Programming for Robotics

Introduction to ROS

Course 4

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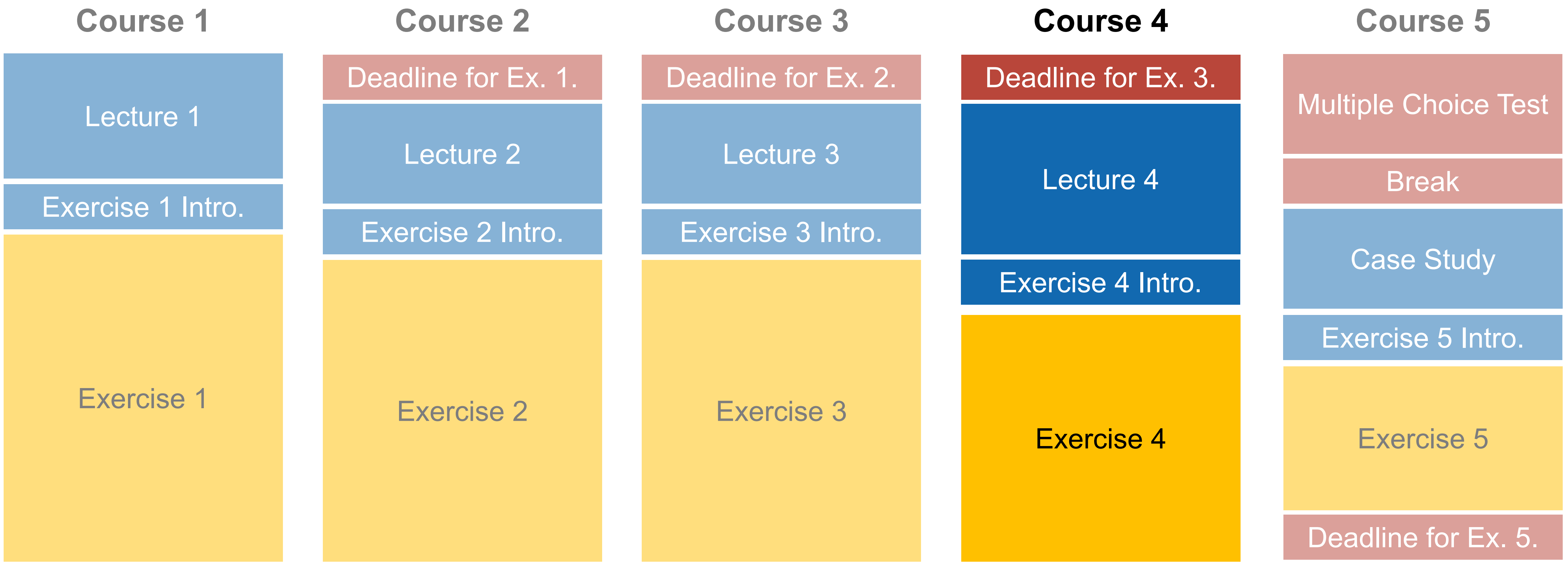
ROS

Robotic Systems Lab

Course Structure



Course 1

- Lecture 1
- Exercise 1 Intro.
- Exercise 1

Course 2

- Deadline for Ex. 1.
- Lecture 2
- Exercise 2 Intro.
- Exercise 2

Course 3

- Deadline for Ex. 2.
- Lecture 3
- Exercise 3 Intro.
- Exercise 3

Course 4

- Deadline for Ex. 3.
- Lecture 4
- Exercise 4 Intro.
- Exercise 4

Course 5

- Multiple Choice Test
- Break
- Case Study
- Exercise 5 Intro.
- Exercise 5
- Deadline for Ex. 5.

Evaluation – Multiple Choice Test

- The test counts for 50 % of the final grade
- The multiple choice test (~40 min) takes place at the last course day:

05.03.2021 at 08:00 (sharp, not 08:15), HG E3

Ex 4 grading session

- Moved to Thursday

04.03.2021 at 08:00 (sharp, not 08:15)

Overview Course 4

- ROS services
- ROS actions (actionlib)
- ROS time
- ROS bags
- Debugging strategies

- Intro to ROS 2 concepts

ROS Services

- Request/response communication between nodes is realized with *services*
  - The *service server* advertises the service
  - The *service client* accesses this service
- Similar in structure to messages, services are defined in **.srv* files

List available services with

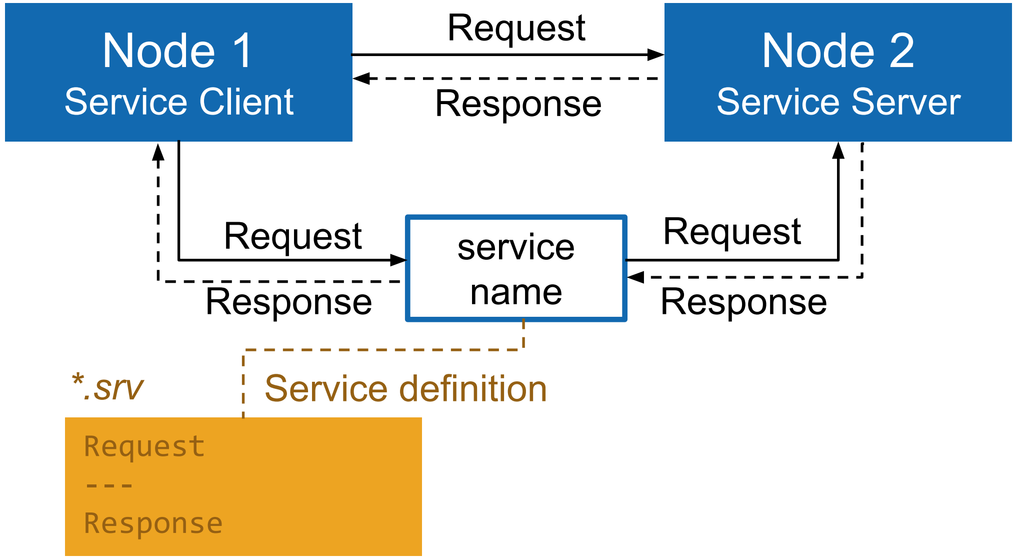
```
> rosservice list
```

Show the type of a service

```
> rosservice type /service_name
```

Call a service with the request contents, autocomplete with `tab`

```
> rosservice call /service_name args
```

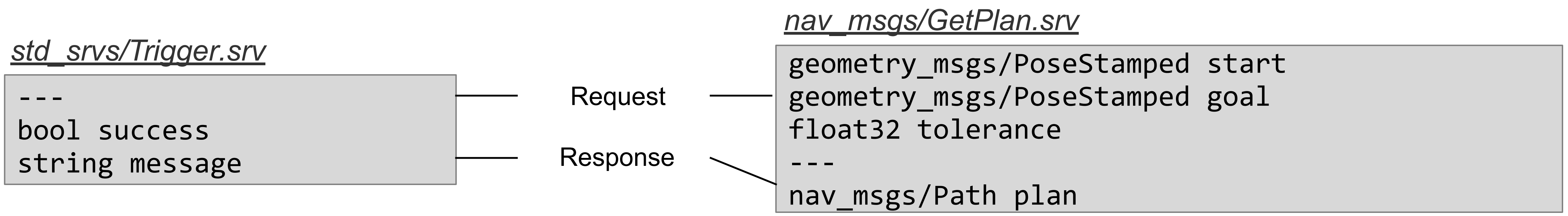


```
Request
---
Response
```

More info
wiki.ros.org/Services

ROS Services

Examples



std_srvs/Trigger.srv

```
---
bool success
string message
```

nav_msgs/GetPlan.srv

```
geometry_msgs/PoseStamped start
geometry_msgs/PoseStamped goal
float32 tolerance
---
nav_msgs/Path plan
```

ROS Service Example

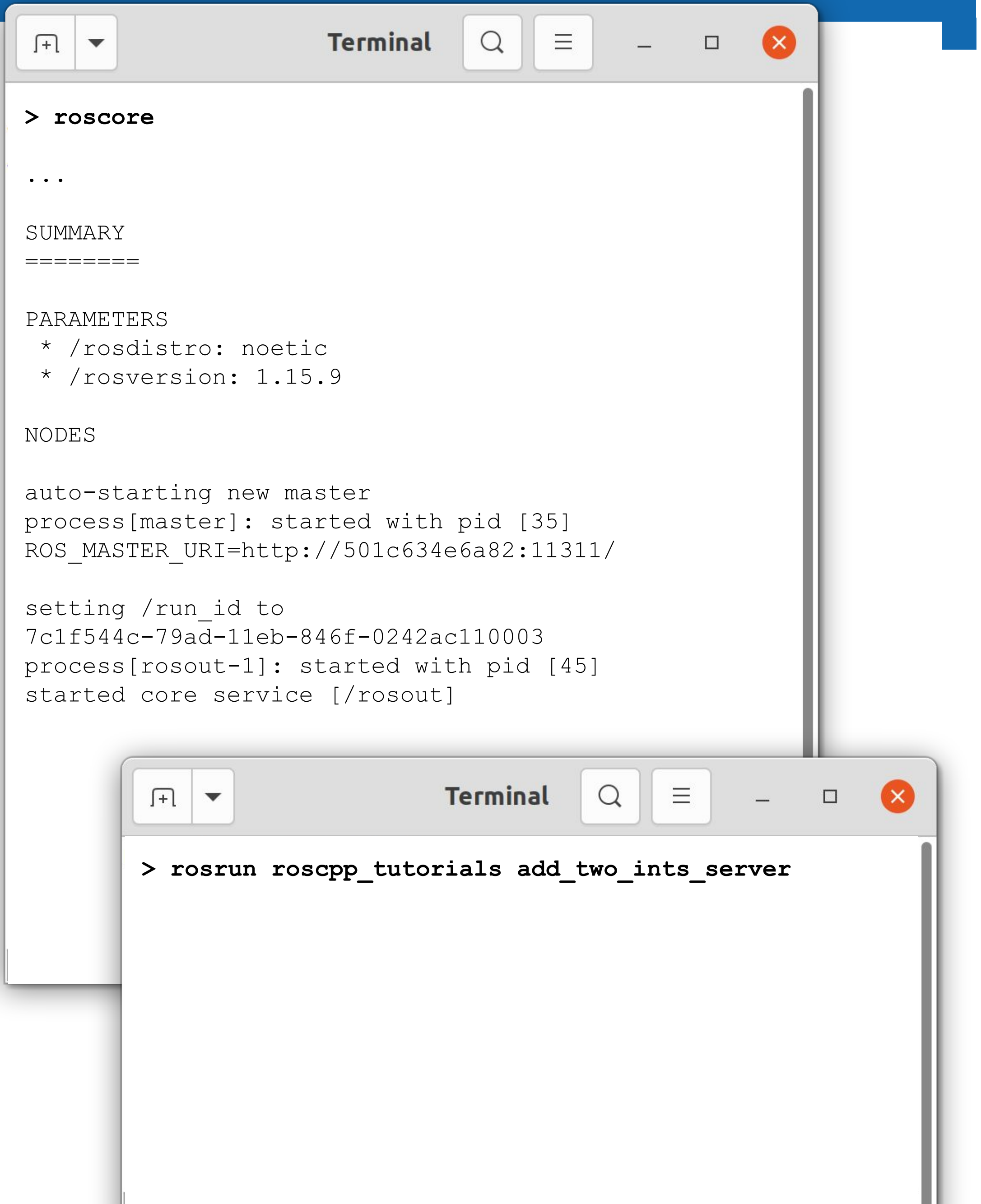
Starting a *roscore* and a *add_two_ints_server* node

In console nr. 1:
Start a roscore with

```
> roscore
```

In console nr. 2:
Run a service demo node with

```
> rosrun roscpp_tutorials add_two_ints_server
```



```
> roscore

...

SUMMARY
========

PARAMETERS
 * /rosdistro: noetic
 * /rosversion: 1.15.9

NODES

auto-starting new master
process[master]: started with pid [35]
ROS_MASTER_URI=http://501c634e6a82:11311/

setting /run_id to
7c1f544c-79ad-11eb-846f-0242ac110003
process[rosout-1]: started with pid [45]
started core service [/rosout]
```

```
> rosrun roscpp_tutorials add_two_ints_server
```

ROS Service Example

Console Nr. 3 – Analyze and call service

See the available services with

```
> rosservice list
```

See the type of the service with

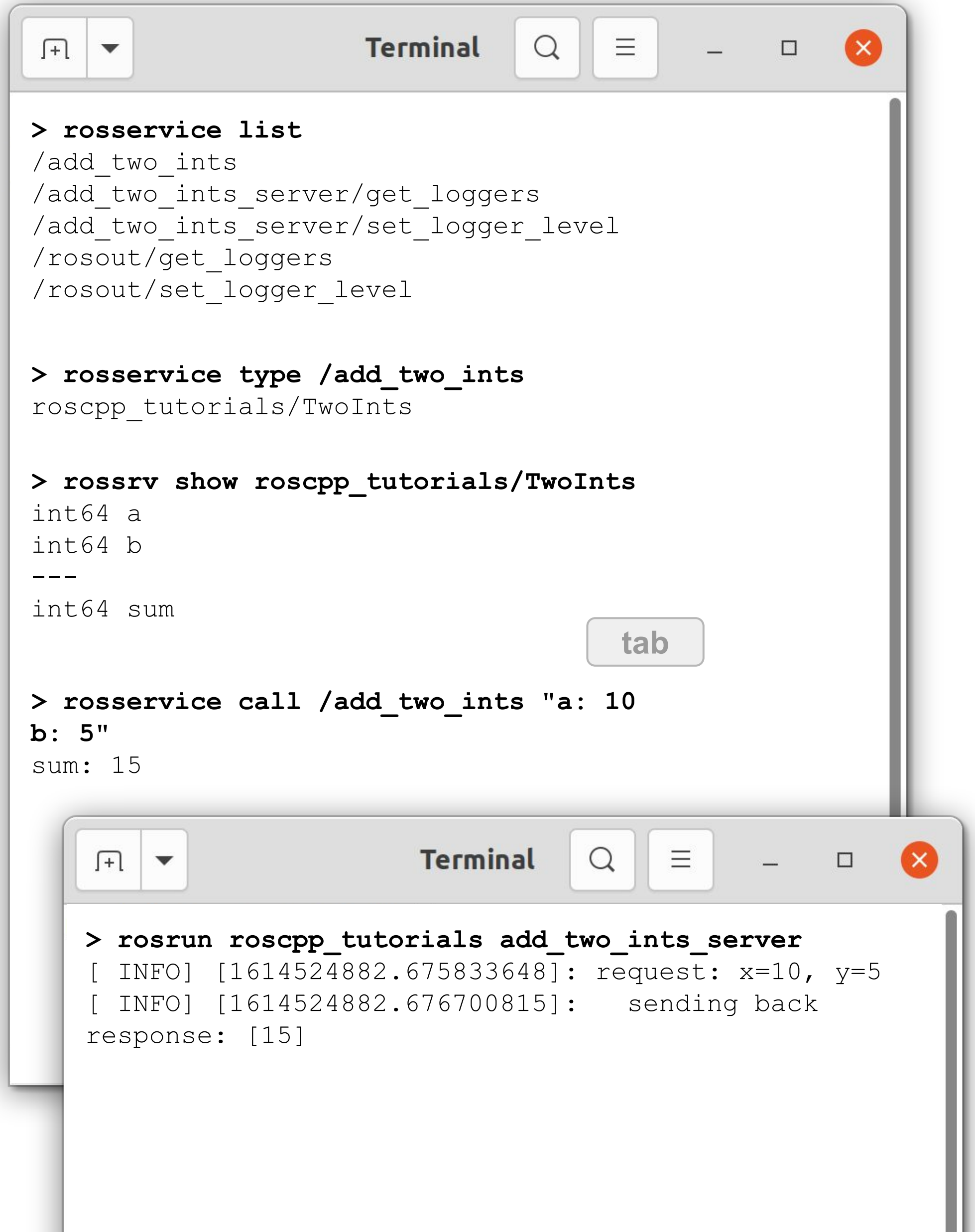
```
> rosservice type /add_two_ints
```

Show the service definition with

```
> rossrv show roscpp_tutorials/TwoInts
```

Call the service (use Tab for auto-complete)

```
> rosservice call /add_two_ints "a: 10
  b: 5"
```



```
> rosservice list
/add_two_ints
/add_two_ints_server/get_loggers
/add_two_ints_server/set_logger_level
/rosout/get_loggers
/rosout/set_logger_level


> rosservice type /add_two_ints
roscpp_tutorials/TwoInts


> rossrv show roscpp_tutorials/TwoInts
int64 a
int64 b
---
int64 sum


> rosservice call /add_two_ints "a: 10
b: 5"
sum: 15
```

```
> rosrun roscpp_tutorials add_two_ints_server
[ INFO] [1614524882.675833648]: request: x=10, y=5
[ INFO] [1614524882.676700815]:   sending back
response: [15]
```

ROS C++ Client Library (*roscpp*)

Service Server

- Create a service server with

```
ros::ServiceServer service =
 nodeHandle.advertiseService(service_name,
                      callback_function);
```

- When a service request is received, the callback function is called with the request as argument
- Fill in the response to the response argument
- Return to function with true to indicate that it has been executed properly

More info
wiki.ros.org/roscpp/Overview/Services

add_two_ints_server.cpp (use OO-approach in exercises)

```
#include <ros/ros.h>
#include <roscpp_tutorials/TwoInts.h>

bool add(roscpp_tutorials::TwoInts::Request &request,
         roscpp_tutorials::TwoInts::Response &response)
{
  response.sum = request.a + request.b;
  ROS_INFO("request: x=%ld, y=%ld", (long int)request.a,
                                    (long int)request.b);
  ROS_INFO("  sending back response: [%ld]",
           (long int)response.sum);
  return true;
}

int main(int argc, char **argv)
{
  ros::init(argc, argv, "add_two_ints_server");
  ros::NodeHandle nh;
  ros::ServiceServer service =
nh.advertiseService("add_two_ints", add);
  ros::spin();
  return 0;
}
```

ROS C++ Client Library (*roscpp*)

Service Client

- Create a service client with

```
ros::ServiceClient client =
    nodeHandle.serviceClient<service_type>
                            (service_name);
```

- Create service request contents `service.request`
- Call service with

```
client.call(service);
```

- Response is stored in `service.response`

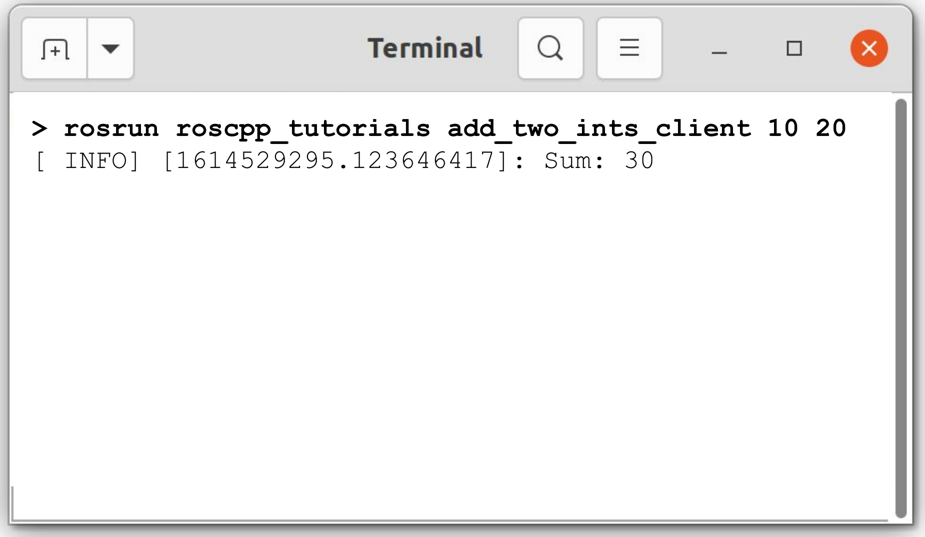
add_two_ints_client.cpp

```
#include <ros/ros.h>
#include <roscpp_tutorials/TwoInts.h>
#include <cstdlib>

int main(int argc, char **argv) {
  ros::init(argc, argv, "add_two_ints_client");
  if (argc != 3) {
    ROS_INFO("usage: add_two_ints_client X Y");
    return 1;
  }

  ros::NodeHandle nh;
  ros::ServiceClient client =
  nh.serviceClient<roscpp_tutorials::TwoInts>("add_two_ints");
  roscpp_tutorials::TwoInts service;
  service.request.a = atoi(argv[1]);
  service.request.b = atoi(argv[2]);
  if (client.call(service)) {
    ROS_INFO("Sum: %ld", (long int)service.response.sum);
  } else {
    ROS_ERROR("Failed to call service add_two_ints");
    return 1;
  }
  return 0;
}
```

More info
wiki.ros.org/roscpp/Overview/Services

ROS C++ Client Library (*roscpp*)

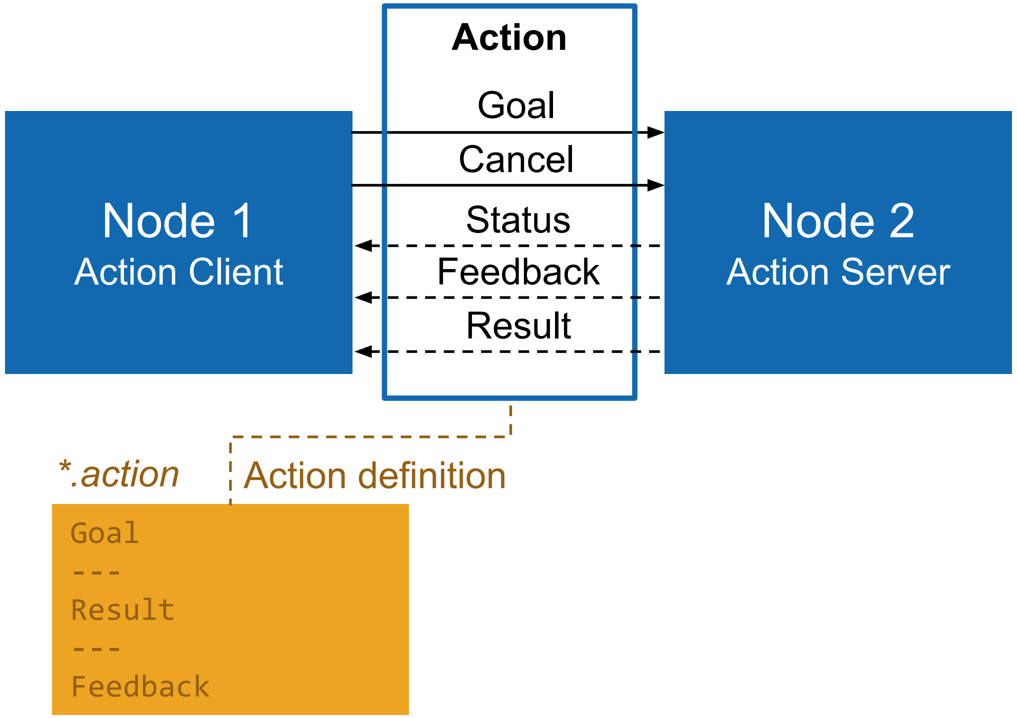
Service Client



```
> rosrun roscpp_tutorials add_two_ints_client 10 20
[ INFO] [1614529295.123646417]: Sum: 30
```

ROS Actions (actionlib)

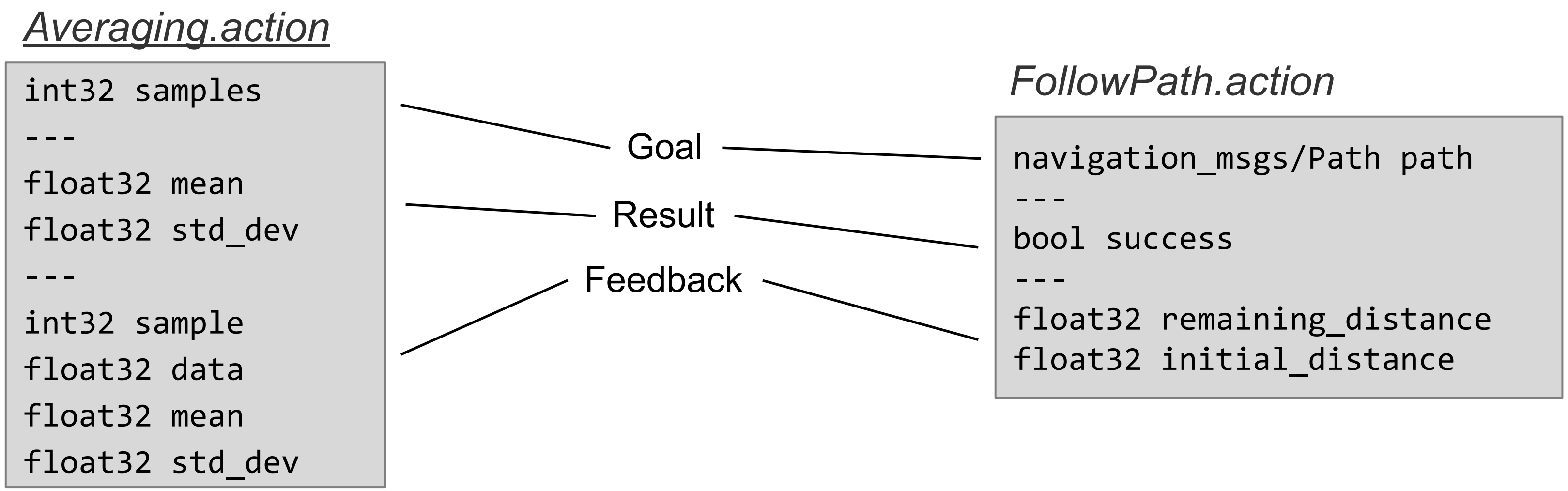
- Similar to service calls, but provide possibility to
  - Cancel the task (preempt)
  - Receive feedback on the progress
- Best way to implement interfaces to time-extended, goal-oriented behaviors
- Similar in structure to services, action are defined in **.action* files
- Internally, actions are implemented with a set of topics



```
Goal
---
Result
---
Feedback
```

More info
wiki.ros.org/actionlib
wiki.ros.org/actionlib/DetailedDescription

ROS Actions (actionlib)



Averaging.action

```
int32 samples
---
float32 mean
float32 std_dev
---
int32 sample
float32 data
float32 mean
float32 std_dev
```

Goal

Result

Feedback

FollowPath.action

```
navigation_msgs/Path path
---
bool success
---
float32 remaining_distance
float32 initial_distance
```

ROS Parameters, Dynamic Reconfigure, Topics, Services, and Actions Comparison

	Parameters	Dynamic Reconfigure	Topics	Services	Actions
Description	Global constant parameters	Local, changeable parameters	Continuous data streams	Blocking call for processing a request	Non-blocking, preemptable goal oriented tasks
Application	Constant settings	Tuning parameters	One-way continuous data flow	Short triggers or calculations	Task executions and robot actions
Examples	Topic names, camera settings, calibration data, robot setup	Controller parameters	Sensor data, robot state	Trigger change, request state, compute quantity	Navigation, grasping, motion execution

ROS Time

- Normally, ROS uses the PC's system clock as time source (*wall time*)
- For simulations or playback of logged data, it is convenient to work with a simulated time (pause, slow-down etc.)
- To work with a simulated clock:
  - Set the `/use_sim_time` parameter

```
> rosparam set use_sim_time true
```

  - Publish the time on the topic `/clock` from
    - Gazebo (enabled by default)
    - ROS bag (use option `--clock`)

More info
wiki.ros.org/Clock
wiki.ros.org/roscpp/Overview/Time

- To take advantage of the simulated time, you should always use the ROS Time APIs:
  - **`ros::Time`**

```
ros::Time begin = ros::Time::now();
double secs = begin.toSec();
```

  - **`ros::Duration`**

```
ros::Duration duration(0.5); // 0.5s
ros::Duration passed = ros::Time()::now()
                                   - begin;
```

  - **`ros::Rate`**

```
ros::Rate rate(10); // 10Hz
```

- If wall time is required, use `ros::WallTime`, `ros::WallDuration`, and `ros::WallRate`

ROS Bags

- A *bag* is a format for storing message data
- Binary format with file extension *.bag
- Suited for logging and recording datasets for later visualization and analysis

Record all topics in a bag

```
> rosbag record --all
```

Record given topics

```
> rosbag record topic_1 topic_2 topic_3
```

Stop recording with `Ctrl` + `C`
Bags are saved with start date and time as file name in the current folder (e.g. `2019-02-07-01-27-13.bag`)

Show information about a bag

```
> rosbag info bag_name.bag
```

Read a bag and publish its contents

```
> rosbag play bag_name.bag
```

Playback options can be defined e.g.

```
> rosbag play --rate=0.5 bag_name.bag
```

`--rate=`*`factor`*	Publish rate factor
`--clock`	Publish the clock time (set param `use_sim_time` to `true`)
`--loop`	Loop playback

etc.

More info
wiki.ros.org/rosbag/Commandline

Debugging Strategies

Debug with the tools you have learned

- Compile and run code often to catch bugs early
- Understand compilation and runtime error messages
- Use analysis tools to check data flow (`rosnode info`, `rostopic echo, roswtf, rqt_graph` etc.)
- Visualize and plot data (RViz, RQT Multiplot etc.)
- Divide program into smaller steps and check intermediate results (`ROS_INFO`, `ROS_DEBUG` etc.)
- Make your code robust with argument and return value checks and catch exceptions
- Extend and optimize only once a basic version works
- If things don't make sense, clean your workspace

```
> catkin clean --all
```

Learn new tools

- Build in *debug* mode and use GDB or Valgrind

```
> catkin config --cmake-args
                 -DCMAKE_BUILD_TYPE=Debug
> catkin config --cmake-args
                -DCMAKE_BUILD_TYPE=Release
```

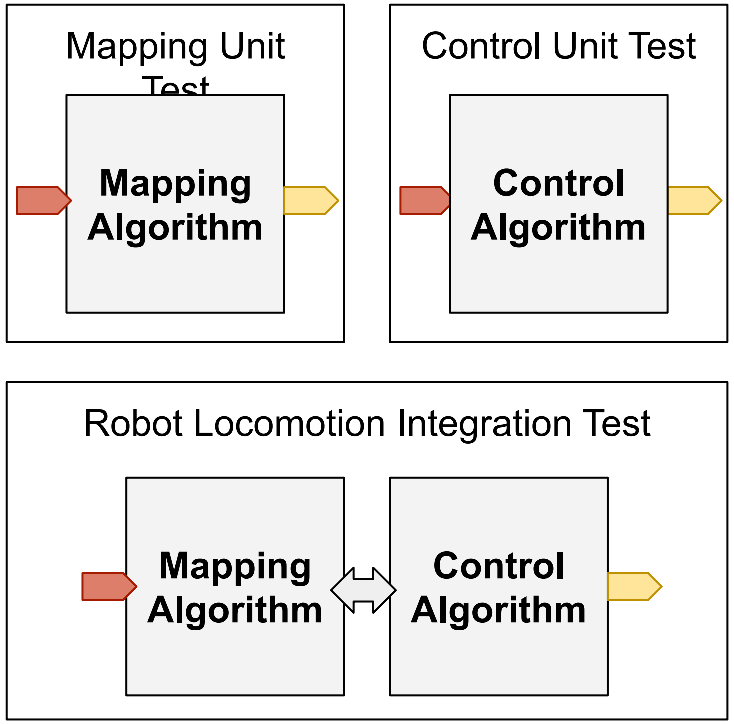
- Use debugger breakpoints, e.g. in Eclipse
- Write unit tests and integration tests to discover regressions

More info
wiki.ros.org/UnitTesting
wiki.ros.org/gtest
wiki.ros.org/rostest
wiki.ros.org/roslaunch/Tutorials/Roslaunch%20Nodes%20in%20Valgrind%20or%20GDB

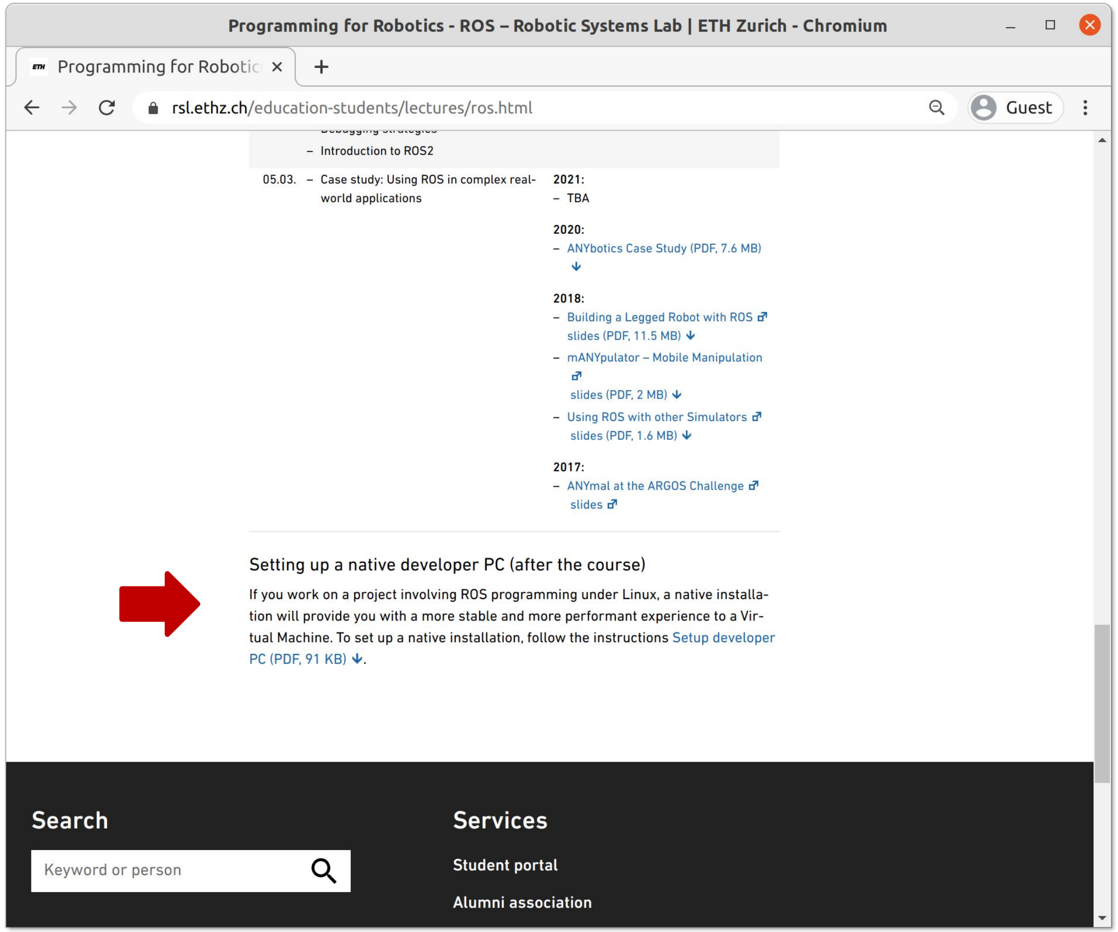
Unit Tests, Integration Tests, Automatic Testing

An investment in the quality of your code

- Unit tests feed a known input to, and expect a known output of your code
- Tests the interface of your code
  - Forces you to reason about its contract
  - Leads to better designed code
- Integrations tests check the functionality and behaviour of your program
- Automated tests reduce the risk of bugs, and regressions



Setting Up up a Developer's PC



Programming for Robotics - ROS – Robotic Systems Lab | ETH Zurich - Chromium

– Debugging strategies
– Introduction to ROS2

05.03. – Case study: Using ROS in complex real-world applications

2021:
– TBA

2020:
– ANYbotics Case Study (PDF, 7.6 MB)

2018:
– Building a Legged Robot with ROS slides (PDF, 11.5 MB)
– mANYpulator – Mobile Manipulation slides (PDF, 2 MB)
– Using ROS with other Simulators slides (PDF, 1.6 MB)

2017:
– ANYmal at the ARGOS Challenge slides

Setting up a native developer PC (after the course)

If you work on a project involving ROS programming under Linux, a native installation will provide you with a more stable and more performant experience to a Virtual Machine. To set up a native installation, follow the instructions Setup developer PC (PDF, 91 KB).

RSL Robotic Systems Lab

Further References

- **ROS Wiki**
  - http://wiki.ros.org/
- **Installation**
  - http://wiki.ros.org/ROS/Installation
- **Tutorials**
  - http://wiki.ros.org/ROS/Tutorials
- **Available packages**
  - http://www.ros.org/browse/
- **ROS Cheat Sheet**
  - https://www.clearpathrobotics.com/ros-robot-operating-system-cheat-sheet/
  - https://kapeli.com/cheat_sheets/ROS.docset/Contents/Resources/Documents/index
- **ROS Best Practices**
  - https://github.com/leggedrobotics/ros_best_practices/wiki
- **ROS Package Template**
  - https://github.com/leggedrobotics/ros_best_practices/tree/master/ros_package_template

Contact Information

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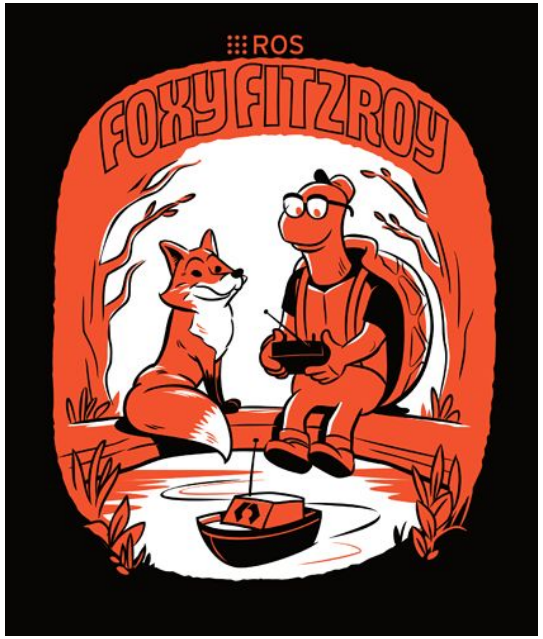
Course website:
rsl.ethz.ch/education-students/lectures/ros.html

ROS 2

- We will give a brief intro and point you to some resources
- There is still a lot of ROS 1 code out there
- ROS 2 intro
  - Philosophy
  - Differences
  - Commands like tools
  - Launch files
  - ROS bridge



Why ROS 2?

- ROS 1 was not designed with all of today’s use cases in mind
- Designed mainly for research
- Initially only designed for PR2
- Never really designed for Real-time

More info
https://design.ros2.org/articles/why_ros2.html

Why ROS 2? - new use cases

- Teams of robots
- Not suited for bare-metal types of micro controlled
- Non real time communication
- Lossy networks
- Uses in research & industry (e.g. certification)
- API redesign

More info
https://design.ros2.org/articles/why_ros2.html

Difference between ROS 1 and ROS 2

- Support for other OS's
- at least C++11 and Python 3 (C++03 before Noetic and Python 2 in ROS 1)
- Using off the shelf middleware (as opposed to custom)
- Tighter Python integration (e.g. launch files are in Python)
- Real time nodes (with some assumptions though)
- etc…
- Technical changes under the hood, fewer conceptual changes

More info
https://design.ros2.org/articles/changes.html

ROS 2 concepts

- Graph Concepts (similar to ROS 1)
  - nodes, messages, topics …
- Nodes (similar to ROS 1)
- ROS Client library (RCL)
  - rclcpp - C++
  - rclpy - Python
- Discovery
  - similar to ROS 1
  - However nodes establish contacts only if they have compatible Quality of service settings

More info
https://design.ros2.org/articles/changes.html

Nodes

- Run a node with

```
ros2 run <package_name> <executable_name>
```

- List all nodes with

```
ros2 node list
```

- Retrieve information about a node with

```
ros2 node info <node_name>
```

More info
https://index.ros.org/doc/ros2/Tutorials/Understanding-ROS2-Nodes/

Where is the rosmaster?

- ROS1 - master-follower architecture
- ROS2 - replaced by Data Distribution Service (DDS)
- DDS is a distributed service that does the discovery, marshalling and transport in the background

More info

https://www.theconstructsim.com/ros2-in-5-mins-003-where-is-roscore-in-ros2/

https://design.ros2.org/articles/ros_on_dds.html

ROS 2 messages

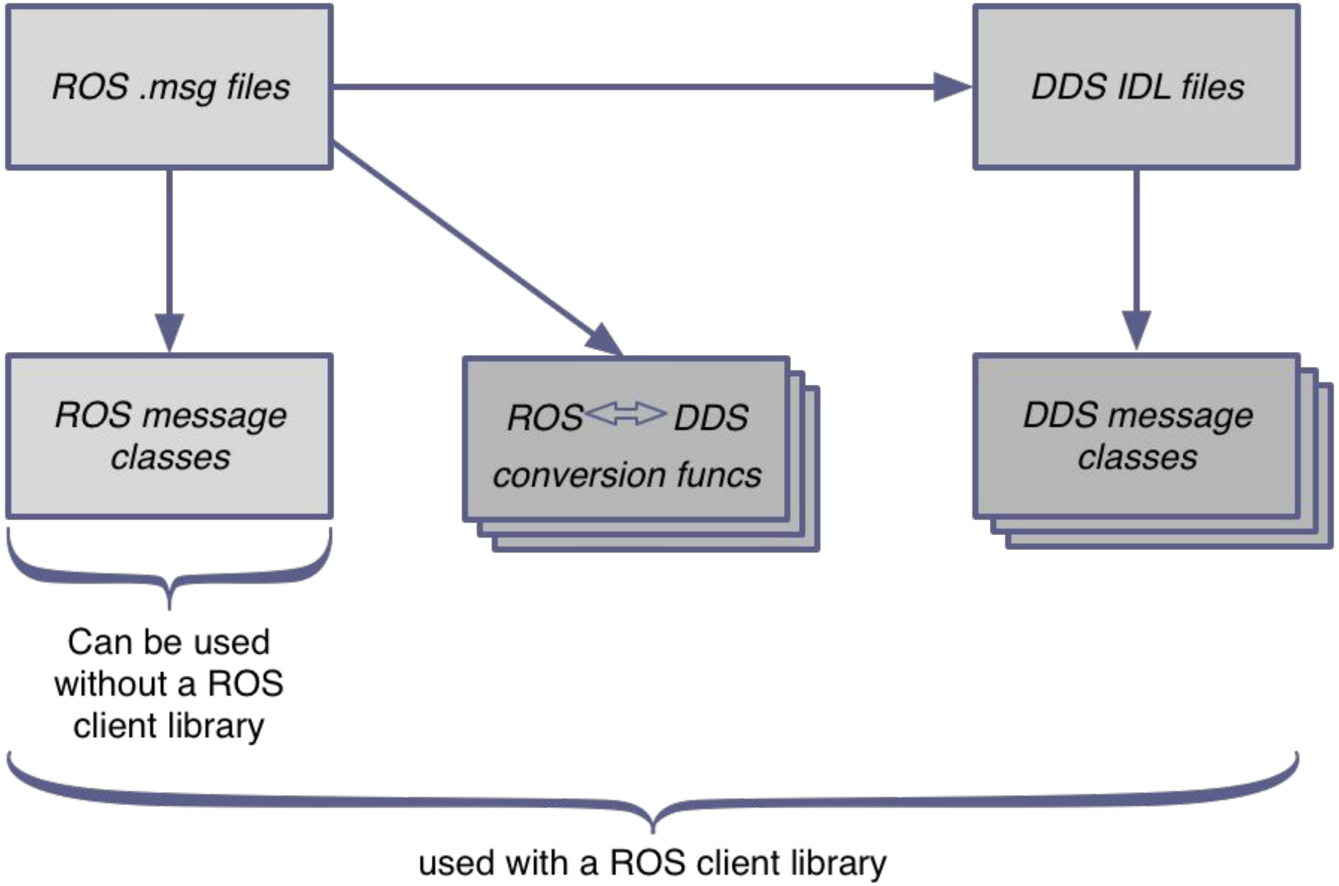
- The messages stay same as in ROS 1
- `.msg` and `.srv` files are converted into `.idl` files and interfaces are created (same as ROS 1)
- You have to create them using `CMakeLists.txt`

```
find_package(rosidl_default_generators
REQUIRED)

rosidl_generate_interfaces(${PROJECT_NAME}
  "msg/Num.msg"
  "srv/AddThreeInts.srv"
  )
```

More info
https://index.ros.org/doc/ros2/Tutorials/Custom-ROS2-Interfaces/

ROS 2 messages


ROS .msg files
DDS IDL files
ROS message classes
ROS <=> DDS conversion funcs
DDS message classes
Can be used without a ROS client library
used with a ROS client library

ROS 2 Workspace Environment

- Defines context for the current workspace, same as ROS 1
- Default workspace loaded with

```
> source /opt/ros/foxy/setup.bash
```

- You can overlay your workspaces, same as in ROS 1
- You can overlay multiple workspaces and more than one ROS 2 distribution installed

Check your ROS2 configuration:

```
printenv | grep ROS
```

More info
https://index.ros.org/doc/ros2/Tutorials/Configuring-ROS2-Environment/

Building packages in ROS 2

- `catkin build` used in ROS1 is replaced by the colcon build tool
- Clone a package:
  - `git clone https://github.com/ros/ros_tutorials.git -b foxy-devel`

- Build from the top level folder (where src is) with:
  - `colcon build`

- You still need to source your workspace
- `source install/setup.bash` -> source workspace and underlay
- `source install/local_setup.bash` -> sources only the workspace

More info
https://index.ros.org/doc/ros2/Tutorials/Colcon-Tutorial/

Creating packages in ROS 2

- You can start by creating a package

  -
    ```
    ros2 pkg create --build-type ament_cmake <package_name>
    ```
- In addition the ros2 can also create a node for you

  -
    ```
    ros2 pkg create --build-type ament_cmake --node-name <node_name> <package_name>
    ```
- You can also list all the dependencies

  -
    ```
    ros2 pkg create <pkg-name> --dependencies [deps]
    ```

More info
https://index.ros.org/doc/ros2/Tutorials/Colcon-Tutorial/

Launching multiple nodes in ROS 2

- No more xml launch files
- Launch files are written in Python
- You can launch a file with:
  - `ros2 launch <pkg_name> <launch_file_name>`
- If you are writing a C++ package, you need to ensure that launch files are copied over

-
  ```
  # Install launch files.
  install(DIRECTORY
    launch
    DESTINATION share/${PROJECT_NAME}/
   )
  ```

More info
https://index.ros.org/doc/ros2/Tutorials/Colcon-Tutorial/

Can you use both ROS1 and ROS2?

- Yes, there is a bridge that will pass messages from both sides
- You need to (in the following order):
  - source ROS1
  - source ROS2
  - export ROS_MASTER_URI
  - run the bridge with: `ros2 run ros1_bridge dynamic_bridge`
- The bridge should be running in the background

More info
https://index.ros.org/p/ros1_bridge/github-ros2-ros1_bridge/

Summary of ROS2 vs ROS1

ROS	ROS 2
Uses TCPROS (custom version of TCP/IP) communication protocol	Uses DDS (Data Distribution System) for communication
Uses ROS Master for centralized discovery and registration. Complete communication pipeline is prone to failure if the master fails	Uses DDS distributed discovery mechanism. ROS 2 provides a custom API to get all the information about nodes and topics
ROS is only functional on Ubuntu OS	compatible with Ubuntu, Windows 10 and OS X
Uses C++ 03 and Python2 before Noetic	Uses C++ 11 (potentially upgradeable) and Python3
ROS only uses CMake build system	ROS 2 provides options to use other build systems
Has a combined build for multiple packages invoked using a single CMakeLists.txt	Supports isolated independent builds for packages to better handle inter-package dependencies
Data Types in message files do not support default values	Data types in message files can now have default values upon initialization
roslaunch files are written in XML with limited capabilities	roslaunch files are written in Python to support more configurable and conditioned execution
Cannot support real-time behavior deterministically even with real-time OS	Supports real-time response with apt RTOS like RTPREEMPT

https://maker.pro/ros/tutorial/robot-operating-system-2-ros-2-introduction-and-getting-started

ROS 2 resources

Awesome ROS 2
https://design.ros2.org/articles/changes.html

ROSCon Content
https://index.ros.org/doc/ros2/ROSCon-Content/#roscon

ROS Index
https://index.ros.org/doc/ros2/

ROS2 package template
https://github.com/leggedrobotics/ros_best_practices/tree/foxy

(package template is still work in progress)