Robotics Programming Laboratory

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Lecture 2: ROS and Roboscoop
Robots of today

- Many sensors and actuators
- Able to operate in familiar or expected environments
- Able to perform specialized tasks
Robots of the future

C-3PO
- Provides etiquette, customs, and translation assistance
- Has own thoughts and feelings

R2-D2
- Rescues people and robots
- Repairs other robots and complex hardware and software

Advanced robots must be able to operate and perform tasks in complex, unknown environments.

As robotics advances, we must be aware that robots can be both helpful and harmful.
Concurrency in robotics

Advanced robotic systems have many hardware components that can operate concurrently.

- Sensors and actuators can run in parallel.
- Locomotion and manipulators can run concurrently.
Concurrency in robotics
Multiprocessing, parallelism

- **Multiprocessing**: the use of more than one processing unit in a system
- **Parallel execution**: processes running at the same time

![Diagram showing parallel execution between CPUs and processes]
Multitasking, concurrency

- **Interleaving**: several tasks active, running one at a time
- **Multitasking**: the OS runs interleaved executions
- **Concurrency**: multiprocessing and/or multitasking

P1: Go to goal  P2: Avoid obstacle
Concurrency

Benefits of introducing concurrency into programs:

- **Efficiency**: time (load sharing), cost (resource sharing)
- **Availability**: multiple access
- **Convenience**: perform several tasks at once
- **Modeling power**: describe systems that are inherently parallel
Concurrency framework for robotics
Roboscoop software architecture

Roboscoop
- Library (set of primitives and tools for their coordination)
- Integration with other robotics frameworks
- External calls

SCOOP
- O-O Structure
- Coordination
- Concurrency

ROS
- Communication
- Navigation, image processing, coordinate transforms, visualization, ...
ROS: Robot Operating System

**ROS**: Open-source, meta-operating system for robots

ROS provides the services of an operating system, including

- hardware abstraction,
- low-level device control,
- implementation of commonly-used functionality,
- message-passing between processes, and
- package management


http://www.ros.org
Goals of ROS

- Support code reuse in robotics research and development.
- Enable executables to be individually designed and loosely coupled at runtime through its distributed framework of processes.
- Group processes for easy sharing and distribution.
- Enable the distribution of collaboration through its repositories.

Properties of ROS

- Thin
- Peer-to-Peer
- Multi-lingual: C++, Python, Lisp
ROS communication

Service

Node

Publication

Subscription

Node

Topic

Topic
ROS node

Node

- A process that performs computation
- Interchangeable with a software module
- Can generate data for and receive data from other nodes

A system is typically comprised of many nodes: robot control node, localization node, path planning node, perception node, etc.

Benefits of using nodes

- Fault-tolerance: crashes are isolated to individual nodes
- Reduction of code complexity
ROS topic

**Topic**

- Named bus over which nodes exchange messages
- Has anonymous publish/subscribe semantics.

A node can publish and/or subscribe to multiple topics. A topic supports multiple publishers and subscribers.
**ROS message**

**Message**: Strictly typed data structure used for communication between nodes

**Message description specification**

- Build-in types
- Names of Messages defined on their own
- Fixed- or variable-length arrays:
- Header type: `std_msgs/Header`:
  ```
  uint32 seq, time stamp, string frame_id
  ```
- Constants

Messages can be arbitrarily nested structures and arrays.

```markdown
int16 x
uint32 y
sensor_msgs/LaserScan s
uint8[] data
float32[10] a
Header header
int32 z=123
string s=foo
```
common_msgs

- Messages that are widely used by other ROS packages
- Provide a shared dependency to multiple stacks, eliminating a circular dependency

Types of common_msgs

- **geometry_msgs**: Point, Pose, Transform, Vector, Quaternion, etc.
- **nav_msgs**: MapMetaData, Odometry, Path, etc.
- **sensor_msgs**: LaserScan, PointCloud, Range, etc.
**ROS service**

**Service**: A pair of strictly typed messages for synchronous transactions

**Service description specification**
- Request messages
- Response messages

Two messages are concatenated together with a ‘---’.

An *service* **cannot** be embedded inside another service.

Only one node can advertise a service of any particular name.

```
int16 x
uint32 y
---
string s
```
**Master**

- Provides naming and registration services to nodes
- Tracks publishers and subscribers to topics and services
- Enables individual nodes to locate one another
ROS topic transport protocol

TCPROS
- Provides a simple, reliable communication stream
- TCP packets always arrive in order
- Lost packets are resent until they arrive.

UDPROS
- Packets can be lost, contain errors, or be duplicated.
- Is useful when multiple subscribers are grouped on a single subnet
- Is useful when latency is more important than reliability, e.g., teleoperation, audio streaming
- Suited for a lossy WiFi or cell modem connection.
ROS topic connection example

Camera

Master

Image Viewer

registerPublisher("camera", "image", "sensor_msgs/Image", "pub:123")

registerSubscriber("image_viewer", "image", "sensor_msgs/Image", "sub:456")

requestTopic("image_viewer", "image", [[TCPROS, "sub:567"]])

[1, "no subscriber", []]

[1, "camera", [pub:123]]

[1, "initialize communication", [TCPROS, "pub:234"]]

Image data message

- XMLRPC
- TCPROS
ROS package

Package

- A software unit with useful functionality
- Aims to provide enough functionality to be useful but still lightweight and reusable in other software.
- Can contain ROS runtime processes (nodes), a ROS-dependent library, datasets, configuration files, etc.

Useful packages for the class

TF: coordinate transformation    RViz: 3D visualization
static tf::TransformBroadcaster br;
tf::Transform transform;
transform.setOrigin( tf::Vector3(x, y, 0.0) );
transform.setRotation(tf::Quaternion(theta, 0, 0));
br.sendTransform(tf::StampedTransform(transform, ros::Time::now(), "world", "robot1"));
Demo

- ROS publish/subscribe
- TF
- RViz
ROS coordinate frame conventions

Axis orientation
- $x$: forward, $y$: left, $z$: up

Rotation representation
- Quaternion: $x, y, z, w$
  - Compact representation
  - No singularities
- Rotation matrix
  - No singularities
- Roll: $x$, pitch: $y$, yaw: $z$
  - No ambiguity in order
  - Used for angular velocities
## Standard SI units

<table>
<thead>
<tr>
<th>Base Units</th>
<th>Derived Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantity</strong></td>
<td><strong>Unit</strong></td>
</tr>
<tr>
<td>Length</td>
<td>Meter</td>
</tr>
<tr>
<td>Mass</td>
<td>Kilogram</td>
</tr>
<tr>
<td>Time</td>
<td>Second</td>
</tr>
<tr>
<td>Current</td>
<td>Ampere</td>
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</table>
Build system

- A software tool for automating program compilation, testing, etc.
- Maps a set of source code (files) to a target (executable program, library, generated script, exported interface)
- Must fully understand the build dependencies

CMake

- Cross-platform build system
- Controls the build process using a CMakeLists.txt file
- Creates native makefile in the target environment

```bash
cmake_minimum_required(VERSION 2.8.3)
project(ProjectName)
add_executable(ExecutableName file.cpp)
```
ROS build system: catkin

**catkin**

- Official build system of ROS
- CMake with some custom CMake macros and Python scripts
- Supports for automatic 'find package' infrastructure and building multiple, dependent projects at the same time
- Simplifies the build process of ROS's large, complex, and highly heterogeneous code ecosystem

**Advantages of using catkin**

- Portability through Python and pure CMake
- Independent of ROS and usable on non-ROS projects
- Out-of-source builds: can build targets to any folder

http://wiki.ros.org/catkin/Tutorials
Dependency management: package.xml

```
<package>
  <name>foo</name>
  <version>1.2.3</version>
  <description>
    This package provides foo capability.
  </description>
  <maintainer email="me@ethz.ch">Me</maintainer>
  <license>BSD</license>
  <url>http://www.ethz.ch/foo</url>
  <author>Me</author>
  <buildtool_depend>catkin</buildtool_depend>
  <build_depend>roscpp</build_depend>
  <run_depend>roscpp</run_depend>
  <test_depend>python-mock</test_depend>
</package>
```

Required tags

Package's build system tools

Packages needed at build time

Packages needed at run time

Additional packages for unit testing

http://wiki.ros.org/catkin/package.xml
Dependency management: CMakeLists.txt

```cmake
# Minimum Cmake version
cmake_minimum_required(VERSION 2.8.3)

# Project name
project(foo)

# Dependent packages
find_package(catkin REQUIRED COMPONENTS roscpp)

# Install package.xml and generate code for find_package
catkin_package(
    INCLUDE_DIRS include
    LIBRARIES ${PROJECT_NAME}
    CATKIN_DEPENDS roscpp
    DEPENDS opencv
)

# Location of header files
include_directories(include ${catkin_INCLUDE_DIRS})

# An executable target to be built
add_executable(foo src/foo.cpp)

# Libraries to be built
add_library(moo src/moo.cpp)

# Libraries the executable target links against
target_link_libraries(foo moo)
```

http://wiki.ros.org/catkin/CMakeLists.txt
Roboscoop software architecture

**Roboscoop**
- Library (set of primitives and tools for their coordination)
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**SCOOP**
- O-O Structure
- Coordination
- Concurrency

**ROS**
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SCOOP: a brief introduction

Simple Concurrent Object Oriented Programming

- Easy parallelization
- One more keyword in Eiffel (separate)
- Natural addition to O-O framework
- Retains natural modes of reasoning about programs
- Coordination is easy to express: close correspondence with behavioral specification[1]

Object and processor architecture

ROBOT_CONTROL

PRIMITIVE_BEHAVIOR

ROBOT_STATE_SIGNALER

STOP_SIGNALER

DIFFERENTIAL_DRIVE

drive

robot

stop

PRIMITIVE_BEHAVIOR

a

b
To go straight, to avoid obstacles ...

Get the state of the robot
- Location and orientation
- Linear and angular velocity
- Sensory information

Control the velocity

Stop if there is a request for stopping (e.g., emergency stop)

P1: Go straight
P2: Avoid obstacle

Separate: objects are potentially on a different processor
r: separate ROBOT_STATE_SIGNALER
d: separate DIFFERENTIAL_DRIVE
s: separate STOP_SIGNALER

Obstacle
**separate calls**

**feature**

- **robot:** *separate* `ROBOT_STATE_SIGNALER` -- Current robot's state
- **drive:** *separate* `DIFFERENTIAL_DRIVE` -- Control robot's velocity
- **stop:** *separate* `STOP_SIGNALER` -- Whether stop requested

**start** -- Start the control

**local**

- `a, b:** separate `PRIMITIVE_BEHAVIOR``

**do**

- `create` `a.make (stop)`
- `create` `b.make (stop)`
- `start_robot_behaviors (a, b)`

**end**

**start_robot_behaviors (a, b:** separate `PRIMITIVE_BEHAVIOR`)**

**do**

- `a.repeat_until_stop_requested (agent a.avoid_obstacle (robot, drive, stop))`
- `b.repeat_until_stop_requested (agent b.go_straight (robot, drive, stop))`

**end**
Synchronization through preconditions

go_straight (a_robot: separate ROBOT_STATE_SIGNALER;
    a_drive: separate DIFFERENTIAL_DRIVE;
    a_stop: separate STOP_SIGNALER)
    -- Move robot unless stopped or an obstacle observed.

require
    (not a_robot.is_moving and not a_robot.has_obstacle)
or a_stop.is_stop_requested

do
    if a_stop.is_stop_requested then
        a_drive.stop
    else
        a_drive.send_velocity (0.03, 0.0) -- 3cm/sec, no spinning
    end
end
How do we cancel all processors?

- **GO_STRAIGHT (BEHAVIOR 1)**
- **AVOID_OBSTACLE (BEHAVIOR 2)**
- **APPLICATION**

**STOP_SIGNALER**
- `is_stop_requested: BOOLEAN`
- `set_stop(val: BOOLEAN)`

- `stop.is_stop_requested`
- `stop.set_stop(FALSE)`
- `stop.is_stop_requested`
Roboscoop

Coordination layer above SCOOP

Three-layer architecture

Synchronization: wait conditions

Interoperability through ROS (external calls)
# Roboscoop repository structure

<table>
<thead>
<tr>
<th>roboscoop_app</th>
<th>application.e</th>
<th>controller</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>roboscoop_lib</td>
<td>controller</td>
<td>sequencer</td>
<td>sensor</td>
</tr>
<tr>
<td></td>
<td>common</td>
<td>utils</td>
<td>signaler</td>
</tr>
<tr>
<td></td>
<td>ros</td>
<td>msgs</td>
<td>actuator</td>
</tr>
<tr>
<td>roboscoop_ros</td>
<td>msg</td>
<td>src</td>
<td></td>
</tr>
</tbody>
</table>
Communication with ROS nodes: publication

**roboscoop_app** ➔ **roboscoop_lib** ➔ **roboscoop_lib/cpp** ➔ **ROS**

**Topic name:**
/aseba/events/sound_cmd

**Message type:**
asebaros/AsebaEvent

```cpp
ROS_PUBLISHER
ASEBA_MSG

pub: ROS_PUBLISHER[ASEBA_MSG]
msg: ASEBA_MSG
create msg.make_with_two_values (0, sound_id)
create pub.make_with_topic ("/aseba/events/sound_cmd")
...
pub.publish (msg)
```
Communication with ROS nodes: subscription

ROS_SUBSCRIBER subscriber.h

ODOMETRY_MSG

Topic name:
/thymio_driver/odometry

Message type:
nav_msgs/Odometry

Header header
string child_frame_id
PoseWithCovariance pose
TwistWithCovariance twist

sub: ROS_SUBSCRIBER[ODOMETRY_MSG]

sig: ODOMETRY_SIGNALER

create sub.make

...

-- inside a wrapper

sub.subscribe ("/thymio_driver/odometry",
agent a_sig.update_odometry)
class YOUR_APPLICATION feature

thymio: separate THYMIO_ROBOT -- The robot.
ros_spinner: separate ROS_SPINNER -- ROS spinner object for communication.

some_feature
    local
        robo_node: separate ROBOSCOOP_NODE
    do
        -- Initialize this application as a ROS node.
        robo_node := (create {ROS_NODE_STARTER}).roboscoop_node

        -- Create a robot object.
        create thymio.make

        -- Listen to ROS.
        create ros_spinner.make
        start_spin (ros_spinner)

        -- Launch Thymio.
        launch_robot (thymio)
    end