IA712: Mobile Robotics

Lecture 2: Software for Robotics

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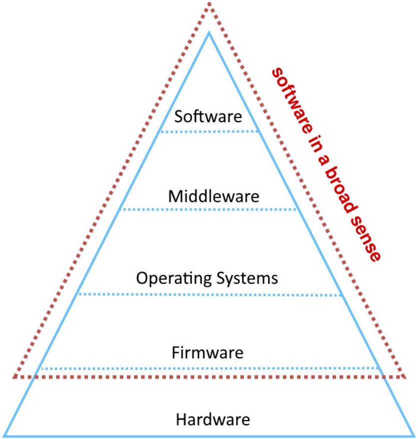
Context: Computer

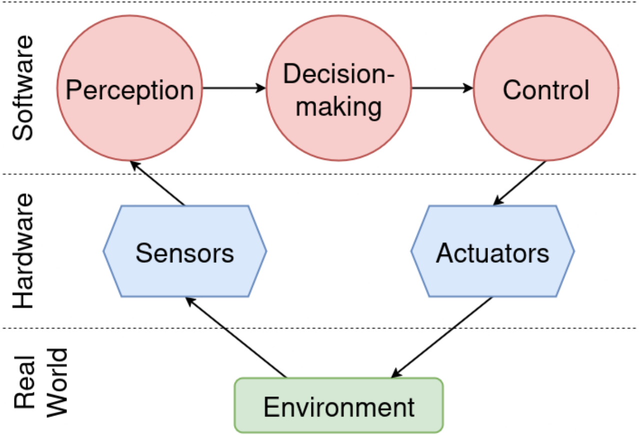
- A **computer system** (or computing device) includes: hardware, firmware, operating system (the “main software”), middleware and software.



Context: Computer

- **Hardware**: CPU, RAM, motherboard, etc.
- **Firmware (stored in ROM)**: BIOS, OpenCR firmware, etc.
- **Operating System (OS)**: Microsoft Windows, macOS, Linux, etc.
- **Middleware**: Tomcat, ROS, ROS 2, etc.
  $\Longrightarrow$ Bridging the gap between an OS or database and applications.
- **Software**: Minecraft, Photoshop, Firefox, etc.

A Robot


Software
Perception
Decision-making
Control
Hardware
Sensors
Actuators
Real World
Environment

A Robot

A complex system with many concurrent processes:

- Reading from multiple sensors (camera, LiDAR, IMU).
- Controlling multiple actuators (wheels, arms).
- Running algorithms for localization, perception, and planning.
- Communicating status to a user.

Why ROS?

Challenges:

- How do we manage this complexity?
- How do we make all these components talk to each other reliably and efficiently?
- How to maximize the reusability of developed software (e.g., from robot A to robot B) ?

Solution:

- A **middleware** like ROS[1] (Robot Operating System) and ROS 2 provides a **abstraction layer** that decouples software components, allowing them to be developed, tested, and run independently.

  $\Longrightarrow$ Since 2010, ROS has become the *de facto* standard for robotics software.

[1] https://www.ros.org/

ROS & ROS 2

What is ROS & ROS 2:

- A distributed architecture for inter-process and inter-machine communication and configuration.
- A collection of software packages and building tools.
- A set of development tools for system execution and data analysis.

What is ROS & ROS 2 not:

- A OS
- A programming language
- A programming environment (e.g., Visual Studio Code)

ROS

- Active years: 2007 - 2025 (**end-of-life on May 31st, 2025**).
- Software organization: (high) modularity.
- Communication between programs: XML-RPC (for “Master”) and TCP/UDP (for “Topic”) sockets.
- Underlying OS: Mainly Linux, limited support for other OS.
- Programming language: Mainly written in C++ and Python.
- Code hosting: GitHub.
- License: 3-clause BSD License (for core of ROS).

ROS

- Supported robot platforms: TurtleBot, HSR, BARAKUDA, and many more.
- Supported sensors: Camera, LiDAR, IMU, and many more.
- Main components:
  - Communication infrastructure (master, publisher, subscriber, etc.).
  - Robot specific features (*_msg, tf, urdf, actionlib, amcl, gmapping, navigation, etc.).
  - Tools (command-line tools, rviz, rqt, etc.).
- Powerful support (integration with other libraries):
  - Gazebo
  - OpenCV
  - PCL
  - MoveIt!
  - etc.

ROS 2

- Active years: 2014 - present.
- Release cycle: once a year.
- Does not break ROS, nor does it rollout into ROS.
- Breaking API with ROS, but conceptually very similar.
- Building on DDS (Data Distribution Service) for real-time systems.

Why Move to ROS 2?

- Modern API, minimal dependencies, and better portability (e.g., small embedded platforms).
- Benefits of underlying DDS middleware:
  - **Master-less** discovery (i.e. decentralized computation graph)
  - **Hard real-time** capable
  - Reliability
  - Efficiency (UDP Multicast, shared memory, TLS over TCP/IP, etc.)
- Easier to work with multiple nodes in one process.
- Lifecycle management and verifiable systems.
- etc.

The ROS 2 Computation Graph

Go after the ball!

The ROS 2 Computation Graph

A ROS 2 system is a network of independent programs called **nodes**.

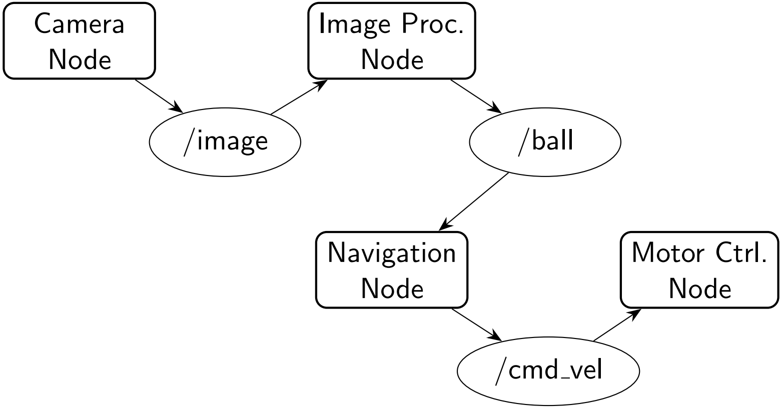


Figure: A simplified representation of a ROS 2 system.

The ROS 2 Computation Graph

- **Nodes:** Executable programs performing a specific task (e.g., controlling a camera, planning a path).
- **Communication:** Nodes communicate via mechanisms like “topics”, “services”, and “actions”.

Topics: Asynchronous Streaming Data

Publish / Subscribe model:

Topics are used for continuous data streams. One node **publishes** data to a topic, and any number of nodes can **subscribe** to that topic to receive the data.

- **Decoupled:** The publisher doesn't know or care who is subscribed.
- **Many-to-Many:** Many nodes can publish to the same topic, and many can subscribe.
- **Asynchronous:** "Fire and forget." The publisher does not wait for a response.

Examples:

- Images from a camera (`/image`)
- Motor commands (`/cmd_vel`)

Topics: Asynchronous Streaming Data

`Topic-MultiplePublisherandMultipleSubscriber.gif`

Services: Synchronous Request / Reply

Client / Server model:

Services are used for remote procedure calls. A **client** node sends a request, and a **server** node performs a task and sends back a response.

- **Coupled:** The client and server are directly connected for the transaction.
- **One-to-One:** A single server handles requests from one or more clients.
- **Synchronous:** The client sends a request and **waits** until it receives a response from the server.

Examples:

- Resetting a simulation (`/reset`).
- Pawning a new robot in a simulator (`/spawn`).

Services: Synchronous Request / Reply

`Service-MultipleServiceClient.gif`

Actions: Asynchronous Long-Running Tasks

Client / Server model with feedback:

Actions are for long-running, goal-oriented tasks that can be preempted. A client sends a goal to an action server. The server executes the task, provides periodic **feedback**, and sends a final **result**.

- **Asynchronous:** The client does not block while the goal is being executed.
- **Preemptible:** The client can cancel the goal at any time.
- **Provides Feedback:** The client is kept informed of the task's progress.

Examples:

- "Navigate to coordinate (x, y)." The feedback could be the robot's current distance to the goal, and the result indicates success or failure.

Actions: Asynchronous Long-Running Tasks

`Action-SingleActionClient.gif`

Messages, Services, and Actions

How is data structured?

- **Messages (`.msg`):** Define the data structure for topics. For example, a simple `Twist.msg` for velocity might contain linear and angular components.
- **Services (`.srv`):** Define the request and response data structures, separated by `---`.
- **Actions (`.action`):** Define the goal, result, and feedback data structures, each separated by `---`.

Good-to-know:

These files (`.msg`, `.srv`, `.action`) are interface definitions, following the **Interface Definition Language (IDL)** format.

Essential Command-Line Tools

The `ros2` command is your main entry point for interacting with a running ROS 2 system.

Introspection Tools

- `ros2 node list`: See all running nodes.
- `ros2 topic list`: See all active topics.
- `ros2 service list`: See all available services.
- `ros2 action list`: See all available actions.
- `ros2 topic echo <topic_name>`: View data being published on a topic.
- `ros2 node info <node_name>`: See a node's publishers, subscribers, etc.

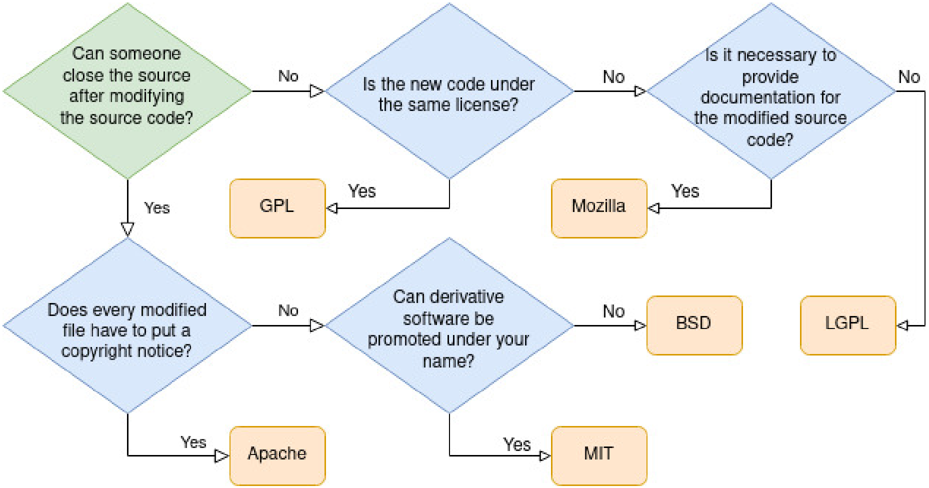
Essential Command-Line Tools

Execution Tools

- `ros2 run <package_name> <executable_name>`: Launch a single node.
- `ros2 launch <package_name> <launch_file>`: Launch a group of nodes and their configurations.

We will use these extensively in the practical work session.

How to Choose a Free Software License


Can someone close the source after modifying the source code?
No
Is the new code under the same license?
No
Is it necessary to provide documentation for the modified source code?
No
GPL
Yes
Mozilla
Yes
Yes
Does every modified file have to put a copyright notice?
No
Can derivative software be promoted under your name?
No
BSD
LGPL
Yes
Apache
Yes
MIT

Questions?

Next: Practical Work 2 - ROS 2 Beginner Level