

AA 274

# Principles of Robotic Autonomy

The Robot Operating System (ROS)

# ROS – Robot Operating System

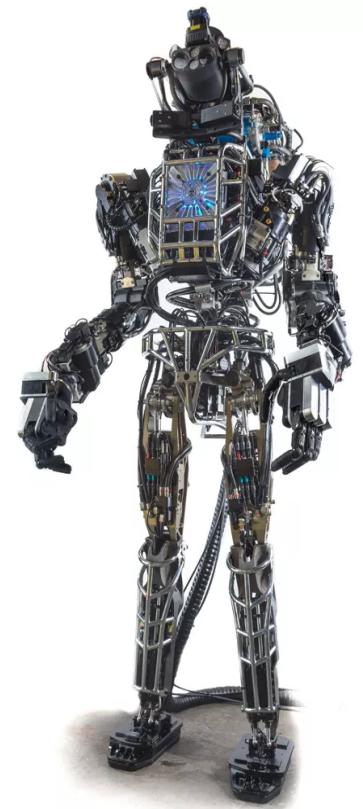
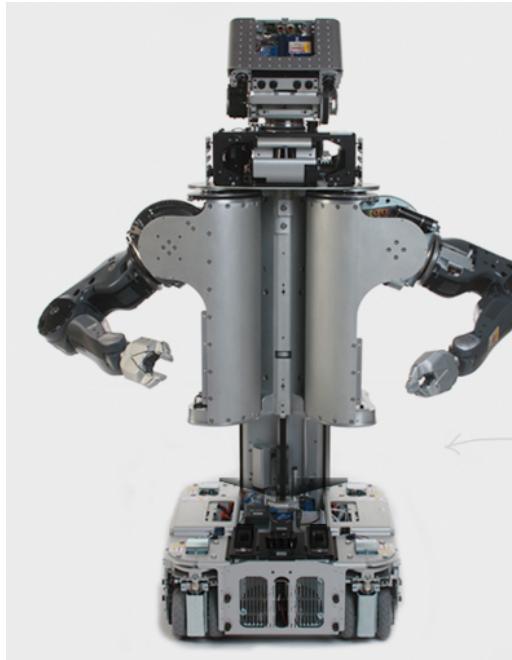
- 2007-Today
  - Stanford AI Robot (STAIR)
  - Willow Garage founded by Scott Hassan (eGroups, Google, Stanford Digital Libraries)
  - Willow awards 11 \$400k PR2 robots to Universities
  - OSRF (Open Source Robotics Foundation) created to maintain ROS and Gazebo
  - ROS is everywhere!

# ROS Integrates Existing Projects

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

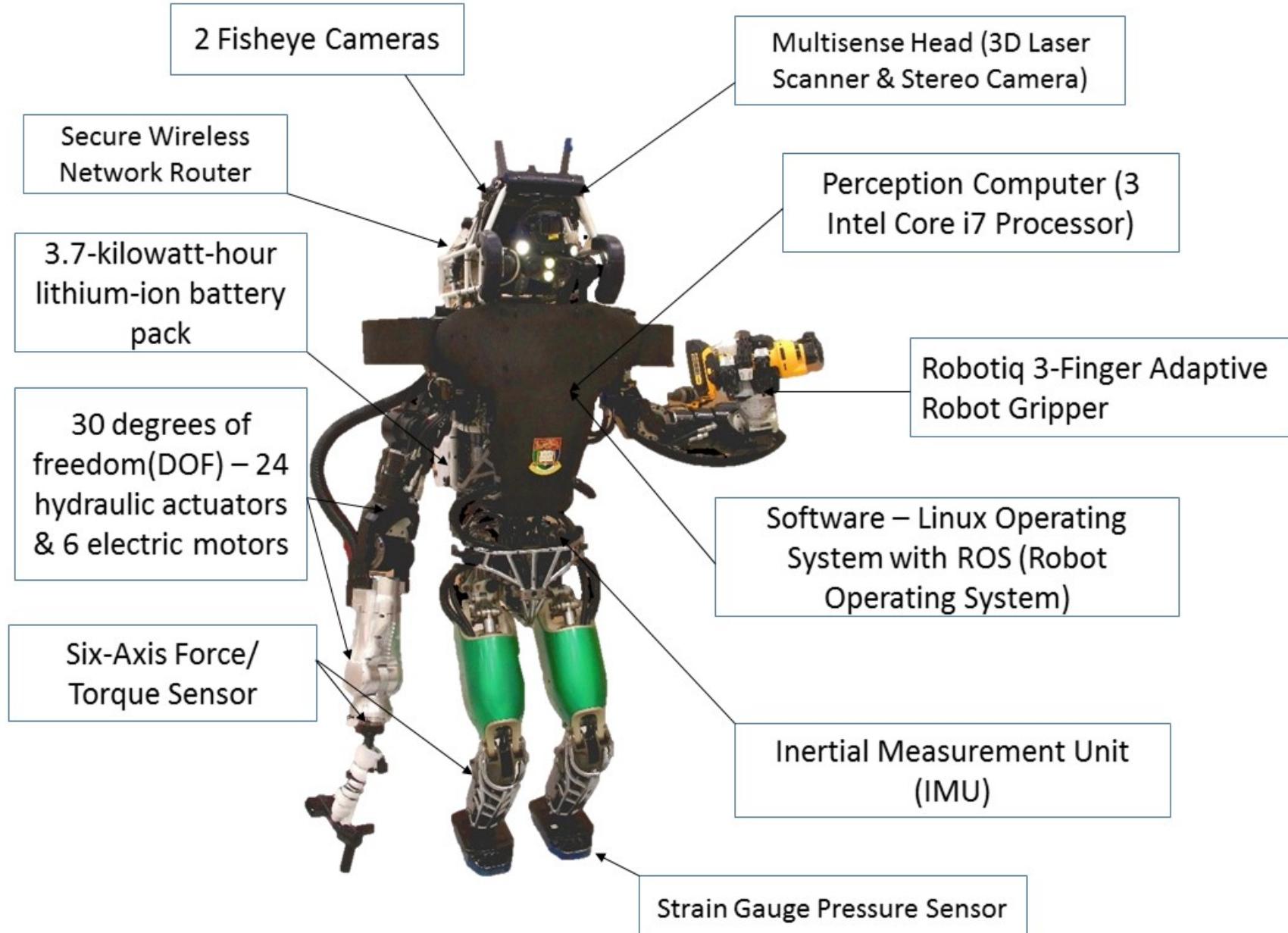
# Writing Software for Robotics

- Robotics requires very complex software
- **Modularity:** a powerful way to handle that complexity
- **Pub/Sub:** a design pattern that enables modularity



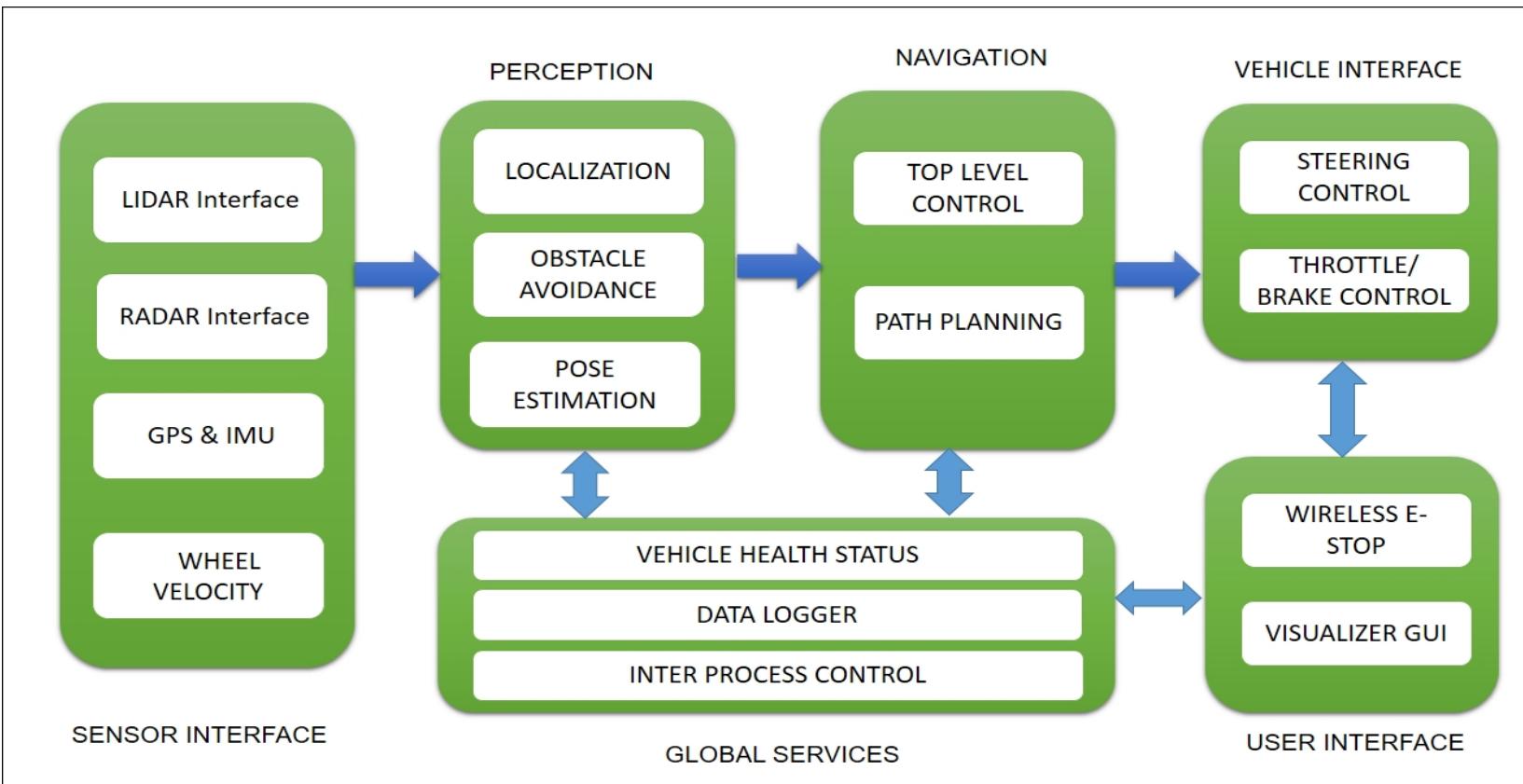
# Modularity

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



# Modularity

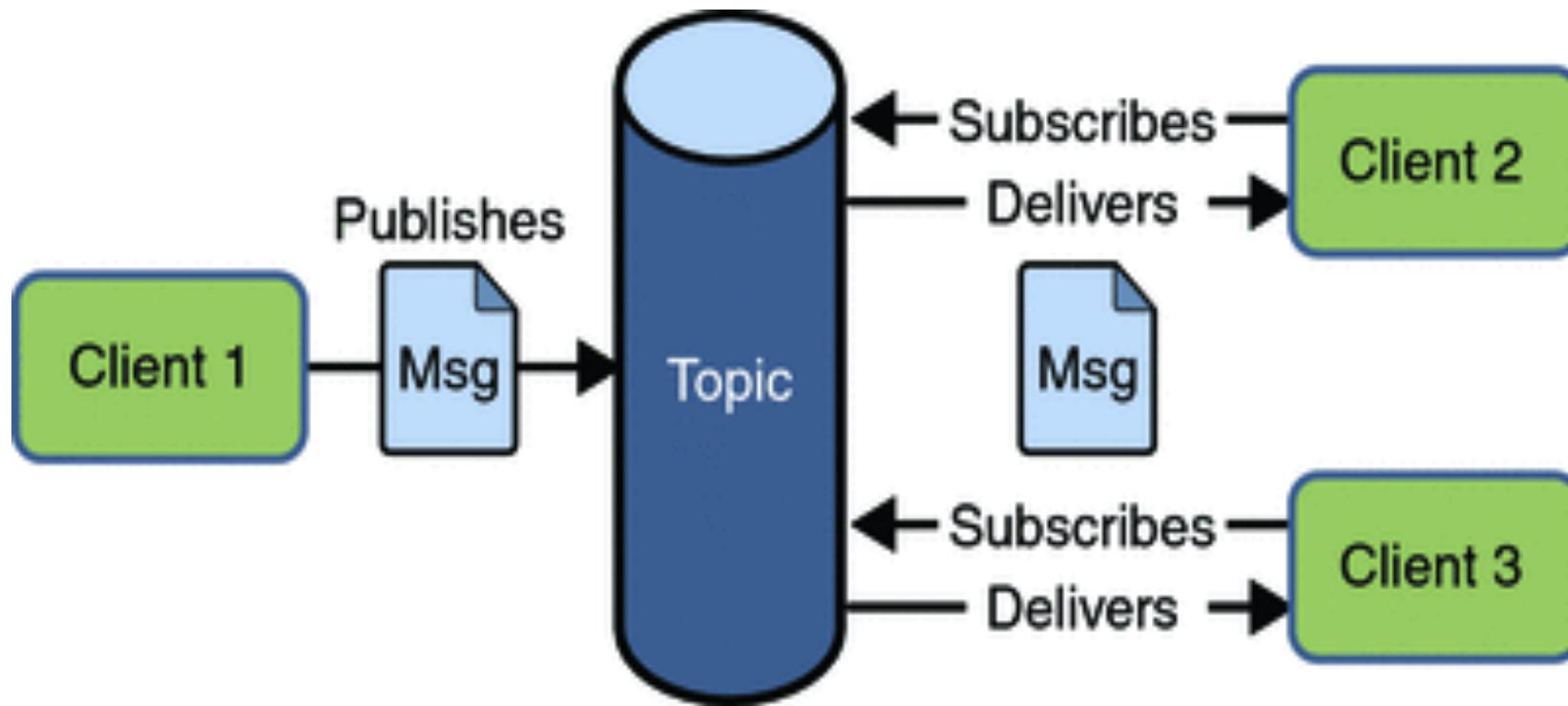
Higher level operations also become nodes in the ROS computational architecture



# The Pub/Sub Design Pattern

- Stands for Publish-Subscribe
- A way for the different parts of a system to communicate with each other
- Each component (i.e. node) can:
  - *Publish*: send messages regardless of whether someone is listening
  - *Subscribe*: receive messages if anyone is sending them regardless of who

# The Pub/Sub Design Pattern



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

# 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

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

# Why ROS 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 ROS in AA274?

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

 ROS.org    [About](#) | [Support](#) | [Status](#) | [answers.ros.org](#)

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**Documentation**

ROS (Robot Operating System) provides libraries and tools to help software developers create robot applications. It provides hardware abstraction, device drivers, libraries, visualizers, message-passing, package management, and more. ROS is licensed under an open source, BSD license.

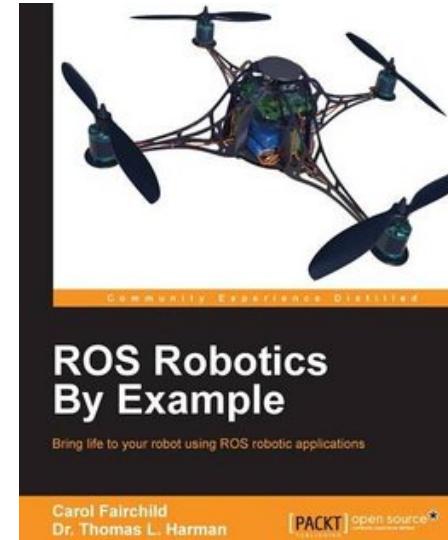
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ROS:

- [Install](#)   Install ROS on your machine.
- [Getting Started](#)   Learn about various concepts, client libraries, and technical overview of ROS.
- [Tutorials](#)   Step-by-step instructions for learning ROS hands-on
- [Contribute](#)   How to get involved with the ROS community, such as submitting your own repository.
- [Support](#)   What to do if something doesn't work as expected.

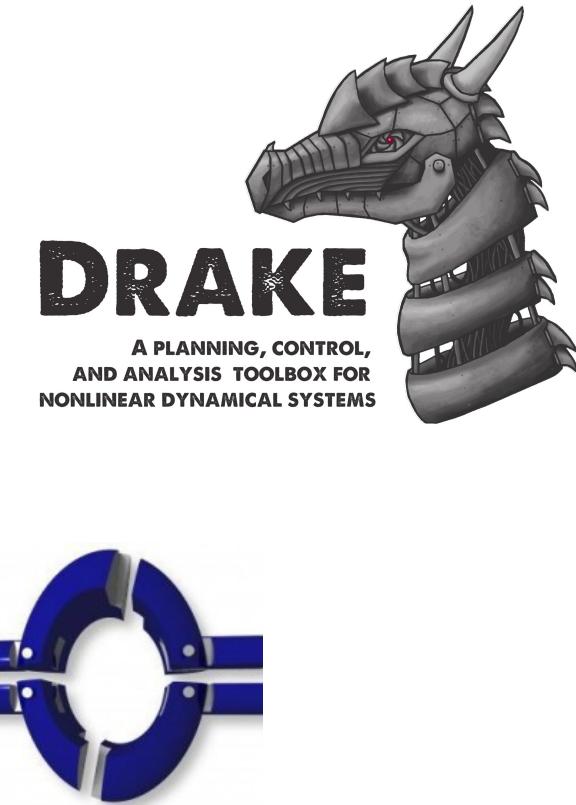
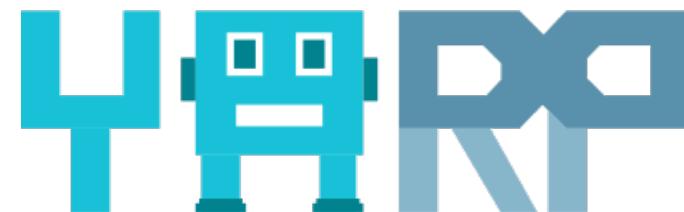
Software:

- [Distributions](#)   View the different release Distributions for ROS.
- [• Packages](#)   Search the 2000+ software libraries available for ROS.
- [Core Libraries](#)   APIs by language and topic.
- [Common Tools](#)   Common tools for developing and debugging ROS software.



# Are there “Alternatives” to ROS?

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



# The Main Components

- Master
- 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*

# ROS Master

- A process that is in charge of coordinating nodes, publishers and subscribers
- 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

```
#!/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

```
#!/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

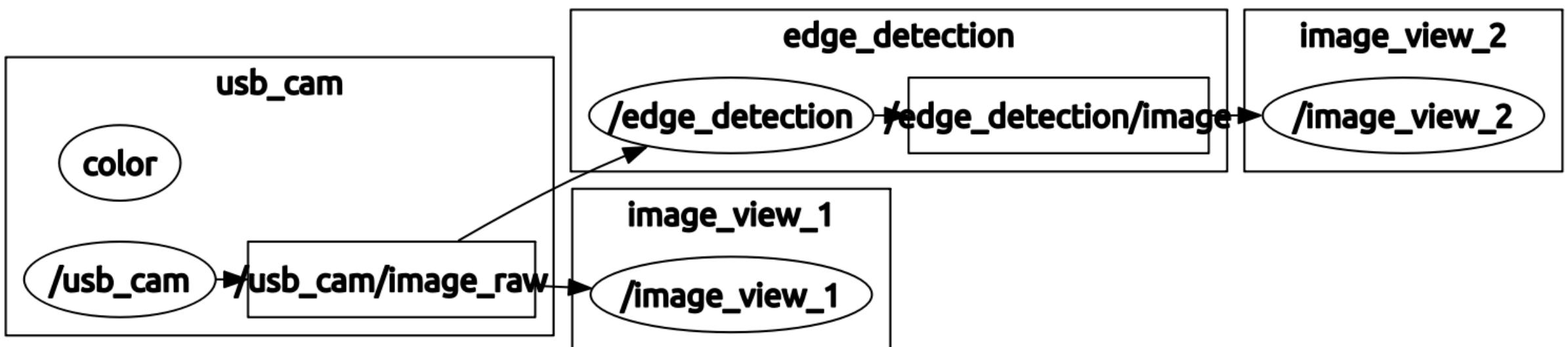
## **Node 4 – image\_view**

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

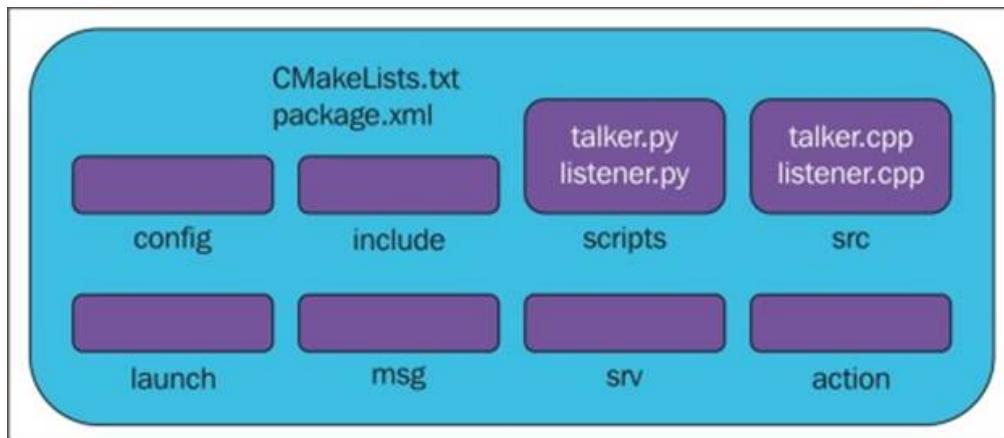
- **Catkin workspace:** a directory that contains all your ROS development
- It sets the right environment variables
- It knows how to compile your nodes (*using cmake which in turn uses a compiler*)

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:

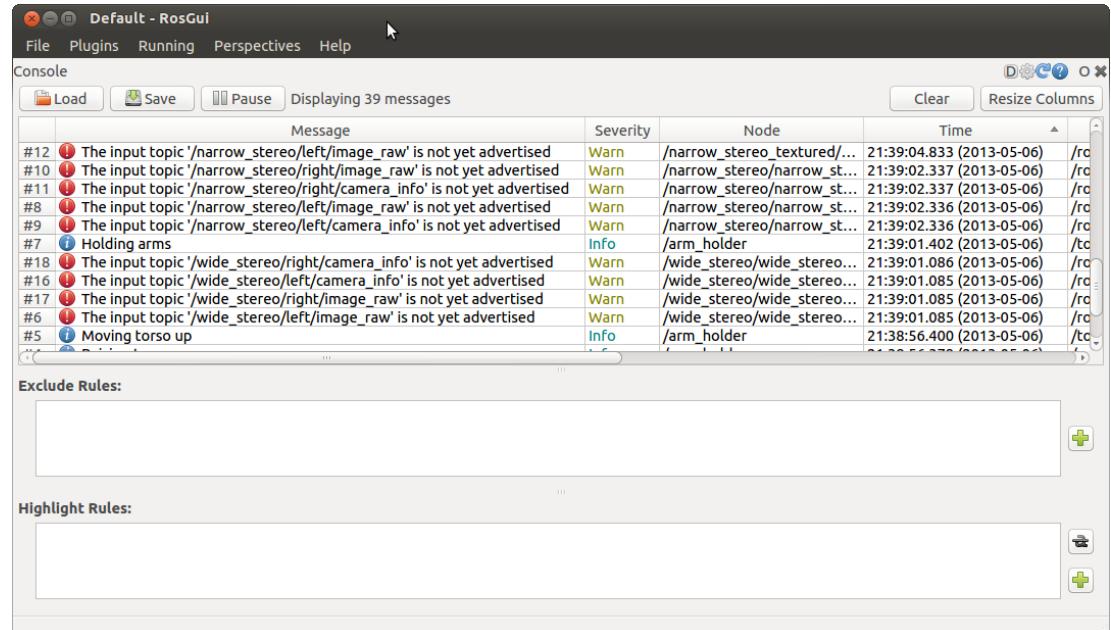


**The command you need to know:**

```
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

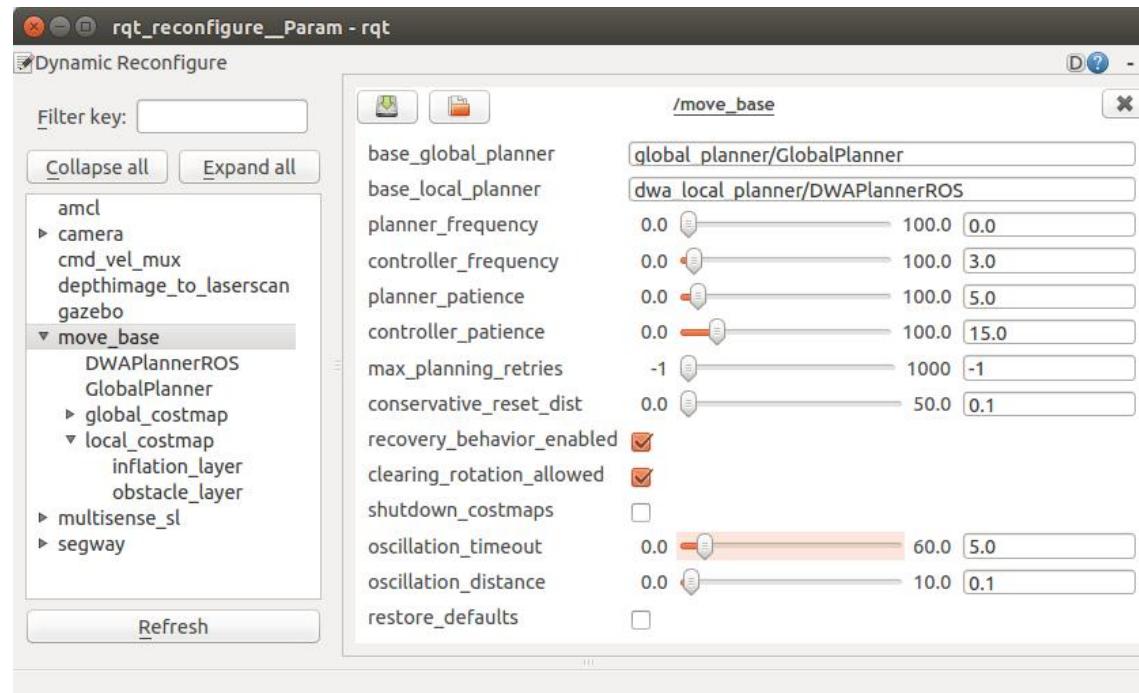
- A different way for nodes to pass messages to each other
- Request/Response scheme (not Pub/Sub!)
- Examples:
  - Turn a light or LED on or off
  - Assign a name to a face and retrain face recognizer
  - Spawn a new model in the Gazebo simulator

# 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

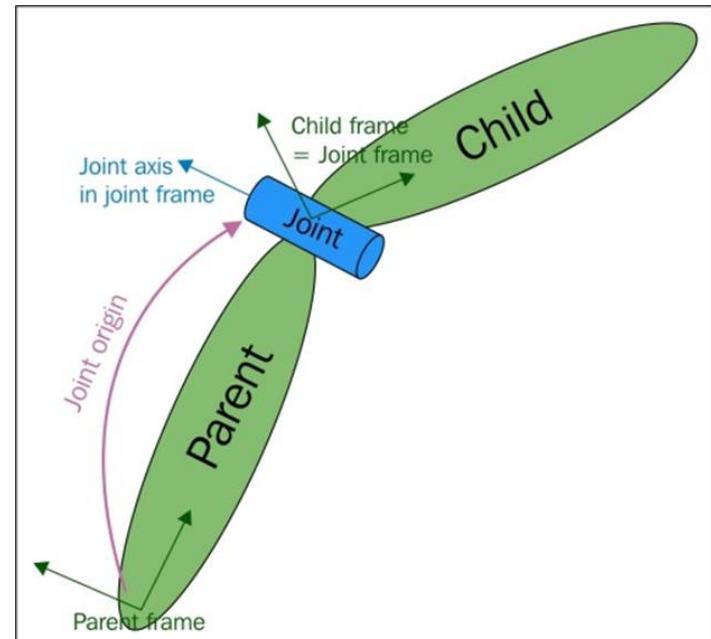
- Some nodes provide dynamically changeable parameters
  - `rosrun rqt_reconfigure rqt_reconfigure`



# 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...

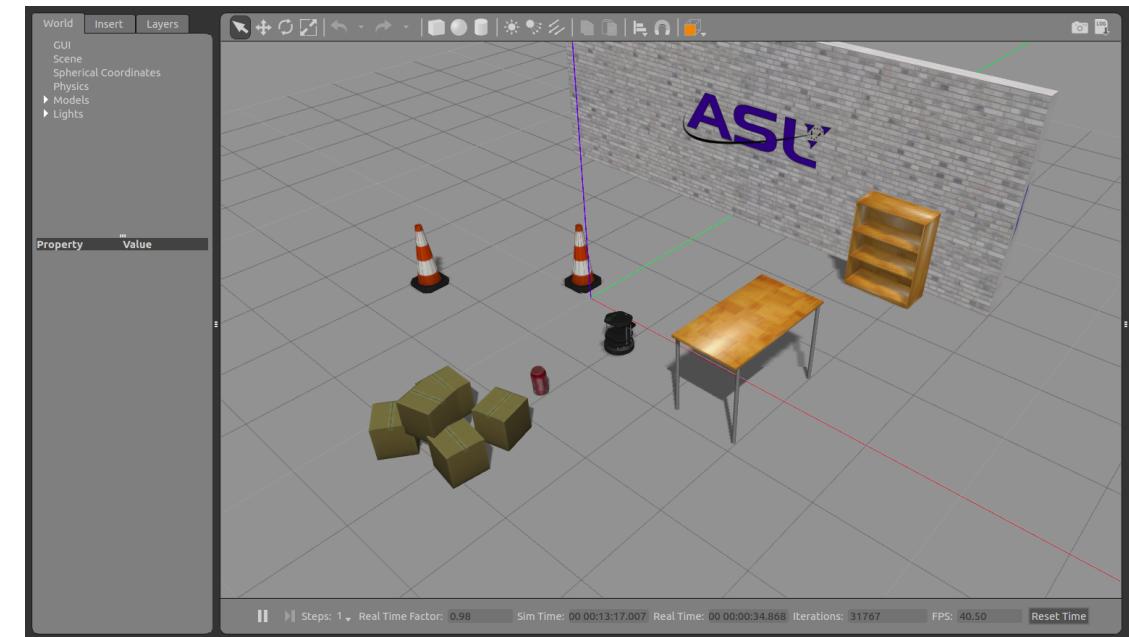
- TF: coordinate frame transform library
- Actionlib: processes with goals and feedback
- dynamic\_reconfigure: making nodes configurable on the fly

# Getting help

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

# Pset 1

- 1) Install VMWare on your computer (or dual-boot)
- 2) Download the VM on canvas and open it
- 3) Make sure you can run the simulation
- 4) Get the simple publisher/subscriber working
- 5) Finish implementing the controller provided



# Next time

- Deep dive in motion control
  - Open-loop optimal control
  - Differential flatness

