Robotics: Principles and Practice

Module 2: The Robot Operating System (ROS)

Lecture 3: Writing ROS software in C++: publishers and subscribers

David Vernon
Carnegie Mellon University Africa

www.vernon.eu

Writing ROS Software

- Creating a ROS workspace and a ROS package
- Writing ROS programs

1. Example program: Hello World!
2. Example program to publish messages

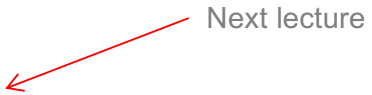
   Send velocity messages on /turtle1/cmd_vel
3. Example program to subscribe to messages

   Receive pose messages on /turtle1/pose

Writing ROS Software

- Writing ROS programs

4. Example program to use services



/reset
/clear
/turtle1/set_pen
/turtle1/teleport_absolute

Creating a ROS workspace

- We first create a ROS workspace and then create our packages in that workspace
- We will refer to is as the workspace directory
- We will create it in the home directory
- We can name the directory anything we wish but, to be consistent with the examples later in the course, we will name it ~/workspace/ros

This has already been done if you are using the rpp-vm virtual machine or if you have installed the Lynxmotion AL5D robot Gazebo simulator ROS package or the example programs ROS package

Creating a ROS workspace

Create a ROS workspace

- We also need to create a src sub-directory in the workspace directory
- We can do all this in one step:

```
~$ mkdir -p ~/workspace/ros/src
```

This has already been done if you are using the rpp-vm virtual machine or if you have installed the Lynxmotion AL5D robot Gazebo simulator ROS package or the example programs ROS package

The -p causes the creation of three directories:
/workspace
/workspace/ros
/workspace/ros/src

Creating a ROS package

Create a package for the example programs

```
~$ cd ~/workspace/ros/src
~/workspace/ros/src$ catkin_create_pkg agitr roscpp
```

The second argument identifies a dependency on roscpp
Other dependencies can be specified by additional arguments

We name the package agitr because these examples are based on A Gentle Introduction to ROS by J. M. O'Kane

This creates

- a directory agitr to hold the package, containing the following files
- package.xml a configuration file containing the manifest we discussed earlier
- CMakeLists.txt a script for CMake, an industrial-strength build system used by ROS
- and the following sub-directories src and include

Creating a ROS package

Make sure you are in the agitr sub-directory

```
~/workspace/ros/src$ cd agitr
~/workspace/ros/src/agitr$
```

Creating a ROS package

Edit package.xml

- Use your preferred editor, e.g. vi or emacs
  - There is an introduction to Emacs here: http://www.vernon.eu/cognitive_robotics/CR08-03.pdf
- Non-essential edits:
  - Update the description
  - Update the name and email of the maintainer

Example Program: Hello World!

Edit CMakeLists.txt

Add the following lines at the end of the file

```
add_executable(${PROJECT_NAME}_hello src/hello.cpp)
set_target_properties(${PROJECT_NAME}_hello PROPERTIES OUTPUT_NAME hello  PREFIX "")
target_link_libraries(${PROJECT_NAME}_hello ${catkin_LIBRARIES})
```

This avoids name pollution and allows different packages to have ROS nodes with the same name

But the executable is still just this
so that you can execute it with rosrun package_name node,
i.e. rosrun agitr hello

Example Program: Hello World!

- Move to the agitr/src sub-directory

~/workspace/ros/src$ cd agitr
~/workspace/ros/src/agitr$ cd src
~/workspace/ros/src/agitr/src$

- Edit hello.cpp and insert the following code

```
/* This is a ROS version of the standard "Hello , World" program */

#include <ros/ros.h>                        // This header defines the standard ROS classes

int main(int argc, char **argv) {
   ros::init(argc, argv, "hello_world");    // Initialize the ROS system
   ros::NodeHandle nh;                      // Register this program as a ROS node
   ROS_INFO_STREAM("Hello World!");         // Send some output as a log message
}
```

This is the name of your node

Example Program: Hello World!

Build the workspace to compile the program

- Because catkin builds all of the packages in the workspace directory, first make sure you are in the workspace directory

```
~/workspace/ros/src/agitr/src$ cd ..
~/workspace/ros/src/agitr$ cd ..
~/workspace/ros/src$ cd ..
~/workspace/ros$
```

or, simply

```
~/workspace/ros/src/agitr$ cd ~/workspace/ros
~/workspace/ros$
```

Example Program: Hello World!

Build the workspace to compile the program

- Run catkin_make

```
~/workspace/ros$ catkin_make
```

- Add the workspace to your ROS environment by sourcing the generated setup file

```
~/workspace/ros$ source devel/setup.bash
```

- Add the setup to your .bashrc file so that you don't have to do this every time you open a new terminal

```
~/workspace/ros$ echo "source $HOME/workspace/ros/devel/setup.bash" >> ~/.bashrc
```

Example Program: Hello World!

Run the ROS master
If you have not already done so, open a terminal and enter

```
~$ roscore
```

Now, use rosrun to execute the program

Open a second terminal and enter

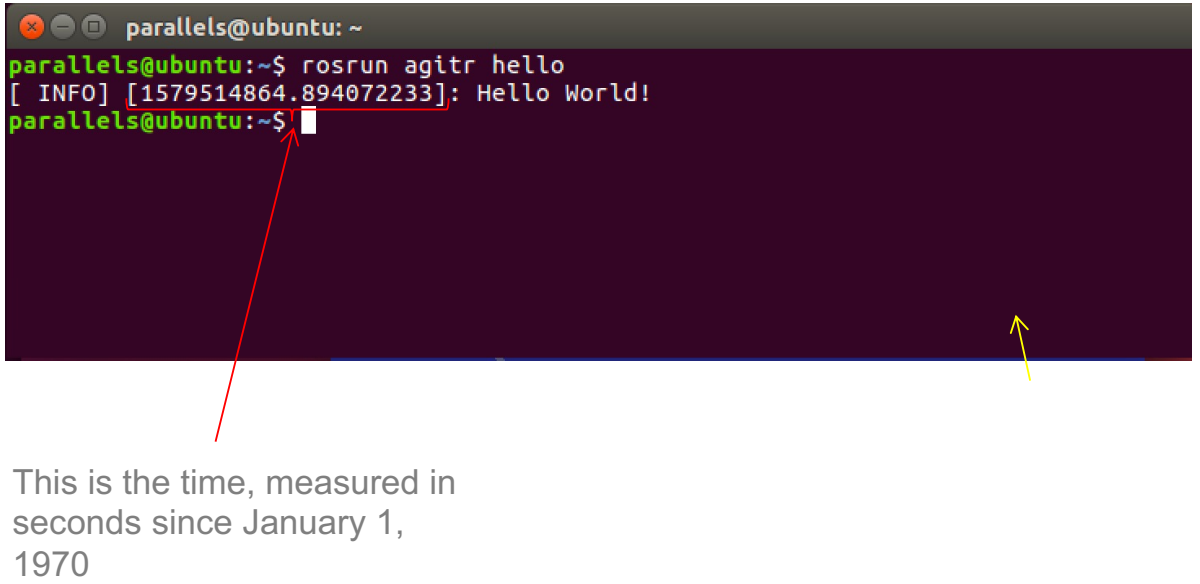
```
~/workspace/ros$ rosrun agitr hello
```

This is the name of your package

This is the name of your program

Example Program: Hello World!

If everything works correctly, you should see a message printed to the terminal



Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Make sure you are in the agitr sub-directory

```
~/workspace/ros/src$ cd ~/workspace/ros/src/agitr
```

Or, better

```
~/workspace/ros/src$ roscd agitr
```

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Edit CMakeLists.txt

Add the following lines at the end of the file

```
add_executable(${PROJECT_NAME}_pubvel src/pubvel.cpp)
set_target_properties(${PROJECT_NAME}_pubvel PROPERTIES OUTPUT_NAME pubvel  PREFIX "")
target_link_libraries(${PROJECT_NAME}_pubvel ${catkin_LIBRARIES})
```

This avoids name pollution and allows different packages to have ROS nodes with the same name

But the executable is still just this so that you can execute it with rosrun package_name node, i.e. rosrun agitr pubvel

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Move to the agitr/src sub-directory

```
~/workspace/ros/src/agitr$ cd src
~/workspace/ros/src/agitr/src$
```

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Edit pubvel.cpp and insert the following code

```
/* This program publishes randomly-generated velocity messages for turtlesim */

#include <ros/ros.h>
#include <geometry_msgs/Twist.h> // For geometry_msgs::Twist
#include <stdlib.h>              // For rand() and RAND_MAX

int main(int argc , char **argv) {
   ros::init(argc, argv, "publish_velocity"); // Initialize the ROS system
   ros::NodeHandle nh;                        // Become a node
   ros::Publisher pub = nh.advertise<geometry_msgs::Twist>("turtle1/cmd_vel", 1000);
   srand(time(0));    // Seed the random number generator
   ros::Rate rate(2); // Loop at 2Hz until the node is shut down

   while(ros::ok()) {

      geometry_msgs::Twist msg;                                    // Create the message
      msg.linear.x  = double(rand())/double(RAND_MAX);             // fill in the fields
      msg.angular.z = 2*3.14159*double(rand())/double(RAND_MAX)-1; // other fields default to 0
      pub.publish(msg);                                            // Publish the message

      /* Send a message to rosout with the details */
      ROS_INFO_STREAM("Sending random velocity command:" << " linear =" << msg.linear.x << " angular =" << msg.angular.z);
      rate.sleep(); // Wait until it's time for another iteration
   }
}
```

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Edit pubvel.cpp and insert the following code

`Twist` type in the `geometry_msgs` package is used to instantiate a message

```
/* This program publishes randomly-generated velocity messages for turtlesim */

#include <ros/ros.h>
#include <geometry_msgs/Twist.h> // For geometry_msgs::Twist
#include <stdlib.h>              // For rand() and RAND_MAX

int main(int argc , char **argv) {
   ros::init(argc, argv, "publish_velocity"); // Initialize the ROS system
   ros::NodeHandle nh;                        // Become a node
   ros::Publisher pub = nh.advertise<geometry_msgs::Twist>("turtle1/cmd_vel", 1000);
   srand(time(0));    // Seed the random number generator
   ros::Rate rate(2); // Loop at 2Hz until the node is shut down

   while(ros::ok()) {

      geometry_msgs::Twist msg;                                    // Create the message
      msg.linear.x  = double(rand())/double(RAND_MAX);             // fill in the fields
      msg.angular.z = 2*3.14159*double(rand())/double(RAND_MAX)-1; // other fields default to 0
      pub.publish(msg);                                            // Publish the message

      /* Send a message to rosout with the details */
      ROS_INFO_STREAM("Sending random velocity command:" << " linear =" << msg.linear.x << " angular =" << msg.angular.z);
      rate.sleep(); // Wait until it's time for another iteration
   }
}
```

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Edit pubvel.cpp and insert the following code

```
/* This program publishes randomly-generated velocity messages for turtlesim */

#include <ros/ros.h>
#include <geometry_msgs/Twist.h> // For geometry_msgs::Twist
#include <stdlib.h>              // For rand() and RAND_MAX

int main(int argc , char **argv) {
   ros::init(argc, argv, "publish_velocity"); // Initialize the ROS system
   ros::NodeHandle nh;                        // Become a node
   ros::Publisher pub = nh.advertise<geometry_msgs::Twist>("turtle1/cmd_vel", 1000);
   srand(time(0));    // Seed the random number generator
   ros::Rate rate(2); // Loop at 2Hz until the node is shut down

   while(ros::ok()) {

      geometry_msgs::Twist msg;                                    // Create the message
      msg.linear.x  = double(rand())/double(RAND_MAX);             // fill in the fields
      msg.angular.z = 2*3.14159*double(rand())/double(RAND_MAX)-1; // other fields default to 0
      pub.publish(msg);                                            // Publish the message

      /* Send a message to rosout with the details */
      ROS_INFO_STREAM("Sending random velocity command:" << " linear =" << msg.linear.x << " angular =" << msg.angular.z);
      rate.sleep(); // Wait until it's time for another iteration
   }
}
```

Instantiate a publisher object

Initialize it by calling the advertise method of the node handle object

Publish message of type `geometry_msgs::Twist`

Publish on the `turtle1/cmd_vel` topic

using a queue that can handle 1000 messages

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Edit pubvel.cpp and insert the following code

```
/* This program publishes randomly-generated velocity messages for turtlesim */

#include <ros/ros.h>
#include <geometry_msgs/Twist.h> // For geometry_msgs::Twist
#include <stdlib.h>              // For rand() and RAND_MAX

int main(int argc , char **argv) {
   ros::init(argc, argv, "publish_velocity"); // Initialize the ROS system
   ros::NodeHandle nh;                        // Become a node
   ros::Publisher pub = nh.advertise<geometry_msgs::Twist>("turtle1/cmd_vel", 1000);
   srand(time(0));    // Seed the random number generator
   ros::Rate rate(2); // Loop at 2Hz until the node is shut down

   while(ros::ok()) {

      geometry_msgs::Twist msg;                                    // Create the message
      msg.linear.x  = double(rand())/double(RAND_MAX);             // fill in the fields
      msg.angular.z = 2*double(rand())/double(RAND_MAX)-1;         // other fields default to 0
      pub.publish(msg);                                            // Publish the message

      /* Send a message to rosout with the details */
      ROS_INFO_STREAM("Sending random velocity command:" << " linear =" << msg.linear.x << " angular =" << msg.angular.z);
      rate.sleep(); // Wait until it's time for another iteration
   }
}
```

Instantiate a `rate` object of the `ros::Rate` class to control how often the messages are published

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Edit pubvel.cpp and insert the following code

```
/* This program publishes randomly-generated velocity messages for turtlesim */

#include <ros/ros.h>
#include <geometry_msgs/Twist.h> // For geometry_msgs::Twist
#include <stdlib.h>              // For rand() and RAND_MAX

int main(int argc , char **argv) {
   ros::init(argc, argv, "publish_velocity"); // Initialize the ROS system
   ros::NodeHandle nh;                        // Become a node
   ros::Publisher pub = nh.advertise<geometry_msgs::Twist>("turtle1/cmd_vel", 1000);
   srand(time(0));    // Seed the random number generator
   ros::Rate rate(2); // Loop at 2Hz until the node is shut down

   while(ros::ok()) {

      geometry_msgs::Twist msg;                                  // Create the message
      msg.linear.x  = double(rand())/double(RAND_MAX);           // fill in the fields
      msg.angular.z = 2*double(rand())/double(RAND_MAX)-1;       // other fields default to 0
      pub.publish(msg);                                          // Publish the message

      /* Send a message to rosout with the details */
      ROS_INFO_STREAM("Sending random velocity command:" << " linear =" << msg.linear.x << " angular =" << msg.angular.z);
      rate.sleep(); // Wait until it's time for another iteration
   }
}
```

Loop, sending messages, while `ros::ok()` returns `true`
(it will return `false` if you use `rosnode kill` on the node,
or send an interrupt signal `cntrl-C`,
or if the program calls `ros::shutdown()` to terminate itself)

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Edit pubvel.cpp and insert the following code

```
/* This program publishes randomly-generated velocity messages for turtlesim */

#include <ros/ros.h>
#include <geometry_msgs/Twist.h> // For geometry_msgs::Twist
#include <stdlib.h>              // For rand() and RAND_MAX

int main(int argc , char **argv) {
   ros::init(argc, argv, "publish_velocity"); // Initialize the ROS system
   ros::NodeHandle nh;                        // Become a node
   ros::Publisher pub = nh.advertise<geometry_msgs::Twist>("turtle1/cmd_vel", 1000);
   srand(time(0));    // Seed the random number generator
   ros::Rate rate(2); // Loop at 2Hz until the node is shut down

   while(ros::ok()) {

      geometry_msgs::Twist msg;                                  // Create the message
      msg.linear.x  = double(rand())/double(RAND_MAX);           // fill in the fields
      msg.angular.z = 2*double(rand())/double(RAND_MAX)-1;       // other fields default to 0
      pub.publish(msg);                                          // Publish the message

      /* Send a message to rosout with the details */
      ROS_INFO_STREAM("Sending random velocity command:" << " linear =" << msg.linear.x << " angular =" << msg.angular.z);
      rate.sleep(); // Wait until it's time for another iteration
   }
}
```

msg.linear.y
msg.linear.z
msg.angular.x
msg.angular.y
are given their
default values of zero

Set the linear velocity between 0 and 2

Set the angular velocity to a number between -1 and 1

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Edit pubvel.cpp and insert the following code

```
/* This program publishes randomly-generated velocity messages for turtlesim */

#include <ros/ros.h>
#include <geometry_msgs/Twist.h> // For geometry_msgs::Twist
#include <stdlib.h>              // For rand() and RAND_MAX

int main(int argc , char **argv) {
   ros::init(argc, argv, "publish_velocity"); // Initialize the ROS system
   ros::NodeHandle nh;                        // Become a node
   ros::Publisher pub = nh.advertise<geometry_msgs::Twist>("turtle1/cmd_vel", 1000);
   srand(time(0));    // Seed the random number generator
   ros::Rate rate(2); // Loop at 2Hz until the node is shut down

   while(ros::ok()) {

      geometry_msgs::Twist msg;                                    // Create the message
      msg.linear.x  = double(rand())/double(RAND_MAX);             // fill in the fields
      msg.angular.z = 2*double(rand())/double(RAND_MAX)-1;         // other fields default to 0
      pub.publish(msg);                                            // Publish the message

      /* Send a message to rosout with the details */
      ROS_INFO_STREAM("Sending random velocity command:" << " linear =" << msg.linear.x << " angular =" << msg.angular.z);
      rate.sleep(); // Wait until it's time for another iteration
   }
}
```

Each call to this method causes a delay in the program. The duration of the delay is calculated to ensure the loop iterates at the required rate (in this case 2 Hz)

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

Build the workspace to compile the program

- Make sure you are in the workspace directory

```
~/workspace/ros/src/agitr/src$ cd ~/workspace/ros
~/workspace/ros$
```

- Run catkin_make

```
~/workspace/ros$ catkin_make
```

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

If you have not already done it, open a terminal and enter

```
~$ roscore
```

Open a second terminal and enter

```
~$ rosrun turtlesim turtlesim_node
```

Open a third terminal and enter

```
~$ rosrun agitr pubvel
```

The separate terminals are intended to allow all three commands to execute simultaneously

Example Program to Publish Messages

Send velocity messages on /turtle1/cmd_vel

If everything works correctly, you should see a graphical window similar to those below with the turtle moving randomly around

Again, the appearance of your turtle may differ. The simulator selects from a collection of “mascot” turtles for each of the historical distributions of ROS

Example Program to Subscribe to Messages

Receive pose messages on /turtle1/pose

Make sure you are in the agitr sub-directory

~/workspace/ros/src$ cd ~/workspace/ros/src/agitr

Example Program to Subscribe to Messages

Receive pose messages on /turtle1/pose

Edit CMakeLists.txt

Add the following lines at the end of the file

```
add_executable(${PROJECT_NAME}_subpose src/subpose.cpp)
set_target_properties(${PROJECT_NAME}_subpose PROPERTIES OUTPUT_NAME subpose  PREFIX "")
target_link_libraries(${PROJECT_NAME}_subpose ${catkin_LIBRARIES})
```

This avoids name pollution and allows different packages to have ROS nodes with the same name

But the executable is still just this so that you can execute it with rosrun package_name node, i.e. rosrun agitr subpose

Example Program to Subscribe to Messages

Receive pose messages on /turtle1/pose

Move to the agitr/src sub-directory

```
~/workspace/ros/src/agitr$ cd src
~/workspace/ros/src/agitr/src$
```

Example Program to Subscribe to Messages

Receive pose messages on /turtle1/pose

Edit subpose.cpp and insert the following code

```
/* This program subscribes to turtle1/pose and shows its messages on the screen */

#include <ros/ros.h>
#include <turtlesim/Pose.h>
#include <iomanip> // for std::setprecision and std::fixed

/* A callback function. Executed each time a new pose message arrives */
void poseMessageReceived(const turtlesim::Pose& msg) {
   ROS_INFO_STREAM(std::setprecision(2) << std::fixed <<
                              "position=(" << msg.x << "," << msg.y << ")" <<
                              " direction=" << msg.theta);
}

int main(int argc, char **argv) {

  /* Initialize the ROS system and become a node */
   ros::init(argc, argv, "subscribe_to_pose");
   ros::NodeHandle nh;

   /* Create a subscriber object */
   ros::Subscriber sub = nh.subscribe("turtle1/pose", 1000, &poseMessageReceived);

   /* Let ROS take over */
   ros::spin();
}
```

Example Program to Subscribe to Messages

Receive pose messages on /turtle1/pose

Edit subpose.cpp and insert the following code

```
/* This program subscribes to turtle1/pose and shows its messages on the screen */

#include <ros/ros.h>
#include <turtlesim/Pose.h>
#include <iomanip> // for std::setprecision and std::fixed

/* A callback function. Executed each time a new pose message arrives */
void poseMessageReceived(const turtlesim::Pose& msg) {
   ROS_INFO_STREAM(std::setprecision(2) << std::fixed <<
                           "position=(" << msg.x << "," << msg.y << ")" <<
                           " direction=" << msg.theta);
}

int main(int argc, char **argv) {

  /* Initialize the ROS system and become a node */
   ros::init(argc, argv, "subscribe_to_pose");
   ros::NodeHandle nh;

   /* Create a subscriber object */
   ros::Subscriber sub = nh.subscribe("turtle1/pose", 1000, &poseMessageReceived);

   /* Let ROS take over */
   ros::spin();
}
```

The callback function is called every time a message is received
We have to put the code to handle the message in this function

The parameter is the message that arrives.
The type of the message is defined in the header file `<turtlesim/Pose.h>`

Here, we simply print the values to the terminal

Example Program to Subscribe to Messages

Receive pose messages on /turtle1/pose

Edit subpose.cpp and insert the following code

```
/* This program subscribes to turtle1/pose and shows its messages on the screen */

#include <ros/ros.h>
#include <turtlesim/Pose.h>
#include <iomanip> // for std::setprecision and std::fixed

/* A callback function. Executed each time a new pose message arrives */
void poseMessageReceived(const turtlesim::Pose& msg) {
   ROS_INFO_STREAM(std::setprecision(2) << std::fixed <<
                           "position=(" << msg.x << "," << msg.y << ")" <<
                           " direction=" << msg.theta);
}

int main(int argc, char **argv) {

  /* Initialize the ROS system and become a node */
   ros::init(argc, argv, "subscribe_to_pose");
   ros::NodeHandle nh;

   /* Create a subscriber object */
   ros::Subscriber sub = nh.subscribe("turtle1/pose", 1000, &poseMessageReceived);

   /* Let ROS take over */
   ros::spin();
}
```

Instantiate a subscriber object

Initialize it by calling the subscribe method of the node handle object

Subscribe on the `turtle1/pose` topic

using a queue that can handle 1000 messages

Pass a pointer to the callback function that is to be called when messages arrive

Example Program to Subscribe to Messages

Receive pose messages on /turtle1/pose

Edit subpose.cpp and insert the following code

```
/* This program subscribes to turtle1/pose and shows its messages on the screen */

#include <ros/ros.h>
#include <turtlesim/Pose.h>
#include <iomanip> // for std::setprecision and std::fixed

/* A callback function. Executed each time a new pose message arrives */
void poseMessageReceived(const turtlesim::Pose& msg) {
   ROS_INFO_STREAM(std::setprecision(2) << std::fixed <<
                           "position=(" << msg.x << "," << msg.y << ")" <<
                           " direction=" << msg.theta);
}

int main(int argc, char **argv) {

  /* Initialize the ROS system and become a node */
   ros::init(argc, argv, "subscribe_to_pose");
   ros::NodeHandle nh;

   /* Create a subscriber object */
   ros::Subscriber sub = nh.subscribe("turtle1/pose", 1000, &poseMessageReceived);

   /* Let ROS take over */
   ros::spin();
}
```

Allow ROS to service the callback by calling `ros::spin()`

Note: won't return control to this main() function; it will just carry on servicing the call the callback function

If you want to do more work here, call `ros::spinOnce()`

This will allow ROS to execute all pending callback calls and then return control to here

You'll probably embed this call in a loop so that you iteratively service the callback and then do some work

Example Program to Subscribe to Messages

Receive pose messages on /turtle1/pose

Build the workspace to compile the program

- Make sure you are in the workspace directory

```
~/workspace/ros/src/agitr/src$ cd ~/workspace/ros
~/workspace/rosr$
```

- Run catkin_make

```
~/workspace/ros$ catkin_make
```

Example Program to Subscribe to Messages

Receive pose messages on /turtle1/pose

If you have not already done it, open a terminal and enter

```
~$ roscore
```

If you have not already done it, open a second terminal and enter

```
~$ rosrun turtlesim turtlesim_node
```

If you have not already done it, open a third terminal and enter

```
~$ rosrun agitr pubvel
```

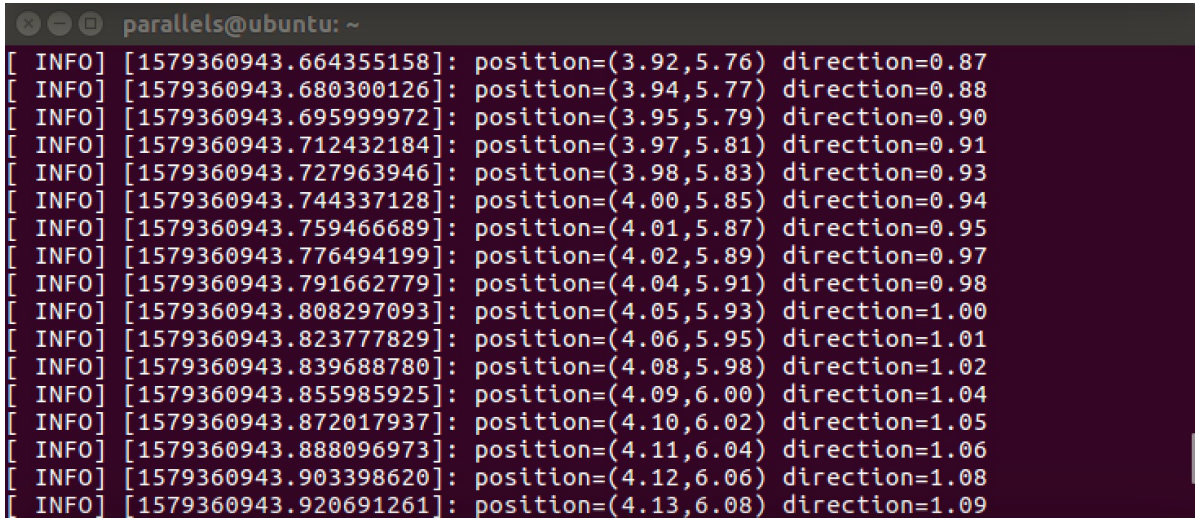
Open a fourth terminal and enter

```
~$ rosrun agitr subpose
```

Example Program to Subscribe to Messages

Receive pose messages on /turtle1/pose

If everything works correctly, you should see messages in the fourth terminal detailing the pose of the turtle



ROS Resources

Wiki	http://wiki.ros.org/
Installation	http://wiki.ros.org/ROS/Installation
Tutorials	http://wiki.ros.org/ROS/Tutorials
Tutorial Videos	http://www.youtube.com/playlist?list=PLDC89965A56E6A8D6
ROS Cheat Sheet	http://www.vernon.eu/RPP/ROS_Cheatsheet.pdf

Recommended Reading

http://wiki.ros.org/catkin/Tutorials/create_a_workspace

http://wiki.ros.org/ROS/Tutorials/CreatingPackage

http://wiki.ros.org/roscpp/Overview/InitializationandShutdown

http://wiki.ros.org/roscpp/Overview/NodeHandles

http://wiki.ros.org/ROS/Tutorials/BuildingPackages

http://wiki.ros.org/ROS/Tutorials/WritingPublisherSubscriber(c++)

J. M. O'Kane, A Gentle Introduction to ROS, 2014.
https://cse.sc.edu/~jokane/agitr/