNavigationLoop {
        serviceChain { Base.BaseStateServer, FrontLaser.LaserScanServer,
            Mapper.MapServer, Planner.GoalServer, ObstacleAvoidance.VelocityServer
        } endCompRef Base
        E2ELatencySpecs { maxAge 1.0 sec maxReaction 1.0 sec }
    }

    // connections related to the fast-reactive navigation loop
    Connection { client FrontLaser.BaseStateClient server Base.BaseStateServer }
    Connection { client ObstacleAvoidance.LaserClient server FrontLaser.LaserScanServer }
    Connection { client Base.VelocityClient server ObstacleAvoidance.VelocityServer }
    // connections related to the slower, planned navigation loop
    Connection { client Mapper.LaserClient server FrontLaser.LaserScanServer }
    Connection { client Planner.MapClient server Mapper.MapServer }
    Connection { client ObstacleAvoidance.PlannerGoalClient server Planner.GoalServer }
    Connection { client Planner.BaseStateClient server Base.BaseStateServer }
}
```

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System Configuration Model - Interpretation and Evaluation

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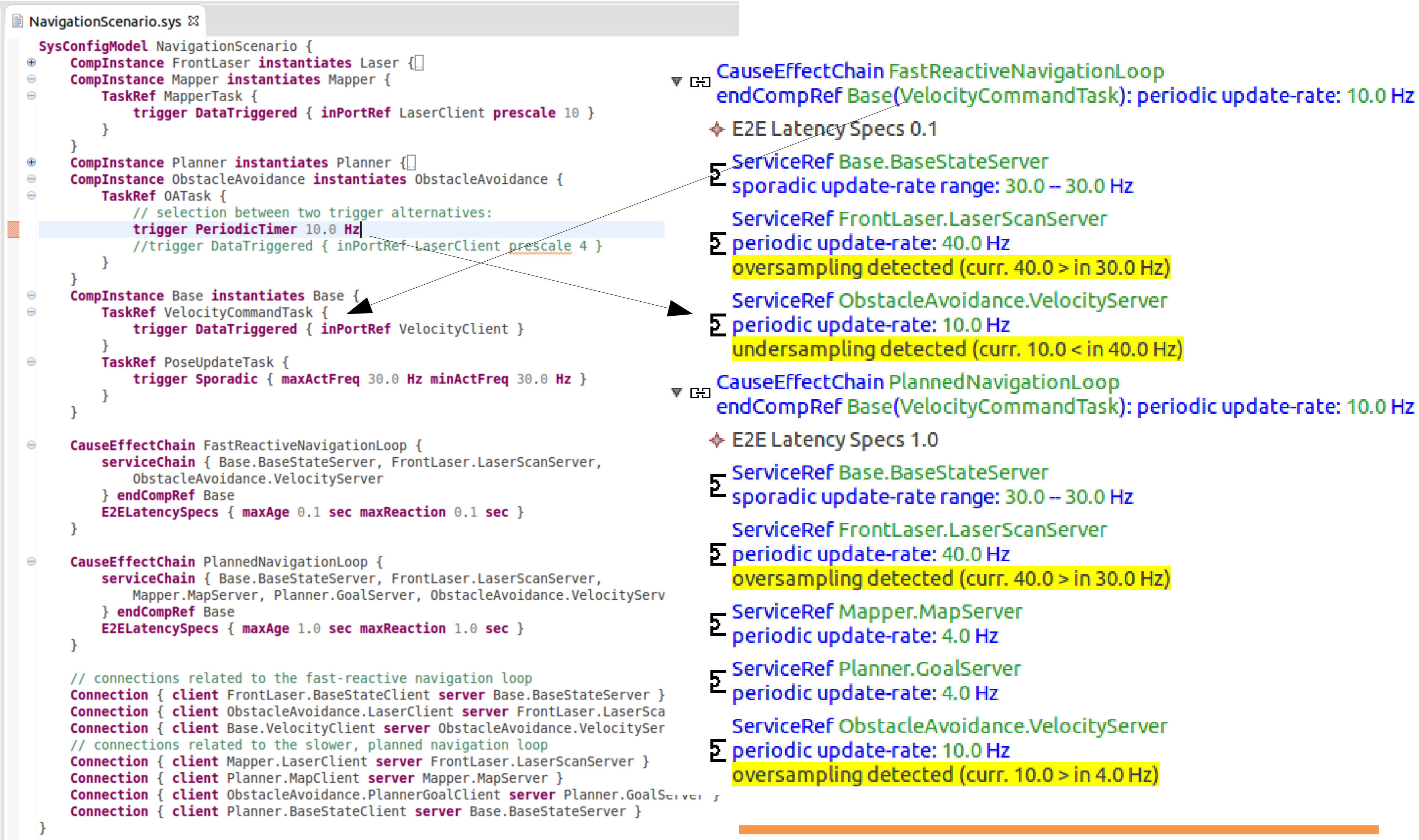

NavigationScenario.sys

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        }
    }
    CompInstance Planner instantiates Planner {
    CompInstance ObstacleAvoidance instantiates ObstacleAvoidance {
        TaskRef OATask {
            // selection between two trigger alternatives:
            trigger PeriodicTimer 10.0 Hz
            //trigger DataTriggered { inPortRef LaserClient prescale 4 }
        }
    }
    CompInstance Base instantiates Base {
        TaskRef VelocityCommandTask {
            trigger DataTriggered { inPortRef VelocityClient }
        }
        TaskRef PoseUpdateTask {
            trigger Sporadic { maxActFreq 30.0 Hz minActFreq 30.0 Hz }
        }
    }

    CauseEffectChain FastReactiveNavigationLoop {
        serviceChain { Base.BaseStateServer, FrontLaser.LaserScanServer,
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    Connection { client ObstacleAvoidance.PlannerGoalClient server Planner.GoalServer }
    Connection { client Planner.BaseStateClient server Base.BaseStateServer }
}
```

CauseEffectChain FastReactiveNavigationLoop
endCompRef Base(VelocityCommandTask): periodic update-rate: 10.0 Hz

E2E Latency Specs 0.1

ServiceRef Base.BaseStateServer
sporadic update-rate range: 30.0 -- 30.0 Hz

ServiceRef FrontLaser.LaserScanServer
periodic update-rate: 40.0 Hz
oversampling detected (curr. 40.0 > in 30.0 Hz)

ServiceRef ObstacleAvoidance.VelocityServer
periodic update-rate: 10.0 Hz
undersampling detected (curr. 10.0 < in 40.0 Hz)

CauseEffectChain PlannedNavigationLoop
endCompRef Base(VelocityCommandTask): periodic update-rate: 10.0 Hz

E2E Latency Specs 1.0

ServiceRef Base.BaseStateServer
sporadic update-rate range: 30.0 -- 30.0 Hz

ServiceRef FrontLaser.LaserScanServer
periodic update-rate: 40.0 Hz
oversampling detected (curr. 40.0 > in 30.0 Hz)

ServiceRef Mapper.MapServer
periodic update-rate: 4.0 Hz

ServiceRef Planner.GoalServer
periodic update-rate: 4.0 Hz

ServiceRef ObstacleAvoidance.VelocityServer
periodic update-rate: 10.0 Hz
oversampling detected (curr. 10.0 > in 4.0 Hz)

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Relation between ActivationConstraints, ActivationSources and E2ELatencySpecs

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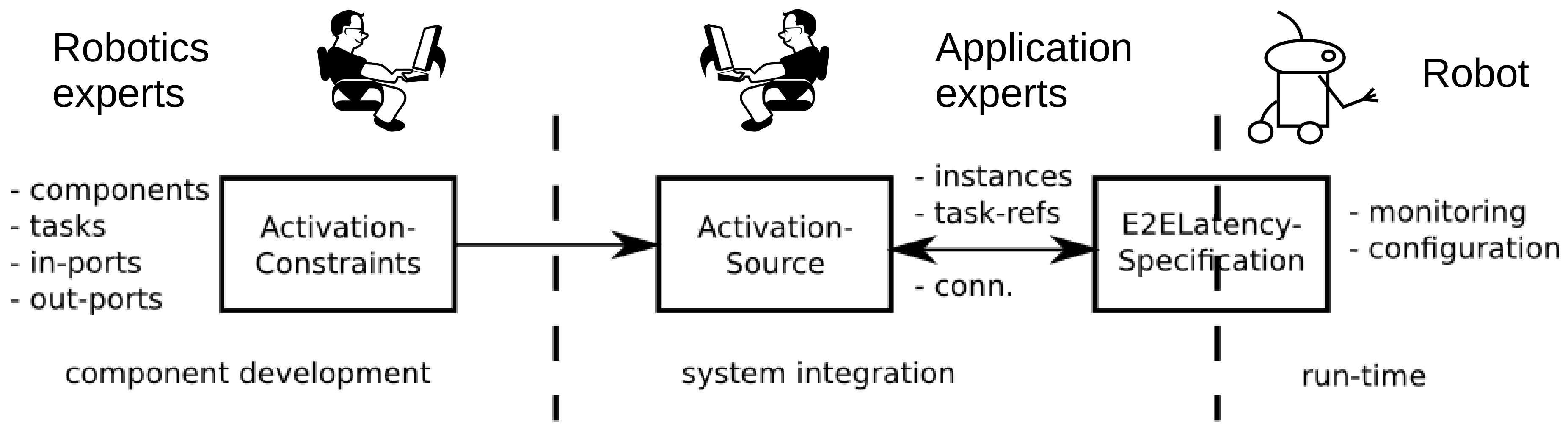

- Robotics experts focus on functional component development without presuming application specific needs
- Application experts configure the components by selecting appropriate ActivationSources within the boundaries of according ActivationConstraints and satisfying the overall E2ELatencySpecs
- E2ELatencySpecs define application-specific boundary conditions for sensor-to-actuator component chains and allow to additionally monitor and verify the actual interaction behavior of components at run-time

Conclusion

- The choice of an *ActivationSource* for individual Tasks in a Component enables system integrators to select the right model of computation and thus purposefully influence the componets' interaction behavior on model level
- CauseEffectChains allow to identify relevant chains of components
- E2ELatencySpecs allow to directly annotate application-specific constraints with respect to latencies and jitter for communication in a chain of interconnected components
- Meta-Model core elements (such as Component, InPort, OutPort) are kept generic, thus allowing to reuse many popular component models in robotics and beyound
- Component developers (i.e. robotics experts) and system integrators (i.e. application domain experts) can focus on their individual expertise while collaborativelly designing and developing the whole robotic system (i.e. separation of roles and concerns)

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