TECHNISCHE UNIVERSITÄT DRESDEN
Faculty of Computer Science, Software Technology Group

A Case Study for Workflow-based Automation in the Internet of Things

IoT-ASAP @ ICSA 2018

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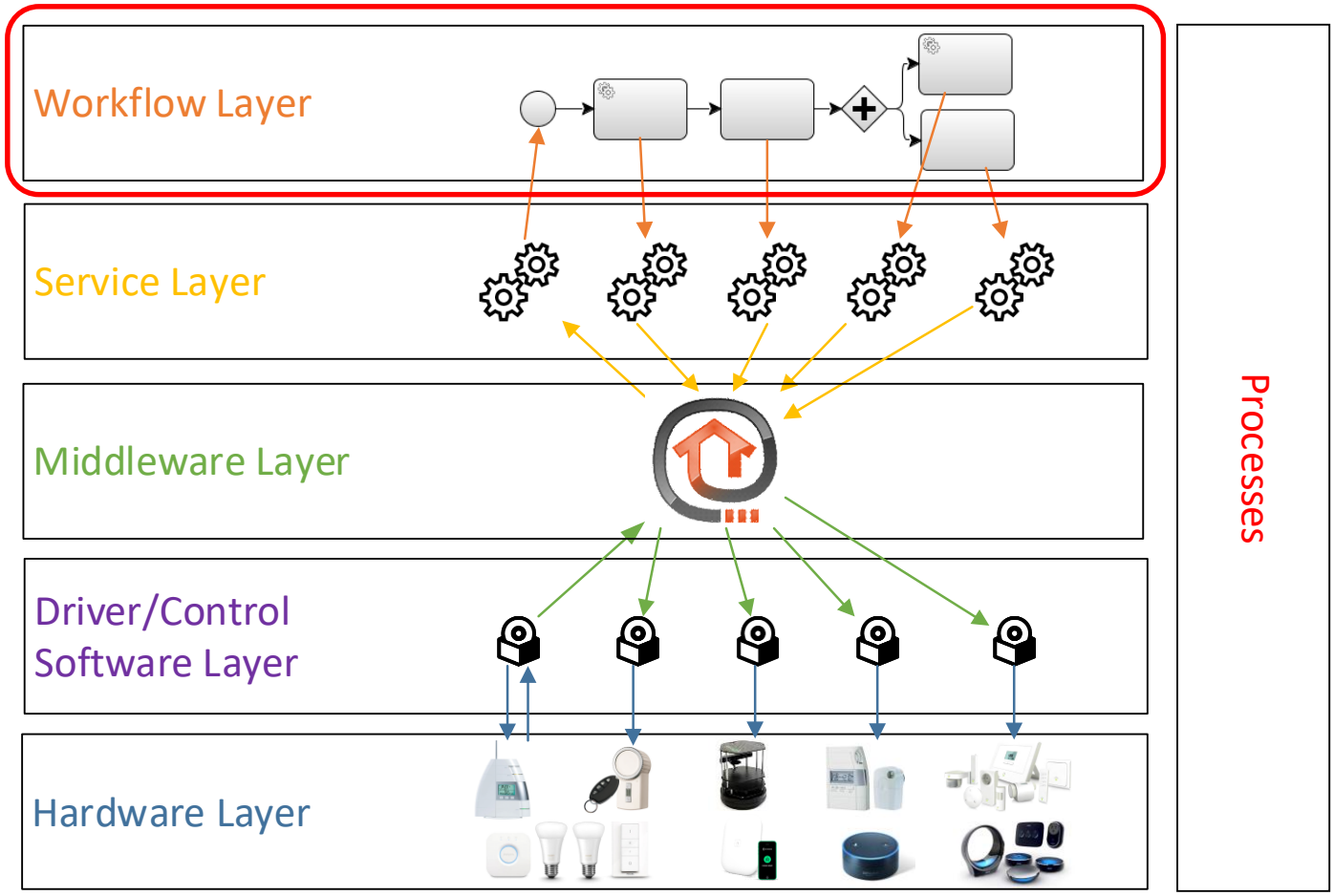
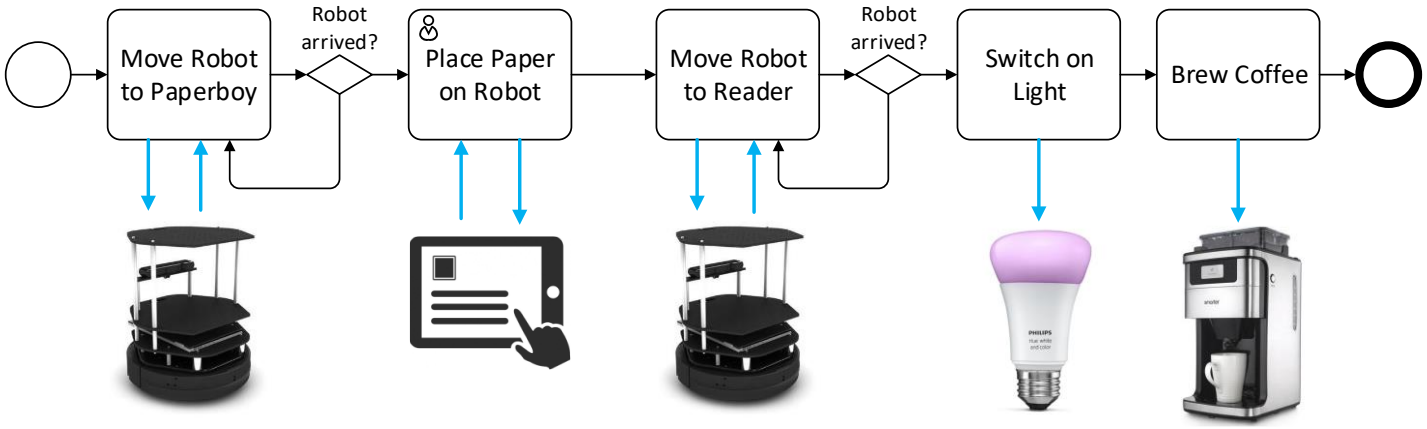
Seattle, 30.04.2018

Workflows in IoT

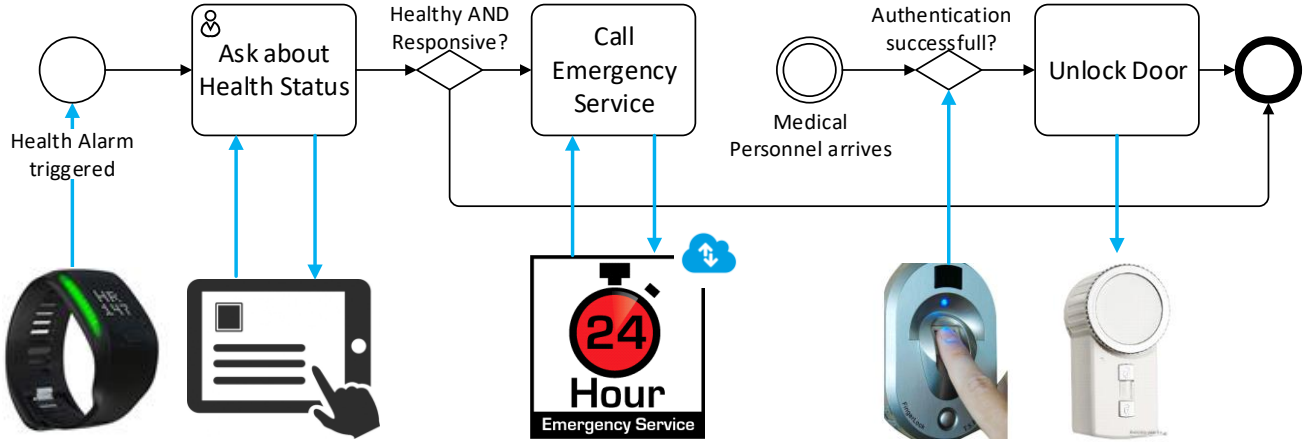


Smart Home Example Processes

Morning Routine Process



Emergency Process



Challenges/Research Issues

- Modelling and execution of workflows/processes in IoT

→ describe interactions of IoT elements on business process level

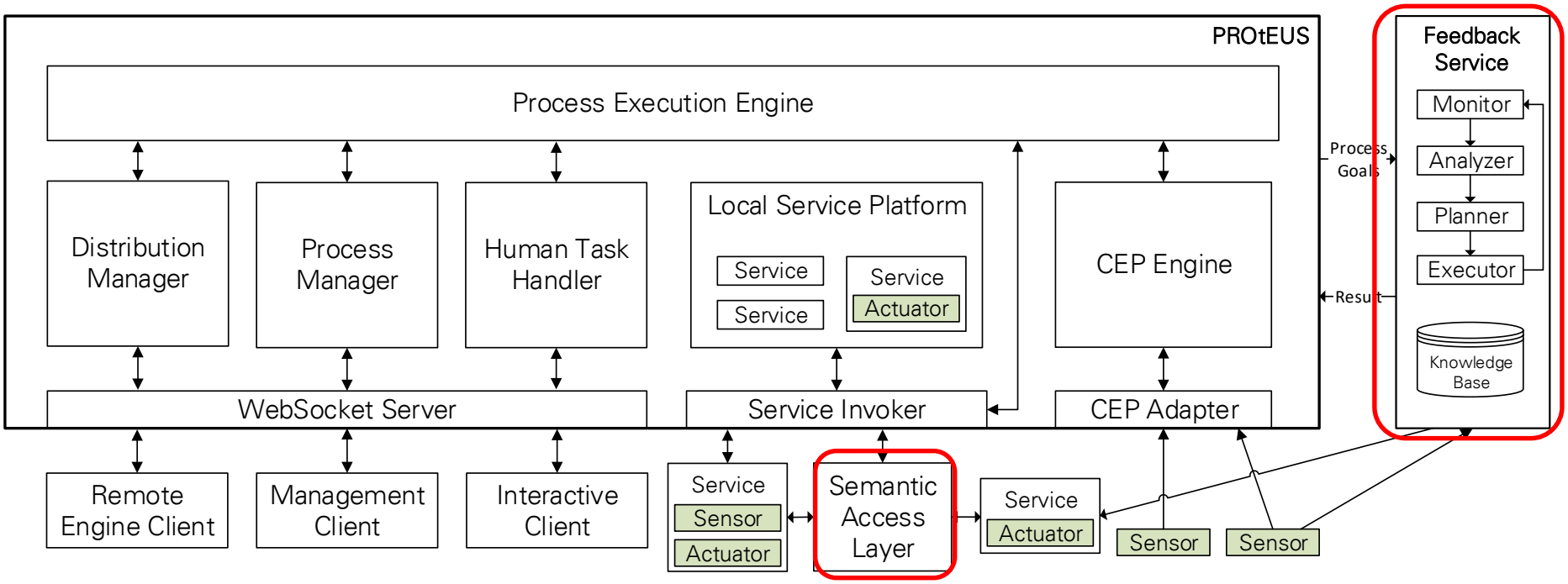
  - Heterogeneous devices
  - Complex sensor networks
  - Resource-constraint, mobile or stationary actuators
  - Humans
  - Smart objects
  - Software services and applications

- Resilient workflow execution

→ detect and handle errors and unanticipated situations

  - Interactions with the physical world
  - Mutual influence between physical and cyber world (CPS)

PROtEUS WfMS[1] [2,3]

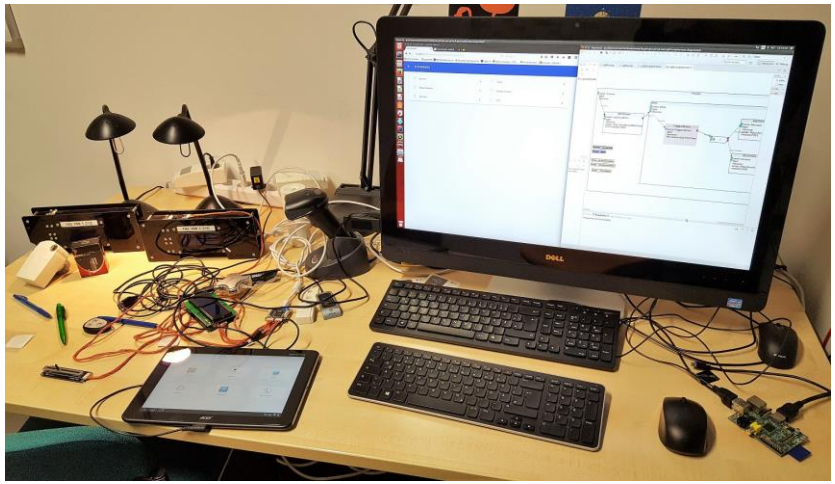


- Complex event processing, Web service invocations, Human Tasks
- Dynamic service selection (Ontology + Semantic Queries): SAL[2] [4]
- Self-adaptive workflow execution: Feedback Service[3] [5,6]
  - Goals define success or error criteria
  - Analysis of external sensor data
  - Process adaptation in case of errors

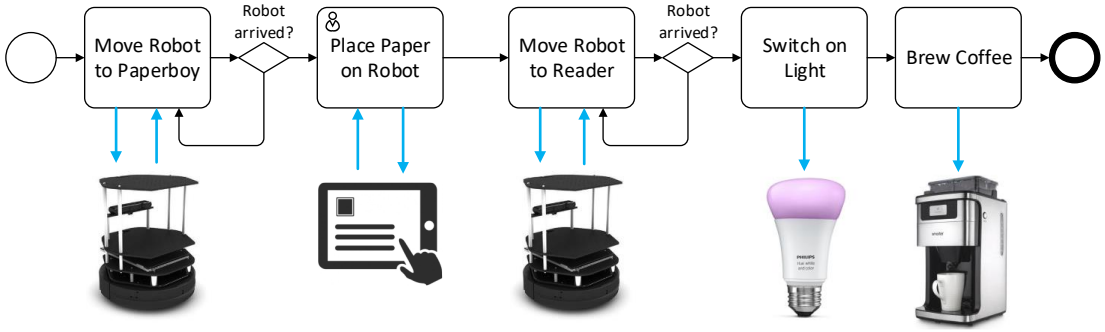
(1) https://github.com/IoTUDresden/proteus
(2) https://github.com/IoTUDresden/openhab2-addons
(3) https://github.com/IoTUDresden/feedback-service

Smart Home Case Study

- Real world case study based on scenario processes
  - Morning Routine process and Emergency process
  - Coffee process and Robot Navigation process
- Controlled lab experiments
  - 1 control computer (Ubuntu Linux) with PROtEUS WfMS + associated services, middleware (OpenHAB)
  - Sensors and actutators from various vendors (Homematic, Tinkerforge, …)
  - Turtlebot 2 robots, Android tablets
  - BeSpoon tracking system

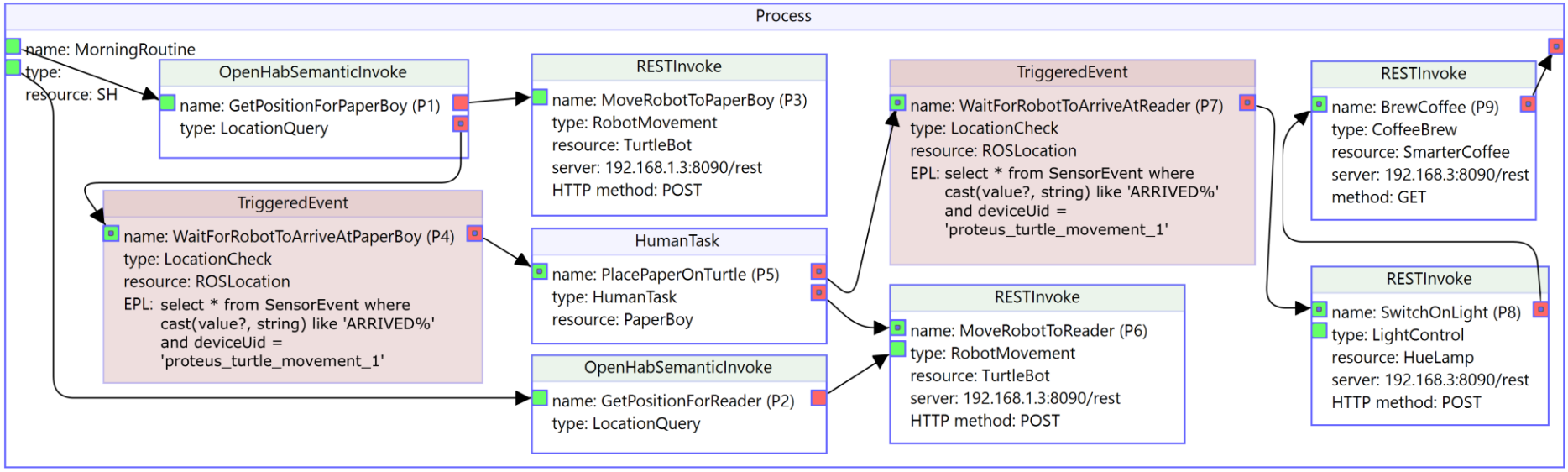


Morning Routine Process

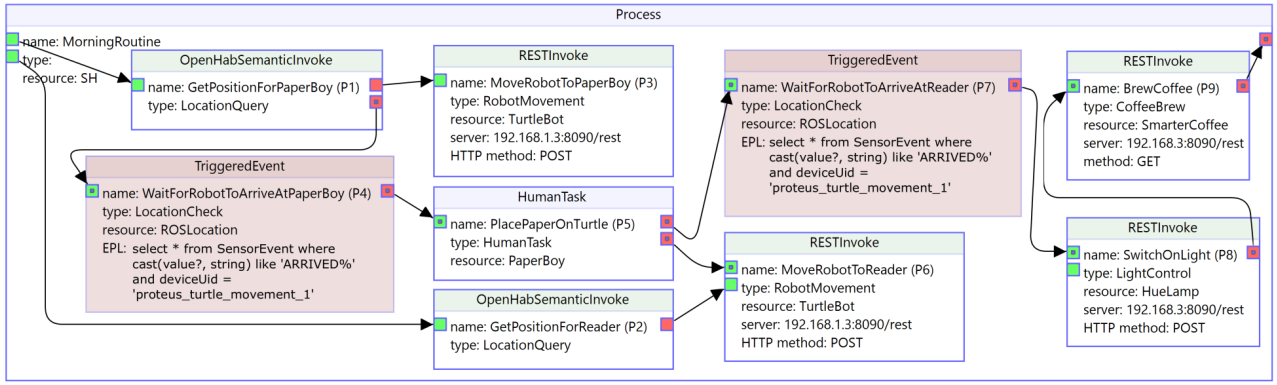


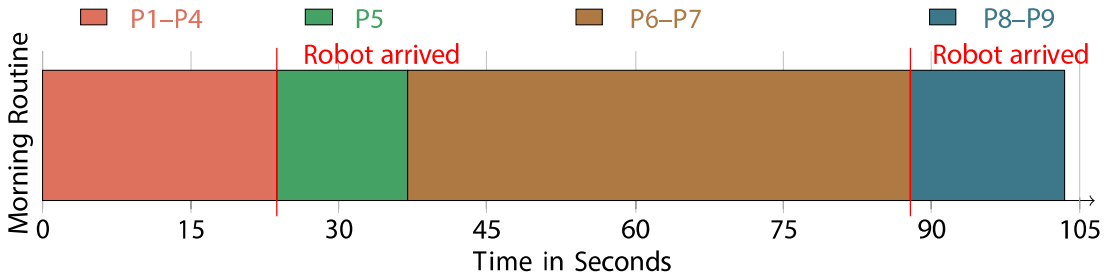
Process Model [1]

- Dynamic sensor selection
  - Position
- RESTful services
  - Send robot to target
  - Trigger light and coffee
- Event processing
  - Robot arrived
- Human Task



Results: Morning Routine Process



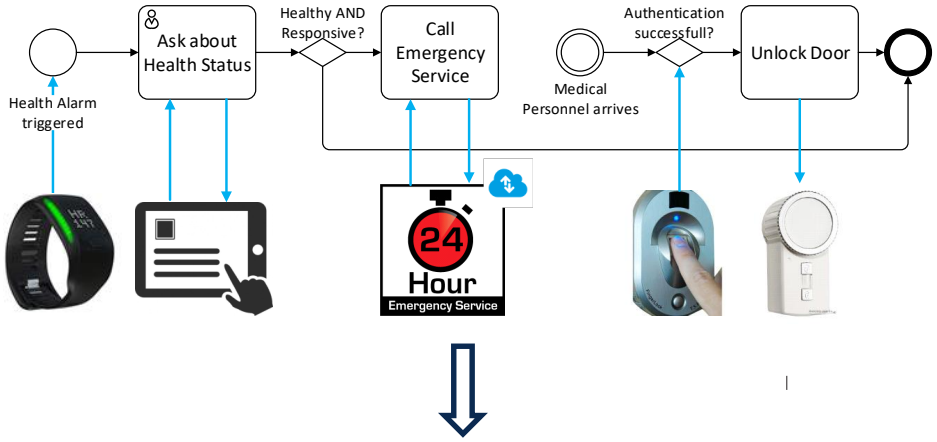


ID	Process Step	Duration (in ms)
P1	GetPositionForPaperBoy	34
P2	GetPositionForReader	42
P3	MoveRobotToPaperBoy	35
P4	WaitForRobotToArriveAtPaperBoy	23631
P5	PlacePaperOnTurtle	13218
P6	MoveRobotToReader	27
P7	WaitForRobotToArriveAtReader	50859
P8	SwitchOnLight	13
P9	BrewCoffee	15586
	MorningRoutine	103.334

- Fast virtual process executions (near real-time, < 100 ms)
- Cyber-physical process steps much longer
- Asynchronous service invocations

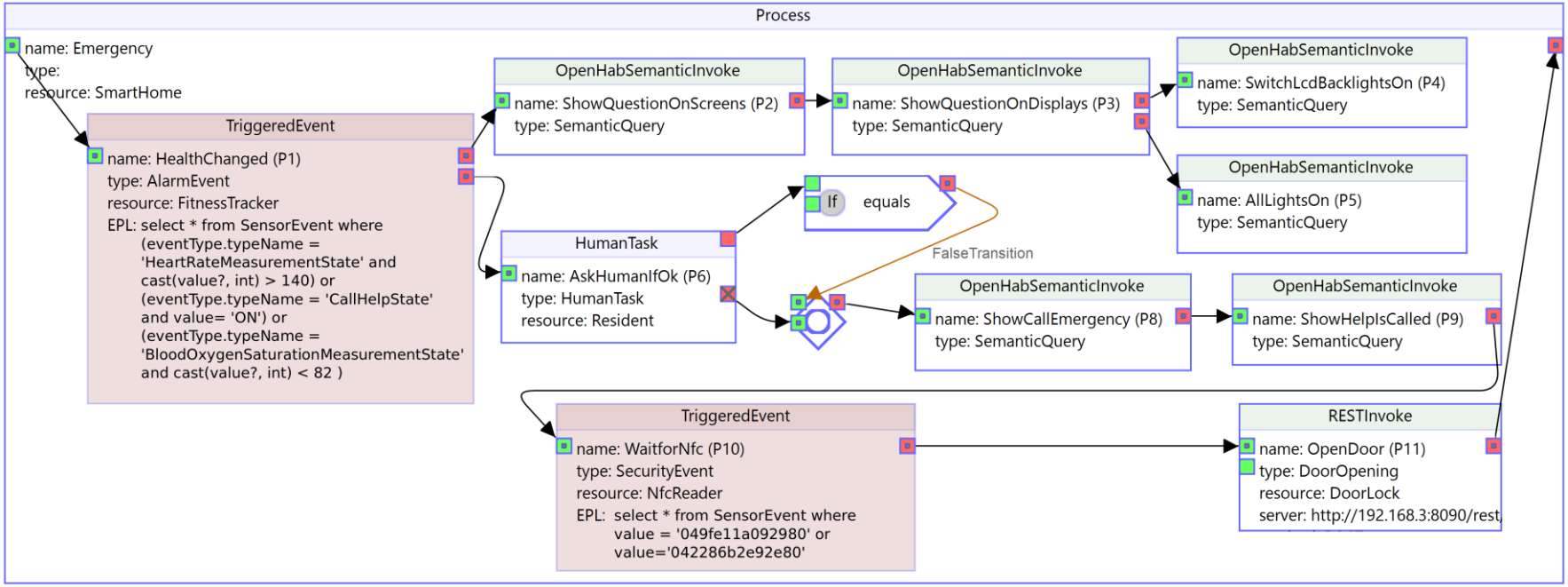
→ require event listeners

Emergency Process

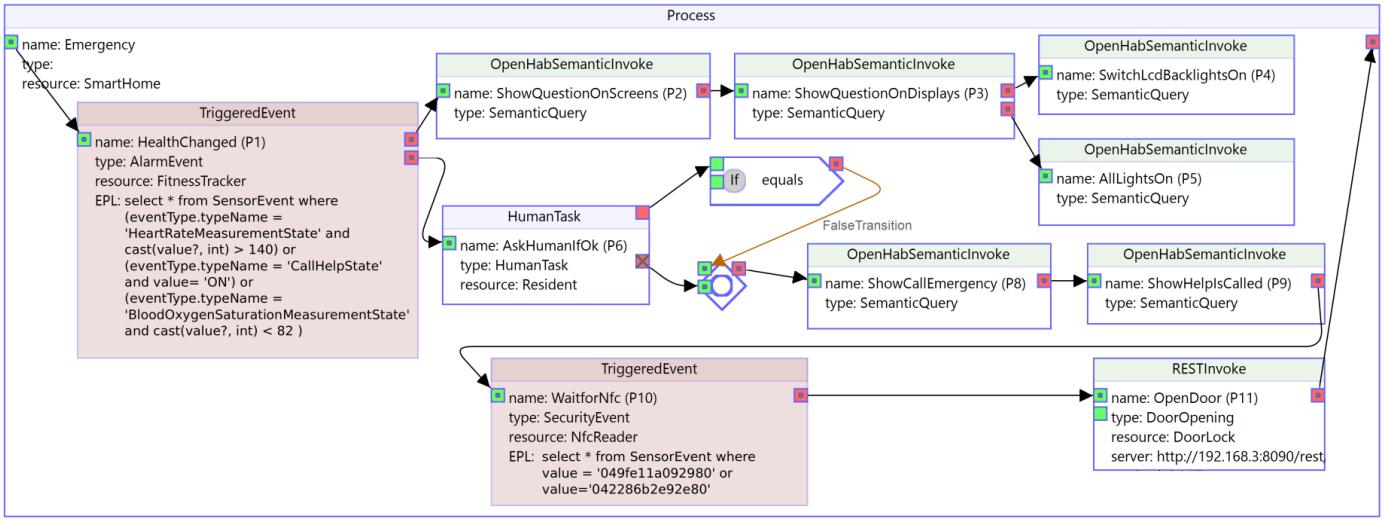


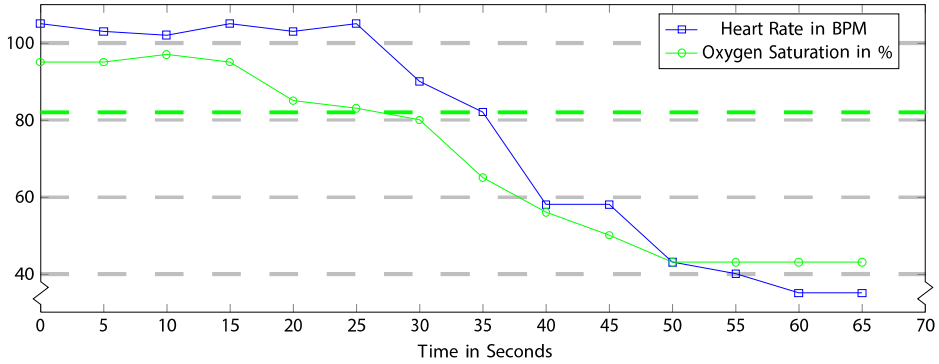
- Event processing
- Human Task
- Dynamic service selection

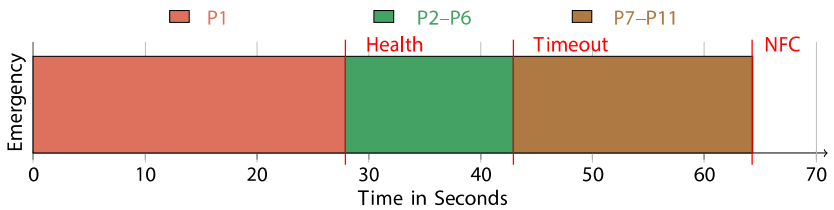
```
1 SELECT   ?func  ?dimmer
2 WHERE {
3   ?dimmerClass      rdfs  :subClassOf     *  dogont :
      DimmerSwitch .
4   ?onClass      rdfs  :subClassOf     *  dogont :OnCommand .
5   ?dimmer    rdf  :type  ?dimmerClass  .
6   ?dimmer    dogont :hasFunctionality  ?func  .
7   ?func     dogont :hasCommand  ?cmd  .
8   ?cmd   rdf  :type  ?onClass  . }
```



Results: Emergency Process







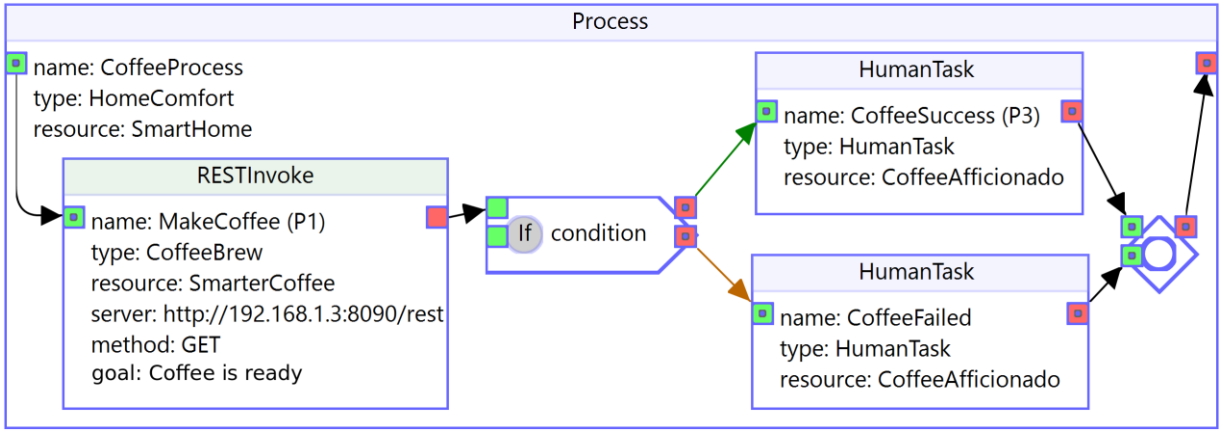
ID	Process Step	Duration (in ms)
P1	HealthChanged	27916
P2	ShowQuestionOnScreens	181
P3	ShowQuestionOnDisplays	47
P4	SwitchLcdBacklightsOn	57
P5	AllLightsOn	111
P6	AskIfHumanOk	15046
P7	OR	7
P8	ShowCallEmergency	131
P9	ShowHelpIsCalled	55
P10	WaitForNfc	21213
P11	OpenDoor	20
	Emergency	64389

Video: Emergency Process

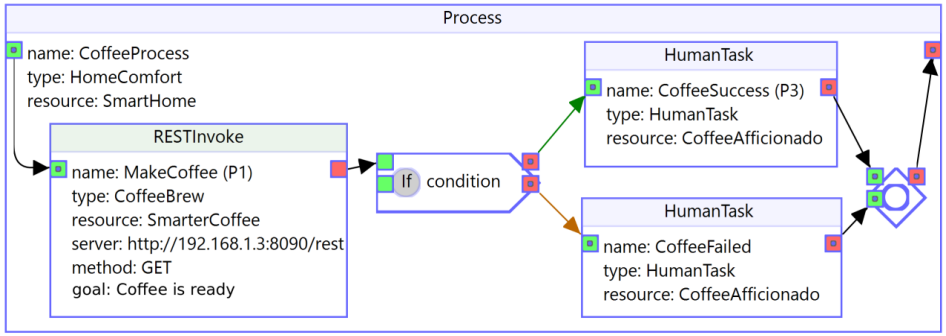
Coffee Process

- Process invokes coffee brewing service
- Use MAPE-K loop to verify process execution
  - Monitor, Analyze, Plan, Execute
- External sensor (infrared) + Feedback Service
- Goal defines success and error criteria

```
"MakeCoffee" : {
"name":"Coffee is ready",
"objectives":[ {
 "name":"coffee temperature > 37 degrees within
        3 minutes",
 "satisfiedCondition":"#coffeeTemp > 37",
 "compensationCondition":"#objective.created.
      isBefore(#now.minusSeconds(180))",
 "contextPaths":[
  "MATCH (ctemp {name: '
      State_tinkerforge_irTemp_irTemp_1'})-[:
      hasStateValue]->(value)",
  "WHERE toFloat(value.realStateValue)>0",
  "RETURN toFloat(value.realStateValue) AS
      coffeeTemp, id(ctemp) AS stateId"
  ] } ] }
```

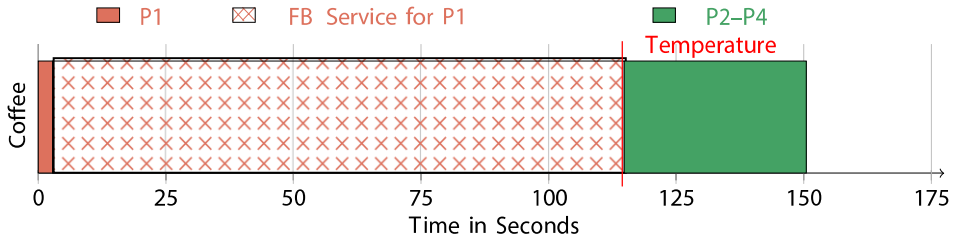


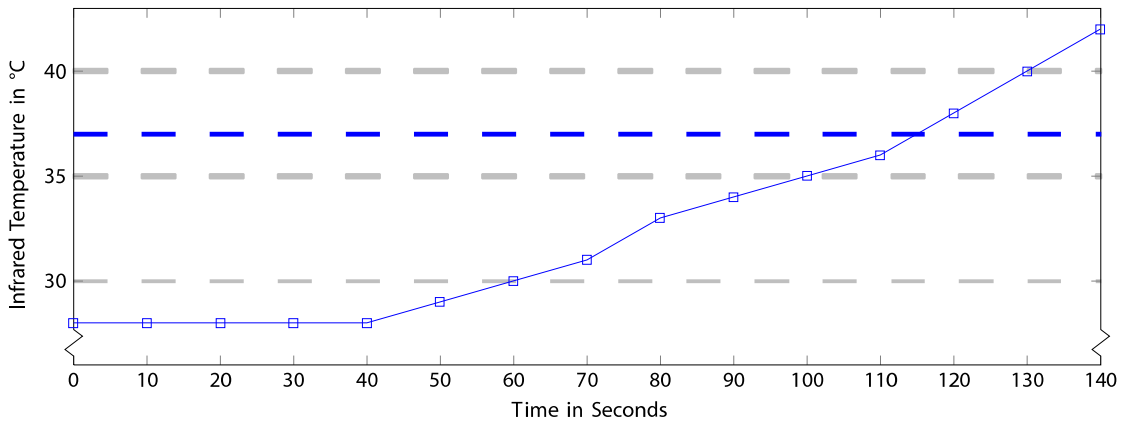
Results: Coffee Process



ID	Process Step	Duration (in ms)
P1	MakeCoffee	114.940
P2	IF	38
P3	CoffeeSuccess	35645
P4	OR	9
	CoffeeProcess	150.632

Metrics \ Phase	M	A	P	E	Loop	FB Service
Iterations (#)	–	148	–	–	148	1
Duration (ø in ms)	–	6	–	–	1023	112.135

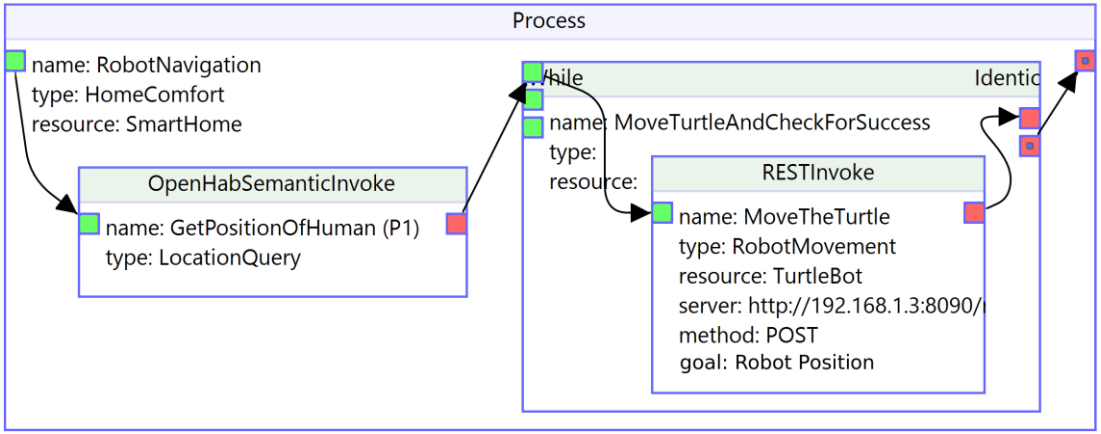




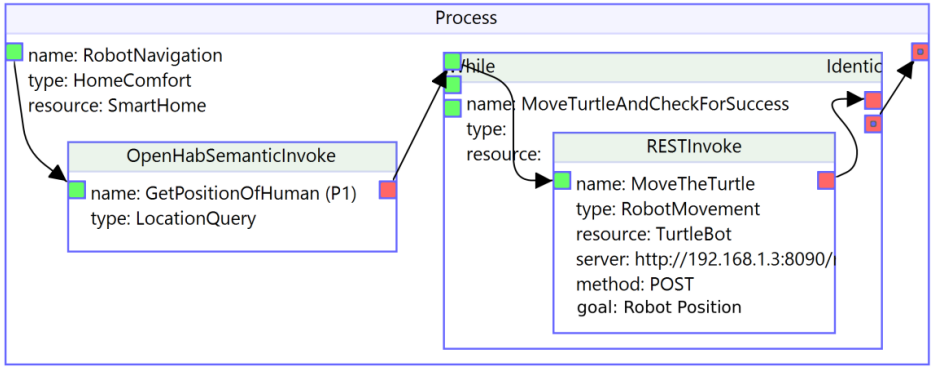
- Link external sensor data to workflow execution
- Verification of process execution
- Fast execution times

Robot Navigation Process

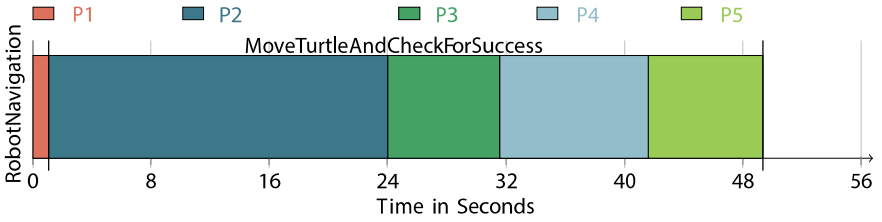
- Process invokes robot service to drive to a target
- Robot's internal SLAM localization prone to errors
- External sensor data (BeSpoon localization) to verify correct position
- Verification and compensation planning in MAPE-K loop (Goal)
  - Success: robot reached specified coordinates and publishes "arrived" event
  - Error: robot publishes "arrived" event and has not reached coordinates
- Error: Planner decides to cancel MAPE-loop and reports error → Process loop is repeated → robot is re-instructed



Results: Robot Navigation Process

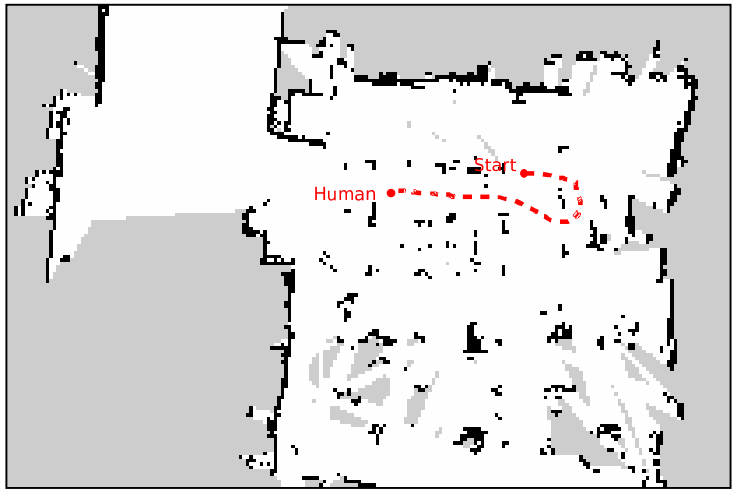


ID	Process Step	Duration (in ms)
P1	GetPositionOfHuman	1079
P2	MoveTheTurtle (1)	22924
P3	MoveTheTurtle (2)	7530
P4	MoveTheTurtle (3)	10065
P5	MoveTheTurtle (4)	7759
	MoveTurtleAndCheckForSuccess	48278
	RobotNavigation	49357



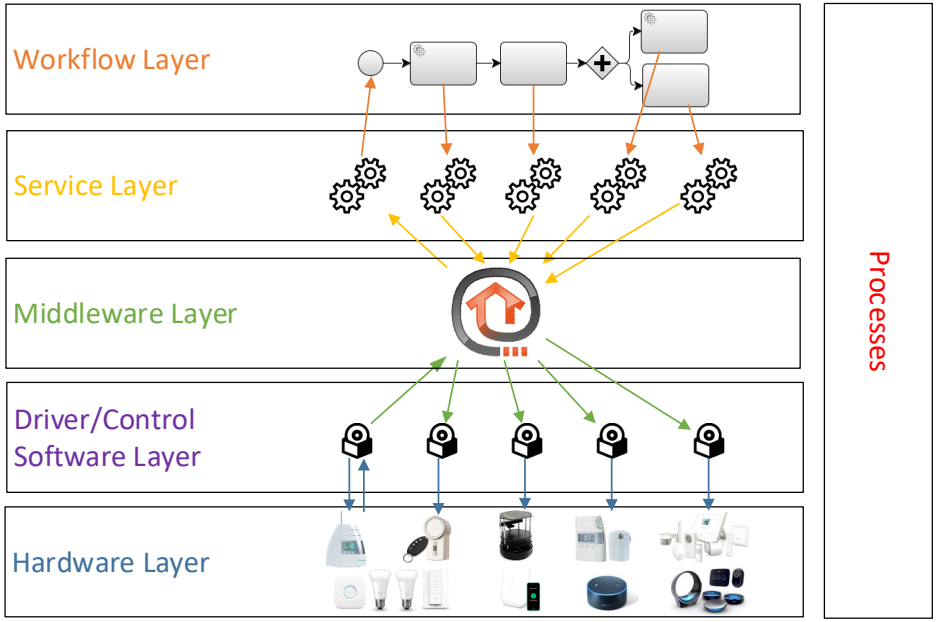
ID	Process Step	#M	#A	#P	#E	Duration (in ms)
P2	MoveTheTurtle (1)	–	17	1	1	21084
P3	MoveTheTurtle (2)	–	6	1	1	7202
P4	MoveTheTurtle (3)	–	9	1	1	10028
P5	MoveTheTurtle (4)	–	6	0	0	7333

- Process verification with external sensors
- Detect and remedy errors
- Simple planning → repeat process step
- Extensible strategies (replace resources)



Conclusion

- Workflows for automation in IoT
  → on top of sensors, actuators, humans, objects, services
- Active and reactive interactions on the business process level
- Smart home case study
  → real world experiments
- Fast virtual computations
- Long running physical executions
- Sensor data ←→ workflow execution
  → execution verification
- MAPE-K loop-based self-management for resilient processes



Questions?

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