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Lab 2

Programming LEGO Mindstorms NXT

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24 September 2019

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Lab Overview

Lab goals

- Real-time programming on an embedded device
- Problem solving using real-time tasks

Schedule

- Slot 1: 25.9.19 13-17:00 ITC 1312, 1313
- Slot 2: 30.9.19 13-17:00 ITC 1312, 1313
- Demonstration 10.10.19 13-17:00 ITC 2315
- Submission Deadline: 10.10.19 23:59

Lab preparation

- Get your lego box from my office (ITC 1252).
- Boxes are available after this class, please get your box before coming to the lab. Check https://slotted.co/ba57bga for my availability (no need to sign-up for a slot).
- Check the lab web page:

http://www.it.uu.se/edu/course/homepage/realtid/ht19/labs/lab2

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LEGO Box

Each group gets one LEGO Mindstorms box:

Follow the instructions in the box to rearrange before return

(contact a TA if your box is missing instructions)

Deadline: 11 October 2019, 16:00 Friday

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Lab Environment

LEGO toolchain +
Libusb +
Fwexec (program uploader)

LEGO VM (Debian 64-bit)

VirtualBox VM manager

Lab PC

Your robot

Username: lego
PW: lego
Root PW: lego
(required
for fwexec)

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Toolchain

Using the provided Virtual Machine (VM)

- Download VM from this link (2.3 GB download):

https://drive.google.com/file/d/1j7j9JH6VbRoziMcB10dE_CQmorXekQ_3/view?usp=sharing

- Import it in Virtualbox of lab computer and start

On your own machine

- GNAT GPL 2011 ARM for Linux

http://www.dit.upm.es/~str/proyectos/mindstorms/2011/index.html

- Adacore GNAT GPL 2012 Windows:

https://www.adacore.com/download/more

- Need to install libusb driver (Linux) or Fantom NXT driver (Windows) (this step is also required if you plan to use the VM on your own machine)
- Installation instructions available on the lab page, non-trivial

We highly recommend that you use the provided VM.

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LEGO NXT

- One main unit with display, speaker, bluetooth
- 3x motors
- Sensors:
  - Light
  - Distance (ultrasound)
  - 2 x touch
  - Sound

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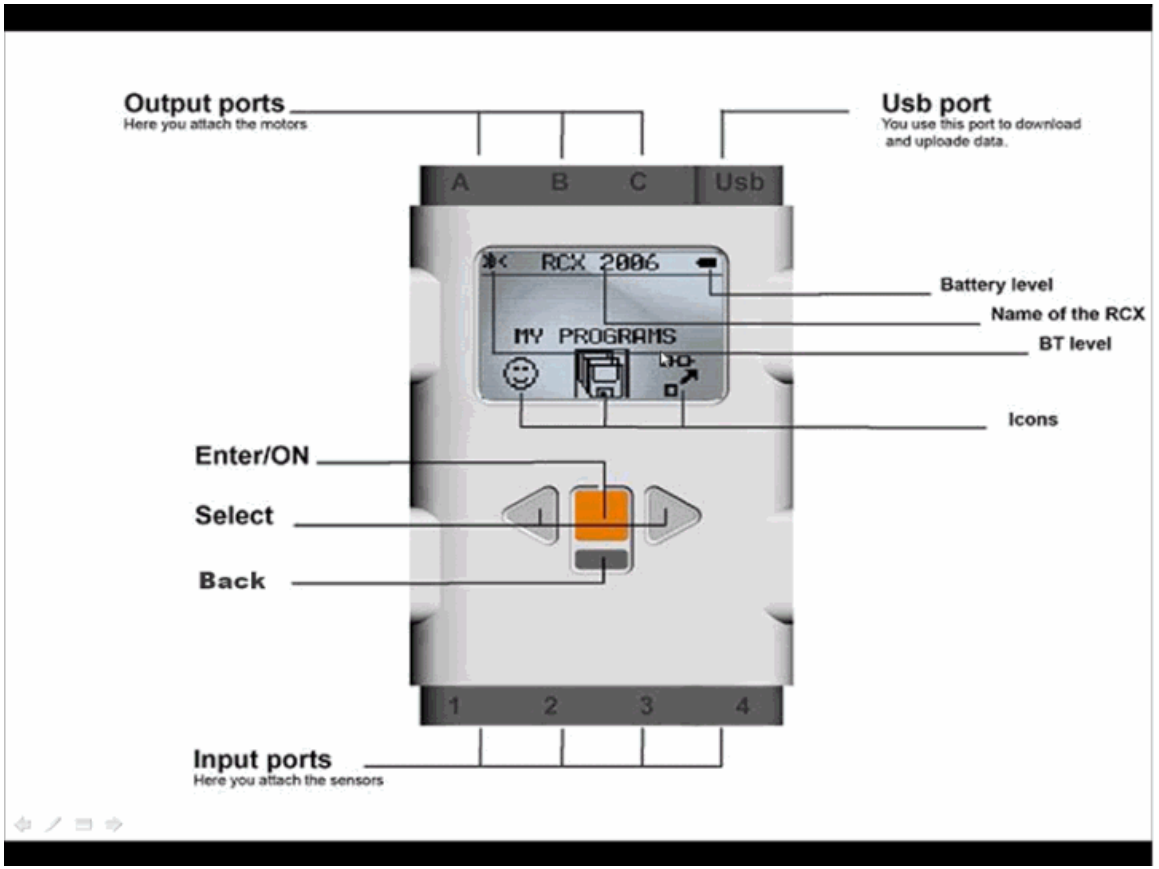
NXT Main Unit



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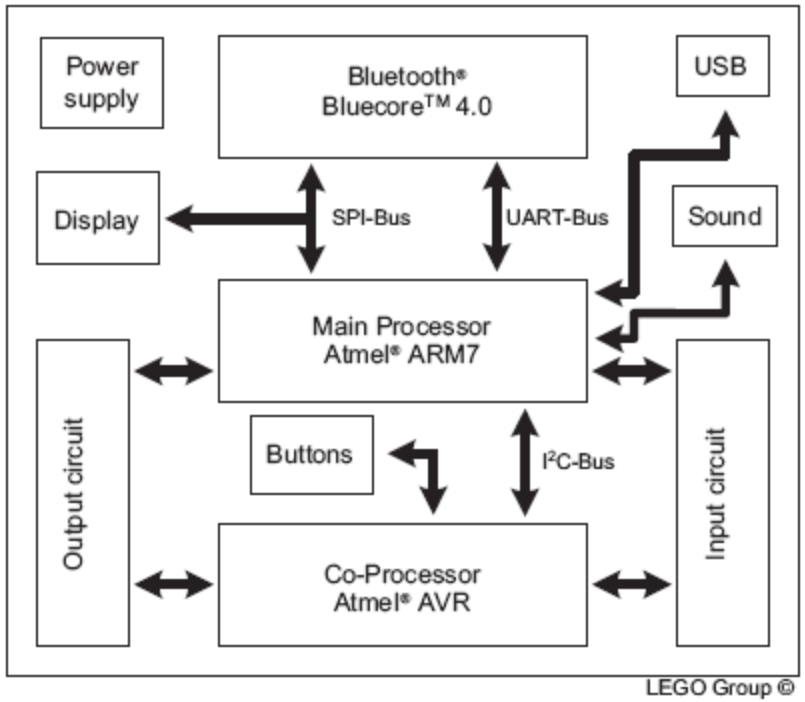
NXT Main Unit



32-bit ARM7 main processor + 8-bit AVR co-processor,
64k RAM, 256k Flash, 48MHz clock

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NXT Sensors

Light sensor:
Passive (ambient) or
Active (using an LED)
Measures intensity

Ultrasonic sensor:
Digital sensor
Range: 255 cm
Precision: +/- 3 cm

Touch sensor:
Push button

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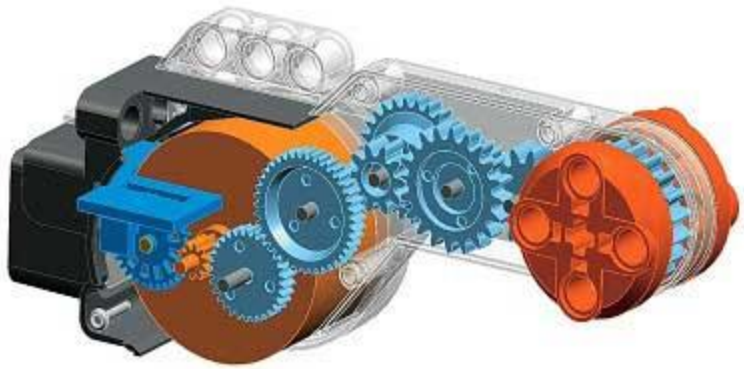
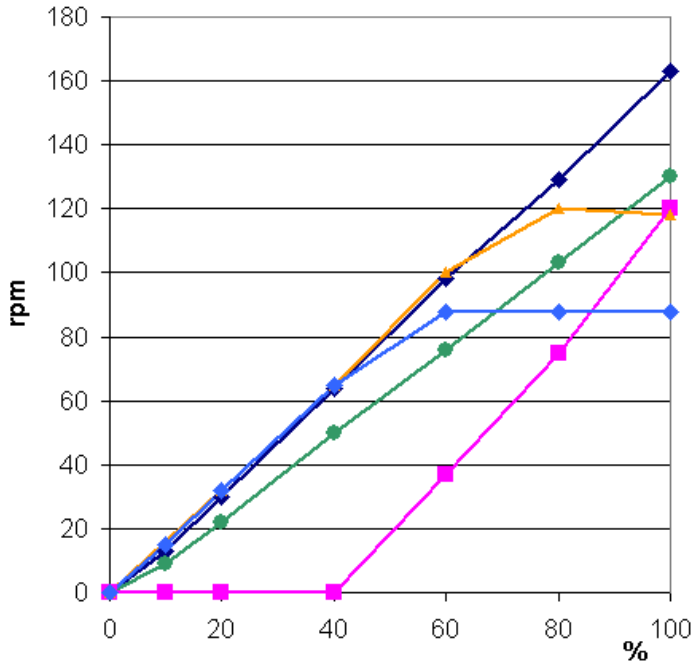
NXT Motor





http://www.philohome.com/nxtmotor/nxtmotor.htm

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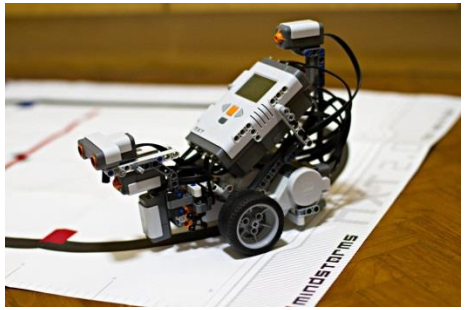
Make Your Robot!



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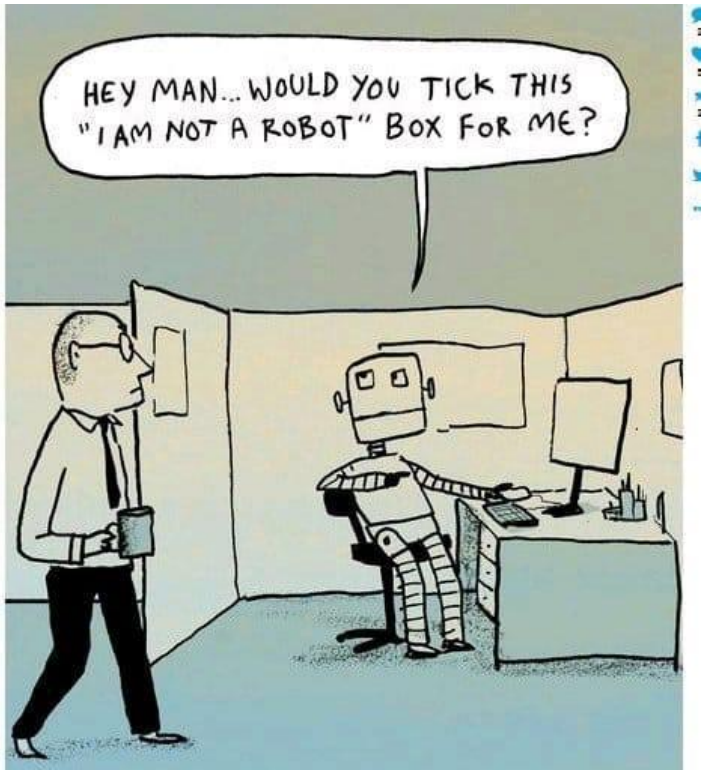
Help It To Run!



source: me.me

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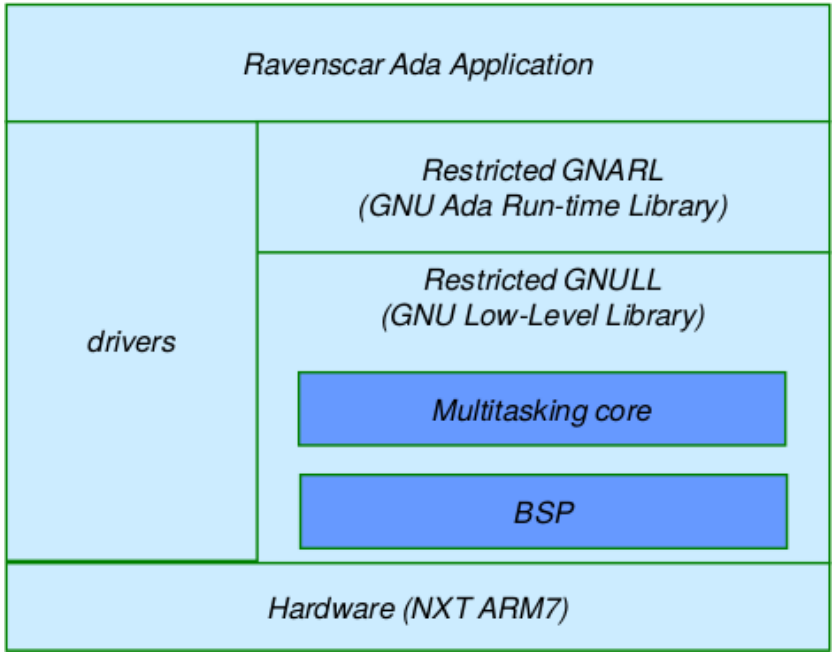
Ada NXT Runtime



Only 4186 lines!

Program + driver + runtime -> in RAM!

Based on Ravenscar small footprint profile (SFP)

http://www.it.uu.se/edu/course/homepage/realtid/ht19/labs/lab2/runtime

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Ravenscar Profile

- Ada subset for safety-critical system
- Important features:
  - No relative delay
  - No select
  - Only one entry per protected object
  - Task declarations in library/package level
  - Only Ada.Real_Time
  - many more …

Check:

http://www.it.uu.se/edu/course/homepage/realtid/ht19/labs/lab2/ravenscar

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Helloworld Again!

Main Procedure

Helloworld.adb

Task Package Specification

Tasks.ads

Task Package Implementation

Tasks.adb

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Main Procdure

```
-- File : hello_world.adb
with System ; --  default package, always include
with Tasks ;  -- Integrate tasks package

procedure hello_world is
      pragma Priority (System.Priority'First);
begin
     Tasks.Background;
end hello_world;
```

Assigning lowest priority

Calling main procedure of tasks pacakge

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Ada Priority Model

FIFO queue within same priority

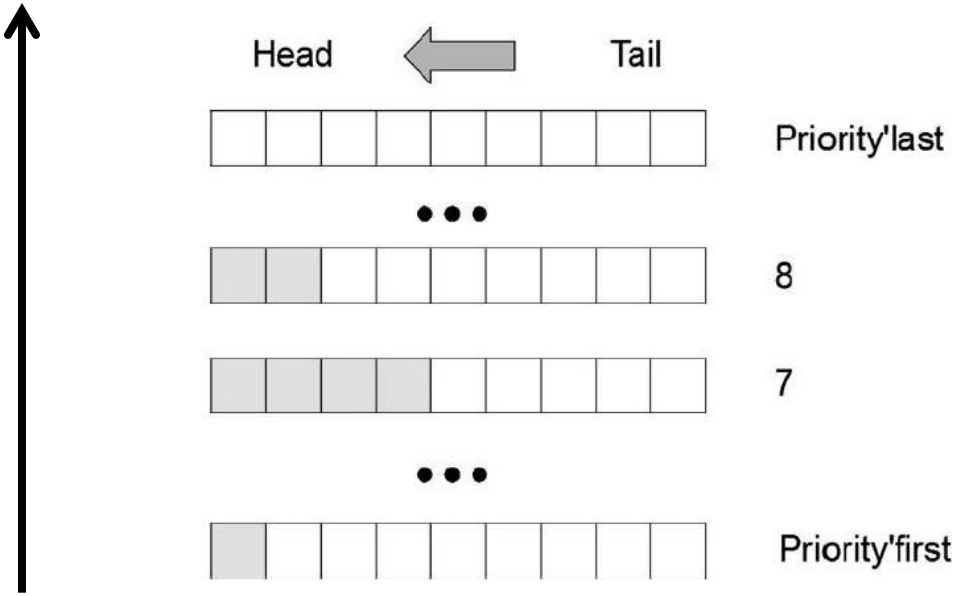

Image Source: Building Parallel, Embedded, and Real-Time Applications with Ada
McCormick, Singhoff, Hugues

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Tasks Package

```
-- File : Tasks. ads
with Ada.Real_Time ;   use Ada.Real_Time;
with NXT;                  use NXT;
-- main NXT package

package Tasks is
      procedure Background;
      private
         -- Define periods and times
         -- Define used sensor ports
         ...
end Tasks;
```

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Tasks Implementation

```
-- File : Tasks. adb

Package body Tasks is
      procedure Background is
      Begin

     end loop

    task HelloworldTask is
        -- Define priority
        pragma Storage_Size(4096);
    end Helloworldtask;

    task body HelloworldTask is

    begin
    ….
```

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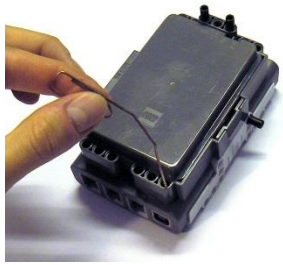
Compilation and Upload

- Check step by step instructions in this file:

http://www.it.uu.se/edu/course/homepage/realtid/ht19/labs/lab2/Compile_Upload_VM.pdf

- Don't forget to charge your robot's battery!
- For first time, you need to put NXT into reset mode:



- You need to be root (type "`su`" and enter password "`lego`") to be able to use `fwexec` to flash the firmware.
- When you reset the robot, everything will be gone.

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HW Interfacing

Example: Initializing sensors and motors

```
1 Touch_Sensor_Id : Touch_Sensor (Sensor_1);
2
3 Light_Sensor1 : Light_Sensor := Make(Sensor_2, True);
4
5
6 Right_Motor_Id : constant Motor_Id := Motor_A;
7 Left_Motor_Id  : constant Motor_Id := Motor_B;
```

Check: programs in low_level_tests.zip
API in drivers.zip

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Motor Control

Example: Using motor control API

```
1  procedure Forwards is
2  begin
3       Control_Motor (Right_Motor_Id, Speed_Full, Forward);
4       Control_Motor (Left_Motor_Id, Speed_Full, Forward);
5  end Forwards;
6
7  procedure Turn_Left is
8  begin
9       Control_Motor (Right_Motor_Id, Speed_Full, Backward);
10      Control_Motor (Left_Motor_Id, Speed_Half, Backward);
11 end Turn_Left;
```

Check: motor_test.zip examples
drivers.zip for API descriptions

Synchronization

- Synchronization between tasks by protected objects
- Ravenscar restriction: **only one entry** per protected object
- Protected object itself should have **priority at least as high** as the maximum priority of the user tasks
- Access to this protected object is controlled by Immediate Ceiling Locking Protocol (ICPP)

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Lab Assignments

- **Part 1: Warm-up**

  Extend helloworld to display light values
- **Part 2: Event-driven scheduling**

  Detect a sensor event
- **Part 3: Periodic task scheduling**

  Add obstacle avoidance
- **Part 4: Line tracker**

  Complete lap following another robot

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Part 4

Follow **it** on the **this** track

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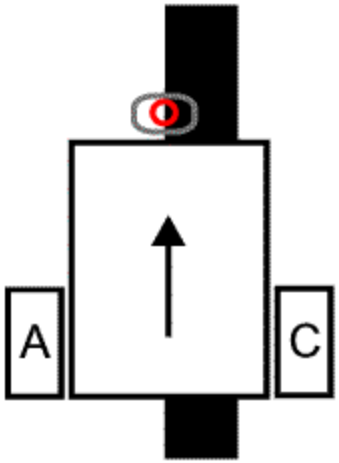
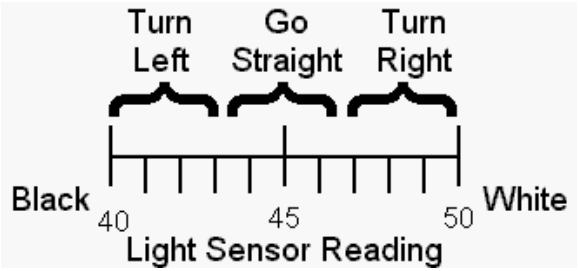
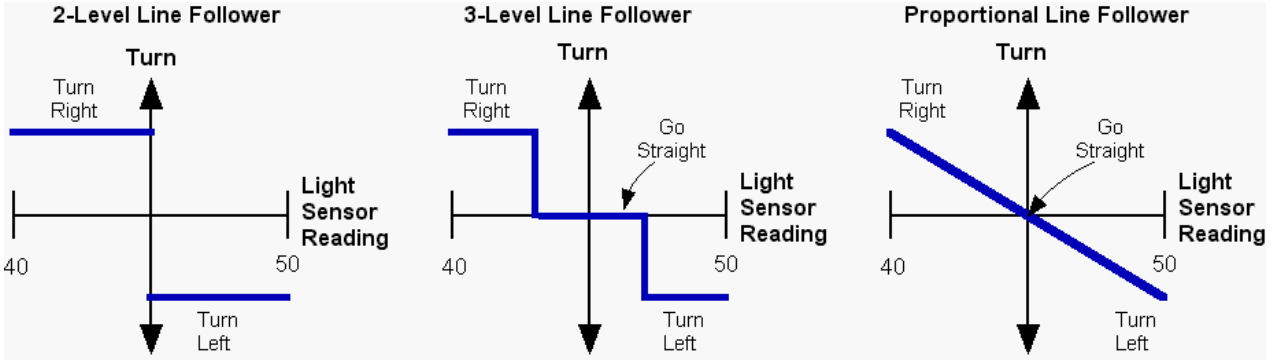
Line Following with NXT







Images from http://www.inpharmix.com/jps/PID_Controller_For_Lego_Mindstorms_Robots.html

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More Tips

Check out the tutorial file which contains:

- tips on getting started with the NXT drivers,
- a simple proportional (P) controller implementation that will come in handy during the later parts of the lab,
- some tips related the VM,
- and lastly solutions to commonly encountered problems (under the Troubleshooting section).

http://www.it.uu.se/edu/course/homepage/realtid/ht19/labs/lab2/rts_lab2_tips.pdf

Do not spend too much time on optimizing the controller, this is not a course on control theory.

If you encounter a problem, please refer to the Troubleshooting section of this document first.