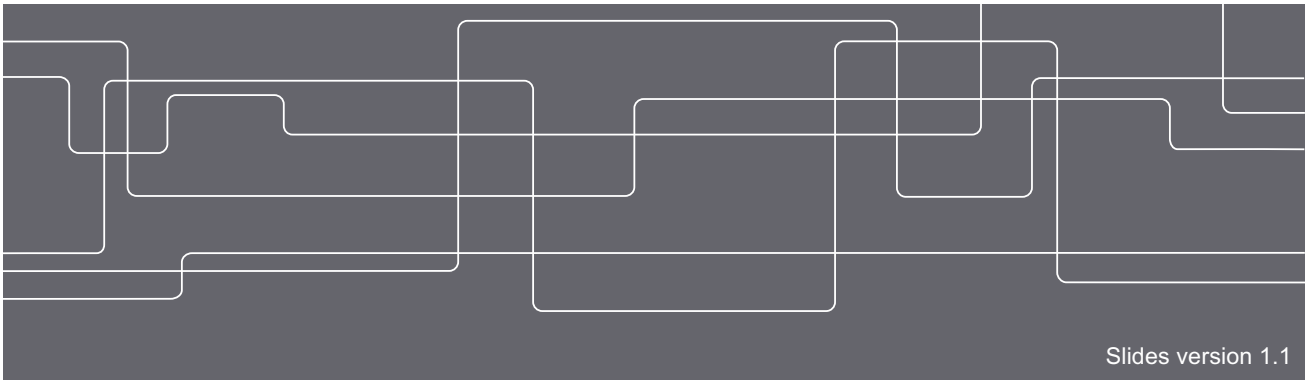
Computer Hardware Engineering (IS1200)
Computer Organization and Components (IS1500)

Spring 2018

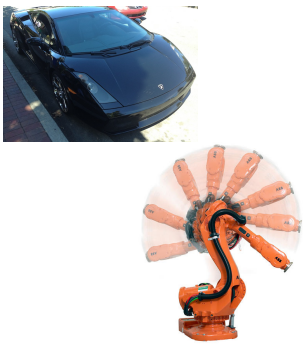
Lecture 1: Course Introduction

David Broman

Associate Professor, KTH Royal Institute of Technology



Different Kinds of Computer Systems



Embedded Real-Time Systems

Photo by Kyro

Personal Computers and Personal Mobile Devices

Photo by Robert Harker

Warehouse Scale Computers

Dependability | Energy | Performance

How is this computer revolution possible?

Moore's law:

- Integrated circuit resources (transistors) double every 18-24 months.
- By Gordon E. Moore, Intel's co-founder, 1960s.
- Possible because of refined manufacturing processes. E.g., Intel Core i7-6800 processors uses 14nm manufacturing.
- Sometimes considered a *self-fulfilling prophecy*. Served as a goal for the semiconductor industry.

Have we reached the limit?

Why?

The Power Wall

http://www.publicdomainpictures.net/view-image.php?image=1281&picture=tegelvagg

During the last decade, the clock rate has increased dramatically.

- 1989: 80486, 25MHz
- 1993: Pentium, 66Mhz
- 1997: Pentium Pro, 200MHz
- 2001: Pentium 4, 2.0 GHz
- 2004: Pentium 4, 3.6 GHz

2017: Intel Core i7-7820X, 3.6 GHz, 8 Cores (Turbo 4.0/4.5Ghz)

Increased clock rate implies increased power

We cannot cool the system enough to increase the clock rate anymore…

"New" trend since 2006: Multicore

- Moore's law still holds (but will end soon)
- More processors on a chip: multicore
- "New" challenge: parallel programming

Agenda

Part I

Course Organization

Part II

Introduction to C

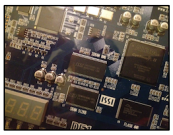
Part I

Course Organization

This Course in one Slide

Module 1
C and Assembly Programming

Compiler Tool Chains



Module 4
Processor Design

Module 2
I/O Systems

Input / Output

Processor

Memory

Module 5
Memory Hierarchy

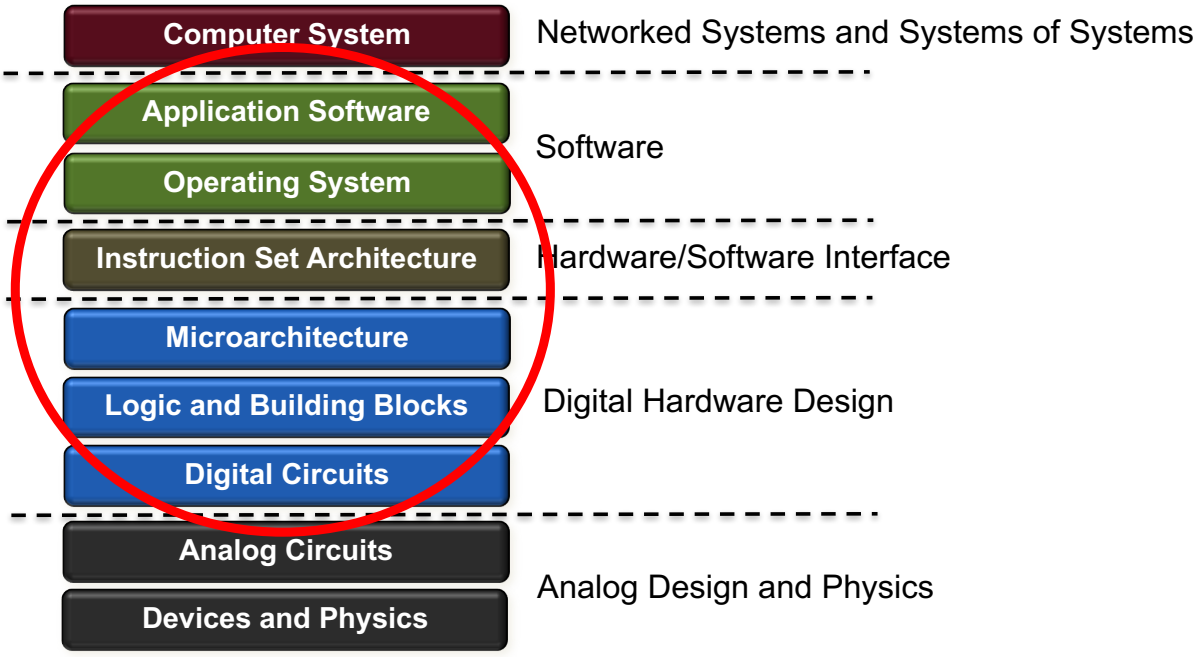
Module 3
Logic Design

Not part of IS1200, only for IS1500.

C C C C
C C C C
Memory

Module 6
Parallel Processors and Programs

Abstractions in Computer Systems



Learning Activities Overview

Lectures
- 12+2 lectures (2x45 min)
- Active participation
- Preslides before lectures

Empty Slides (Handouts)

Lecture Bugs

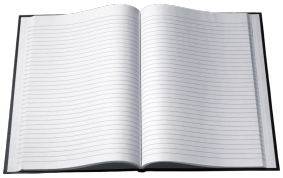
Physical Q and A

Exercises and Seminars
- 6 exercise classes with teaching assistants.
- 4 optional seminars with bonus (learning) points for the exam

Laboratory Exercises
- 4 laboratory exercises with examination at the KTH class labs
- 1 laboratory exercise for self study (only for IS1500)

Mini-project
- Project work on the ChipKIT board. 2 students in each group.

Exercises and Seminars

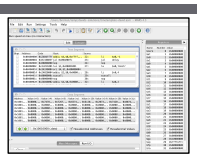


Exercises (optional)
- 6 traditional KTH exercises lead by teaching assistants (TA).
- Try to prepare solutions in advance.
- Solutions are available on the course web.

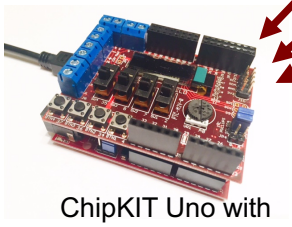
Seminars (optional)
- 4 optional seminars.
- Students prepare (individually) solutions and brings them to the seminar.
- If you do not bring solutions, you cannot attend the seminar.
- Exercises are corrected together, while the TA explains the solutions.
- If you pass an exercise, you get 1 bonus point on the fundamental part of the exam.
- The bonus points are valid on the main exam + two the following retake exams.

NOTE: The main purposes of seminars are that you learn and prepare for the exam, not that you get bonus points (although you get this as a bonus).

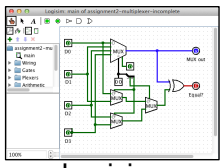
Laboratory Exercises



MARS MIPS Simulator



ChipKIT Uno with Basic I/O Shield

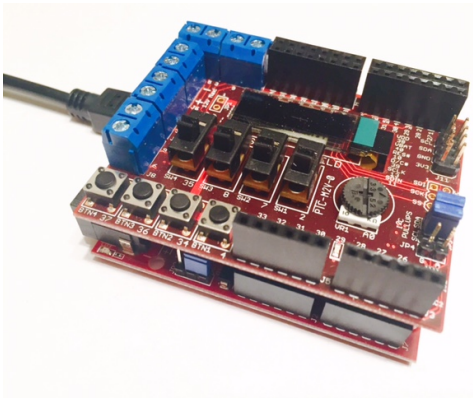


Logisim

#	Lab	Examination
LAB1	Assembly Programming	KTH Lab Room
LAB2	C Programming	KTH Lab Room
LAB3	I/O Programming	KTH Lab Room
LD-LAB	Logic Design	(IS1500 only)
LAB4	Processor Design	KTH Lab Room

- Prepare labs at KTH's computers or on your own computer.
- Preparation time for each lab: 8-24h
- 1 surprise exercise at the lab occasion.
- Each student book lab time separately in *Canvas*.

Mini Project



- Each group should consist of 2 students. Should be the same as the lab groups.
- Student groups may collaborate, i.e., projects may be connected.
- You must use the ChipKIT hardware and you may add additional hardware components.
- Each group can borrow a hardware kit for free!
- Either you do a basic project or an advanced project (required to be able to get grades A or B)
- More info will come on lecture 6. See also the course web.

Prestudy
Play around with the hardware, do labs, and think about what you want to do.

Extended abstract
1-2 pages, what you do, why, design, verification, etc.
Draft: Feb 9
Final abstract: March 2

Project Expo
March 5
One day: everyone show their great project!
Nominations and Awards!

Course Structure

Module 1: C and Assembly Programming

LE1 → LE2 → LE3 → LE4 → EX1 LAB1 S1 LAB2

Module 4: Processor Design

LE9 → LE10 → EX4 S2 LAB4

Module 2: I/O Systems

LE5 → LE6 → EX2 LAB3

Module 5: Memory Hierarchy

LE11 → EX5 S3

Module 3: Logic Design (IS1500 only) PROJ START

LE7 → LE8 → EX3 LD-LAB

Module 6: Parallel Processors and Programs

LE12 → LE13 → EX6 S4

Proj. Expo LE14

Examined Course Parts

1.5hp ANN1. LA-LAB, Logic Design
Grades P and F
(IS1500 only, not IS1200)

4.5hp LAB1. Labs 1,2,3,4 and Mini Project
Grades P and F

3hp TEN1. Written Exam (tenta)
Grades A, B, C, D, E, FX, F

Written Exam

Written Exam (Tenta)

- Thursday, March 15, 2017, 8.00-13.00
- Retake exams, June 2018, Jan 2019
- Allowed aids: One sheet of handwritten A4 paper (both sides) with notes.

The exam has two parts

- **Part I: Fundamentals**
  - Max 40 points.
  - 8 points for each of the 5 modules.
  - Short questions with short answers.
- **Part II: Advanced**
  - Max 50 points.
  - Comprehensive questions. Discuss, analyze, construct.

Grading of Exam

- To get a pass grade (A, B, C, D, or E), it is required to get at least 2 points on each module and in total 30 points on Part I (including bonus points).

Grading scale:

- A: 41-50 points on Part II
- B: 31-40 points on Part II
- C: 21-30 points on Part II
- D: 11-20 points on Part II
- E: 0-10 points on Part II
- FX: At least 30 points on Part I, and at most one module with less than 2 points.
- F: otherwise

To get A or B, you also need to have done an advanced project.

Policy for Plagiarism

Note that all forms of cheating and plagiarism will be reported. Please see KTH's policy for handling plagiarism (see course web page).

Seminar exercises

- You are allowed to discuss the solutions of the exercises, but the final solutions must be written down and solved individually.
- It is not allowed to copy solutions in any way.

Written Exam

- You are allowed to bring one handwritten sheet of A4 paper. You may write on both sides. The A4 paper must not be printed or copied.
- All other aids (for instance calculators or text books) are not allowed.

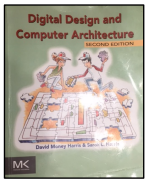
Labs and Project code

- You may collaborate and discuss with anyone, but you must be able to explain all code you present to us individually, including your lab partner's code.
- When requested in the lab and project instructions, you must clearly declare who has authored the code that you hand in or show at lab examinations.

Written reports and project abstracts

- You are not allowed to copy, cut, or paste any text into your report that is not produced by you.
- The only exception is if you quote text properly, and give a citation to the original source.

Course Literature

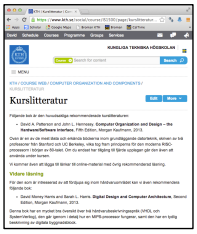


Two Recommended Course Books

- David Money Harris and Sarah L. Harris. ***"Digital Design and Computer Architecture"***, Second Edition, Morgan Kaufmann, 2013.

- D. A. Patterson and J. L. Hennessy, ***"Computer Organization and Design – the Hardware/Software Interface"***, Fifth Edition, Morgan Kaufmann, 2013.

You may use the 4th edition instead (available online)



Additional Online Course Material

- Laboratory Exercises
- Comics
- Manuals
- Other online material
- Exercises
- Lecture Slides

See the course webpage for detailed **reading guidelines.**

Teachers and Assistants

David Broman
dbro@kth.se
Examiner and Course responsible.

Fredrik Lundevall
flu@kth.se
Exercises and Admin

Gunnar Johansson
gujo@kth.se
Labs and Admin

If it is not a personal message, *please* email *is1200@ict.kth.se* (goes to all the above)

Lectures

- David Broman
- Fredrik Lundevall (guest lectures)

Written Examination

- David Broman

Labs

- Gunnar Johansson
- Romy Tsoupidi
- Saranya Natarajan
- Daniel Lundén
- Fredrik Lundevall
- John Wikman
- Joey Öhman
- Emma Nimstad

Exercises and Seminars

- Fredrik Lundevall
- Saranya Natarajan
- Daniel Lundén
- Johan Myrsmeden
- Romy Tsoupidi

Mini Project

- Romy Tsoupidi (Q&A)
- David Broman
- Fredrik Lundevall
- Gunnar Johansson
- Saranya Natarajan
- Daniel Lundén

Feedback

Web-based Course Evaluation
Standard course evaluation (after the course) is used to improve the course next year.

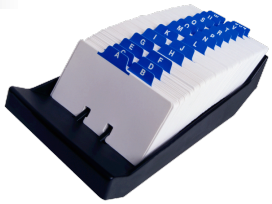
Photo by Julius Schorzman

Personal Feedback
Send me an email (dbro@kth.se) with feedback or let's talk over a cup of coffee!

Muddy Cards Course Evaluation (half time)
3-4 weeks into the course, we will hand out blank cards. Students write (anonymously) pros and cons about the course. The examiner collects, presents, and takes actions!

Course committee (kursnämnd)
A group of students meet up with me at the middle and at the end of the course. Informal oral feedback.

Course Registration



Registration
- You must register for the course using KTH's web system. See the course web page "Registration" for more info.
- If you are re-registering for the course, you should send an email to studentexp@ict.kth.se.
  Deadline February 2 (needed to take part in labs or seminars)

If you have any questions about course registration
- Send an email to studentexp@ict.kth.se. We (the teaching team) does not handle course registrations anymore.

Getting Help?

Canvas

- Post <u>all</u> questions about course content on the course website.
- Assistants and teachers will answer within the next working day. Everyone can see the answers.

Lunch Office Hours

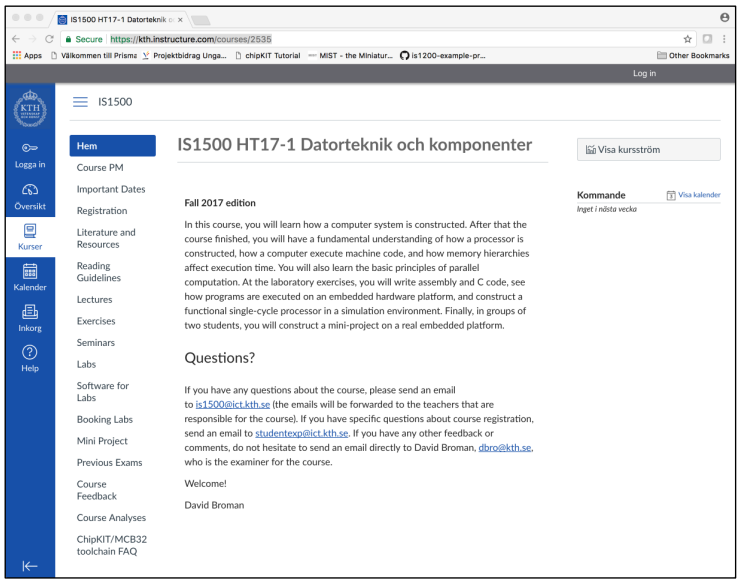
- Every Wednesday 12.15 – 13.00 teaching assistants will be available to answer questions about labs, project etc.
- See the course schedule for locations.

Email is1200@ict.kth.se

- Send administrative questions to: is1200@ict.kth.se
- <u>Please</u> post questions about exercises, labs, project etc. on Canvas.

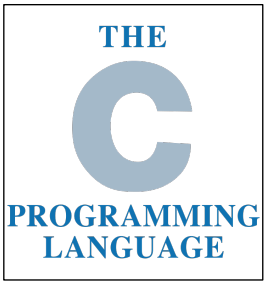
The course web pages in Canvas…

… contain a lot of useful information. Please read them carefully.

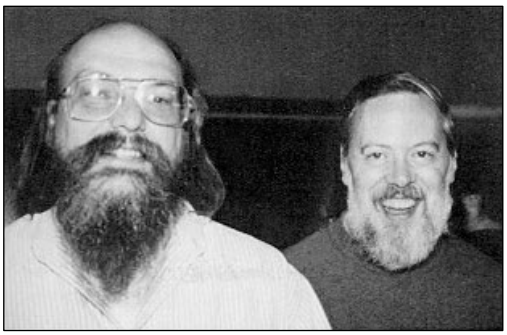


Part I

Introduction to C



Where is C coming from?



The beginning

- Developed at AT&T Bell Labs in the years 1969-1973 by Dennis Ritchie (right in picture).
- C was developed in parallel with UNIX, originally designed by Ken Thompson (left in picture).

Dennis Ritchie and Ken Thompson received the Turing Award in 1983.

Standards

- The K&R book "**The C Programming Language**" (1st edition, 1978) by Brian Kernighan and Dennis Ritchie.
- ANSI C or C89 in 1989. Revised version, C99.
- Current standard, C11, approved December 2011.

What is C?

C is an **imperative** low-level programming language (statements change program states).

C is **not object-oriented** (as Java and C++), **not functional** (as Haskell, ML, and Ocaml), and **not interpreted** (as Perl, PHP, and Python typically are).

C has types, but it is **not type safe** (in contrast to e.g., Java or Haskell)

C allows **low-level memory access**, direct access to hardware, and has no garbage collection.

C has minimal run-time requirements and can be compiled to many platforms. It is **very portable**.

C is one of the most **widely used** programming language in the world. It is used in everything from from microcontrollers to supercomputers.

Hello World!

Include library functions for handling standard input/output.

Comments start with /* and ends with */. Can be several lines.

Main function. Returns an integer value. Return code 0 = no error.

```
#include <stdio.h>

/* The main function. */
int main(void){
  printf("Hello World!\n");
  return 0;
}
```

Compilation using **gcc** (GNU Compiler Collection). Without the output flag -o, the compiler produces an executable file named a.out.

```
$ gcc hello.c -o hello
$ ./hello
Hello World!
```

Library function **printf** prints to the standard output. "\n" means new line.

Shortcut (try it!)

```
$ gcc hello.c && ./a.out
```

Constants and Literals

Integer Literals

`233`	Decimal
`0x1A`	Hexadecimal (prefix 0x)
`012`	Octal (prefix of 0)

Warning. A prefix 0 means that the base is 8 (octal numbers). This number means 10 in decimal representation.

Floating-point Literals

`3.1415`	With a decimal point
`74e-6`	With exponent

Character constants

`'a'`	A character
`'\n'`	New line
`'\\'`	`\` character
`'\''`	`'` character
`'\"'`	`"` character

String Constant

```
"This is a string"
```


Whitespace, Identifiers, and Keywords

Tokens and Whitespace

Whitespace (space, newline, tab) separates tokens, but does not affect the program otherwise.

```
printf("Hello World!\n");
```

```
   printf   (
  "Hello World!\n"
  )
;
```

These programs have the same meaning.

An **identifier** is a name used to identify user defined items, such as variables and functions.

```
foo   _myVal
A32   Foo
```

Can contain underscore, **A** to **Z**, **a** to **z**, and **0** to **9**, but cannot start with a digit (**0** to **9**).

Case sensitive. **foo** and **Foo** are different.

A **keyword** is a reserved words that cannot be used as an identifiers.

`auto`	`double`	`int`	`struct`
`break`	`else`	`long`	`switch`
`case`	`enum`	`register`	`typedef`
`char`	`extern`	`return`	`union`
`const`	`float`	`short`	`unsigned`
`continue`	`for`	`signed`	`void`
`default`	`goto`	`sizeof`	`volatile`
`do`	`if`	`static`	`while`

Example: Variables, Statements, and Expressions

A **variable** is defined by giving it a name and a type.

A variable can be assigned a value.

The right hand side of an assignment is an **expression**.

%d means print out decimal number (special for printf).

All **statements** end with a semicolon. Statements are executed in sequence.

```
#include <stdio.h>

int main(void){
  int a, b;
  int c = 5;
  b = 10;
  a = b * c;
  printf("%d\n", a);
  return 0;
}
```

What is the answer if
`int c = 5;`
is replaced with
`int c;`

Answer: Different, depending on what is in the memory.

Variables must be initialized carefully!

What is printed to the standard output?

Answer: 50

Conditional Statements `if`-statements

```
int x = 0;
if(x)
  printf("true");

if(x){
  printf("true");
  x = 1;
}
```

C has no boolean type without including any extra library. Integer value 0 is interpreted as false, everything else as true.
Note: From version C99, a boolean type **bool** is available if library <stdbool.h> is included.

If there is more than one statement, the sequence of statements should be defined within a **block**, using { and }.

```
int y = 0, x = 1;
if(y)
  printf("true");
else{
  if(x)
    printf("false");
}
```

If-then-else constructs.

If-statements can be **nested**.

What is the output?
Answer: “false”

Operators (1/3)
Arithmetic Operators

Binary Operators

```
int z;
z = 3 + 6;
z = 3 - 6;
z = 20 * 6;
z = 20 / 6;
z = 20 % 6;
```

addition: z = 9
subtraction: z = -3
multiplication: z = 120
division: z = 3
modulo: z = 2

```
int z = 10;
int x = 0;
if(++z == 10)
   x = 1;
```

pre-increment: z = 11, x = 0

Unary Operators

```
int z = 5;
z++;
z--;
++z;
--z;
```

post-increment: z = 6
post-decrement: z = 5
pre-increment: z = 6
pre-decrement: z = 5

```
int z = 10;
int x = 0;
if(z++ == 10)
   x = 1;
```

post-increment: z = 11, x = 1

Operators (2/3)
Logical and Bitwise Operators

```
int z;
int a = 1, b = 0, c = 3, d = 6;
z = a & b;
z = a && b;
z = c & d;
z = c && d;

z = a | b;
z = a || b;
z = c | d;
z = c || d;

z = c ^ d;

z = c << 3;
z = d >> 1;
```

bitwise AND: z = 0
boolean AND: z = 0
bitwise AND: z = 2
boolean AND: z = 1 (values other than 0 are treated as true)

bitwise OR: z = 1
boolean OR: z = 1
bitwise OR: z = 7
boolean OR: z = 1

bitwise XOR: z = 5

bitwise shift left: z = 24
bitwise shift right: z = 3

Physical Q/A (bitwise XOR)
Stand up for c ^ d = 5
On the table for c ^ d = 7

Operators (3/3)
Relational Operators

The **relational operators** return 1 if the relation is true and 0 if it is false.

Symbol	Description	Example
==	equal	x == 5
!=	not equal	y != z
<	less than	y < 7
>	greater than	y > z
<=	less than or equal	y ≤ 7
>=	greater than or equal	y ≥ z

Note the difference between assignment **=** and test for equality **==**

Loops (1/2)
while

```
int x = 0;
while(x < 10){
  x++;
  printf("%d\n",x);
}
```

Loop while the expression is true (not 0)

Exercise:
A **break**-statement exits the loop. Rewrite the above using **while(1)**

```
int x = 0;
while(1){
  if(x >= 10)
    break;
  x++;
  printf("%d\n",x);
}
```

Loops (2/2)
`for`

After C99, it is allowed to declare the iteration variable in the for loop.

```
#include <stdio.h>

int main(void){
  for(int i=0; i<128; i++){
    printf("%3d %3x  %c\n",i,i,i);
  }
  return 0;
}
```

First element: initiate the counter.

Second element: the condition is tested in each iteration.

Third element: the increment is performed **at the end** of the block

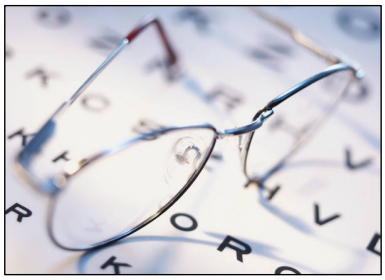
Print the ASCII character value

Print the hexadecimal value (force 3 characters wide formatting)

What is this program doing?

It prints out the **ASCII** (American Standard Code for Information Interchange) table. **Try it!**

Reading Guidelines – Module 1



Reading Guidelines
See the course webpage for more information.

Introduction
P&H5 Chapters 1.1-1.4, or P&H4 1.1-1.3

Number systems
H&H Chapter 1.4

C Programming
H&H Appendix C
Online links on the literature webpage

Assembly and Machine Languages
H&H Chapters 6.1-6.9, 5.3
The MIPS sheet (see the literature page)

Almost at the end…

Summary

Some key take away points:

- **Moore's law**: Integrated circuit resources (transistors) double every 18-24 months.
- **The Power Wall**: Clock rates cannot be increased anymore. Too high power; the chip gets too hot.
- C is a **portable**, **low-level** language, used in everything from microcontrollers to supercomputers.
- C is **imperative**; states are updated by using assignments.

Thanks for listening!