AA 274
Principles of Robotic Autonomy
The Robot Operating System (ROS)
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
- 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

```xml
<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:
```bash
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
```
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
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

- Github
- Stack Overflow
- The Construct / Robot Ignite Academy
- Google :(
ROS 2

• A major overhaul of ROS
• Not yet feature equivalent to ROS 1
• Keep an eye on it!

http://design.ros2.org/articles/why_ros2.html
Logistics

• Pset 1 released Friday

• Simulation and basic setup in sections
Next time

• Motion control