Introduction to Cognitive Robotics

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www.vernon.eu/cognitive_robotics

Lecture 34

www.vernon.eu/cognitive_robotics/CR_34.pdf

The CRAM Cognitive Architecture: Cognitive Robot Abstract Machine

1. Overview of CRAM
2. The main tools: Lisp, Emacs, CRAM Language, ROS
3. CRAM Beginner Tutorials with Turtlesim
4. A pick-and-place CRAM plan with a simulation of the PR2 robot

Lecture 34

www.vernon.eu/cognitive_robotics/CR_34.pdf

The CRAM Cognitive Architecture: Cognitive Robot Abstract Machine

1. Overview of CRAM
2. The main tools: Lisp, Emacs, CRAM Language, ROS
3. CRAM Beginner Tutorials with Turtlesim
   - Creating a CRAM package
   - Controlling Turtlesim from CRAM
   - Implementing simple plans to move a turtle
   - Using Prolog for reasoning
   - Creating motion designators for the TurtleSim
   - Creating process modules
   - Automatically choosing a process module for a motion
   - Using location designators with the TurtleSim
   - Writing high-level plans for the TurtleSim
   - Implementing failure handling for the TurtleSim
   - Writing tests

The CRAM Beginner Tutorials

Based on CRAM tutorials
http://cram-system.org/tutorials

Creating a CRAM Package

Based on Create a CRAM Package
http://cram-system.org/tutorials/beginner/package_for_turtlesim

Creating a CRAM Package

Set up a ROS package to use the CRAM plan language within the Lisp REPL

1. Create a ROS package that depends on cram_language

The second argument identifies a dependency on cram_language

```
~$ cd ~/workspace/ros/src
~/workspace/ros/src$ catkin_create_pkg cram_my_beginner_tutorial cram_language
```

We name the package cram_my_beginner_tutorial

Creating a CRAM Package

Set up a ROS package to use the CRAM plan language within the Lisp REPL

1. Create a ROS package that depends on cram_language

The second argument identifies a dependency on cram_language

```
~$ cd ~/workspace/ros/src
~/workspace/ros/src$ catkin_create_pkg cram_my_beginner_tutorial cram_language
```

We name the package cram_my_beginner_tutorial

This creates

- a directory cram_my_beginner_tutorial 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 CRAM Package

Set up a ROS package to use the CRAM plan language within the Lisp REPL

2. Set up the Lisp infrastructure …

   - Create an ASDF system
   - Create the Lisp package
   - Export the ASDF system to ROS

Creating a CRAM Package

Create an ASDF system

Make sure you are in the cram_my_beginner_tutorial sub-directory

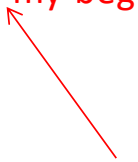
```
~$ cd ~/workspace/ros/src/cram_my_beginner_tutorial
~/workspace/ros/src/cram_my_beginner_tutorial$
```

Creating a CRAM Package

Create an ASDF system

Edit cram-my-beginner-tutorial.asd

```
~/workspace/ros/src/cram_my_beginner_tutorial$ emacs cram-my-beginner-tutorial.asd
```



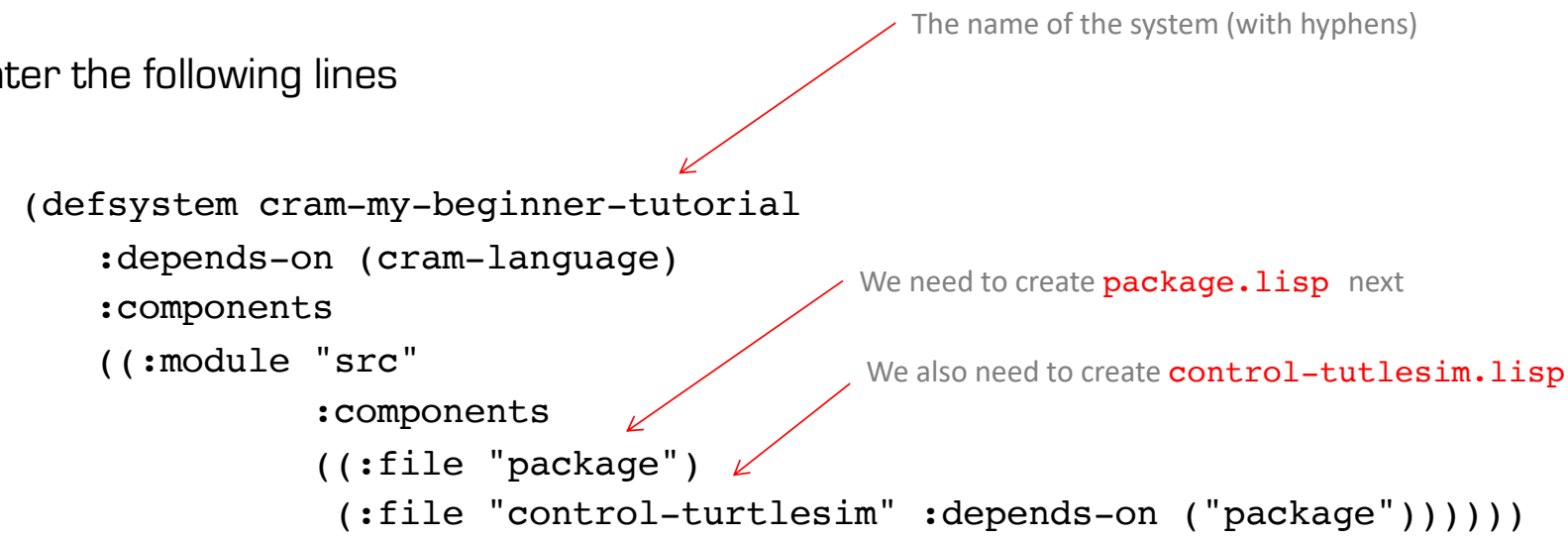
NB: use hyphens, not underscores
Why? Because we will define a system in this file with the same name as the filename and, In general, we don't use underscore characters in Lisp

Creating a CRAM Package

Create an ASDF system

Edit cram-my-beginner-tutorial.asd

Enter the following lines




```
(defsystem cram-my-beginner-tutorial
    :depends-on (cram-language)
    :components
    ((:module "src"
              :components
              ((:file "package")
               (:file "control-turtlesim" :depends-on ("package"))))))
```

Creating a CRAM Package

Create the Lisp package

Make sure you are in the cram_my_beginner_tutorial/src sub-directory

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

Creating a CRAM Package

Create the Lisp package

Edit package.lisp

```
~/workspace/ros/src/cram_my_beginner_tutorial/src$ emacs package.lisp
```

Creating a CRAM Package

Create the Lisp package

Edit package.lisp

Enter the following lines

```
(defpackage :cram-my-beginner-tutorial
  (:nicknames :tut)
  (:use :cpl))
```

The name of the system (with hyphens)

Define a nickname for `cram-my-beginner-tutorial` package

Nickname for the `cram_language` package

Creating a CRAM Package

Create the Lisp package

Edit control-turtlesim.lisp

```
~/workspace/ros/src/cram_my_beginner_tutorial/src$ emacs control-turtlesim.lisp
```

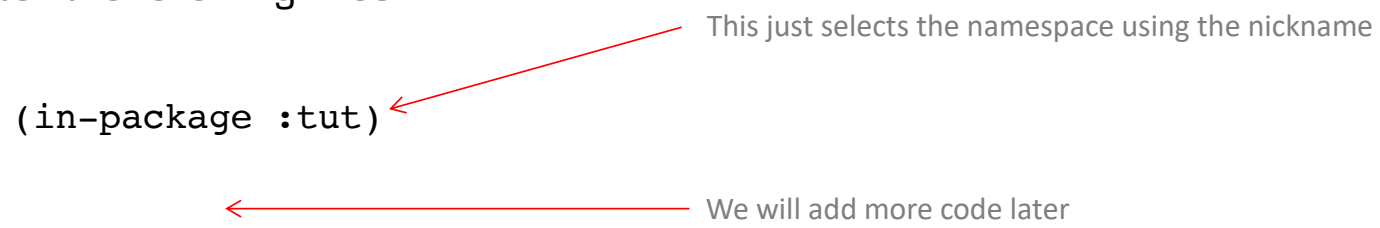
NB: use hyphens, not underscores

Creating a CRAM Package

Create the Lisp package

Edit control-turtlesim.lisp

Enter the following lines



Creating a CRAM Package

Export the ASDF system to ROS

Make sure you are in the workspace directory

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

Alternatively

```
~/workspace/ros/src/cram_my_beginner_tutorial/src$ roscd
~/workspace/ros/devel$ cd ..
~/workspace/ros$
```

Build the workspace to compile the program:
run catkin_make

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

Creating a CRAM Package

Launch the Lisp REPL:

```
~/workspace/ros$ roslisp_repl
```

Load the system:

```
CL-USER> (ros-load:load-system "cram_my_beginner_tutorial" :cram-my-beginner-tutorial)
```

Check that everything is fine (it won't do much):

```
CL-USER> (in-package :tut)
TUT>
```

Controlling Turtlesim from CRAM

Based on Controlling turtlesim from CRAM
http://cram-system.org/tutorials/beginner/controlling_turtlesim_2

Controlling Turtlesim from CRAM

Now, let's develop some code to interact with Turtlesim

To do this:

- Update the dependencies in package.xml
- Update the dependencies in cram-my-beginner-tutorial.asd
- Update the dependencies in package.lisp
- Add the new code to control-turtlesim.lisp
- Test the code
  - Run the ROS master
  - Run the Lisp REPL, loading the new program, creating a ROS node
  - Run turtlesim
  - Run turtlesim_teleop
  - Calling the new functions

Controlling Turtlesim from CRAM

Update the ROS dependencies

Make sure you are in the cram_my_beginner_tutorial sub-directory

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

Controlling Turtlesim from CRAM

Update the ROS dependencies

Edit package.xml

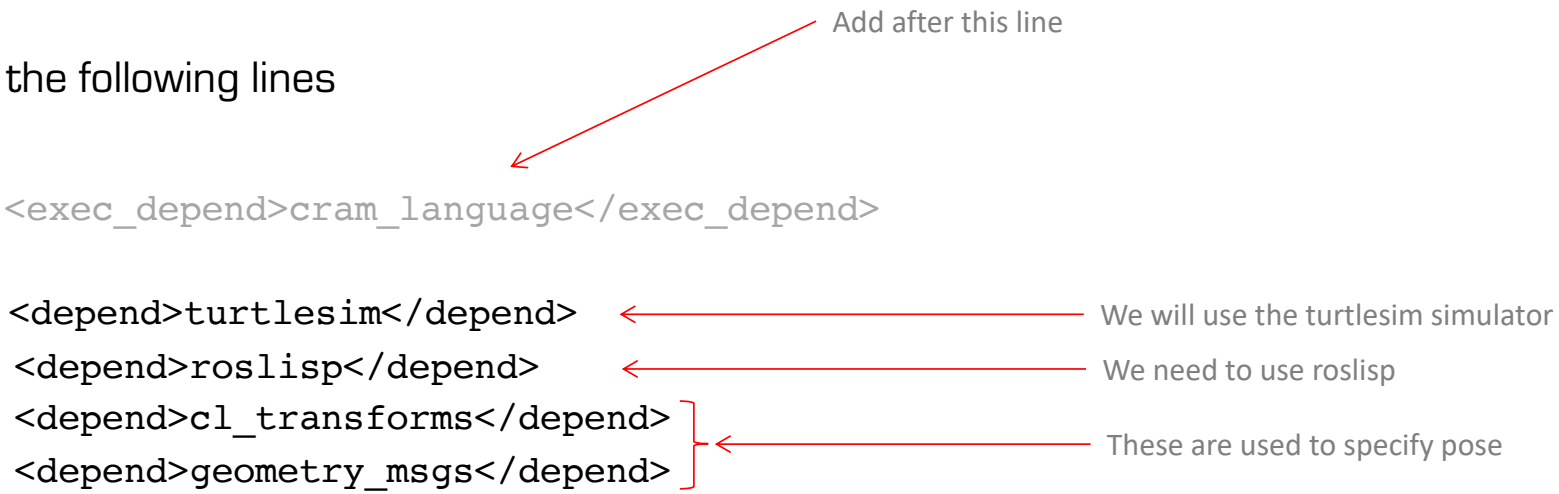
```
~/workspace/ros/src/cram_my_beginner_tutorial$ emacs package.xml
```

Controlling Turtlesim from CRAM

Update the ROS dependencies

Edit package.xml

Add the following lines

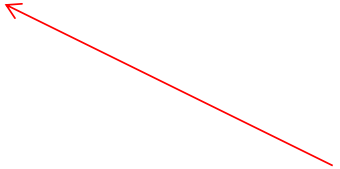


Controlling Turtlesim from CRAM

Update the ASDF dependencies

Make sure you are in the cram_my_beginner_tutorial sub-directory

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



You should be there already from the previous step

Controlling Turtlesim from CRAM

Update the ASDF dependencies

Edit cram-my-beginner-tutorial.asd

```
~/workspace/ros/src/cram_my_beginner_tutorial$ emacs cram-my-beginner-tutorial.asd
```

Controlling Turtlesim from CRAM

Update the ASDF dependencies

Edit cram-my-beginner-tutorial.asd

Replace the `:depends-on(...)` lines with the text below below:

```
(defsystem cram-my-beginner-tutorial
  :depends-on (roslisp cram-language
               turtlesim-msg turtlesim-srv
               cl-transforms geometry_msgs-msg)
  :components
  ((:module "src"
            :components
            ((:file "package")
             (:file "control-turtlesim" :depends-on ("package"))))))
```

The file should now look like this

Controlling Turtlesim from CRAM

Update the Lisp package to add to `roslisp` and `cl-transforms` to the namespace

Make sure you are in the cram_my_beginner_tutorial/src sub-directory

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

Controlling Turtlesim from CRAM

Update the Lisp package to add to `roslisp` and `cl-transforms` to the namespace

Edit package.lisp

~/workspace/ros/src/cram_my_beginner_tutorial/src$ emacs package.lisp

Controlling Turtlesim from CRAM

Update the Lisp package to add to `roslisp` and `cl-transforms` to the namespace

Edit package.lisp

Add `:roslisp :cl-transforms` to the `(:use :cpl))` line:

```
(defpackage :cram-my-beginner-tutorial
  (:nicknames :tut)
  (:use :cpl :roslisp :cl-transforms))
```

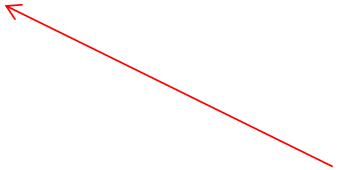
Add these to the namespace so that we don't have to include the package name when we use the functions in the control program

Controlling Turtlesim from CRAM

Update the Lisp package to allow it to communicate with turtlesim

Make sure you are in the cram_my_beginner_tutorial/src sub-directory

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



You should be there already from the previous step

Controlling Turtlesim from CRAM

Update the Lisp package to allow it to communicate with turtlesim

Edit control-turtlesim.lisp

```
~/workspace/ros/src/cram_my_beginner_tutorial/src$ emacs control-turtlesim.lisp
```

Controlling Turtlesim from CRAM

Update the Lisp package to allow it to communicate with turtlesim

Edit control-turtlesim.lisp

Add the code on the next two slides …

```
(in-package :tut)

(defvar *color-value* (make-fluent :name :color-value) "current color under the turtle")
(defvar *turtle-pose* (make-fluent :name :turtle-pose) "current pose of turtle")

(defvar *color-sub* nil "color ROS subscriber")
(defvar *pose-sub* nil "pose ROS subscriber")
(defvar *cmd-vel-pub* nil "velocity commands ROS publisher")

(defvar *pen-srv* nil "name of ROS service for controlling the pen")


(defun init-ros-turtle (name)
  "Subscribes to topics for a turtle and binds callbacks.
   'name' specifies the name of the turtle."

  (setf *color-sub* (subscribe (format nil "~a/color_sensor" name)
                               "turtlesim/Color"
                               #'color-cb))

  (setf *pose-sub* (subscribe (format nil "~a/pose" name)
                              "turtlesim/Pose"
                              #'pose-cb))

  (setf *cmd-vel-pub* (advertise (format nil "~a/cmd_vel" name)
                                 "geometry_msgs/Twist"))

  (setf *pen-srv* (concatenate 'string "/" name "/set_pen")))
```

```
(defun color-cb (msg)
  "Callback for color values. Called by the color topic subscriber."
  (setf (value *color-value*) msg))

(defun pose-cb (msg)
  "Callback for pose values. Called by the pose topic subscriber."
  (setf (value *turtle-pose*) msg))

(defun send-vel-cmd (lin ang)
  "Function to send velocity commands."
  (publish *cmd-vel-pub*
           ;; short syntax:
           ;; (make-message "geometry_msgs/Twist" (:x :linear) lin (:z :angular) ang)
           ;; more understandable syntax:
           (make-message "geometry_msgs/Twist"
                         :linear (make-msg "geometry_msgs/Vector3" :x lin)
                         :angular (make-msg "geometry_msgs/Vector3" :z ang))))

(defun call-set-pen (r g b width off)
  "Function to call the SetPen service."
  (call-service *pen-srv* 'turtlesim-srv:SetPen
                :r r
                :g g
                :b b
                :width width
                :off off))
```

```
(in-package :tut)
```

Already there from when we created this file

```
(defvar *color-value* (make-fluent :name :color-value) "current color under the turtle")
(defvar *turtle-pose* (make-fluent :name :turtle-pose) "current pose of turtle")
```

Create two fluents so that we are informed of any changes in the color or pose

```
(defvar *color-sub* nil "color ROS subscriber")
(defvar *pose-sub* nil "pose ROS subscriber")
(defvar *cmd-vel-pub* nil "velocity commands ROS publisher")
```

Create global variables for the `color-sub` and `pose-sub` subscribers and the cmd_vel publisher

```
(defvar *pen-srv* nil "name of ROS service for controlling the pen")
```

Create global variables for the `pen` service

```
(defun init-ros-turtle (name)
  "Subscribes to topics for a turtle and binds callbacks.
   'name' specifies the name of the turtle."

  (setf *color-sub* (subscribe (format nil "~a/color_sensor" name)
                               "turtlesim/Color"
                               #'color-cb))

  (setf *pose-sub* (subscribe (format nil "~a/pose" name)
                              "turtlesim/Pose"
                              #'pose-cb))

  (setf *cmd-vel-pub* (advertise (format nil "~a/cmd_vel" name)
                                 "geometry_msgs/Twist"))

  (setf *pen-srv* (concatenate 'string "/" name "/set_pen")))
```

```
(in-package :tut)

(defvar *color-value* (make-fluent :name :color-value) "current color under the turtle")
(defvar *turtle-pose* (make-fluent :name :turtle-pose) "current pose of turtle")

(defvar *color-sub* nil "color ROS subscriber")
(defvar *pose-sub* nil "pose ROS subscriber")
(defvar *cmd-vel-pub* nil "velocity commands ROS publisher")

(defvar *pen-srv* nil "name of ROS service for controlling the pen")


(defun init-ros-turtle (name)
  "Subscribes to topics for a turtle and binds callbacks.
   'name' specifies the name of the turtle."

  (setf *color-sub* (subscribe (format nil "~a/color_sensor" name)
                               "turtlesim/Color"
                               #'color-cb))

  (setf *pose-sub* (subscribe (format nil "~a/pose" name)
                              "turtlesim/Pose"
                              #'pose-cb))

  (setf *cmd-vel-pub* (advertise (format nil "~a/cmd_vel" name)
                                 "geometry_msgs/Twist"))

  (setf *pen-srv* (concatenate 'string "/" name "/set_pen")))
```

Define a function to initialize the turtle given by name, e.g. `turtle1`

Subscribe to a topic; use name as the prefix, e.g.. `turtle1/color_sensor`

Message type

Use the `color-cb` callback function to handle the messages received (note the sharp quote)

```
(in-package :tut)

(defvar *color-value* (make-fluent :name :color-value) "current color under the turtle")
(defvar *turtle-pose* (make-fluent :name :turtle-pose) "current pose of turtle")

(defvar *color-sub* nil "color ROS subscriber")
(defvar *pose-sub* nil "pose ROS subscriber")
(defvar *cmd-vel-pub* nil "velocity commands ROS publisher")

(defvar *pen-srv* nil "name of ROS service for controlling the pen")


(defun init-ros-turtle (name)
  "Subscribes to topics for a turtle and binds callbacks.
   'name' specifies the name of the turtle."

  (setf *color-sub* (subscribe (format nil "~a/color_sensor" name)
                               "turtlesim/Color"
                               #'color-cb))

  (setf *pose-sub* (subscribe (format nil "~a/pose" name)
                              "turtlesim/Pose"
                              #'pose-cb))

  (setf *cmd-vel-pub* (advertise (format nil "~a/cmd_vel" name)
                                 "geometry_msgs/Twist"))

  (setf *pen-srv* (concatenate 'string "/" name "/set_pen")))
```

Subscribe to a topic; use name as the prefix, e.g.. `turtle1/pose`

Message type

Use the `pose-cb` callback function to handle the messages received

```
(in-package :tut)

(defvar *color-value* (make-fluent :name :color-value) "current color under the turtle")
(defvar *turtle-pose* (make-fluent :name :turtle-pose) "current pose of turtle")

(defvar *color-sub* nil "color ROS subscriber")
(defvar *pose-sub* nil "pose ROS subscriber")
(defvar *cmd-vel-pub* nil "velocity commands ROS publisher")

(defvar *pen-srv* nil "name of ROS service for controlling the pen")


(defun init-ros-turtle (name)
  "Subscribes to topics for a turtle and binds callbacks.
   'name' specifies the name of the turtle."

  (setf *color-sub* (subscribe (format nil "~a/color_sensor" name)
                               "turtlesim/Color"
                               #'color-cb))

  (setf *pose-sub* (subscribe (format nil "~a/pose" name)
                              "turtlesim/Pose"
                              #'pose-cb))

  (setf *cmd-vel-pub* (advertise (format nil "~a/cmd_vel" name)
                                 "geometry_msgs/Twist"))

  (setf *pen-srv* (concatenate 'string "/" name "/set_pen")))
```

Publish on a topic; use name as the prefix, e.g.. `turtle1/cmd_vel`

Message type

```
(in-package :tut)

(defvar *color-value* (make-fluent :name :color-value) "current color under the turtle")
(defvar *turtle-pose* (make-fluent :name :turtle-pose) "current pose of turtle")

(defvar *color-sub* nil "color ROS subscriber")
(defvar *pose-sub* nil "pose ROS subscriber")
(defvar *cmd-vel-pub* nil "velocity commands ROS publisher")

(defvar *pen-srv* nil "name of ROS service for controlling the pen")


(defun init-ros-turtle (name)
  "Subscribes to topics for a turtle and binds callbacks.
   'name' specifies the name of the turtle."

  (setf *color-sub* (subscribe (format nil "~a/color_sensor" name)
                               "turtlesim/Color"
                               #'color-cb))

  (setf *pose-sub* (subscribe (format nil "~a/pose" name)
                              "turtlesim/Pose"
                              #'pose-cb))

  (setf *cmd-vel-pub* (advertise (format nil "~a/cmd_vel" name)
                                 "geometry_msgs/Twist"))

  (setf *pen-srv* (concatenate 'string "/" name "/set_pen")))
```

Create the service name, e.g. `/turtle1/set_pen`

```
(defun color-cb (msg)
  "Callback for color values. Called by the color topic subscriber."
  (setf (value *color-value*) msg))
```

Callback: copy the color message received to the fluent

```
(defun pose-cb (msg)
  "Callback for pose values. Called by the pose topic subscriber."
  (setf (value *turtle-pose*) msg))
```

Callback: copy the pose message received to the fluent

```
(defun send-vel-cmd (lin ang)
  "Function to send velocity commands."
  (publish *cmd-vel-pub*
           ;; short syntax:
           ;; (make-message "geometry_msgs/Twist" (:x :linear) lin (:z :angular) ang)
           ;; more understandable syntax:
           (make-message "geometry_msgs/Twist"
                         :linear (make-msg "geometry_msgs/Vector3" :x lin)
                         :angular (make-msg "geometry_msgs/Vector3" :z ang))))
```

Define a function to combine the linear and angular velocities and publish them

Use the `lin` and `ang` parameters to create the message

```
(defun call-set-pen (r g b width off)
  "Function to call the SetPen service."
  (call-service *pen-srv* 'turtlesim-srv:SetPen
                :r r
                :g g
                :b b
                :width width
                :off off))
```

Define a function to set the pen parameters using the SetPen service

Controlling Turtlesim from CRAM

Now, let's experiment with this code

First, we need to make sure a ROS master is running

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

```
~$ roscore
```

Controlling Turtlesim from CRAM

Launch the Lisp REPL

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

```
~/workspace/ros$ roslisp_repl
```

Load the system

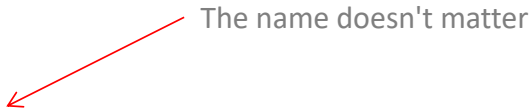
```
CL-USER> (ros-load:load-system "cram_my_beginner_tutorial" :cram-my-beginner-tutorial)
```

Switch to the package

```
CL-USER> (in-package :tut)
TUT>
```

Controlling Turtlesim from CRAM

Start a ROS node

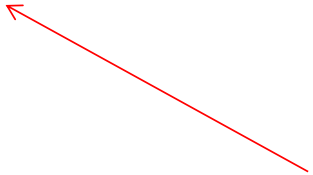



```
TUT> (start-ros-node "cram_tutorial_client")
[(ROSLISP TOP) INFO] 1292688669.674: Node name is cram_tutorial_client
[(ROSLISP TOP) INFO] 1292688669.687: Namespace is /
[(ROSLISP TOP) INFO] 1292688669.688: Params are NIL
[(ROSLISP TOP) INFO] 1292688669.689: Remappings are:
[(ROSLISP TOP) INFO] 1292688669.691: master URI is 127.0.0.1:11311
[(ROSLISP TOP) INFO] 1292688670.875: Node startup complete
```

Controlling Turtlesim from CRAM

Call the function we wrote to perform the initialization

```
TUT> (init-ros-turtle "turtle1")
```



Use turtle1 ... remember, this forms the prefix on the topic names
This is the name of the first turtle that turtlesim spawns

Notice that we haven't launch turtlesim yet but ROS still allows us to subscribe to the turtlesim topics even through turtlesim hasn't yet advertized them

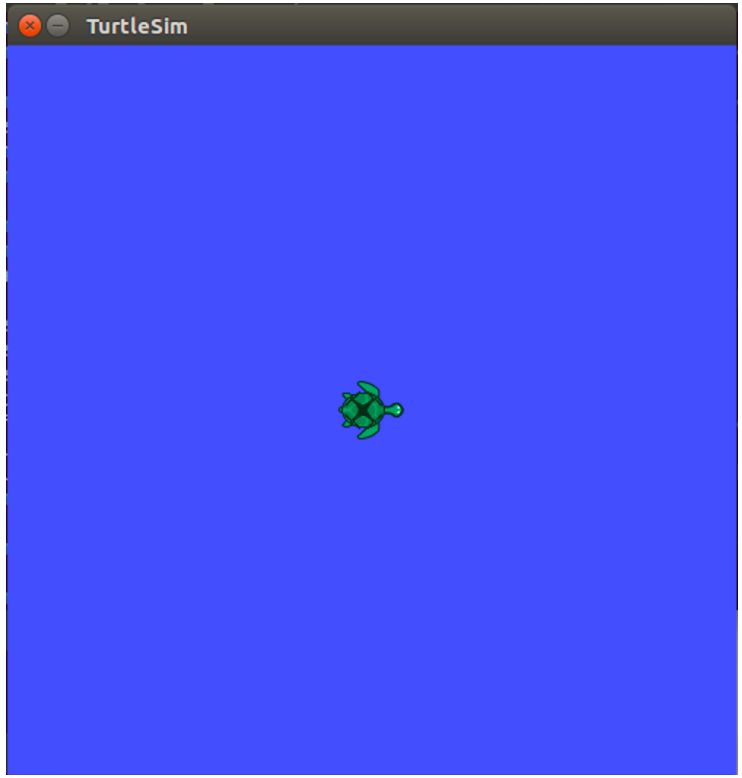
Controlling Turtlesim from CRAM

Now, start turtlesim

Open a new terminal and enter

~$ rosrun turtlesim turtlesim_node

This is what you should see



Controlling Turtlesim from CRAM

Let's see if the fluents have the correct values

Be careful not to leave out the * characters in the variable name
If you do, you'll get a UNBOUND VARIABLE error
and you'll be transferred into the minibuffer
If that happens, type 1 to abort and return to the main buffer

```
TUT> (value *turtle-pose*)
[TURTLESIM-MSG:POSE
  X:
   5.5444445610046390d0
  Y:
   5.5444445610046390d0
  THETA:
   0.0d0
  LINEAR_VELOCITY:
   0.0d0
  ANGULAR_VELOCITY:
   0.0d0]
```

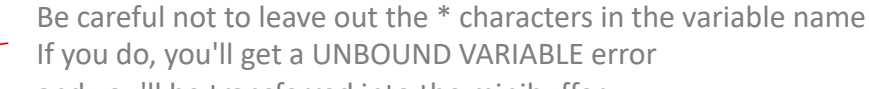
The turtle is at the centre (5.54, 5.54)

The turtle is facing left

and it is not moving

Controlling Turtlesim from CRAM

Let's see if the fluents have the correct values




```
TUT> (value *color-value*)
[TURTLESIM-MSG:COLOR
  R:
   69
  G:
   86
  B:
   255]
```

Controlling Turtlesim from CRAM

Now, let's move the turtle using turtle_teleop_key

Open a new terminal and enter

~$ rosrun turtlesim turtle_teleop_key

Make sure this terminal (the one executing the turtle_teleop_key command) is in focus, (i.e. is selected

Press the Up, Down, Left, or Right arrow key to move the turtle and leave a trail behind it

Controlling Turtlesim from CRAM

Let's see if the fluents have the new values

```
TUT> (value *turtle-pose*)
[TURTLESIM-MSG:POSE
  X:
   5.1362395286560 06d0
  Y:
   2.6341807842254 64d0
  THETA:
   0.1280000088818 36d0
  LINEAR_VELOCITY:
   0.0d0
  ANGULAR_VELOCITY:
   0.0d0]
```

Note: fluents are proxies so, to get the values, we need to use the value function

The turtle is at the new coordinates

The turtle now has an orientation of 0.128 radians

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Aside: coupled with the wait-for function,
the fluent allows a process to block until some event occurs

For example, the following blocks until the x coordinate is less than 5.0

```
TUT> (wait-for (< (fl-funcall #'turtlesim-msg:x *turtle-pose*)  5.0))
```

This creates a new fluent that returns the x coordinate of the turtle pose

This is also an example of a fluent network: the new fluent is created by using the existing fluent

Controlling Turtlesim from CRAM

Aside: execute this expression

```
TUT> (wait-for (< (fl-funcall #'turtlesim-msg:x *turtle-pose*)  5.0))
```

- If the turtle's x position is already smaller than 5, the expression should return T immediately
- If not, the expression should block until you move the turtle far enough to the left using the teleop

Controlling Turtlesim from CRAM

Move the turtle using Lisp

We defined this in control-turtlesim.lisp

forward linear velocity of 1
angular velocity of 1

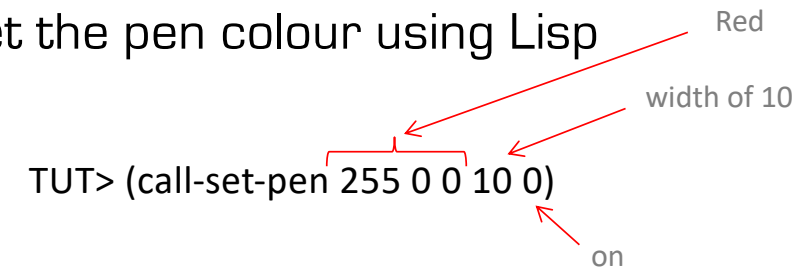
```
TUT> (dotimes (i 10) (send-vel-cmd 1 1) (sleep 1))
```

wait 1 second after each velocity command

- The turtle moves in a circle because the angular velocity is non-zero and constant (1)
- with constant forward velocity (1)

Controlling Turtlesim from CRAM

Set the pen colour using Lisp



TUT> (dotimes (i 10) (send-vel-cmd 1 1) (sleep 1))

CRAM Beginner Tutorials

Create a CRAM Package	http://cram-system.org/tutorials/beginner/package_for_turtlesim
Controlling turtlesim from CRAM	http://cram-system.org/tutorials/beginner/controlling_turtlesim_2

Background Reading

G. Kazhoyan, Lecture notes: Robot Programming with Lisp 7. Coordinate Transformations, TF, ActionLib, slides 5-8.
`https://ai.uni-bremen.de/_media/teaching/7_more_ros.pdf`

`http://wiki.ros.org/tf/Overview/Transformations`

T. Rittweiler, CRAM – Design and Implementation of a Reactive Plan Language, Bachelor Thesis, Technical University of Munich, 2010.
`https://common-lisp.net/~trittweiler/bachelor-thesis.pdf`