ETH Zürich
Chair of Software Engineering

Robotics Programming Laboratory

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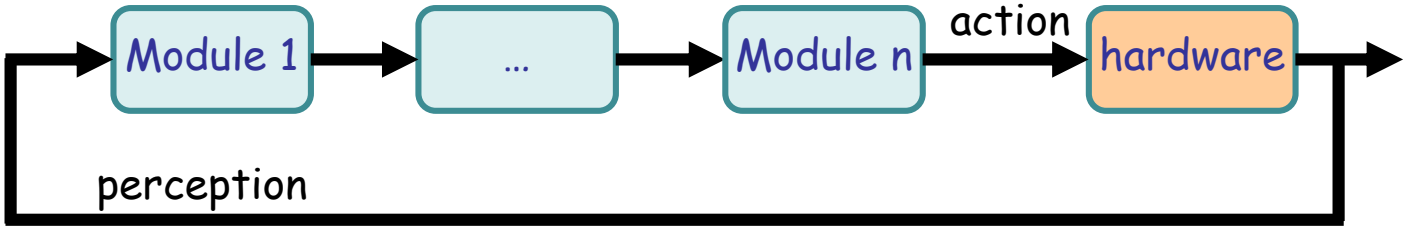
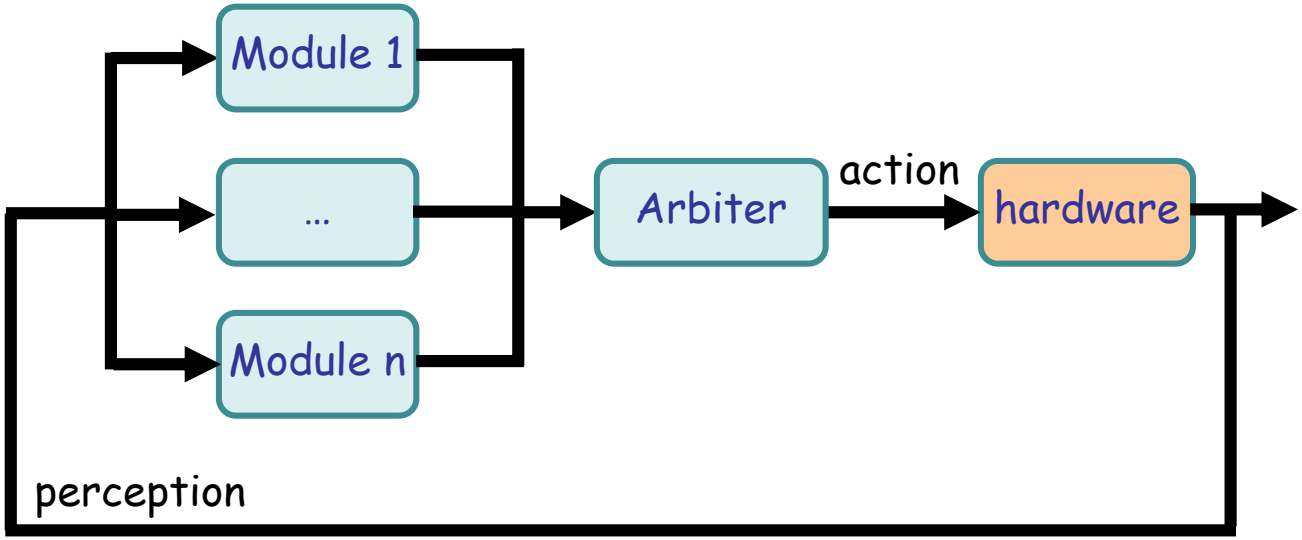
Lecture 9: Software Architecture in Robotics

Control and navigation architecture

Serial architecture



Parallel architecture



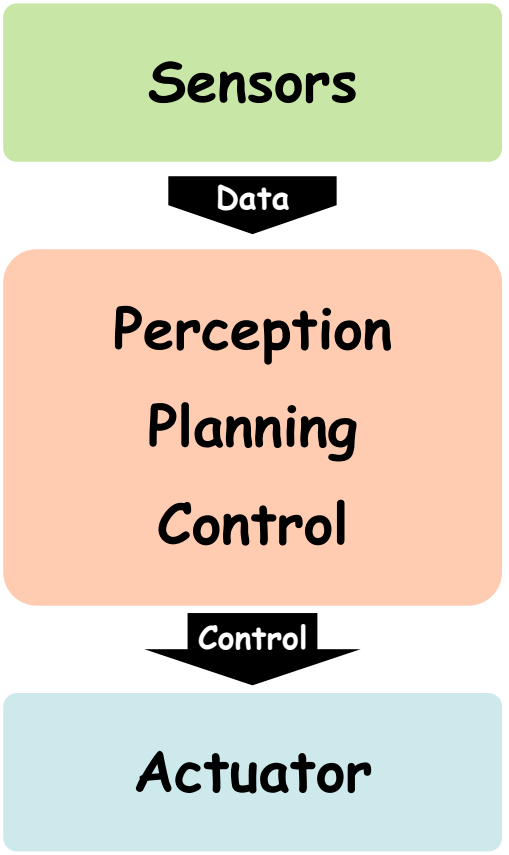
Sense-Plan-Act

Architecture

- Sense the environment.
- Plan the next move based on the goals.
- Execute the plan through the actuators.

Properties

- Easy to execute a plan
- Must generate a plan and model the world
- No feedback: insufficient to handle environmental uncertainty and unpredictability.

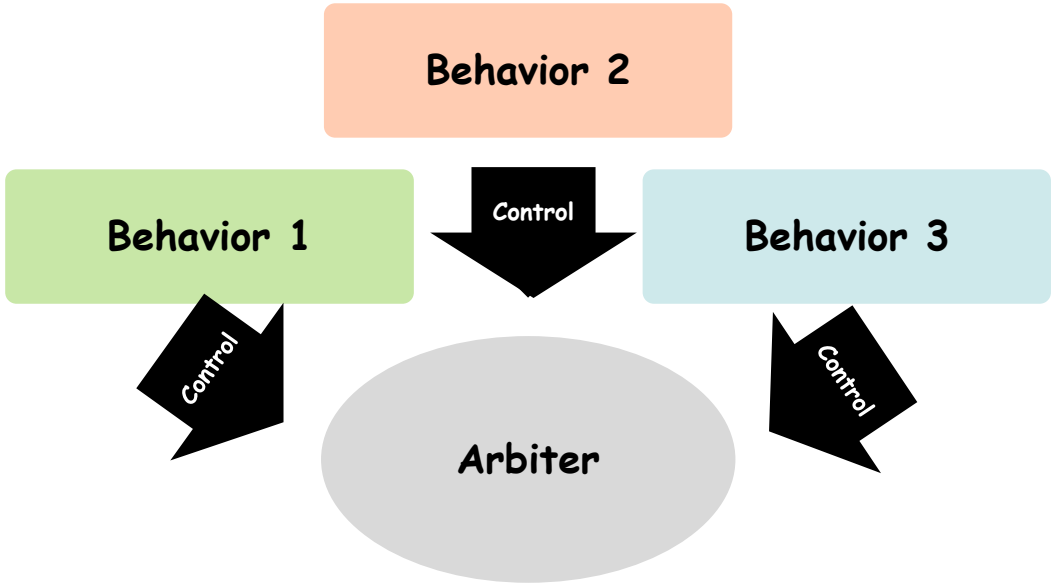


Nilsson, N. *Principles of Artificial Intelligence*. Palo Alto: Tioga. 1980.

Subsumption architecture

Architecture

- Divide the control into different behaviors, where the higher level behavior subsumes the lower level behaviors.
- Let the arbiter pick the appropriate behavior for the given condition.



Brooks, R. "A robust layered control system for a mobile robot". *IEEE Journal of Robotics and Automation*, 2 (1): 14–23. 1986.

Subsumption Architecture

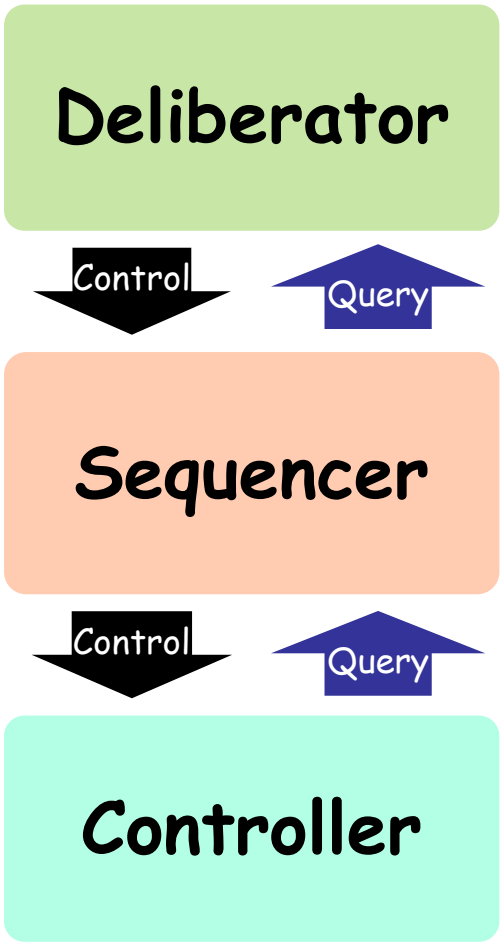
Properties

- Each layer/behavior as a small finite state machine
  - Each behavior achieves a single goal
  - No cooperation of different behaviors
  - Deduce the best next action based on the current sensor readings
- Reactive: rapidly responds to environmental changes
- No global representation nor world model
- No planning nor meta-reasoning
- Not taskable
  - Does not remember the current goals

Three-layer architecture

Architecture

- **Deliberator**: perform high-level computations
- **Sequencer**: select which primitive behavior the controller should use at a given time and supply parameters for the behavior.
- **Controller**: Perform primitive behaviors, with tight coupling of sensors to actuators



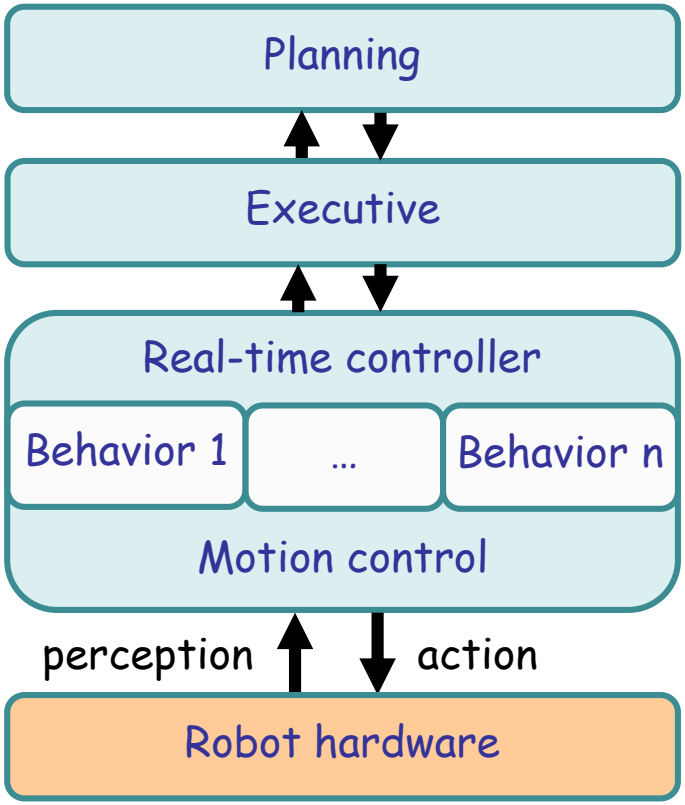
Properties

- Avoids the bottleneck problem
- Can plan and learn
- Can operate in dynamic environment

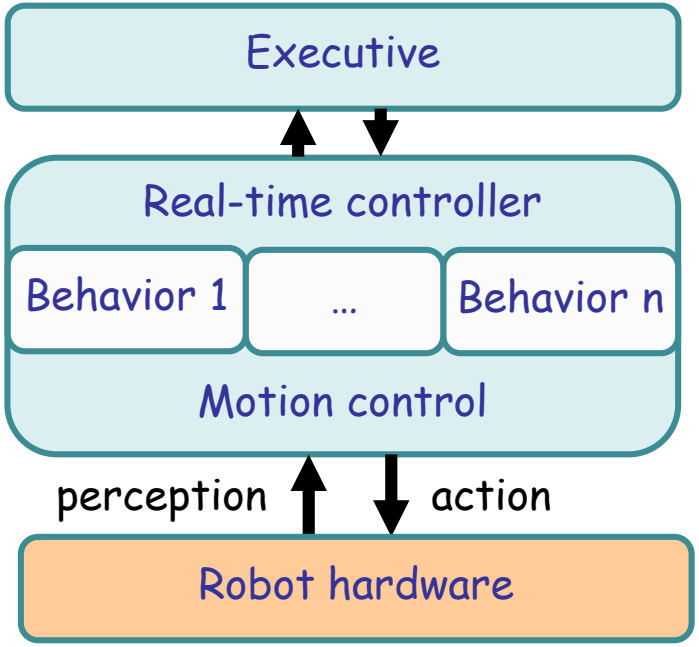
Gat, E. "On three-layer architectures". *Artificial Intelligence and Mobile Robots*. AAAI Press. 1998.

Tiered robot architecture examples

Three-tiered architecture



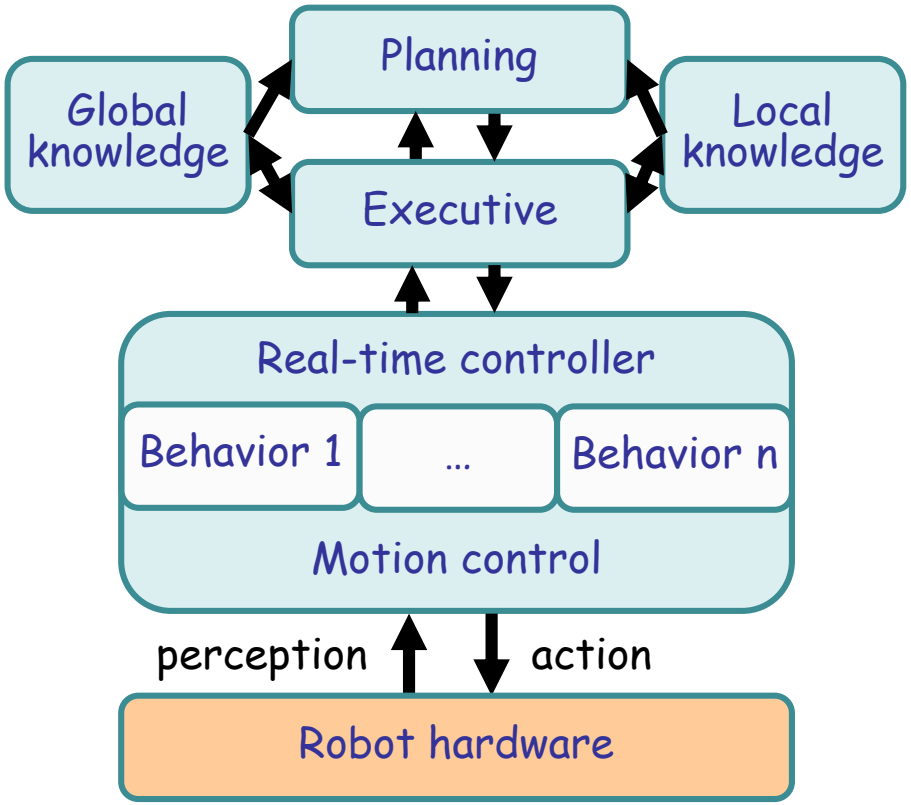
Two-tiered architecture with offline planning



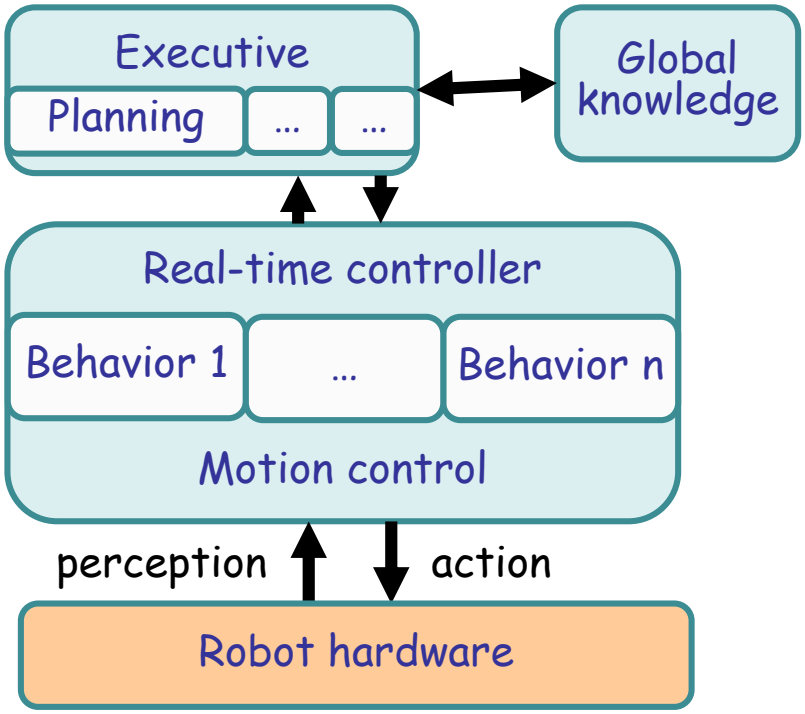
Pell, B., Bernard, D., Chien, S., Gat, E., Muscettola, N., Nayak, P., Wagner, M., Williams, B. 1998. "An Autonomous Spacecraft Agent Prototype." Autonomous Robots, No. 5, 1–27.

Tiered robot architecture examples

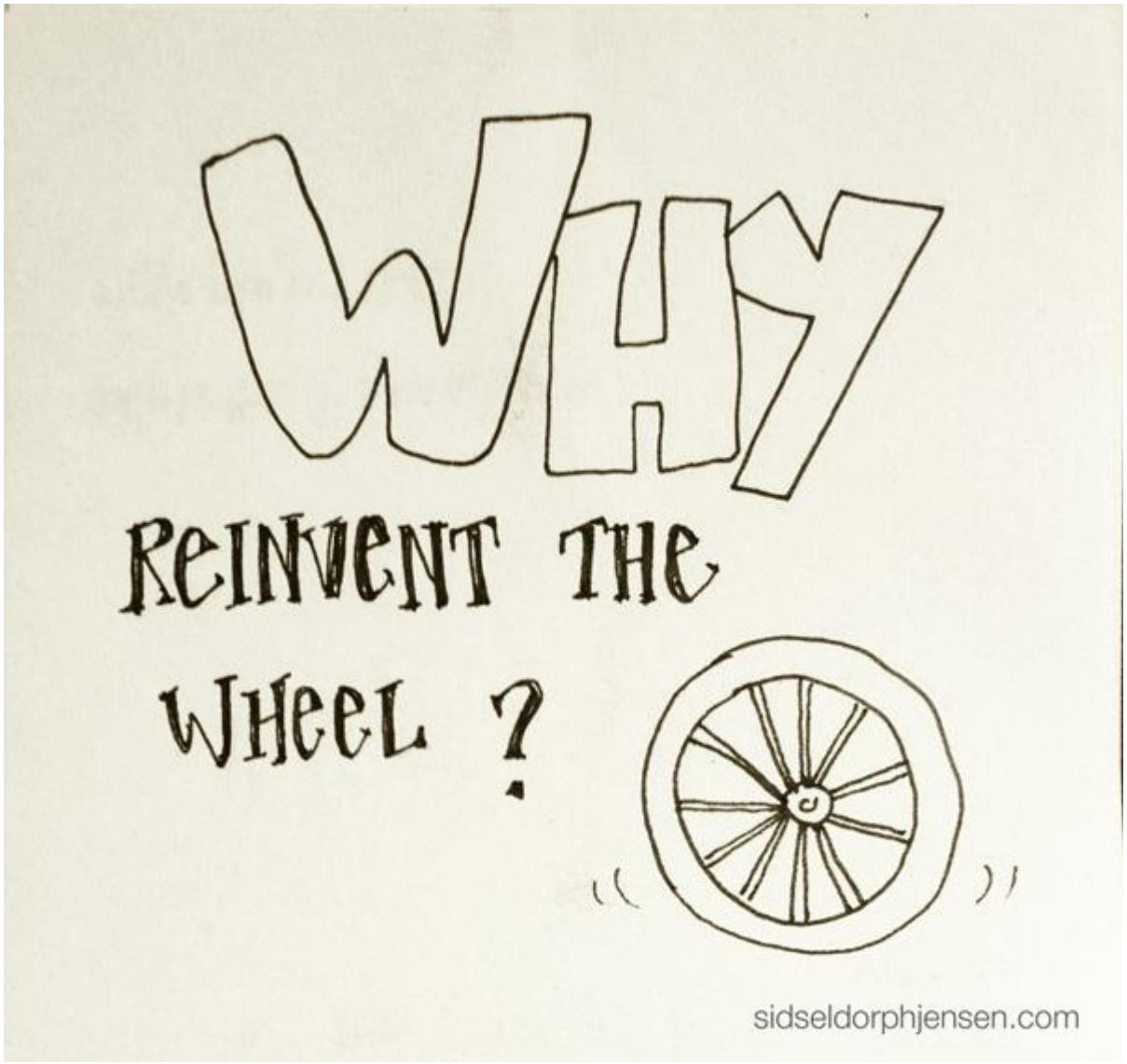
Three-tiered architecture with episodic planning



Two tiered with integrated planning



It’s all good but …

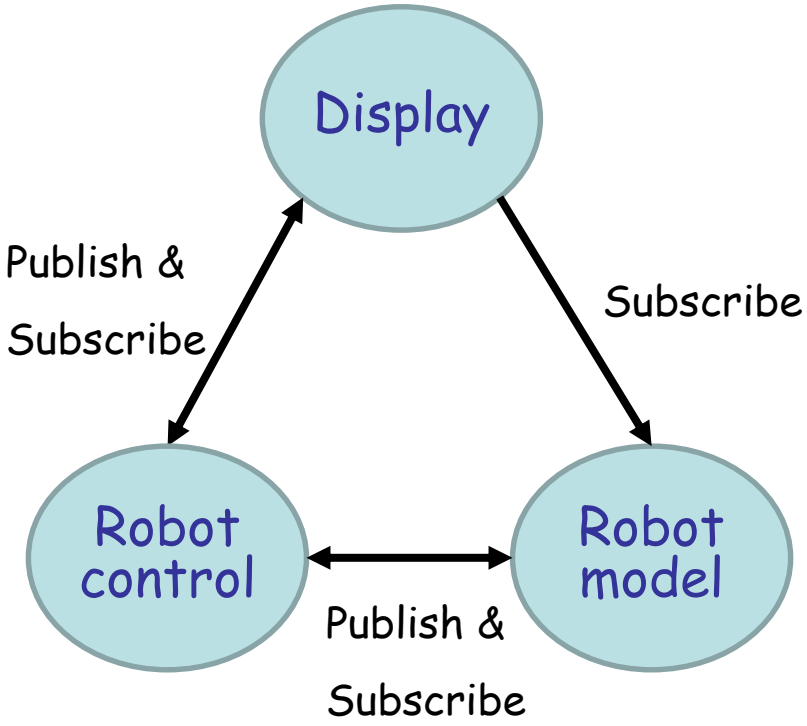


Robotics Frameworks

- Ease the development of control software for robots.
- Provide standards, principles, applications, and libraries to support common tasks.
- Exemplary frameworks
  - The Carnegie Mellon Navigation Toolkit (CARMEN)
  - Yet Another Robot Platform (YARP)
  - Universal Robotic Body Interface (URBI)
  - Mission-Orientated Operating Suite (MOOS)
  - Microsoft Robotics Development Studio
  - Robot Operating System (ROS)

Model-View-Controller (MVC)

- A central hub coordinates the communication.
- The modules read parameters and maps from a centralized model repository.
- The modules communicate over the network with a publish/subscribe pattern.
- The modules are arranged in layers.



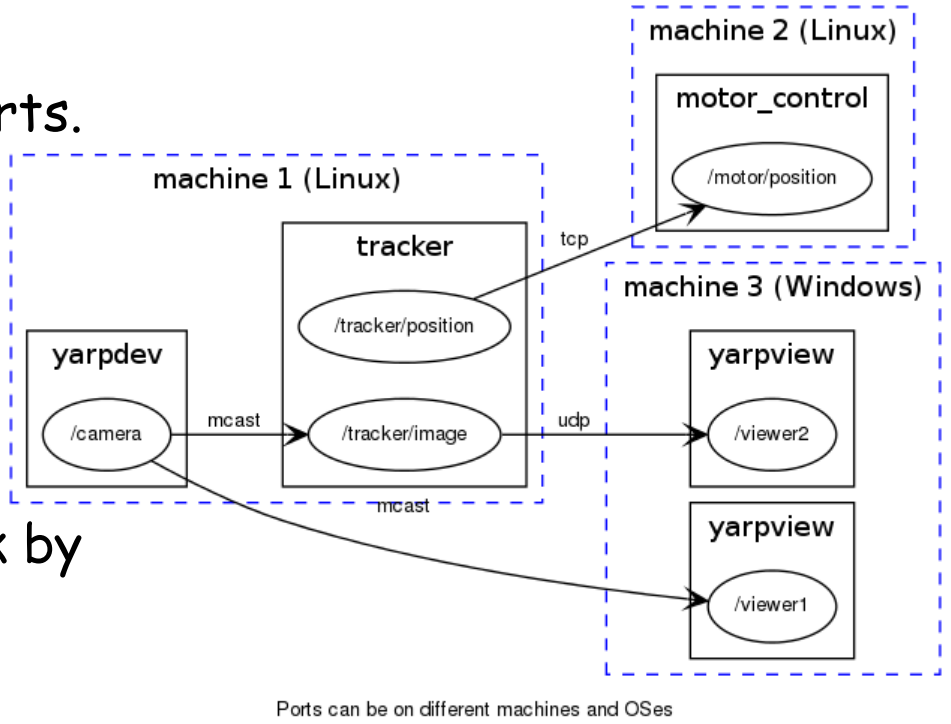
CARMEN modules

Application Layer	• High-level tasks, e.g. tour giving, interaction, etc.
Navigation Layer	• localization, planning, mapping, visual processing, logging, and simulation
Base Layer	• Hardware management and communication • Collision detection
Non-autonomous Layer	• Display modules, editors, etc.

YARP

Observer pattern

- Special port objects deliver messages to other observers/ports.
- Every connection can take place using a different protocol.
- Every port belongs to a process.
- Ports are located on the network by symbolic names.
- A name server maps the names into the IP address, port number, and interface name.



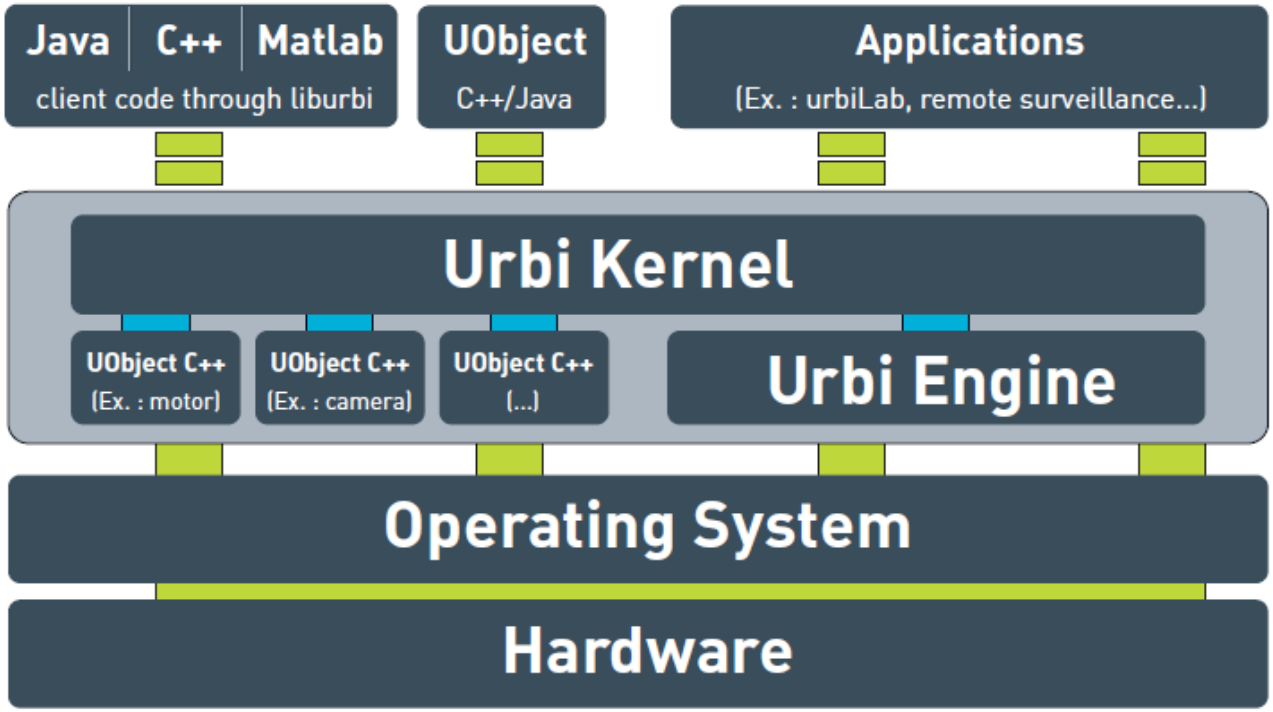
YARP components

libYARP_OS	• Interface with operating system(s) • Data streaming across many threads across many machines
libYARP_sig	• Signal processing tasks (visual, auditory) • Easy interface with commonly used libraries
libYARP_dev	• Interface with common devices used in robotics: framegrabbers, digital cameras, motor control boards, etc.

URBI

Client-server architecture

- Several clients can interact with the server simultaneously.
- Remote objects can also connect to the server.



URBI components

UObject

- C++ component library that comes with a robot standard API to describe motors, sensors and algorithms.

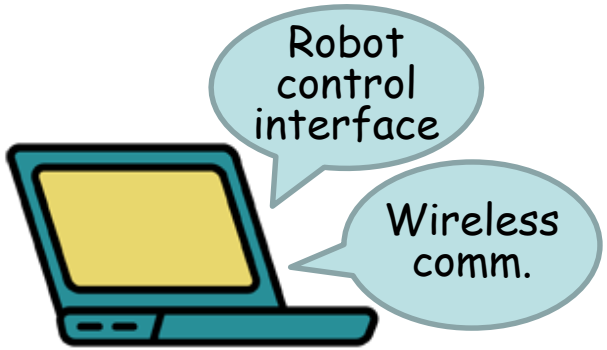
UrbiScript

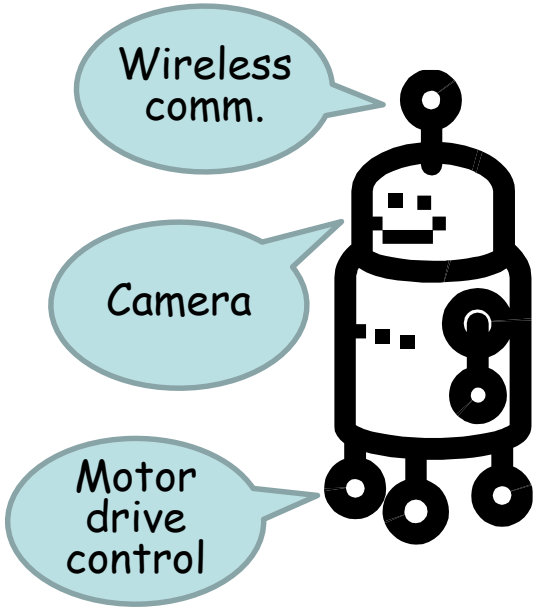
- Orchestration scripting language
- Runs on top of Urbi Virtual Machine
- Glues components together and describes high level behaviors
- Supports parallel and event-driven programming

Microsoft Robotics Development Studio

Representational State Transfer (REST) pattern

- A program interacts with a robot through multiple software services.
- A distributed messaging system enables services to communicate on the same computer over the network.
- A configuration manifest file defines the interaction of services in a particular control system.





MRDS core features

Coordination and Concurrency Runtime (CCR)

- Handles state updates and message processing

Decentralized Software Services Protocol (DSSP)

- Launches services from its manifest descriptions
- Provides for partnering
- Facilitates communications between message ports on individual services

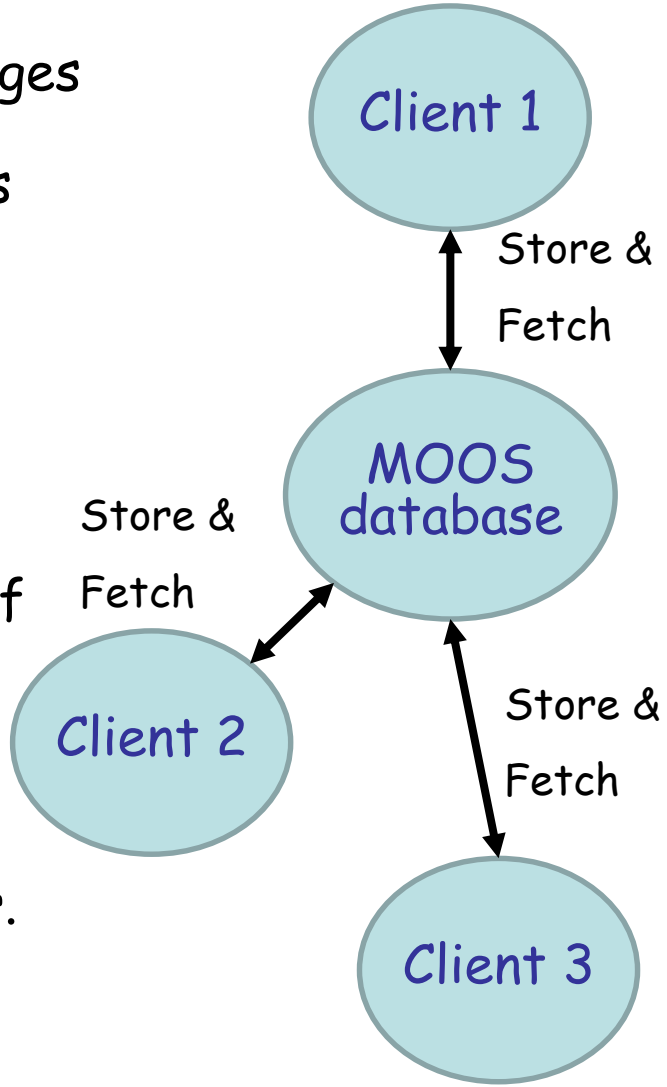
Generic contracts for common elements of a robotic system

- New services can specify to which contracts it conforms
- A discovery service lists all currently running services that conform to a certain contract.

MOOS

A star topology with layered architecture

- A central server with a database of messages
- Each client bundles its messages and sends them to the server.
- All communication between the client and the server is instigated by the client.
  - A client subscribes for messages of the right type.
  - The client picks up the messages whenever it connects to the server.
- No peer-to-peer communication.



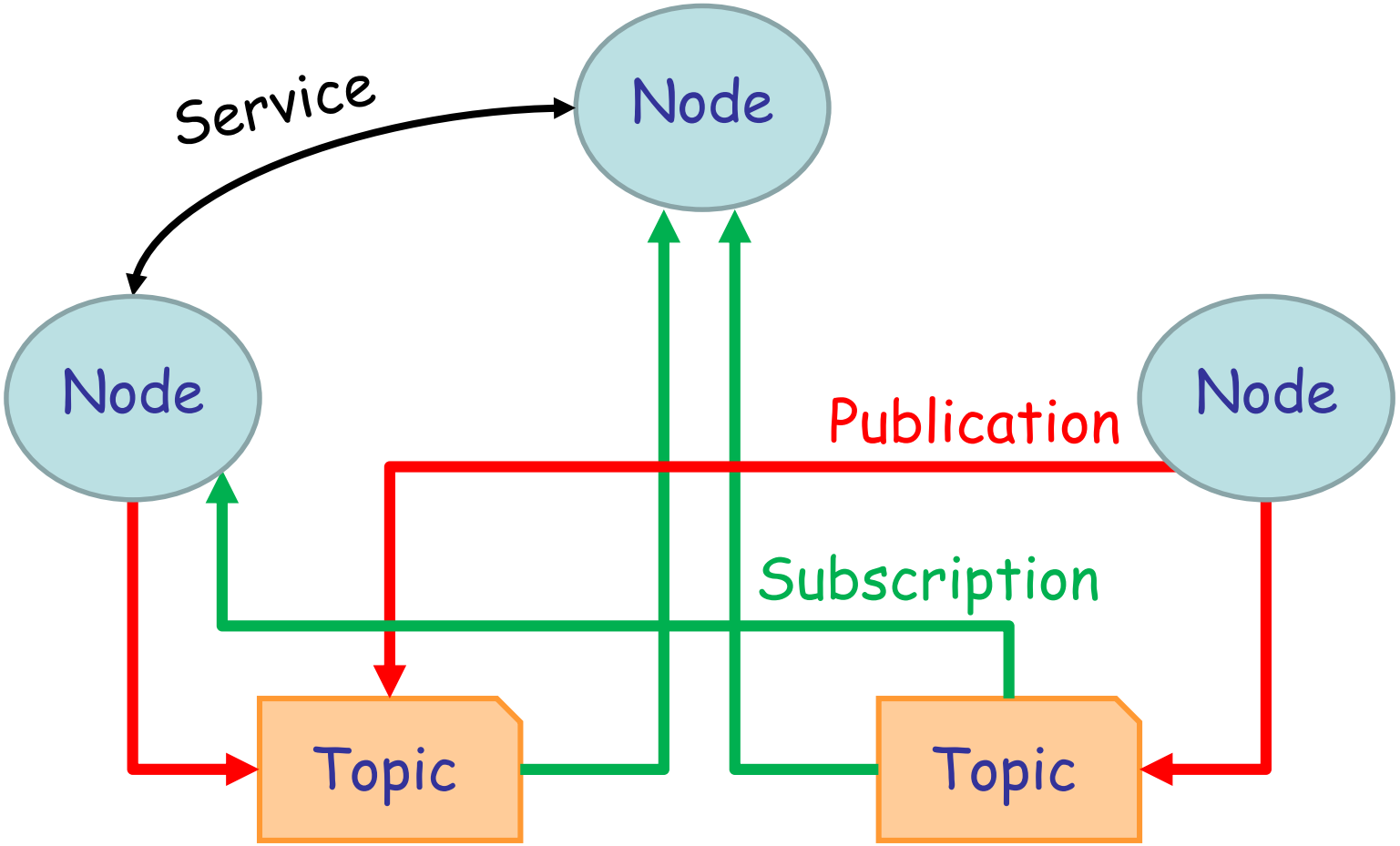
MOOS client

Application Layer	• Applications
Essentials Layer	• Commonly used functionality such as control and logging
Communication Layer	• connects clients (e.g. sensors, actuators, processes, etc.) through a network with a star topology

ROS

Peer-to-peer network architecture

- A central naming service to allow nodes to find other nodes
- Publish-subscribe model for asynchronous transactions
  - A node can publish and subscribe to topics.
  - Many nodes can publish and subscribe to a single topic.
- Service for synchronous transactions
  - Only one node can advertise a service.
  - A response follows a request.


Service
Node
Node
Node
Publication
Subscription
Topic
Topic