Signals, Instruments, and Systems

School of Architecture, Civil and Environmental Engineering

EPFL, SS 2015-2016

http://disal.epfl.ch/teaching/signals_instruments_systems/
Signals, Instruments, and Systems – W1

Part I: Course Organization, Team, and Content
Team beyond this course
Distributed Intelligent Systems and Algorithms Laboratory:
http://disal.epfl.ch

• **Instructor**: Alcherio Martinoli
• **Guest lecturers**: Ali Marjovi, Felix Schill, Zeynab Talebpour
• **Teaching assistants**:
  – Steven Roelofsen (head TA, PhD student)
  – Guillaume Jornod (TA, R&D engineer)
  – Ali Marjovi (TA, postdoctoral fellow)
  – Milos Vasic (TA, PhD student)
  – Clémence Le Cornec (help TA, master student)
• **Support staff**:
  – Alexander Bahr (visiting researcher)
  – Faezeh Rahbar (PhD student)
  – Felix Schill (postdoctoral fellow)
  – Zeynab Talebpour (PhD student)
Course Rationale, Content, and Prerequisites
Typical Field Instrumentation for Environmental Monitoring

- Ultrasound anemometer
- Laser-based disdrometer
- Integrated compact weather station (temperature, humidity, anemometer disdrometer)
- Data logger
Local Climate Monitoring

Features:
- Very low sampling frequency < 1Hz
- Very low power consumption: 25mW
- Solar panel
- Radio communication

Sensors:
- Air Temperature and Humidity
- Infrared Surface Temperature
- Anemometer
- Solar Radiation
- Pluviometer
- Soil moisture
- Soil pressure

Visit http://sensorscope.epfl.ch for further details!
Permafrost Monitoring

• What is measured:
  – rock temperature
  – rock resistivity
  – crack width
  – earth pressure
  – water pressure

Pictures: courtesy of Permasense
Seismic Event Monitoring

- 38 strong-motion seismometers in 17-story steel-frame Factor Building.
- 100 free-field seismometers in UCLA campus ground at 100-m spacing

Source: D. Estrin, UCLA
Ecosystem Monitoring

Science
• Understand response of wild populations (plants and animals) to habitats over time.
• Develop in situ observation of species and ecosystem dynamics.

Techniques
• Data acquisition of physical and chemical properties, at various spatial and temporal scales, appropriate to the ecosystem, species and habitat.
• Automatic identification of organisms (current techniques involve close-range human observation).
• Measurements over long period of time, taken in-situ.
• Harsh environments with extremes in temperature, moisture, obstructions, ...

Source: D. Estrin, UCLA
Embedded Systems at the Heart of Modern Environmental Engineering

• Moving the lab to the field is “in”!
• Most of the applications require large spatial distributions (scale of the domain $\gg$ scale of a node) $\rightarrow$ sensor networks
• The underlying hardware/software technology (at the single device level) share the same principles
What These Systems Share at their Core?

- Sensing
- Processing
- Mobility
- Communication
- Processing
- Visualization
- Storing

In-situ instrument → Transportation channel → Base station

The goal of this course is to shed light on this process and blocks!
What This Course Is About

• Fundamentals of computer science:
  – Basics of computer architecture
  – C programming consolidation (vs. Matlab)
  – C for embedded and real-time systems

• Fundamentals of signal processing:
  – Analog/Digital signals, sampling and reconstruction
  – Time/Frequency domains and transforms
  – Filters, Converters

• Fundamentals of embedded systems:
  – Microprocessors, microcontrollers, memory
  – Sensors and actuators
  – Basic control and communication techniques and concepts
Course Prerequisites

• Fundamentals in C and Matlab programming
• Fundamentals in probability calculus
• Fundamentals in analysis (Analysis I to IV, ODE, Fourier series and analysis, transforms)
• The Introduction to Control of Dynamical Systems course will help although for now not fully leveraged
• Quantitative Methods II also help with fundamentals in signal processing
Rationale (1)

• This course must allow you to become a power user of the key instruments in environmental engineering used nowadays (sensor networks, meteorological stations, data loggers, etc.) and in the future (drones, remotely operated vehicles, robotic sensor networks, etc.)

• Being a power user means not only being an advanced user but also understand enough to collaborate with EE/CS/ME engineers to design the instruments of the future in environmental engineering; idea: complexity shifted more and more from hardware to software → a lot of domain knowledge can be transferred to the instruments at software level
Rationale (2)

• **Well-balanced course**: theory, algorithms, tools and practical exercises

• It should prepare you to better follow a number of master courses (especially in the new **Environmental Monitoring and Modeling specialization**)

• This course can be considered as an **elevator** to the **master** course “Distributed Intelligent Systems” for SIE students where various other sections and programs attend

• It should get you prepared for carrying out a design/semester/master **project** at DISAL
Organization of the Course
Credits and Workload

• 5 ECTS
• 1 ECTS = 30 h workload → 150 h workload total
• Rough breakdown
  – 60 h lecture (including reading, exam preparation)
  – 45 h lab (including verification tests and their preparation)
  – 45 h course project (including implementation, reporting, reviewing and defense)
Grade

- Final written exam, summer; 180 minutes
- 60% performance during semester, 40% performance during the exam (compromise US/Europe style)
- During semester: mean performance 2 lab verification tests (30%) and course project (30%)
- During exam: all covered material is subject to examination, but the exam is open book (no electronic equipment allowed other than a basic, non programmable pocket calculator)
Lecture Notes & Reading

- Policy: no manuscript, but slides and your own notes
- Preliminary lecture slides in pdf format available for download on the course web site before each lecture (wed evening), definitive ones after lecture (couple of days max); e-mail notification only when definitive slides are posted
- Reading will be added on Moodle as the course progresses
- Access to Moodle: in principle you should be all set because compulsory course and therefore inclusion by default; if issues contact sis-ta@groupes.epfl.ch
Tools used in Exercises and Course Projects

- C programming environment
- Matlab
- High-fidelity simulator (Webots)
- Real devices (desktop robots: e-puck; desktop sensor nodes: Mica-Z)
- OS: UNIX (Linux), TinyOS
MICAZ (only one Lab)

- **Microprocessor**
  - 8 bit microprocessor, ~8MHz
  - 128kB program memory, 4kB SRAM
  - 512kB external flash (data logger)

- **Transceiver**
  - 802.15.4 (Zigbee)

- **TinyOS**

- **Sensor board**
  - Light
  - Temperature
  - Microphone
  - Buzzer (4 kHz Resonator)
e-puck Robot (Labs & Projects)

Computation and memory

Communication

Actuators

Sensors

I/O

- low battery detection
- power-on led
- low battery indicator
- extension connectors
- programming/debug connector
- RS232 connector
- IR remote control
- bluetooth radio link
- dsPIC 30F6014 30MHz
- 3.3V regul.
- to all devices
- 2x stepper motors
- body light
- 8x IR prox.
- 8x Red Leds
- 10MHz clock
- 2.5V 1.8V regul.
- CMOS color camera
- 3D accelerometer
- 3x micro speaker
- battery protection
- LiION Battery 3.6V 1.4Ah
- audio codec
- ON-OFF
- running mode selector
- RESET
Webots (Labs & Projects)

- High-fidelity simulation
- Discrete sensor and actuators
- Noise and nonlinear characteristics faithfully reproduced
- Different trade-offs faithfulness/computational cost
Labs (1)

• Lab session 16:15-19:00 on Mon, GR B0 01 (first lab session: next week)
• Mini-tutorial (5-10 min) by the main lab designer at the beginning of the lab
• 10 lab sets total
• Official solution available on Moodle after the lab session
• sis-ta@groupes.epfl.ch for ANY issue!
Labs (2)

• Lab assignment posted on Friday of the previous week
• Lab presence not compulsory but
  – We do not repeat labs
  – If you do not come to labs you will have a hard time in lab verification tests and being efficient in the course project
  – Certain labs involve HW which we do not distribute outside the lab sessions
• I think it is a lot of fun and really helps you understand lecture stuff
• Assistants are well prepared (2 TAs, designer and tester, and help TA)
• Dedicated feedback forms for each lab on Moodle
Lab Verification Tests

- Worked well in the last 3 editions of our courses; very efficient replacement of homework; save time to students, result in a fairer (among students) and more rewarding (for TA) grading, and reduce grade gaps between continuous control checkpoints and final exam
- In week 8 (Lab 1-6) and 14 (Lab 7-10)
- 3 h duration, during exercise session (in the computer room)
- Graded and individually reviewed (no official solution)
Suggestions for a Successful Exercise Series

From our teaching experience:

• Read the assignment in advance (i.e. before the lab, you have always a “free” evening), in this way you will be more efficient when the TAs are around for helping you on the toughest questions…

• Take advantage of office hours (upon appointment using the sis-ta list) if additional explanations are needed

• Do the labs seriously, do not wait for the solution distributed a couple of days later.
Course Project (1)

- Course project list distributed in Week 5, kick-off in Week 8
- 45 h effort, defenses first week after the end of the semester, Tue June 7? (1.5 h presence max, can pick the time slot).
- Team of 3 students (ad hoc solution for numbers of students not divisible by 3)
- Will distribute HW/SW at home
- Short progress report (compulsory but not graded) in Week 10
- Final report to be submitted (pre-established max # of pages and format) by end of Week 14.
Course Project (2)

• Final presentation in front of the class (15 minutes + 10 min questions)
• Each of the project will have another team of students as reviewers
• Each of the team members has to present
Suggestions for a Successful Course Project

From our teaching experience:

• Contact ASAP the responsible supervisor when the projects will have been assigned for getting started

• Plan your effort (milestone, time, etc.), coordinate your team

• Arrive at the progress report milestone with project objective understood, reading over, a clear plan, tool familiarization over, and preliminary implementation results
Final Notes
8th Iteration at ENAC

• “Movie” organization confirmed: multiple lecturers ("actors"), one organizer ("director"); this year more presence of the main instructor in the lecture

• Same organization and content as last year; target: incremental improvement of the course content, as much as possible further leveraging of other courses

• Target: additional alignment between lab verification tests and labs (same "guidance flavor"); labs also asking a few pen/paper questions for additional exam training

• TA/staff involvement rationalized for lab/tests and course projects (only way to make the course viable; in the future more drastic reductions might be possible)
Signals, Instruments, and Systems – W1

Part II: C programming refresher
Linux Operating System

• Interface between hardware and applications. Manages and coordinates activities and sharing of the limited computer resources
• Standard shell commands (ls, cd, pwd, cp, mv, rm, mkdir, man...)
• Absolute and relative paths
• Environmental variables ($PATH, $HOME)
• Redirection of input and output
• Pipes

Source: http://en.wikipedia.org/wiki/Operating_system
Remember `man`?

- You can use `man` to show information about functions in the standard libraries of C:
  - e.g. `man printf`
  - or `man atan2`

- To type in the terminal!
Main differences with Java

• C is NOT object oriented. (C++ is OO)
• Code is directly translated into binary that can be directly executed by the machine. With C, the programmer can directly access machine resources (memory, processes).
• It’s not ‘safe’ (Java is ‘safe’)
• Full comparison of C vs. Java: http://introcs.cs.princeton.edu/java/faq/c2java.html
Compilation

```
int main() {
    int a = 5;
    double b = 4.3;
    return a * b;
}
```

```
1010010101010010 1010010101001010 1001010010100101 0001010100111110
1010010101010010 1010010101001010 1001010010100101 0001010100111110
0010010101010010
```
The C Compiler Pipeline

**Header Files**
- `stdio.h`
- `common.h`

**Source File**
- `main.c`

**C Preprocessor**

**C Compiler**
- `main.o`

**Object Files**
- `module.o`
- `libc.so`
- `main`

**Library Files**

**Object File**
- `main.o`

**Linker**

**Executable File**
“.h” vs “.c”

- Usually header files should contain all the necessary functions, structures, typedef and enum declarations such that another programmer can use your code without having to look at your c file.

- C files contain the actual implementation and “hidden” declarations.
Libraries

- Libraries provide special functionality in the form of collections of ready-made functions:

**Library:**
- `stdio.h`
- `math.h`
- `time.h`
- `stdlib.h`

**Example:**
- `printf(const char* format, ...)`
- `sqrt(double x)`
- `gettimeofday()`
- `rand()`

**Usage:**
- `#include <stdlib.h>`
- `#include "my_library.h"` : your own collection of function declarations
Compilation Example

**Main source file**

```
gcc help.o file.o main.c -o program -lm
```

**Complementary file**

1. help.c → help.o
   
   ```
gcc -c help.c -o help.o
```

2. file.c → file.o
   
   ```
gcc -c file.c -o file.o
```

**Libraries**

- libc: standard C library
- libm: math library

**Program**
Makefile: Example

(see previous slide)

```makefile
CC = gcc
LDLIBS = -lm
all: main

main: main.o help.o file.o

clean:
    rm -rf *.o main
```

- compiler
- additional library
- targets
- label
- [TAB] !!
  [TAB] rm -rf *.o main

Note: Run make clean all for a totally new compilation
Variables

• There are several types of variables in C:
  – Integers: char, short, int, long
  – Floating point: float, double
  – Characters: char
  – There is no Boolean nor String type.

• Variables can be either signed or unsigned:
  – Ex.: unsigned int, signed char
Variables

<table>
<thead>
<tr>
<th>Type</th>
<th>Storage size</th>
<th>Value range</th>
</tr>
</thead>
<tbody>
<tr>
<td>char</td>
<td>1 byte</td>
<td>-128 to 127 or 0 to 255</td>
</tr>
<tr>
<td>unsigned char</td>
<td>1 byte</td>
<td>0 to 255</td>
</tr>
<tr>
<td>signed char</td>
<td>1 byte</td>
<td>-128 to 127</td>
</tr>
<tr>
<td>int</td>
<td>2 or 4 bytes</td>
<td>-32,768 to 32,767 or -2,147,483,648 to 2,147,483,647</td>
</tr>
<tr>
<td>unsigned int</td>
<td>2 or 4 bytes</td>
<td>0 to 65,535 or 0 to 4,294,967,295</td>
</tr>
<tr>
<td>short</td>
<td>2 bytes</td>
<td>-32,768 to 32,767</td>
</tr>
<tr>
<td>unsigned short</td>
<td>2 bytes</td>
<td>0 to 65,535</td>
</tr>
<tr>
<td>long</td>
<td>4 bytes</td>
<td>-2,147,483,648 to 2,147,483,647</td>
</tr>
<tr>
<td>unsigned long</td>
<td>4 bytes</td>
<td>0 to 4,294,967,295</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>Storage size</th>
<th>Value range</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>float</td>
<td>4 byte</td>
<td>1.2E-38 to 3.4E+38</td>
<td>6 decimal places</td>
</tr>
<tr>
<td>double</td>
<td>8 byte</td>
<td>2.3E-308 to 1.7E+308</td>
<td>15 decimal places</td>
</tr>
<tr>
<td>long double</td>
<td>10 byte</td>
<td>3.4E-4932 to 1.1E+4932</td>
<td>19 decimal places</td>
</tr>
</tbody>
</table>
Variables

• Variables need to be declared before they are used.
• In correct ANSI C89, variables need to be declared at the beginning of a block (after “{”).

```c
int main() {
    int a = 5;
    double b = 4.3;
    return (int)((double)a * b);
}
```

Remark: A variable type can be modified with a cast.
Variables - Cast

- The cast operator is an operator which forces a particular type mould or type cast onto a value:

```
char ch = 'a';
int i;
i = (int)ch;
```

```markdown
i = 97
careful!
```

```
int i = 1;
int j = 3;
double k;
k = i/j;
```

```markdown
k = 0
```

```
int i = 1;
int j = 3;
double k;
k = (double)i/(double)j;
```

```markdown
k = 0.3333
```
Variables - enum

- Enumeration of tags. The tags are numbered (0,1,..) by default.

Def.: `enum identifier { enumerator-list }`

Ex.: ```
enum BOOLEAN {
    false = 0,
    true       // =1
};
enum BOOLEAN is_empty = false;
```
Variables - typedef

- Typedef allows you to define your own types.

**Def.:**

```
type typedef-name
```

**Ex.:**

```
typedef int BOOLEAN;
BOOLEAN is_empty = 0;
```
Controlling the execution flow

- Algorithms are all about controlling the execution flow.
- Algorithms are all about deciding how to proceed depending on some conditional statements.

```c
float max = 0.0;
float a = 5.0;
float b = 2.1;

if (a > b) {
    max = a;
} else {
    max = b;
}

return max;
```
Conditions

- Conditions can be expressed using logical expressions:
  - > (greater than)
  - < (less than)
  - >= (for greater than or equal to)
  - <= (for less than or equal to)
  - != (not equal)
  - == (to test for equality)

- In C, there is no boolean variable (true or false). Instead, true is represented by any value not equal to 0 and false is represented by the value 0.

```c
int a = 0;
if (a = 1) {
    // this code is reached
} else {
    // this won’t happen
}

int a = 0;
if (a == 1) {
    // this won’t happen
} else {
    // this code is reached
}
```

Do not confuse `a == 1` (equality) with `a = 1` (assignment).

Wrong: `if (a = 1) {`  
Correct: `if (a == 1) {`
Conditional branches

The `switch` structure is very useful when the execution flow depends on the value of a single integral variable (int, char, short, long).

```c
switch (a) {
    case 1:
        // if a == 1, do this
        break; // jump to the rest of the code
    case 2:
        // if a == 2, do this
        break; // jump to the rest of the code
    default:
        // otherwise, do this
}
// rest of the code
```

```c
if (a == 1) {
    // if a == 1, do this
} else if (a == 2) {
    // if a == 2, do this
} else {
    // otherwise, do this
} // rest of the code
```

Both codes have exactly the same behavior!

---

**Do not forget the `break` instructions, otherwise the statements in the rest of the `switch` will also be executed!**
Conditional loops are a combination of “if..then” and a jump.

```c
int total = 0;
int i = 0;
int array[3] = {12, 3, -5};

while (i < 3) {
    total += array[i];
    i++;
}

return total;
```

What is the value of total at the end of the program?

```
total = 10
```
Conditional loops

The loop `for` is useful when an iteration count (`i` in the example below) needs to be maintained, but the number of iterations must be known.

```c
int total = 0;
int i = 0;
int array[3] = {12, 3, -5};

for (i = 0; i < 3; i++) {
    total += array[i];
}

return total;
```

What is the value of `total` at the end of the program?

`total = 10`
The statements `break` and `continue` cause the program to exit a loop or to jump directly to its next iteration, respectively.

```c
int total = 0; int i = 0; int array[3] = {12, 3, -5};
while (1) {
    if (i < 3) {
        total += array[i];
        i++;
        continue;
    } else {
        break;
    }
    // unreachable code
}
return i;
```
stdin - stdout

• Standard input and standard output are file streams
• `printf("Hello")` is equivalent to `fprintf(stdout,"Hello")`
• `scanf("%d", &i)` is equivalent to `fscanf(stdin,"%d", &i)`
• `stderr` is useful to display errors, because it is not affected by redirection (>):
  ```
  ./my_program > out.txt  -- the errors will still be displayed!
  ```
## Printing – Format

Most commonly used:

- `%d` integer
- `%u` unsigned integer
- `%f` double
- `%s` string
- `%c` char

<table>
<thead>
<tr>
<th>Object</th>
<th>Control spec.</th>
<th>Actual output</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>%6d</td>
<td>42</td>
</tr>
<tr>
<td>‘z’</td>
<td>%3c</td>
<td>z</td>
</tr>
<tr>
<td>2.71828</td>
<td>%10f</td>
<td>2.71828</td>
</tr>
<tr>
<td>2.71828</td>
<td>%10.2f</td>
<td>2.71</td>
</tr>
<tr>
<td>“printf”</td>
<td>%s</td>
<td>printf</td>
</tr>
</tbody>
</table>
Indentation

• Indentation and spacing helps you and others read your code.
• It has to be systematic and consistent.

```c
int main() {
    int i, j;
    for (i = 0; i < 3; i++) {
        for (j = 0; j < 3; j++) {
            if (i == j) {
                printf("%d\n", i);
            }
        }
    }
    return 0;
}
```

```c
int main() {
    int i, j;
    for (i = 0; i < 3; i++) {
        for (j = 0; j < 3; ++j) {
            if (i == j) {
                printf("%d\n", i);
            }
        }
    }
    return 0;
}
```
Complete Example

• Module for representing, adding and subtracting complex numbers
• Manual compilation vs. Makefile
• Compilation errors
• See the archive on Moodle
Conclusion
Summary

• Basics in Linux:
  – How to navigate, how to manipulate files
  – How to combine commands
  – Where to look for information (man pages)

• Refresher on C programming:
  – Compilation
  – Variables and main function
  – Basic control structures (if, case, while, for)
Additional Literature – Week 1

• Nice summary on linux shell usage: http://linuxcommand.org/learning_the_shell.php

• Classical book for C programming:
  ‘C Programming Language’, Prentice Hall
  Brian W. Kernighan , Dennis M. Ritchie

• Popular C link:
  http://www.c-faq.com/

• And many more – Google is your friend