ROBOTIC MIDDLEWARES

ROBOTICS

POLITECNICO
MILANO 1863

MIDDLEWARE ORIGINS

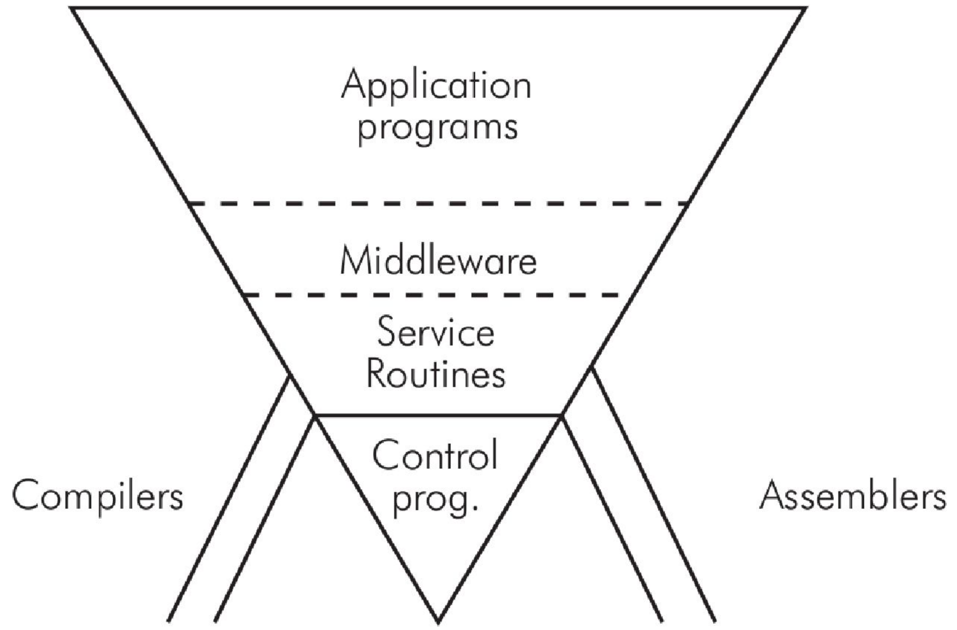
The origins

1968 introduced by d'Agapeyeff

80's wrapper between legacy systems and new applications

Nowadays: widespread in different domain fields (including Robotics)

Some (non robotics) examples: Android, SOAP, Web Services, ...



MIDDLEWARE ORIGINS

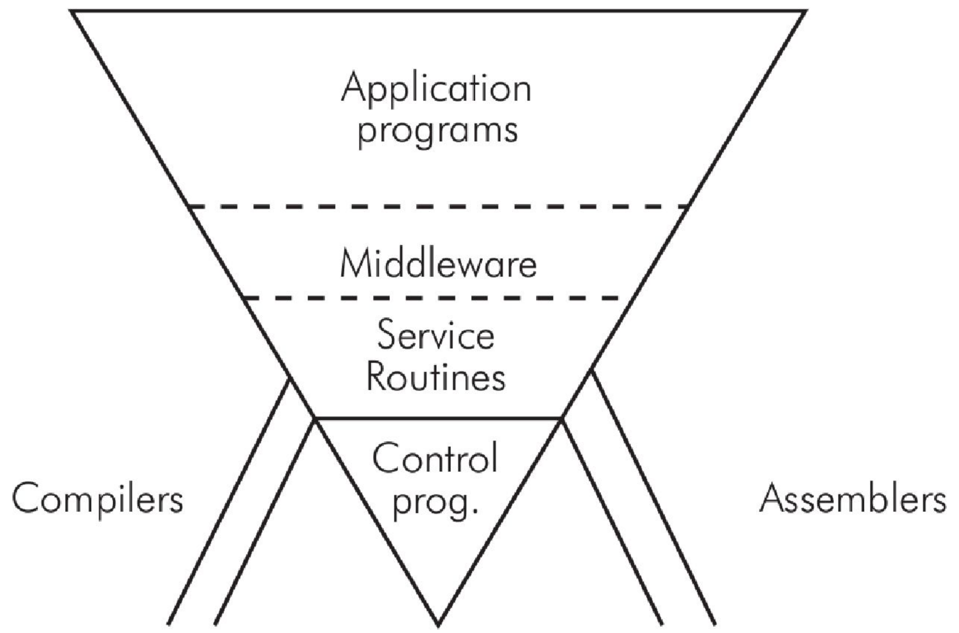
The Middleware idea

Well-known in software engineering

It provides a computational layer

A bridge between the application and the low-level details

It is not a set of API and library



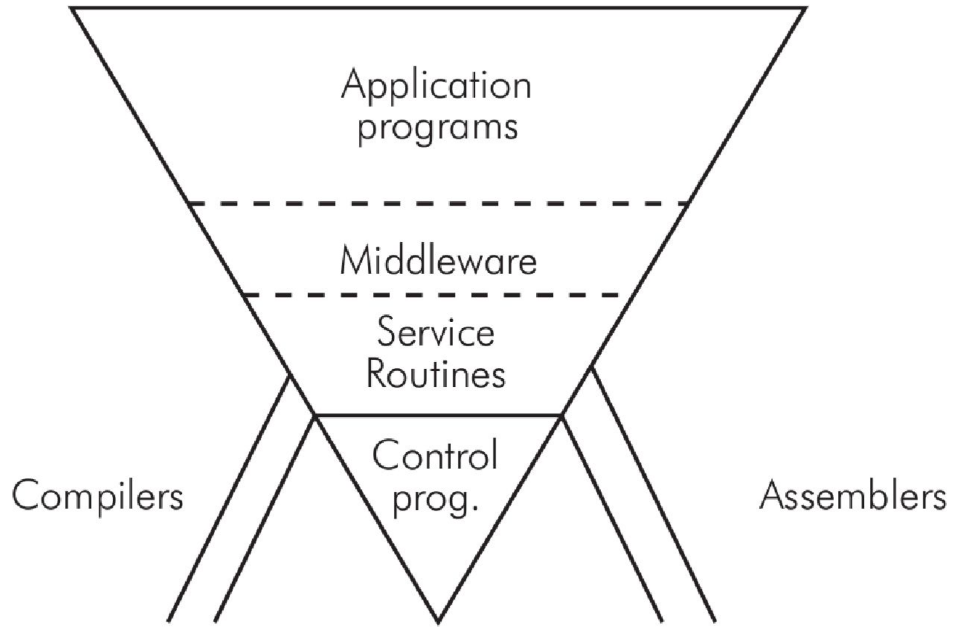
MIDDLEWARE ORIGINS

Issues in developing real robots

Cooperation between hardware and software

Architectural differences in robotics systems

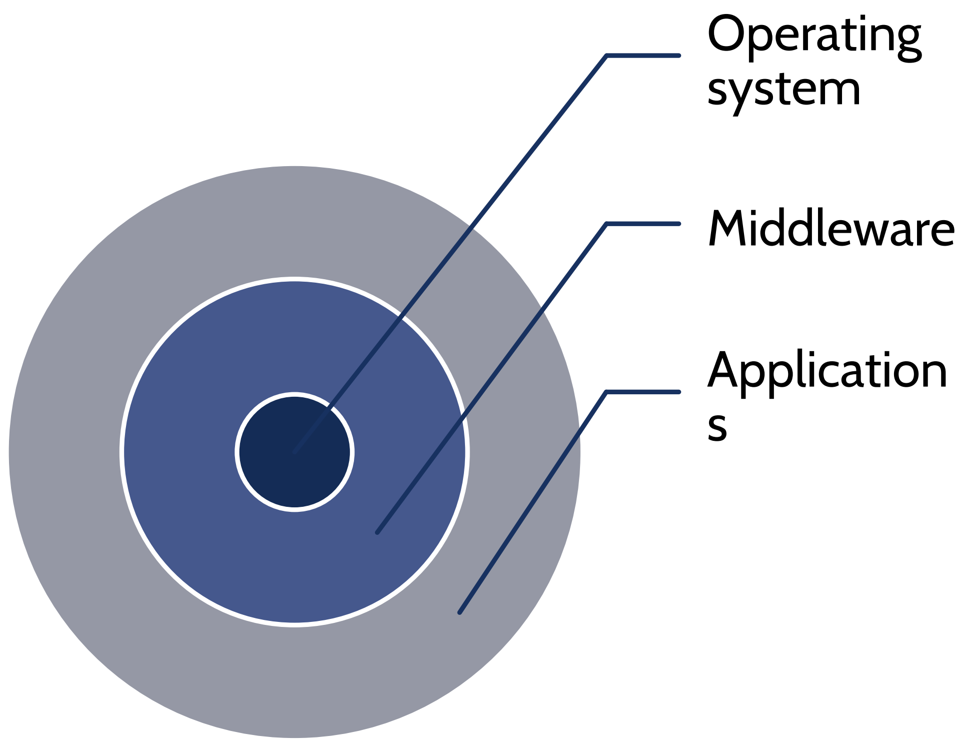
Software reusability and modularity



WHAT IS A MIDDLEWARE?

*Software that **connects** different software components or applications:*

- Set of services that permits to several processes to interact
- Framework used to reduce the developing time in complex systems.



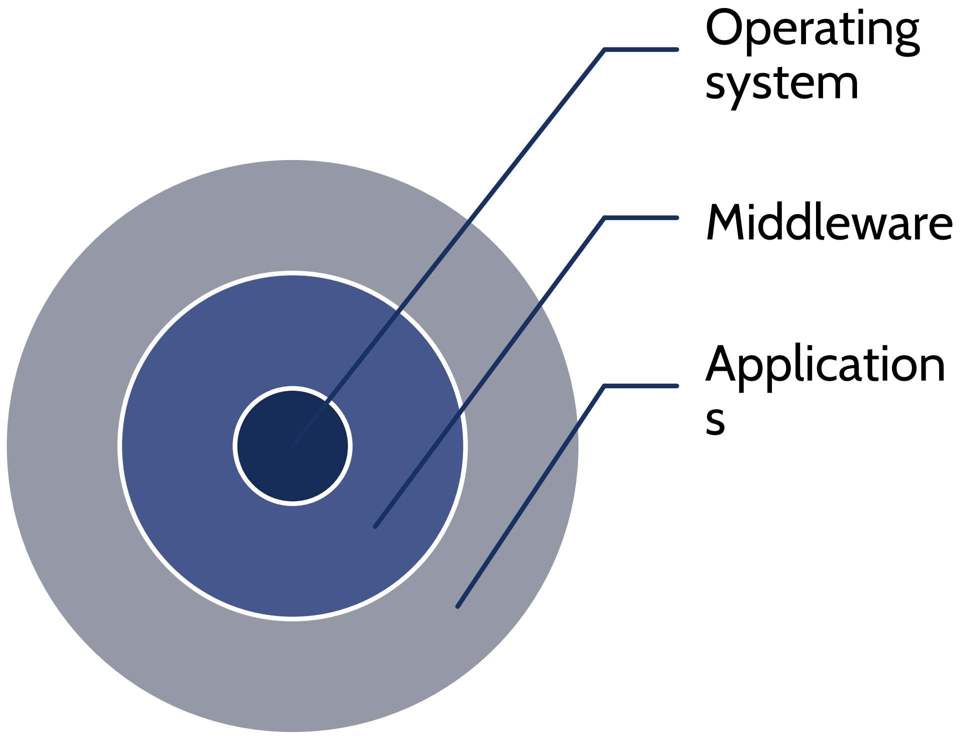
WHAT IS A MIDDLEWARE?

Middleware vs. Operating System

The middleware stays between software and different operating systems.

The distinction between operating system and middleware is sometimes arbitrary.

Some features of a middleware are now integrated in operating systems (e.g., TCP/IP stack).



MIDDLEWARES MAIN FEATURES

Portability*:* provides a common programming model regardless the programming language and the system architecture.

Reliability: middleware are tested independently. They permit to develop robot controllers without considering the low level details and using robust libraries.

Manage the complexity: low-level aspects are handled by libraries and drivers inside the middleware. It (should) reduce(s) the programming error and decrease the development time.

ROBOT MIDDLEWARES: A LIST

Several middleware have been developed in recent years:

OROCOS	[Europe]
ORCA	[Europe]
YARP	[Europe / Italy]
BRICS	[Europe]
OpenRTM	[Japan]
OpenRave	[US]
ROS	[US]
…	

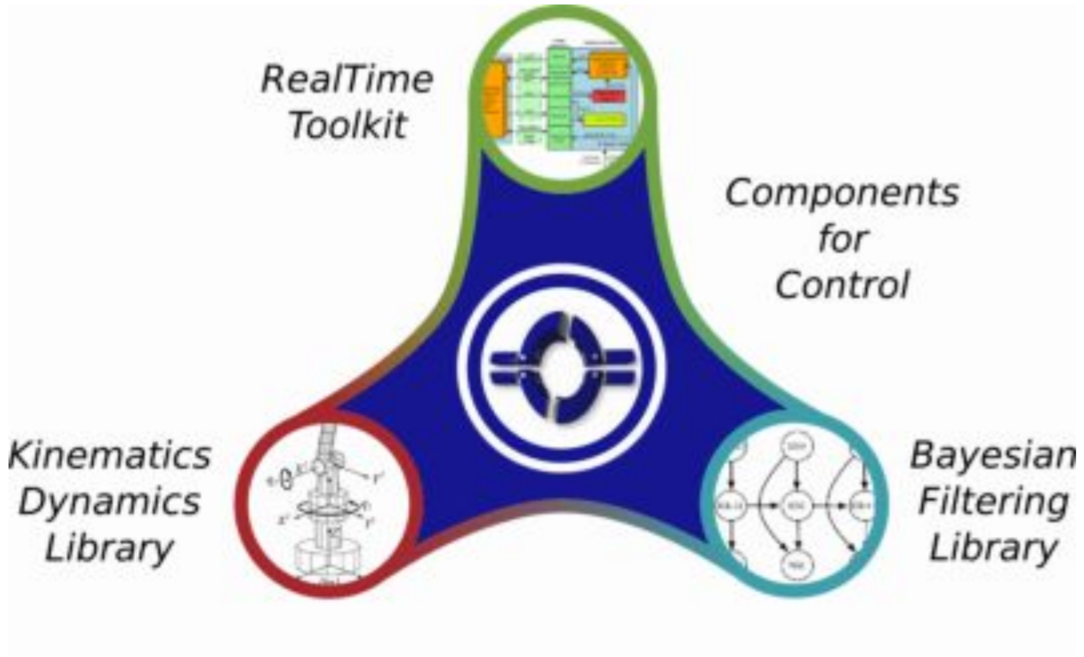
Let’s see their common features and main differences

OROCOS: OPEN ROBOT CONTROL SOFTWARE

The project started in December 2000 from an initiative of the mailing list EURON then it become an European project with 3 partners: K.U. Leuven (Belgium), LAAS Toulouse (France), KTH Stockholm (Sweden)

OROCOS requirements:

- Open source license
- Modularity and flexibility
- Not related to robot industries
- Working with any kind of device
- Software components for kinematics, dynamics, planning, sensors, controller
- Not related to a unique programming language



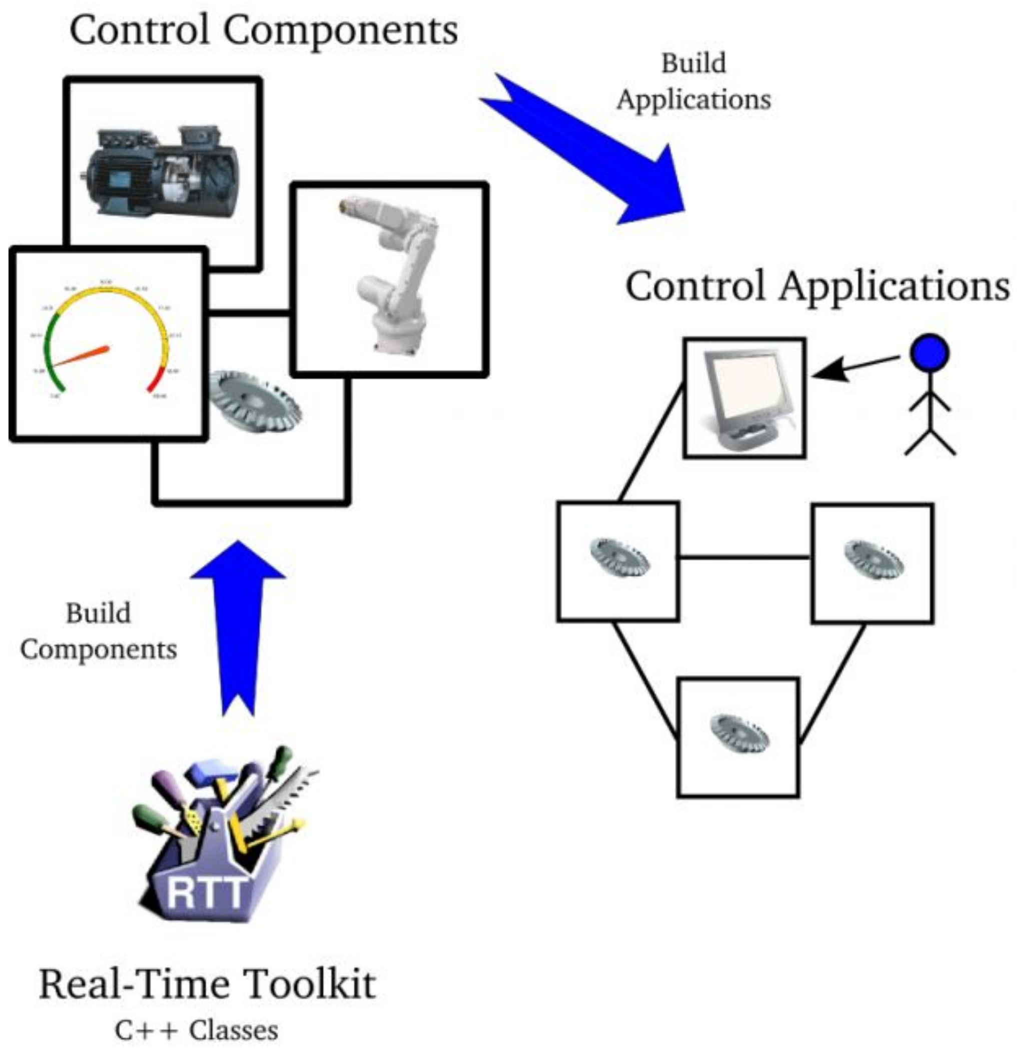
OROCOS STRUCTURE

Real-Time Toolkit (RTT)

- infrastructure and functionalities for real-time robot systems
- component-based applications

Component Library (OCL)

- provides ready-to-use components, e.g., device drivers, debugging tools, path planners, task planners



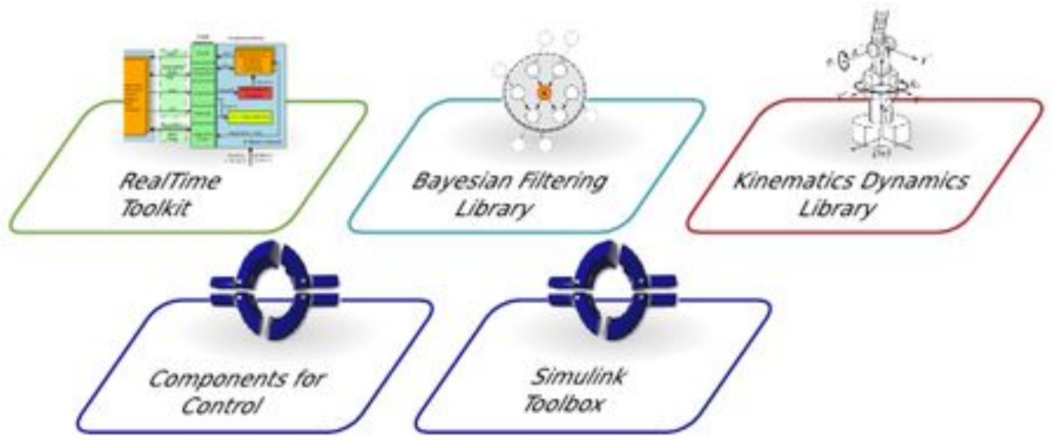
OROCOS STRUCTURE

Bayesian Filtering Library (BFL)

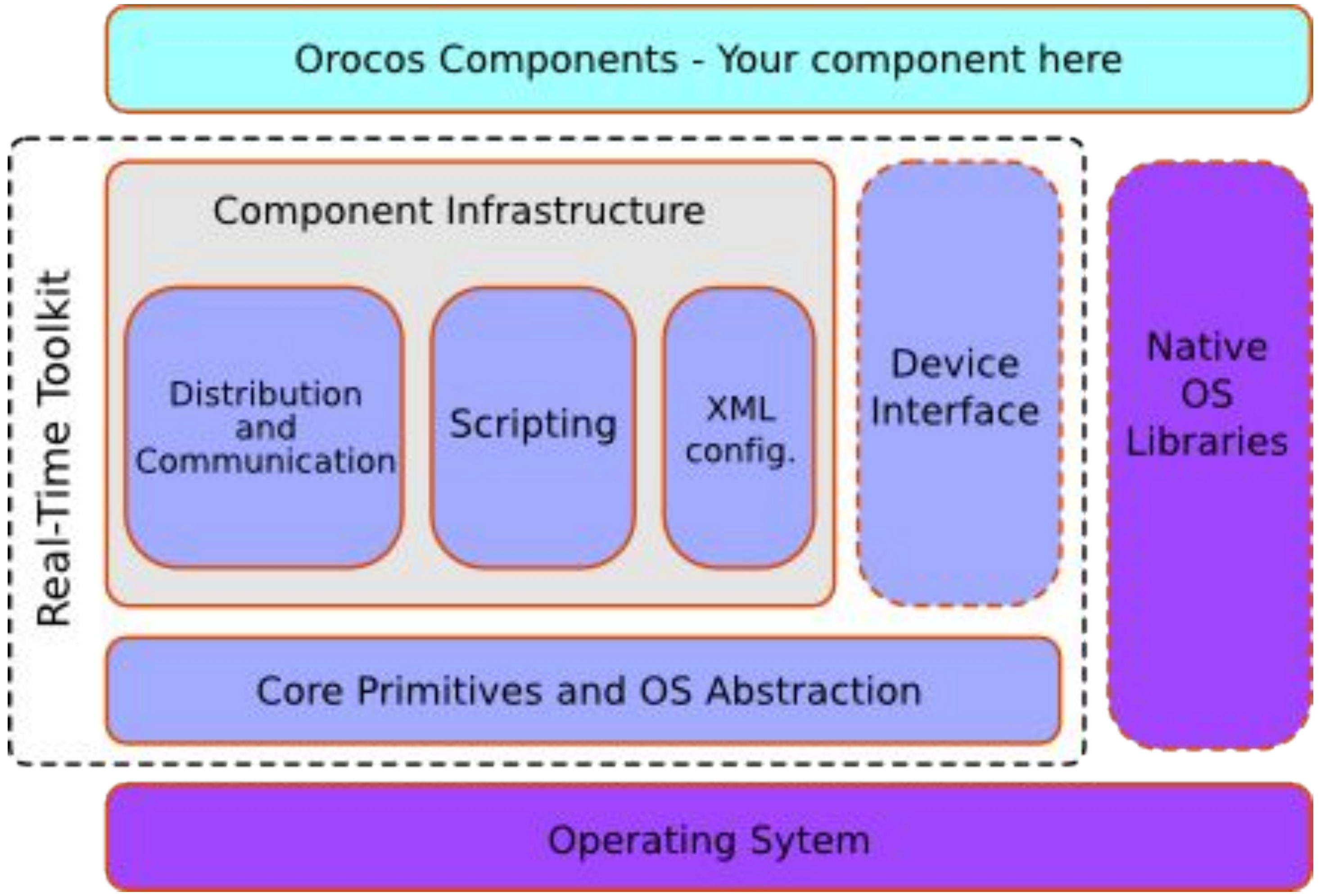
- application independent framework, e.g., (Extended) Kalman Filter, Particle Filter

Kinematics & Dynamics Library (KDL)

- real-time kinematics & dynamics computations



OROCOS RTT FRAMEWORK



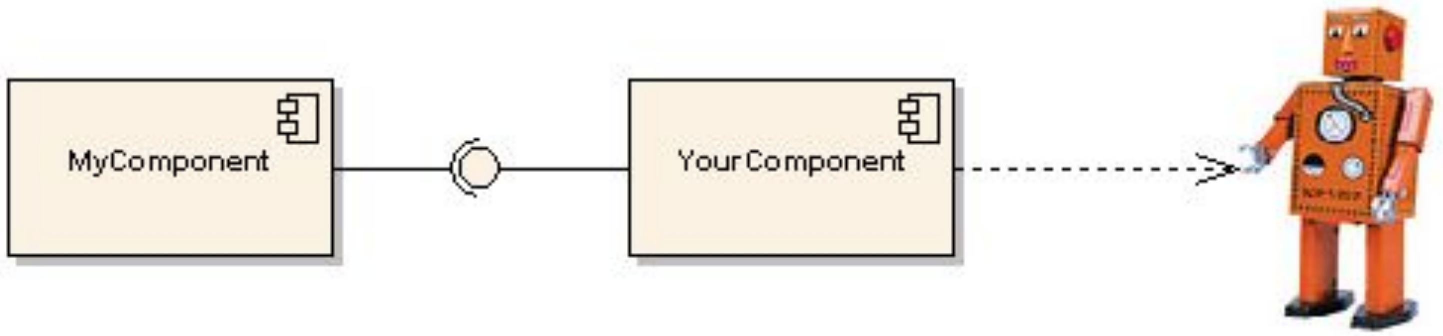
ORCA: COMPONENTS FOR ROBOTICS

The aim of the project is to focus on software reuse for scientific and industrial applications

Key properties:

- **Enable software reuse** defining commonly-use interfaces
- **Simplify software reuse** providing high-level libraries
- **Encourage software reuse** updated software repositories

ORCA defines itself as "unconstrained component-based system"



ORCA AND ICE

The main difference between OROCOS and ORCA is the communication toolkit; OROCOS uses CORBA while ORCA uses ICE

- ICE is a modern framework developed by ZeroC
- ICE is an open-source commercial communication system
- ICE provides two core services
  - IceGrid registry (Naming service): which provides the logic mapping between different components
  - IceStorm service (Event service): which constitute the publisher and subscriber architecture

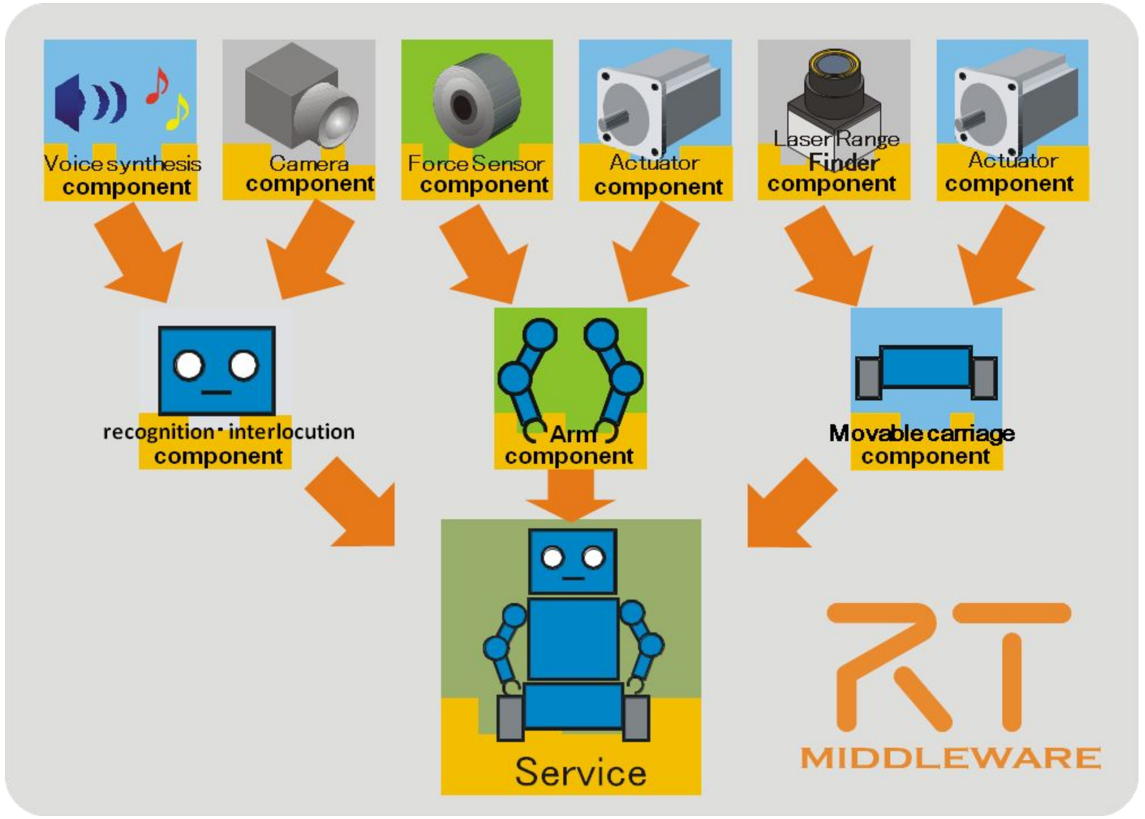
"A component can find the other components through the IceGrid registry and can communicate with them through the IceStorm service."

RT MIDDLEWARE

RT-Middleware (RTM) is a common platform standard to construct the robot system by combining the software modules of the robot functional elements (RTC):

- Camera component
- Stereovision component
- Face recognition component
- Microphone component
- Speech recognition component
- Conversational component
- Head and arm component
- Speech synthesis component

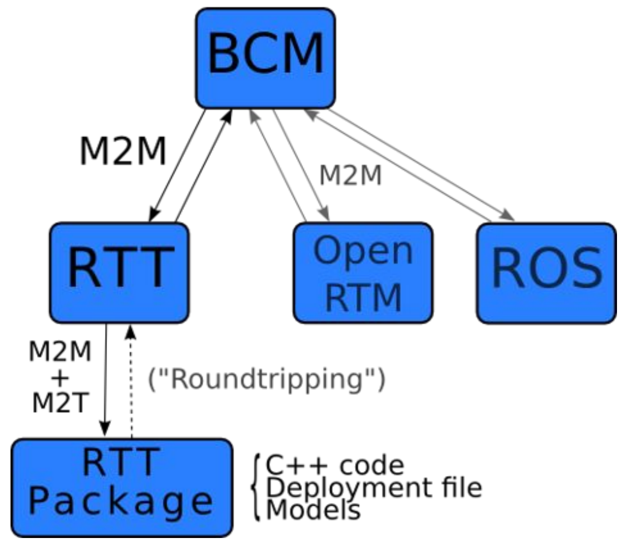
OpenRTM-aist (Advanced Industrial Science & Technology) is based on the CORBA technology to implement RTC extended specification


Voice synthesis component
Camera component
Force Sensor component
Actuator component
Laser Range Finder component
Actuator component
recognition · interlocution component
Arm component
Movable carriage component
Service
RT MIDDLEWARE

BRICS: BEST PRACTICES IN ROBOTICS

Aimed at find out the "best practices" in the developing of the robotic systems:

- Investigate the weakness of robotic projects
- Investigates the integration between hardware & software
- Promote model driven engineering in robot development
- Design an Integrated Development Environment for robotic projects (BRIDE)
- Define showcases for the evaluation of project robustness with respect to BRICS principles.

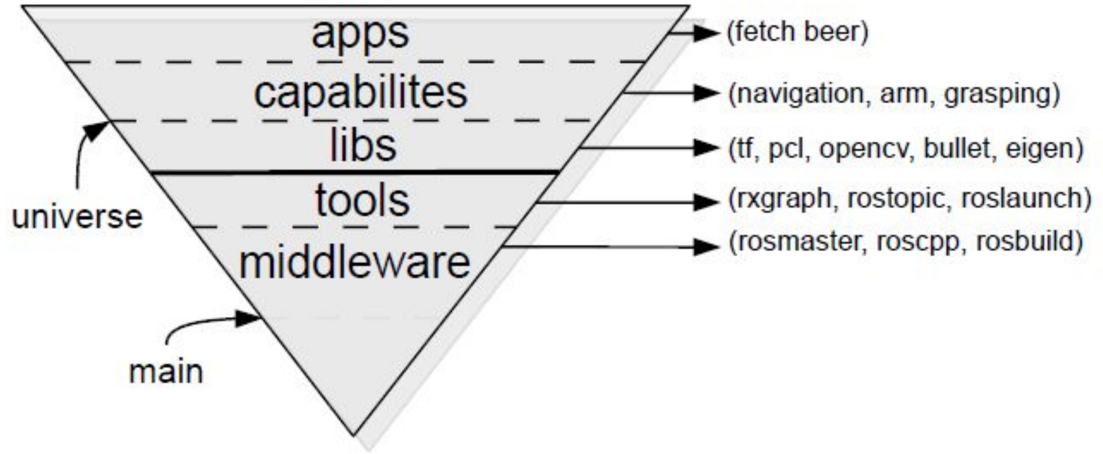


“The prime objective of BRICS is to structure and formalize the robot development process itself and to provide tools, models, and functional libraries, which help accelerating this process significantly.”

ROS: ROBOT OPERATING SYSTEM

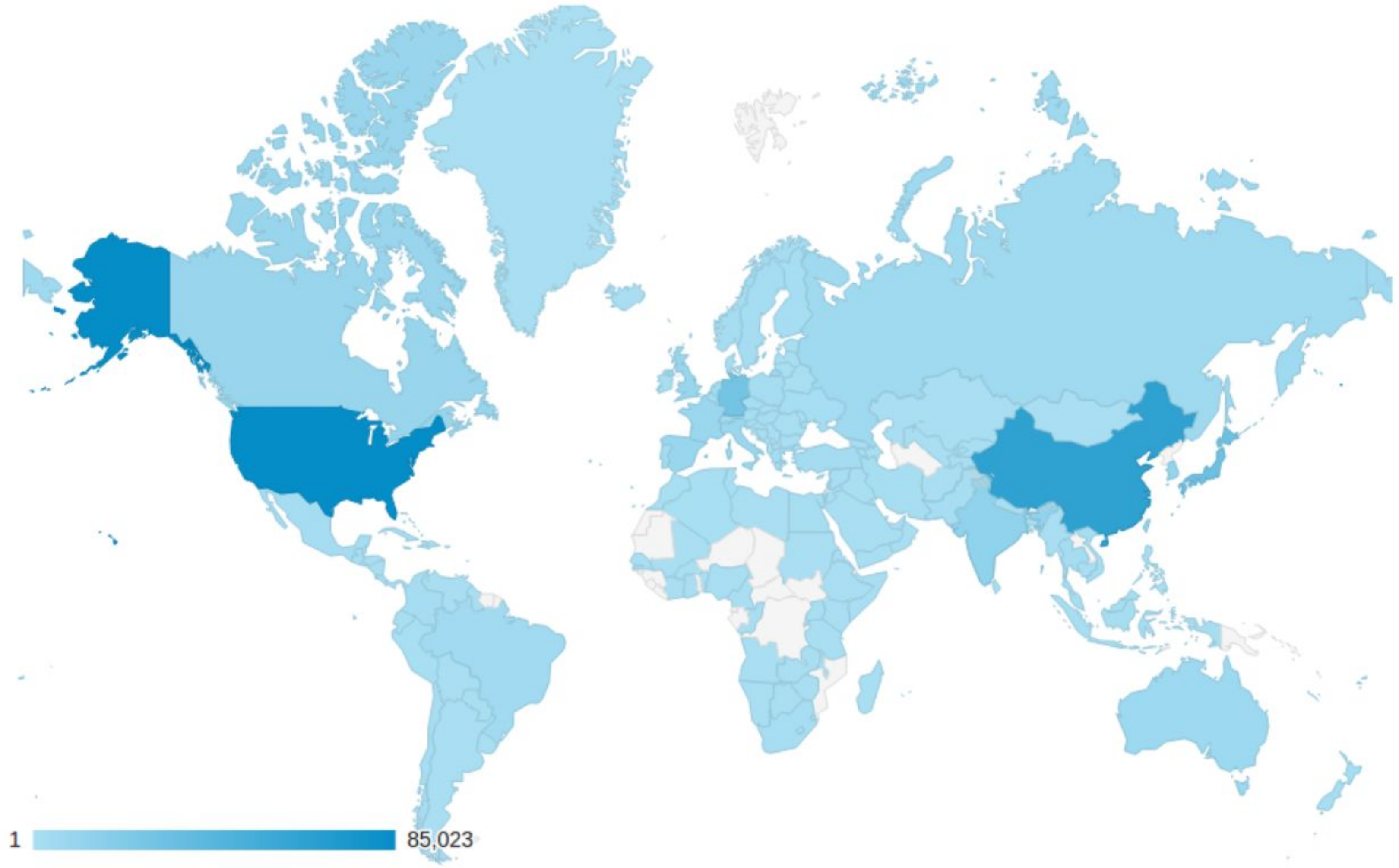
Presented in 2009 by Willow Garage, is a meta-operating system for robotics with a rich ecosystem of tools and programs

ROS
=
Plumbing
+
Tools
+
Capabilities
+
Ecosystem



apps
capabilites
libs
tools
middleware
universe
main
(fetch beer)
(navigation, arm, grasping)
(tf, pcl, opencv, bullet, eigen)
(rxgraph, rostopic, roslaunch)
(rosmaster, roscpp, rosbuild)

WHY ROS?



ROS has grown to include a large community of users worldwide

The community of developer is one of the most important characteristics of ROS

A LOT OF RESOURCES

ROS Wiki

- Archive for the existing ROS component
- Installation and configuration guides
- Information about the middleware itself
- Lots of tutorials

ROS Q&A

- For specific problems
- Thousand of already answered questions
- Active community
- Like *Stack Overflow* for ROS

SOME NUMBERS

ROS wiki:

pages: 17058

edits: 14,7/day

views: 44794/day

ROS Q&A:

total Q: 30243

total A: 21697

avg Q: 17,2/day

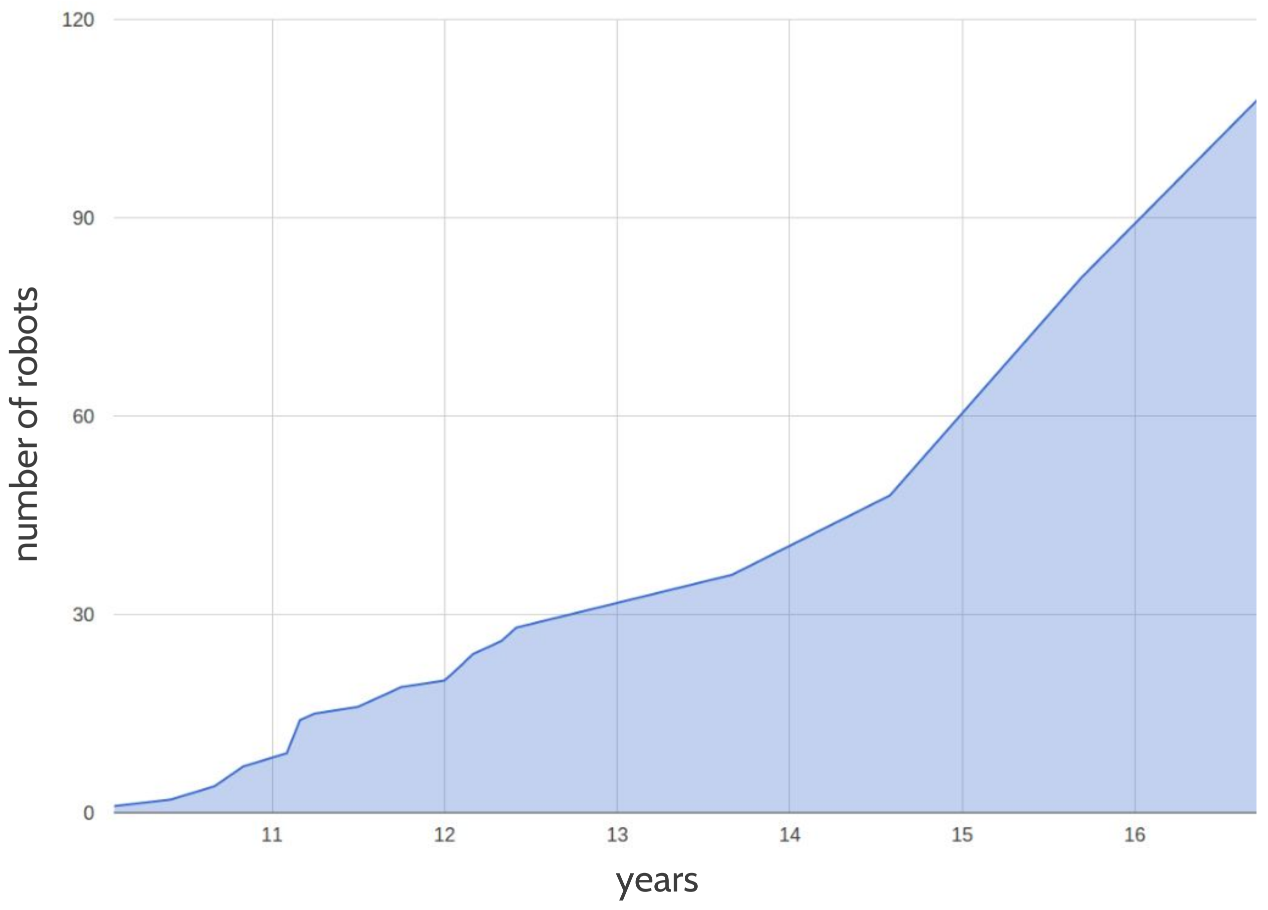
ROS deb:

total DL: 8441279

unique DL: 7582

unique IP: 113345

ROBOT AND RESEARCH



Total number of papers citing *ROS: an open-source Robot Operating System* (Quigley et al., 2009)
2683 (+46%)

ROS INTRODUCTION

ROBOTICS

POLITECNICO
MILANO 1863

ROS: ROBOT OPERATING SYSTEM

ROS main features:

- Distributed framework
- Reuse code
- Language independent
- Easy testing on Real Robot & Simulation
- Scaling

ROS Components

- File system tools
- Building tools
- Packages
- Monitoring and GUIs
- Data Logging

INSTALLATION

WARNING

This instruction are for:

Ubuntu 16.04 (suggested)

and **Ubuntu 15.10** only

INSTALLATION

Initial setup for sources and keys for downloading the packages

```
sudo sh -c 'echo "deb http://packages.ros.org/ros/ubuntu $(lsb_release -sc) main" >
/etc/apt/sources.list.d/ros-latest.list‘
```

```
sudo apt-key adv --keyserver hkp://ha.pool.sks-keyservers.net:80 --recv-key
421C365BD9FF1F717815A3895523BAEEB01FA116
```

INSTALLATION

Update the packaged index

```
sudo apt-get update
```

Choose between the four pre-packaged ROS installation

Desktop-Full Install: `sudo apt-get install ros-kinetic-desktop-full`

Desktop Install: `sudo apt-get install ros-kinetic-desktop`

ROS-Base: `sudo apt-get install ros-kinetic-ros-base`

INSTALL

How to install single packages:

```
sudo apt-get install ros-kinetic-PACKAGE
```

Example

```
sudo apt-get install ros-kinetic-slam-gmapping
```

To find the exact name of a package you can use the usual aptitude search:

```
apt-cache search ros-kinetic
```

INITIALIZATION AND SETUP

rosdep enables you to easily install system dependencies and it's required by some ROS packages

```
sudo rosdep init
rosdep update
```

To use catkin (the compiling environment of ROS) you need to define the location of your ROS installation.

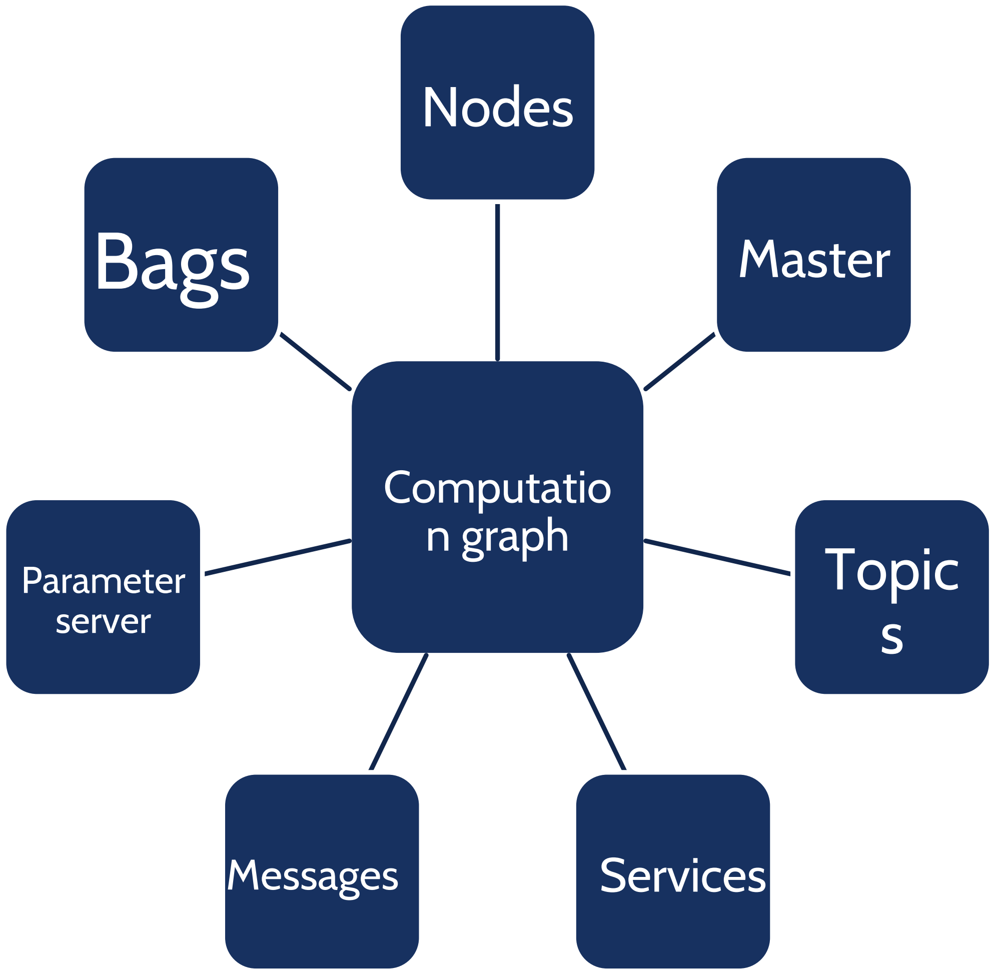
In each new terminal type:

```
source /opt/ros/kinetic/setup.bash
```

Or put it inside your .bashrc

```
echo "source /opt/ros/kinetic/setup.bash" >> ~/.bashrc
source ~/.bashrc
```

ROS STRUCTURE: COMPUTATIONAL GRAPH



The *Computation Graph* is the peer-to-peer network of ROS processes that are processing data together.

NODES

Executable unit of ROS:

- Scripts for Python
- Compiled source code for C++

Process that performs computation

Nodes exchange information via the graph

Meant to operate at fine-grained scale

A robot system is composed by various nodes

```
rosrun package_name node_name

rosrun turtlesim turtlesim_node
```

MASTER

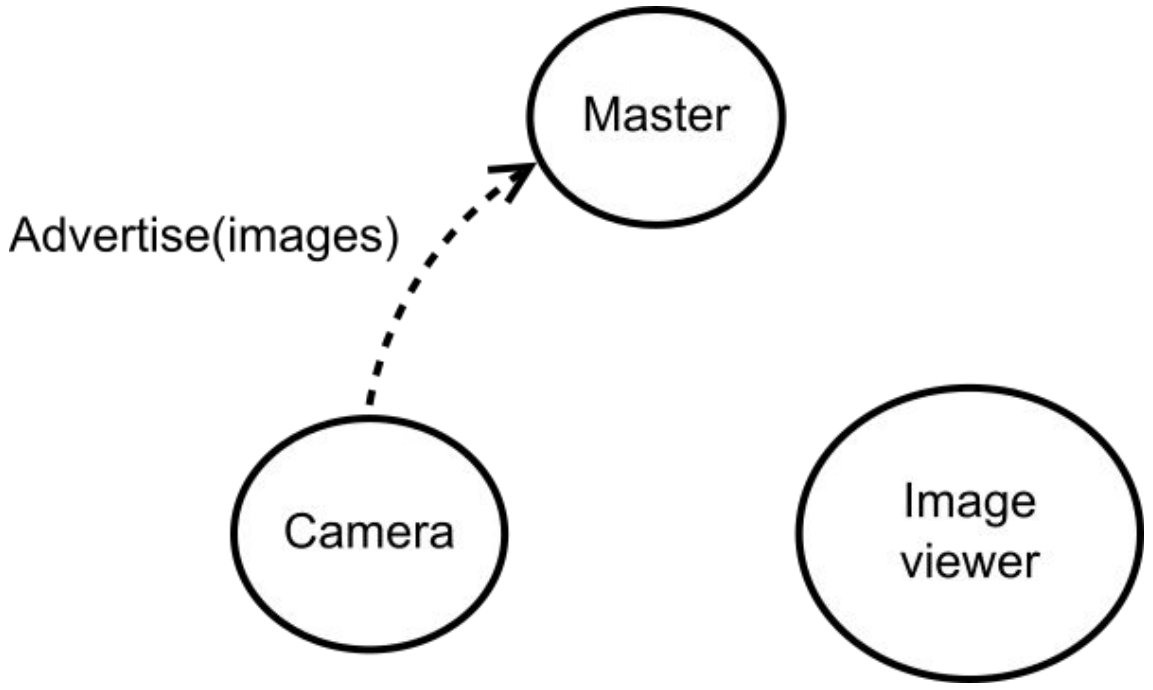
Provides naming and registration services

Essential for nodes interactions

One master for each system, even on distributed architectures

Enables individual ROS nodes to locate one another

One of the functionalities provided by roscore



MASTER

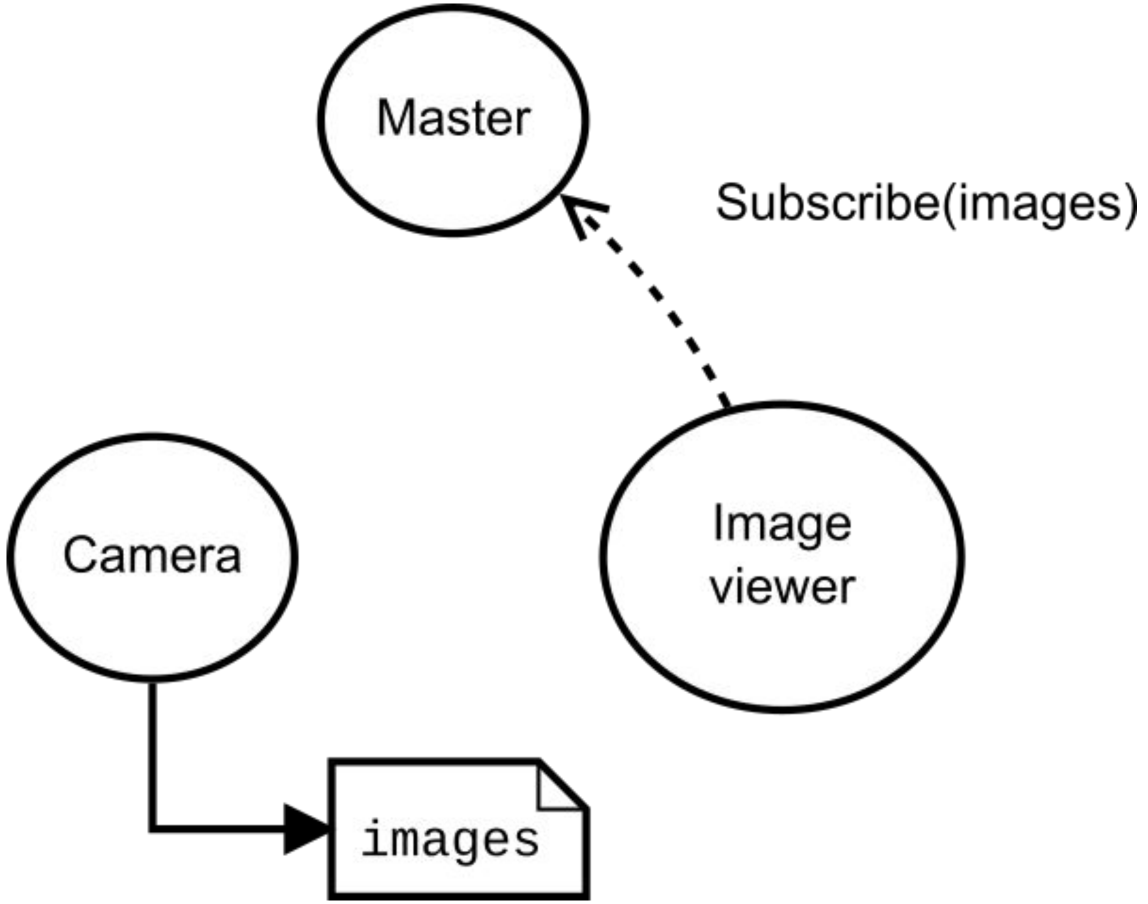
Provides naming and registration services

Essential for nodes interactions

One master for each system, even on distributed architectures

Enables individual ROS nodes to locate one another

One of the functionalities provided by roscore



MASTER

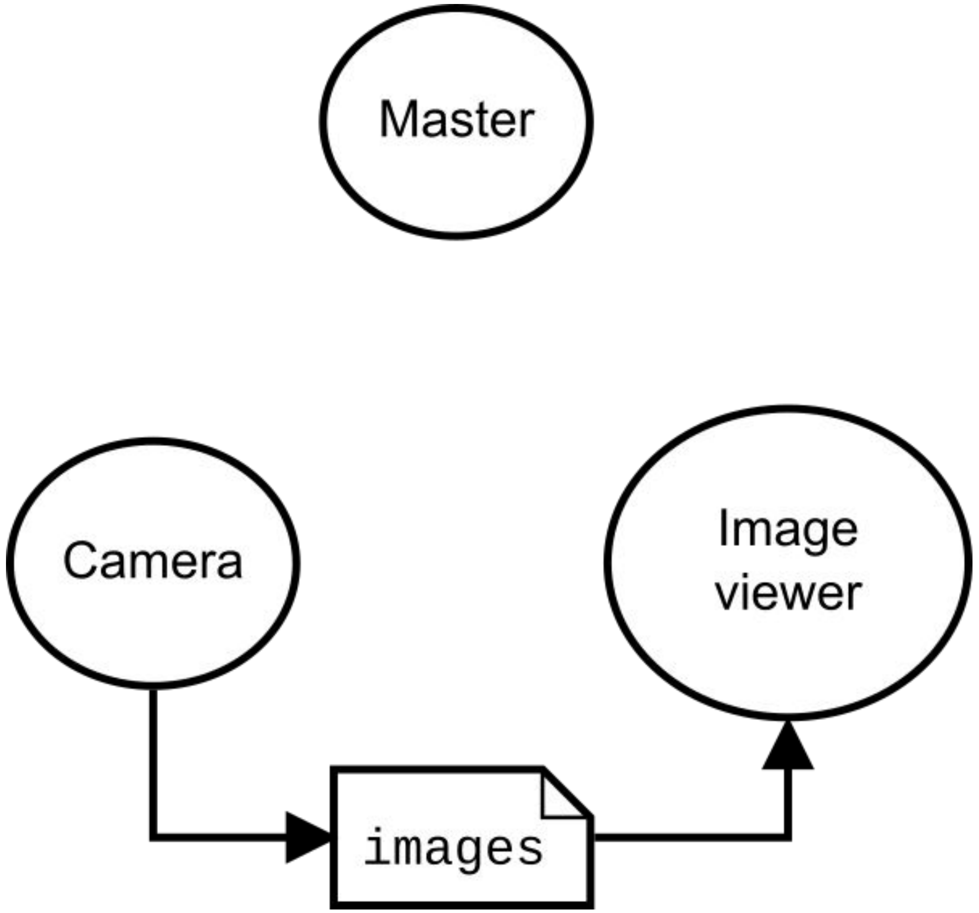
Provides naming and registration services

Essential for nodes interactions

One master for each system, even on distributed architectures

Enables individual ROS nodes to locate one another

One of the functionalities provided by roscore



TOPICS

Named channels for communication

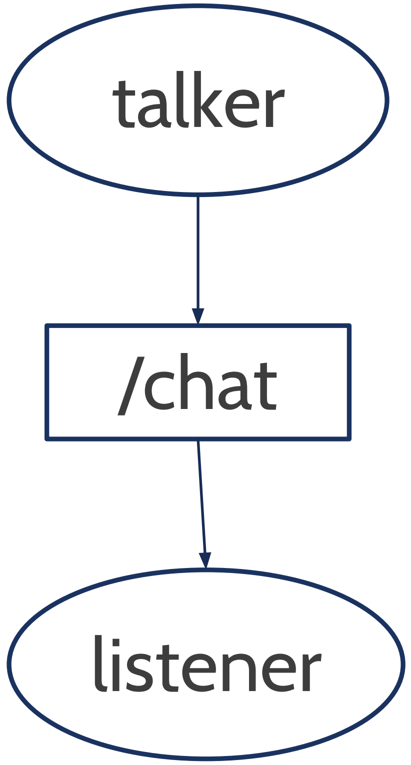
Implement the publish/subscribe paradigm

No guarantee of delivery

Have a specific message type

Multiple nodes can publish messages on a topic

Multiple nodes can read messages from a topic



TOPICS

Named channels for communication

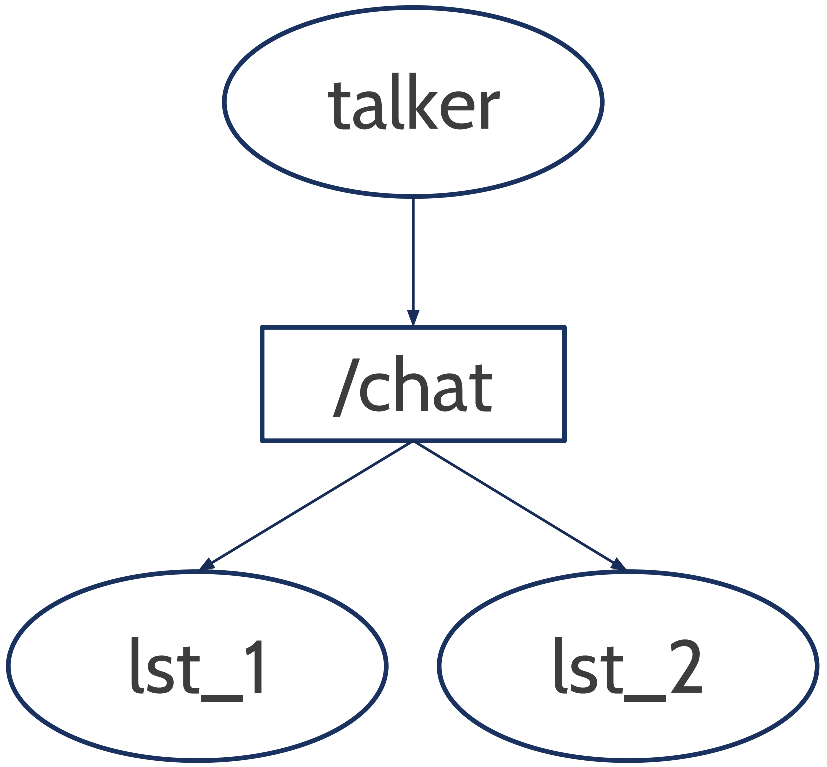
Implement the publish/subscribe paradigm

No guarantee of delivery

Have a specific message type

Multiple nodes can publish messages on a topic

Multiple nodes can read messages from a topic



TOPICS

Named channels for communication

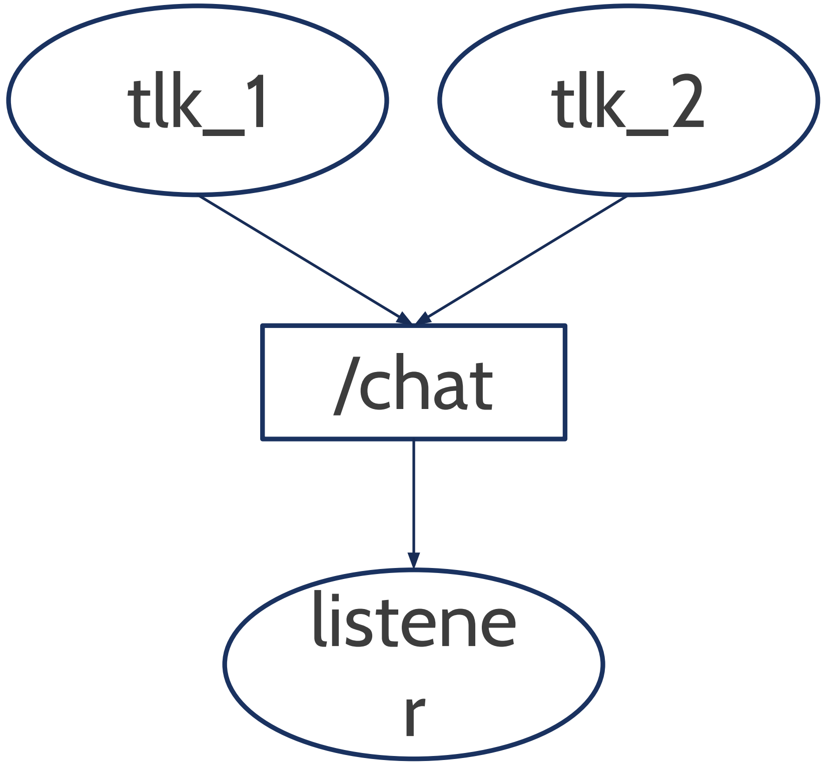
Implement the publish/subscribe paradigm

No guarantee of delivery

Have a specific message type

Multiple nodes can publish messages on a topic

Multiple nodes can read messages from a topic



MESSAGES

Messages are exchanged on topics

They define the type of the topic

Various already available messages

It is possible to define new messages using a simple language

Existing message types can be used in new messages together with base types

```
std_msgs/Header.mgs

    uint32 seq
    time stamp
    string frame_id

std_msgs/String.msg

    string data

sensor_msgs/Joy.msg

    std_msgs/Header header

    float32[] axes

    int32[] buttons
```

MESSAGES

Messages are exchanged on topics

They define the type of the topic

Various already available messages

It is possible to define new messages using a simple language

Existing message types can be used in new messages together with base types

Quick recap:

14 base types

32 std_msgs

29 geometry_msgs

26 sensor_msgs

...and more

SERVICES

Work like remote function calls

Implement the client/server paradigm

Code waits for service call to complete

Guarantee of execution

Use of message structures

example/AddTwoInt.srv

```
int64 A
int64 B
---
int64 Sum
```

PARAMETER SERVER

Shared, multivariable dictionary that is accessible via network

Nodes use this server to store and retrieve parameters at runtime

Not designed for performance, not for data exchange

Connected to the master, one of the functionalities provided by roscore

```
rosparam [set|get] name value

rosparm set use_sim_time True

rosparam get use_sim_time
   True
```

PARAMETER SERVER

Shared, multivariable dictionary that is accessible via network

Nodes use this server to store and retrieve parameters at runtime

Not designed for performance, not for data exchange

Connected to the master, one of the functionalities provided by roscore

Available types:

- 32-bit integers
- Booleans
- Strings
- Doubles
- ISO8601 dates
- Lists
- Base64-encoded binary data

BAGS

File format (**.bag*) for storing and playing back messages

Primary mechanism for data logging

Can record anything exchanged on the ROS graph (messages, services, parameters, actions)

Important tool for analyzing, storing, visualizing data and testing algorithms.

```
rosbag record –a
rosbag record /topic1 /topic2

rosbag play ~/bags/fancy_log.bag

rqt_bag ~/bags/fancy_log.bag
```

ROSCORE

roscore is a collection of nodes and programs that are pre-requisites of a ROS-based system

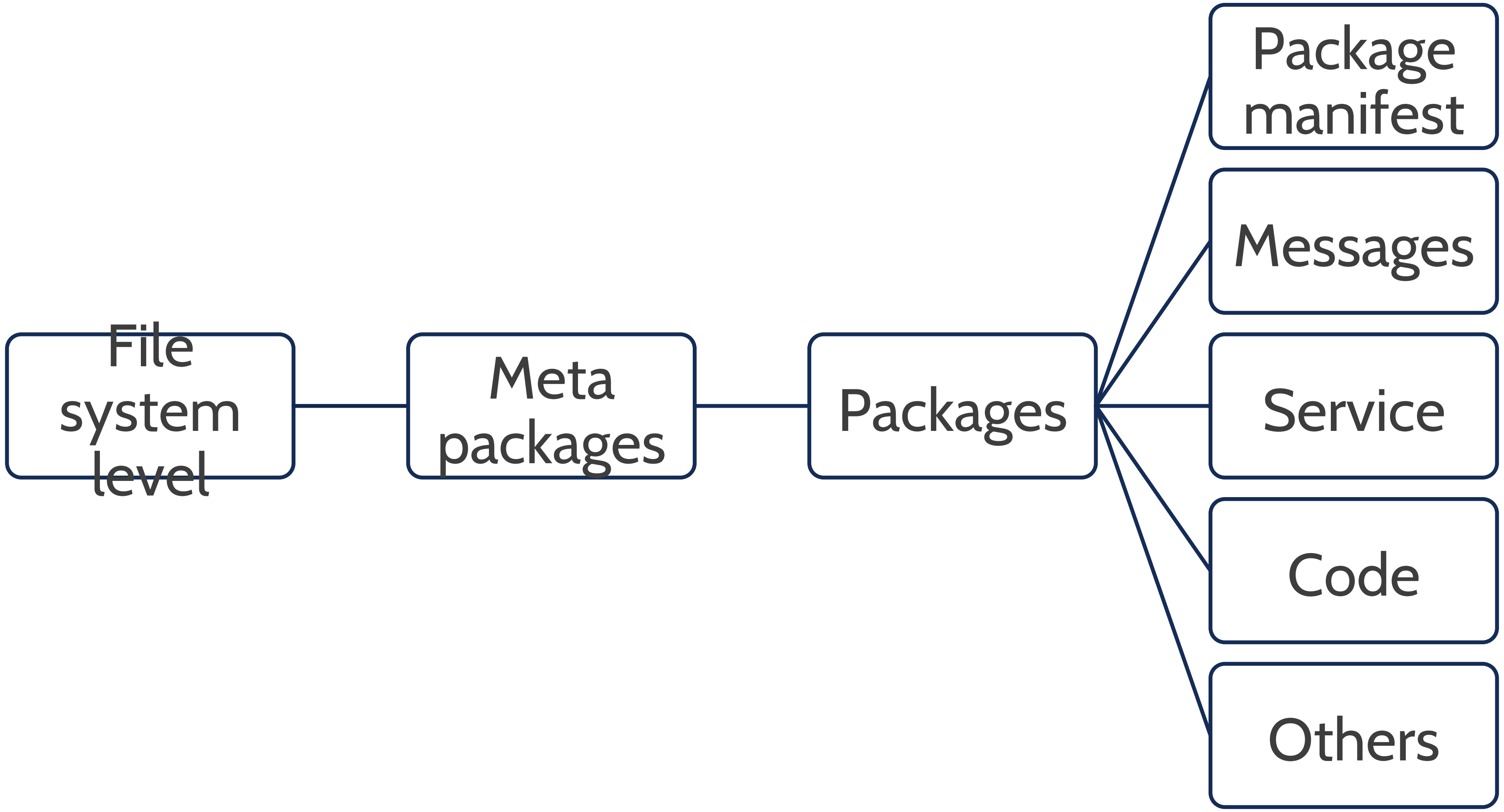
Must be running in order for ROS nodes to communicate

Launched using the roscore command.

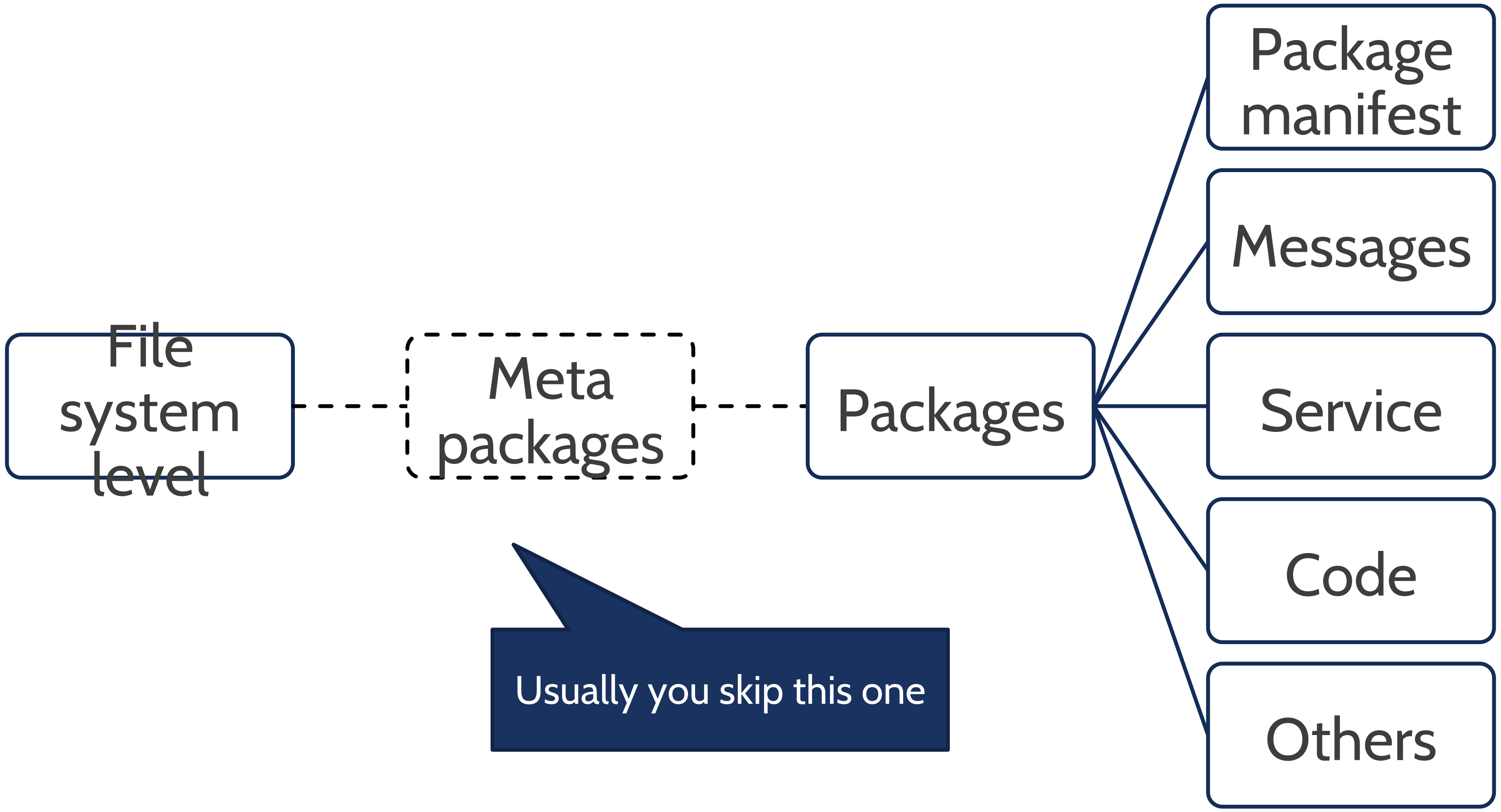
Elements of roscore:

- a ROS Master
- a ROS Parameter Server
- a rosout logging node

ROS FILE SYSTEM



ROS FILE SYSTEM



PACKAGES AND METAPACKAGES

PACKAGES

- Atomic element of ROS file system
- Used as a reference for most ROS commands
- Contains nodes, messages and services
- package.xml used to describe the package
- Mandatory container

METAPACKAGES

- Aggregation of logical related elements
- Not used when navigating the ROS file system
- Contains other packages
- package.xml used to describe the package
- Not required

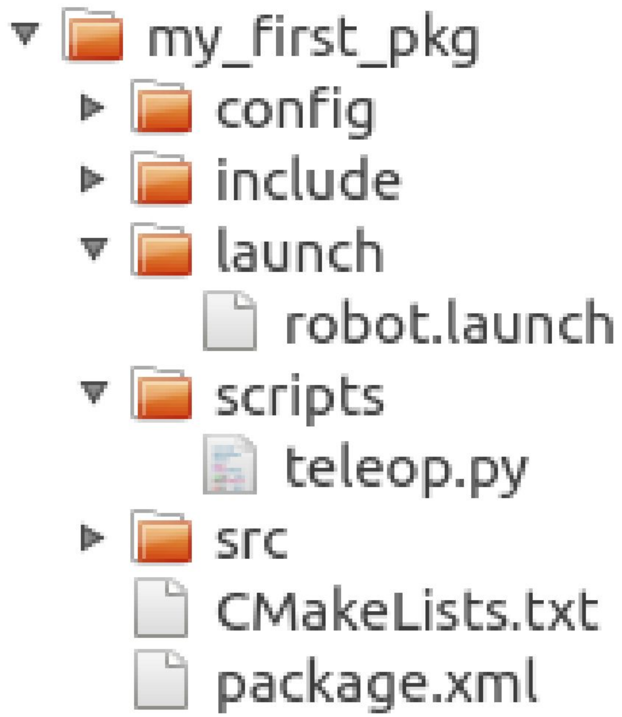
STRUCTURE OF A PACKAGE

Folder structure:

- /src, /include, /scripts (coding)
- /launch (launch files)
- /config (configuration files)

Required files:

- CMakeList.txt: Build rules for catkin
- package.xml: Metadata for ROS



```
▼ my_first_pkg
  ▶ config
  ▶ include
  ▼ launch
      robot.launch
  ▼ scripts
      teleop.py
  ▶ src
    CMakeLists.txt
    package.xml
```