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Mobile Robotics

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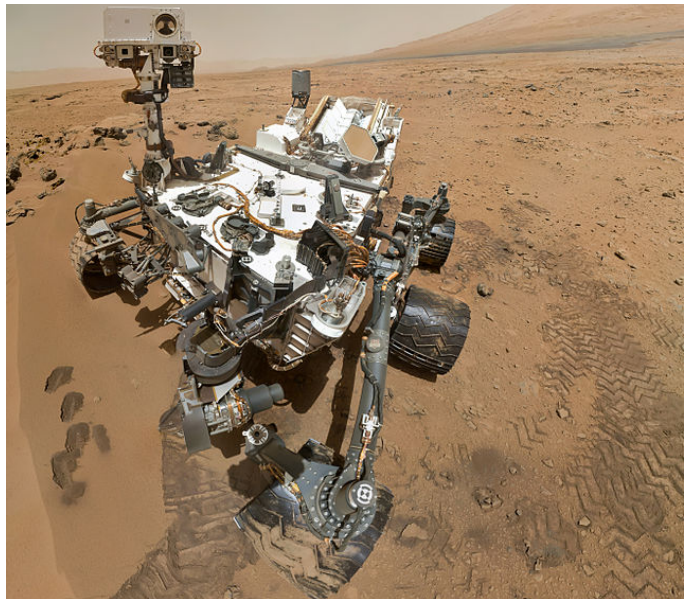
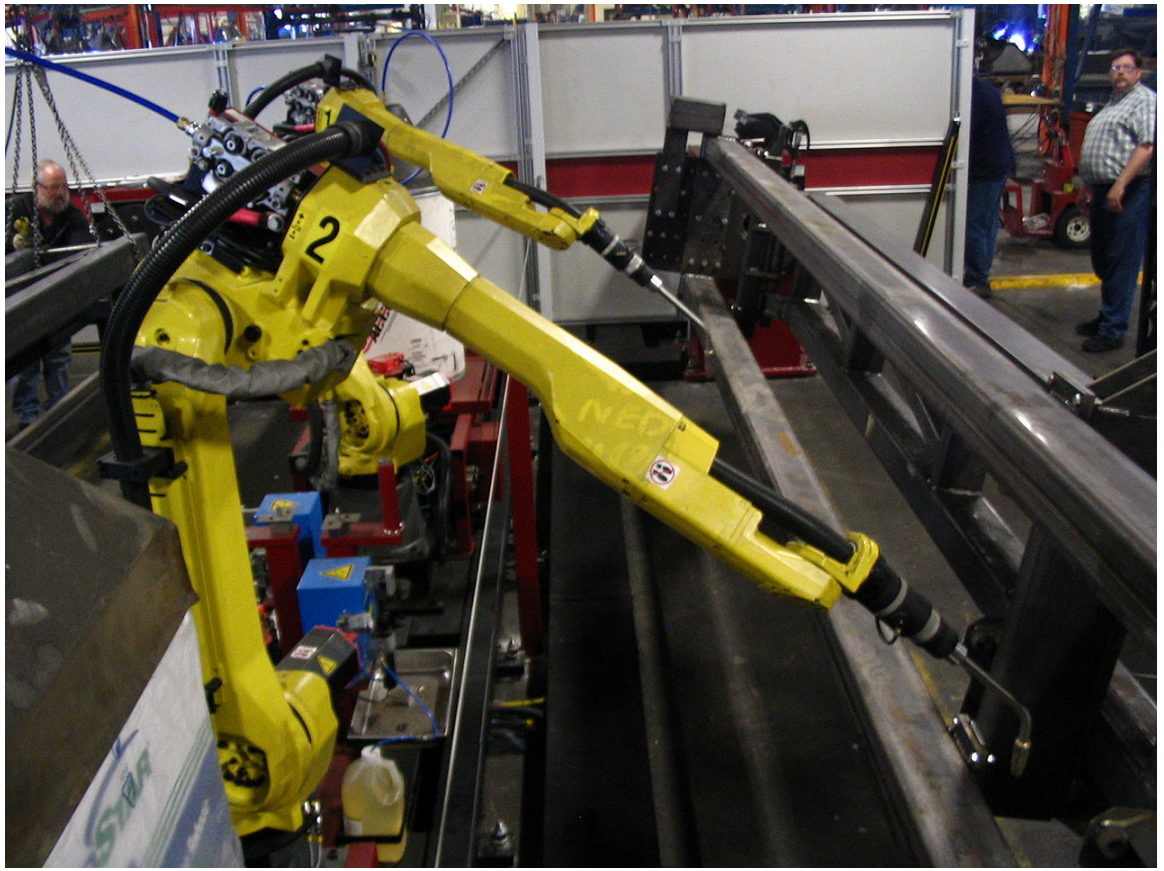
Lecture 2

Review

- Definition Robot: A machine capable of performing complex tasks in the physical world, that is using sensors to perceive the environment and acts tele-operated or autonomous.
- Usually Industrial Robots are stationary.
- Most other Robots move.





- Autonomous mobile robots move around in the environment. Therefore **ALL** of them:
  - They need to know **where** they **are.**
  - They need to know **where** their **goal** is.
  - They need to know **how** to get there.

- Where am I?
  - GPS, Guiding system
  - Build a map: Mapping
  - Find position in a map: Localization
  - Both: Simultaneous Localization and Mapping (SLAM)
- Where is my goal?
  - What is the goal: map or object recognition
  - Where is that goal?

- Autonomous mobile robots move around in the environment. Therefore **ALL** of them:
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- Different levels:
  - Control:
    - How much power to the motors to move in that direction, reach desired speed
  - Navigation:
    - Avoid obstacles
    - Classify the terrain in front of you
    - Predict the behavior (motion) of other agents (humans, robots, animals, machines)
  - Planning:
    - Long distance path planning
    - What is the way, optimize for certain parameters

Most important capability

(for autonomous mobile robots)

How to get from A to B?

(safely and efficiently)

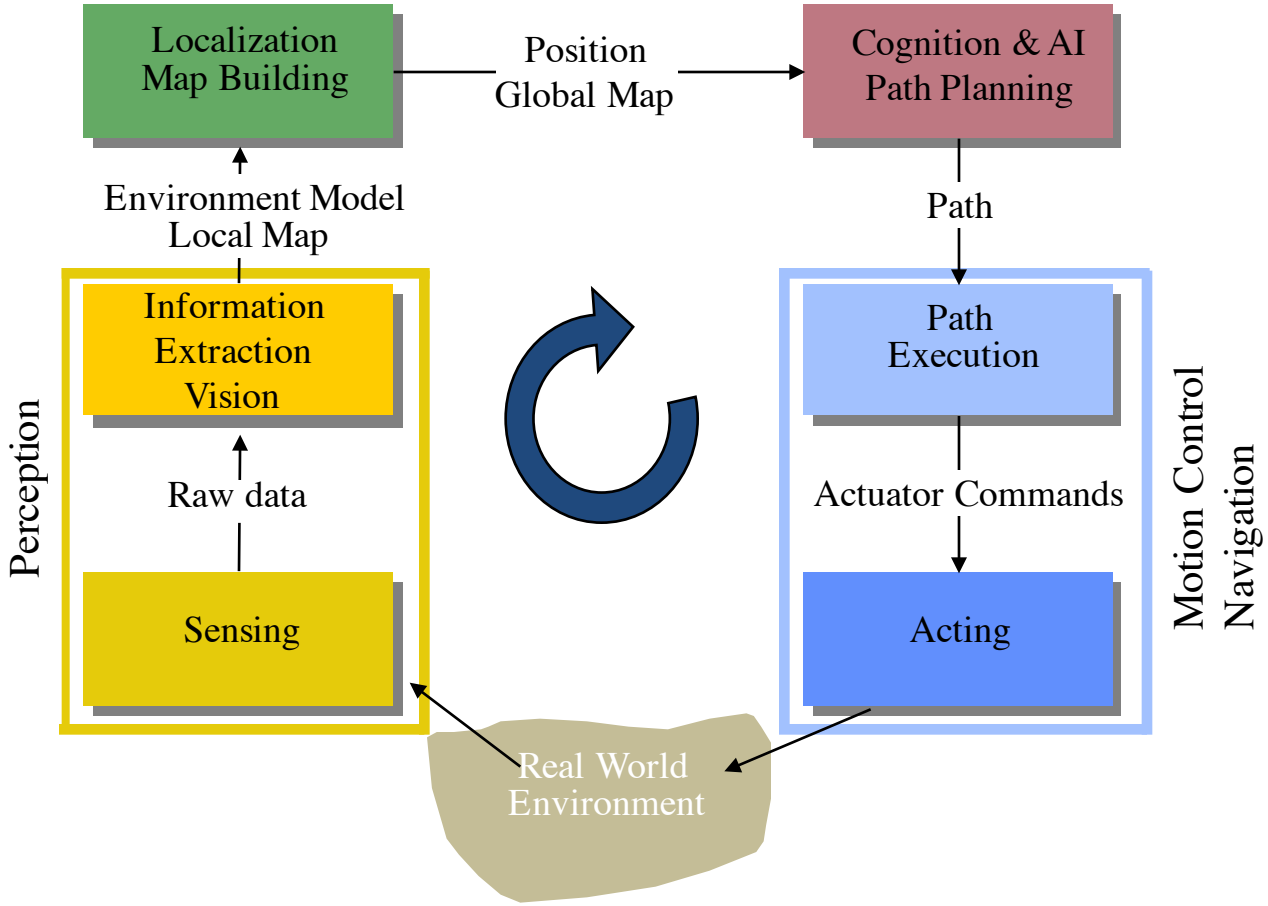
Outline

- Software
  - Software Design
  - Programming Review
  - Robot Operating System (ROS)

How to get from A to B?

How to program an intelligent ROBOT to go from A to B?

General Control Scheme for Mobile Robot Systems

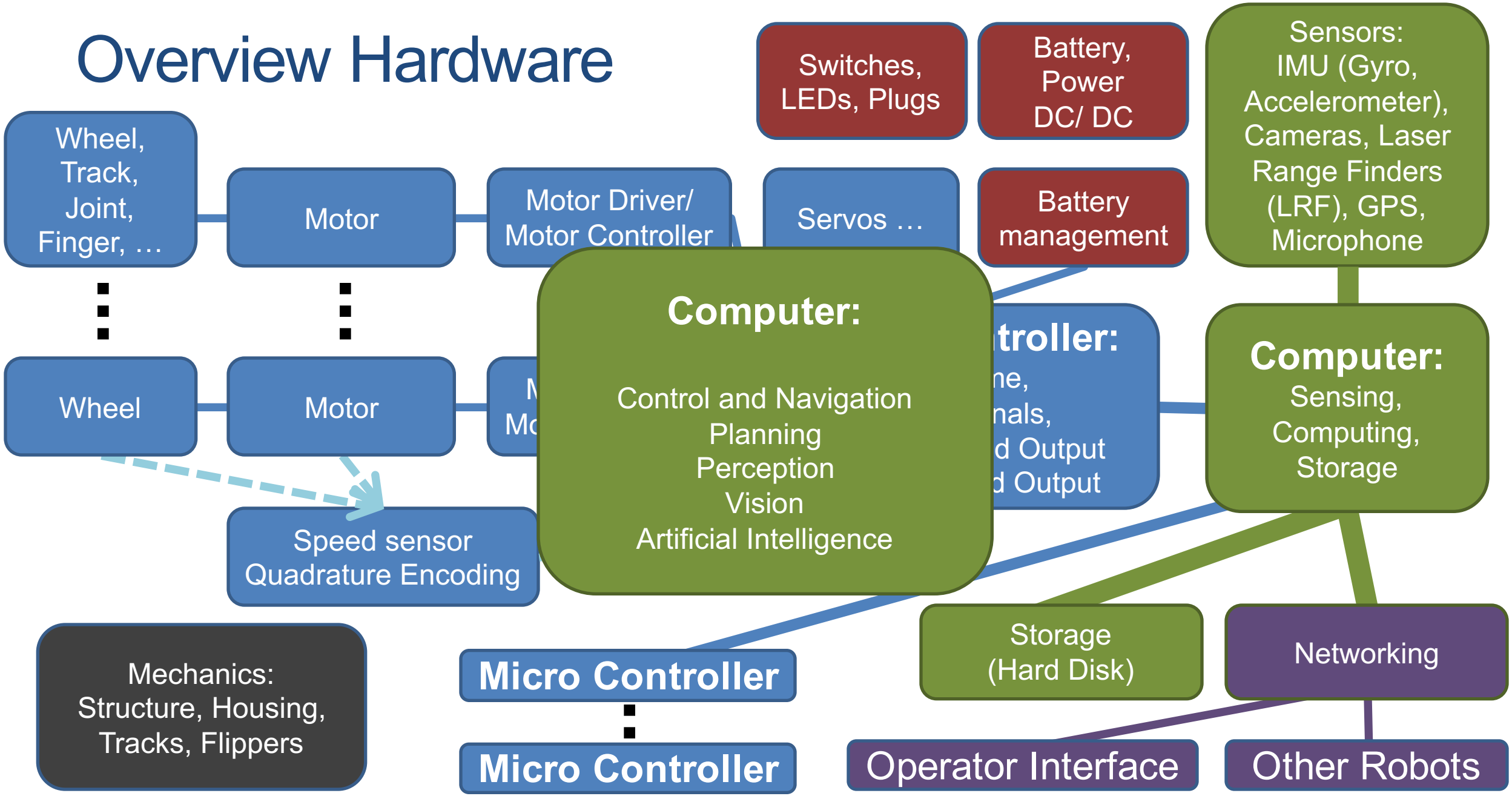


With material from Roland Siegwart and Davide Scaramuzza, ETH Zurich

How to get from A to B?

What are the components of a ROBOT?

Overview Hardware



Robot Software: Tasks/ Modules/ Programs (ROS: node)

Support

- Communication with Micro controller
- Sensor drivers
- Networking
  - With other PCs, other Robots, Operators
- Data storage
  - Store all data for offline processing and simulation and testing
- Monitoring/ Watchdog

Robotics

- Control
- Navigation
- Planning
- Sensor data processing
  - e.g. Stereo processing, Image rectification
- Mapping
- Localization
- Object Recognition
- Mission Execution
- Task specific computing, e.g.:
  - View planning, Victim search, Planning for robot arm, …

Software Design

- Modularization:
  - Keep different software components separated
  - ☺ Keep complexity low
  - ☺ Easily exchange a component (with a different, better algorithm)
  - ☺ Easily exchange multiple components with simulation
  - ☺ Easily exchange dada from components with replay from hard disk instead of live sensor data
  - ☺ Multiple programming teams working on different components easier
  - Need: Clean definition of interfaces or exchange messages!
  - Allows: Multi-Process (vs. Single-Process, Multi-Thread) robot software system
  - Allows: Distributing computation over multiple computers

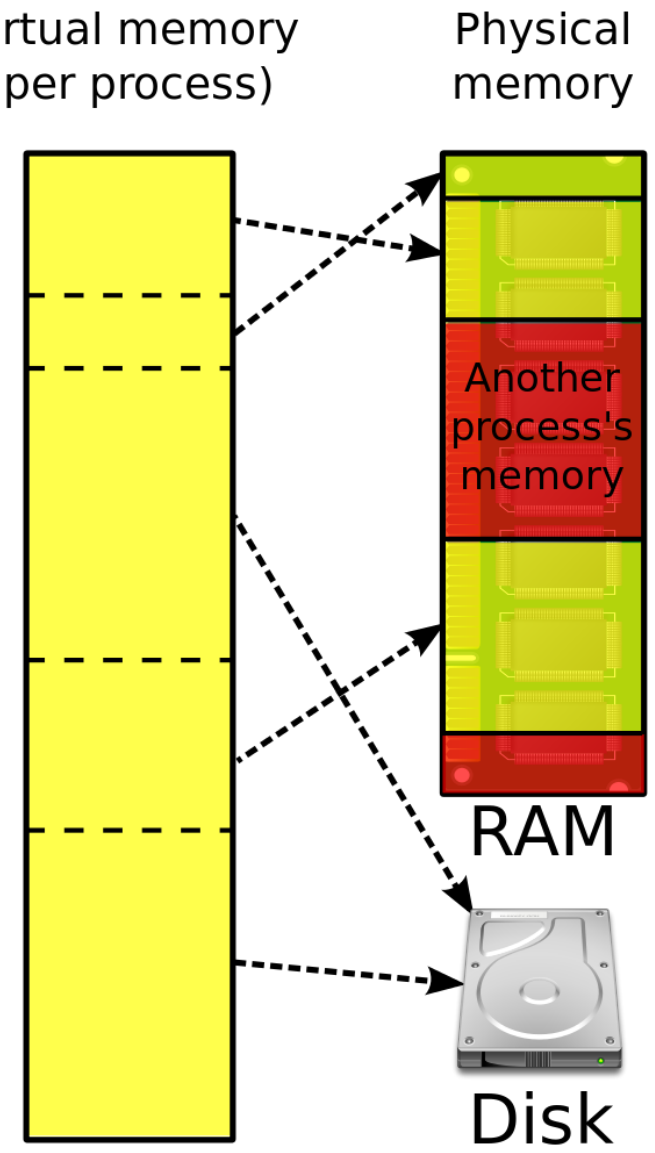
Programming review

- Process vs. Thread
- C++ Object Orientation
- Constant Variables
  - const-correctness
- C++ Templates
- Shared Pointer

- Objective:
  - Prerequisites for understanding ROS.
  - Understand how we can efficiently retrieve and transfer data in ROS.

Process

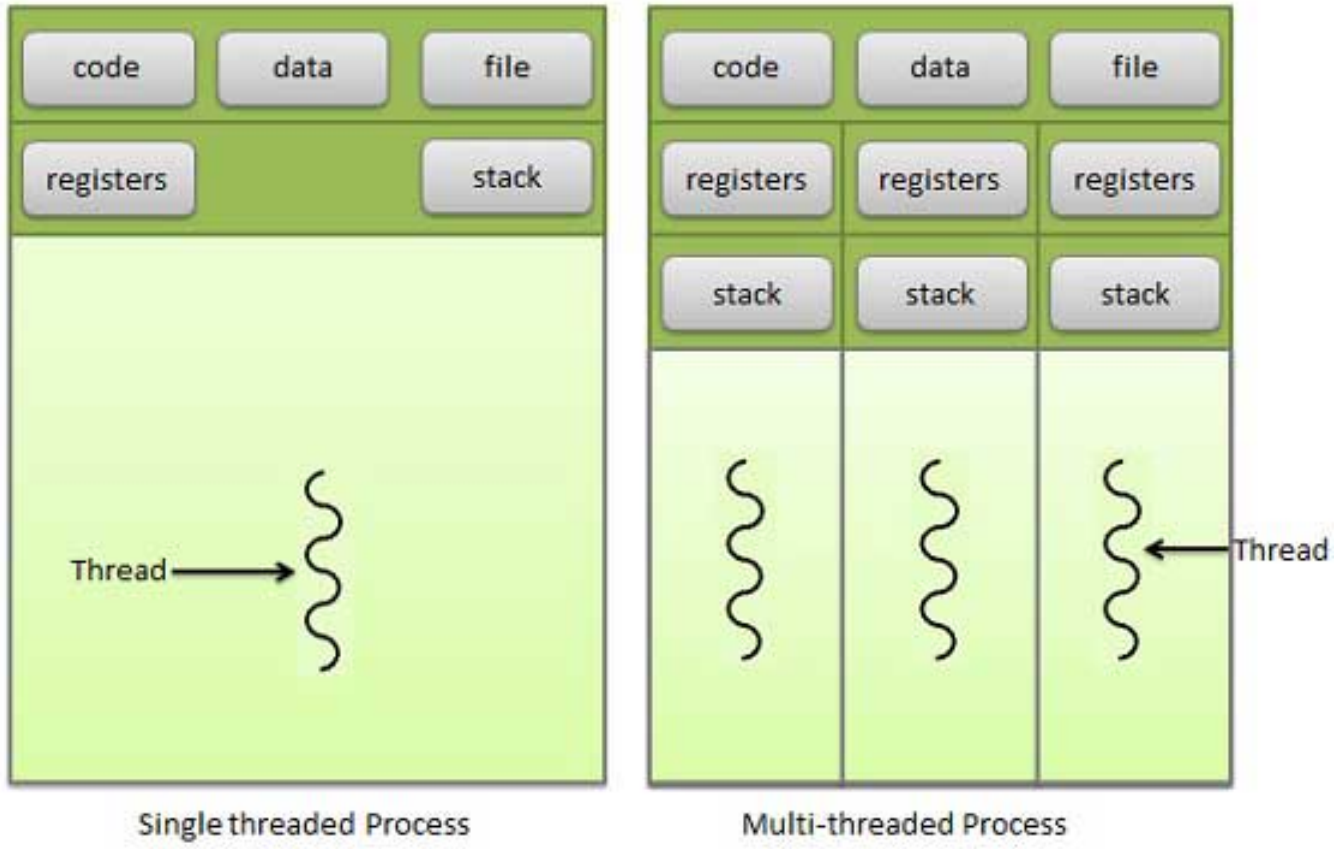
- Execution of one instance of a computer program
- Virtual memory:
  - Contains only code and data from this program, the libraries and the operating system
  - Other processes (programs) can not access this memory (shared memory access is possible but complicated)
- Operating system gives each process equal amount of processing time (scheduling) – if the processes need it
  - Good support from the operating system to give certain processes higher or lower priority
  - Linux console program to see processes: **top**



(From Wikipedia)

Multi-Threading

- In one process, multiple threads => parallel execution
- ☺ Code and Memory is shared => easy exchange of data, save mem.
- 😐 Synchronization can be tricky (mutex, dead lock, race condition)
- ☹ If one thread crashes, the whole process (all threads) die



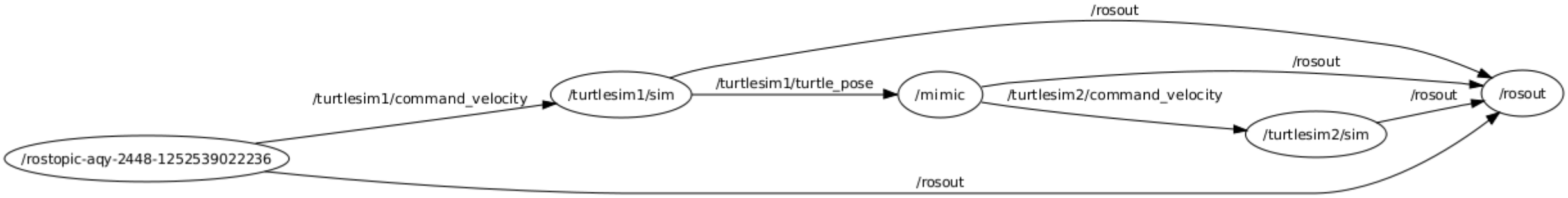
(from http://www.tutorialspoint.com)

Processes and Threads in Robotics - Messages

- Both approaches have been implemented!
- Both are used and important!
- Robot Operating System (ROS): Multiple Processes:
  - Each component runs in its own process: called **node**
  - A node can have multiple threads => faster computation
  - Nodes communicate using **messages**
  - A node can send (**publish**) **messages** under different names called **topic**
  - Nodes can listen to (**subscribe**) **messages** under different **topics**
  - The messages are transferred over the network (TCP/IP) => multiple computers work together transparently
  - ☹ Messages are serialized, copied and de-serialized even if both nodes on the same computer => slow (compared to pointer passing)
    - Optimization: **Nodelet**: run different nodes in the SAME process => pointer passing => fast

ROS nodes

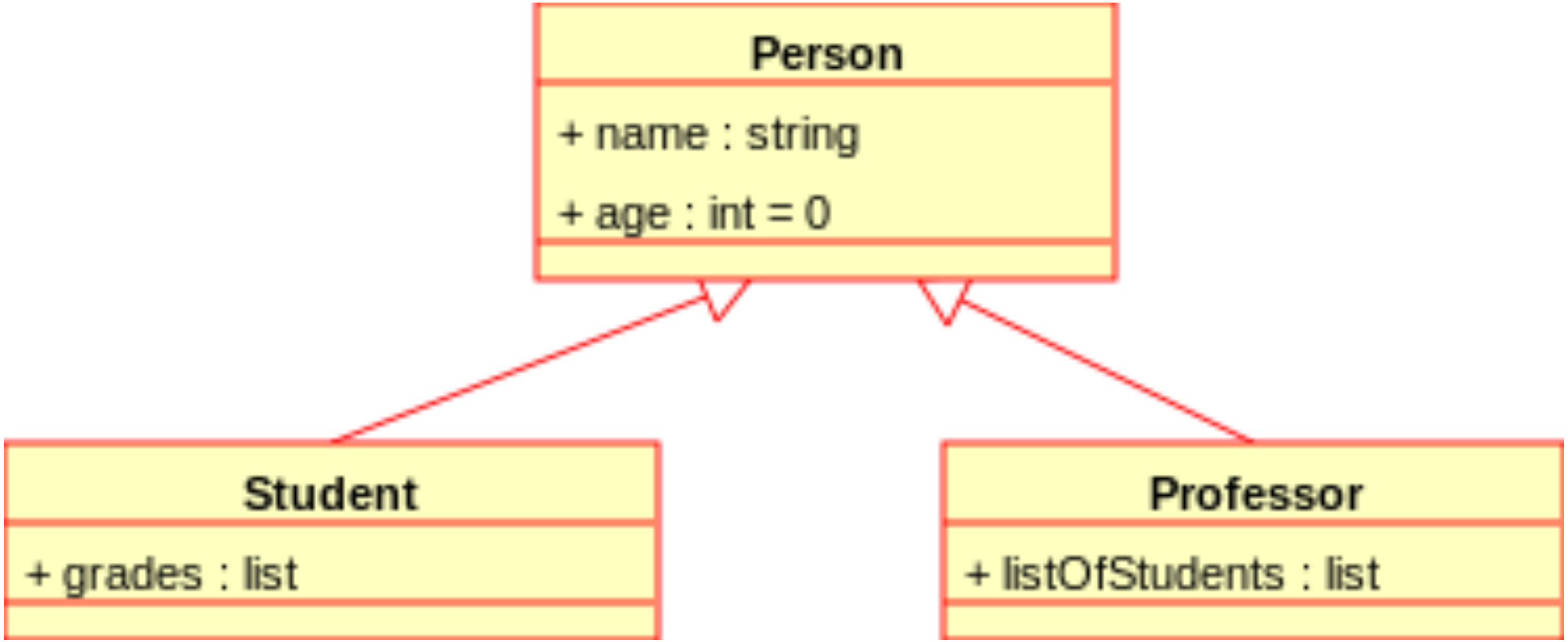
- **ROS core**: keep track which **nodes** are running and their **topics**
- Show all nodes and topics in a graph: `rosrun rqt_graph rqt_graph`
  - `/rosout` : special node for output on console (standard out)
  - `/turtlesim1/sim, /turtlesim2/sim` : simulated robots (**nodes**) (multiple nodes per simulated robot)
  - `/command_velocity` : set the speed of a robot (**topic**)
  - **Node** `/turtlesim1/sim` **publishes** on **topic** `/turtlesim1/turtle_pose`
  - **Node** `/mimic` **subscribes** to **topic** `/turtlesim1/turtle_pose`



Object Oriented (OO) Programming

- C++ is OO … C is not
- Object: have data fields (variables) and associated procedures (methods)
- Instance of an object: created with keyword **new**
- Object: Abstract data type: has data and code
  - encapsulation and information hiding: private variables not visible for outside code – interact through the methods
  - Methods can be private, too: can only be used by (methods of) the object itself
  - Inheritance: code-reuse through re-use of variables and methods from base class. Child class extends/ modifies functionality
  - Polymorphism: Base class defines interface to some functionality (e.g. Method for getting a camera image). A child implements the actual code for a specific use case (e.g. A certain driver for a specific camera) – this is **NOT** how ROS works
    - ROS uses **messages** as “interface”
- Objects have destructors for deletion/ cleanup

Object Orientation: Example



(From Wikipedia)

Constant Variables

- Declare variables that do not change (anymore) in the code: `const`
- Works for variables and objects
- Const Objects:
  - Only methods that do not change any variable of the object may be called =>
  - Those methods have to be declared const
- Used for program-correctness
- Especially for multi-threading:
  - Share the data (e.g. image)
  - Make it read only via const
  - => no side-effects between different threads

1. `const int x = 5; // x may not be changed`
2. `int * someValue = &x; // pointer – compilation error!!`
3. `const int * pointy = &x; // good`
4. `*pointy = 8; // error – pointing to const!`
5. `int y = 4;`
6. `pointy = &y; // from non const to const is always possible!`
7. `const int * p2 const = &y; // pointing to const variable and p2 is also const`
8. `p2 =&x; // error – p2 is const`

QUESTIONS REGARDING HW1?

Bring your HW1 with you next Tuesday!

C++ Templates

- Functions and classes that operate with generic types
- Function or class works on many different data types without rewrite
  - `template <typename T> int compare( T v1, T v2);`
  - Type of T is determined during compile time => errors during compilation (and not run-time)
  - Any type (type == class) that offers the needed methods & variables can be used
  - Usage: `compare<string>( string("string number one"), "hello world" );`
    - Explicit declaration: typename T = string
    - typename T can (most often) deducted by the compiler from the argument types
- Class template:
  - ```
    template <typename T> class myStuff{
        T v1, v2;
        myStuff(T var1, T var2){  v1 = var2; v2 = var2; }
    };
    ```
    ```

Template example

```
//This example throws the following error : call of overloaded 'max(double, double)' is ambiguous
template <typename Type>
Type max(Type a, Type b) {
    return a > b ? a : b;
}
```

```
#include <iostream>

int main(int, char**)
{
  // This will call max <int> (by argument deduction)
  std::cout << max(3, 7) << std::endl;
  // This will call max<double> (by argument deduction)
  std::cout << max(3.0, 7.0) << std::endl;
  // This type is ambiguous, so explicitly instantiate max<double>
  std::cout << max<double>(3, 7.0) << std::endl;
  return 0;
}
```

Shared Pointer

- C++ Standard Library (std): heavily templated part of C++ Standard (many parts used to be in boost library)
- Pointer: address of some data in the heap – in the virtual address space
- Space for data has to be allocated (reserved) with: `new`
- After usage of data it has to be destroyed to free the memory: `delete`
- Problem: Data (e.g.) image is shared among different modules/ components/ threads. Who is the last user – who has to delete the data?
  - Shared pointer: counts the number of users (smart pointers); upon destruction of last user (smart pointer) the object gets destroyed : called “Reference counting”
  - Problem: Shared pointer needs to know the destructor method for the pointer =>
  - Shared pointer is a templated class: Template argument: class type of the object pointed to
  - Shared pointer can also point to const object!

Shared pointer example

```
std::shared_ptr<int> p1(new int(5));
std::shared_ptr<int> p2 = p1; //Both now own the memory.

p1.reset(); //Memory still exists, due to p2.
p2.reset(); //Deletes the memory, since no one else owns the memory.
```

- Earlier, shared_ptr used to be in boost
- Excerpt from ROS message of type “String” :

```
typedef boost::shared_ptr< ::std_msgs::String_<ContainerAllocator> > Ptr;
typedef boost::shared_ptr< ::std_msgs::String_<ContainerAllocator> const> ConstPtr;
```

- typedef: create another (shorter) name for a certain type
- Our type: a shared pointer that points to a (complicated) String object

```
void chatterCallback(const std_msgs::String::ConstPtr& msg)
{
  ROS_INFO("I heard: [%s]", msg->data.c_str());
}
```

Review for ROS

- Different components, modules, algorithms run in different processes: **nodes**
- Nodes communicate using **messages** (and **services** …)
- Nodes **publish** and **subscribe** to **messages** by using names (**topics**)
- **Messages** are often passed around as shared pointers which are
  - “write protected” using the const keyword
  - The shared pointers take the message type as template argument
  - Shared pointers can be accessed like normal pointers

```cpp
#include "ros/ros.h"
#include "std_msgs/String.h"
#include <sstream>

int main(int argc, char **argv){
  ros::init(argc, argv, "talker");
  ros::NodeHandle n;

  ros::Publisher chatter_pub = n.advertise<std_msgs::String>("chatter", 1000);

  ros::Rate loop_rate(10);
  int count = 0;
  while (ros::ok()){
    std_msgs::String msg;
    std::stringstream ss;
    ss << "hello world " << count;
    msg.data = ss.str();

    chatter_pub.publish(msg);

    ros::spinOnce();

    loop_rate.sleep();
    ++count;
  }
  return 0;
}
```

ROS Tutorial: Listener

```
1  #include "ros/ros.h"
2  #include "std_msgs/String.h"
3
4  void chatterCallback(const std_msgs::String::ConstPtr& msg){
5    ROS_INFO("I heard: [%s]", msg->data.c_str());
6  }
7
8  int main(int argc, char **argv){
9    ros::init(argc, argv, "listener");
10   ros::NodeHandle n;
11
12   ros::Subscriber sub = n.subscribe("chatter", 1000, chatterCallback);
13
14   ros::spin();
15
16   return 0;
17 }
```

Messages

- Publisher does not know about subscribers
- Subscribers do not know publishers
- One topic name: many subscribers and many publishers possible, BUT: same message type (determined by the first publisher)!
- List all topics in the current system:
  - rostopic list
  - Other commands: `rostopic echo`, `rostopic hz`, `rostopic pub` , `rostopic pub /test std_msgs/String “Hello World!"`

Create own message: Text format

- Types:
  - int8, int16, int32, int64 (plus uint*)
  - float32, float64
  - string
  - time, duration
  - other msg files
  - variable-length array[] and fixed-length array[C]
- Save in folder “msg”, start with big letter, end with “.msg”

```
string first_name
string last_name
uint8 age
uint32 score
```

Services

- ROS **service**: send a “message” or command to service provider, wait for reply
- Text format: First message for **request**
  - Separation: three dashes
  - Then message for **response**
- A call to a service blocks

```
float32 x
float32 y
float32 theta
string name
---
string name
```

```
 2 #include "beginner_tutorials/AddTwoInts.h"
 3
 4 bool add(beginner_tutorials::AddTwoInts::Request  &req,
 5         beginner_tutorials::AddTwoInts::Response &res)
 6 {
 7   res.sum = req.a + req.b;
 8   ROS_INFO("request: x=%ld, y=%ld", (long int)req.a, (long int)req.b);
 9   ROS_INFO("sending back response: [%ld]", (long int)res.sum);
10   return true;
11 }
```

```
ros::ServiceServer service = n.advertiseService("add_two_ints", add);
```

Compiler, Linker

- Standard in Linux: gcc: GNU Compiler Collection
- Compiler: Create machine code out of programming language
  - For C++ code: g++
  - g++ -o helloworld -I/homes/me/randomplace/include helloworld.cc
  - Options:
    - -g - turn on debugging (so GDB gives more friendly output)
    - -o <name> - name of the output file
    - -O to -O4 - turn on optimizations
    - -L<library path> - specify a lib directory
    - -Wall - turns on most warnings
    - -c - output an object file (.o)
    - -I<include path> - specify an include directory
    - -l<library> - link with library lib<library>.a
- Linker: Link the machine code with other machine code (provided by libraries)
  - Static link library: executable includes the statically linked library
  - Dynamic link library: upon execution the program is linked against the library: Multiple programs will use the same code => save memory
  - Program: ln
  - Show dynamic linked libraries used by a program: ldd

Makefile, CMake

- Avoid typing g++ and ln
- Makefile:
  - Commands for compiling and linking the program: “make” uses the file “Makefile”
  - May provide additional commands like “make clean”
  - Can be used to run arbitrary commands, e.g. to create pdf files from LaTeX
- Cmake
  - Cross-platform Makefile generator
  - Searches for dependencies (libraries, headers, etc.)
  - Autoconfigure with “cmake .”
  - “CMakeLists.txt”: specify which files to make, etc.

GIT: distributed revision control and source code management

- Every Git working directory is a full-fledged repository
  - => can work without server, two repos can pull/ push from each other
- Working directory has a hidden .git folder in its root
- Automatically merges common changes in same files
- Non-linear development:
  - Create branches, merge them
- Cryptographic authentication of history
- See Cheat Sheet

Recourses:

- http://wiki.ros.org/ROS/Tutorials/
- https://en.wikipedia.org/wiki/Object-oriented_programming
- C++: http://www.cplusplus.com/doc/tutorial/
  - http://www.cplusplus.com/doc/tutorial/templates/
- https://en.wikipedia.org/wiki/Smart_pointer
  - http://en.cppreference.com/w/cpp/memory/shared_ptr
- http://www.cprogramming.com/tutorial/const_correctness.html

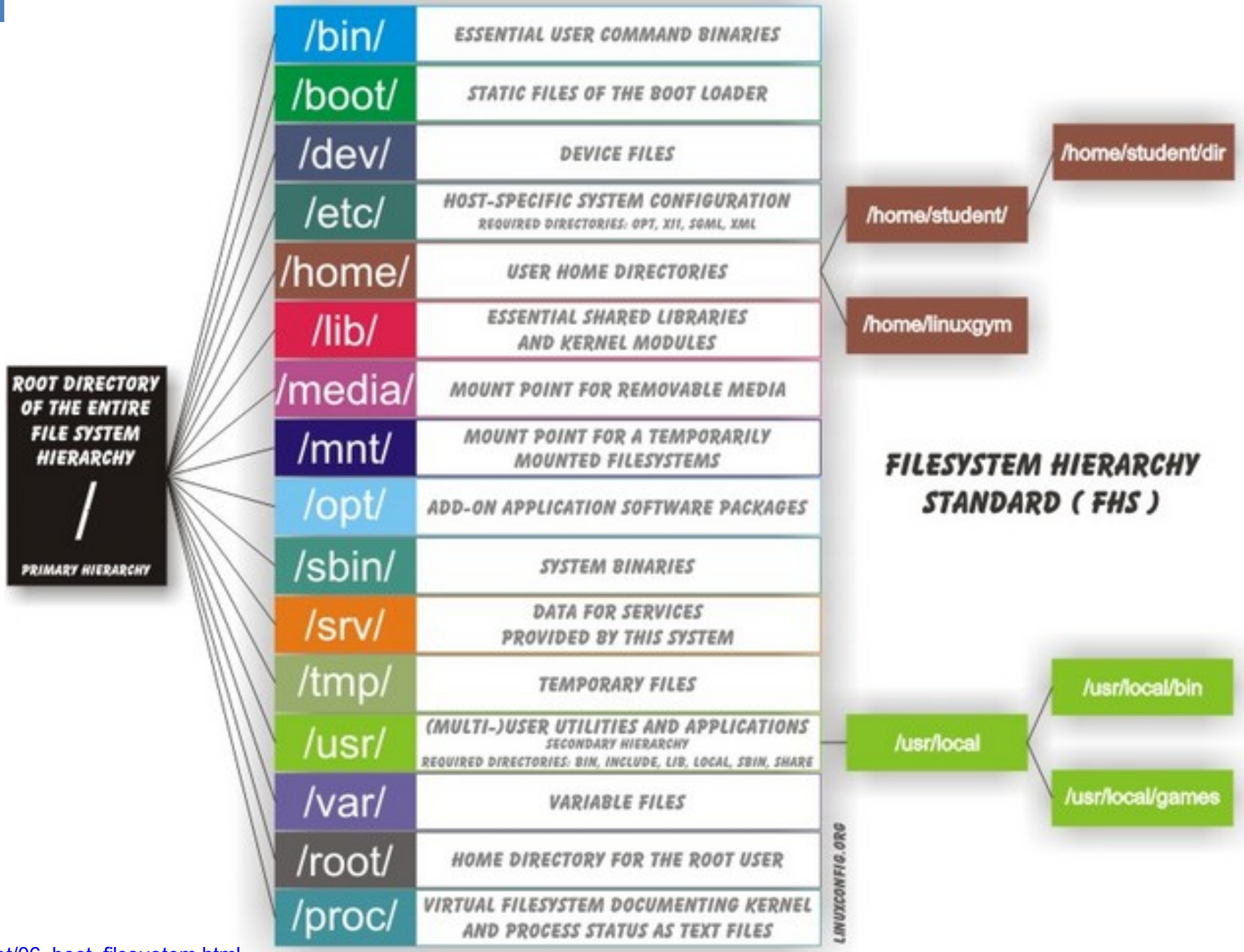
Cheat Sheets

- http://sist.shanghaitech.edu.cn/faculty/soerensch/mobile_robotics_2014/cheat_cheets/bash_cheat_sheet.pdf
- http://sist.shanghaitech.edu.cn/faculty/soerensch/mobile_robotics_2014/cheat_cheets/gitCheatCheet.pdf
- http://sist.shanghaitech.edu.cn/faculty/soerensch/mobile_robotics_2014/cheat_cheets/vim-cheat-sheet.png
- http://sist.shanghaitech.edu.cn/faculty/soerensch/mobile_robotics_2014/cheat_cheets/regular_expressions_cheat_sheet.png
- http://sist.shanghaitech.edu.cn/faculty/soerensch/mobile_robotics_2014/cheat_cheets/cpp_reference_sheet.pdf
- http://sist.shanghaitech.edu.cn/faculty/soerensch/mobile_robotics_2014/cheat_cheets/ROScheatsheet.pdf
- http://sist.shanghaitech.edu.cn/faculty/soerensch/mobile_robotics_2014/cheat_cheets/ROS-Cheat-Sheet-Landscape-v2.pdf

Unix File System

- File types: regular, directory, link, (sockets, named pipes, block devices)
- Slash “/” instead of backslash “\” for folders - distinction between small and big letters!
- One file system tree, beginning with root: “/”
  - Mount partitions (areas of the hard disk): any folder can be the mount point, e.g.: /media/<user_name>/usbDiskName
- Home folders of different users in “/home/<user_name>”
- Hidden files and folders: begin with a dot “.”
- In Unix/ Linux, (almost) everything is a file: devices, partitions, …in “/dev”, e.g. “/dev/video0”
- Show files: “ls”; more info: “ll”; human readable: “-h” – e.g. “ll -h”
- Free space: “df -h”
- Symbolic links (symlink): point to another file or folder. Create with “ln -s from to”

Overview



From: http://devopsbootcamp.readthedocs.org/en/latest/06_boot_filesystem.html

Misc

- Files have access rights: users and groups and others
  - r: read w: write x: execute (for directories: go in)
  - chmod a+w => all (three) are allowed to write
  - chmod o-r => others are not allowed to read
- chown user:group file_name_or_dir change ownership
- Super user: root: can access all files
- sudo <command>: execute a command as root
- sudo su: (one way) to become root
- Compress files: zip + rar for Windows => no support for permissions/ symbolic links
  - tar : tape archive (lol) – sequentially store files and folders (no compression)
  - gzip : compress one file
  - combine: tar gzip: archive.tar.gz

Bash: GNU Unix Shell

- Program that runs in your terminal – executes your commands
- Keyboard up: go through history of last commands
- Tab-complete: any time, press tab to complete the command/ path/ file-name/ … - if a unique solution exists; double tab for list of possible options
- Control C to tell program to stop; Control | to quit;
- Control Z to stop (pause) program: fg to run in foreground again, bg to run in background, kill %1 to kill the last program (in background)
- Start program in background: command &
- Pipe: send output of program 1 as input to program 2: prog1 | prog2; e.g. “ll /dev | less”
- Send standard output to file use “>” e.g.: “ll > file.txt”
- Wildcards: “*” matches anything with any length, “?” matches any one char, e.g. “ll /dev/tty*”

.bashrc

- .bashrc is executed every time a new shell (terminal) is opened
- Execute by hand: “source ~/.bashrc” or “. ~/.bashrc”
- “~” is replaced by your home directory
- Setup variables, e.g.:
  - alias df='df -h' # when calling df, acutally "df -h“ is called – human readable
  - alias ..='cd ..' # executing "..“ will go one level up in the file tree
  - Option: setup ros path always here: “source ~/my_ws/devel/setup.bash”
- Edit input.rc to search history of commands with page up, down:
  - “sudo vi /etc/inputrc” – uncomment “# alternate mappings for "page up" and "page down" to search the history”

vi: editor for the console

- Command mode (press escape) and input mode (press i)
- Install vim for more comfort: sudo apt-get install vim
- Command mode:
  - Press escape to enter command mode
  - “: w” write file
  - “: q” quit
  - “: wq” write file and quit
  - “: q!” quit without writing changes to file
  - Press “d” to delete a char; press “dd” to delete a line
  - Press “/” and enter a regular expression to search
  - Press “n” or “N” for next, previous search result

ssh: secure shell

- Login to remote computer, using encrypted communication
- sudo apt-get install ssh : Installs the ssh server
- Usage: ssh user@host e.g.: ssh schwerti@robotics.shanghaitech.edu.cn
- Option: -X forward X-server: see GUI of remote application on your screen (-Y without encryption)
- ssh-keygen : generate authentication keys – public and private keyfile in .ssh
- ssh-copy-id : copy your public key to remove hose => no login needed anymore!
- Copy files: scp [-r] <from> <to>
  - Either from or to can be remote host: [user@]host:path, e.g. scp hw2.tar.gz test@robotics:homeworks/
  - -r: recursive – copies whole directories