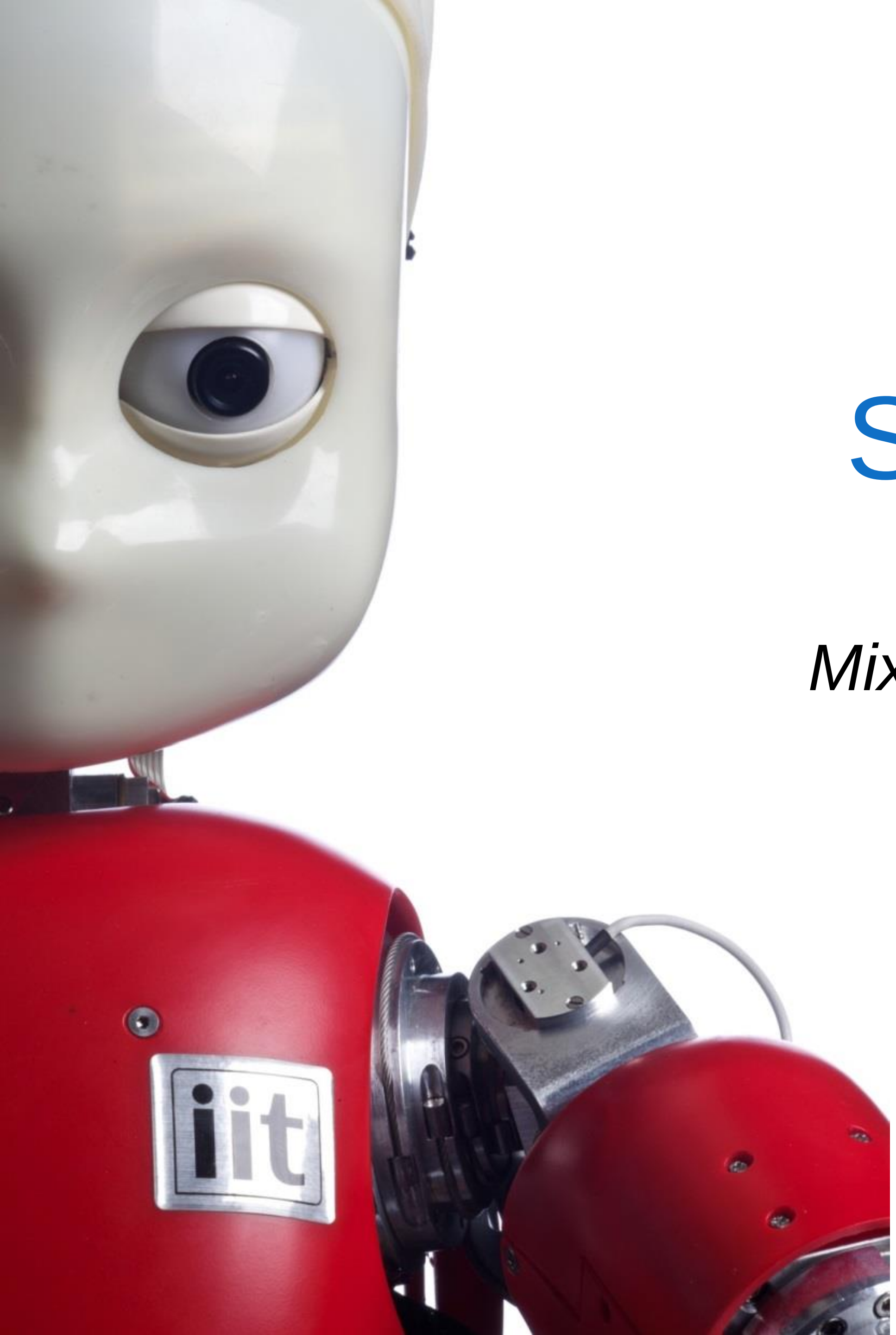

Software componentization for robotics

Mixing middleware, architectures, and several robot types

ISTITUTO ITALIANO
DI TECNOLOGIA

Giorgio Metta

Scientific Director
Italian Institute of Technology

L. Natale, D. Pucci, U. Pattacini

Italian Institute of Technology

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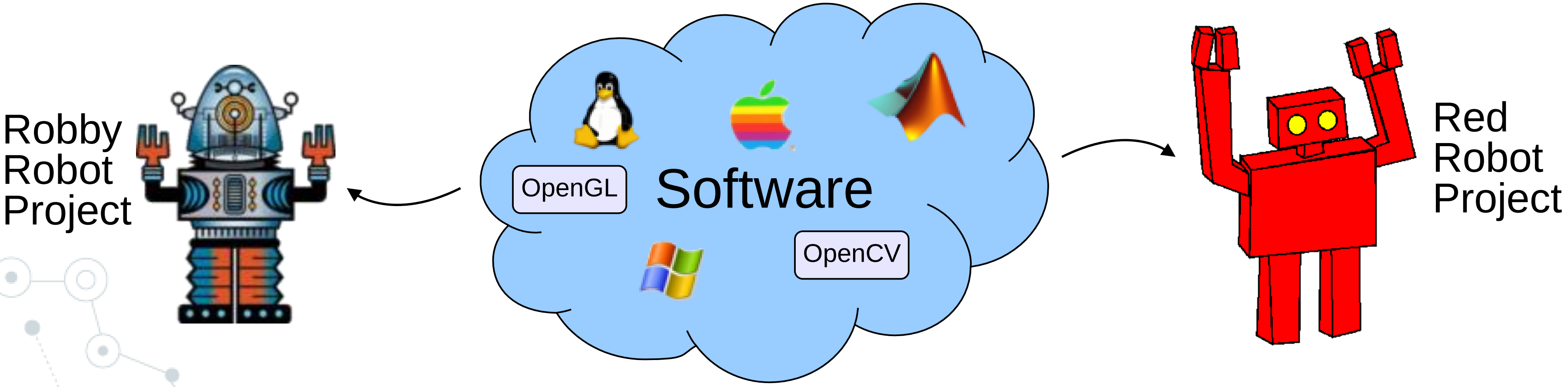
Once upon a time...

The sad fate of most robot software

- Writing software is difficult and time consuming
- Our software tends to die with our projects/students
- Sad! Software collaboration speeds things up
- Code sharing could promote successful components



Barriers to software collaboration

- Groups developing on different robots face obstacles
  - Differences in sensors, actuators, bodies...
  - Differences in processors, operating systems, libraries, frameworks, languages, compilers...
- Lack of reward for producing reusable code
- Research groups that all use a specific robot (Khepera, Pioneer, AIBO, ...) often form a natural software community
  - But each alone is a small subset of robotics

The popular robots in year 2001

Yet Another Robot Platform

- YARP is an open-source (BSD) middleware for humanoid robotics
- History
  - An MIT / Univ. of Genoa collaboration
  - Born on Kismet, grew on COG, under QNX
  - With a major overhaul, now used by RobotCub consortium
- Exists as an independent open source project (GitHub)
- C++ source code (mostly)

2000-2001

2001-2002

2003

2004-Today

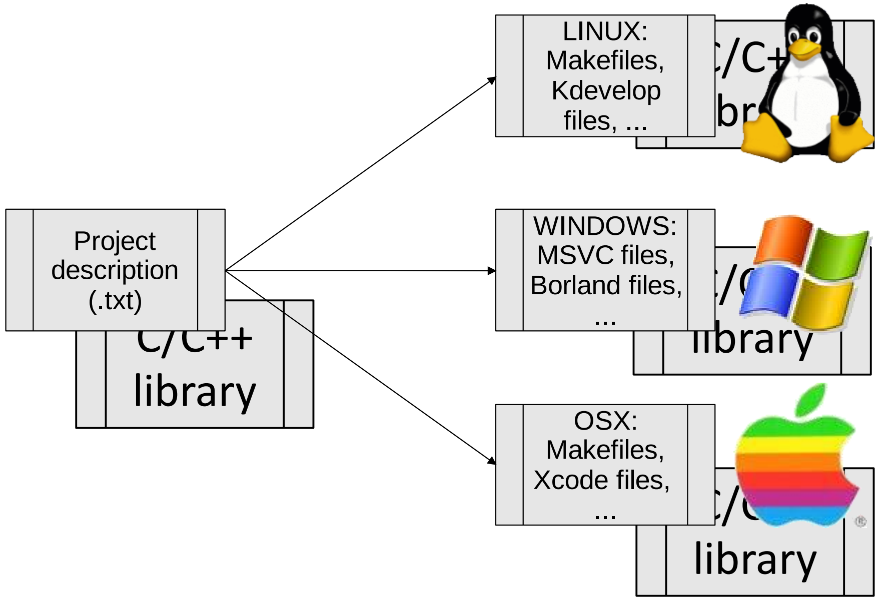
YARP philosophy

- One processor is never enough
- Modularity
- Minimal interference
- Stopping (the robot) hurts
- Humble approach (thin middleware)
- Exploit diversity

Fitzpatrick, Metta, Natale. *Towards Long-lived Robot Genes.* Robotics and Autonomous Systems, 56(1):29-45, 2008

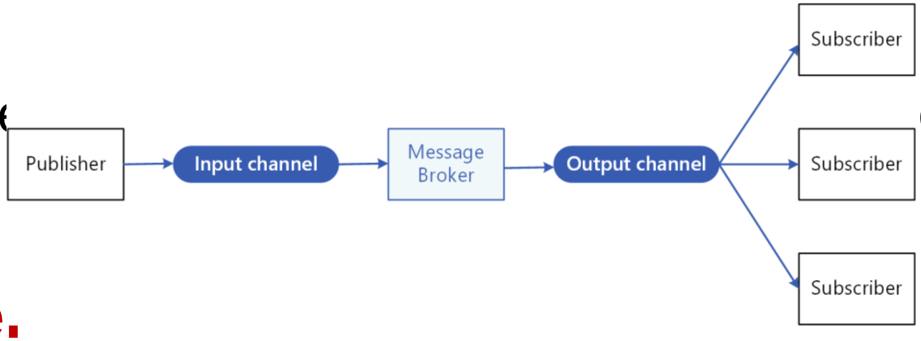
Exploit diversity: portability

- Operating system portability:
  - Adaptive Communication Environment , C++ OS wrapper: e.g. threads, semaphores, sockets
- Development environment portability:
  - CMake
- Language portability:
  - Via Swig: Java (Matlab), Perl, Python, C#

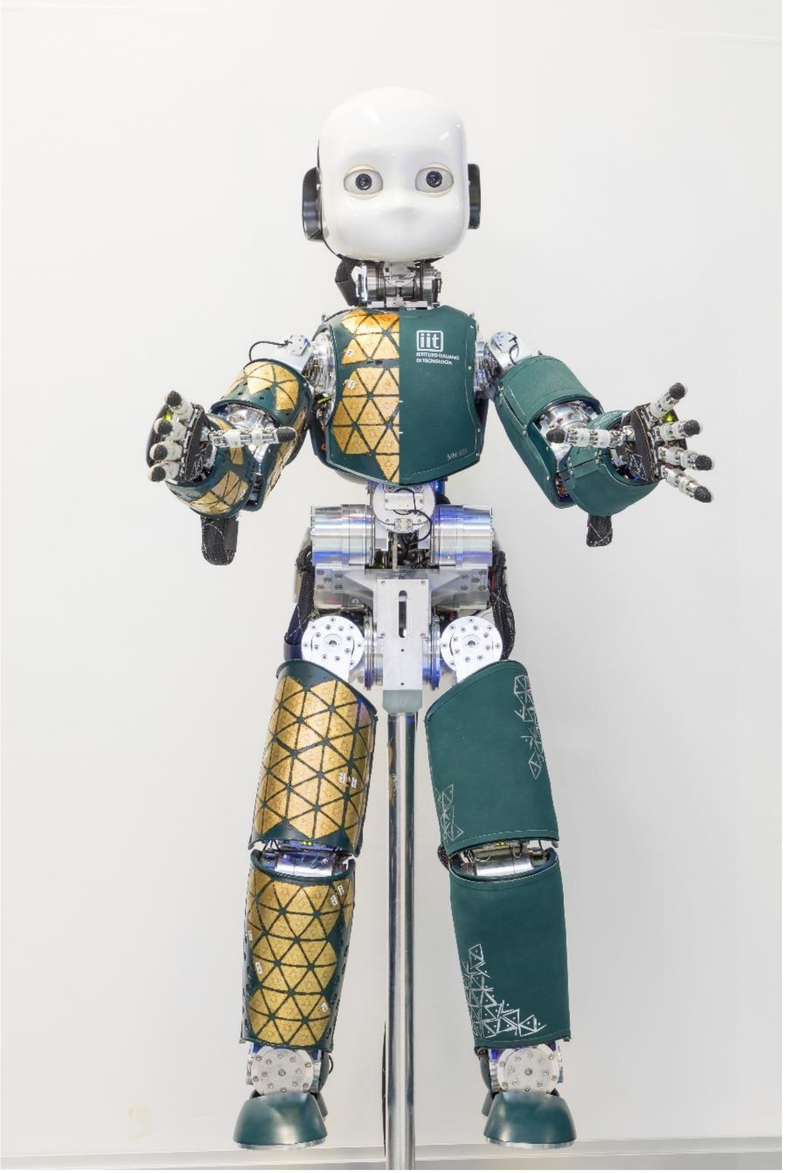


Achieving modularity

- Factor out **details of data flow between programs** from program source code
  - Data flow is very specific to robot platform, experimental setup, network layout, communication protocol, etc.
  - Useful to keep “algorithm” and “plumbing” separate
- Factor out **details of devices used by programs** from program source code
  - The devices can then be replaced ove e code can be used in other systems

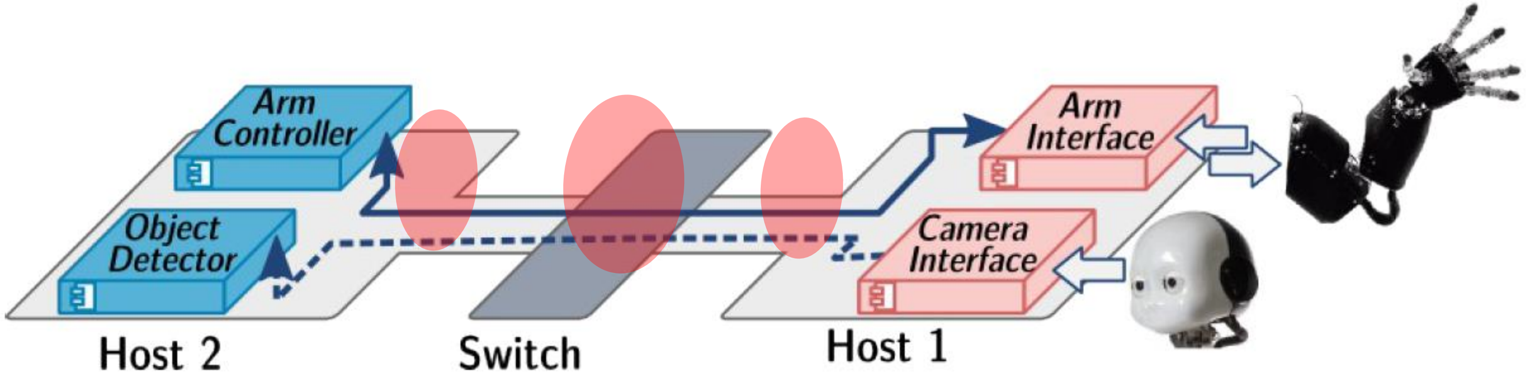


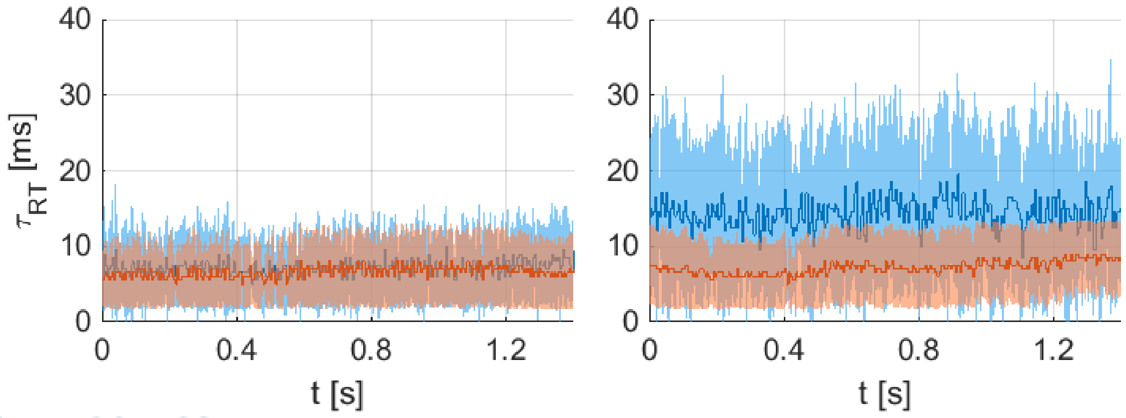
- The pattern: **publisher-subscribe.**

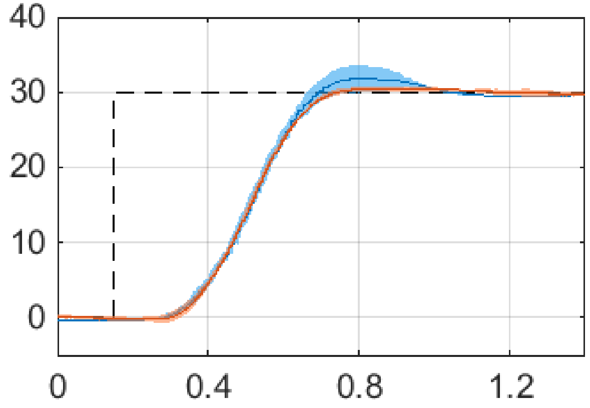


SCUDERIA FERRARI

YARP channel prioritization

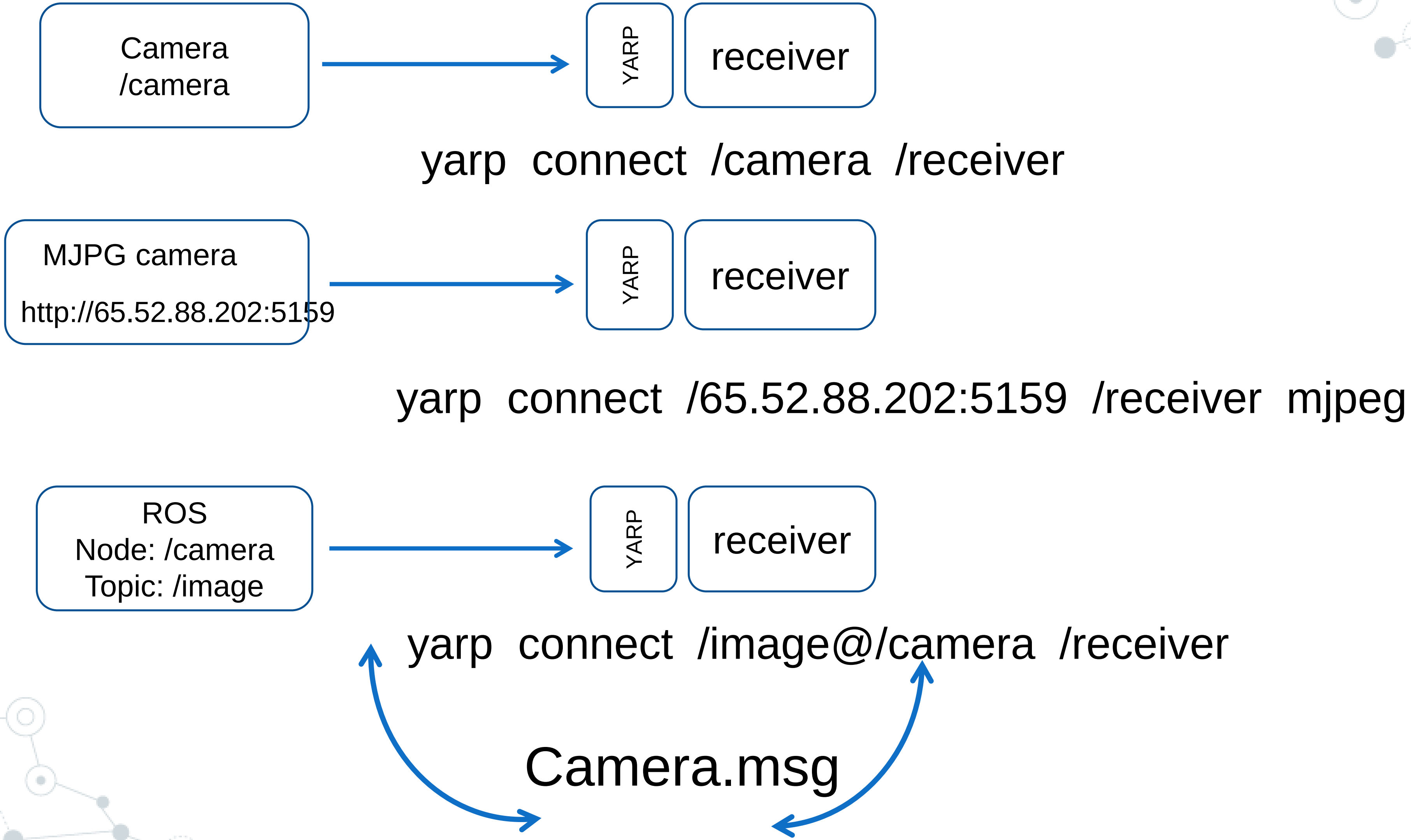




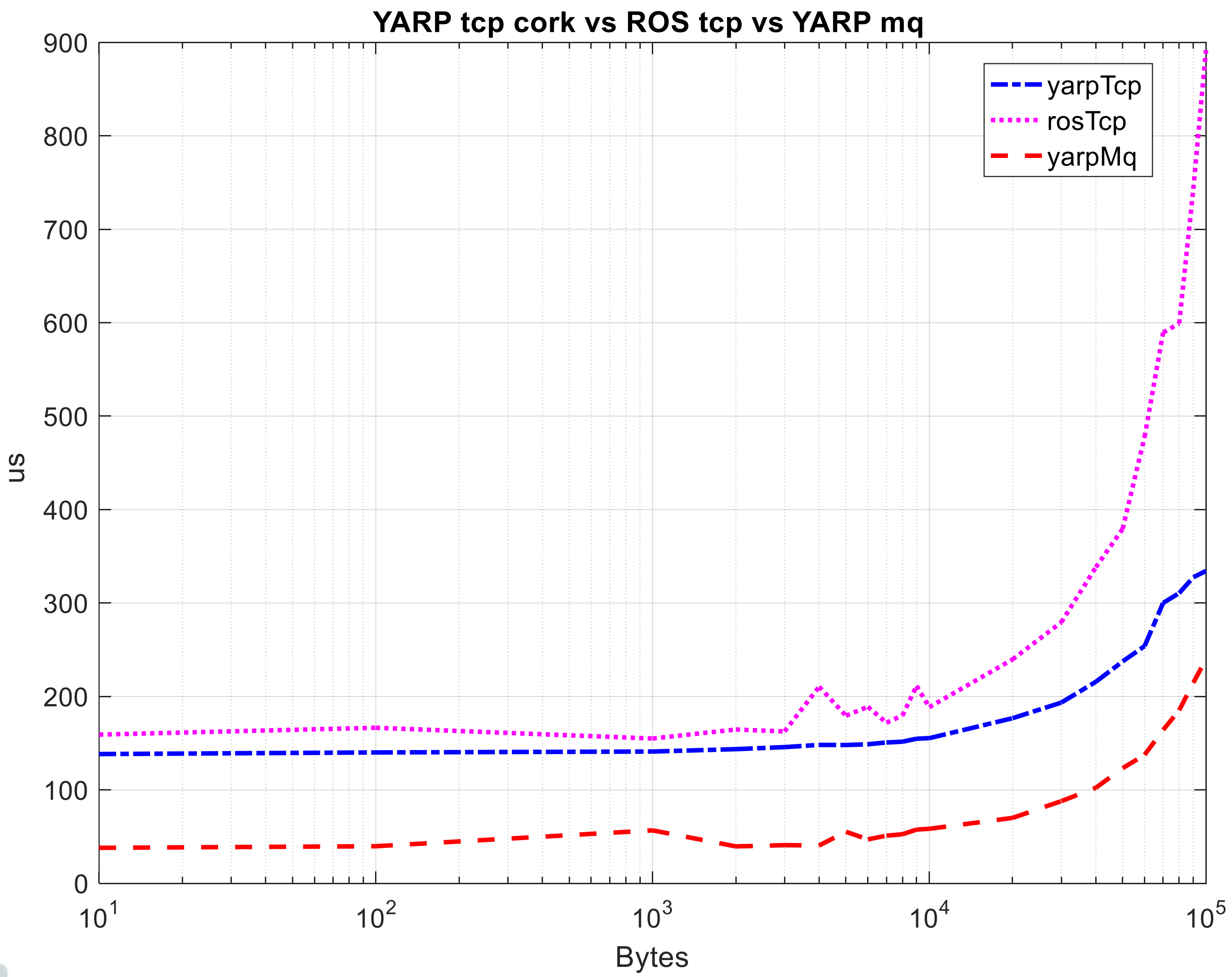


Paikan, A., et al., A Best-Effort Approach for Run-Time Channel Prioritization in Real-Time Robotic Application, IROS 2015
Paikan, A., et al. Data Flow Port's Monitoring and Arbitration, Journal of Software Engineering for Robotics, 2014

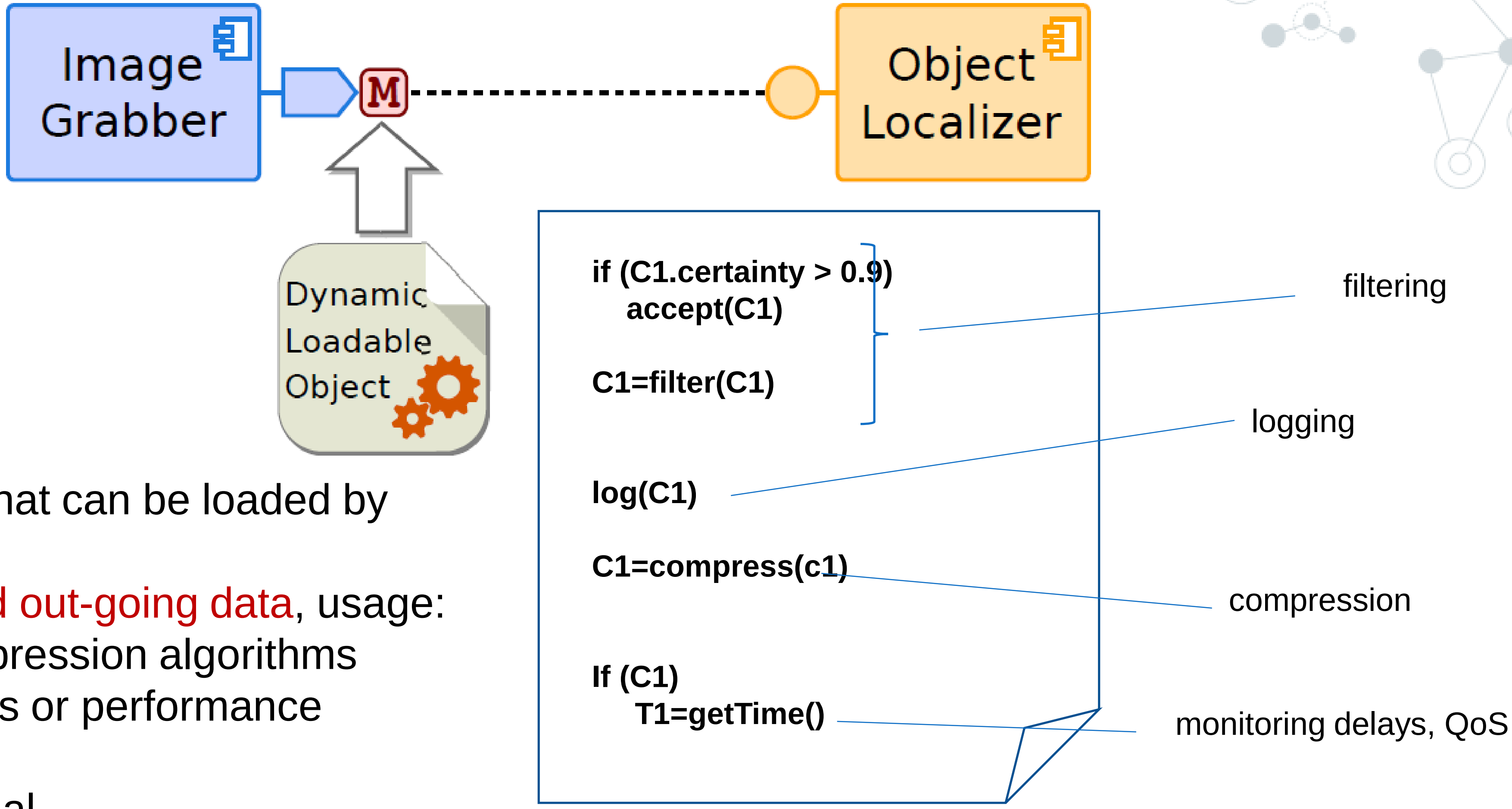
carrier plug-ins



custom, efficient, protocols



Port Monitor



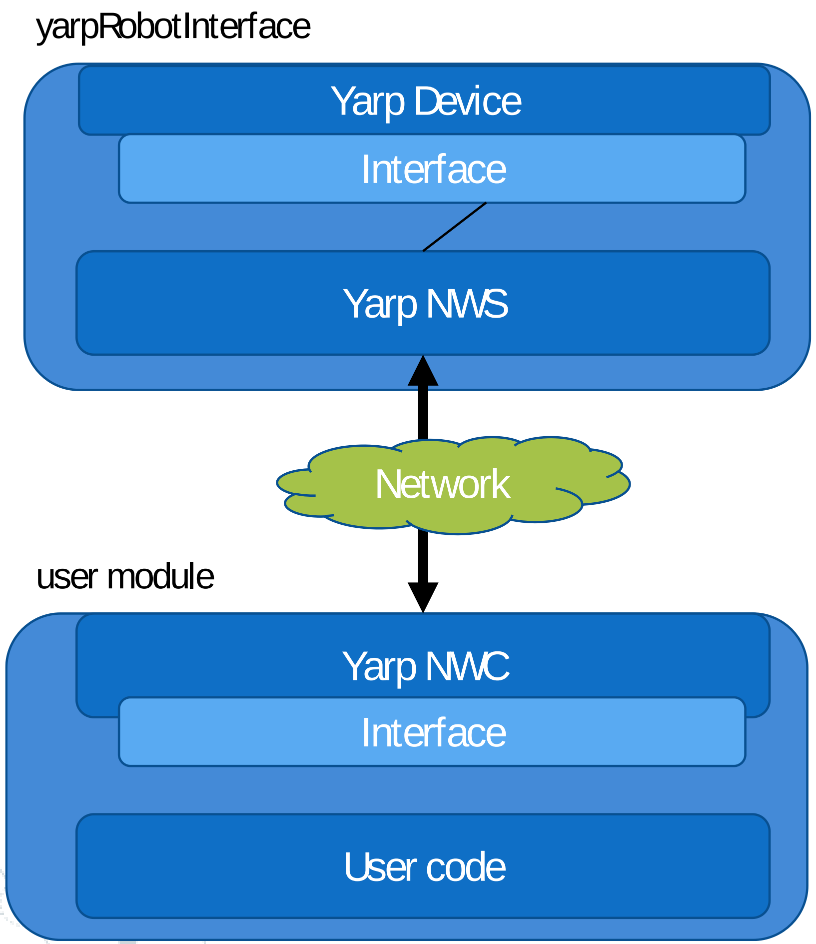
The Port Monitor is a plug-in that can be loaded by any connection point

It has access to in-coming and out-going data, usage:

- Add compression/de-compression algorithms
- Log (e.g. compute statistics or performance indicators)
- Sniff data, also bi-directional

Avoid explicit man-in-the-middle components

device modularity



Yarp Device:

- A plugin which exposes the functionalities of a hardware device through a standardized Yarp C++ Interface.

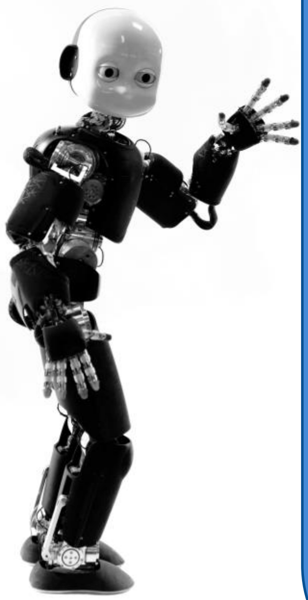
Yarp NWS:

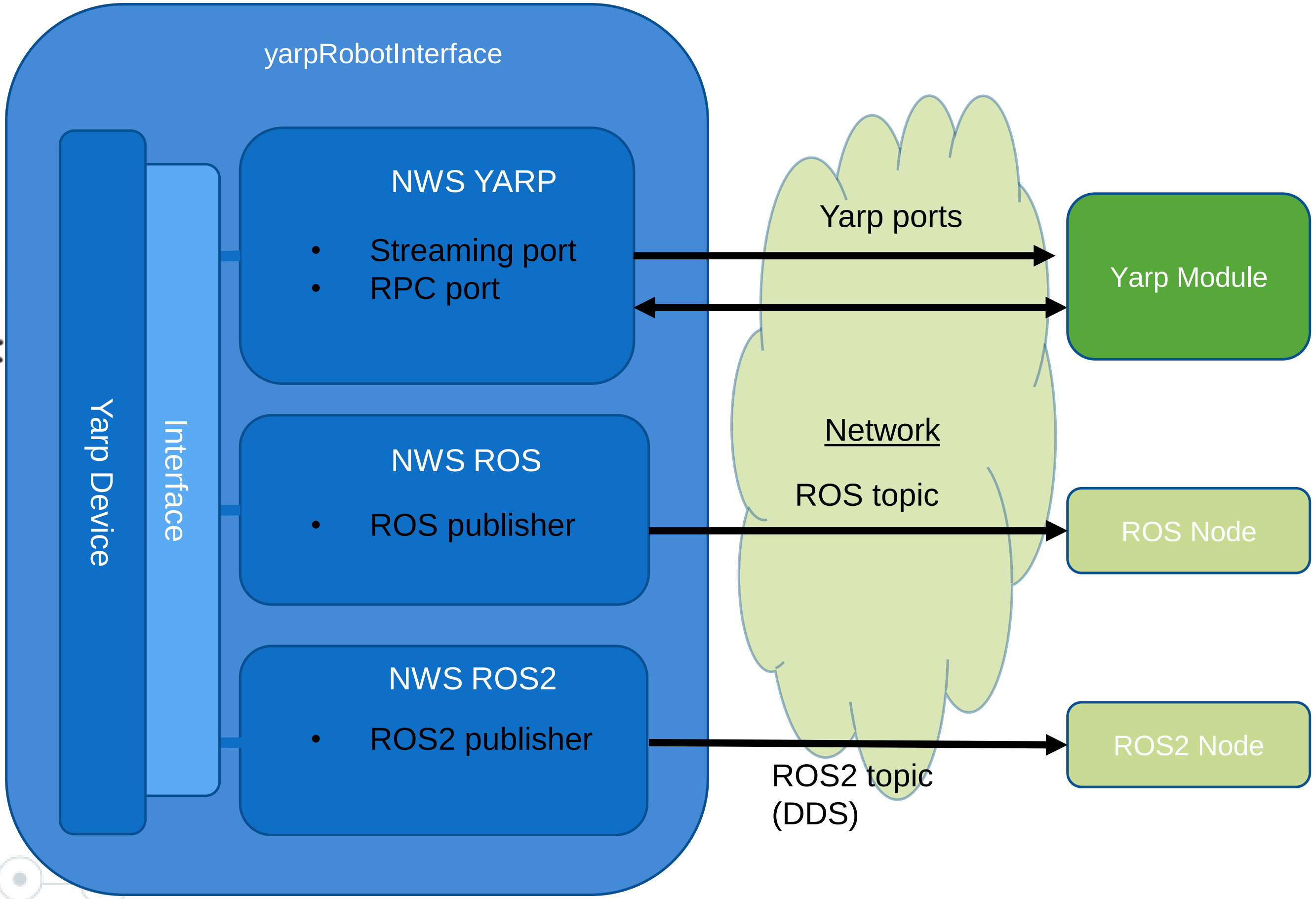
- A Network Wrapper Server (NWS) is a software component (plugin) attached to a physical device. It does not contain any logic. It just exposes the interface to the network.

Yarp NWC:

- A Network Wrapper Client (NWC) is a software component which implements the same interface of a real device, but instead of being connected to a physical hardware, it communicates with a Yarp NWS.

NWS/NWC





NWS/NWC ARCHITECTURE

- The code is well separated, and the functionality of each component is clear.
- Easy to maintain.
- Easy to extend.

- **NWS** can be used to make Yarp to communicate with different middlewares (which use different network/serialization protocols)
  - Yarp (yarp ports protocol)
  - ROS noetic (ros topics)
  - ROS2 humble (ros2 topics with DDS)
  - IsaacSDK Nvidia

- **Multiple NWSs** can be used simultaneously to expose the same plugin to multiple middlewares.

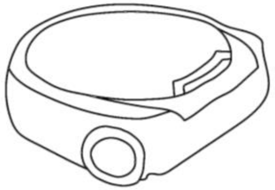
Orchestration of behaviors: the problem

*Due to a **human programming error**, the robot fell when transitioning from the **driving task** to the **egress task** (the foot **throttle controller wasn't turned off**). This caused the robot to the fall and faceplant out of the car onto the asphalt.*

Source: http://drc.mit.edu/

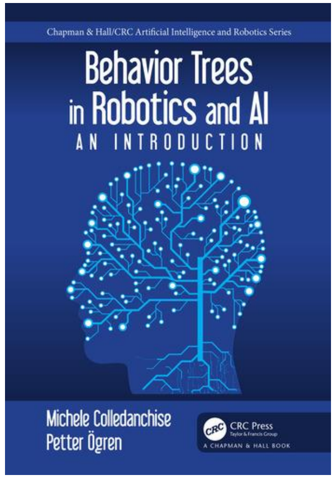
NAV 2
ROS2

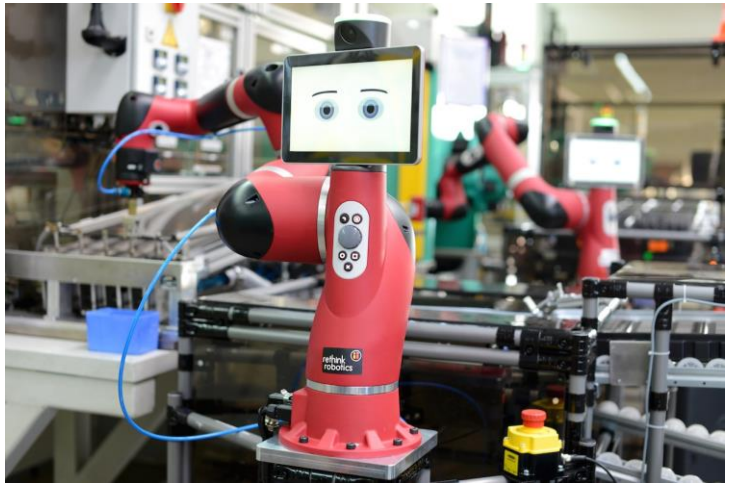
scania.com



bosch.com

toyota.com



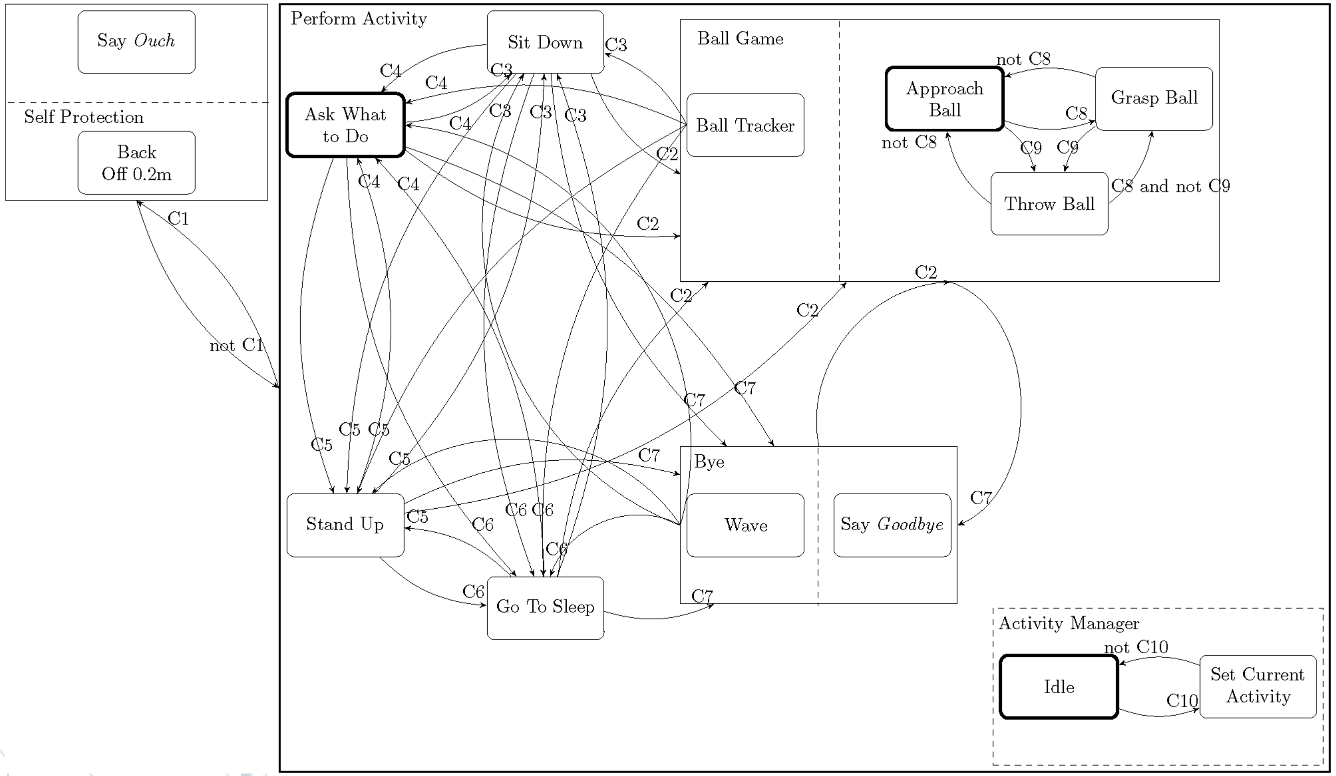


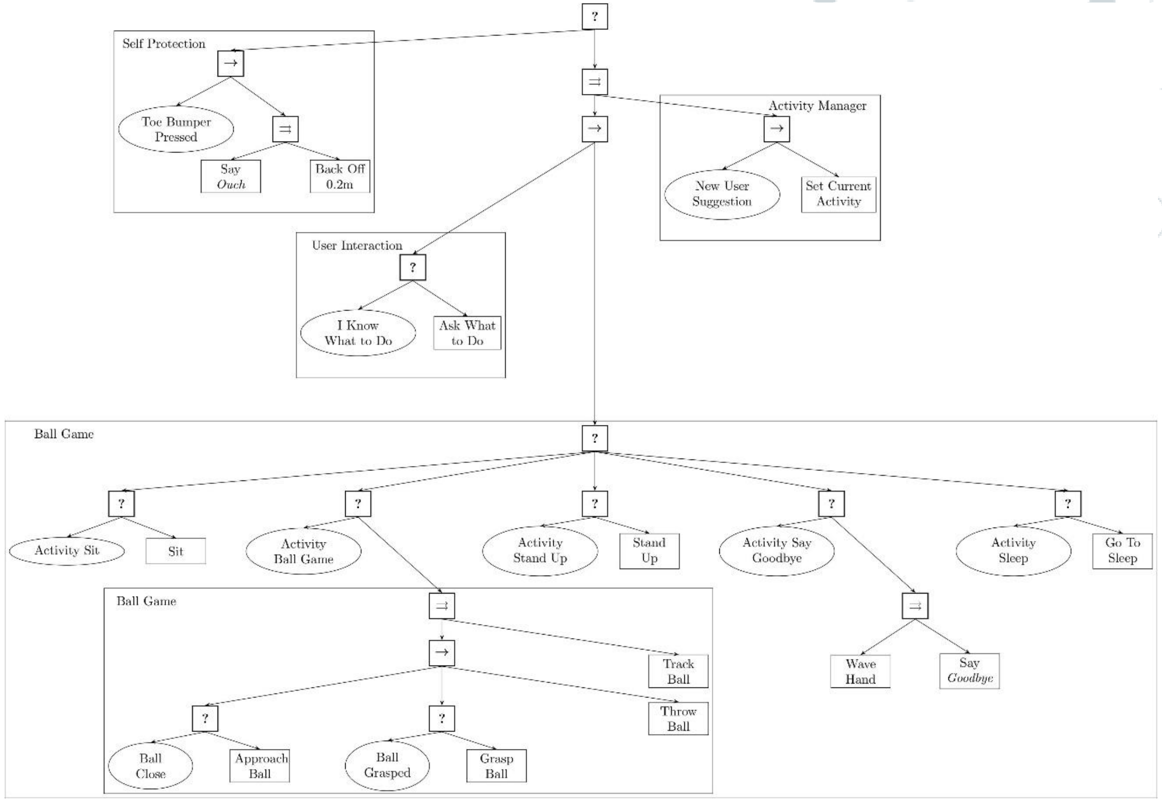
Rethink's Robots Get Massive Software Upgrade, Rodney Brooks "So Excited" (IEEE Spectrum)

bostondynamics.com

Slide credits: Michele Colledanchise

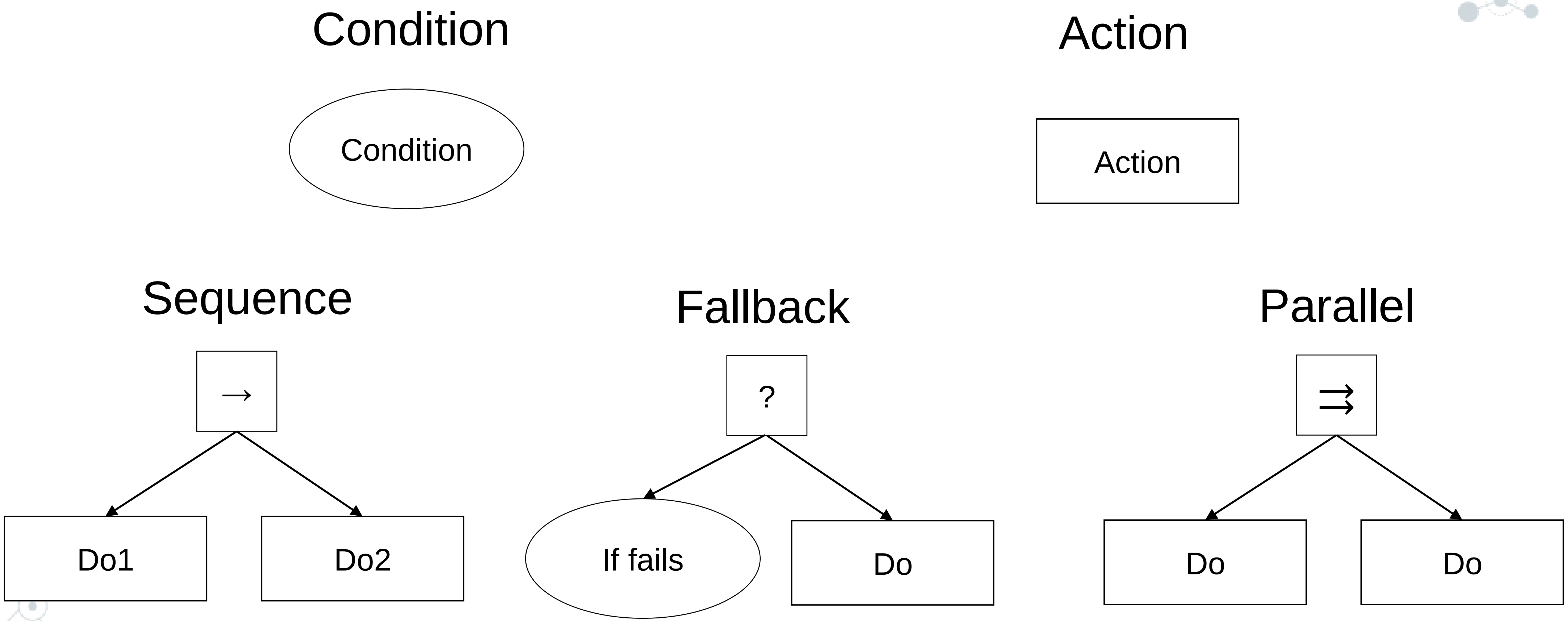
State charts vs. behavior trees (BT)



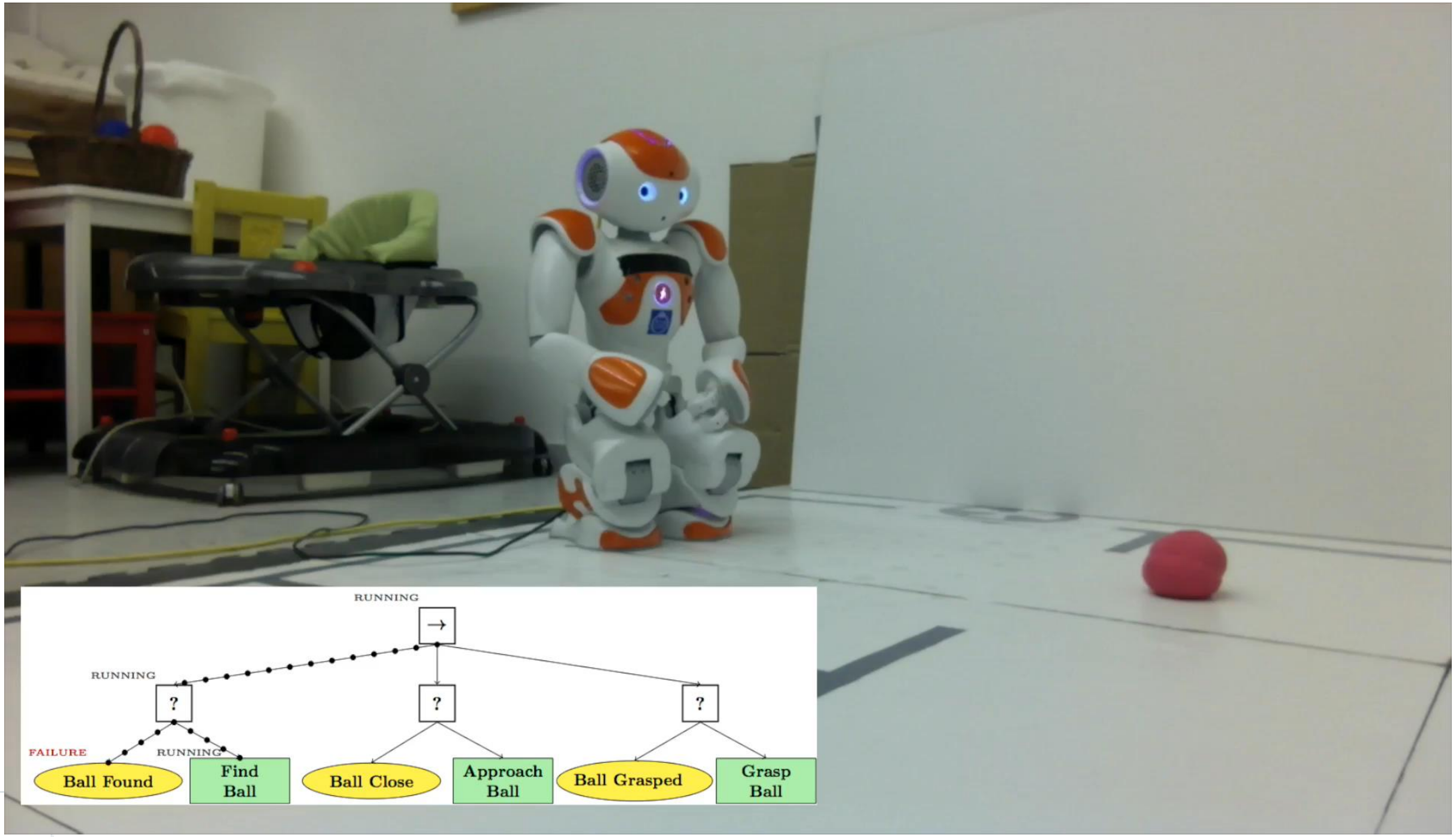


Slide credits: Michele Colledanchise

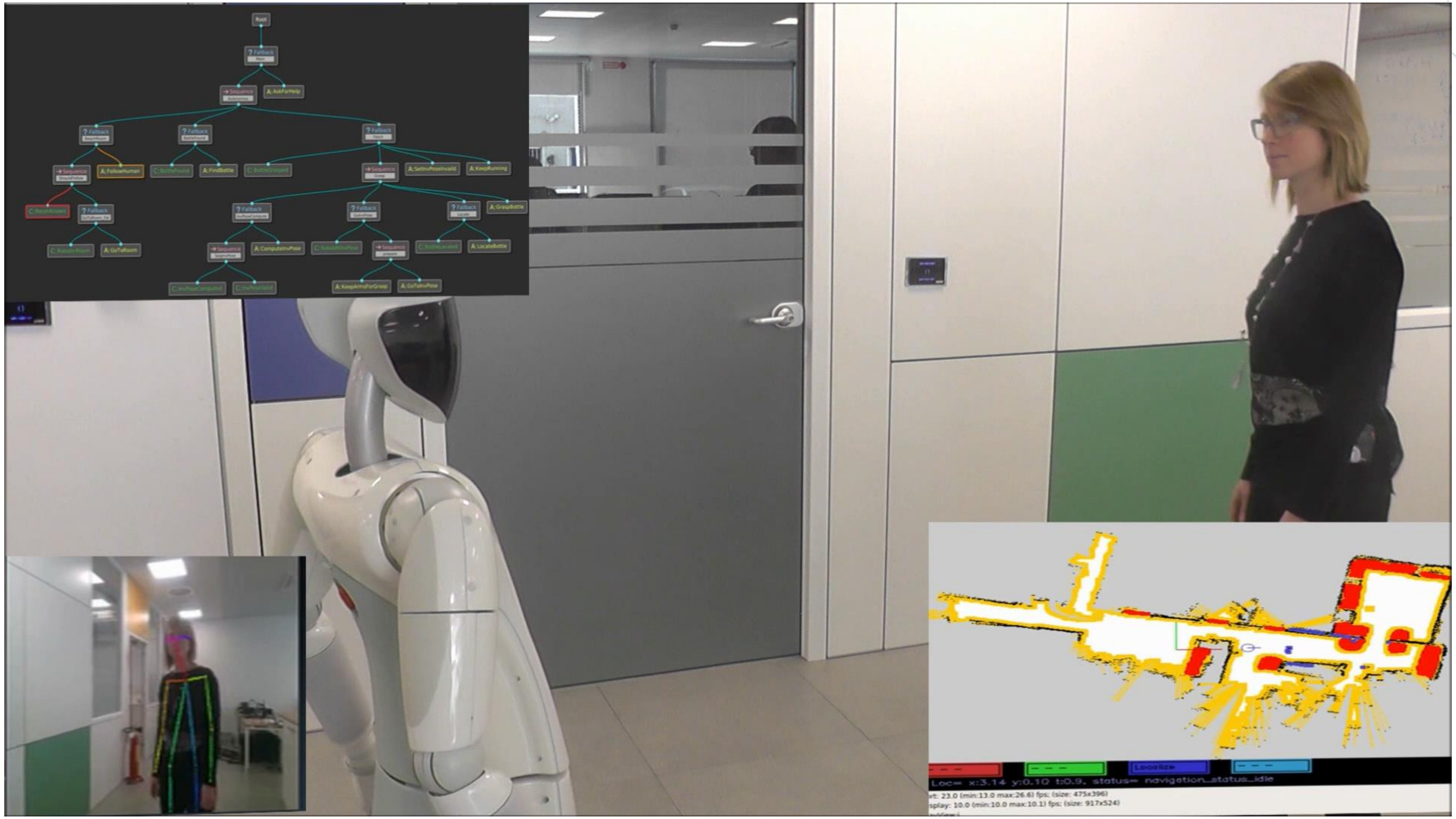
Behavior trees: a primer



Reactive behaviors: a simple example

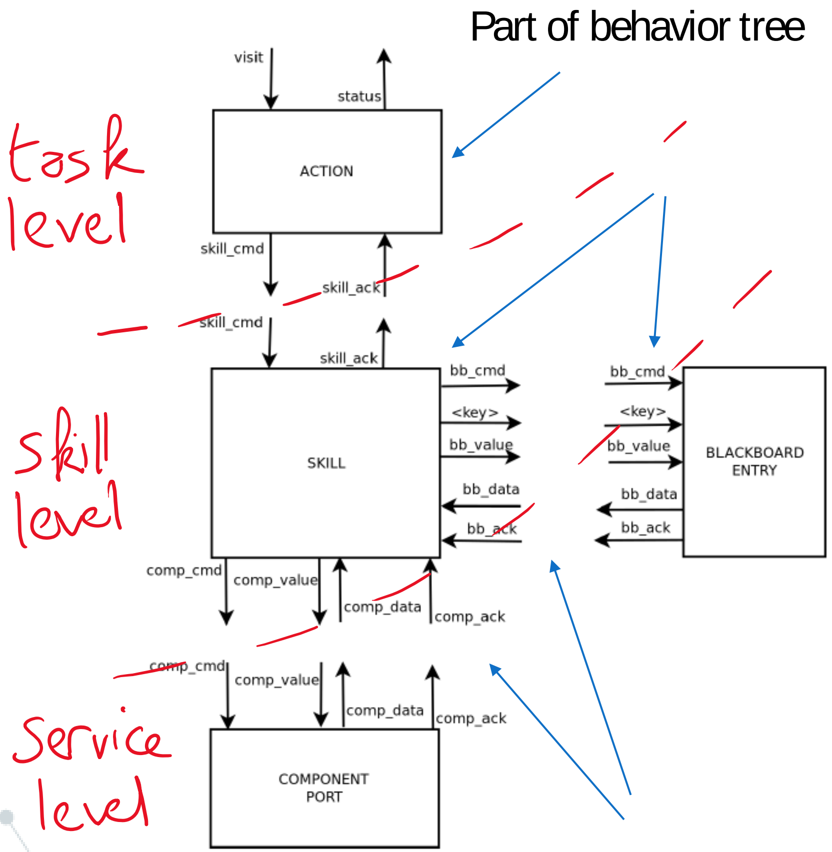


Slide credits: Michele Colledanchise

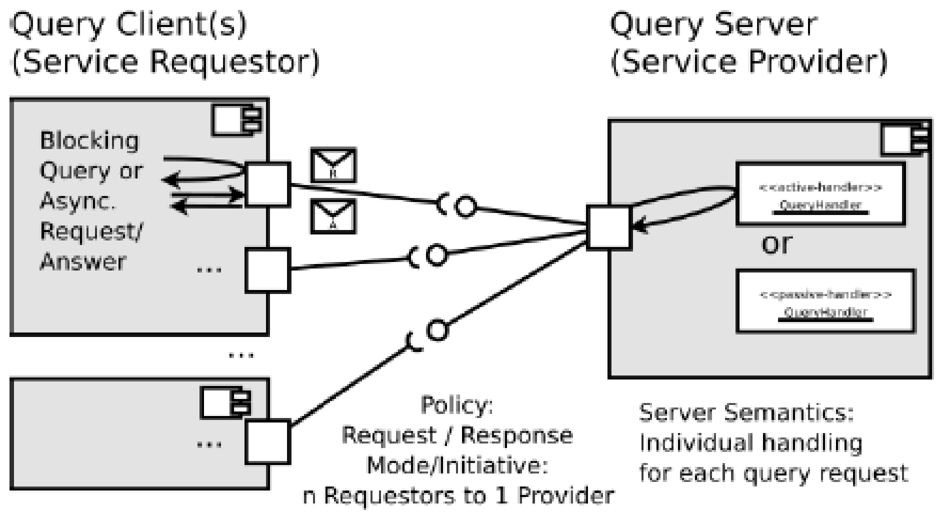


Colledanchise, et al., Formalizing the Execution Context of Behavior Trees for Runtime Verification of Deliberative Policies, IROS 2021
Colledanchise and Natale, On the Implementation of Behavior Trees in Robotics, IEEE Robotics and Automation Letters, 2021

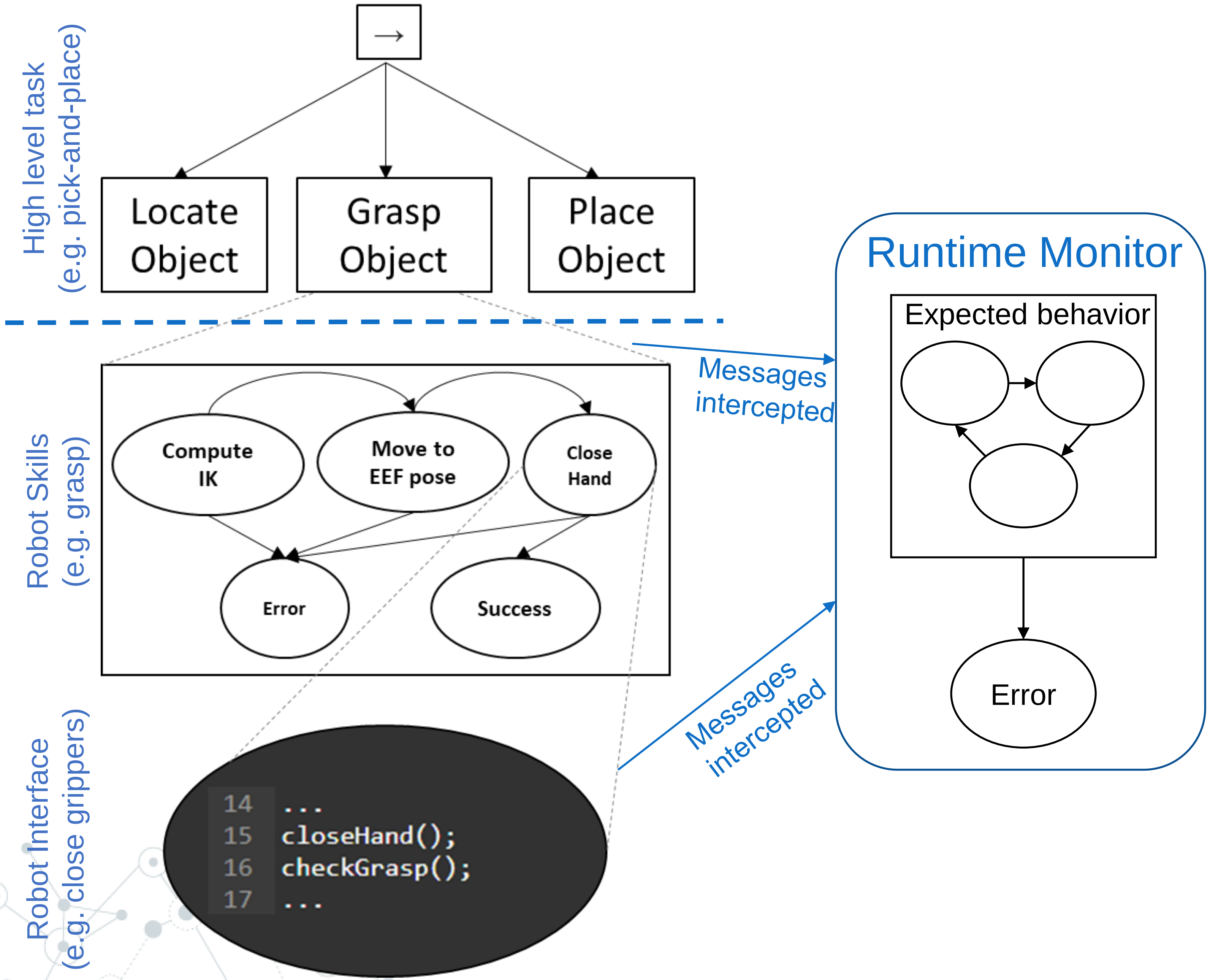
Semantics of BT + Skills + Components



- BT, skills and components modelled as communicating transition systems - **asynchronous** execution (threads)
- Properties specified with SCOPE language (OTHELLO subset)



- Communication follows the **Query Pattern**
- Interfaces are specified using an **interface definition language**



- “Sniff” the messages passed across layers.
- Intercept message by a *runtime monitor*
- A runtime monitor detects differences between the expected behaviors and the actual one

A robotic museum guide

What's needed:

- Dialog management
- Human-detection
- Self-localization
- Navigation

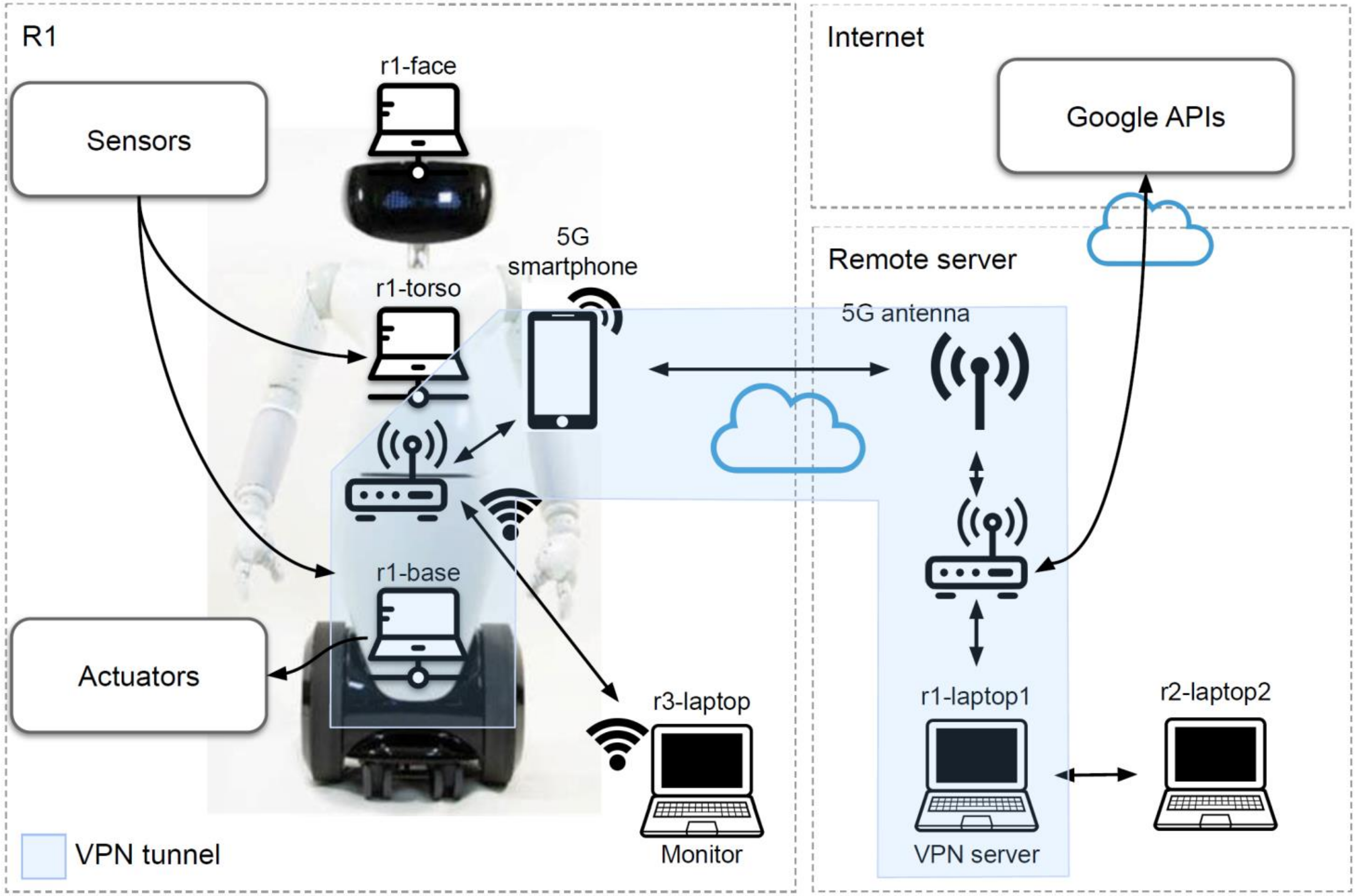
Cloud connectivity:

- Through 5G

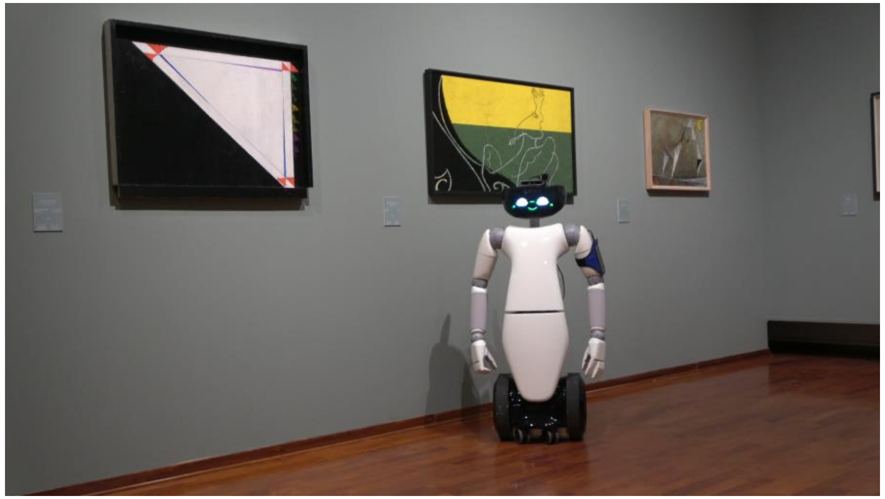
How long:

- 200 meters, 20+ minutes (70 with questions)
- 110+ tours in two weeks

Hardware architecture



Software “tricks”



Galleria Arte Moderna, Turin

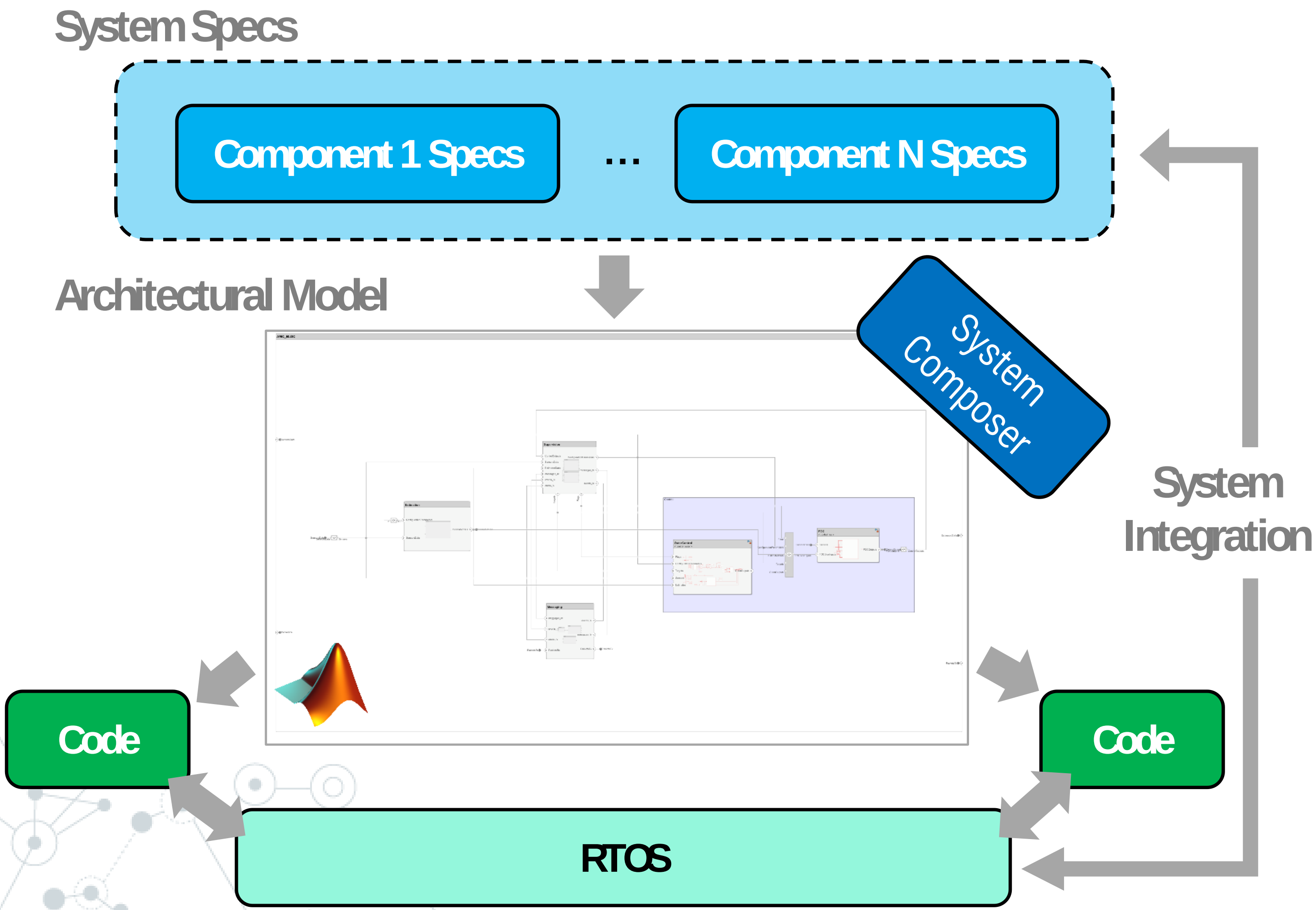
Palazzo Madama, Turin

- **Port monitors** to implement data compression: images and LIDAR over 5G
- **Behavior trees** to implement the behavior coordination as shown earlier
- **Multiple middleware** systems: ROS for navigation, YARP to control the robot, Google APIs for speech, etc.
- **Flexible plug-ins** and remotization to handle distributed processing with controlled latency

Below YARP

Model-Based System Engineering (MBSE)

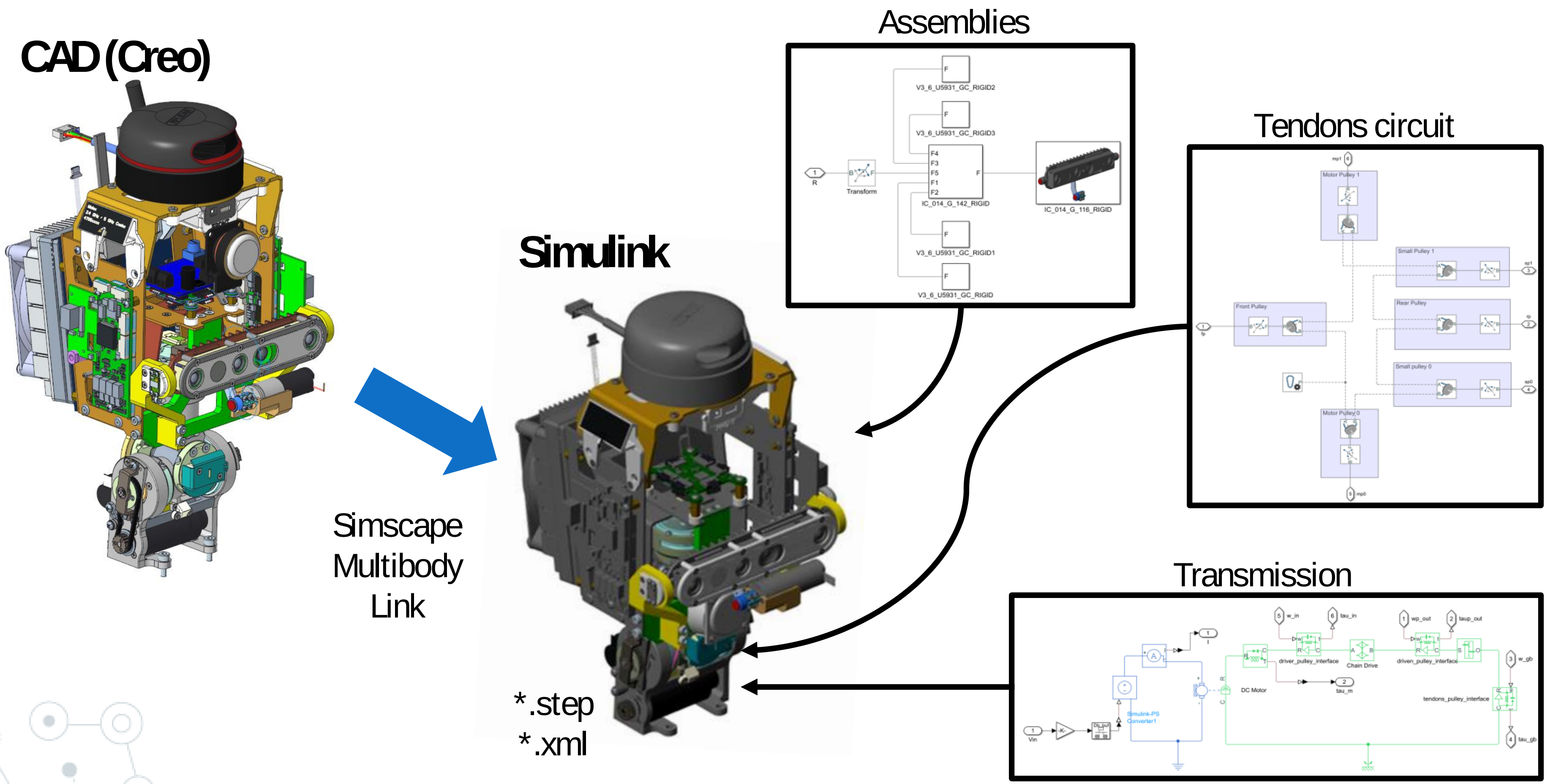
MBSE = MBD + System Engineering



- Complex Systems
  - Hierarchal components
  - Functional, logical, physical decompositions
  - Catch errors early, minimize rework
- Standardization
  - Data dictionaries for I/F’s
  - Ports and connections
- Design Optimization
  - Static analysis
- Effective Communication
  - Implementable descriptions
  - Requirements

From CAD design to realistic simulations

Simulink/Simscape

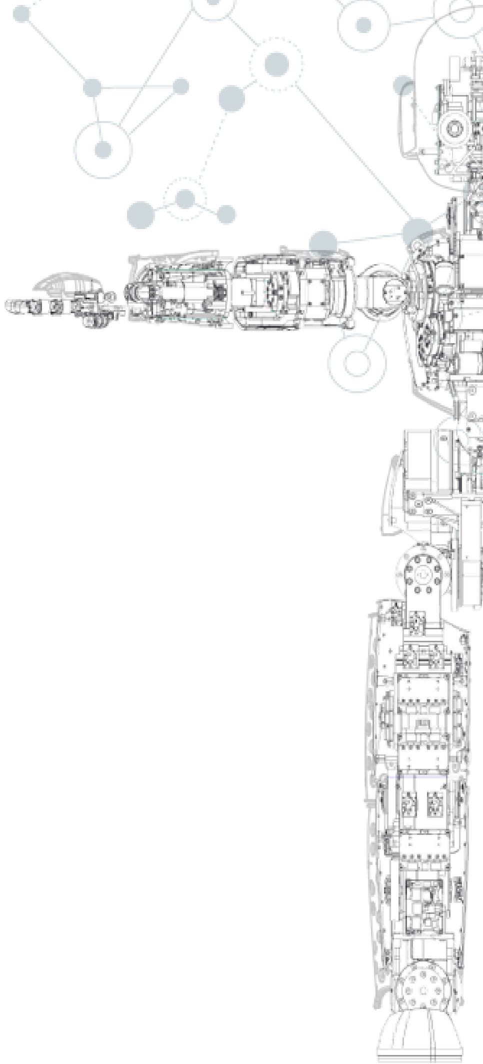


JAXsim

A scalable physics engine for robot learning implemented in pure Python with JAX.

Diego Ferigo, Silvio Traversaro, Daniele Pucci

ami-iit/jaxsim




PORTO ANTICO

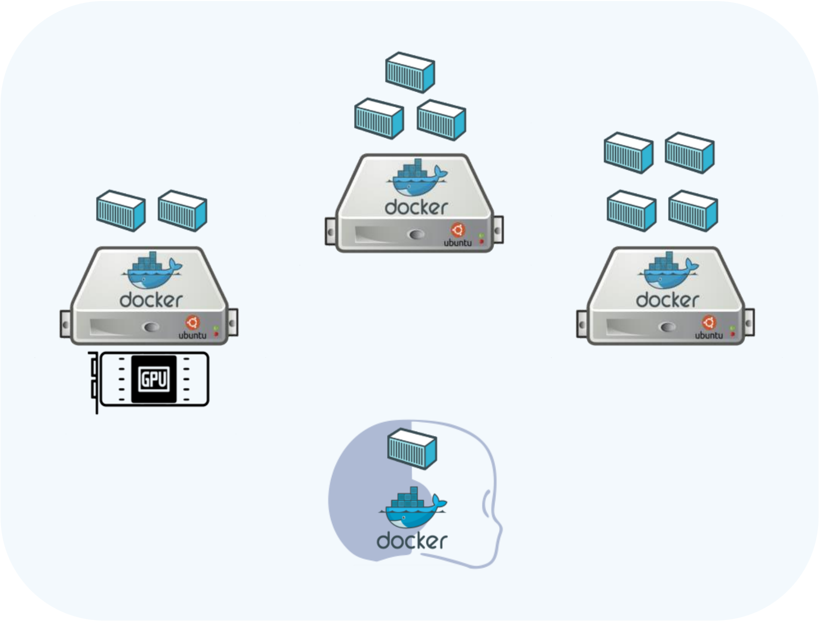
AboveYARP

Collaborative software & the robot apps

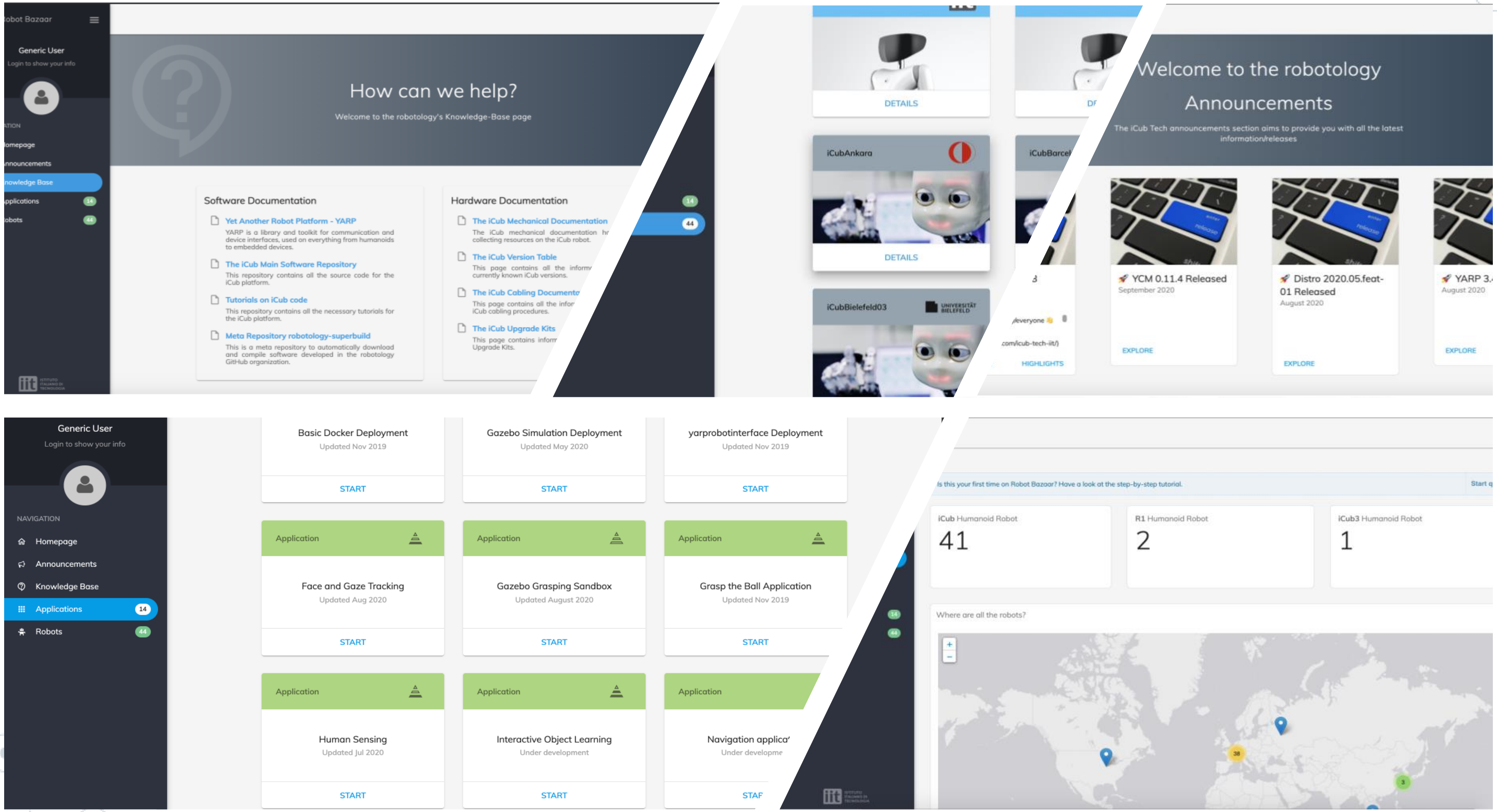
Docker

Docker Compose

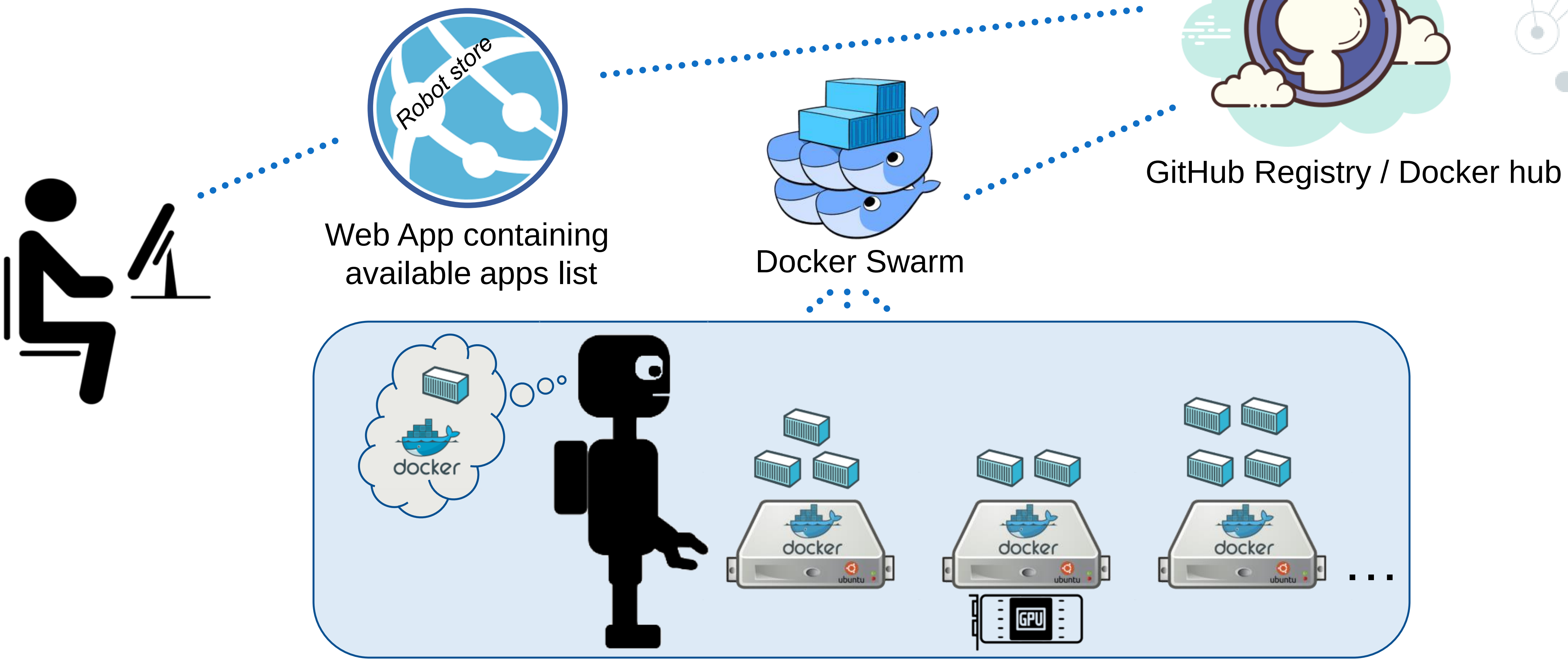
Docker Swarm

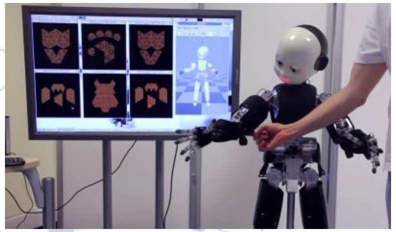


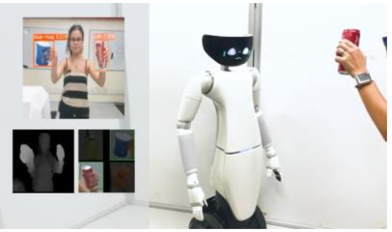
Community hub



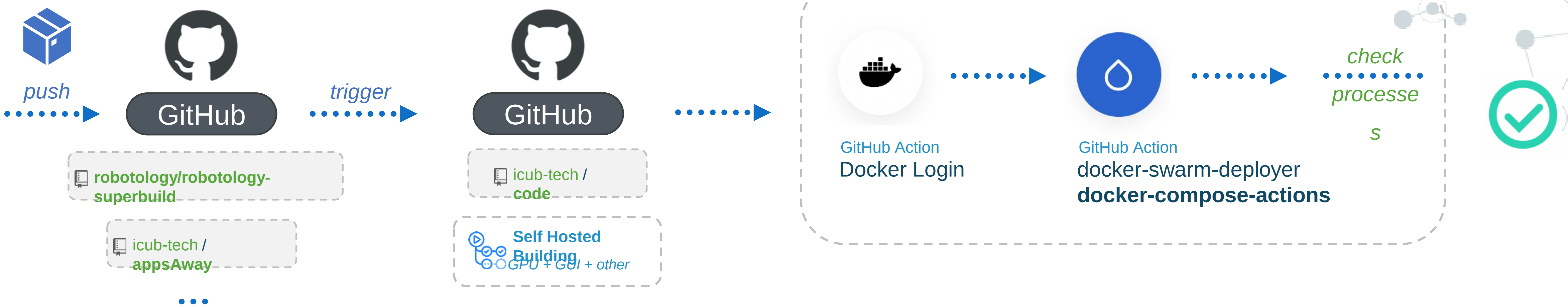
Development steps

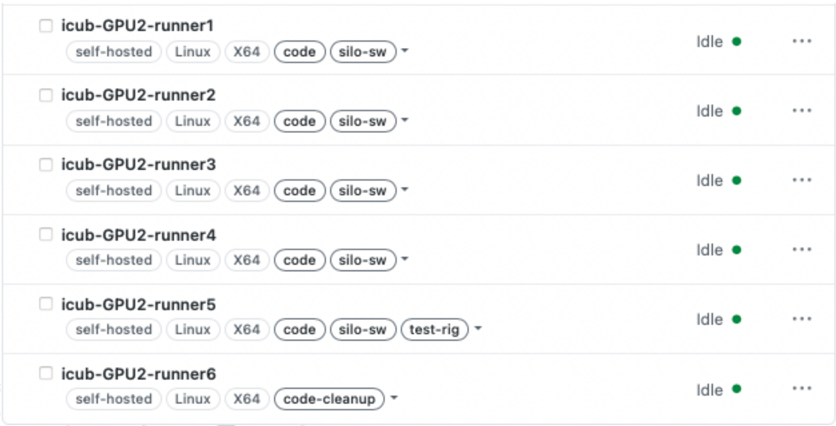


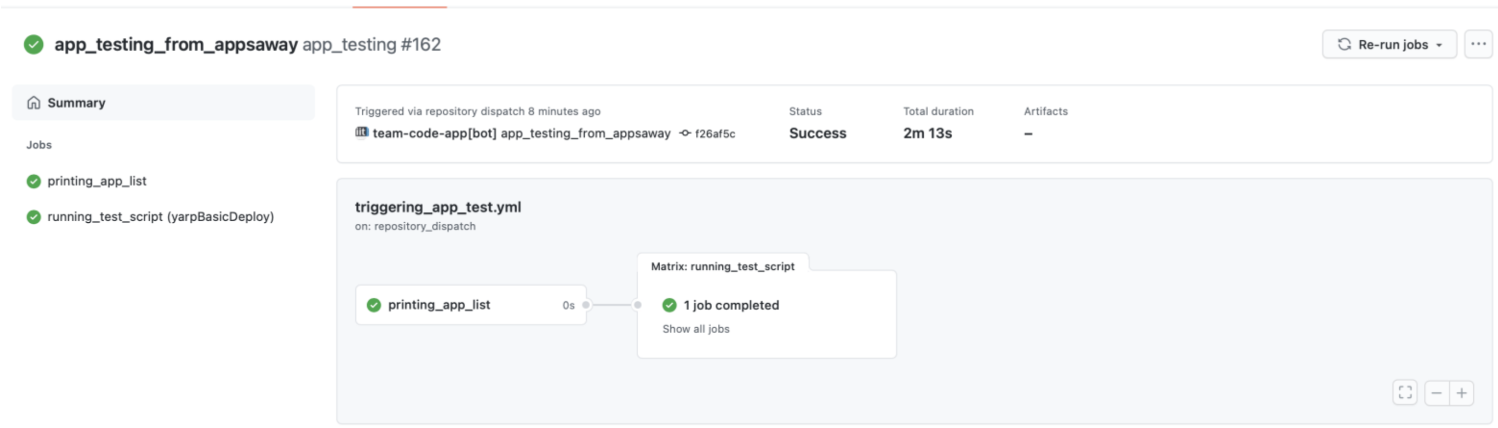




Automatic building & testing







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