How Cyber-Physical Systems will Change The World

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Courtesy to Christian Piechnick, Julia Schroeter, Sebastian Richly, Max Leuthäuser, Claas Wilke, Sebastian Götz

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1) Cyber-Physical Systems (CPS)

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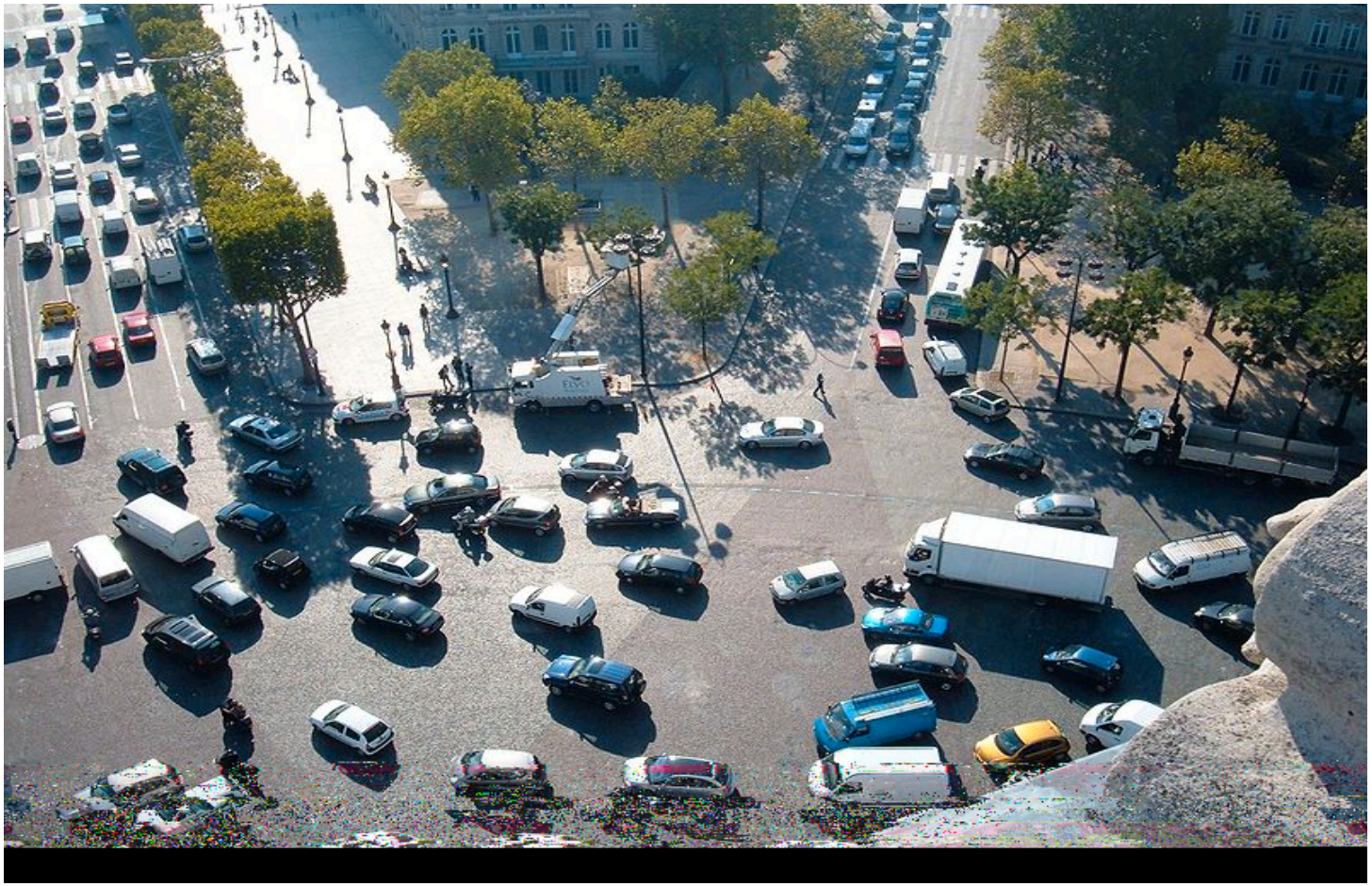
A Cyber-Physical System (Res Ubique *lat.*, Resubic System)



http://commons.wikimedia.org/wiki/File:Traffic_seen_from_top_of_Arc_de_Triomphe.JPG

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BMW Connected Drive Connect (CDC)

http://www.digitaltrends.com/cars/destination-home-how-fully-autonomous-driving-might-come-sooner-than-we-think/

http://www.microsoft.com/showcase/en/us/details/e7728af1-3fe4-4e25-a907-3dbf689fe11a

Mobile Luminar: a „Human“ Cyber-Physical System

Fakultät Informatik Institut Software- und Multimediatechnik, Lehrstuhl Softwaretechnologie

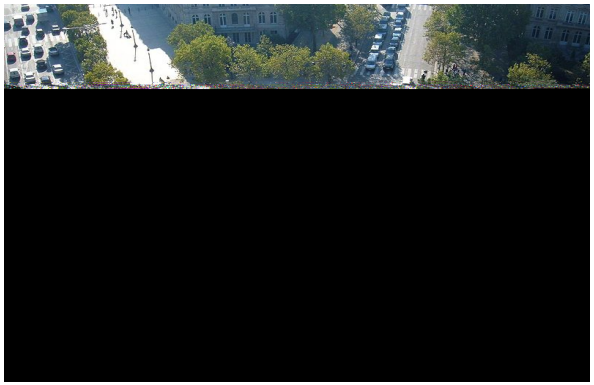
Human-CPS („Everyware“)

Mixed-Reality Interaction

Cloud

Embedded

Ubiquitous



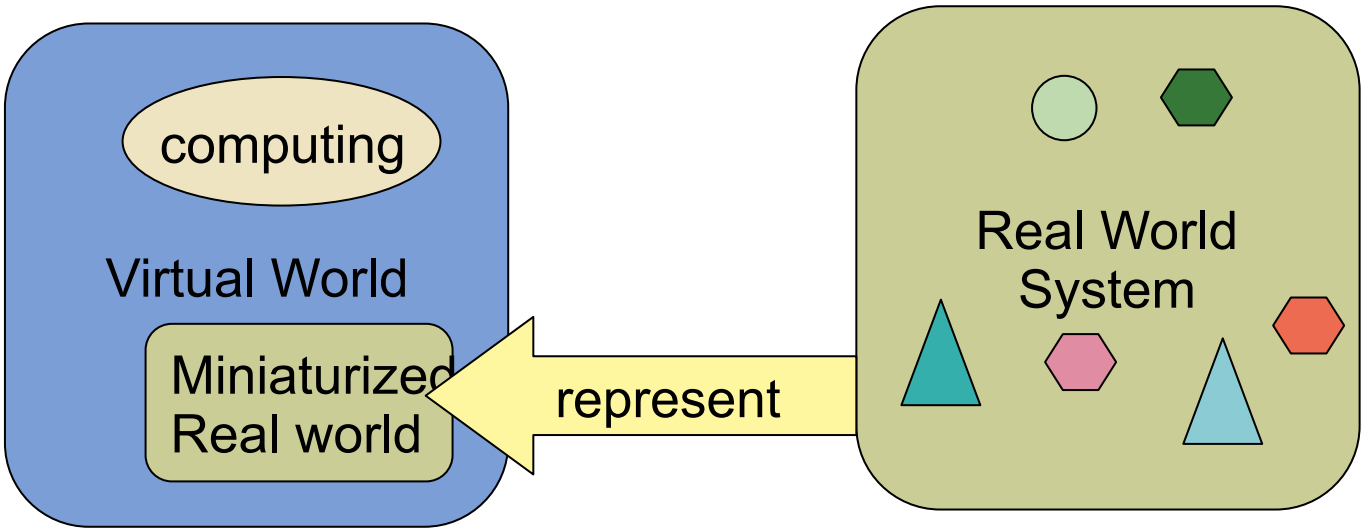
Cyber-physical

Embedded systems networked with cloud

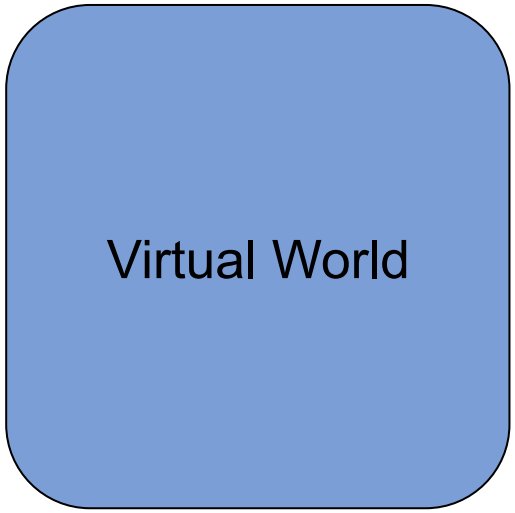
„Human CPS“
„Everyware“

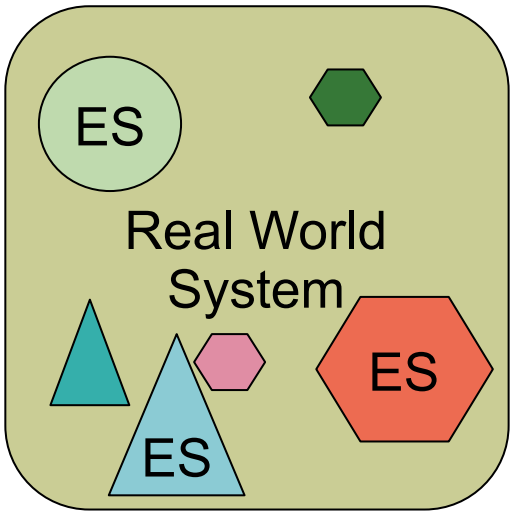
„Standard“ Computing

- „Standard“ Computing maps the real world into the computer and computes about it by simulation



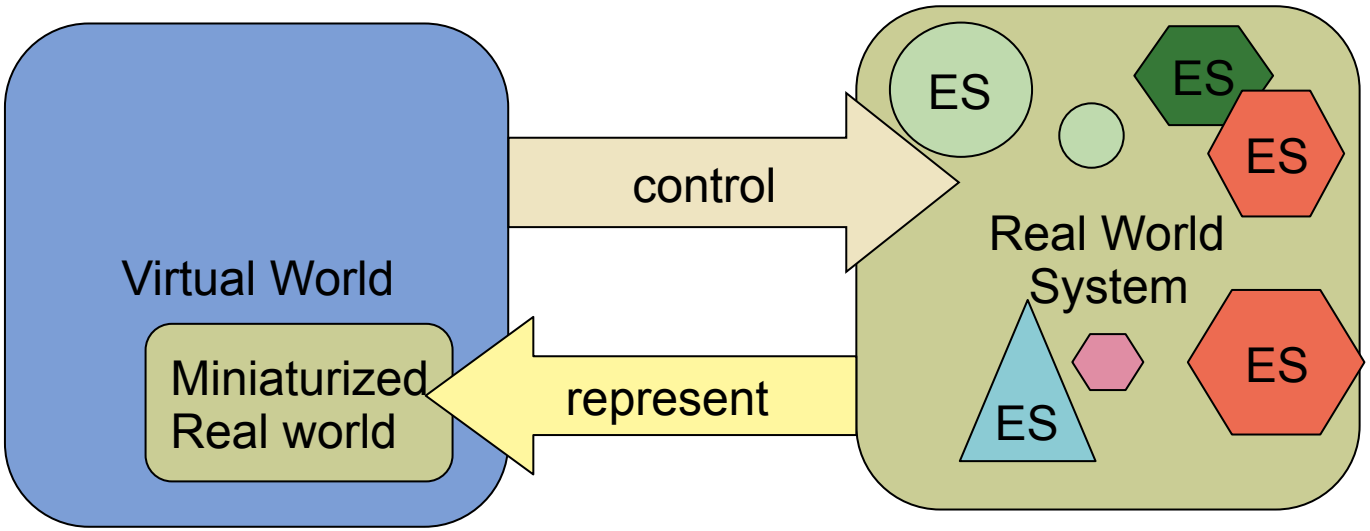
- The computer is integrated into the real-life object



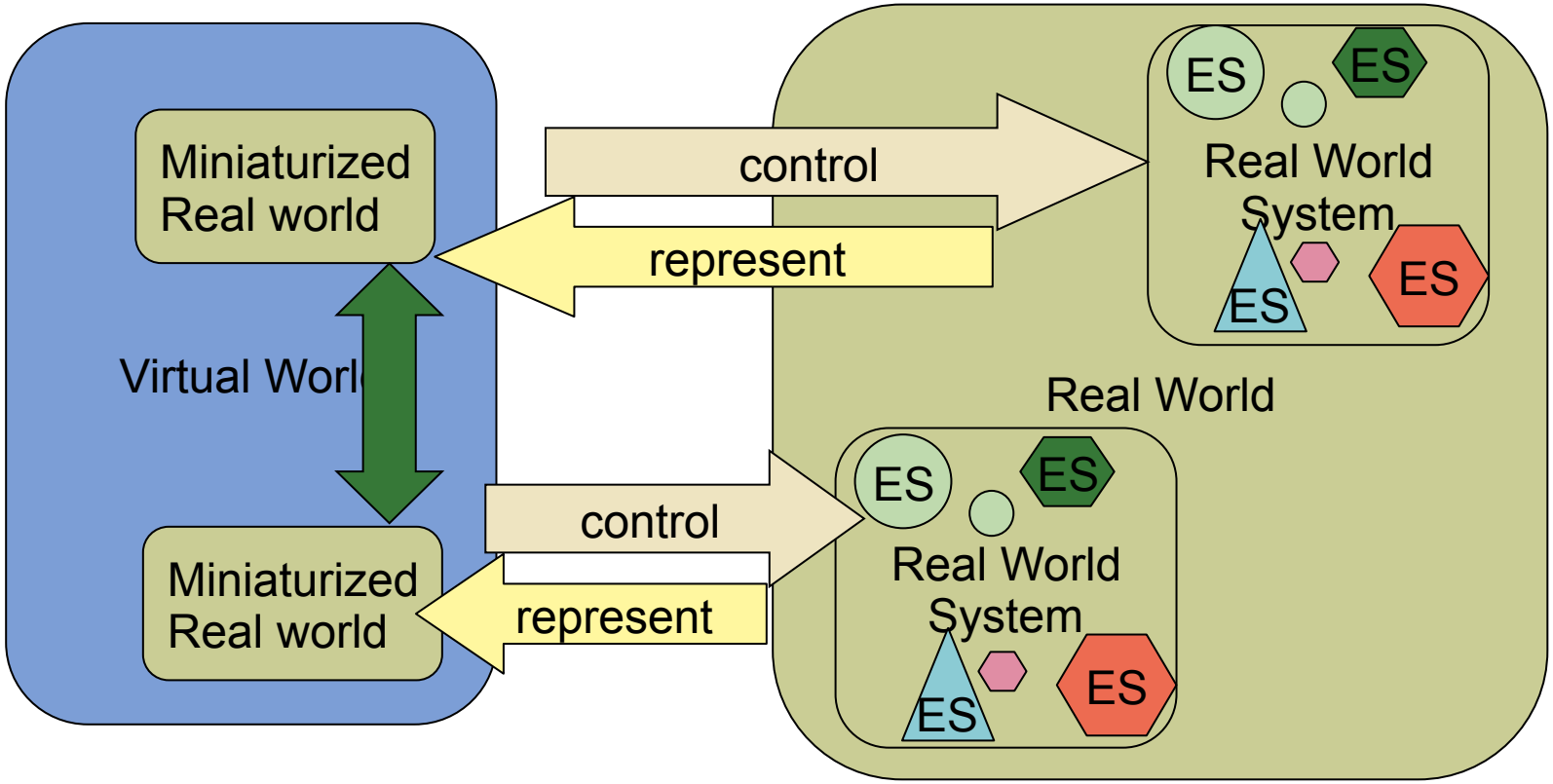


Cyber-Physical System (CPS)

- Dual reality
- Control of space and time of all things

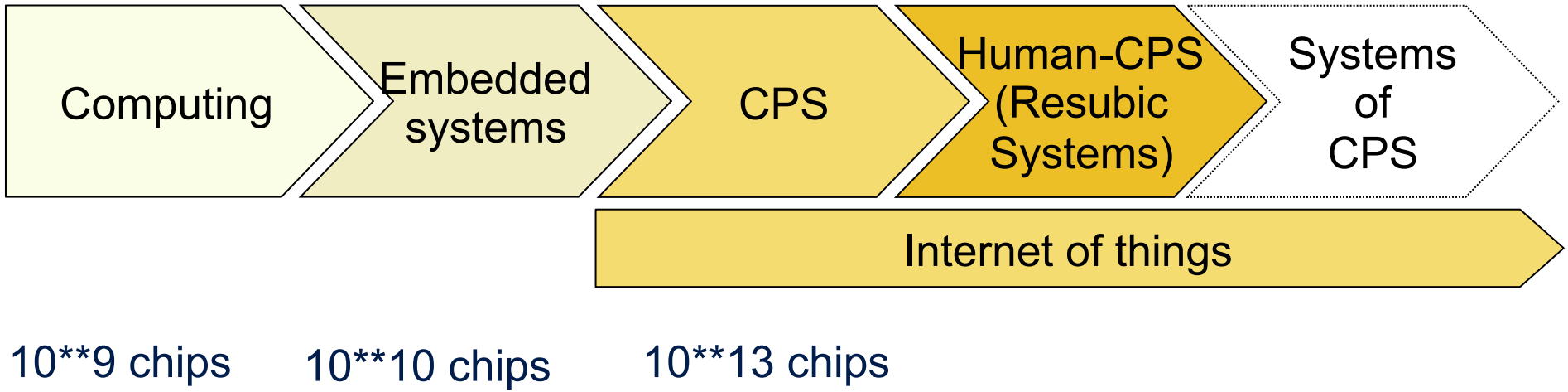


- The Internet of Things consists of *Systems of Cyber-Physical Systems*



Trend CPS

- Cyber-physical systems are the first step in the internet of things



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2. Industry-4.0 – An Application Area for CPS Producing a Product in “Nachtsprung”

With Cloud Robots

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And the Topping Makes the Difference

https://www.flickr.com/photos/amiga-commodore/10059167335/

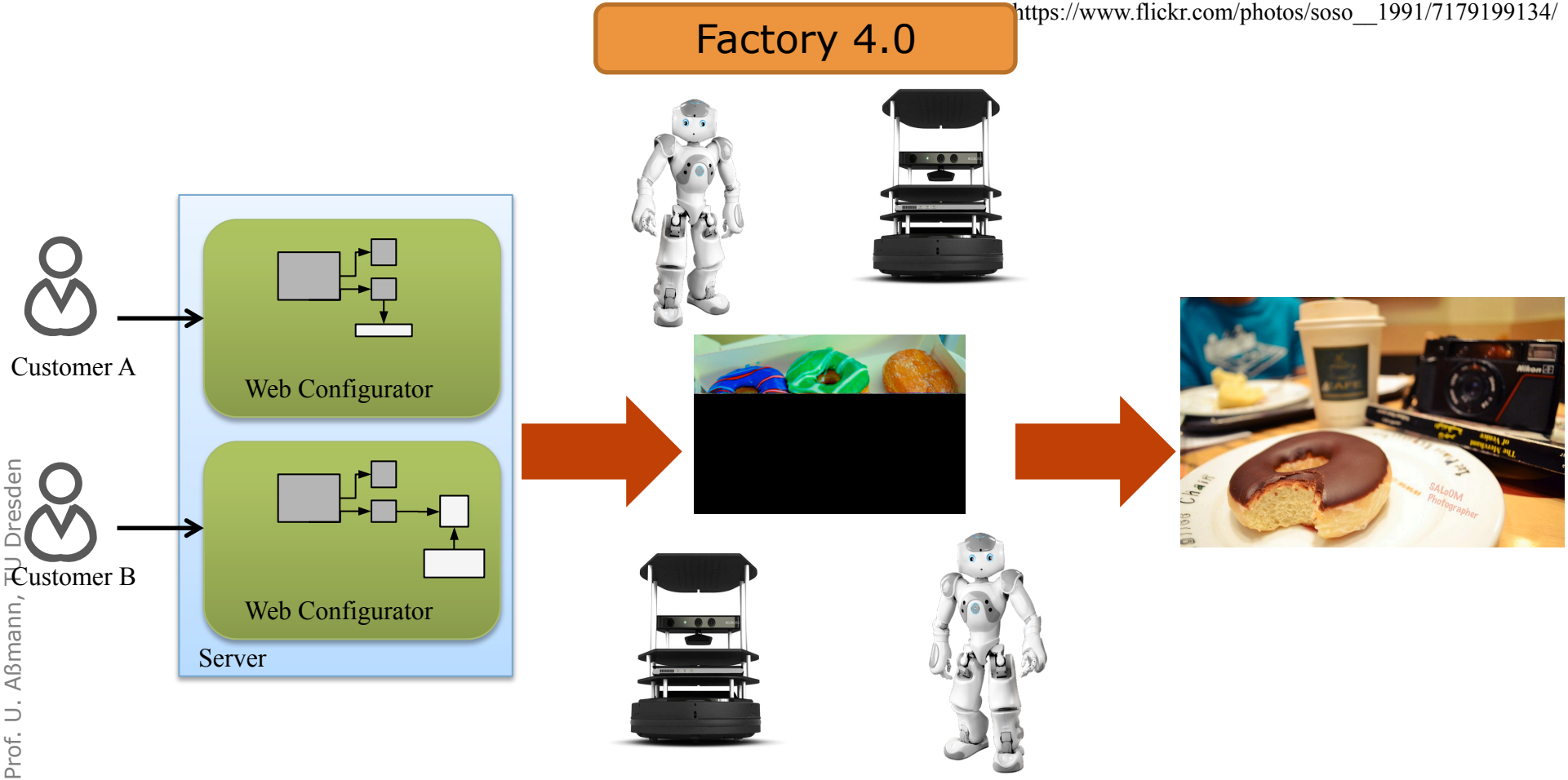
Situation Today

https://www.flickr.com/photos/jeades/2383525381/

- Mass production
- No individual configuration
- No fast, individualized production
- No „Nachtsprung“

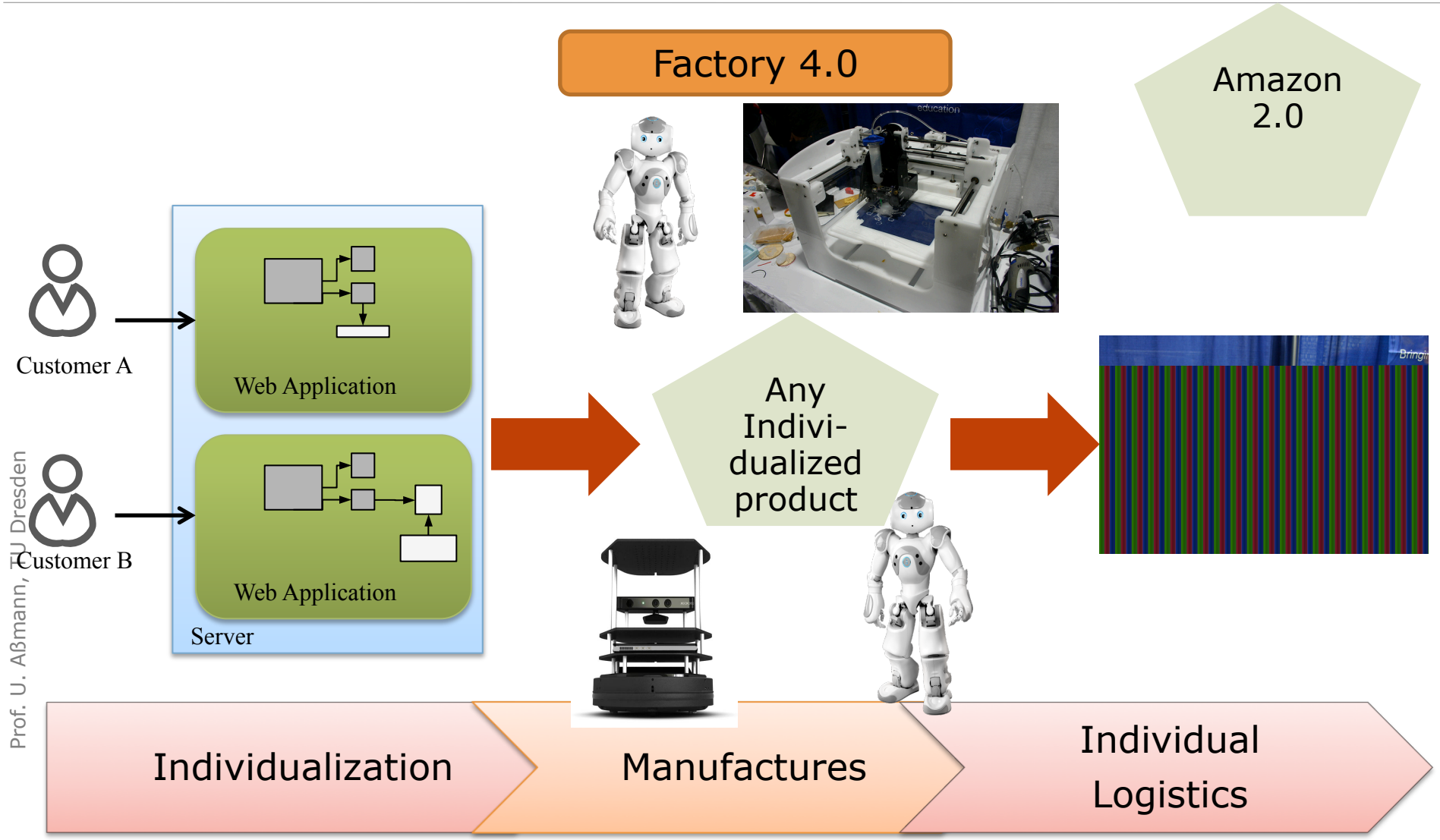
Donut Industry-4.0: Pulling Individual Donuts out in Nachtsprung

https://www.flickr.com/photos/soso__1991/7179199134/



Configuring in the evening → Producing in the night → Shipping in the early morning

Industry-4.0: Economic Consequences



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https://www.flickr.com/photos/ideonexus/7311859510

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2.2. What is a Cloud Robot?

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A Cloud Robot uses a Standard Robotic Platform
Hello, I‘m NAO

Made by

- ALDEBARAN Robotics Paris, Frankreich

  [http://www.aldebaran-robotics.com/]

Application fields

- Teaching (Robot programming)
- Research
  - Robotics, AI
  - RoboCup
  - **Software Engineering**

Price

- 9.000 – 12.000 €

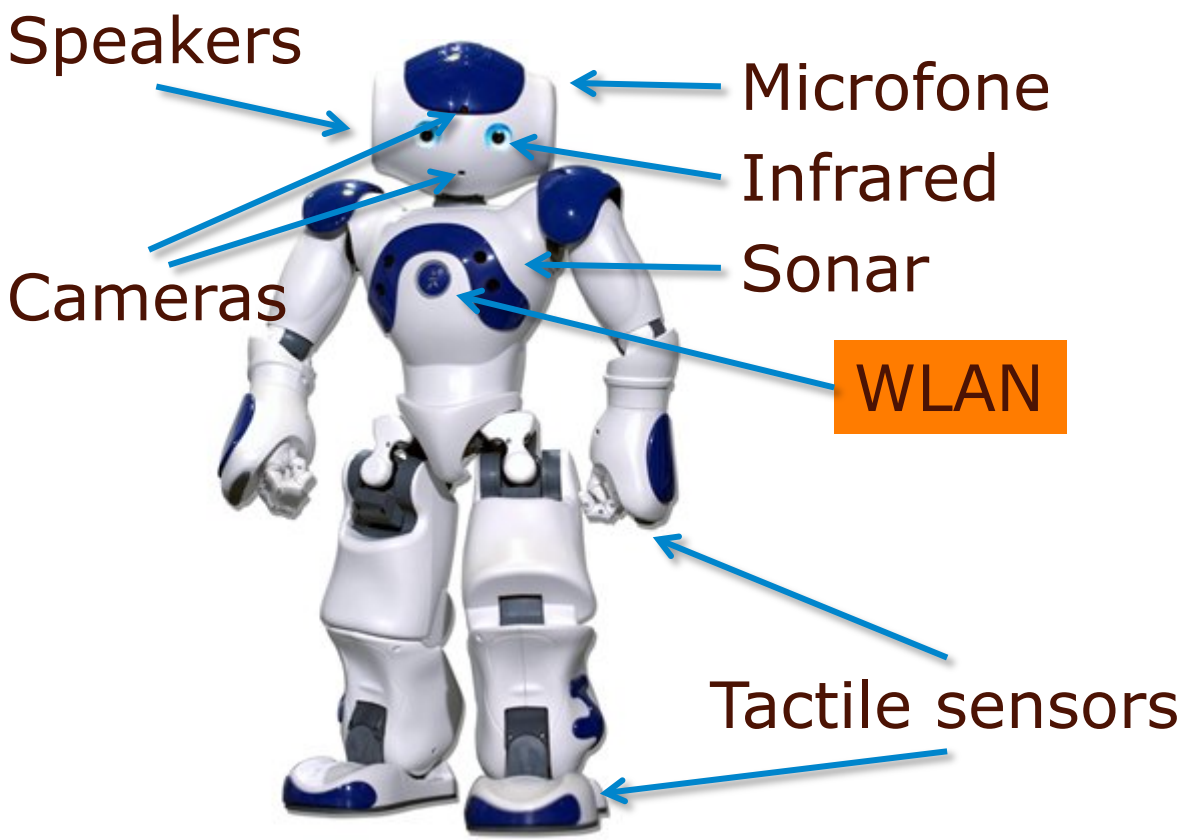
Nao Fact Sheet

Length: 58cm

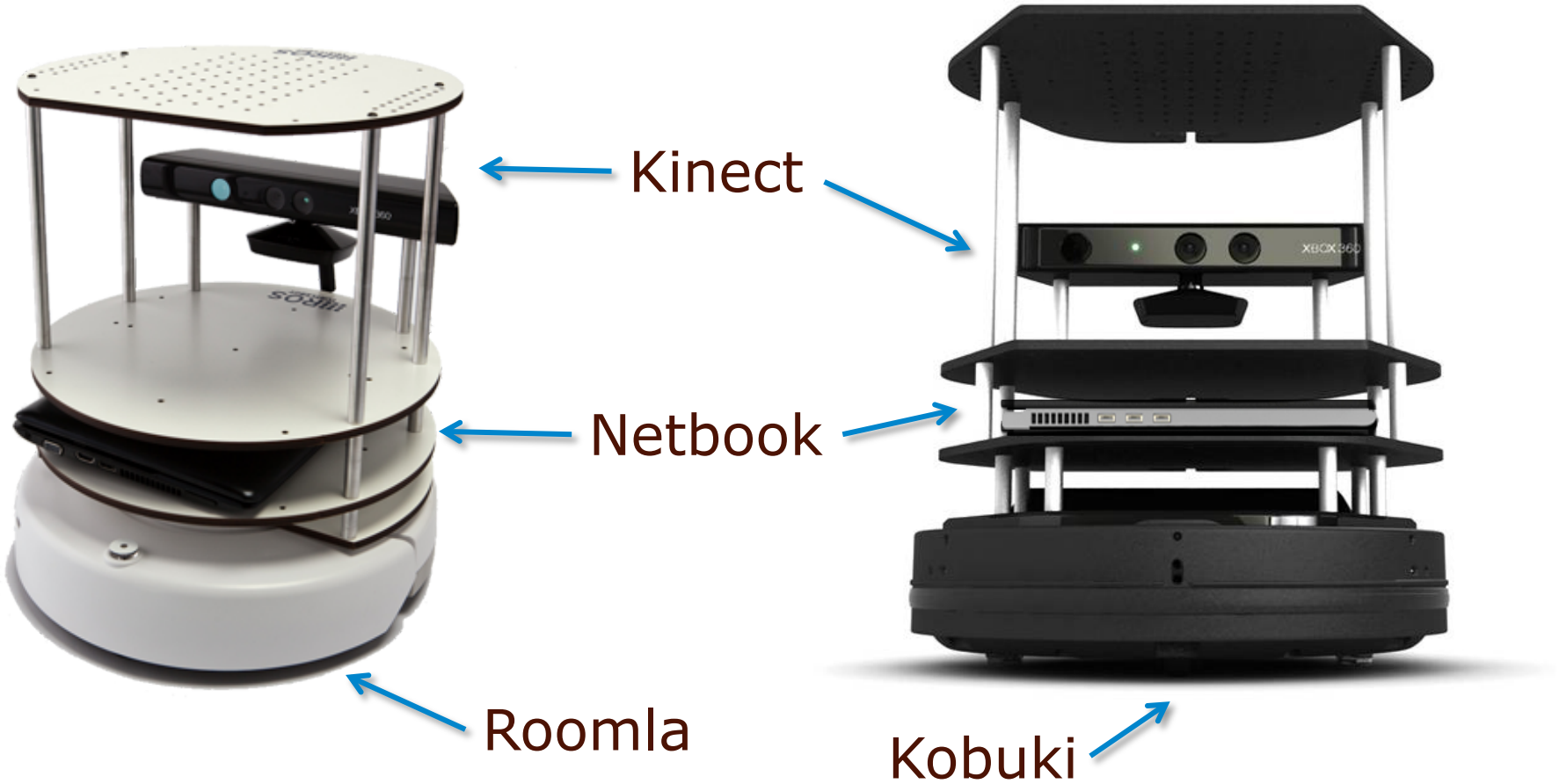
Weight: 5kg

Hardware:
- x86 AMD GEODE 500MHz
- 256MB RAM
- 21 motors
- Battery 55Wh

OS:
Embedded Linux 32bit



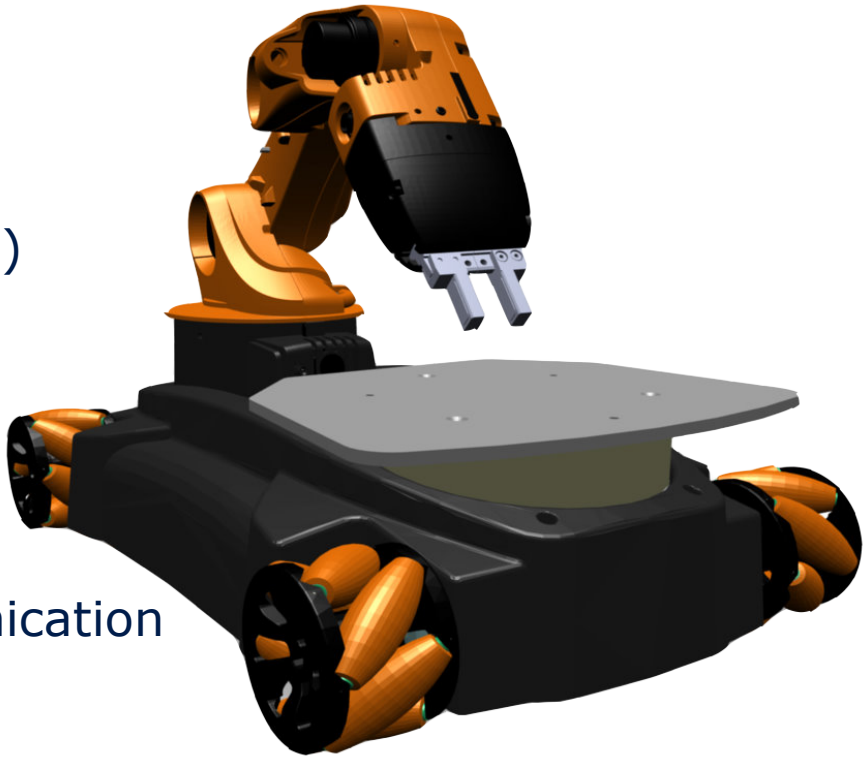
Turtle Bot



http://wiki.ros.org/Robots/TurtleBot
http://www.turtlebot.com

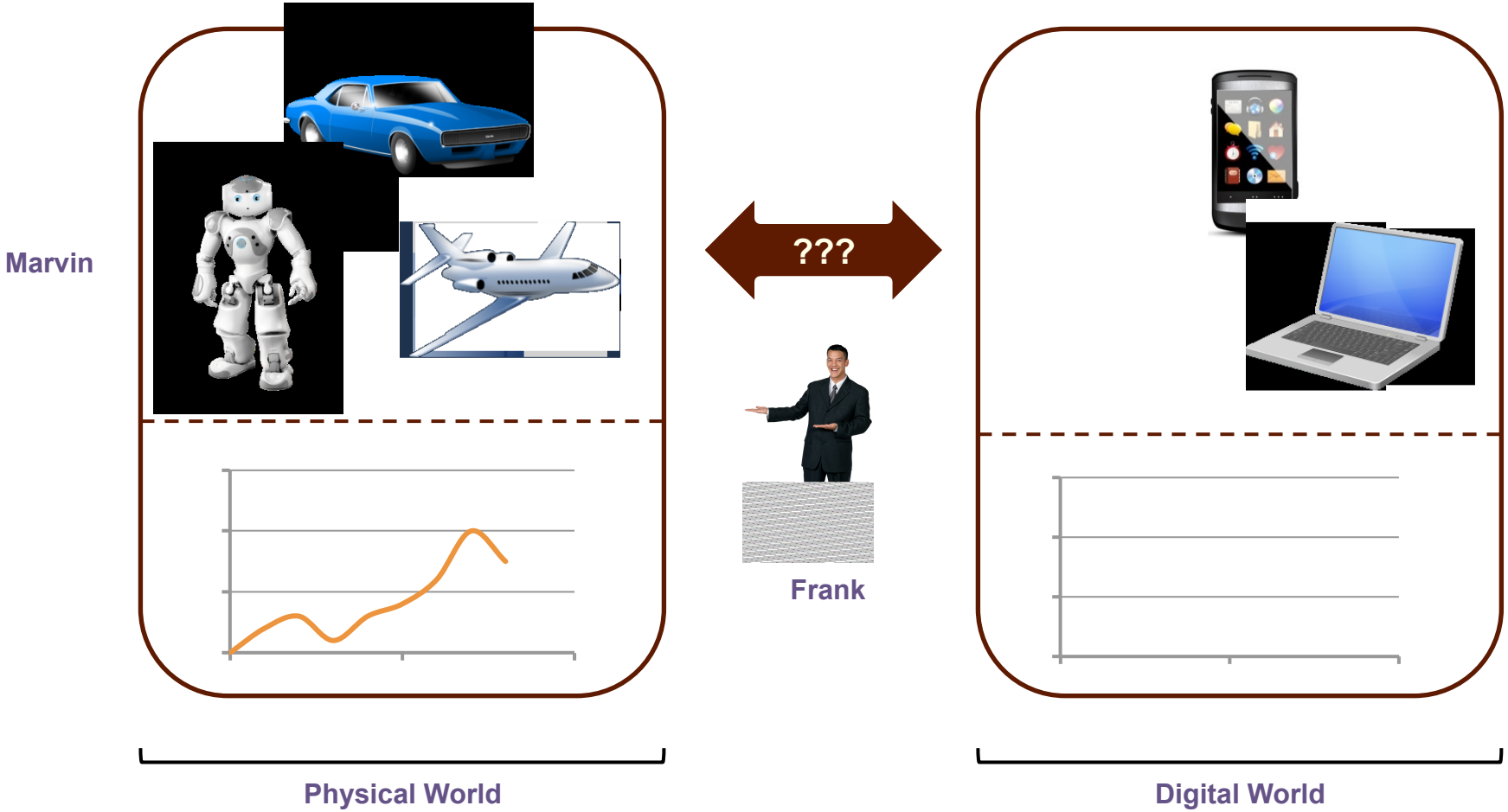
The Youbot Platform of Kuka

- Omni-directional, mobile platform
- 24 kg weight– 24 kg load
- PC with Linux
  (1 Ghz, 2GB RAM, 32GB SSD)
- 5-DOF-Manipulator
- 2-Finger-Gripping
- Real-Time EtherCAT communication
  Between platform and manipulator
- [Project VICCI]

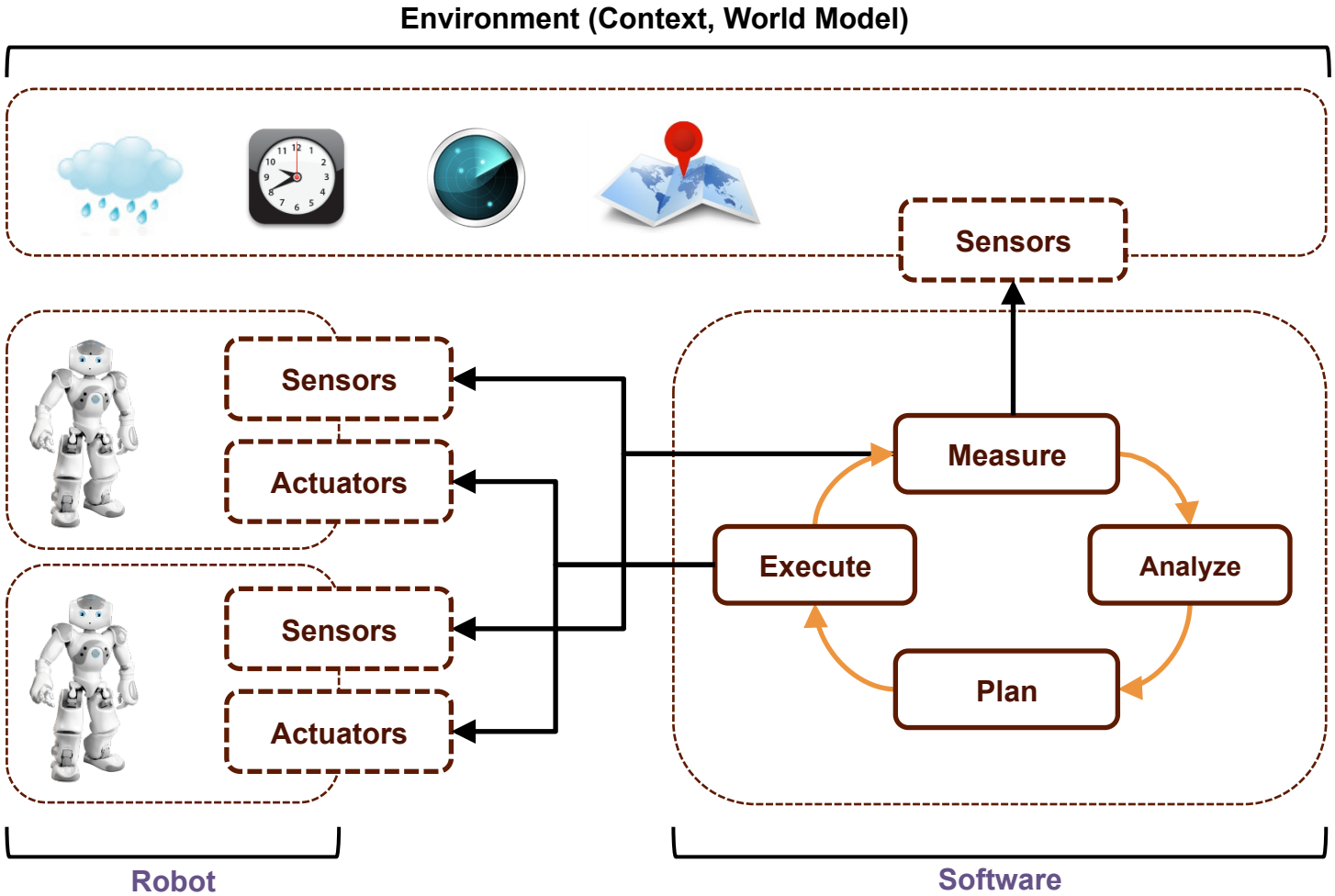


KUKA

Cloud Robots are Distributed Cyber-Physical Systems

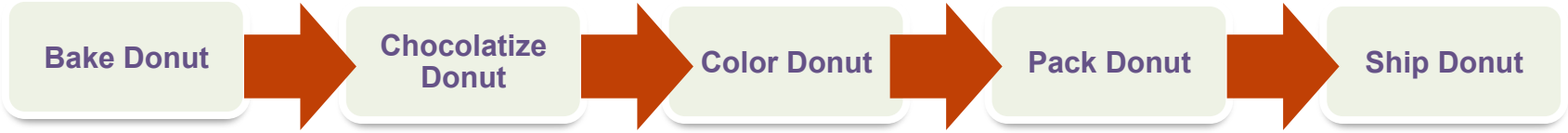


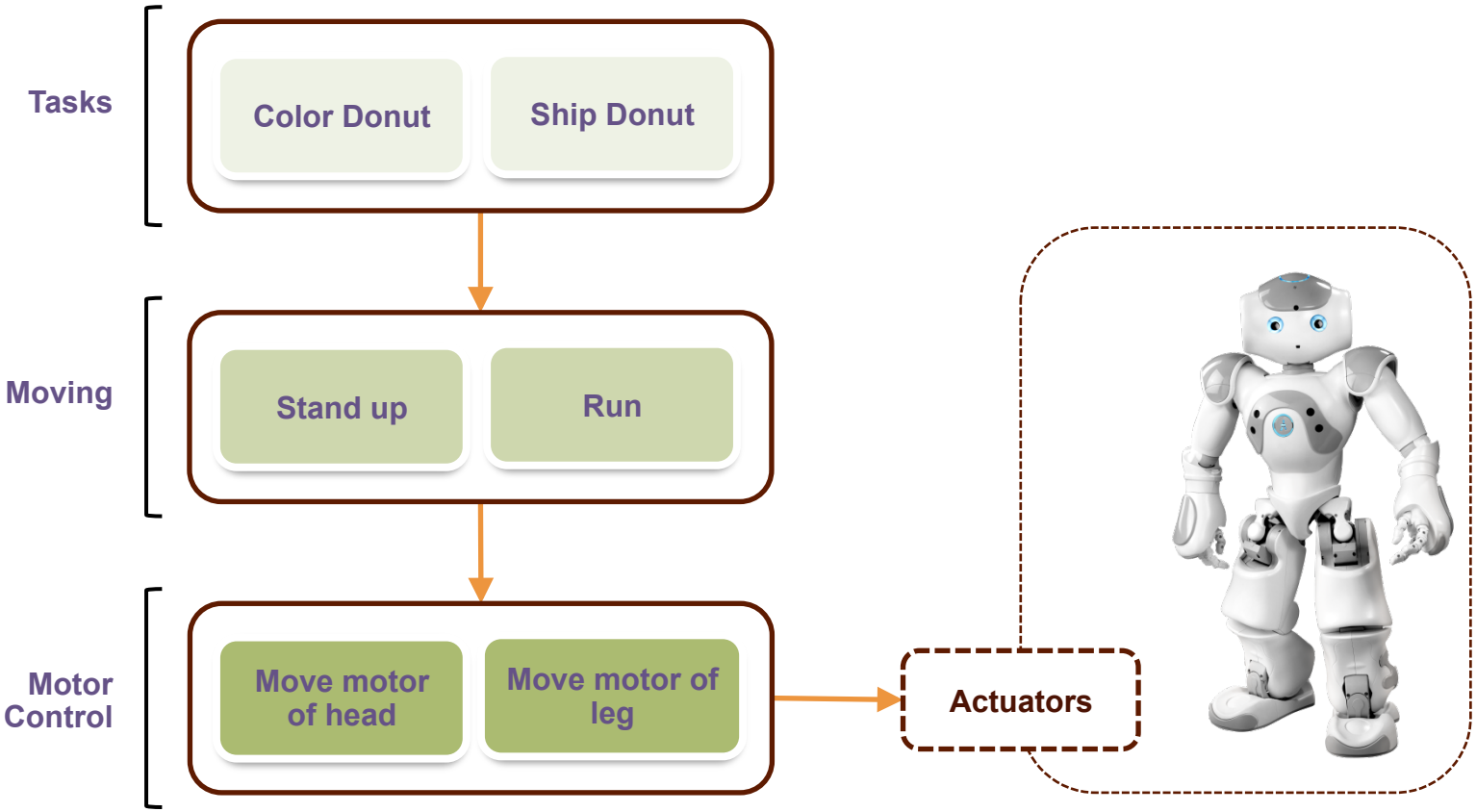
Cloud Robots are Context-Adaptive Systems



Elastic Architecture

Industry-4.0: Cloud Robots Produce Things in Workflows





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2.3. Two Classes of CPS

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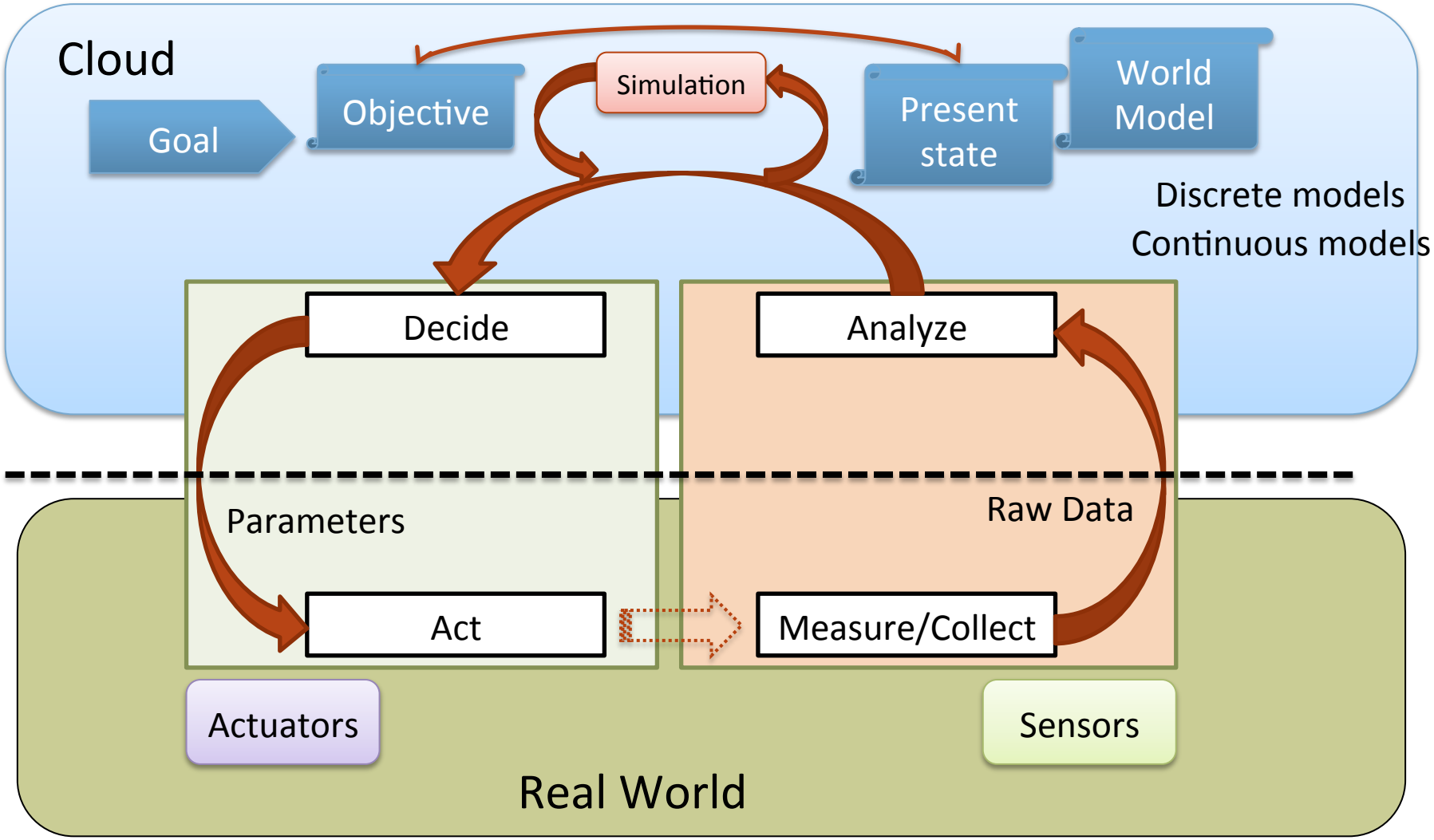
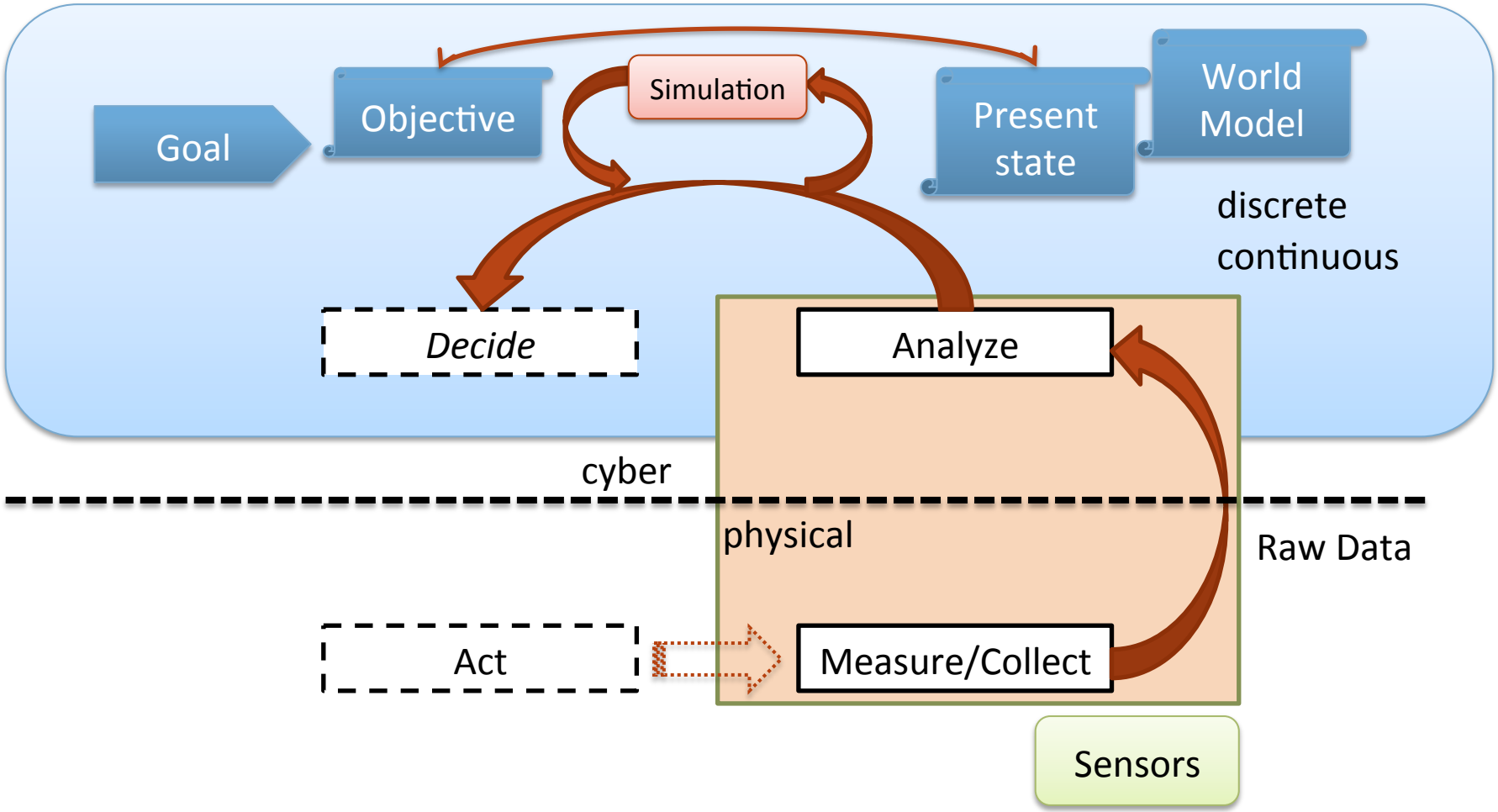
Cloud Robots are Cyber-Physical Systems

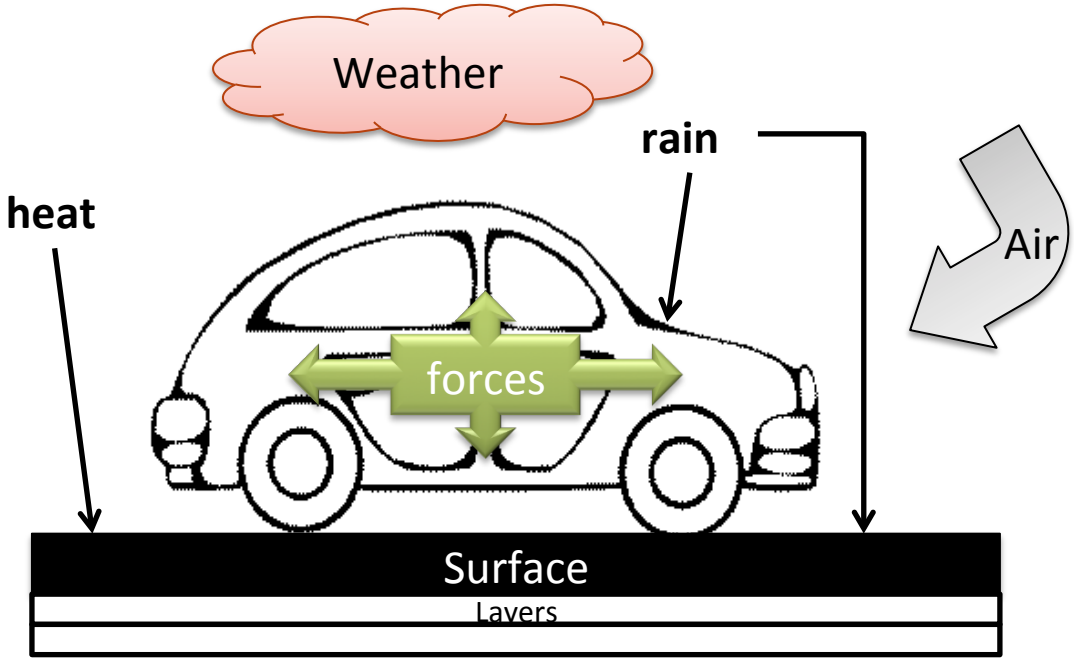



Goal
Objective
Simulation
Present state
World Model
discrete
continuous
Decide
Analyze
cyber
physical
Raw Data
Act
Measure/Collect
Sensors

Physical Dynamics (Movement) of Robot

- How does a robot move in space?
  - depends on environment properties
  - depends on device/environment interfaces

Cloud Robots Need Continuous Models

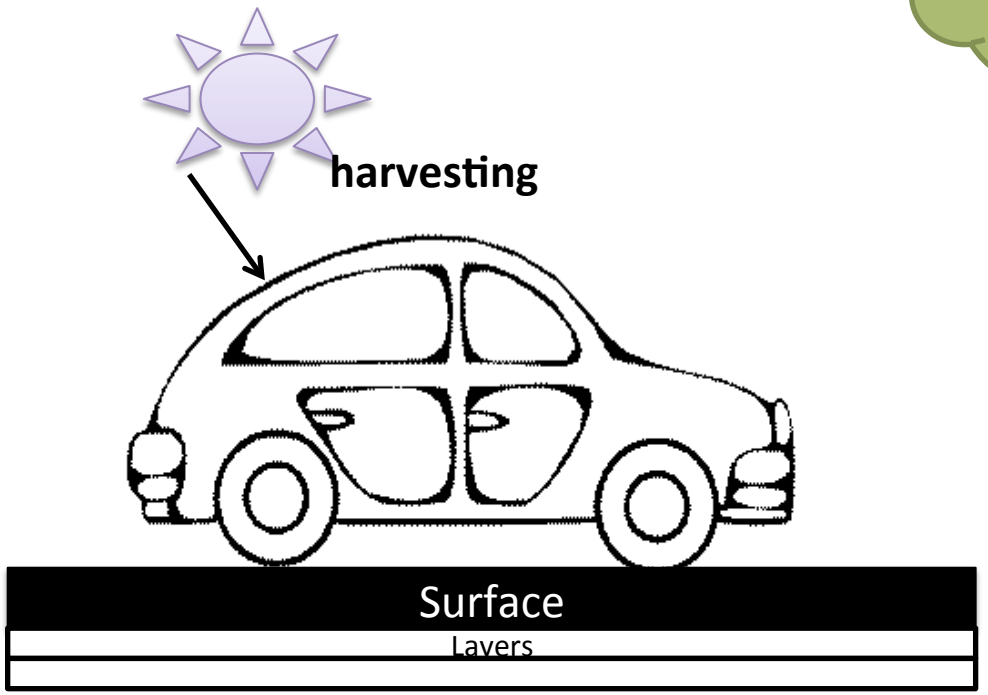


complex interplay of
-surface props
-weather: wind, rain, heat

Energy Consumption of Robot

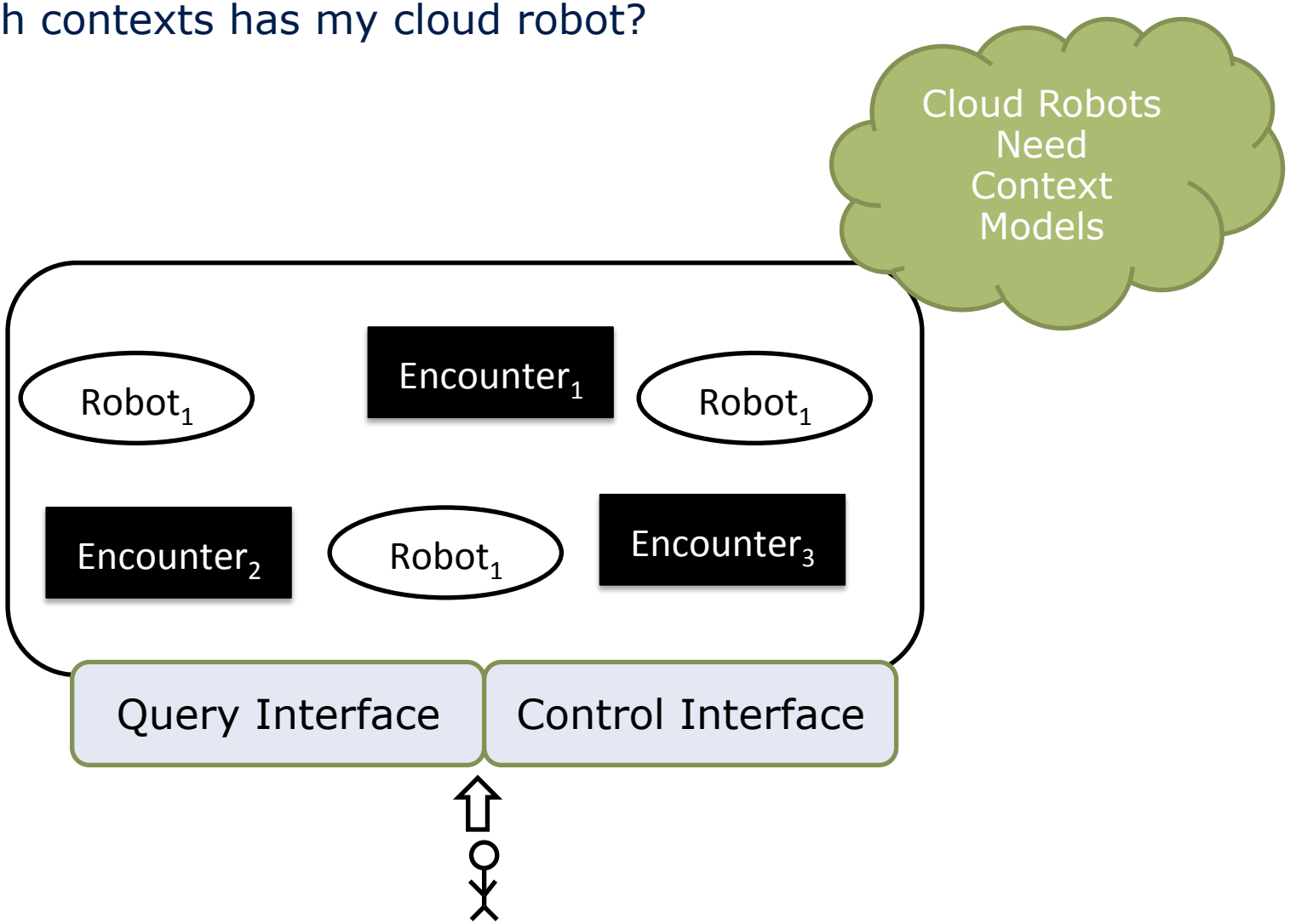
- How much energy is left for its tasks?
  - depends on harvesting

Cloud Robots Need Energy Models



Physical Composition of a Robot

- Which contexts has my cloud robot?



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3. Why Were Factory Robots in the Cage?

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Cloud Service Robots require to let them free

Adaptive and Defensive Reaction required

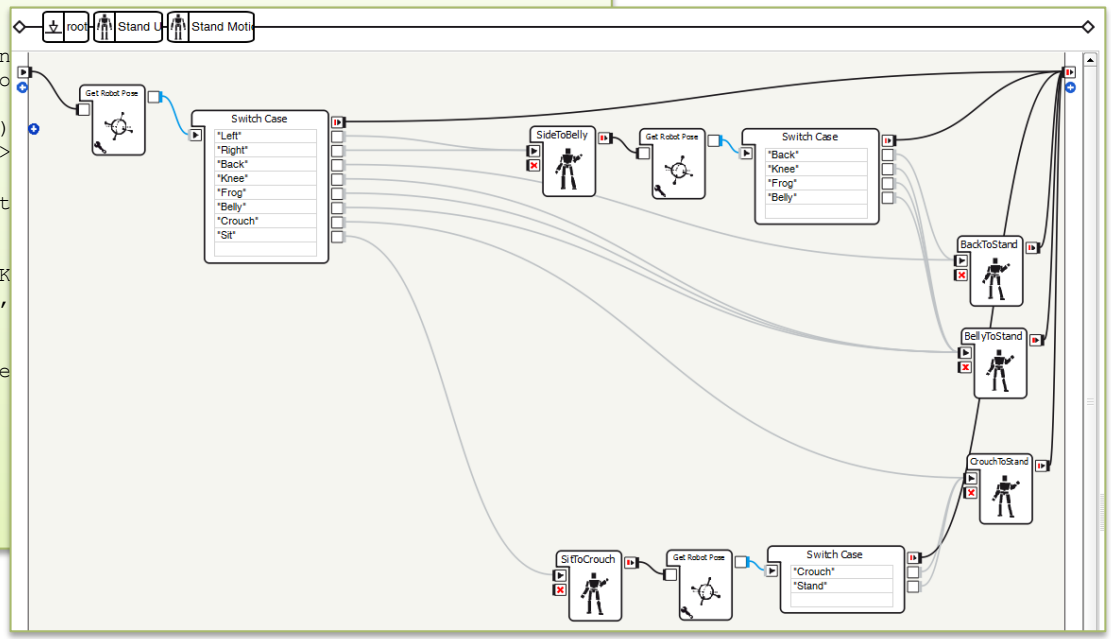
Problem: Current Approaches to Robot Programming are not Adaptive

- C, C++, Java produce “if-bloating code”
- DSLs like Aldebaran Choregraphe, RCX-Code, MS VPL are not adaptive
- NO elastic cloud infrastructure

```
bool Kinematics::readJoints(urdf::Model &robot_model) {
    num_joints = 0;
    // get joint maxs and mins
    boost::shared_ptr<const urdf::Link> lin
    boost::shared_ptr<const urdf::Joint> jo

    while (link && link->name != root_name)
        joint = robot_model.getJoint(link->
        if (!joint) {
            ROS_ERROR("Could not find joint
            return false;
        }
        if (joint->type != urdf::Joint::UNK
            ROS_INFO( "adding joint: [%s]",
            num_joints++;
        }
        link = robot_model.getLink(link->ge
    }
    //...
}
```

[http://ros.org/wiki/arm_kinematics]



Blocking Factors for Freeing Robots from the Cage

Adaptive Defensive Behavior

- If in contact with humans
- Slow down
- React defensively

Adaptive Energy Consumption

- If not in contact with humans
- Switch off defensive behavior

Run-Time Verification

- To prove defensive behavior and energy safety

Real-Time Simulation

- To simulate it and predict it

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3.2. Context-Adaptive Apps for CPS and Cloud Robots

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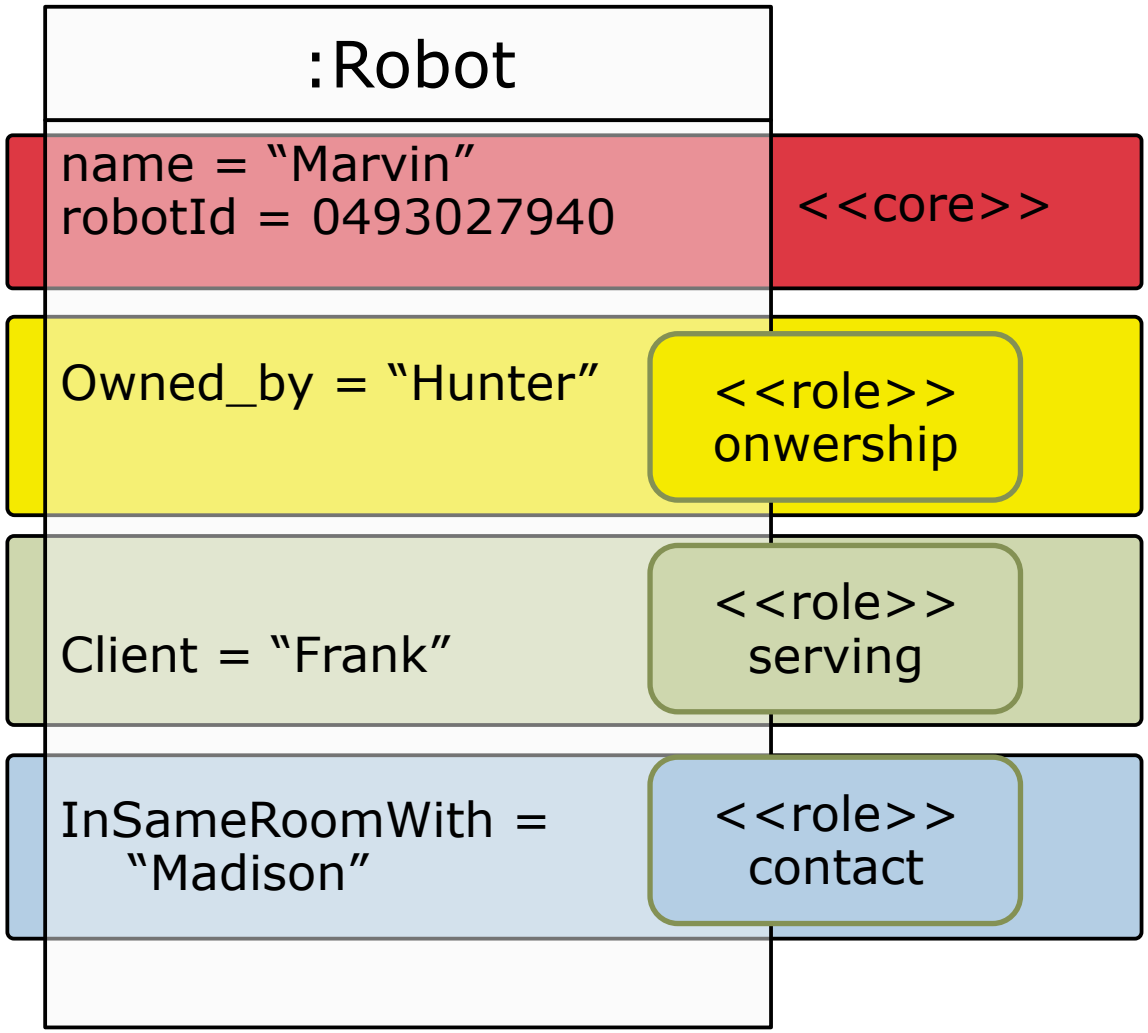
A Simple Industry-4.0 Manufacture

Roles are State and Behaviour in Context

:Robot
name = “Marvin” robotId = 0493027940 Owned_by = “Hunter” Serving = “Frank” InSameRoomWith = “Barbarine”

Roles are State and Behaviour in Context



Roles compartmentalize objects

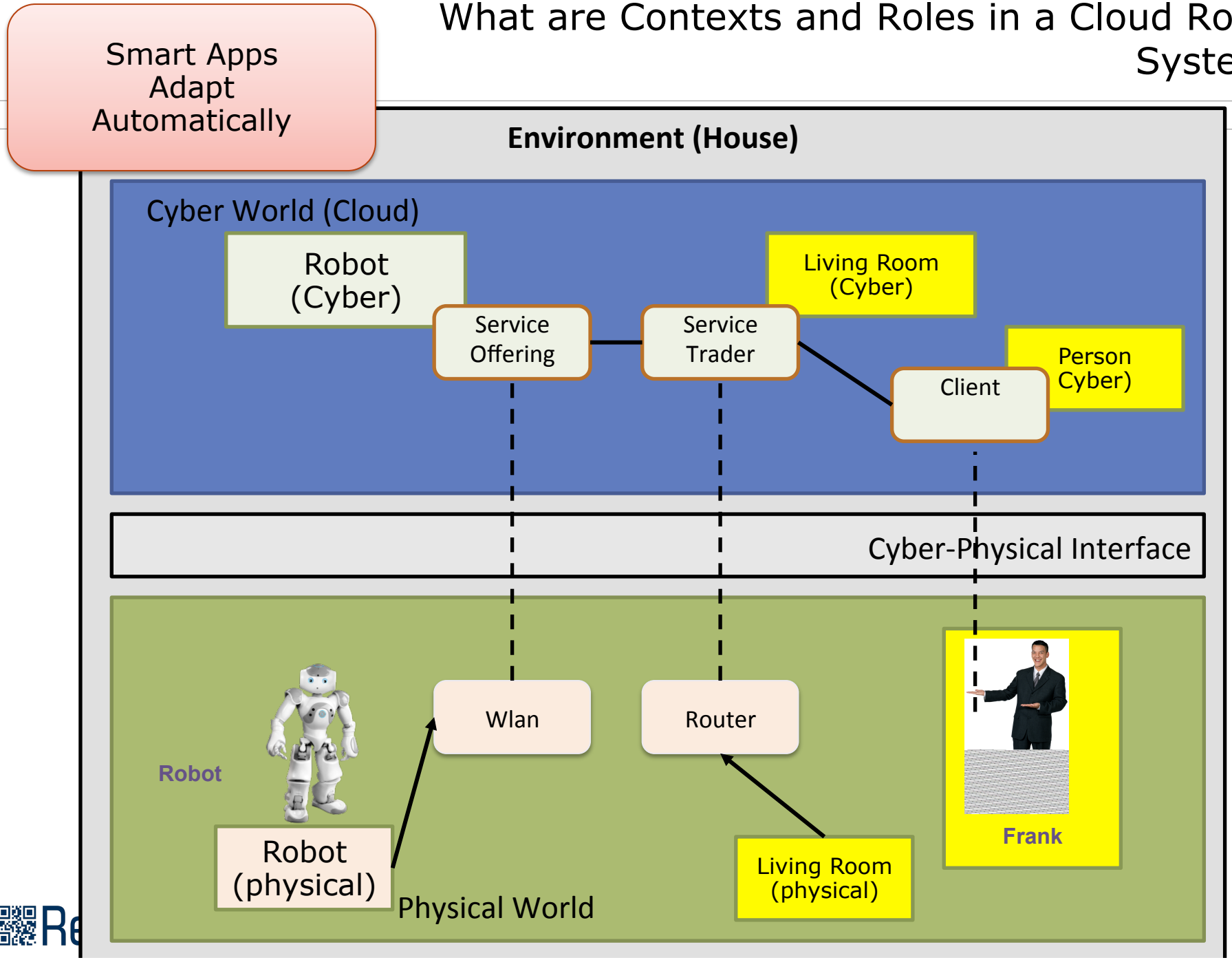
Why are Roles Important for Cloud Robots?

Alternating the contexts adapts the role-based software automatically

Adapting robots is automatic

(Smart Apps)

What are Contexts and Roles in a Cloud Robot System?



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3.3. Solution: Frank's Smart Home Equipped with Smart Apps

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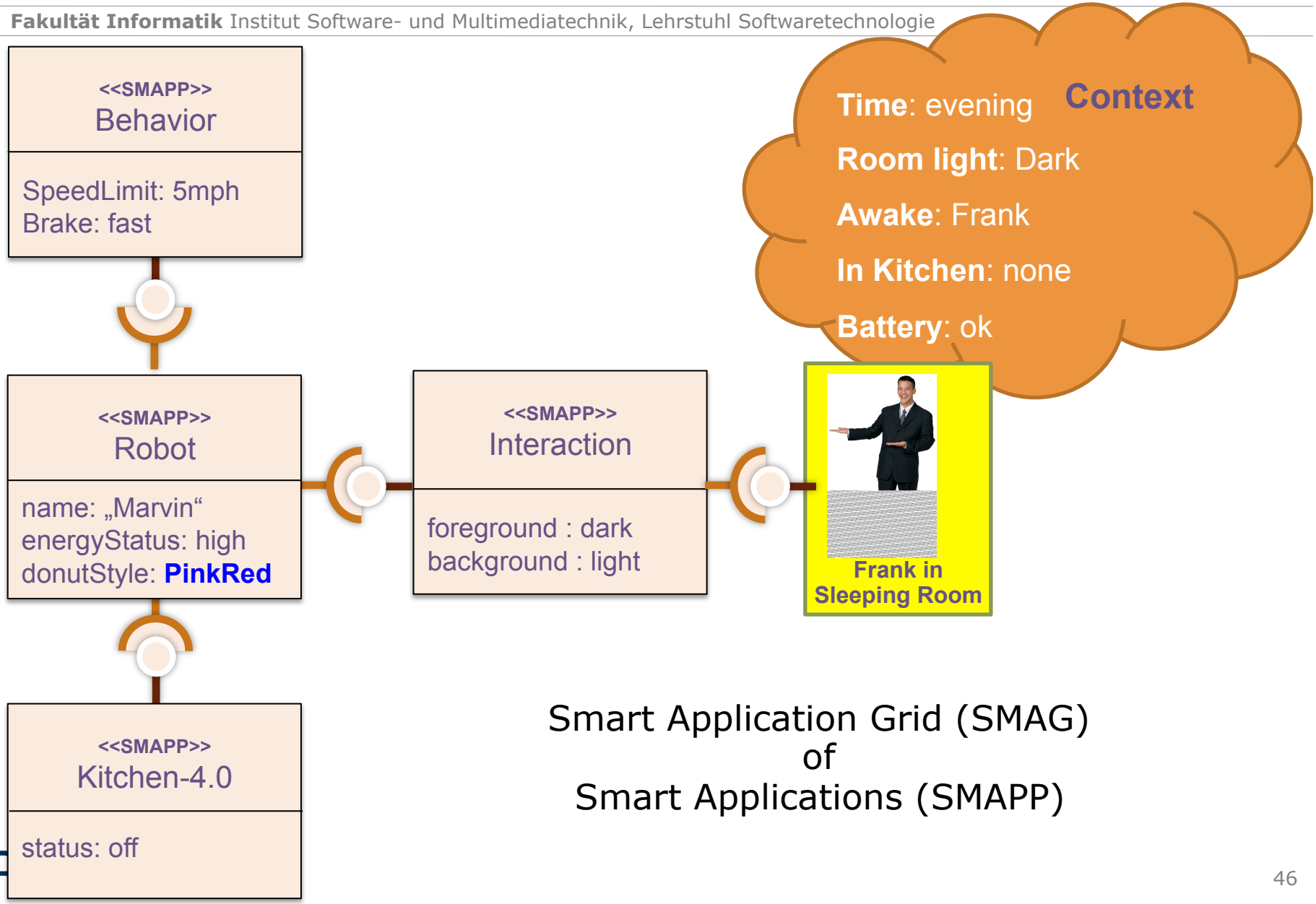
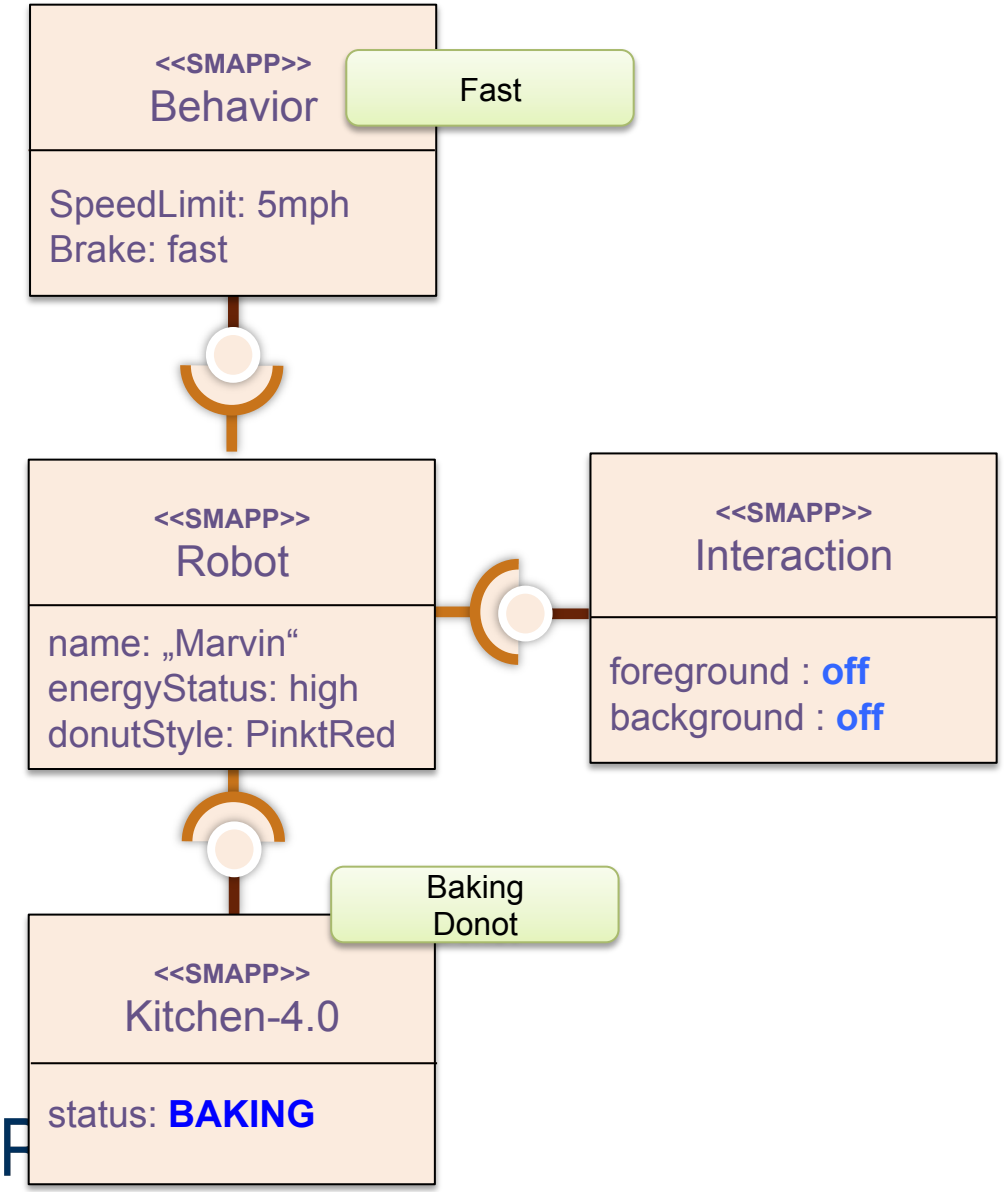
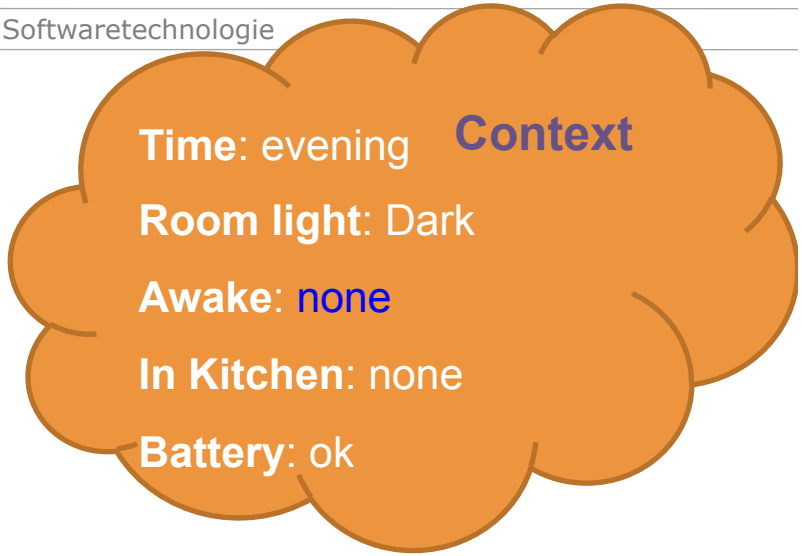
Evening; Frank Selects Donut for Next Morning



Smart Application Grid (SMAG)
of
Smart Applications (SMAPP)

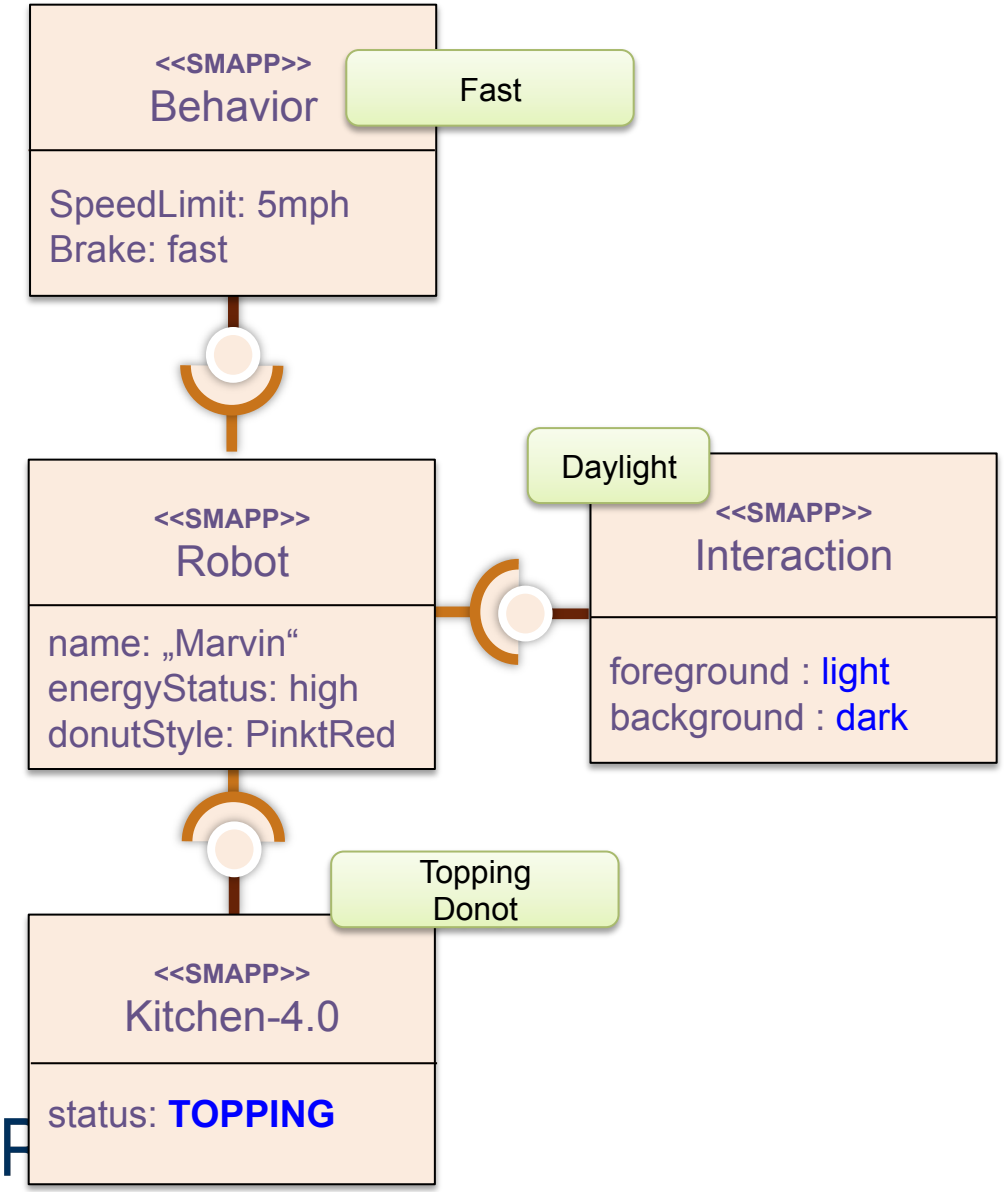
Marvin at Night Producing Donut; Frank Sleeps

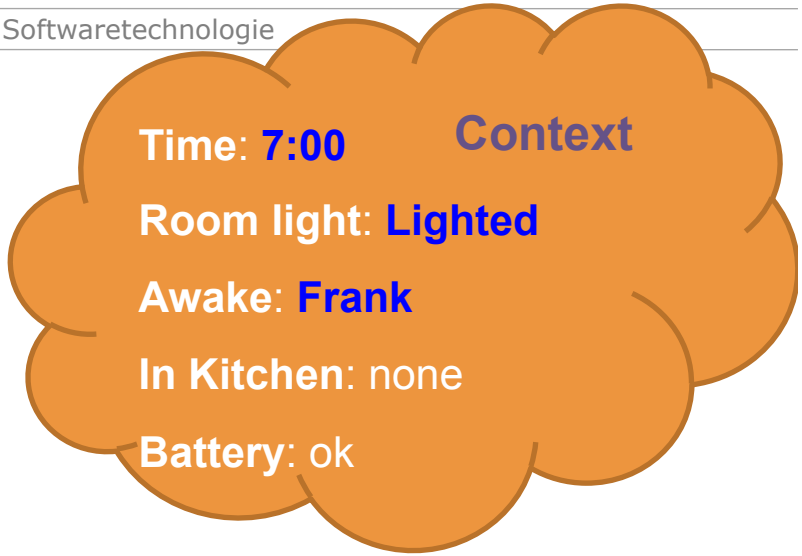




- **Adaptive behavior by switching on and off roles**

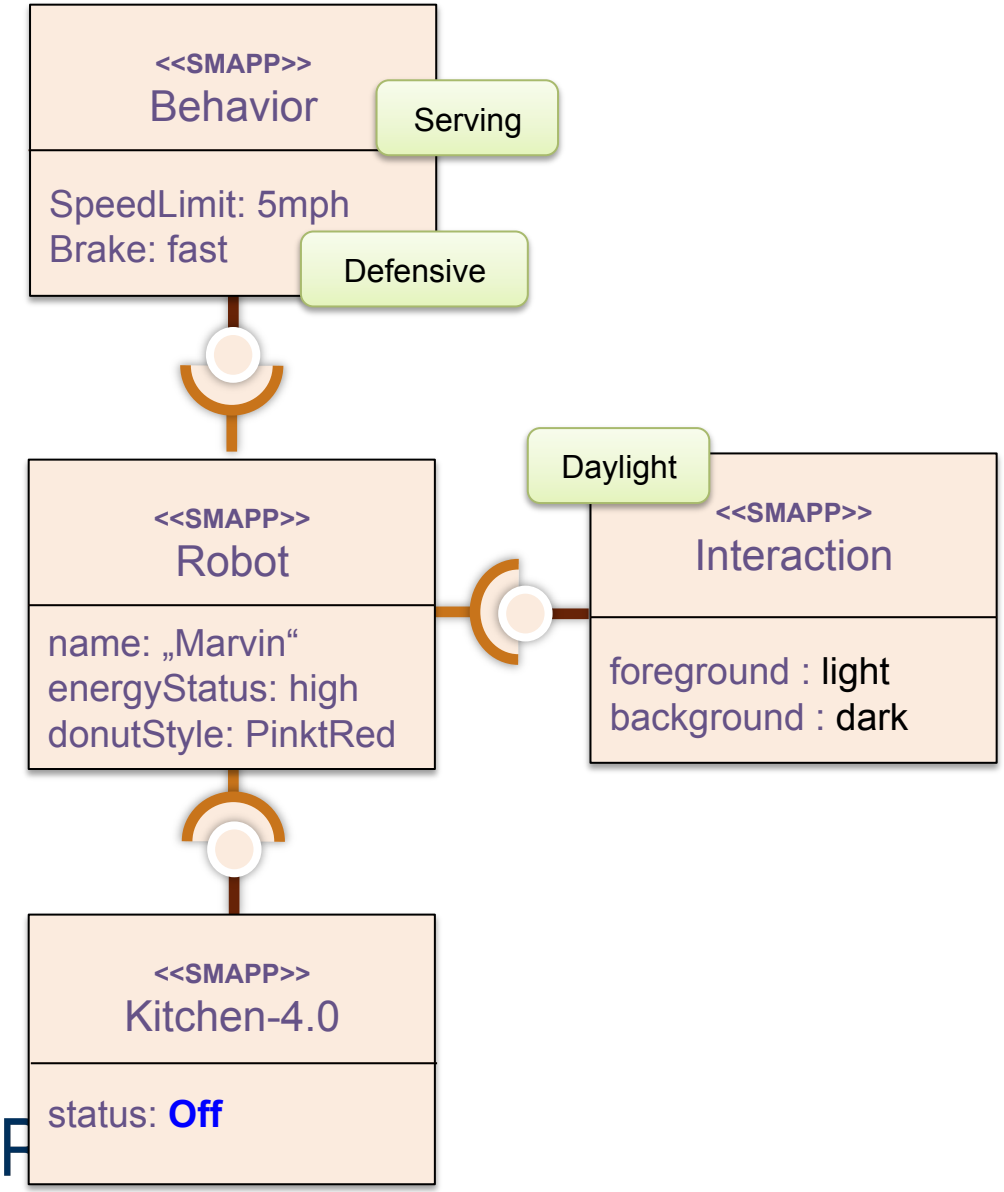
7:00; Daylight; Frank wakes up

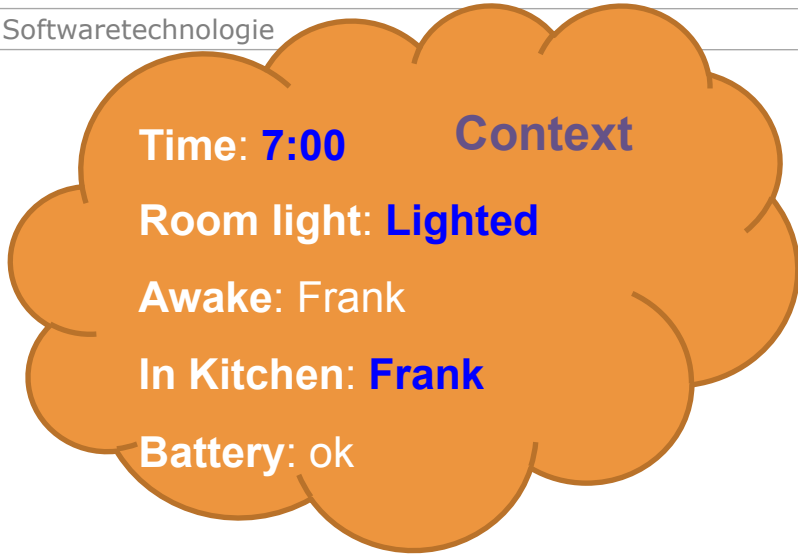




- **Adaptive behavior by switching on and off roles**
- **Driven by context changes**

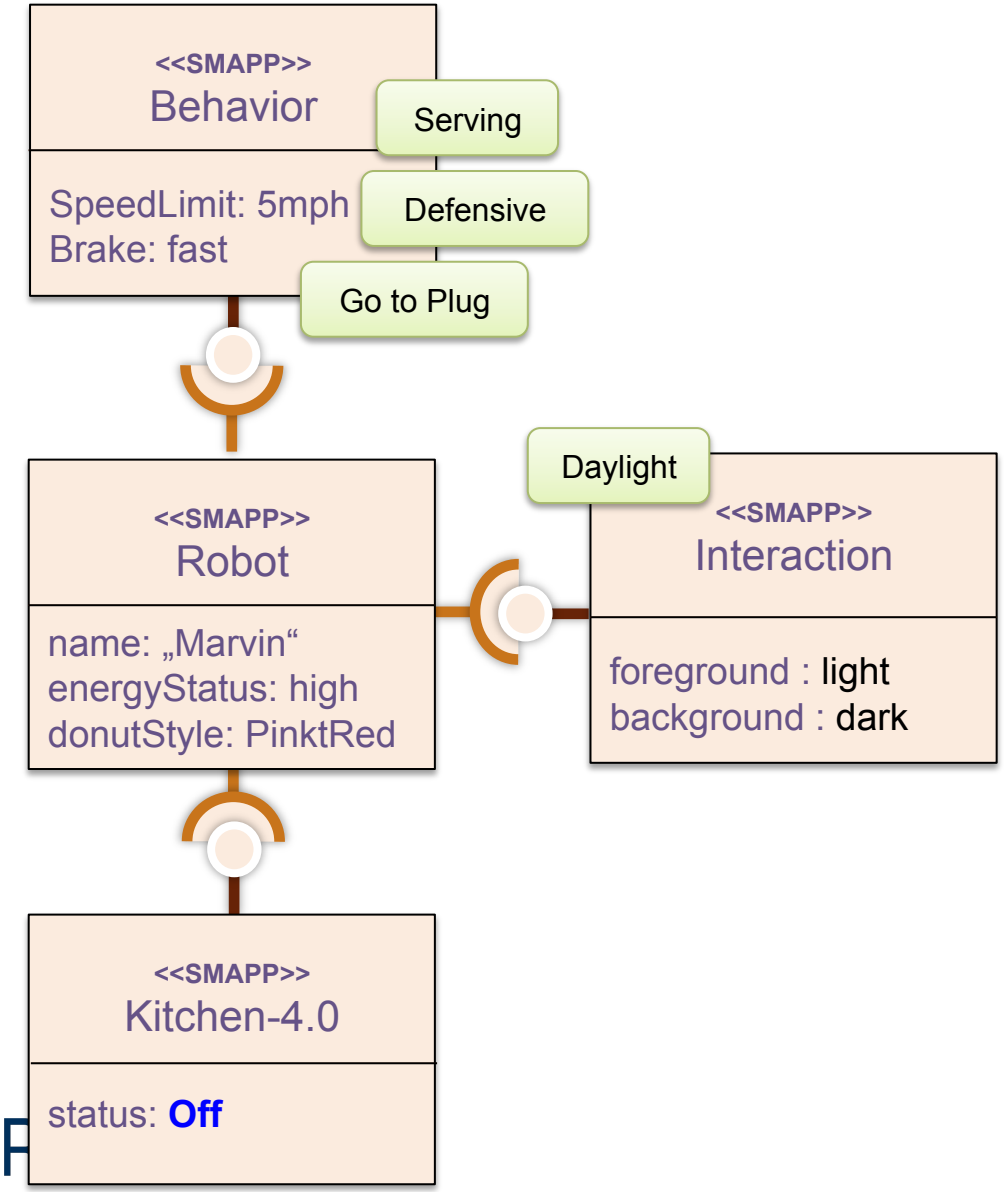
Frank Enters Room, Serving





- **Switching on defensive behavior**

Marvin's Energy Is Low

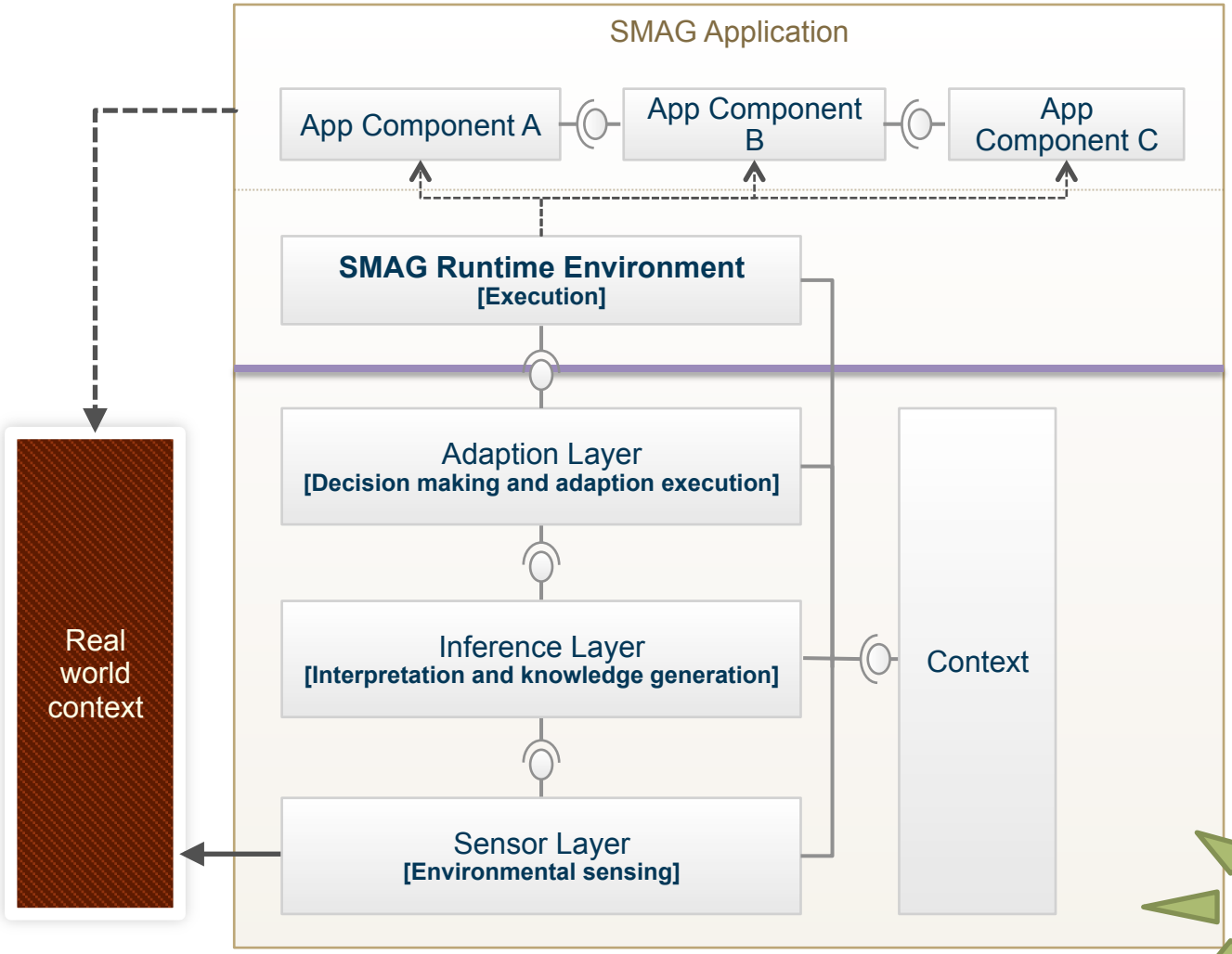


- **Adaptive defensive behavior**

and

- **Adaptive energy safety**

The Solution: Smart Applications on Smart App Grid Infrastructure

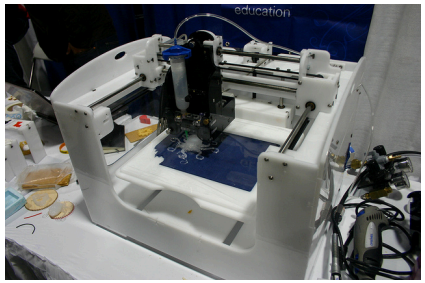


Film

Adaptive Defensive Behavior is Important in Industry-4.0, Smart Homes, Smart Cars, Smart Logistics

http://commons.wikimedia.org/wiki/File:Factory_Automation_Robotics_Palettizing_Bread.jpg?uselang=de

Adaptive Breaking
Adaptive Driving Speed
Adaptive Routing
Adaptive Collision Avoidance



Elastic Architecture

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4. Software Ecosystems for CPS

- Staying Power [Cusomano, Gawer]

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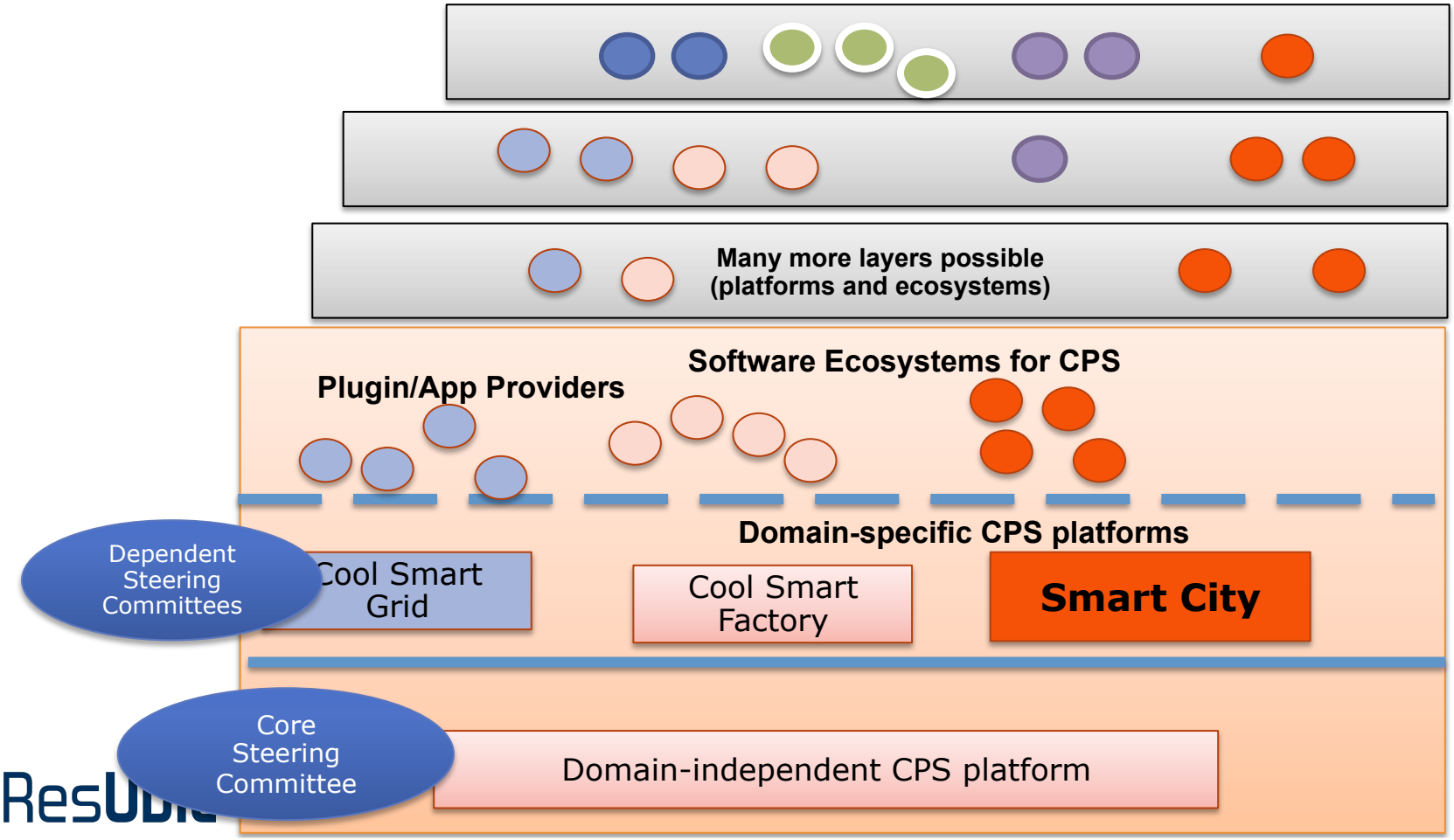
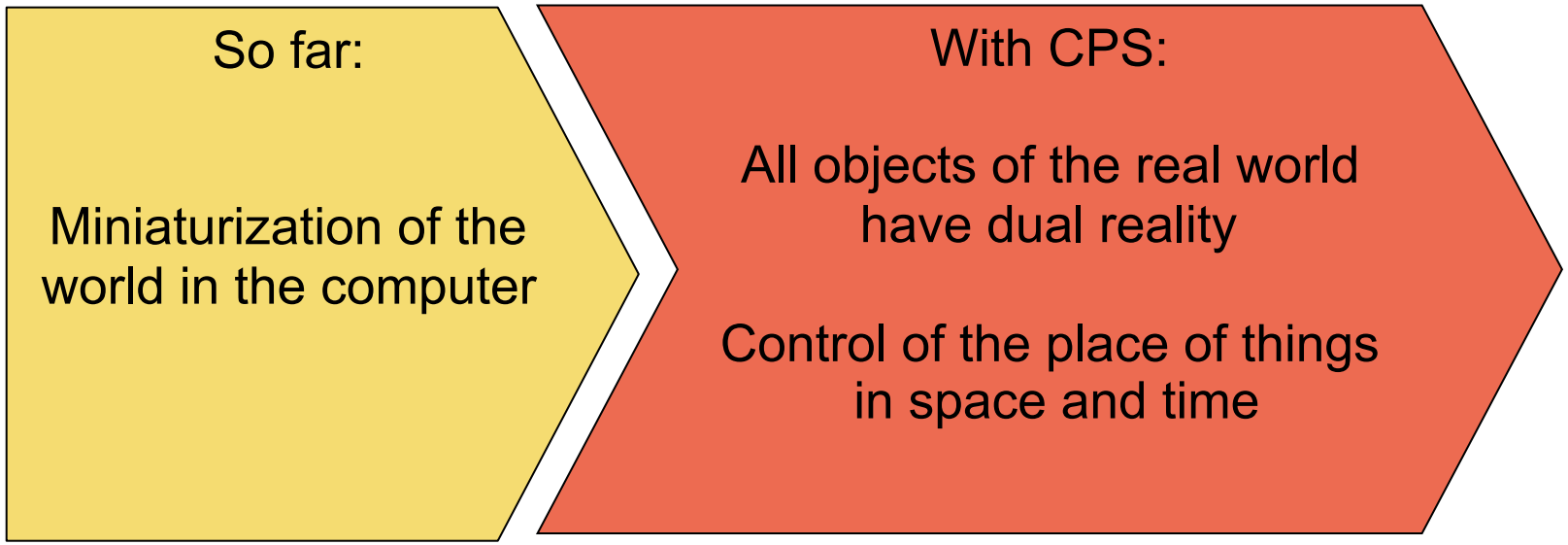
- Who will have it?



- All domains in transport, logistics, assembly, housing, cities will change
- Nothing will stay as it is
- All engineering disciplines will change until 2020
- Who will have the platforms?



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5. The 5G Lab

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5G – “Massive” Requirements

State of the art

- Massive throughput
- Massive low latency
- Massive sensing
- Massive resilience
- Massive safety and security
- Massive fractal heterogenity

5G

The Tactile Internet

> 10Gbit/s per user

< 1ms RTT

> 10k sensors per cell

> 99.999% availability

> 99.999% security

10x10 heterogeneity

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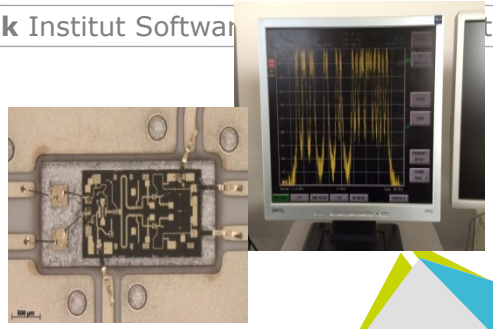
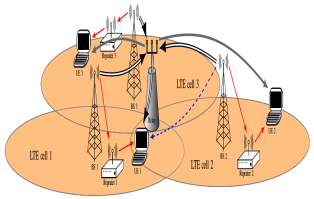
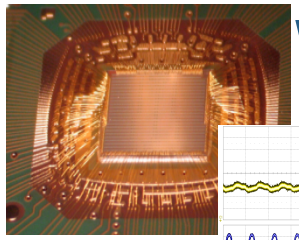
5G Research on four Tracks

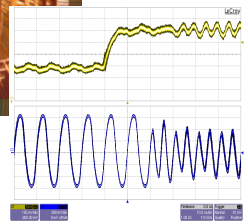
Dresden 5G Lab



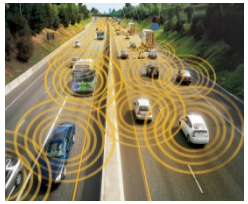


Wireless

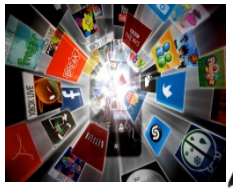




Silicon systems



Tactile Internet applications



Mobile edge cloud

Dresden - **5G** Lab Germany

ResUbic

www.dresden5glab.org

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Team Members

Dresden 5G Lab

Fakultät Informatik Institut Software- und Multimediatechnik, Lehrstuhl Softwaretechnologie

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Wireless Communication

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RFIC Design

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SoC Integration

D. Plettemeier
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M. Schröter
Electronic Devices & Integrated Circuits

E. Jorswieck
Information Theory

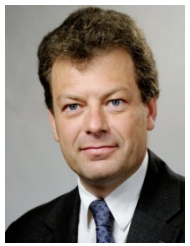
C. Baier
Formal Methods

K. Janschek
Automation

U. Aßmann
Software Engineering

F. Fitzek
Communication and Storage

S. Santini
Wireless Sensor Networks

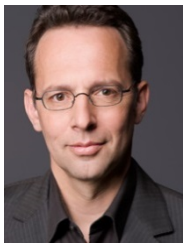


W. Lehner
Databases

W. Nagel
Big Data and HPC

C. Fetzer
Resilience and Safety

T. Strufe
Privacy and Security



L. Urbas
Human-Machine-Interfaces

E. Altinsoy
Audio & Haptic Engineering

H. Härtig
Operating Systems

ResUbic

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6. Summary

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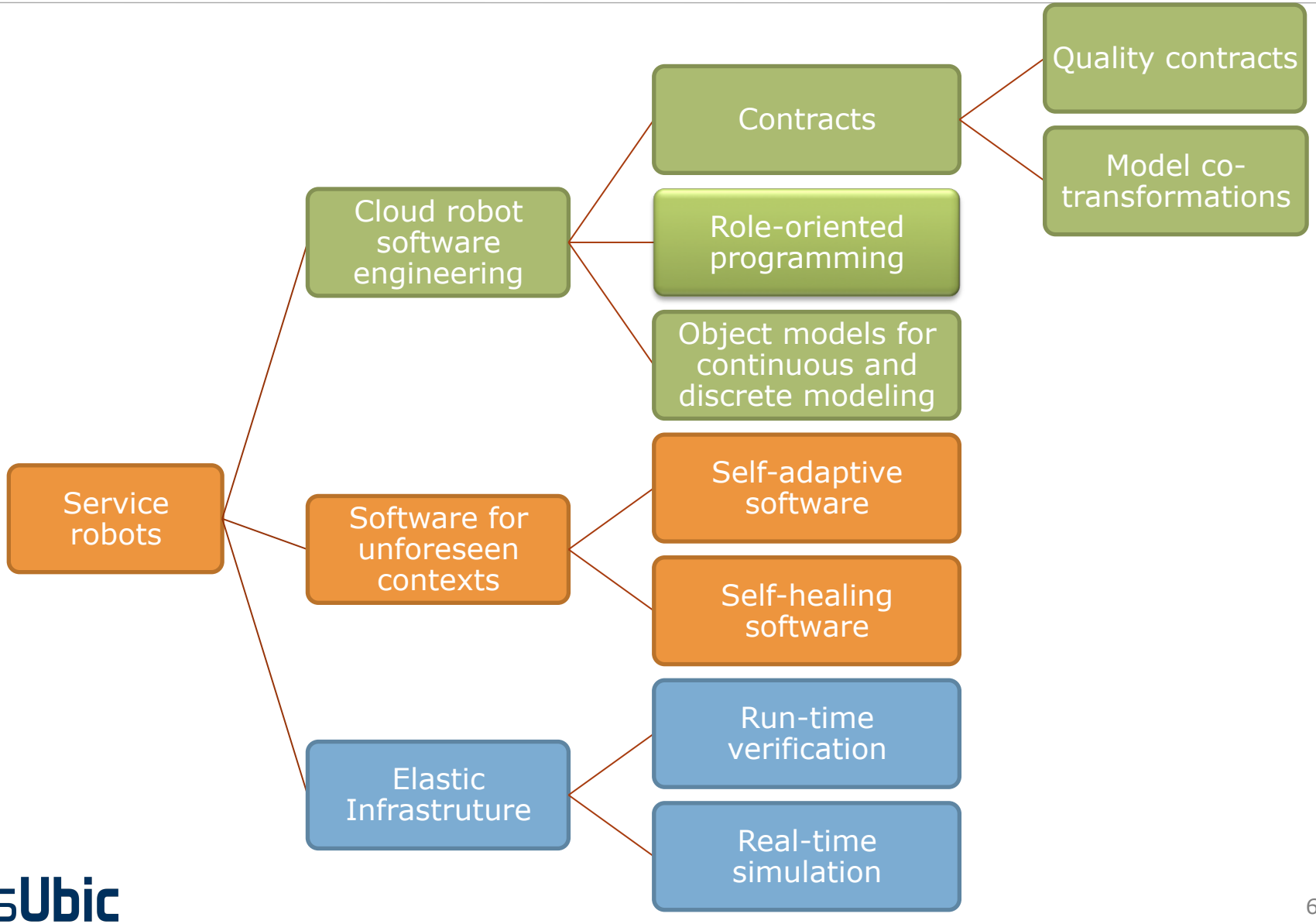
Observations

- Otherwise no adaptive defensive behavior
- Otherwise no adaptive energy optimization

- We need new programming and modeling languages with roles and contexts

Elastic Infrastructure required for runtime verification and simulation

Some Tasks of Software Engineering for Cloud Robots



- NAOText, a domain-specific role-based language for robots
- http://www.qualitune.org/?page_id=453
- Götz, S., Leuthäuser, M., Reimann, J., Schroeter, J., Wende, C., Wilke, C., Aßmann, U.: A Role-based Language for Collaborative Robot Applications. In: Proceedings of 1st ISoLA Workshop on Software Aspects of Robotic Systems (ISoLA SARS'11).

- Smart Apps (SMAPPs) and Smart Application Grids (SMAGs)
- Under development by Christian Piechnick
- C. Piechinick, S. Richly, S. Götz, C. Wilke, U. Aßmann. Using Role-Based Composition to Support Unanticipated, Dynamic Adaptation – Smart Application Grids. Adaptive and Self-adaptive Systems and Applications (Adaptive 2012)

Literature

- Martin Franke, Christoph Seidl, and Thomas Schlegel. A Seamless Integration, Semantic Middleware for Cyber-Physical Systems. In Proceedings of the 10th International Conference on Networking, Sensing and Control, ICNSC'13, 2013.
- Christoph Seidl and Uwe Aßmann. Towards Modeling and Analyzing Variability in Evolving Software Ecosystems. In Proceedings of the 7th International Workshop on Variability Modelling of Software-intensive Systems (VaMoS), VaMoS'13, 2013.
- Georg Püschel, Sebastian Götz, Claas Wilke, and Uwe Aßmann. Towards systematic model-based testing of self-adaptive systems. In Proceedings of The Fifth International Conference on Adaptive and Self-Adaptive Systems and Applications (ADAPTIVE), 2013.

Thank You!

The Resubic Lab: Exploring Human Cyber-Physical Systems

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Software Technology Group

http://st.inf.tu-dresden.de/

ResUbic
www.resubic.org

Qualitune
www.qualitune.org

COOL Software
www.cool-software.org

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A.1. Programming with SMAG

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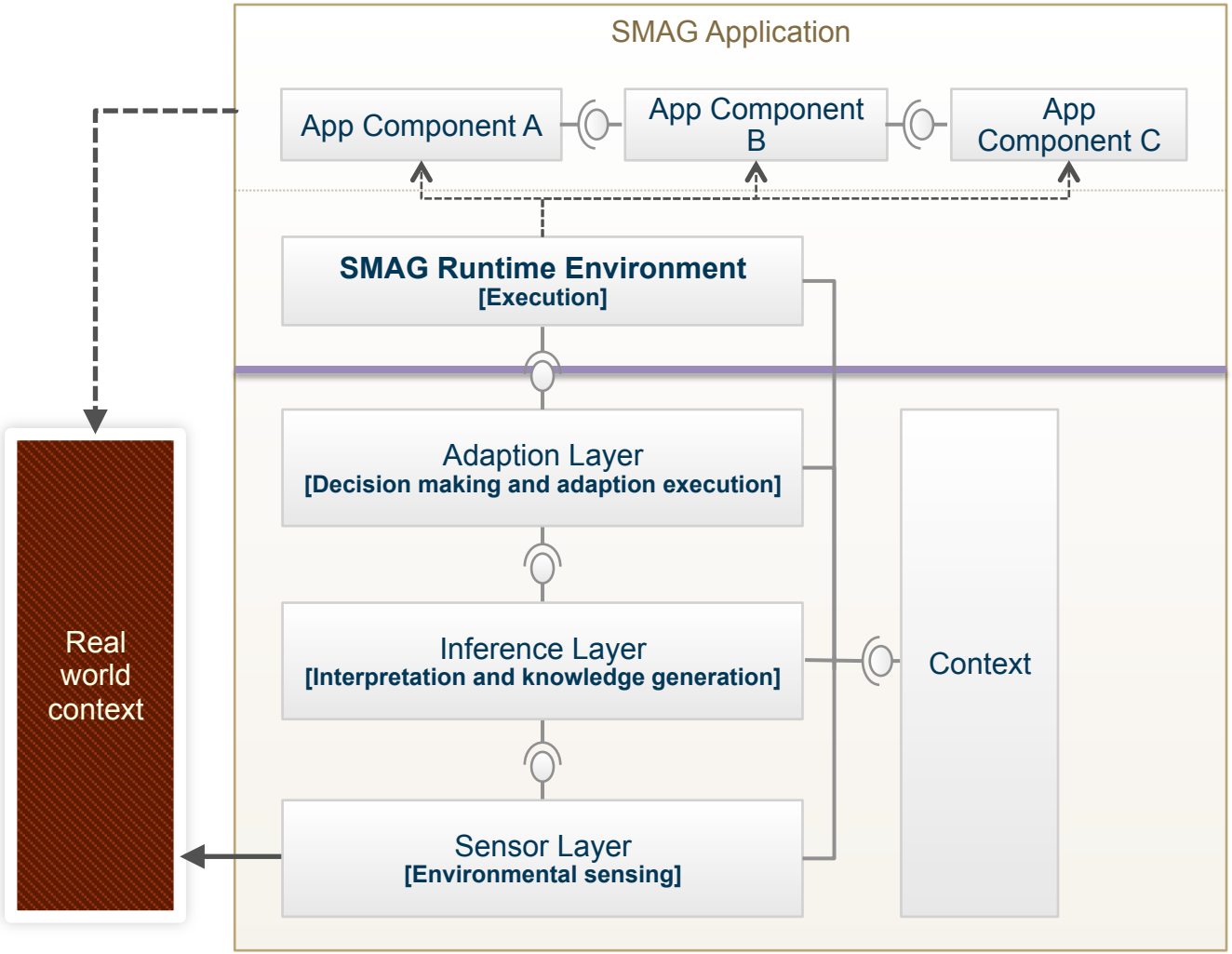
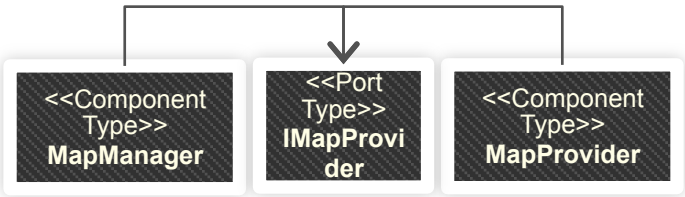
Smart Application Grids Relies on an Architecture Language



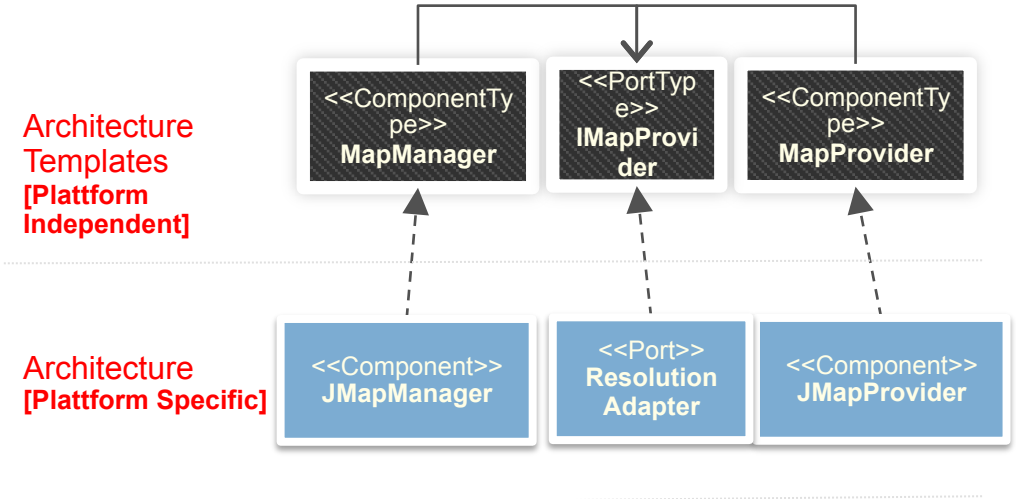
Dynamic Context Adaptation – Architecture Templates

Architecture Templates **[Plattform Independent]**



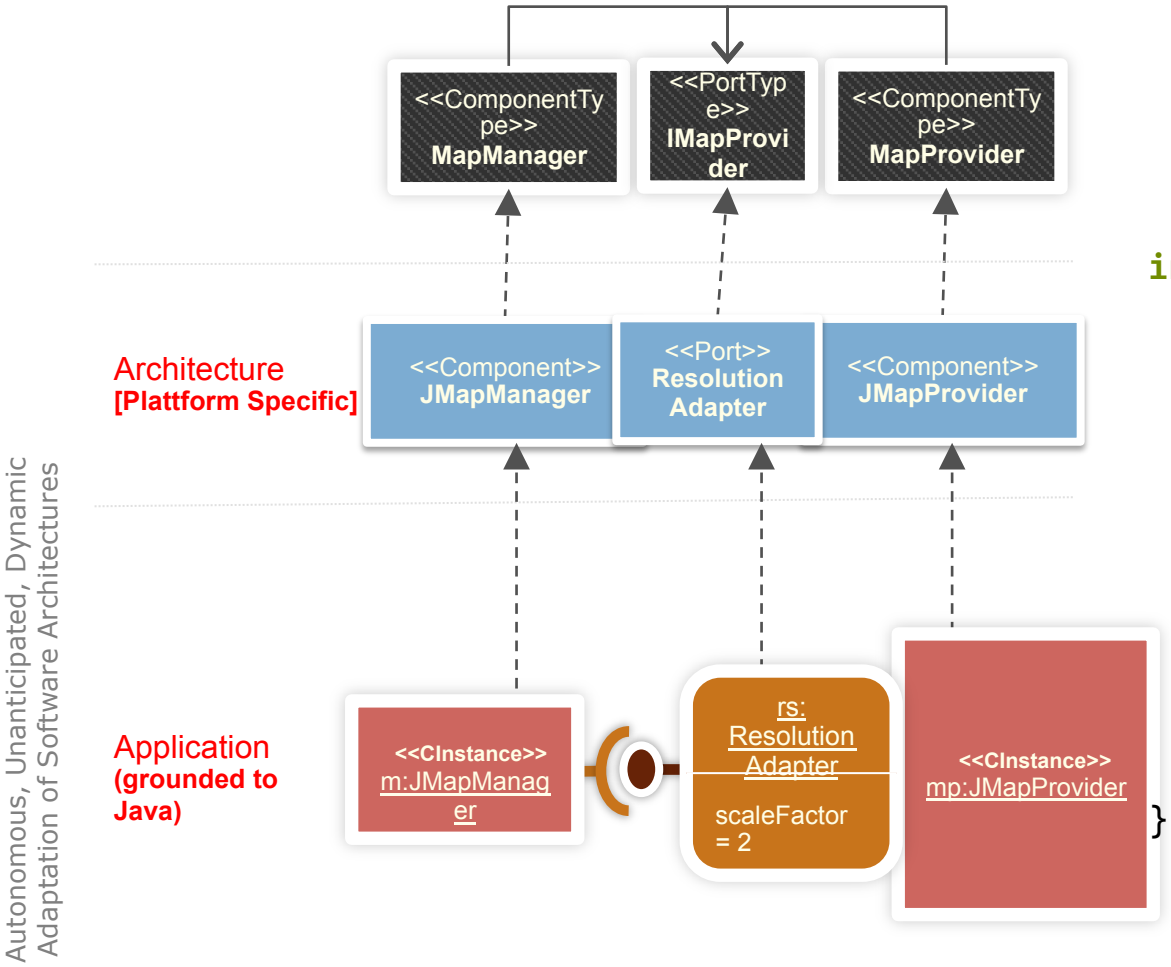

```
import "platform:/.../
StandardTypes.madl";
namespace "org.sample.ResilientMaps";

meta architecture ResilientMaps {
  type libraries:
  type library ResilientMapTypes{
    complex ImageMap{
      property id : String;
      property name : String;
      property data : List<Byte>;
    }
  }

  port types:
  port type IMapProvider {
    ImageMap getMap();
  }

  component types:
  component type MapProvider{
    provides IMapProvider;
  }

  component type MapManager{
    requires IMapProvider[1 to 1];
  }
}
```

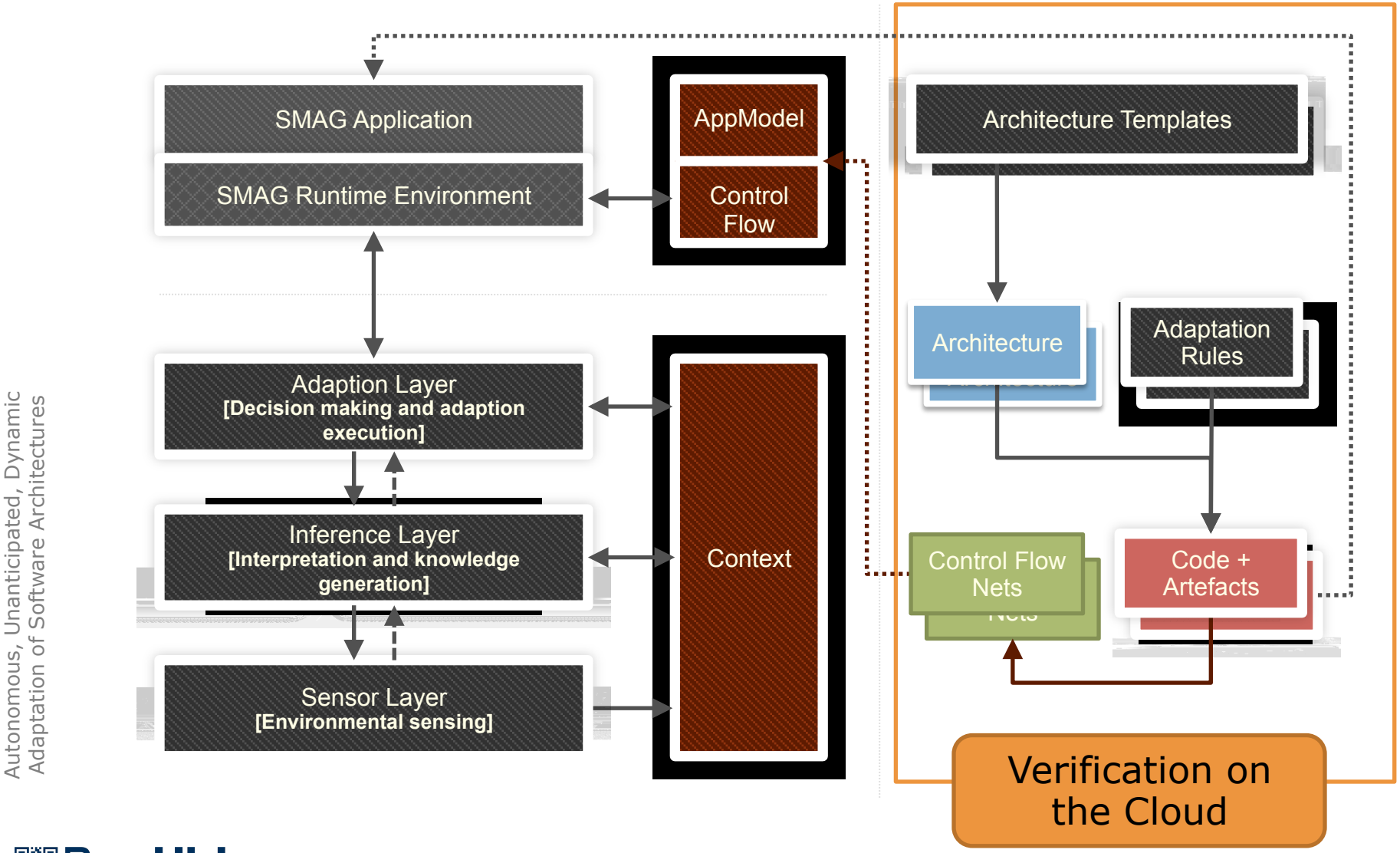
Dynamic Context Adaptation – Architecture




```
import "platform:/.../
StandardTypes.madl";
import "platform:/.../
Java7Platform.pdl";
import "maps.madl";

namespace "org.sample.ResilientMaps"

app JResilientMaps{
  platform: Java7;

  ports:
  filter port ResolutionAdapter
    is IMapProvider{
    parameter scale : Double;
  }

  components:
  component JMapProvider implements
    MapProvider{
  }

  component JMapManager implements
    MapManager{
  }
}
```

Dynamic Context Adaptation – Role-Based Adaptation




```
initialization{
  port rs = new ResolutionAdapter{
    set scale = 2.0;
  };

  component mp = new JMapProvider{
    bind port rs
    to offer IMapProvider;
  };

  component m = new JMapManager;

  connect m.IMapProvider to offer mp;
}
```

Challenge: Adaption Architecture and Cloud-based Verification