AA 274
Principles of Robotic Autonomy

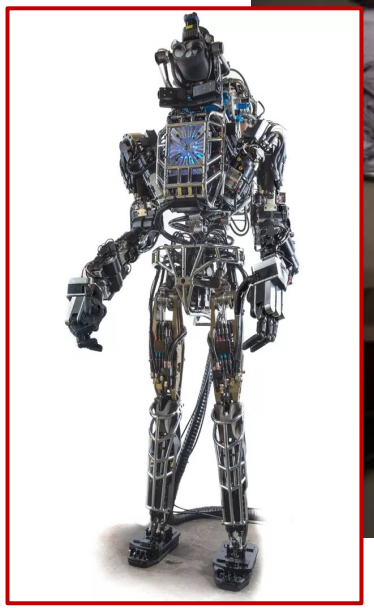
The Robot Operating System (ROS)

Stanford University

IPRL

Writing Software for Robotics

- Robotics requires very complex software
- The software you will deal with in AA274A has ***way*** more moving parts than what you've dealt with in most other classes…



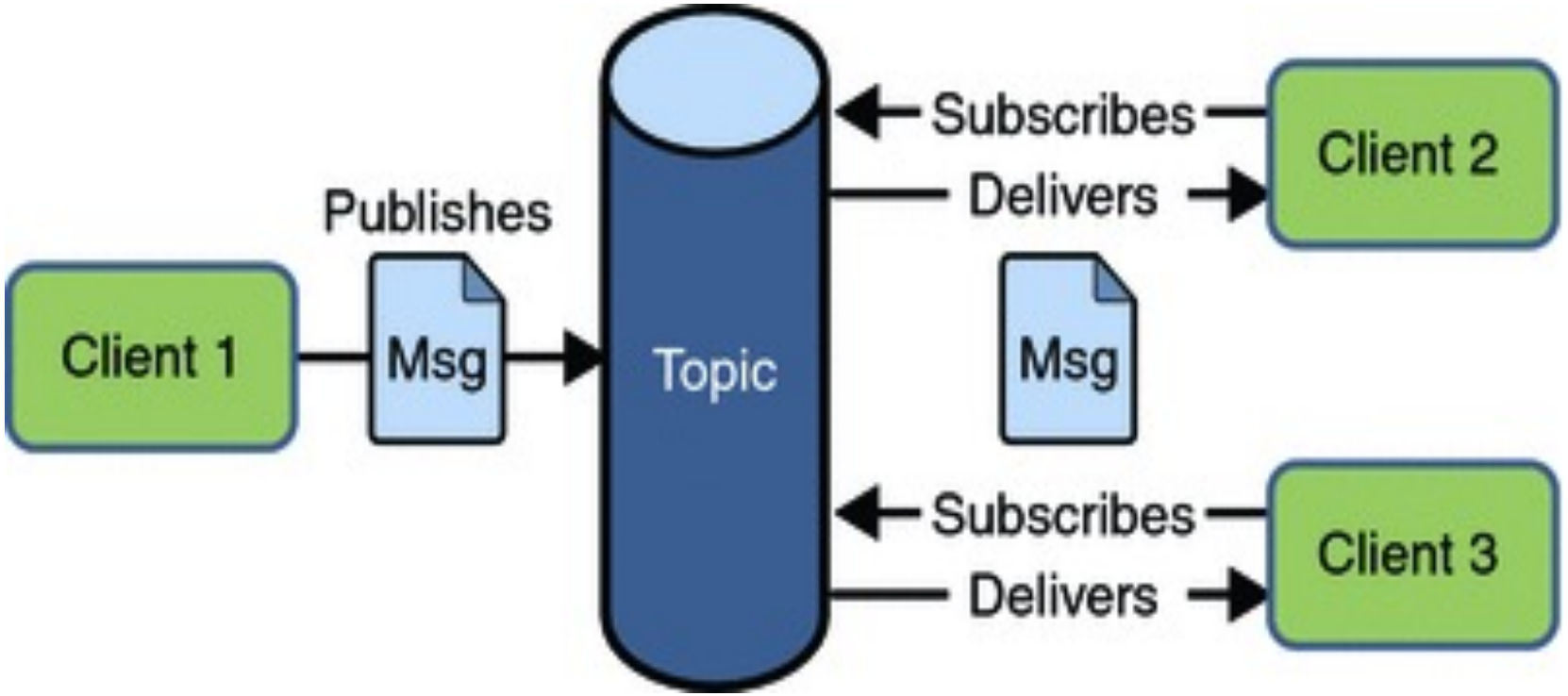
Writing Software for Robotics

- We deal with the complexity through **modularity**
- We enable modularity by following the right **design pattern:** "a general, reusable solution to a commonly occurring problem within a given context in software design" – Wikipedia

The Pub/Sub Design Pattern

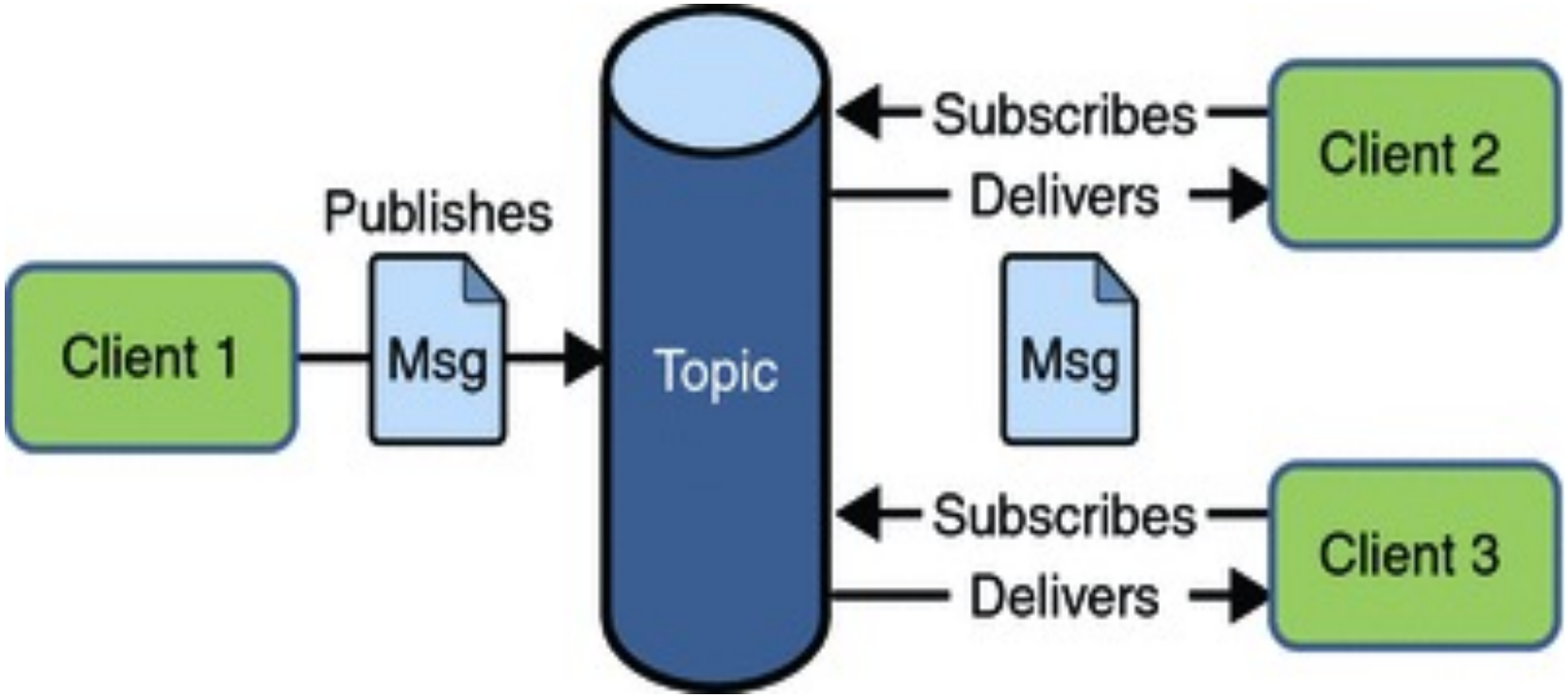
- We divide our software into individual components
- We define “topics” (think chat rooms) where components can broadcast information to anyone listening
- Each component can:
  - *Publish*: send messages to a topic regardless of whether someone is listening or not
  - *Subscribe*: receive messages on a topic if anyone is sending them regardless of who

The Pub/Sub Design Pattern



Note: there are countless ways to **IMPLEMENT** pub/sub!

The Pub/Sub Design Pattern



Note: there are countless ways to **IMPLEMENT** pub/sub!

You already use Pub/Sub every day! Where???

Alternatives to Pub/Sub

- Request/Reply (RPC)
- Push/Pull
- Data binding (e.g. shared data members)
- Observers

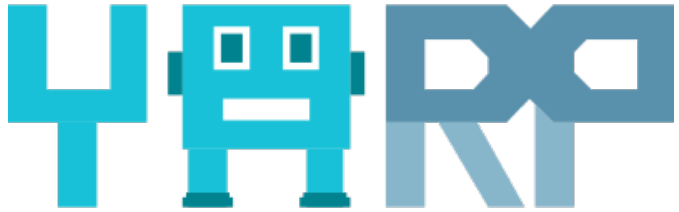
What is ROS?

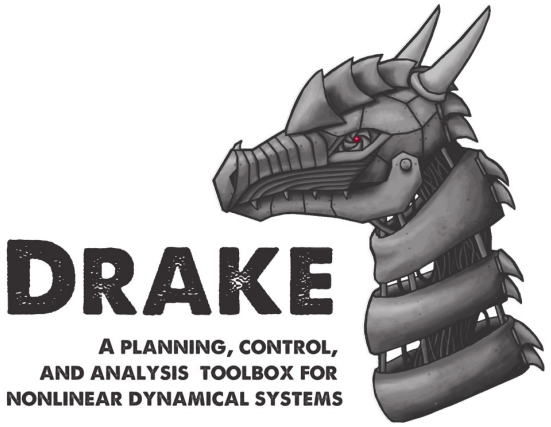
Depending on who you are talking to…

- An **implementation of pub/sub** geared towards robotic applications and that is network-aware
- Lots of open-source software shared by the community:
  - SLAM (gmapping, amcl)
  - Vision (OpenCV, PCL, OpenNI)
  - Arm Navigation (MoveIt)
  - Simulation (Gazebo)

Are there “Alternatives” to ROS?

- LCM
- Drake
- Player
- YARP
- Orocos
- MRPT
- And many others!



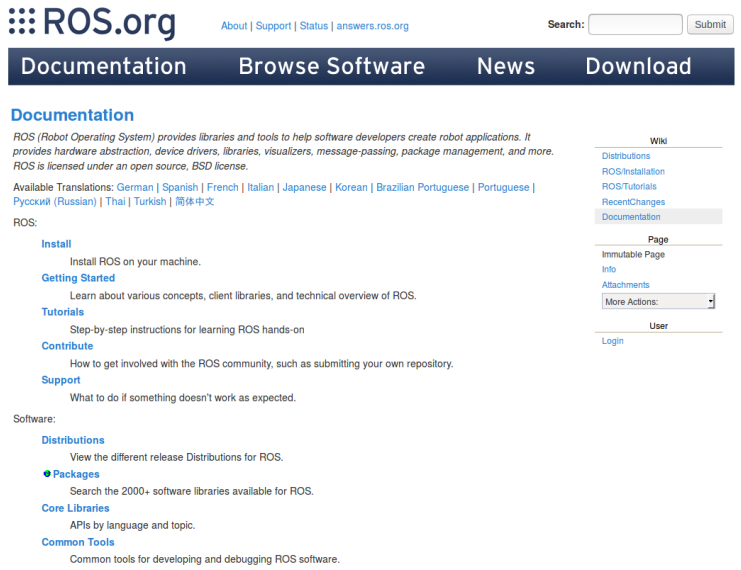


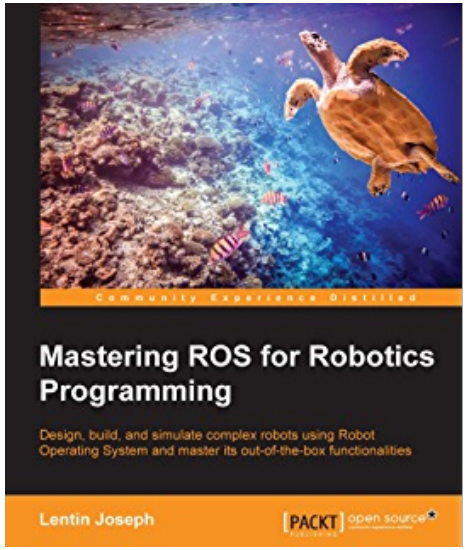
Why is ROS popular in industry?

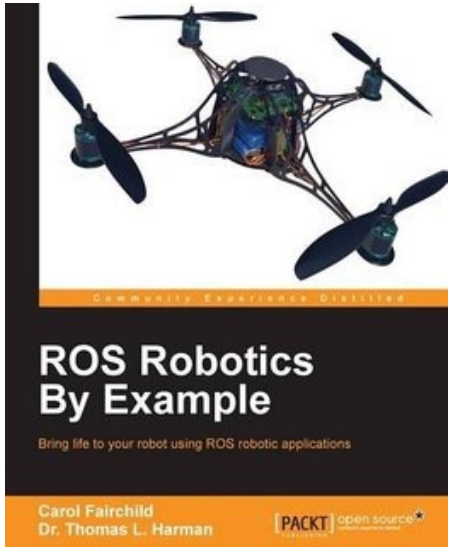
- Not reinventing the wheel is generally good
- Robotics is hard! It's great to offload some of the work to smart people
- ROS is now 12 years old and still going strong

Why are we using ROS in AA274?

- The closest thing we have to an “industry standard”
- It’s an insurance policy for you (stability, online teaching resources)







ROS – Robot Operating System

- 2007-Today
  - Stanford AI Robot (STAIR)
  - Willow Garage founded by Scott Hassan (eGroups, Google, Stanford Digital Libraries)
  - Willow awards 11 $400k PR2 robots to Universities
  - OSRF (Open Source Robotics Foundation) created to maintain ROS and Gazebo
  - ROS is everywhere!

ROS Integrates Existing Projects

- OpenCV (computer vision)
- Stage, Gazebo (simulation)
- OpenSLAM (navigation)
- Orocos KDL (arm navigation)
- Many ROS “wrappers” to existing software

The Main Software Components

1) Master
2) Nodes

- Nodes talk to each other over topics (think chat rooms). Master coordinates the whole thing
- Message types: abstraction away from specific hardware
  - Camera image
  - Laser scan data
  - Motion control

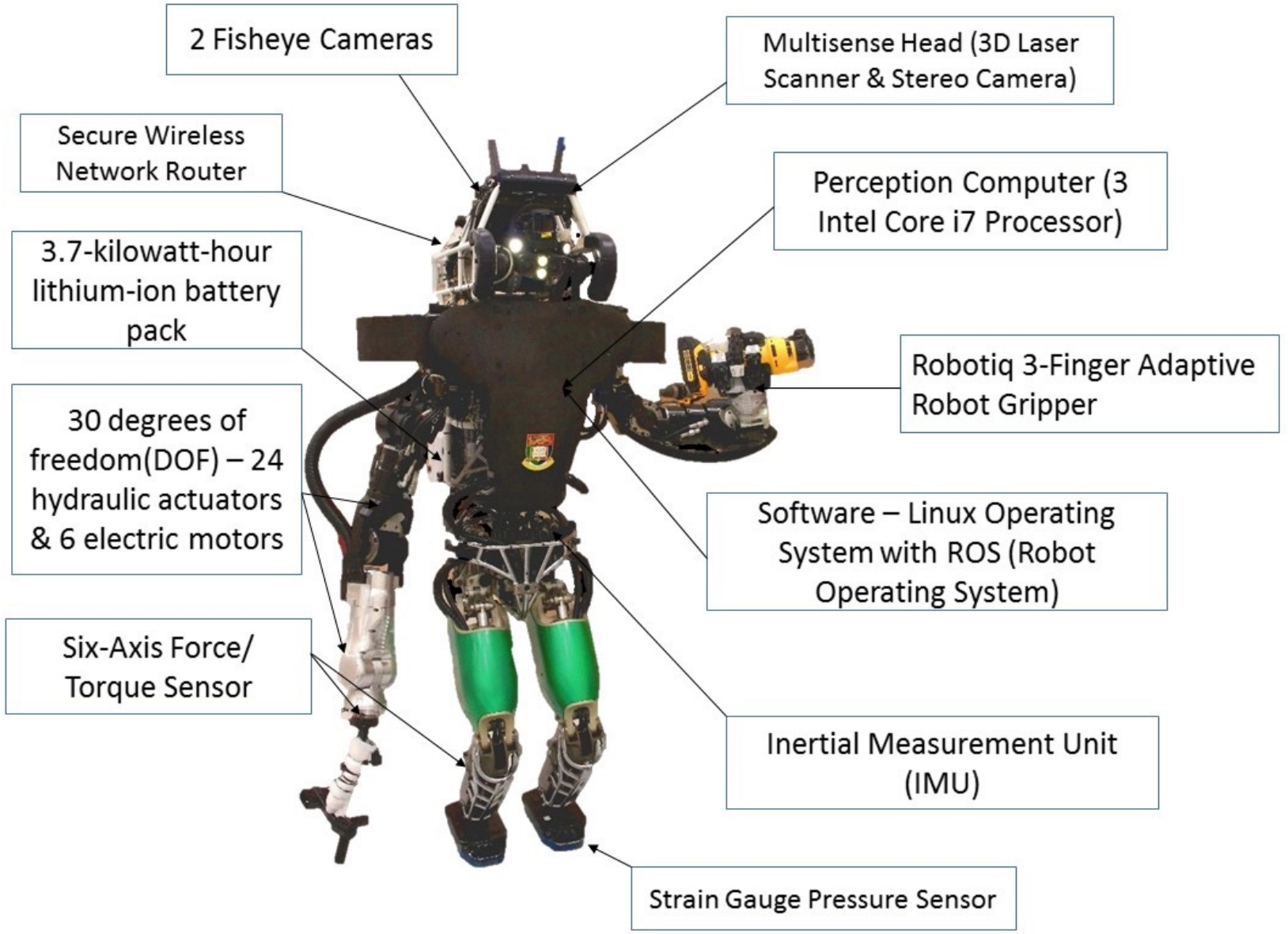
ROS Node

- A process (typically Python or C++) that runs some computation
- The “fundamental” building block
- Can act as a subscriber, publisher or both
- Nodes talk to each other over “topics”
- Run them using rosrun <package> <node>
- Initialize using rospy.init_node()

Note: nodelets are different. They are not individual processes, they share memory

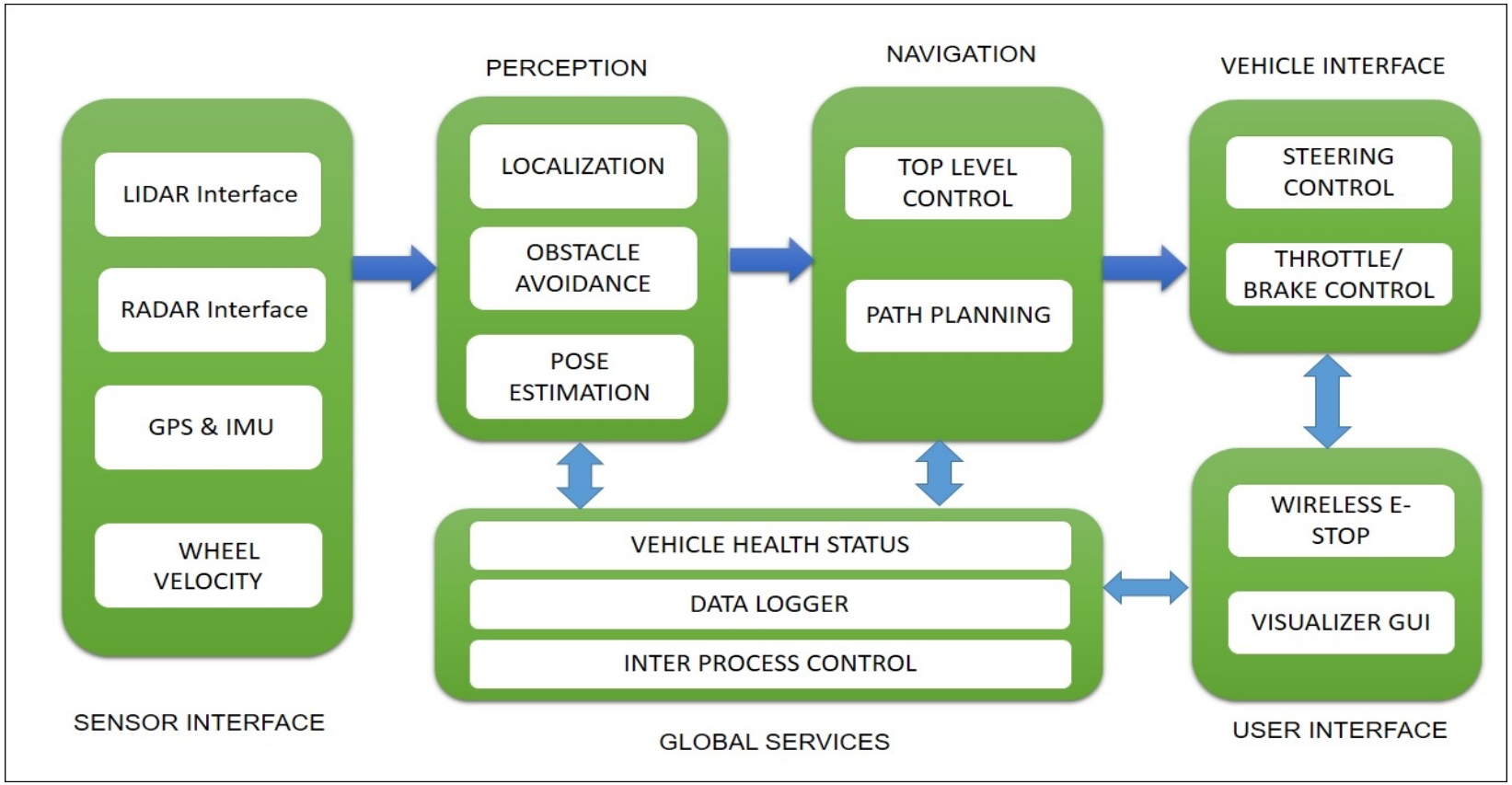
Node Examples

Sensors and **actuators** are wrapped in self-contained, reusable software containers called “nodes”



Node Examples

Higher level operations also become nodes in the ROS computational architecture



More Concrete Node Examples

- LiDAR node publishes laser scan arrays
- Camera node publishes RGB images (+depth if RGBD) and camera info (resolution, distortion coefficients)
- Mobile robot controller publishes odometry values (e.g. x-y coordinates and velocities, +z for UAVs or underwater vehicles)
- Navigation node subscribes to LiDAR and odometry messages, publishes motion control messages

ROS Master

- A process that is in charge of coordinating nodes, publishers and subscribers
- Also provides a global parameter server
- Exactly one of them running at any time
- Messages do NOT go through Master (i.e. peer-to-peer)
- Nodes will not be able to find each other without Master

Sending Messages

- `pub = rospy.Publisher()`
- `msg = ...`
- `pub.publish(msg)`

ROS Node - Publisher

```python
#!/usr/bin/env python
import rospy
from std_msgs.msg import String

def talker():
    rospy.init_node('talker', anonymous=True)

    pub = rospy.Publisher('chatter', String, queue_size=10)

    rate = rospy.get_param('~rate', 1)
    ros_rate = rospy.Rate(rate)

    rospy.loginfo("Starting ROS node talker...")

    while not rospy.is_shutdown():
        msg = "Greetings humans!"

        pub.publish(msg)
        ros_rate.sleep()

if __name__ == '__main__':
    try:
        talker()
    except rospy.ROSInterruptException:
        pass
```

Monitoring Messages

- You can check if you are sending messages using the *rostopic* command line tool:

- `rostopic list` – lists all the active topics
- `rostopic echo <topic>` – prints messages received on <topic>
- `rostopic hz <topic>` – measures topic publishing rate

Receiving Messages

- `rospy.Subscriber("chatter", String, callback)`
- `def callback(msg): …`

(in C++ need to call `spinOnce()`, not in Python)

ROS Node - Subscriber

```python
#!/usr/bin/env python
import rospy
from std_msgs.msg import String

def callback(msg):
    rospy.loginfo("Received: %s", msg.data)

def listener():
    rospy.init_node('listener', anonymous=True)

    rospy.Subscriber("chatter", String, callback)

    rospy.loginfo("Listening on the chatter topic...")

    rospy.spin()

if __name__ == '__main__':
    listener()
```

ROS Launch Files

- Simple XML files that allow you to
  - Launch multiple nodes at once
  - Set parameters for those nodes
  - Start Master

- `roslaunch <package> <file>.launch`

ROS Launch File Example

```
<launch>
  <!-- Start the talker node -->
  <node name="talker" pkg="aa274" type="talker.py" output="screen">
     <param name="rate" value="5"/>
  </node>
</launch>
```

A Case Study

- Edge detection in camera images

Node 1 – Camera Driver
Subscribes to: Nothing
Publishes: Camera images

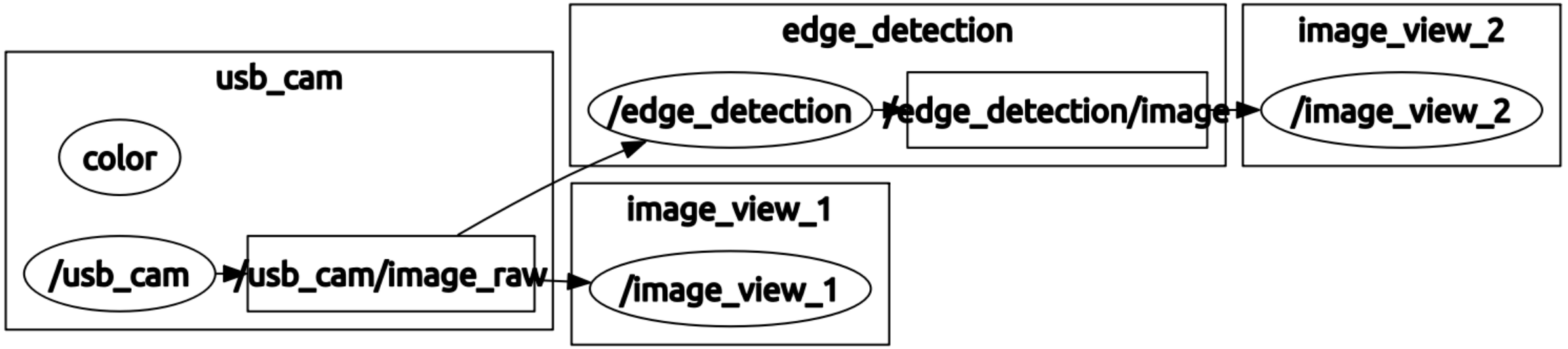
Node 2 – Edge Detection
Subscribes to: Camera images
Publishes: Image with edges

Node 3 – image_view
Subscribes to: Camera images
Publishes: Nothing

Node 4 – image_view
Subscribes to: Image with edges
Publishes: Nothing

A Case Study

- Edge detection in camera image
- rqt_graph



ROS Launch File for Edge Detection

```
<launch>
  <arg name="video_device" default="/dev/video0" />

  <include file="$(find aa274)/launch/usbcam_driver.launch">
     <arg name="video_device" value="$(arg video_device)" />
  </include>

  <node name="image_view_1" pkg="image_view" type="image_view">
     <remap from="image" to="/camera/image_color" />
     <param name="autosize" value="true"/>
  </node>

  <node name="image_view_2" pkg="image_view" type="image_view">
     <remap from="image" to="/edge_detection/image" />
     <param name="autosize" value="true" />
  </node>

  <node name="edge_detection" pkg="opencv_apps" type="edge_detection">
     <remap from="image" to="/camera/image_color" />
     <param name="debug_view" value="false" />
  </node>
</launch>
```

Developing with ROS

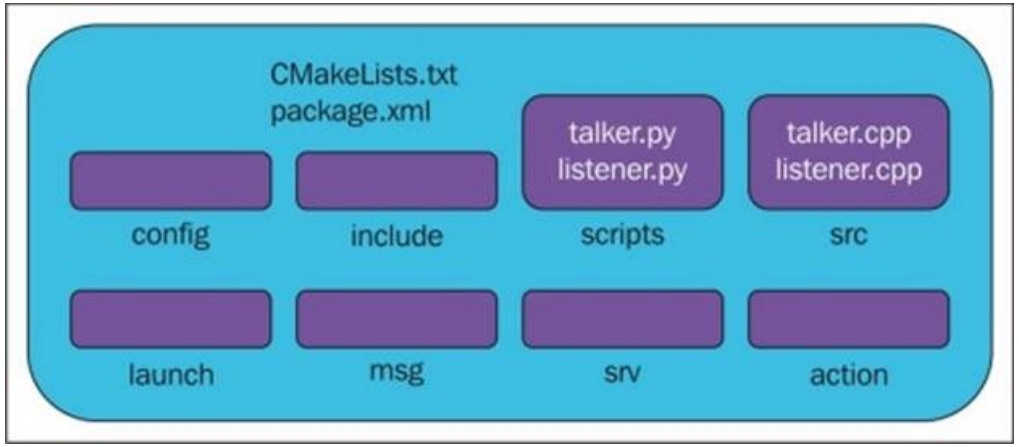
- **Catkin workspace**: a directory that contains all your ROS development
- It sets the right environment variables
- It knows how to compile your nodes (using *cmake which in turn uses a compiler*)

The commands you need to know:

- `mkdir -p ~/catkin_ws/src`
- `cd ~/catkin_ws`
- `catkin_make`

ROS Packages

- The basic organization structure for your nodes
- Usually corresponds to a “functionality” (e.g. a SLAM package)
- Can contain code for multiple nodes
- Directory structure:



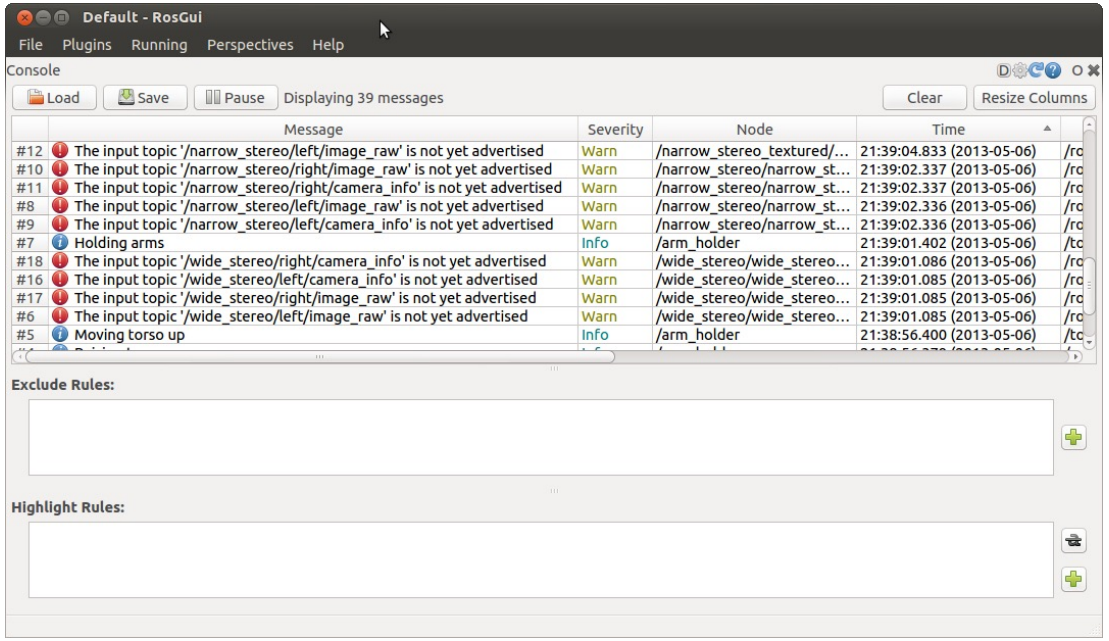
The command you need to know:

```
catkin_create_pkg <name> roscpp rospy std_msgs
```

Debugging

- `rospy.loginfo()`
- `rqt_console`
- `rosbag record <topic>`
- `rosbag play file.bag`

- **pdb – Python Debugger**
  - `import pdb`
  - `pdb.set_trace()`



Creating Custom Messages

- Write message definitions (.msg) that are language agnostic
- ROS generates the right files so that roscpp and rospy can use your message
- `rosmsg show student`

```
[aa274/Student]:
string name_first
string name_last
uint8 age
uint32 grade
```

Primitive Type	Serialization	C++	Python
bool (1)	unsigned 8-bit int	uint8_t (2)	bool
int8	signed 8-bit int	int8_t	int
uint8	unsigned 8-bit int	uint8_t	int (3)
int16	signed 16-bit int	int16_t	int
uint16	unsigned 16-bit int	uint16_t	int
int32	signed 32-bit int	int32_t	int
uint32	unsigned 32-bit int	uint32_t	int
int64	signed 64-bit int	int64_t	long
uint64	unsigned 64-bit int	uint64_t	long
float32	32-bit IEEE float	float	float
float64	64-bit IEEE float	double	float
string	ascii string (4)	std::string	str
time	secs/nsecs unsigned 32-bit ints	ros::Time	rospy.Time
duration	secs/nsecs signed 32-bit ints	ros::Duration	rospy.Duration

ROS Services

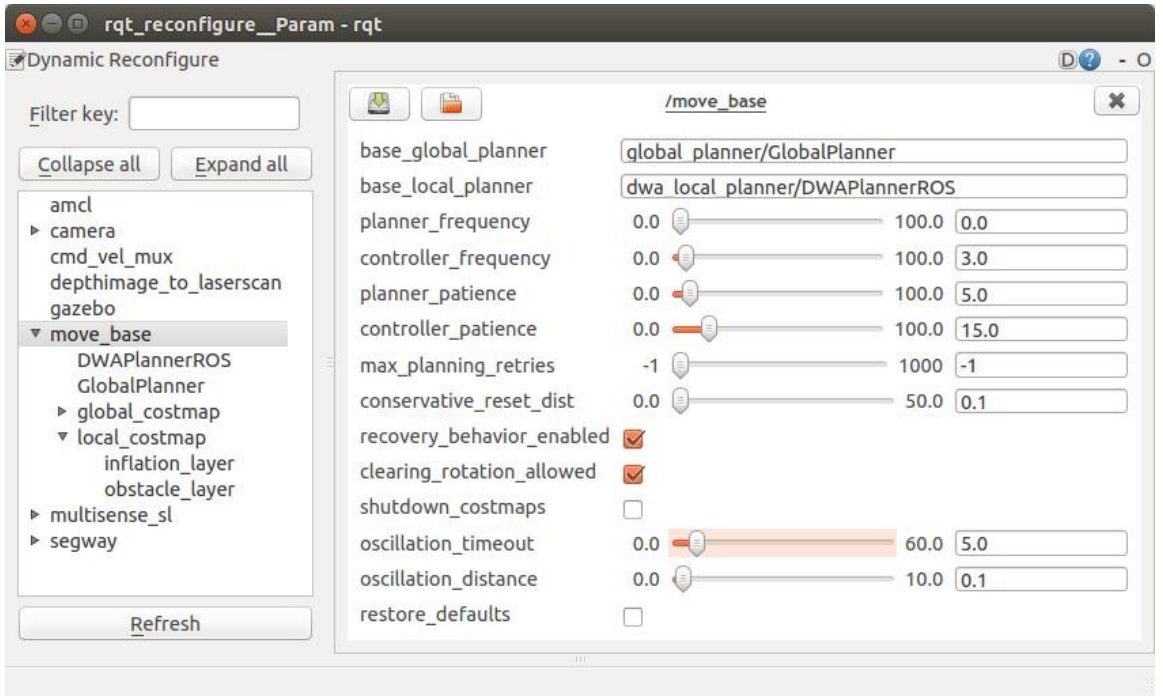
- A different way for nodes to pass messages to each other
- Request/Response scheme (not Pub/Sub!)
- Examples:
  - Turn a light or LED on or off
  - Assign a name to a face and retrain face recognizer
  - Spawn a new model in the Gazebo simulator

The Parameter Server

- Parameters are stored under namespaces; e.g.
  - `/move_base/local_costmap/height`
  - `/usb_cam/framerate`
  - `/gazebo/time_step`
- Setting and getting parameters:
  - `rosparam set param_name param_value`
  - `param_value = rospy.get_param("param_name")`
- NOTE: Setting a parameter does not affect a running node!

Dynamic Reconfigure

- Some nodes provide dynamically changeable parameters
  - `rosrun rqt_reconfigure rqt_reconfigure`

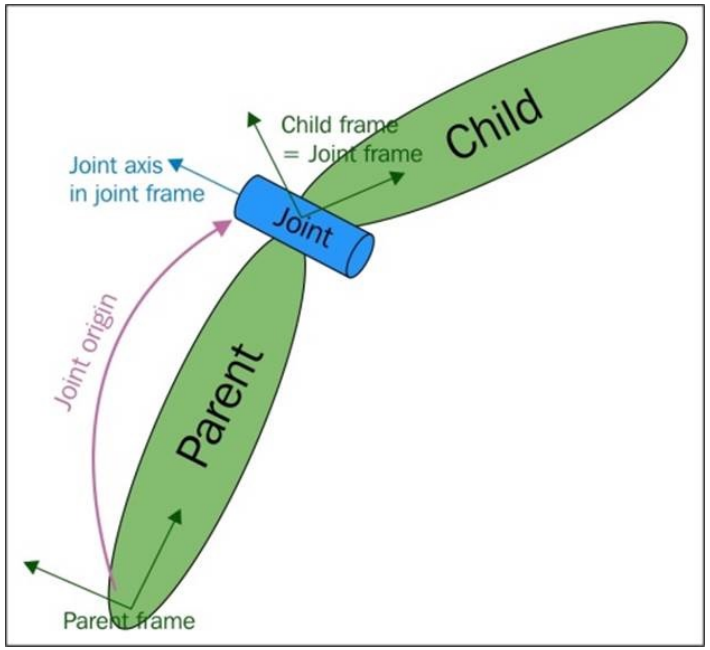


URDF

- Universal Robot Description Format
- An XML file that describes the kinematic chain of your robot

```
<link name="base_link">
  <visual>
    <geometry>
      <cylinder length="0.6" radius="0.2"/>
    </geometry>
    <material name="blue">
      <color rgba="0 0 .8 1"/>
    </material>
  </visual>
  <collision>
    <geometry>
      <cylinder length="0.6" radius="0.2"/>
    </geometry>
  </collision>
  <inertial>
    <mass value="10"/>
    <inertia ixx="0.4" ixy="0.0" ixz="0.0" iyy="0.4" iyz="0.0" izz="0.2"/>
  </inertial>
</link>
```

```
<joint name="head_swivel" type="continuous">
  <parent link="base_link"/>
  <child link="head"/>
  <axis xyz="0 0 1"/>
  <origin xyz="0 0 0.3"/>
</joint>
```



Gazebo

- Same code that will run in production
- Physics is mostly accurate

Some more libraries you will hear about…

- TF: coordinate frame transform library
- Actionlib: processes with goals and feedback
- dynamic_reconfigure: making nodes configurable on the fly

Getting help

- ROS wiki (http://wiki.ros.org/)
- Github
- Stack Overflow
- The Construct / Robot Ignite Academy
- Google :)

Next time

- Motion control