

# Mastering your Linux: C and Shell Programming

Martin Quinson <[martin.quinson@loria.fr](mailto:martin.quinson@loria.fr)>

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# Introduction

## Course Goals

- ▶ Help you mastering your third programming language
  - ▶ Basics about the syntax
  - ▶ Caveats (of memory management, amongst other)
  - ▶ Get some good style
- ▶ Help you mastering your Linux box (or any other UNIX-based one)
  - ▶ Fluent use of the terminal
  - ▶ Non-trivial command lines
  - ▶ Simple scripts

## Prerequisite

- ▶ Algorithmic Background: you cannot program without that
- ▶ Scala/Java Programming: we won't learn to program, but how to write it in C

## Course Context at Telecom Nancy

- ▶ Part of Programming Track (courses PPP, TOP, POO, SD, CSH)
- ▶ Starts a new track on Operating System (courses CSH, RS, RSA)

# Administrativae

## Module Time Table

- ▶ Three lectures
- ▶ 7 practical labs + 3 repetition sessions (+ exam): The C language
- ▶ 6 practical labs + 2 small group lectures (+ exam): Shell Scripting

## Evaluation

- ▶ Test on table (*partiel*) on C language
  - ▶ **What:** Content of lectures and labs (of course)
  - ▶ **When:** someday in march (check ADE agenda)
  - ▶ **Allowed material during test:** one A4 sheet of paper only
    - ▶ Hand-written (not typed)
    - ▶ From you (no photocopy)
- ▶ **Homework:** Do whatever you want (in C)
- ▶ Test on table on Shell Scripting
  - ▶ **When:** someday in may (check ADE agenda)
  - ▶ (Ask Suzanne Collin for details)

# About me

## Martin Quinson

- ▶ **Study:** Université de Saint Étienne, France
- ▶ **PhD:** Grids and HPC in 2003 (team Graal of INRIA / ENS-Lyon, France)
- ▶ **Since 2005:**
  - ▶ Assistant professor at Telecom Nancy (Université de Lorraine)
  - ▶ Researcher of AlGorille team of LORIA/Inria
- ▶ **Research interests:**
  - ▶ **Context:** Distributed Systems (Grids, HPC, Clusters)
  - ▶ **Main:** Simulation of Distributed Applications (SimGrid project)
  - ▶ **Others:** Experimental Methodology, Model-Checking, ...
- ▶ **Teaching duties:**
  - 1A: PPP: introduction to Java; TOP: Technics and tOols for Programming; CSH: C as Second Language (and Shell)
  - 2A: RS: System Programming (and Networking)
  - 3A: Peer-to-Peer Systems and Advanced Distributed Algorithms (master)
- ▶ **More infos:**
  - ▶ <http://www.loria.fr/~quinson> (Martin.Quinson@loria.fr)

## References: Courses on Internet

- ▶ **Introduction to Systems Programming** (C. Grothoff)  
C covered, but not only.  
<http://grothoff.org/christian/teaching/2009/2355/>
- ▶ **C / Shell** (A. Crouzil, J.D. Durou et Ph. Joly; U. Paul Sabatier, Toulouse)  
Good coverage of the whole module (in French).  
[http://www.irit.fr/ACTIVITES/EQ\\_TCI/ENSEIGNEMENT/CetSHELL/](http://www.irit.fr/ACTIVITES/EQ_TCI/ENSEIGNEMENT/CetSHELL/)
- ▶ **Support de Cours de Langage C** (Christian Bac; Telecom SudParis)  
The C Language (in French).  
<http://picolibre.int-evry.fr/projects/svn/coursc/>

# Table of Contents

## ▶ Introduction and Generalities

- ▶ Introduction; Motivation; History.

## 1 Part I: C as Second Language

- ▶ Syntax and Basic usage
  - ▶ Introduction; First C program and compilation; Syntax, printf; C vs. Java.
- ▶ Memory Management in C
  - ▶ Variable visibility, storage class; Malloc and friends; Debugging problems.
- ▶ Advanced C Topics
  - ▶ Modularity in C; Makefile; Performance tuning; Game programming.

## 2 Part II: Shell Scripting

- ▶ Low Script-fu knowledge
  - ▶ Introduction; First shell “scripts”; Redirecting I/O & Pipes; basic commands.
- ▶ Medium Script-fu knowledge
  - ▶ More Syntax for Advanced Scripts; Not so basic commands.
- ▶ Advanced Script-fu knowledge
  - ▶ Shell functions; Variable Substitutions; Sub-shells; Arrays.

# Chapter 1

## C and Unix

- Introduction

- C? UNIX? What is all this about?

- Why do we need to study C?

- Why do we need to study C and UNIX together?

- C as Second Language

- C vs. Java

- How to survive in C?

- Your first C program

- First steps in Unix

- Désignation des fichiers

- Protection des fichiers

- Using the terminal

# C? UNIX? What is all this about?

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Telecom Nancy population very heterogeneous

- ▶ Usually about  $\frac{1}{3}$  didn't heard about Unix before arriving, and  $\frac{1}{3}$  use it already
- ▶ We are here to level everybody
- ▶ Yep, some of you already know the first lectures (go get some maths)
- ▶ But be patient, soon, everyone will be lost (including YOU!)

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Further Quizz

- ▶ Could you define Unix in a word?



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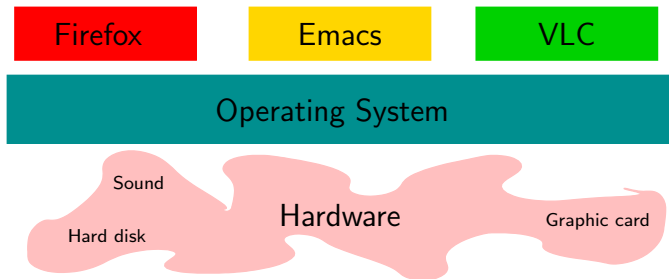
Further Quizz

- ▶ Could you define Unix in a word? That's an Operating System


# Operating System

## What is an Operating System?

- ▶ That's the software between the applications and the hardware
- ▶ Handles (and protects) the resources
- ▶ Offers an unified interface to the applications



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(not 'cause it sucks) Because Windows is quite too different from Unix
- ▶ If so, why do we speak of Unix anyway?
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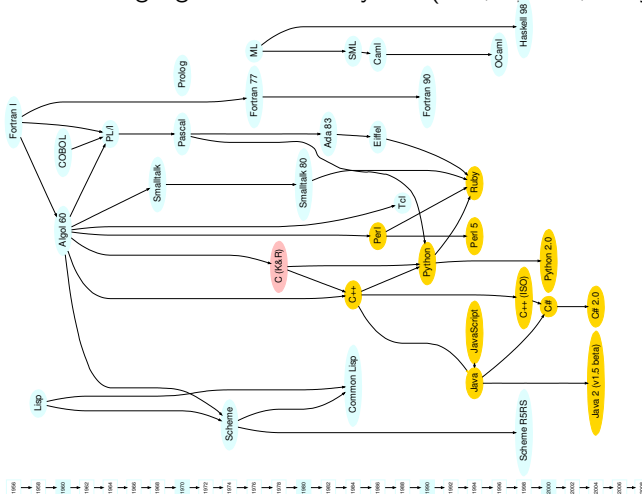
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  2. Because it's heavily connected to C (Why should we study the C language?)

# Why should we study the C language? Huge impact

- ▶ C++ is an object extension of C (you cannot master C++ without C)
- ▶ Java is some sort of (safe) subset of C++; C# is a variation of Java
- ▶ Several other languages have C-like syntax (Perl, Python, Ruby, PHP)



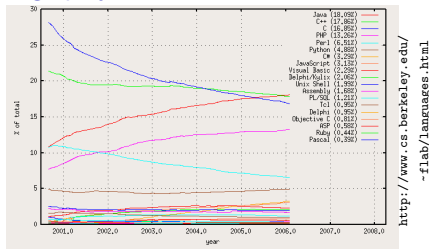
<http://merd.sourceforge.net/pixel/language-study/diagram.html>

See also <http://www.digibarn.com/collections/posters/tongues/>

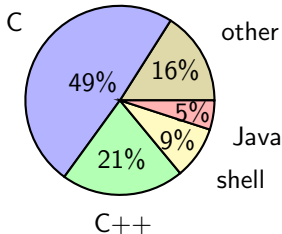


# Why should we study the C language? Widespread

- ▶ De facto standard for System Programming: Windows, OS X, Linux, BSD in C
- ▶ Counting SourceForge projects. Java: 18%; C++: 17.9%; C: 15.9%



- ▶ Counting SLOC in Debian. Quite different numbers...



More details:

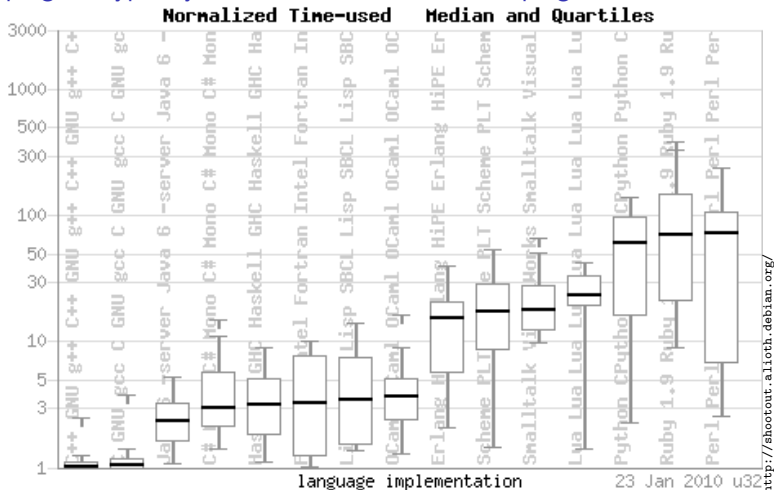
<http://debian-counting.libresoft.es/lenny/>

See also: <http://www.dwheeler.com/sloc/>

- ▶ Big codes are in C/C++
- ▶ Toy projects tend to be in Java (but things change)

# Why should we study the C language? Fast

- C program typically execute faster than in other programs



- One could argue that this is because it has the best tools, but not only

# Studying the C language for educational purpose

## Understanding C helps you understanding the system as a whole

- ▶ C is the closest high-level language to the machine
- ▶ Every OS are written in C, so lower interface is in C/C++ too
- ▶ OS/hardware co-evolution: C conceptual model describes most hardware

## Understanding C helps you writing better Java code

- ▶ Java/.Net/Perl/etc hide underlying low-level mechanism
- ▶ But these mechanism can be very important (to performance for example)
- ▶ To understand how objects get passed by ref, realize that they are pointers



# What is Special About C?

Low Level: sort of abstract assembly language of historical processors

- ▶ Was invented on a PDP-11 with 24kb of memory: KISS!
- ▶ Process memory visible as an array of bytes
- ▶ Nothing in the language will prevent you from doing (really) stupid things

*C combines the power of assembler with the portability of assembler.*

Extensible: most higher-level features doable in C

- ▶ Self-modifying code, Introspection, Code migration, etc. (but all by yourself)
- ▶ (actually, JVM partially written in C/C++)

*If you can't do it in ANSI C, it isn't worth doing.*

Relatively Stable: almost backward compatible since seventies

- ▶ Other languages got heavily lifted too often (but some heritages unpleasant)

C has hardly any runtime system

- ▶ Small footprint, easily ported to new architectures (need to reinvent the wheel)

# So, should we use C once studied?

## Benefits

- ▶ More control over the execution behaviour of programs
- ▶ More opportunity for performance tuning
- ▶ Access to low-level features of system

## Disadvantages

- ▶ Need to do your own memory management
- ▶ Typically takes more lines of code to accomplish each task
- ▶ More opportunity to make mistakes

## Summary

- ▶ C is a powerful programming tool for experts
- ▶ Presents many potential hazards for novices
- ▶ Helps you to understand low-level execution ideas
- ▶ Helps transforming you from a novice to an expert

↪ Use it when you need it, avoid it when you don't need it

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- C as Second Language

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# C as Second Language

## Similarities between C and Java

### ► Operators

- Arithmetic (+, -, \*, /, % ; ++, --, \*=, ...); Bitwise (&, |, ^, ~, <<, >>)
- Relational (<, >, <=, >=, ==, !=); Logical &&, ||, !, (a?b:c)

### ► Keywords and Language Constructs

- `if( ){ } else { }`
- `while( ){ }`
- `switch( ) { case 0: ... }`
- `for(i=0; i<100; i++){ }`
- `do { } while( )`
- `break, continue, return`
- Basic (primitive) types: void, int, short, long; float, double; char.  
No boolean, use int instead (0=False; anything else=True)
- Function declarations: `int fact(int a){return a==0 ? 1 : a*fact(a-1);}`

## Differences between C and Java

- No exception: usually rely on int error code instead (and usually a pain)
- No class/package/interface: code modularity different (not compiler-enforced)
- No garbage collector: alloc and free manually needed memory (incredible pain)



# C as Second Language

## C seems familiar when you know Java

- ▶ Actually, that's Java which is highly inspired from C/C++
- ▶ Feels like a Java without any object but with full access to everything

## C is like Java without comfort and without any protections

- ▶ Standard library is poor (but huge amount of extensions)
- ▶ Compiler is incredibly permissive (by default)
- ▶ It's possible to shoot yourself in the foot in Java, that's common in C
- ▶ On error, Java displays a stack trace, C spits “segfault” or “invalid free” errors

*Unix was not designed to stop people from doing stupid things, because that would also stop them from doing clever things.*

– Doug Gwyn

## C main specificities in a Nutshell

- ▶ Memory fully accessible through *pointers*
- ▶ Arrays are handled as pointer to memory
- ▶ Declaration syntax very similar to usage syntax (to the price of readability)

# How to survive in C?

## Use the tools that can help you

- ▶ Use the **compiler warning flags** `-Wall` mandatory, other useful
- ▶ Use a **proper editor** (able of colorization, auto-indent, compile easily)
  - ▶ **Good editors:** emacs & vi (historical), Eclipse/CDT (my personal favorite)
  - ▶ **Bad editor:** gedit (not good for text, BAD for code)
- ▶ The **debugger** (gdb) must become your friend quickly
- ▶ **valgrind** is a piece of magic (C coding without it is masochism)

## Don't assume you're a genius (ie, don't do stupid things — yet)

- ▶ Pay attention to the modularity of your code (not compiler-enforced anyhow)
- ▶ Document your code (with readable comments, or doxygen for bigger projects)
- ▶ Get some discipline (coding convention), and stick to it
  - ▶ Symbol naming (`my_variable` or `myVariable`), indentation, etc.
  - ▶ Which one is not very important. Pick one, and stick to it
- ▶ Keep it simple: it's easy to write unreadable C code

# Bad Style Coding as a Game

## The International Obfuscated C Code Contest ([www.ioccc.org](http://www.ioccc.org))

- ▶ Yearly contest of intentionally obfuscated codes (in C; exist for other languages)

### Example:

(arachnid, 2004 entry)

```
#include <ncurses.h>/*****
int m[256] [ 256 ],a
, b ;;; ;;; WINDOW*w; char*l="" "\176qxl" "q" "q" "k" "w\
xm" "x" "t" "j" "v" "u" "n" ,Q[
]= "Z" "pt!ftd" "qdc!'eu" "dq!$c!nnwf"/** *** */"t\040\t";c(
int u , int v){ v?m [u] [v-
1] |=2,m[u] [v-1] & 48?W [v-1] & 15] }):0:0;u?m[u -1] [v] |=1 ,m[
u- 1] [ v]& 48? W-1 ] [v ]&
15] }):0:0;v< 255 ?m[ u] [v+1] |=8,m[u] [v+1]& 48? W [ v+1]&15]
):0 :0; u < 255 ?m[ u+1 ] [v ] |=
4,m[u+1] [ v]&48?W+1] [v]&15] }):0:0;W [ v]& 15] ]);}cu(char*q){ return
*q ?cu (q+ 1)& 1?q [0] ++:
q[0 ]-- :1; }d( int u , int/**/v, int/**/x, int y){ int
Y=y -v, X=x -u; int S,s ;Y< 0?Y =-Y ,s,
s=- 1:( s=1);X<0?X=-X,S =-1 :(S= 1); Y<= 1;X<=1; if(X>Y){
int f=Y -(X >>1 );; while(u!= x){
f>= 0?v+=s,f-=X:0;u +=s ;f+= Y;m[u] [v] |=32;mvwaddch(w,v ,u, m[u]
][ v]& 64? 46) ;if (m[ u] [
v]&16){c(u,v); ;;; ;;; return;}} }else{int f=X -(Y>>1);; while
(v !=y )){f >=0 ?u +=S, f-= Y:0
;v +=s ;f+=X;m[u] [v] |= 32;mvwaddch(w,v ,u,m[u] [v]&64?60:46);if(m[u]
][ v]& 16) {c( u,v );
; return;};}}Z( int/**/a, int b){ }e( int/**/y,int/**/ x){
int i ; for (i= a;i <=a
+S;i++)d(y,x,i,b),d(y,x,i,b+L);for(i=b;i<=b+L;i++)d(y,x,a,i),d(y,x,a+ S,i
);
mvwaddch(w,x,y,64); ;;; ;;; prefresh( w,b,a,0,0 ,L- 1,S-1
);}
) }
} }FILE*f= fopen(V="1?arachnid.c"/**/ :C[ 1],"r");int/**/x,y,c,
(source code cut here)
```

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## Example: Full (interactive) Maze Escape Game ([arachnid](#), 2004 entry)

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b ;;; ;;; WINDOW*w; char*l="" "\176qxl" "q" "q" "k" "w\  
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u- 1] [ v]& 48? W-1 ] [v ]&  
15] )]:0:0;v< 255 ?m[ u] [v+1]|=8,m[u] [v+1]& 48? W [ v+1]&15]]  
) :0 :0; u < 255 ?m[ u+1 ] [v ]|=  
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q[0 ]-- :1; }d( int u , int/**/v, int/**/x, int y){ int  
y=y -v, X=x -u; int S,s ;Y< 0?Y =-Y ,s,  
s=- 1:( s=1);X<0?X=-X,S =-1 :(S= 1); Y<= 1;X<=1; if(X>Y){  
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f>= 0?v+=s,f-=X:0;u +=s ;f+= Y;m[u] [v] |=32;mvwaddch(w,v ,u, m[u]  
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int i ; for (i= a;i<=b:L;i++)d(y,x,a,i),d(y,x,a+ S,i  
+S;i++)d(y,x,i,b),d(y,x,i,b+L);for(i=b;i<=b+L;i++)d(y,x,a,i),d(y,x,a+ S,i  
); ;;; ;;; ;;; ;  
mvwaddch(w,x,y,64); ;;; ;;; prefresh( w,b,a,0,0 ,L- 1,S-1  
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Martin Quinson Mastering your Linux: C / Shell (2013-2014)
```

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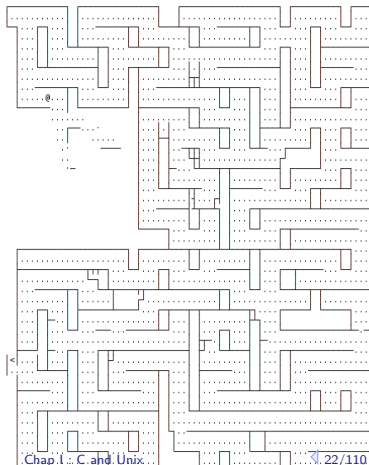
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,b ;;; ;;; WINDOW*W; char*l="" "\176qxl" "q" "q" "k" "w\  
xm" "x" "t" "j" "v" "u" "n" "n" ,Q[  
]= "Z" "pt!ftd" "qdc!'eu" "dq!$c!nnwf"/** *** */"t\040\t";c  
int u , int v){ v?m [u] [v-  
1] |=2,m[u] [v-1] & 48?W[v-1] & 15]]):0:0;u?m[u -1] [v]|=1 ,m[  
u- 1] [ v]& 48? W-1 ] [v ]&  
15] )]:0:0;v< 255 ?m[ u] [v+1]|=8,m[u] [v+1]& 48? W] [ v+1]&15]]  
*q ?cu (q+ 1)& 1?q [0] ++:  
q[0 ]-- :1; }d( int u , int/**/v, int/**/x, int y){ int  
X=y -v, X=x -u; int S,s Y< 0?Y =-Y ,s,  
s=- 1:( s=1);X<0?X=-X,S =-1 :(S= 1); Y<= 1;X<=1; if(X>Y){  
int f=Y -(X >>1 );; while(u!= x){  
f>= 0?v+=s,f-=X:0;u +=S ;f+= Y;m[u] [v] |=32;mvwaddch(w,v ,u, m[u]  
][ v]& 64? 60: 46) ;if (m[ u] [v]  
v]&16){c(u,v); ;;; ;;; return;}} }else{int f=X -(Y>>1); while  
(v !=y )}{f >=0 ?u +=S, f-= Y:0  
;v +=s ;f+=X;m[u] [v] |= 32;mvwaddch(w,v ,u,m[u] [v]&64?60:46);if(m[u]  
][ v]& 16) {c( u,v );  
; return;}};}Z( int/**/a, int b){ }e( int/**/y,int/**/ x){  
int i; for (i= a;i<=b+L;i++)d(y,x,a,i),d(y,x,a+ S,i  
+S;i++)d(y,x,i,b),d(y,x,i,b+L);for(i=b;i<=b+L;i++)d(y,x,a,i),d(y,x,a+ S,i  
);  
mvwaddch(w,x,y,64); ;;; ;;; prefresh( w,b,a,0,0 ,L- 1,S-1  
)};  
main( int V, char *C[  
] )){FILE*f= fopen(V="1?arachnid.c"/**/ :C[ 1],"r");int/**/x,y,c,  
(source code cut here)
```



# Recreational Obfuscation: Phillips entry of IOCCC'88

## Program code

```
#include <stdio.h>
main(t,_,a)char *a;{return!0<t?t<3?main(-79,-13,a+main(-87,1-_,
main(-86,0,a+1)+a)):1,t<_?main(t+1,_,a):3,main(-94,-27+t,a)&&t==2?_<13?
main(2,_,+1,"%s %d %d\n"):9:16:t<0?t<-72?main(_,t,
"@n'+,#'/*{*}w+/w#cdnr/+,}{r/*de}+,/*{*+/,w{%+/,w#q#n+/,#{l,+,/n{n+,/+#n+,/#\
;#q#n+,/+k#;+/,/'r : 'd*'3,}{w+K w'K:'+'e#';dq#'l \
q#'+d'K#!/+k#;q#r'eKK#}w'r'eKK{nl}'/;#q#n'}){#}w')}{nl}'/+#n';d}rw' i;# \
){nl}'/n{n#'; r{#w'r nc{nl}'/#{l,+ 'K {rw' iK{;[{nl}'/w#q#n'wk nw' \
iwk{KK{nl}'/w{% 'l##w# ' i; :{nl}'/*{q#ld;r'}{nlwb!/*de}'c \
; ;{nl}'-}{rw}'/+,}{##}*#nc,',#nw}'/ +kd'+e}+;#rdq#w! nr'/ ' ) }+}{rl#'{n' ' )# \
}' +}{##(!/"/)
:t<-50?_==*a?putchar(31[a]):main(-65,_,a+1):main((*a=='/')+t,_,a+1)
:0<t?main(2,2,"%s"):a=='/'||main(0,main(-61,*a,
"!ek;dc i@bK'(q)-[w]*%n+r3#l,{ }:\nuwloca-0;m .vpbks,fxntdCeghiry"),a+1);}
```

## Output

On the first day of Christmas my true love gave to me  
a partridge in a pear tree.

On the second day of Christmas my true love gave to me  
two turtle doves  
and a partridge in a pear tree.

On the third day of Christmas my true love gave to me  
three french hens, two turtle doves  
and a partridge in a pear tree.

On the fourth day of Christmas my true love gave to me  
four calling birds, three french hens, two turtle doves  
and a partridge in a pear tree.

## Output (cont)

On the eighth day of Christmas my true love gave to me  
eight maids a-milking, seven swans a-swimming,  
six geese a-laying, five gold rings;  
four calling birds, three french hens, two turtle doves  
and a partridge in a pear tree.

On the ninth day of Christmas my true love gave to me  
nine ladies dancing, eight maids a-milking, seven swans a-swimming,  
six geese a-laying, five gold rings;  
four calling birds, three french hens, two turtle doves  
and a partridge in a pear tree.

On the tenth day of Christmas my true love gave to me  
ten lords a-leaping,  
nine ladies dancing, eight maids a-milking, seven swans a-swimming,  
six geese a-laying, five gold rings;  
four calling birds, three french hens, two turtle doves  
and a partridge in a pear tree.

# Bad Style Coding as an Art

## Another example

```
#include <stdio.h>
int l;int main(int o,char **0,
int I){char c,*D=0[1];if(o>0){
for(l=0;D[l]          ];D[l
++]-=10){D    [l++]-=120;D[l]-=
110;while    (!main(0,0,l))D[l]
+=    20;    putchar((D[l]+1032)
/20    )    ;}putchar(10);}else{
c=o+    (D[I]+82)%10-(I>1/2)*
(D[I-l+I]+72)/10-9;D[I]+=I<0?0
:!(o=main(c/10,0,I-1))*((c+999
)%10-(D[I]+92)%10);}return o;}
```

# Bad Style Coding as an Art

## Another example: Computing Integer Square Roots

```
#include <stdio.h>
int l;int main(int o,char **0,
int I){char c,*D=0[1];if(o>0){
for(l=0;D[l]          ];D[l
++]-=10){D    [l++]-=120;D[l]-=
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### It actually works

```
$ ./cheong 1234
35
```

$(35 \times 35 = 1225; 35 \times 36 = 1296)$

```
$ ./cheong 112233445566
335012
```

$335012 \times 335012 = 112233040144$

$335013 \times 335013 = 112233710169$



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### Author claim: code self-documented...

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```

*It is an old observation that the best writers sometimes disregard the rules of rhetoric. When they do so, however, the reader will usually find in the sentence some compensating merit, attained at the cost of the violation. Unless he is certain of doing as well, he will probably do best to follow the rules.*

– William Strunk, Jr. (1918)

Saitou Hajime image

[illegible][illegible]





Saitou Hajime image that prints a prog that prints a prog that prints a prog

## Output 2

[illegible][illegible]



# Your first C program

## The classical Hello World

hello.c

```
#include <stdio.h>
int main(int argc, char *argv[]){
    printf("Hello, world\n");
}
```

## For the record: same in Java

hello.c

```
class HelloWorld {
    public static void main(String[] arg){
        System.out.println("Hello, world");
    }
}
```

## Compile and run it

```
$ gcc -Wall hello.c -o hello
$ ./hello
```

## Compiling and running Java code

```
$ javac HelloWorld.java
$ java -cp . HelloWorld
```

## Explanations

- ▶ `#include` can be seen as the equivalent of `import` directives
- ▶ `main` is the *entry point* of every program (same in C and Java)



# C Compilation Process

## Compiling a C program involves 3 separate tools

1. **Pre-processor:** Rewrites the code according to the defined *macros*
  - ▶ Lines beginning with "`#`" are macros
  - ▶ `#define name value`: declare a sort of automatic search/replace
  - ▶ `#define name(params) value`: search/replace but with arguments
  - ▶ `#include "file"`: inline the content of the given file
  - ▶ `#ifdef name/#else/#endif`: mask parts of the file if `name` is defined
2. **Compiler:** Translates the code into assembly
3. **Linker:** Take elements in assembly and resolve library dependencies
  - ▶ If your code uses function `cos()`, you need the math lib
  - ▶ The linker solves a puzzle to ensure that every used function get defined

## This process is rather transparent to the user

- ▶ You edit your code (in emacs/vi/eclipse)
- ▶ You launch gcc, which launches mandatory tools automatically
- ▶ You mainly need to know that when you get error messages

# What if you get error messages when compiling

## Some examples

- ▶ `foo.c:71:2: error: invalid preprocessing directive #deifne`  
The preprocessor is not happy: check file `foo.c`, line 71, column 2
- ▶ `foo.c:72: error: expected '))' before 'char'`  
Compiler's not happy (syntax error)
- ▶ `foo.c:74: error: redefinition of 'myFunc'`  
`foo.c:72: error: previous definition of 'myFunc' was here`  
Defining the same function twice makes the linker unhappy
- ▶ `/usr/lib/crt1.o: In function '_start':`  
`(.text+0x18): undefined reference to 'main'`  
`collect2: ld returned 1 exit status`  
A function is used, but never defined  
(see RS lecture next year to understand the detail of the message)
- ▶ `Segmentation fault ./myProg`  
Your program messed up the memory (valgrind knows where)

## How to react when you get error messages (and you will)

- ▶ **Don't panic**, even if the message seem cryptic (they often are)
- ▶ **Read the message**: they are sometimes even understandable
- ▶ **Don't even read the second message**: the parser often gets lost after first error

# Conclusion on C (for now)

## C is the modern assembly language

- ▶ It's quite prehistorical
  - ▶ Compilation process not trivial (even with only one file)
  - ▶ Cryptic error messages
  - ▶ No fancy stuff in standard library
- ▶ Programs can be really fast
  - ▶ If you do them right; easy to code slow C programs too
- ▶ You have the full power of doing everything
  - ▶ No matter what you want to code, it's possible in C
  - ▶ A lot of code were already developed in C (check [koders.com](http://koders.com))
  - ▶ C poses no rule to limit your imagination...
  - ▶ ...but there is no barrier to prevent you doing stupid things

## You need to master C to understand your machine

- ▶ The operating system is in C, just like the virtual machines
- ▶ And then, you're free to use it or not
  - Depending on whether you're seeking for fast programs or fast coding

# Chapter 1

## C and Unix

- Introduction

- C? UNIX? What is all this about?

- Why do we need to study C?

- Why do we need to study C and UNIX together?

- C as Second Language

- C vs. Java

- How to survive in C?

- Your first C program

- First steps in Unix

- Désignation des fichiers

- Protection des fichiers

- Using the terminal

# First steps in Unix

This OS gives a central role to **files**

- ▶ Contains data and executable programs (quite usual)
- ▶ Communication with user : config files, stdin, stdout
- ▶ Communication between processes: sockets, pipes, etc.
- ▶ Interface to the kernel: /proc
- ▶ Interface to the hardware: peripheral in /dev

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The **Terminal** is an interface of choice

- ▶ Graphical interfaces exist too, but I still prefer the terminal
- ▶ Lots of tricks make you more efficient with the terminal (more button on my keyboard than on my mouse)
- ▶ If you can't do it in one step, type a one-line script directly

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Read The Fine Manual (RTFM)

- ▶ The command `man` gives you access to a large corpus of knowledge
- ▶ `man prog` or `man function`  $\leadsto$  documentation of that program or function

# Désignation des fichiers

## Désignation symbolique (nommage): Organisation hiérarchique

- ▶ **Noeuds intermédiaires:** répertoires (*directory* – ce sont aussi des fichiers)
- ▶ **Noeuds terminaux:** fichiers simples
- ▶ **Nom absolu d'un fichier:** le chemin d'accès depuis la racine

### Exemples de chemins absolus :

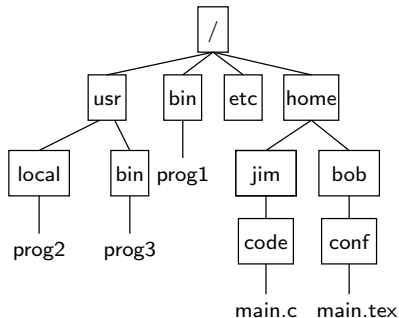
/

/bin

/usr/local/bin/prog

/home/bob/conf/main.tex

/home/jim/code/main.c





# Raccourcis pour simplifier la désignation

## Noms relatifs au répertoire courant

- ▶ Depuis `/home/bob`, `conf/main.tex` = `/home/bob/conf/main.tex`

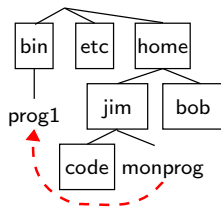
## Abréviations

- ▶ **Répertoire père**: depuis `/home/bob`, `../jim/code` = `/home/jim/code`
- ▶ **Répertoire courant**: depuis `/bin`, `./prog1` = `/bin/prog1`
- ▶ Depuis n'importe où, `~bob/` = `/home/bob/` et `~/` = `/home/<moi>/`

## Liens symboliques

Depuis `/home/jim`

- ▶ Création du lien: `ln -s cible nom_du_lien`  
Exemple: `ln -s /bin/prog1 monprog`
- ▶ `/home/jim/prog1` désigne `/bin/prog1`
- ▶ Si la cible est supprimée, le lien devient invalide



# Règles de recherche des exécutables

- ▶ Taper le chemin complet des exécutable (/usr/bin/lis) est lourd
- ▶  $\Rightarrow$  on tape le nom sans le chemin et le shell cherche
- ▶ Variable environnement PATH: liste de répertoires à examiner successivement  
/usr/local/bin:/usr/local/sbin:/sbin:/usr/sbin:/bin:/usr/bin:/usr/bin/X11
- ▶ Commande which indique quelle version est utilisée

Exercice : Comment exécuter un script nommé gcc dans le répertoire courant?

- ▶ Solution 1:
- ▶ Solution 2:

# Utilisations courantes des fichiers

- ▶ Unix: fichiers = suite d'octets sans structure interprétée par utilisateur
- ▶ Windows: différencie fichiers textes (où \n est modifié) des fichiers binaires

## Programmes exécutables

- ▶ Commandes du système ou programmes créés par un utilisateur
- ▶ Exemple: `gcc -o test test.c ; ./test`

- ▶ Question: pourquoi ./test ?

## Fichiers de données

- ▶ Documents, images, programmes sources, etc.
- ▶ Convention:

Exemples : `.c` (programme C), `.o` (binaire translatable, cf. plus loin), `.h` (entête C), `.gif` (un format d'images), `.pdf` (Portable Document Format), etc.

Remarque: ne pas faire une confiance aveugle à l'extension (cf. `man file`)

## Fichiers temporaires servant pour la communication

- ▶ Ne pas oublier de les supprimer après usage
- ▶ On peut aussi utiliser des tubes (cf. RS l'an prochain)

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- ▶ Convention: le suffixe indique la nature du contenu  
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# Protection des fichiers: généralités

## Définition (générale) de la sécurité

- ▶ confidentialité :
- ▶ intégrité :
- ▶ contrôle d'accès :
- ▶ authentification :

## Comment assurer la sécurité

- ▶ Définition d'un ensemble de règles (politiques de sécurité) spécifiant la sécurité d'une organisation ou d'une installation informatique
- ▶ Mise en place **mécanismes de protection** pour faire respecter ces règles

## Règles d'éthique

- ▶ Protéger ses informations confidentielles (comme les projets et TP notés!)
- ▶ Ne pas tenter de contourner les mécanismes de protection (c'est la loi)
- ▶ Règles de bon usage avant tout:  
*La possibilité technique de lire un fichier ne donne pas le droit de le faire*

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- ▶ contrôle d'accès : qui a le droit de faire quoi
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- ▶ Définition d'un ensemble de règles (politiques de sécurité) spécifiant la sécurité d'une organisation ou d'une installation informatique
- ▶ Mise en place **mécanismes de protection** pour faire respecter ces règles

## Règles d'éthique

- ▶ Protéger ses informations confidentielles (comme les projets et TP notés!)
- ▶ Ne pas tenter de contourner les mécanismes de protection (c'est la loi)
- ▶ Règles de bon usage avant tout:  
*La possibilité technique de lire un fichier ne donne pas le droit de le faire*

# Protection des fichiers: généralités

## Définition (générale) de la sécurité

- ▶ confidentialité : informations accessibles aux seuls usagers autorisés
- ▶ intégrité : pas de modifications indésirées
- ▶ contrôle d'accès : qui a le droit de faire quoi
- ▶ authentification : garantie qu'un usager est bien celui qu'il prétend être

## Comment assurer la sécurité

- ▶ Définition d'un ensemble de règles (politiques de sécurité) spécifiant la sécurité d'une organisation ou d'une installation informatique
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*La possibilité technique de lire un fichier ne donne pas le droit de le faire*

# Protection des fichiers sous Unix

## Sécurité des fichiers dans Unix

- ▶ Trois types d'opérations sur les fichiers : lire (r), écrire (w), exécuter (x)
- ▶ Trois classes d'utilisateurs vis à vis d'un fichier:  
propriétaire du fichier ; membres de son groupe ; les autres

rwx	rwx	rwx
propriétaire	groupe	autres

Granularité plus fine avec les Access Control List (peu répandus, pas étudiés ici)

- ▶ Pour les répertoires, r = ls, w = créer des éléments et x = cd.
- ▶ ls -l pour consulter les droits; chmod pour les modifier (cf. man chmod)

## Mécanisme de délégation

- ▶ **Problème** : programme dont l'exécution nécessite des droits que n'ont pas les usagers potentiels (**exemple**: gestionnaire d'impression, d'affichage)
- ▶ **Solution** (**setuid** ou **setgid**): ce programme s'exécute toujours sous l'identité du propriétaire du fichier; identité utilisateur momentanément modifiée  
identité réelle (celle de départ) vs identité effective (celle après setuid)

# Crash course on using the terminal

## Main idea

- ▶ Your shell is somewhere in the filesystem tree (current directory)
- ▶ You issue commands to interact with the system

## Commands Basic Syntax

- ▶ Every command follows this syntax: `<command name> <arguments>`
- ▶ Arguments are space separated
- ▶ Flags are specific arguments beginning usually with - (minus)

## Minimal set of commands to remember

Action	Command	Memoing
Examine content of current dir	ls	listing
Know name of current dir	pwd	Print Working Directory
Change current dir	cd	change directory
Copy a file into another	cp	copy
Create a new dir	mkdir	make directory
Destroy a file, a dir	rm, rmdir	remove
Usual shorthand for files and dirs	. .. / ~ * ~user	

# Using the terminal efficiently

## Common Tricks

- ▶ Typing everything is really to slow. You need to be lazy here.
- ▶ `Up`/`Down`: see commands typed previously. Edit it, and go!
- ▶ `Ctrl-A`/`Ctrl-E`: jump to begin/end of line
- ▶ `Tab`: auto-complete what you are currently typing

## Medium Tricks

- ▶ `Ctrl-R`: begin to search a text pattern in the command history
- ▶ `!command`: directly relaunch the last command involving that `command`
- ▶ `!!`: directly relaunch the last command

## Advanced Tricks

- ▶ Master your terminal (know the base commands)
- ▶ Assemble commands in pipe to get more advanced ones
- ▶ Write one-line scripts directly in the terminal
- ▶ Configure your environment: Declare aliases, write scripts, etc.

# Conclusion on Unix (for now)

Unix is one of the most influent operating system

- ▶ Around since 40 years, still there for a long time
- ▶ Most of the OS research innovation go in Unix first (open source power)
- ▶ Other OSes become Unixes (OS X) or get portability layers (z/OS, windows)

You can use that powerful tool too

- ▶ Not as much game as on your Wii, but fully usable and free
- ▶ The interface may be different of what you're used to
- ▶ May be less intuitive at first glance, but there's a strong underlying philosophy
- ▶ Constitute a playground of choice for CS students

Mastering this system is the goal of that course

# Chapter 2

## C as Second Language

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# We said that C and Java are quite similar

## Similarities between C and Java

### ► Operators

- Arithmetic (+, -, \*, /, % ; ++, --, \*=, ...); Bitwise (&, |, ^, !, <<, >>)
- Relational (<, >, <=, >=, ==, !=); Logical &&, ||, !, (a?b:c)

### ► Keywords and Language Constructs

- `if( ){ } else { }`
- `while( ){ }`
- `switch( ) { case 0: ... }`
- `for(i=0; i<100; i++){ }`
- `do { } while( )`
- `break, continue, return`

### ► Basic (primitive) types: void, int, short, long; float, double; char.

No boolean, use int instead (0=False; anything else=True)

### ► Function declarations: `int fact(int a){return a==0 ? 1 : a*fact(a-1);}`

## Differences between C and Java

- No exception: usually rely on int error code instead (and usually a pain)
- No class/package/interface: code modularity different (not compiler-enforced)
- No garbage collector: alloc and free manually needed memory (incredible pain)
- Terse standard library: reimplement your datastructures (but tons of extra libs)



# Paradigm difference between C and Java

The syntax is not everything. Java and C are really different

Paradigm shift seen from the C side

- ▶ Object-Oriented Programming Paradigm
  - ▶ Decide which classes you need
  - ▶ Provide a full set of operations for each class
  - ▶ Make commonality explicit by using inheritance
- ▶ Procedural Programming Paradigm
  - ▶ Decide which procedures and data structures you want
  - ▶ Use the best algorithms

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- ▶ Procedural Programming Paradigm
  - ▶ Decide which procedures and data structures you want
  - ▶ Use the best algorithms

## Reality is a bit different

- ▶ Nothing forces you to any sort of organization in C. You're free of the worst  
*Oh, I am a C programmer and I'm okay.*  
*I muck with indices and structs all day.*  
*And when it works, I shout hoo-ray.*  
*Oh, I am a C programmer and I'm okay.*
- ▶ (but you're free of the best, too, even if “good style in C” is a relative notion)

# C Quick Reference

We won't get into details here. References are for later use, not for beginners

## Complete list of keywords (in ANSI C)

- ▶ Storage specifiers: `auto register static extern typedef`
- ▶ Type specifiers: `char double enum float int long short signed struct union unsigned void (+sizeof, which is an operator on types)`
- ▶ Type quantifiers: `const volatile`
- ▶ Controls: `break case continue default do else for goto if return switch while`

## Operators Precedence (and Associativity)

1. Functions calls, subscripting and selection: `() [] ->` →
2. Not: `! ~ Inc/Dec: ++ -- Unary - Cast (type) Indir./address * & sizeof` ←
3. Math operators: `* / %` 4. Other math operators: `+ -(binary)` →
5. Bitwise shifts: `<< >>` 6. Relational operators: `< <= > >=` →
7. Equality: `== !=` 8. Bitwise AND: `&` 9. Bw XOR: `^` 10. Bw OR: `|` →
11. Logical AND: `&&` 12. Logical OR: `||` →
13. Ternary Operator `?:` (condition ? `exprIfTrue` : `exprIfFalse`) ←
14. Assignments with operator: `= += -= *= /= %= &= ^= |= <<= >>=` ←
15. Sequencing expressions: `,` (comma) →

# C base types

## C and the types

- ▶ The C language is (really) weakly typed (wrt CAML for example)
- ▶ C types look like Java ones at the first glance, but include some . . . surprises

## What defines a type in computer languages?

- ▶ **Value domain:** what can be encoded in that type
- ▶ **Operators:** what can be done with values of that type

# C base types

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## What defines a type in computer languages?

- ▶ **Value domain**: what can be encoded in that type
- ▶ **Operators**: what can be done with values of that type

## Existing types in the C language

- ▶ **void**: **Domain**:  $\emptyset$  (none); **Operators**: none  
Placeholder for type where there is no value (type of return when no return)
- ▶ **int**: **Domain**: integers; **Operators**: All numerical, logical and bitwise ones  
**Variants**: short/long and also signed/unsigned
- ▶ **float** and **double**: floating point numbers (IEEE754 compliant, no variant)
- ▶ **char**: **Domain**: chars such as 'a', '1', '\$' and some less common ones  
**Operators**: numerical, logical and bitwise ones. **Variants**: signed/unsigned  
Yep, chars are “small numbers” in C

# Beware, type sizes are not known in C

Type	Java	C
char	16 bits	8 bits
short	16 bits	16 bits
int	32 bits	16, 32 or 64 bits
long	64 bits	32 or 64 bits
float	32 bits	32 bits
double	64 bits	64 bits
boolean	1 bit	–
byte	8 bits	–
long long	–	64 bits
long double	–	80, 96 or 128 bits

(“most natural size for architecture”)

No such thing in C, use int (or bit fields)

Doesn't exist, use char

This type is not standard/unofficial  
this one either

## Type domains also naturally vary

Type size	Range when signed	Range when unsigned
8 bits	$[-2^7; 2^7[ = [-128; 128[$	$[0; 2^8[ = [0; 256[$
16 bits	$[-2^{15}; 2^{15}[ = [-32\,768; 32\,768[$	$[0; 2^{16}[ = [0; 65\,535[$
32 bits	$[-2^{31}; 2^{31}[ = [-2\,147\,483\,648; 2\,147\,483\,648[$	$[0; 2^{32}[ = [0; 4\,294\,967\,295[$
64 bits	$[-9\,223\,372\,036\,854\,775\,808; 9\,223\,372\,036\,854\,775\,808[$	$[0; 18\,446\,744\,073\,709\,551\,615[$

Use `sizeof()` when you need to know a type size on current machine  
(and the `limits.h` file)

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# Type Constructors

## How to keep together related data grouped in C?

- ▶ **Arrays** (similar to Java) ordered list of elements  
Ex: Values of the fibonacci suite; Temperature over the time; Data to sort ...
- ▶ **Structures**: like java objects without methods, or SQL records  
Ex: A car; A student; A group of students; A school ...
- ▶ **Enumerations** group of related values (exists also in Java, but rarely used)  
Ex: Colors; Cards in a deck; Direction (north/south/east/west)...
- ▶ **Unions**: Like structures, but stores everything at the same memory location  
Advanced stuff, useful for strange memory tricks (data conversion)
- ▶ **Bit fields**: arrays of bits. Advanced stuff allowing direct access to memory  
Useful to encode several booleans in a compact way

## Let's detail the basic ones

- ▶ Aka, Arrays, structures and enumerations.
- ▶ Unions and bit fields are kinda advanced C-fu



# Arrays in C

## Similarity to Java

- ▶ **Defining:** `int T[5]` defines 5 integers, noted T[0], T[1], T[2], T[3] and T[4]
- ▶ **Initialization:** `int T[5] = {10,20,30,40,50};` does what you expect  
For the record, in Java, you'd write `int[] T = new int[] {10,20,30,40,50};`
- ▶ **No global operators:** `Ta==Tb` and `Ta+Tb` ... does not do what you think

## C arrays specificities from Java ones

- ▶ You must write `int T[5]` because `int[5] T` is forbidden  
To understand a C (or Java) complex type, you must read from right to left
- ▶ You cannot retrieve the **size of an array**: `T.length()` does not exist  
You must store the array size alongside to the array, in an integer
- ▶ **Dynamically sized arrays** are not allowed in C [without dynamic memory]
  - ▶ Array sizes must be known at compilation time
  - ▶ `int T[] = new int[a];` is just impossible (in ANSI C)
- ▶ There is **no bound checking** on arrays in C (and C memory is a big magma)

# Strings in C

Unfortunately, there is no standard type in C to describe strings...

- ▶ Instead, the C idiomatic is to use **arrays of chars**
- ▶ In turn, arrays are unpleasant because they do not contain their own length
- ▶ So **by convention** every C string should be zero-terminated  
i.e. the last value in the array is the special char `'\0'` (different from `'0'`)
- ▶ Beware, to store a string of 5 letters, you need 6 positions:

```
char str[6]="hello";
```

h	e	l	l	o	\0
---	---	---	---	---	----

- ▶ Useful functions for such strings: `strlen()`, `strcpy()`, `strcmp()`, ...
- ▶ But you are free to not follow that convention if you prefer to do otherwise (you just have to do it all by yourself then)
- ▶ If the size is given elsewhere, you can use `char *str;` for `char str[5];`  
(MUCH more to come on that little `*` sign)
- ▶ Don't mix the char `'a'` with the string `"a"`

# Structures in C

This is a fundamental construction in C

- ▶ Group differing aspects of a given concept, just like Java objects  
**Vocabulary:** We speak of **structure members** and **object fields**
- ▶ But they (usually) don't contain the associated methods/functions

## Definition example

```
struct point {  
    double x;  
    double y;  
    int rank;  
}; // beware of the trailing ;
```

## Usage example

```
struct point p1; // the type name is "struct point"  
p1.x = 4.2;  
p1.y = 3.14;  
p1.rank = 1;  
struct point p2 = { 4.2, 3.14, 2 };
```

## Structures as parameter and return values

```
struct point translate(struct point p,  
                      double dx, double dy) {  
    struct point res = p;  
    res.x += dx;  
    res.y += dy;  
    return res;  
}
```

## Declare and use at once

```
struct point {  
    int x;  
} p1,p2; // variables of that type
```

```
struct { // Anonymous structure  
    int x;  
} p1,p2; // variables of that type
```

- ▶ Parameter and return values are *copied* (no border effect; inherent inefficiency)
- ▶ **Remarks:** Members can be structs too; No global operators (such as ==)

# Enumerations in C

## Basics

- ▶ They are used to group **values** of the same lexical scope
- ▶ A variable of type *color* can take a value within {blue, red, white, yellow}

### Definition example

```
enum color {  
    blue, red, white, yellow  
}; // beware of the trailing ;
```

### Usage example

```
enum color bikesheld; // the type name is "enum color"  
bikesheld = white;
```

## Enumerations can be used as parameter and return values

```
enum color make_white(enum color c) {  
    return white; // Yes, this function is useless as is...  
}
```

- ▶ **Main advantage:** there is a compilation error if you forget a value in a switch (instead of silently ignoring the whole block when the case occurs, which is a pain)
- ▶ Every arithmetic and logical operators can be used (white+1→yellow)

## Java enums

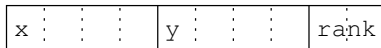
- ▶ They exist in Java, too. Much more powerful and complicated. Rarely used.

# Memory layout of C type constructors

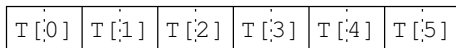
Impossible to master C without understanding the memory layout

- ▶ (This is because memory is a kind of unsorted magma in C)
- ▶ **First absolute rule:** successive elements are stored in order in memory

```
struct point {  
    double x;  
    double y;  
    int rank;  
};
```

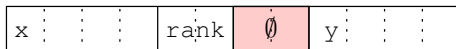


```
int T[6];
```



- ▶ But the compiler is free to add **padding space** to respect alignment constraints

```
struct point {  
    double x;  
    int rank;  
    double y;  
};
```



- ▶ Compiler-dependent/processor-dependent, so you can hardly rely on it...

# Type aliasing in C

## Motivation

- ▶ Type names quickly become quite long: `enum color`,
  - ▶ Variable `square` being an array of four points: `struct point square[4]`
- ⇒ Keyword `typedef` used to declare **type aliases**

## Usage

- ▶ **Reading a typedef**: “the last word is an alias for everything else on the line”

### Basic example

```
struct point {  
    double x;  
    double y;  
};  
typedef struct point point_t;  
...  
point_t p;  
p.x = 4.2;  
p.y = 3.14;
```

### All-in-one example

```
typedef struct point {  
    double x, y;  
} point_t;
```

### Complex example

```
typedef point_t square_t[4];  
square_t s;      s[0].x=3.14;
```

- ▶ typedefs are mandatory to organize your code...
- ▶ ...but can easily be misused to make your code messy and unreadable (just like about every C idiomatic constructs)

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# Lexical Structure of a Typical Program

- ▶ **Header inclusions:** Load the prototypes of function that you want to use
  - ▶ Lines begin with `#include`
  - ▶ Loaded files are called **headers**
  - ▶ `#include <file>` for system-wide headers
  - ▶ `#include "file"` for project-wide headers
- ▶ **Preprocessor directives; types defs; globals&constants; function prototypes**
  - ▶ typedefs as seen before
  - ▶ `const` are just like `final` in Java
  - ▶ Globals visible from the whole program
  - ▶ Prototypes tell the compiler about functions
- ▶ **Function definitions, including the `main()` function**
  - ▶ There must be one unique `main()` function
  - ▶ Program entry point: started first
  - ▶ *Should* return `EXIT_SUCCESS` or `EXIT_FAILURE`
  - ▶ Several prototypes exist, this one is classical
- ▶ The program can spread over several files (more to come on this)

```
#include <stdlib.h>
#include <stdio.h>
#include "my_prototypes.h"
```

```
#define MAX 42
const int size = 5;
int ranking = 3;
int array[MAX];
void compute_ranking(int from);
```

```
void main(int argc, char *argv[]){
    /* My code here */
    return EXIT_SUCCESS;
}
```



# Source Formatting Best Practices

## Identifier naming schema

- ▶ There is a religion war between `this_naming_schema` and `thisNamingSchema`
- ▶ I personally use the first one in C, and the second one in Java
- ▶ Pick your own, and **STICK TO IT!**

## Indenting

- ▶ There is another religion war between these two styles (and others)

```
if (cond) {  
    /* body */  
}
```

```
if (cond)  
{  
    /* body */  
}
```

- ▶ I personally use the first one (more compact), but YMMV:
- ▶ As long as you **DO** indent your code consistently, that's fine with me

## Spacing (no real flame war here, boring)

- ▶ No spaces around these: `->` `.` `[]` `!` `~` `++` `--` `&` unary `*` and `-`
- ▶ One space around these: `=` `+=` `?:` `+` `<` `&&` and binary operators

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# Terminal I/O

## Interactions with the external world in C and Java

- ▶ **Java**: easy to build a GUI and painful to interact through the console
- ▶ **C**: the contrary (GUI require external libs such as Gnome, KDE, ncurses)

## Standard Communication Channels

- ▶ **Standard input** (stdin): keyboard, unless it got redirected
- ▶ **Standard output** (stdout): screen, unless it got redirected
- ▶ **Standard error** (stderr): screen, unless it got redirected
- ▶ Example of redirection: `prog < in_file > out_file 2>err_file`

## Single character I/O

- ▶ `int getchar()`: returns the next character from input (or EOF in case of End Of File, this constant is defined in `stdio.h`)
- ▶ `int putchar(int c)`: writes `c` to output
- ▶ Yes these functions consider chars as ints. Sorry.

# Multiple Characters Terminal I/O

## Motivation

- ▶ Single char I/O works, but that's a real pain. We want the equivalent of `System.out.println("hello "+name+". How are you today?");`
- ▶ No `toString()` magic functions nor magic `+` string concatenation in C

## Interacting with the terminal in C

- ▶ Actually there is two major interfaces for that in C
- ▶ **Low-level API** (`write()` / `read()`): better performance *when used correctly*
- ▶ **High-level API** (`printf()` / `scanf()`): easier to use; **way to go this year**
- ▶ You need to load `stdio.h` to use all these functions

# Writing to the stdout with the printf function

## Naive usage

- ▶ Write the fixed string "hello" to the terminal: `printf("hello")`
- ▶ Write that string and return to the line beginning: `printf("hello\n")`

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## Basic usage

- ▶ To output variables, put place holders in the format string:

```
int x=3; printf("value: %d\n",x)
```

- ▶ Use several place holders to display several variables:

```
int x=3; int y=2; printf("x: %d; y: %d\n",x,y)
```

- ▶ The kind of place holder gives the type of variable to display

%d	integer (decimal)
%f	floating point number
%c	char
%s	string (nul-terminated char array)
%%	the % char

- ▶ If you use the wrong conversion specifier, strange things will happen including a brutal ending of your program – SEGFAULT

# Advanced printf usage

## Other conversion specifiers

%u	unsigned integer
%ld	long integer
%lu	long unsigned integer
%o	integer to display in octal
%x	integer to display in hexadecimal
%e	floating point number to display in scientific notation

## Formating directive modifiers

- ▶ You can specify that you want to see at least 3 digits: `printf("%3d",x);`
- ▶ Or that you want exactly 2 digits after the dot: `printf("%.2d",x);`
- ▶ Or both at the same time: `printf("%3.2f",x);`
- ▶ Or that the output must be 0-padded: `printf("%03.2f",x);`  $\leadsto$  003.14
- ▶ Or that you want to see at most 3 chars: `printf("%.3s",str);`

Many other options exist, full list in man 3 printf

# Reading from stdin with the scanf function

Works quite similarly to printf, but...

- ▶ Read an integer: `int x; scanf("%d", &x);`
- ▶ Read a double: `double d; scanf("%f", &d);`
- ▶ Read a char: `char c; scanf("%c", &c);`
- ▶ Read a string: `char str[120]; scanf("%c", str);`
- ▶ Read two things: `int x; char c; scanf("%d%c", &x, &c);`

So...

- ▶ You need to add a little & to the variable...
- ▶ ...unless when the variable is a string (we'll explain later why)
- ▶ Format string can contain other chars than converters: they **must** be in input
- ▶ A space in format will match any amount of white chars (spaces, \n, tabs)
- ▶ Note that scanf returns the amount of chars it managed to read  
Useful for error checking: what if that's not an integer but something else?



# File I/O

#include <stdio.h>

printf/scanf functions have nice friends for that

- ▶ Writing to stderr: `fprintf(stderr, "warning\n")`
  - ▶ `fprintf` works just like `printf`, taking a file handler as first argument
  - ▶ Likewise `fscanf` is just like `scanf`, with a handler as first argument
- ▶ Declaring a file handler (a variable describing a file): `FILE* handler;`
- ▶ Opening a file for reading `handler = fopen("myfile", "r");`
- ▶ Opening a file for writing `handler = fopen("myfile", "w");`
- ▶ Opening a file in read/write mode `handler = fopen("myfile", "r+");`
- ▶ Checking that the opening went well: `if (handler==NULL) {problem}`
- ▶ Checking whether we reached the end of file `if (feof(handler)) {done}`
- ▶ Closing a file: `fclose(handler);`

In UNIX, everything is a file, and it makes things easier

# Chapter 2

## C as Second Language

- Syntax of the C language
  - C Quick Reference
  - Type Constructors
  - Lexical Structure
- Interactions with the Environment
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# Command line arguments

## Motivation

- ▶ Classical tools such as `ls` or `mv` get arguments from the command line
- ▶ How can we do the same? From the `main()` arguments of course

# Command line arguments

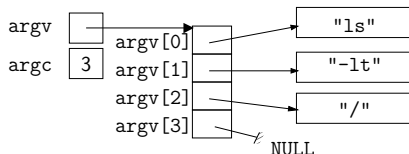
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```
int main(int argc, char *argv[]) {...}
```

- ▶ **argc**: amount of parameter received; **argv**: array of strings received
- ▶ (**note**: these names are conventions, doing really otherwise hinders readability)

Memory layout for `ls -lt /`



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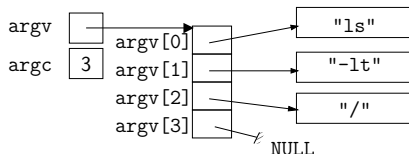
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- ▶ (**note**: these names are conventions, doing really otherwise hinders readability)

Memory layout for `ls -lt /`



## Displaying the arguments

```
int main(int argc, char *argv[]) {  
    int i;  
    for (i=1; i<argc; i++) {  
        printf("Argument #%d:  %s\n",  
              i, argv[i]);  
    }  
    return EXIT_SUCCESS;  
}
```

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# Interacting with Processes

First of all, what is a process?

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- ▶ That's a box encapsulating the execution of a task
- ▶ The operating system uses these boxes to let several tasks coexist in memory
- ▶ Processes are to programs what objects are to classes: living instances  
You can use the same program than me, but you cannot use my processes



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## Basic shell interaction

- ▶ Start a process, simply type the name of the program with arguments  
With `&`, the process runs in **background**. Ex: `emacs &`  
Else, `CTRL-Z` suspends process; then `bg`  $\leadsto$  **background**; `fg`  $\leadsto$  **foreground**
- ▶ List all existing processes `ps -ef` all mine `ps -aux` bob's `ps -u bob`
- ▶ Kill a process knowing its PID: `kill pid`
- ▶ Kill a process knowing its name: `killall name`

# Interacting with Processes from C

## Starting an external process

- ▶ This is as easy as `system("mkdir /tmp/directory")`
- ▶ **Trick 1:** the return value is a bit counter-intuitive (0 –false– if ok)
- ▶ **Trick 2:** stdin/stdout of started process get to stdin/stdout of father  
This limits the possible interaction between both processes

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## Starting and interacting with external processes

- ▶ Use `FILE* popen(char *command, char *type)` for that
- ▶ If type is "r", read from process. If "w", write to it (cannot do both this way)
- ▶ Use `pclose(FILE*handle)` instead of `fclose()` to close such a descriptor
- ▶ After the RS course, you'll find implementing `popen` boring because simple

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# The C preprocessor

## Motivation

- ▶ C designed to work at (very) low level on a variety of machines  
Sometimes, the only way to portability for a given function is:  
Have several versions (windows, linux, mac); pick the right one at compilation
- ▶ C is a very old language  $\leadsto$  we sometimes want to *extend* it a bit

## The C preprocessor: in direct line with Paleolithic

- ▶ I'm not sure you'll ever have to use such a rudimentary tool
- ▶ It's as dumb as possible, but it perfectly fulfills its tasks
- ▶ It's even sometimes used outside of the C ecosystem
- ▶ Beware, that's the perfect tool to make your code unreadable

# Preprocessor: Macros without Arguments

## `#define MACRO_NAME value`

- ▶ This requests a **find/replace**  
Ex: `#define MAX 12`  $\leadsto$  change every "MAX" into 12
- ▶ Numerical constants must be defined that way (or const variables, or enums)
- ▶ Always write macro names in **all upper case** (to make clear what they are)
- ▶ Preprocessor lines expect **no final semi-column** (";")
- ▶ **Always put too much parenthesis**. Think of the result of:

```
#define TWELVE 10+2
int x = TWELVE * 2; //  $\leadsto$  x equals 10+2*2 = 14, not 12*2=24
// #define TWELVE (10+2) would fix it
```

- ▶ Preprocessor directive must be on one line only  $\leadsto$  **escape return carriages**

```
#define MY_MACRO this is \  
                    a multi-line \  
                    macro definition
```

# More on Preprocessor Macros

## Predefined macros

- ▶ `__STDC__`: 1 if the compiler conforms to ANSI C
  - ▶ `__FILE__`: current file; `__LINE__`: current line in that file
- ~> `printf("%s:%d: was here\n", __FILE__, __LINE__);`

## `#define MACRO_NAME(parameters) value`

- ▶ **Programmable find/replace**

Ex: `#define MAX(a,b) ((a)>(b)?(a):(b))` (yep, there is no `max()` in C)

## `#undef MACRO`

- ▶ Forget previous definition of this macro

## `#include <header file>`

- ▶ As previously said, line replaced by whole content of file
- ▶ Header files are source file intended to be loaded this way

# Conditional compilation with the preprocessor

## Conditional on macro definitions

```
#ifdef macro_name
/* Code to use if macro defined */
#else
/* Code to use otherwise */
#endif

#ifdef macro_name
/* Code if macro not defined */
#else
/* Code if defined */
#endif
```

## Conditional on expressions

```
#if constant_expression1
/* some C code */
#elif constant_expression2
/* some C code */
#else
/* some C code */
#endif

#if 0
code to kill
#endif
```

## Protect against multiple inclusions

```
/* mainly useful for header files */
#ifndef SOME_UNIQUE_NAME
#define SOME_UNIQUE_NAME
...
#endif
```

## Redefine a macro

```
#ifdef MACRO
#undef MACRO
#endif
#define MACRO blabla
```

`#error "biiirk"`

- Raises a compilation error with given message (yep, that's sometimes useful)



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# Compiling the code

## One file, one pass

- ▶ `gcc -o binary source.c` (beware of inversions, possibly erasing source.c)
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## Several files, one pass

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- ▶ Compilation involves 2 steps:
  - ▶ Converting each file into assembly (actually compiling them)
  - ▶ Linking parts together (big puzzle game to get a proper binary)
- ▶ Compilation is much more costly than linking
- ~> Avoid redoing it when file was not changed

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- ▶ Compilation is much more costly than linking
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## Several files, several passes

- ▶ **Compilation:** `gcc -c source1.c` `gcc -c source2.c` `gcc -c source3.c`  
generates `source1.o`, `source2.o`, `source3.o`
- ▶ **Linking:** `gcc -o binary source1.o source2.o source3.o`
- ▶ If only one file is touched, only recompile it, and relink everything

# Dependency nightmare, make and Makefiles

## Motivation

- ▶ Deciding what to recompile quickly becomes hairy and error-prone
- ▶ Particularly when the touched file is a header itself loaded in a header...
- ▶ Tracking dependency is the job of the `make` command
- ▶ Explain your project once, and get the job always done properly then

*(this ends the second lecture)*

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## Makefile: explaining the project building process

### Example of such file

```
prog: toto.o tutu.o
    gcc toto.o tutu.o -o prog

toto.o: toto.c
    gcc -c toto.c

tutu.o: tutu.c
    gcc -c tutu.c
```

- ▶ Set of rules formatted as follows:  
    <target file>: <list of dependencies>  
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- ▶ It rebuilds what should be (and nothing more)
- ▶ By default, builds the first target of file
- ▶ Give specific target as `make` argument

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- ▶ `make` is used widely, not only for C. You should use it for you Java code!

*(this ends the second lecture)*



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# Chapter 3

## Memory Management in C

- Static Memory

- Variables in C

- Processes Memory Layout

- Addresses

- Pointers

- Basics

- Pointers vs. Arrays

- Casting Pointers

- Dynamic Memory

- Memory Blocs and Pointers

# Memory Management in C

## Introduction

- ▶ Main specificity of the C language: **Memory Management**
- ▶ You have **full control** over the memory in C
- ▶ That gives you the full power ... to shoot you in the foot

## Lecture agenda

- ▶ First explore the basic notions over memory
  - ▶ Local and Global variables; Scope and Lifetime; Notion of Address and Pointers
- ▶ Then, (quick) look at the system side of memory management
  - ▶ Memory Layout of a typical UNIX Process (more details in RS next year)
- ▶ Finally, go into the full details of memory allocation/deallocation
  - ▶ Student's hated malloc and associated madness

# Variables in C

## Kind of identifiers in C

- ▶ Little difference between variables and functions: they are all **identifiers**
- ▶ Every C identifiers can be either **global** or **local**
- ▶ Main differences: **scope** (visibility) and **lifetime**

## Local Identifiers

- ▶ They are declared within a function
- ▶ **Side note:** nested functions are forbidden in standard C  
gcc allows nested functions as a language extension – I recommend not using them
- ▶ **Scope:** Usable from the block where they are declared
- ▶ **Lifetime:** Valid only until the execution leaves the block

## Global identifiers

- ▶ They are declared outside of any function
- ▶ **Scope:** Usable from the whole project
- ▶ **Lifetime:** permanent
- ▶ (yes, there is no such thing in Java)

# First Weird Code with Variables

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10: }
11: a += 5;
12: {
13:   int b=a;
14:   printf("a: %d, b: %d\n",a,b);
15:   b += 5;
16:   {
17:     int b=0;
18:     printf("a: %d, b: %d\n", a,b);
19:   }
20:   printf("a: %d, b: %d\n", a,b);
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```

## Remarks

- ▶ Yes, we can use anonymous blocks
- ▶ We can declare variables in there
- ▶ We can override variables this way
- ▶ All this is possible in Java too!

## What does this code do?

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l1 a ☐

l3 b ☐

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l1 a 0

l3 b 0

l5 a: 0; b: 0

l6 a 5

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l8  $a_8$  ??

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l9 a: ??; b: 0

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1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10: }
11: a += 5;
12: {
13:   int b=a;
14:   printf("a: %d, b: %d\n",a,b);
15:   b += 5;
16:   {
17:     int b=0;
18:     printf("a: %d, b: %d\n", a,b);
19:   }
20:   printf("a: %d, b: %d\n", a,b);
21: }
22: printf("a: %d, b: %d\n",a,b);
23: return 0;
24:}
```

## Remarks

- ▶ Yes, we can use anonymous blocks
- ▶ We can declare variables in there
- ▶ We can override variables this way
- ▶ All this is possible in Java too!

## What does this code do?

l1 a<sub>1</sub> 0

l3 b<sub>3</sub> 0

l5 a: 0; b: 0

l6 a<sub>1</sub> 5

l8 a<sub>8</sub> ??

l9 a: ??; b: 0

l11 a<sub>1</sub> 10

# First Weird Code with Variables

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10: }
11: a += 5;
12: {
13:  int b=a;
14:  printf("a: %d, b: %d\n",a,b);
15:  b += 5;
16:  {
17:    int b=0;
18:    printf("a: %d, b: %d\n", a,b);
19:  }
20:  printf("a: %d, b: %d\n", a,b);
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22: printf("a: %d, b: %d\n",a,b);
23: return 0;
24:}
```

## Remarks

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## What does this code do?

l1 a<sub>1</sub> 0

l13 b<sub>13</sub> 10

l3 b<sub>3</sub> 0

l5 a: 0; b: 0

l6 a<sub>1</sub> 5

l8 a<sub>8</sub> ??

l9 a: ??; b: 0

l11 a<sub>1</sub> 10

# First Weird Code with Variables

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
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11:  a += 5;
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13:    int b=a;
14:    printf("a: %d, b: %d\n",a,b);
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16:    {
17:      int b=0;
18:      printf("a: %d, b: %d\n", a,b);
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20:    printf("a: %d, b: %d\n", a,b);
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l13 b<sub>13</sub> 10

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l14 a: 10; b: 10

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l6 a<sub>1</sub> 5

l8 a<sub>8</sub> ??

l9 a: ??; b: 0

l11 a<sub>1</sub> 10



# First Weird Code with Variables

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10:  }
11:  a += 5;
12:  {
13:    int b=a;
14:    printf("a: %d, b: %d\n",a,b);
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17:      int b=0;
18:      printf("a: %d, b: %d\n", a,b);
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20:    printf("a: %d, b: %d\n", a,b);
21:  }
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```

## Remarks

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## What does this code do?

l1 a<sub>1</sub> 0

l13 b<sub>13</sub> 10

l3 b<sub>3</sub> 0

l14 a: 10; b: 10

l5 a: 0; b: 0

l15 b<sub>13</sub> 15

l6 a<sub>1</sub> 5

l8 a<sub>8</sub> ??

l9 a: ??; b: 0

l11 a<sub>1</sub> 10

# First Weird Code with Variables

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10:  }
11:  a += 5;
12:  {
13:    int b=a;
14:    printf("a: %d, b: %d\n",a,b);
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17:      int b=0;
18:      printf("a: %d, b: %d\n", a,b);
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20:    printf("a: %d, b: %d\n", a,b);
21:  }
22:  printf("a: %d, b: %d\n",a,b);
23:  return 0;
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```

## Remarks

- ▶ Yes, we can use anonymous blocks
- ▶ We can declare variables in there
- ▶ We can override variables this way
- ▶ All this is possible in Java too!

## What does this code do?

l1 a<sub>1</sub> 0

l13 b<sub>13</sub> 10

l3 b<sub>3</sub> 0

l14 a: 10; b: 10

l5 a: 0; b: 0

l15 b<sub>13</sub> 15

l6 a<sub>1</sub> 5

l17 b<sub>17</sub> 0

l8 a<sub>8</sub> ??

l9 a: ??; b: 0

l11 a<sub>1</sub> 10

# First Weird Code with Variables

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
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5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10: }
11: a += 5;
12: {
13:   int b=a;
14:   printf("a: %d, b: %d\n",a,b);
15:   b += 5;
16:   {
17:     int b=0;
18:     printf("a: %d, b: %d\n", a,b);
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20:   printf("a: %d, b: %d\n", a,b);
21: }
22: printf("a: %d, b: %d\n",a,b);
23: return 0;
24:}
```

## Remarks

- ▶ Yes, we can use anonymous blocks
- ▶ We can declare variables in there
- ▶ We can override variables this way
- ▶ All this is possible in Java too!

## What does this code do?

l1 a<sub>1</sub> 0

l13 b<sub>13</sub> 10

l3 b<sub>3</sub> 0

l14 a: 10; b: 10

l5 a: 0; b: 0

l15 b<sub>13</sub> 15

l6 a<sub>1</sub> 5

l17 b<sub>17</sub> 0

l8 a<sub>8</sub> ??

l18 a: 10; b: 0

l9 a: ??; b: 0

l11 a<sub>1</sub> 10

# First Weird Code with Variables

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10:  }
11:  a += 5;
12:  {
13:    int b=a;
14:    printf("a: %d, b: %d\n",a,b);
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17:      int b=0;
18:      printf("a: %d, b: %d\n", a,b);
19:    }
20:    printf("a: %d, b: %d\n", a,b);
21:  }
22:  printf("a: %d, b: %d\n",a,b);
23:  return 0;
24:}
```

## Remarks

- ▶ Yes, we can use anonymous blocks
- ▶ We can declare variables in there
- ▶ We can override variables this way
- ▶ All this is possible in Java too!

## What does this code do?

l1	$a_1$	0	l13	$b_{13}$	10
l3	$b_3$	0	l14	a: 10; b: 10	
l5	a: 0; b: 0		l15	$b_{13}$	15
l6	$a_1$	5	l17	$b_{17}$	0
l8	$a_8$	??	l18	a: 10; b: 0	
l9	a: ??; b: 0		l20	a: 10; b: 15	
l11	$a_1$	10			

# First Weird Code with Variables

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10:  }
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18:      printf("a: %d, b: %d\n", a,b);
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23:  return 0;
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```

## Remarks

- ▶ Yes, we can use anonymous blocks
- ▶ We can declare variables in there
- ▶ We can override variables this way
- ▶ All this is possible in Java too!

## What does this code do?

l1	a <sub>1</sub>	0	l13	b <sub>13</sub>	10
l3	b <sub>3</sub>	0	l14	a: 10; b: 10	
l5	a: 0; b: 0		l15	b <sub>13</sub>	15
l6	a <sub>1</sub>	5	l17	b <sub>17</sub>	0
l8	a <sub>8</sub>	??	l18	a: 10; b: 0	
l9	a: ??; b: 0		l20	a: 10; b: 15	
l11	a <sub>1</sub>	10	l22	a: 10; b: 0	

# First Weird Code with Variables

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10:  }
11:  a += 5;
12:  {
13:    int b=a;
14:    printf("a: %d, b: %d\n",a,b);
15:    b += 5;
16:    {
17:      int b=0;
18:      printf("a: %d, b: %d\n", a,b);
19:    }
20:    printf("a: %d, b: %d\n", a,b);
21:  }
22:  printf("a: %d, b: %d\n",a,b);
23:  return 0;
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```

## Remarks

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## What does this code do?

l1 a<sub>1</sub> 0

l13 b<sub>13</sub> 10

l3 b<sub>3</sub> 0

l14 a: 10; b: 10

l5 a: 0; b: 0

l15 b<sub>13</sub> 15

l6 a<sub>1</sub> 5

l17 b<sub>17</sub> 0

l8 a<sub>8</sub> ??

l18 a: 10; b: 0

l9 a: ??; b: 0

l20 a: 10; b: 15

l11 a<sub>1</sub> 10

l22 a: 10; b: 0

Ok, but how to **understand** it?

# First Weird Code with Variables

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
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11:  a += 5;
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13:    int b=a;
14:    printf("a: %d, b: %d\n",a,b);
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16:    {
17:      int b=0;
18:      printf("a: %d, b: %d\n", a,b);
19:    }
20:    printf("a: %d, b: %d\n", a,b);
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22:  printf("a: %d, b: %d\n",a,b);
23:  return 0;
24:}
```

## Remarks

- ▶ Yes, we can use anonymous blocks
- ▶ We can declare variables in there
- ▶ We can override variables this way
- ▶ All this is possible in Java too!

## What does this code do?

l1	a <sub>1</sub>	0	l13	b <sub>13</sub>	10
l3	b <sub>3</sub>	0	l14	a: 10; b: 10	
l5	a: 0; b: 0		l15	b <sub>13</sub>	15
l6	a <sub>1</sub>	5	l17	b <sub>17</sub>	0
l8	a <sub>8</sub>	??	l18	a: 10; b: 0	
l9	a: ??; b: 0		l20	a: 10; b: 15	
l11	a <sub>1</sub>	10	l22	a: 10; b: 0	

Ok, but how to understand it?

- ▶ Think of a stack containing locals

# Variables are Stored on a Stack

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10: }
11: a += 5;
12: {
13:   int b=a;
14:   printf("a: %d, b: %d\n",a,b);
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16:   {
17:     int b=0;
18:     printf("a: %d, b: %d\n", a,b);
19:   }
20:   printf("a: %d, b: %d\n", a,b);
21: }
22: printf("a: %d, b: %d\n",a,b);
23: return 0;
24: }
```

## Explaining the outputs

l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones



# Variables are Stored on a Stack

```
1:int a;
2:int main() {
3:  int b;
4:  a=0;
5:  b=a;
6:  printf("a: %d, b: %d\n",a,b);
7:  a += 5;
8:  {
9:    int a;
10:   printf("a: %d, b: %d\n",a,b);
11:  }
12:  a += 5;
13:  {
14:    int b=a;
15:    printf("a: %d, b: %d\n",a,b);
16:    b += 5;
17:    {
18:      int b=0;
19:      printf("a: %d, b: %d\n", a,b);
20:    }
21:    printf("a: %d, b: %d\n", a,b);
22:  }
23:  printf("a: %d, b: %d\n",a,b);
24:  return 0;
25:}
```

## Explaining the outputs

l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones

a 

# Variables are Stored on a Stack

```
1:int a;
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3:  int b;
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16:    b += 5;
17:    {
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21:    printf("a: %d, b: %d\n", a,b);
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23:  printf("a: %d, b: %d\n",a,b);
24: return 0;
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```

## Explaining the outputs

l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones



# Variables are Stored on a Stack

```
1:int a;
2:int main() {
3:  int b;
4:  a=0;
5:  b=a;
6:  printf("a: %d, b: %d\n",a,b);
7:  a += 5;
8:  {
9:    int a;
10:   printf("a: %d, b: %d\n",a,b);
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24: return 0;
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```

## Explaining the outputs

l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones



# Variables are Stored on a Stack

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1:int a;
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3:  a=0;
4:  b=a;
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```

## Explaining the outputs

l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones

b	0
a	0

# Variables are Stored on a Stack

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
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8:    int a;
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22: printf("a: %d, b: %d\n",a,b);
23: return 0;
24: }
```

## Explaining the outputs

l5 a: 0; b: 0    l18 a: 10; b: 0  
l9 a: ??; b: 0    l20 a: 10; b: 15  
l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones

b	0
a	0

l5

# Variables are Stored on a Stack

```
1: int a;
2: int main() {
3:     int b;
4:     a=0;
5:     b=a;
6:     a += 5;
7:     {
8:         int a;
9:         printf("a: %d, b: %d\n",a,b);
10:    }
11:    a += 5;
12:    {
13:        int b=a;
14:        printf("a: %d, b: %d\n",a,b);
15:        b += 5;
16:        {
17:            int b=0;
18:            printf("a: %d, b: %d\n", a,b);
19:        }
20:        printf("a: %d, b: %d\n", a,b);
21:    }
22:    printf("a: %d, b: %d\n",a,b);
23:    return 0;
24: }
```

## Explaining the outputs

l5 a: 0; b: 0      l18 a: 10; b: 0

l9 a: ??; b: 0      l20 a: 10; b: 15

l14 a: 10; b: 10      l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones

b	0	b	0
a	0	a	5

l5

# Variables are Stored on a Stack

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:      int a;
9:      printf("a: %d, b: %d\n",a,b);
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19:     }
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21: }
22: printf("a: %d, b: %d\n",a,b);
23: return 0;
24: }
```

## Explaining the outputs

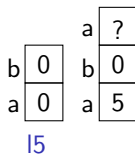
l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones



# Variables are Stored on a Stack

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
7:  {
8:    int a;
9:    printf("a: %d, b: %d\n",a,b);
10:  }
11:  a += 5;
12:  {
13:    int b=a;
14:    printf("a: %d, b: %d\n",a,b);
15:    b += 5;
16:    {
17:      int b=0;
18:      printf("a: %d, b: %d\n", a,b);
19:    }
20:    printf("a: %d, b: %d\n", a,b);
21:  }
22:  printf("a: %d, b: %d\n",a,b);
23:  return 0;
24:}
```

## Explaining the outputs

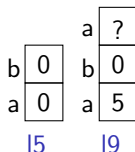
l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones





# Variables are Stored on a Stack

```
1:int a;
2:int main() {
3:  int b;
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20:   printf("a: %d, b: %d\n", a,b);
21: }
22: printf("a: %d, b: %d\n",a,b);
23: return 0;
24: }
```

## Explaining the outputs

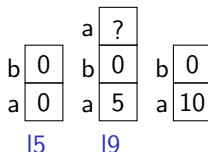
l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones



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```

## Explaining the outputs

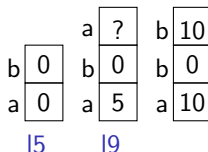
l5 a: 0; b: 0      l18 a: 10; b: 0

l9 a: ??; b: 0      l20 a: 10; b: 15

l14 a: 10; b: 10      l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones



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21:  }
22:  printf("a: %d, b: %d\n",a,b);
23:  return 0;
24:}
```

## Explaining the outputs

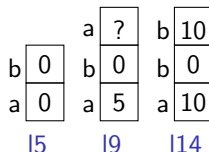
l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

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## The stack over time

- Higher variables mask deeper ones



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22:  printf("a: %d, b: %d\n",a,b);
23:  return 0;
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```

## Explaining the outputs

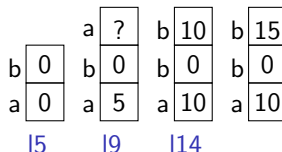
l5 a: 0; b: 0    l18 a: 10; b: 0

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## The stack over time

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17:      int b=0;
18:      printf("a: %d, b: %d\n", a,b);
19:    }
20:    printf("a: %d, b: %d\n", a,b);
21:  }
22:  printf("a: %d, b: %d\n",a,b);
23:  return 0;
24:}
```

## Explaining the outputs

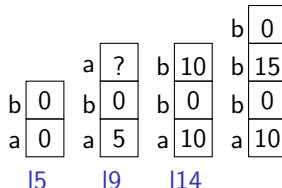
l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones



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13:    int b=a;
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22:  printf("a: %d, b: %d\n",a,b);
23:  return 0;
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```

## Explaining the outputs

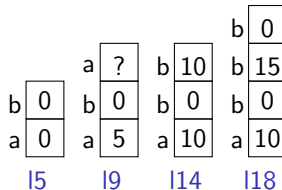
l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

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## The stack over time

- Higher variables mask deeper ones



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```

## Explaining the outputs

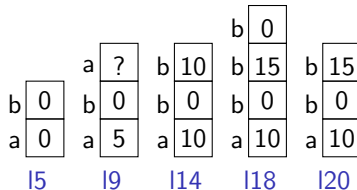
l5 a: 0; b: 0    l18 a: 10; b: 0

l9 a: ??; b: 0    l20 a: 10; b: 15

l14 a: 10; b: 10    l22 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones



# Variables are Stored on a Stack

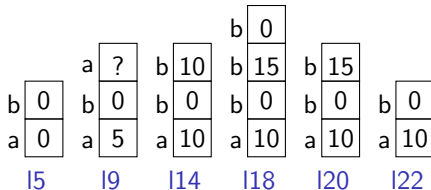
```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printf("a: %d, b: %d\n",a,b);
6:  a += 5;
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17:      int b=0;
18:      printf("a: %d, b: %d\n", a,b);
19:    }
20:    printf("a: %d, b: %d\n", a,b);
21:  }
22:  printf("a: %d, b: %d\n",a,b);
23:  return 0;
24:}
```

## Explaining the outputs

15 a: 0; b: 0    118 a: 10; b: 0  
19 a: ??; b: 0    120 a: 10; b: 15  
114 a: 10; b: 10    122 a: 10; b: 0

## The stack over time

- Higher variables mask deeper ones



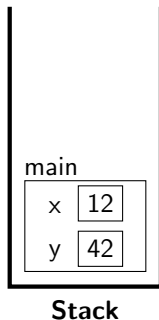


# Function Parameters

## Parameters are stacked too

- ▶ One **stack frame** per function (containing local vars and parameters)
- ▶ Stack frame: created on function call, destructed when the function returns
- ▶ Parameters can be seen as local variables (can even be modified)
- ▶ Parameters are **passed by value** (ie, copied over)

```
int max(int a, int b) {  
    return a>b ? a : b;  
}  
  
int main() {  
    int x=12;  
    int y=42;  
    return max(x,y);  
}
```

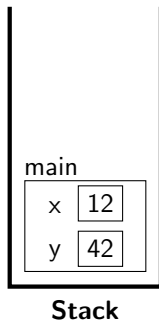


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}
```

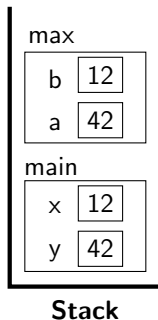


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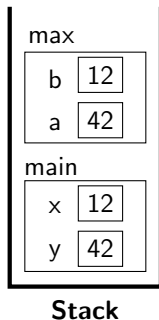


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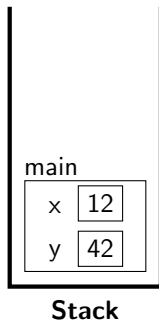


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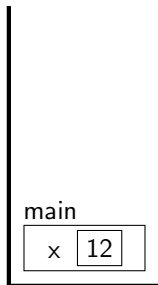


# Function Parameters Tricks

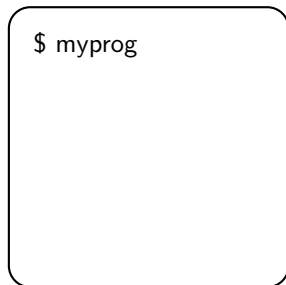
## Parameters are passed by value

- ▶ We just said that but it is not as natural as it seems
- ▶ It forbids any side effects on parameters

```
void triple(int a) {  
    a=a*3;  
    return;  
}  
  
int main() {  
    int x=12;  
    triple(x);  
    printf("x: %d",x);  
    return EXIT_SUCCESS;  
}
```



**Stack**



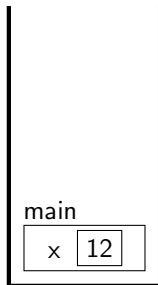
**Output**

# Function Parameters Tricks

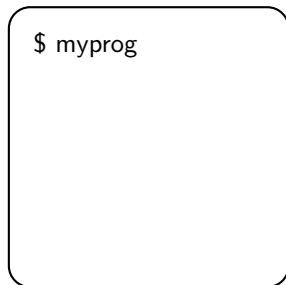
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    return EXIT_SUCCESS;  
}
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**Stack**



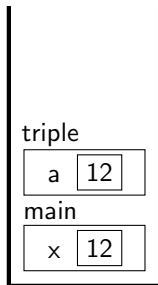
**Output**

# Function Parameters Tricks

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    printf("x: %d",x);  
    return EXIT_SUCCESS;  
}
```



**Stack**

\$ myprog

**Output**

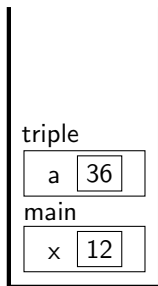


# Function Parameters Tricks

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    return EXIT_SUCCESS;  
}
```



**Stack**

\$ myprog

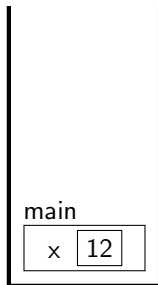
**Output**

# Function Parameters Tricks

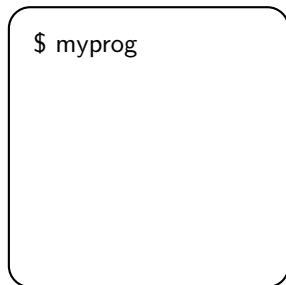
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**Stack**



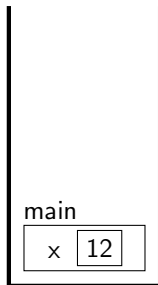
**Output**

# Function Parameters Tricks

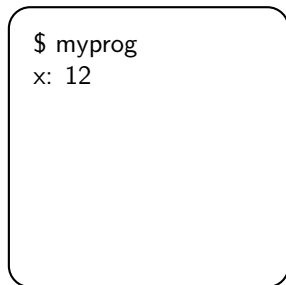
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    return EXIT_SUCCESS;  
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**Stack**



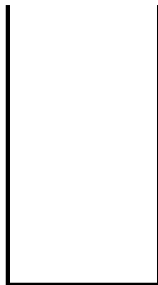
**Output**

# Function Parameters Tricks

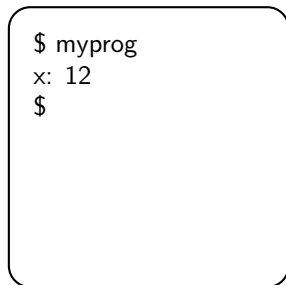
## Parameters are passed by value

- ▶ We just said that but it is not as natural as it seems
- ▶ It forbids any side effects on parameters
- ▶ There is no way to avoid passing by value
- ▶ But pointers help: scanf manages to “modify its arguments”

```
void triple(int a) {  
    a=a*3;  
    return;  
}  
  
int main() {  
    int x=12;  
    triple(x);  
    printf("x: %d",x);  
    return EXIT_SUCCESS;  
}
```



**Stack**



**Output**

# Weird Code with Function Calls

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printab(a,b);
6:  a += 5;
7:  { int a;
8:    printab(a,b);
9:  }
10: a += 5;
11: { int b=a;
12:   printab(a,b);
13:   b += 5;
14:   { int b=0;
15:     printab(a,b);
16:   }
17:   printab(a,b);
18: }
19: printab(a,b);
20: return 0;
21:}
22:int printab(int b, int a) {
23:  printf("a:%d, b:%d\n",a,b);
24:}
```

Code similar to previously

- Call `printab()` for display, not `printf()`

# Weird Code with Function Calls

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13:   b += 5;
14:   { int b=0;
15:     printab(a,b);
16:   }
17:   printab(a,b);
18: }
19: printab(a,b);
20: return 0;
21:}
22:int printab(int b, int a) {
23:  printf("a:%d, b:%d\n",a,b);
24:}
```

Code similar to previously

- Call printab() for display, not printf()

Old Output

```
l5 a: 0; b: 0      l18 a: 10; b: 0
l9 a: ??; b: 0     l20 a: 10; b: 15
l14 a: 10; b: 10   l22 a: 10; b: 0
```

New Output

```
l5 a:0; b:0        l18 a:0; b:10
l9 a:0; b:??       l20 a:15; b:10
l14 a:10; b:10     l22 a:0; b:10
```

This is all inverted!

The trick comes from...

# Weird Code with Function Calls

```
1:int a;
2:int main() {
3:  int b;
3:  a=0;
4:  b=a;
5:  printab(a,b);
6:  a += 5;
7:  { int a;
8:    printab(a,b);
9:  }
10: a += 5;
11: { int b=a;
12:   printab(a,b);
13:   b += 5;
14:   { int b=0;
15:     printab(a,b);
16:   }
17:   printab(a,b);
18: }
19: printab(a,b);
20: return 0;
21:}
22:int printab(int b, int a) {
23:  printf("a:%d, b:%d\n",a,b);
24:}
```

Code similar to previously

- Call printab() for display, not printf()

Old Output

15 a: 0; b: 0	118 a: 10; b: 0
19 a: ??; b: 0	120 a: 10; b: 15
114 a: 10; b: 10	122 a: 10; b: 0

New Output

15 a:0; b:0	118 a:0; b:10
19 a:0; b:??	120 a:15; b:10
114 a:10; b:10	122 a:0; b:10

This is all inverted!

The trick comes from...

- printab's parameters, which are inverted

# The keyword static

This little keyword has two (quite differing) meanings

## When applied to global identifiers

- ▶ Reduces visibility: from “the whole project” to “this file” (as if it were local)
- ▶ Lifetime remains unchanged
- ▶ Java equivalent: private

## When applied to local identifiers

- ▶ Increases lifetime: from “for this call” to “for ever” (as if it were global)
- ▶ Visibility remains unchanged
- ▶ Similar concept in Java: static



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	Visibility	Lifetime
Functions	Whole Project	For Ever
Global Variable	Whole Project	For Ever
Local Variable	Current Block	Until End of Block

# The keyword static

This little keyword has two (quite differing) meanings

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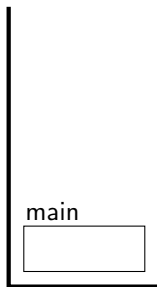
## When applied to local identifiers

- ▶ Increases lifetime: from “for this call” to “for ever” (as if it were global)
- ▶ Visibility remains unchanged
- ▶ Similar concept in Java: static

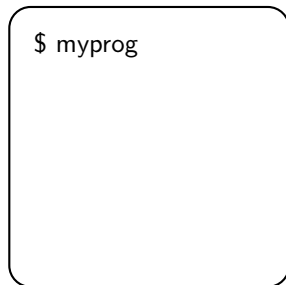
	Visibility	Lifetime
Functions	Whole Project	For Ever
Global Variable	Whole Project	For Ever
Static Global Variable	This File Only	For Ever
Static Local Variable	Current Block	For Ever
Local Variable	Current Block	Until End of Block

# More on Static Local Variables

```
int nextInt() {  
    static int res=0;  
    res+=1;  
    return res;  
}  
  
int main() {  
    printf("next:%d",nextInt());  
    printf("next:%d",nextInt());  
    return EXIT_SUCCESS;  
}
```



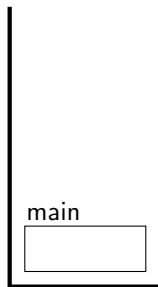
**Stack**



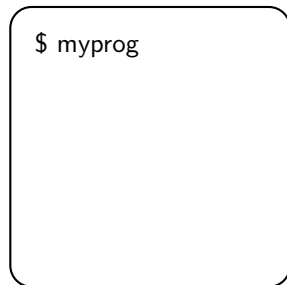
**Output**

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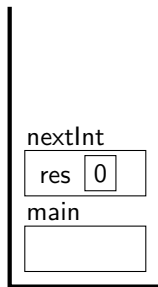
**Stack**



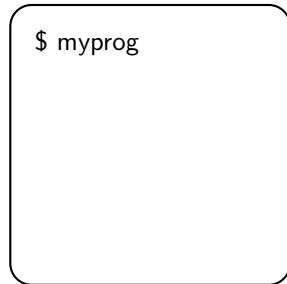
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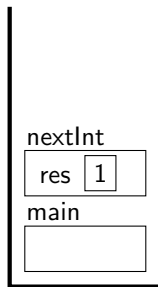
**Stack**



**Output**

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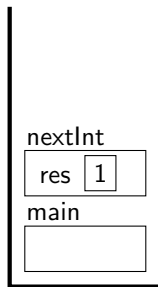
**Stack**

\$ myprog

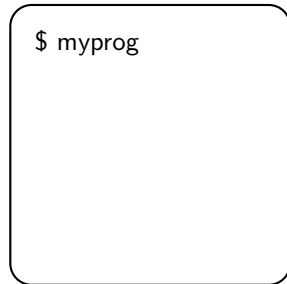
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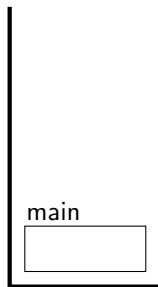
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**Output**

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**Stack**

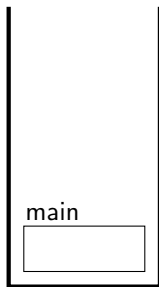


**Output**



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}  
  
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    printf("next:%d",nextInt());  
    return EXIT_SUCCESS;  
}
```



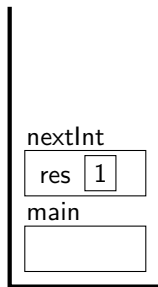
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**Output**

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**Stack**

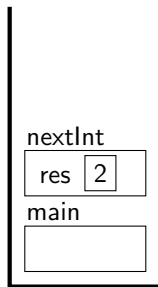
```
$ myprog  
next: 1
```

**Output**

- The value remains from one call to another (initializer evaluated only once)

# More on Static Local Variables

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    return res;  
}  
  
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    return EXIT_SUCCESS;  
}
```



**Stack**

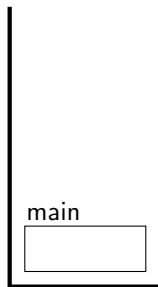
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**Stack**

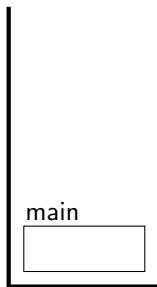


**Output**

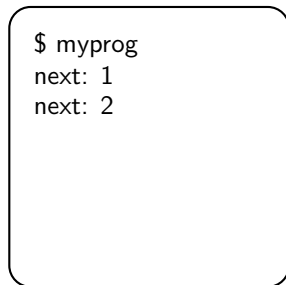
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**Stack**

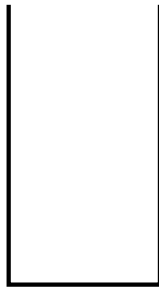


**Output**

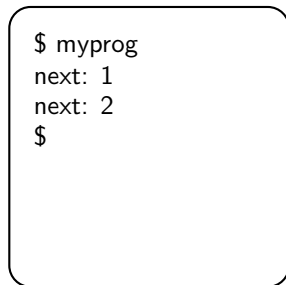
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    return EXIT_SUCCESS;  
}
```



**Stack**



**Output**

- ▶ The value remains from one call to another (initializer evaluated only once)
- ▶ This variable cannot live on the stack: would have been erased by another call
- ▶ Understanding where it lives require some more background on the system (actually, the globals are not on the stack either)

# Processes Memory Layout

## Primer from Next Year in System Course

- ▶ The memory of each process is split in 3 big **segments**
- ▶ Heap is for the manually managed memory (see in half an hour)
- ▶ This is a simplification, but the ideas are there

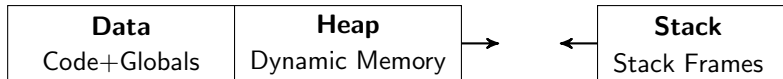
<b>Data</b>	<b>Heap</b>
Code+Globals	Dynamic Memory

<b>Stack</b>
Stack Frames

# Processes Memory Layout

## Primer from Next Year in System Course

- ▶ The memory of each process is split in 3 big **segments**
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Conversely, the heap can grow toward the stack
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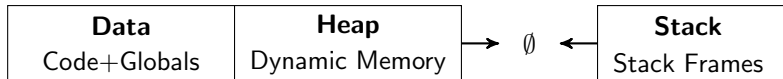




# Processes Memory Layout

## Primer from Next Year in System Course

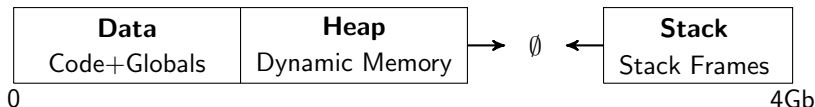
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- ▶ Between Heap and Stack, there is a hole
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# Processes Memory Layout

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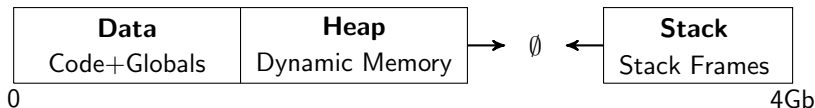
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- ▶ Between Heap and Stack, there is a hole in the addressing space
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## Where do symbols live?

- ▶ **Functions**: in Data segment
- ▶ **Locals**: in Stack segment
- ▶ **Globals**: in Data segment
- ▶ **Static Locals**: in Data segment (just like globals!)

# More on Memory

## Solving the Enigma of Static Locals Storage raises New Questions

- ▶ What is the addressing space?
  - ▶ How to get a valid mental representation of the memory?
- 
- ▶ What is an address?
  - ▶ Why the stack bottom at 4Gb?
  - ▶ Where is my stack if my laptop does not have 4Gb?

# More on Memory

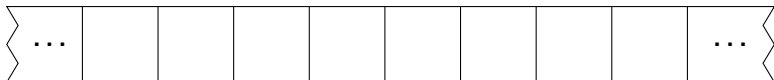
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 $\leadsto$  Think of a very large array of cells. Each cell is 1 byte (8 bits) wide.

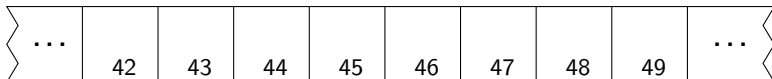


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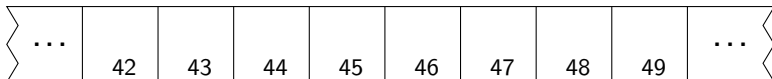


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The **address** of a given memory cell is its number in rank
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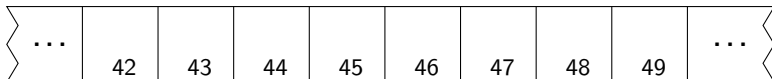
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And the picture supposed that we were in 32bits for simplicity sake.
- ▶ Where is my stack if my laptop does not have 4Gb?



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- ▶ Why the stack bottom at 4Gb?  $\leadsto$  Because this is MAXINT on 32bits  
And the picture supposed that we were in 32bits for simplicity sake.
- ▶ Where is my stack if my laptop does not have 4Gb?
  - ▶ Within the process, we are speaking of *virtual addresses*
  - ▶ They get converted into *physical ones* by the OS
  - ▶ But this all is to be seen in RSA (not even RS – end of next year)

# Storing Data in Memory

## What can get stored in a Memory Cell?

- ▶ It's 8 bits long, so it can take  $2^8$  values
- ▶ The value range is thus  $[0; 255]$  (or  $[-127; 128]$  if signed)

## How to store bigger values?

- ▶ For that, we aggregate memory cells, *i.e.* we interpret together adjacent cells
- ▶ `int` are stored on 4 cells  Resulting range:  $[0; 2^{8 \times 4}] = [0; 2^{32}] \approx [0; 4e^{10}]$
- ▶ `short` are stored on 2 cells  Resulting range:  $[0; 2^{16}] = [0; 65\,535]$

## Problem

- ▶ Impossible to interpret a memory area without infos on data type stored
- ▶ Remember: C memory is a big magma (never forget!)
- ▶ Veery different from Java where you have introspection abilities

# Chapter 3

## Memory Management in C

- Static Memory

- Variables in C

- Processes Memory Layout

- Addresses

- Pointers

- Basics

- Pointers vs. Arrays

- Casting Pointers

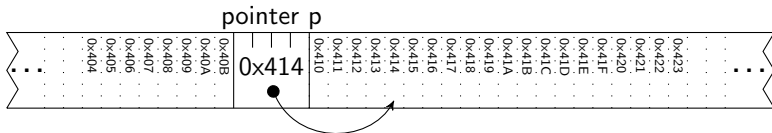
- Dynamic Memory

- Memory Blocs and Pointers

# Pointers

## What is it?

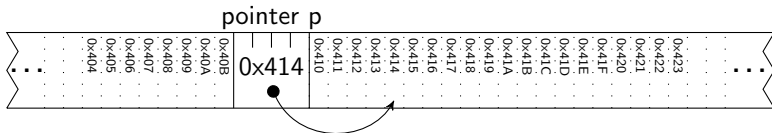
- ▶ **Variable storing a memory address:** Pointer value = rank of a memory cell
- ▶ On 32 bits, I need 4 bytes to store an address since biggest address= $2^{32 \times 8}$  (8 bytes on 64 bits)
- ▶ Pointers are often written in hexadecimal (just a convention)
- ▶ Most of the time, numerical value is meaningless; where it points to is crucial



# Pointers

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## But we can't interpret memory areas w/o info on stored type!

- ▶ This information is given by the type of pointer



- ▶ It is possible to store the address of a pointer of a pointer: `int ***p;`

**Remember:** types are to be read from right to left

# Pointers Pitfalls

## There is reasons why students don't like pointers

### Pitfall #1: \* has a very heavy semantic

- ▶ This little char is very loaded of semantic in C
- ▶ Forget only one \* somewhere, and you're running into the segfault  
Same thing when writing a \* too much

### Pitfall #2: \* actually has two differing meanings

- ▶ `int *p` declares a **pointer variable** p which is a pointer to an integer value
- ▶ `*p` is then the **pointed value**, interpreted according to the pointer type
- ▶ (that's actually three meanings when counting  $\times$ , the multiplication)
- ▶ `int *p; p=12;` selects where it points in memory
- ▶ `int *p; *p=12;` changes the memory in the pointed area
- ▶ Pascal was a bit more reasonable: `INTEGER ^p` vs. `p^` (at least other order)
- ▶ In Java, there is no pointers, but reference to objects are close to that concept

# Retrieving the address of something

## Motivation

- ▶ Knowing that your pointer `p` points to `0x2342` is almost never relevant
- ▶ Knowing that it points to your variable `i` is what you need

This is what the `&` operator does

▶ `int i=42;`

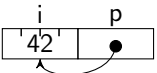


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- ▶ `int i=42; int *p=&i;`  (successive variables are (often) adjacent)

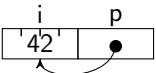


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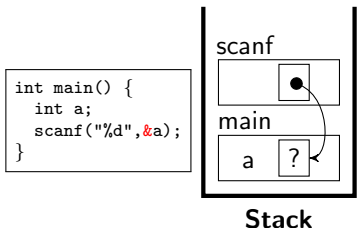
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## This is what the `&` operator does

- ▶ `int i=42; int *p=&i;`  (successive variables are (often) adjacent)

## We can now explain how `scanf` “modifies its arguments”



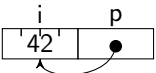
- ▶ `scanf` parameter: an address  
“`%d`” tells how to interpret it
- ▶ That’s copied over, but that’s fine
- ▶ `scanf` can modify the a variable, even if it’s not in its scope  
(remember: C memory is a magma)
- ▶ other mystery:

# Retrieving the address of something

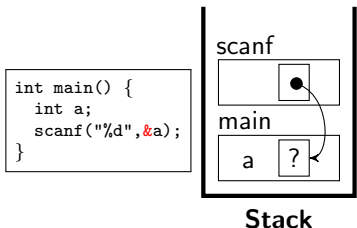
## Motivation

- ▶ Knowing that your pointer `p` points to `0x2342` is almost never relevant
- ▶ Knowing that it points to your variable `i` is what you need

## This is what the `&` operator does

- ▶ `int i=42; int *p=&i;`  (successive variables are (often) adjacent)

## We can now explain how `scanf` “modifies its arguments”

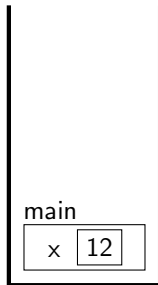


- ▶ `scanf` parameter: an address  
"`%d`" tells how to interpret it
- ▶ That's copied over, but that's fine
- ▶ `scanf` can modify the a variable, even if it's not in its scope  
(remember: C memory is a magma)
- ▶ other mystery: variable amount of params  
`man stdarg` ;)

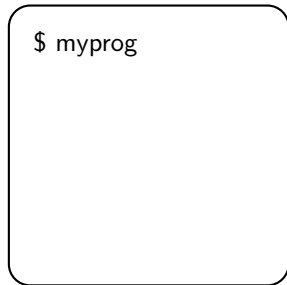
# Fixing the triple() function

- ▶ Remember our broken triple() function, which were unable to triple its argument
- ▶ That was because parameters are passed by value (copied over)
- ▶ To fix it, we simply use a pointer parameter

```
void triple(int *a) {  
    *a=(*a)*3;  
    return;  
}  
  
int main() {  
    int x=12;  
    triple(&x);  
    printf("x: %d",x);  
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}
```



**Stack**

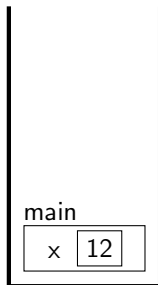


**Output**

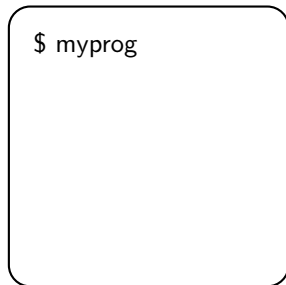
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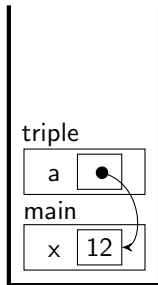


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**Stack**

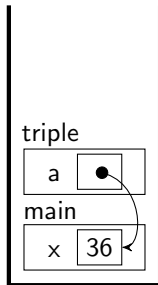
\$ myprog

**Output**

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**Stack**

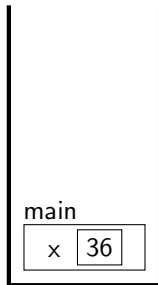
\$ myprog

**Output**

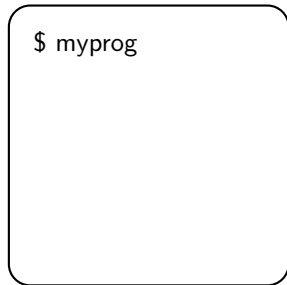
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**Stack**

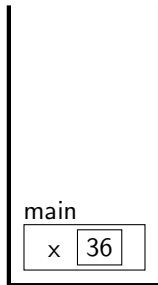


**Output**

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```



**Stack**

```
$ myprog  
x: 36
```

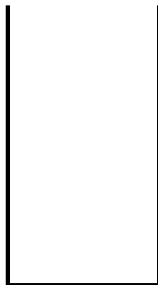
**Output**



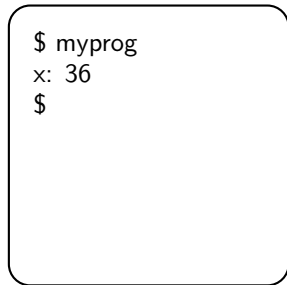
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**Stack**



**Output**

- ▶ Pointers are powerful tools (that's why they are dangerous)

# Pointers vs. Arrays

In C, Arrays are Pointers (at least, most of the time)

- ▶ Unfortunate heritage of C first years; One of the major pitfall for newcomers
- ▶ `char name[32];` pointer to a **reserved** area of 32 bytes
- ▶ `int ai[ ] = {0,1,2};` pointer to a reserved and initied area of 3 ints
- ▶ `void max(int ai[ ])`  $\approx$  `void max(int *ai)` Expects an int pointer
- ▶ `void max(int ai[32])` Similar, but whole array is copied on stack
- ▶ When using name after `char name[32]` as if it were an automatic & name, when looked at as pointer, is the address of the first array cell
- ▶ This explains why strings don't take any & in scanf: they already are pointers

## Considering Pointers as Arrays

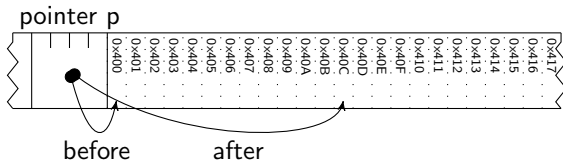
- ▶ `int *pi=...; pi[3];` This is valid; Behave as expected  
(no bound checking, as usual in C)

# Pointer Arithmetic

## Adding and subtracting integers to pointers is valid

- ▶ It represents a **shift in cell (not in bytes)**

```
int *pi=0x400;  
pi=pi+3;  
printf("pi:%x\n",pi);
```



- ▶ Value change in `*pi`:  $\text{value\_after} = \text{value\_before} + \text{sizeof}(\text{int}) \times 3$  because it points on integers

## Subtracting 2 pointers is valid

- ▶ It gives the shift between them (in cells, not in byte)

Other arithmetic operations are **not valid** on pointers

## Pointers, Arithmetic, and Arrays

- ▶ `p[i]` is equivalent to `*(p+i)` (yes, C notations about arrays are messy)

# Chapter 3

## Memory Management in C

- Static Memory

  - Variables in C

  - Processes Memory Layout

  - Addresses

- Pointers

  - Basics

  - Pointers vs. Arrays

  - Casting Pointers

- Dynamic Memory

  - Memory Blocs and Pointers

# Casting Data

## What is it?

- ▶ This is the well known `int a = (int)b` notation. More generally, `(type)`
- ▶ It is used to convert something in a type into something else
- ▶ Two meanings, depending on whether it's applied on scalars or pointers
- ▶ Quite the same story in Java, actually

## Casting Scalars: Converting values

- ▶ 

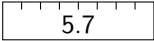

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double d = 5.7;  
int i = (int)d;
```

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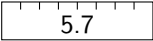

- ▶ `double d = 5.7;`   
`int i = (int)d;` 
- ▶ Casting Scalars can lead to:
  - ▶ Change the memory representation of the value
  - ▶ Change the amount of memory needed to represent the value
  - ▶ Lead to precision loss (!)

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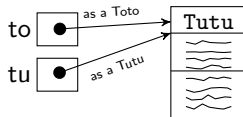
## Casting Pointers: Changing the semantic

- ▶ It's written exactly the same way ... but the meaning is very different
- ▶ Let's look again at the Java semantic of reference casting

# Casting Objects in Java

## Java Semantic Casting

```
Toto to = new Tutu();  
Tutu tu = (Tutu)to;
```



- ▶ Through `tu`, I consider the object to be a `Tutu`
- ▶ It does not change the value of the object, only what I expect from it
- ▶ Only valid if `Tutu` extends `Toto` (and useless if `Toto` extends `Tutu`)

## Side note: Static vs. Dynamic typing is a creepy part of Java

- ▶ Casts relax constraints at compilation time; Enforced at execution time  
That is what `TypeCastException` is made for
- ▶ Guessing which method gets called is sometimes excessively difficult  
Check again TD4 of POO if you forgot
- ▶ But it's hard to depreciate the Java typing system in a course on C...

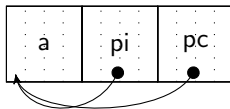


# Casting Pointers in C

## They change the Pointer Semantic

- ▶ The numeric value of the pointer does not change
- ▶ But the dereferencing is completely different
- ▶ Also has a huge impact on pointer arithmetic

```
int a;  
int *pi=&a;  
char *pc=pi;  
pi++;  
pc++;
```

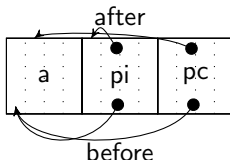


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```



# Generic Pointers

## Generic pointers are sometimes handy

- ▶ To describe pointers that can point to differing data  
**Example:** in `scanf`, how to interpret the pointer is given by the format
- ▶ To describe pointers to *raw* data (ie, you don't care about the pointed type)  
**Example:** When copying memory chunk over, content does not matter

## That is what `void*` is made for

- ▶ Modern compiler even allow you to do pointer arithmetic on them  
supposing that `sizeof(void)=1`, which is ... arbitrary
- ▶ Older compiler force you to cast them to `char*` before

# Chapter 3

## Memory Management in C

- Static Memory
  - Variables in C
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  - Addresses
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  - Basics
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  - Casting Pointers
- Dynamic Memory
  - Memory Blocs and Pointers

# Dynamic Memory

## Motivation

- ▶ Arrays are statically sized in C (*i.e.* their size must be known at compilation)
- ▶ It is forbidden to write:

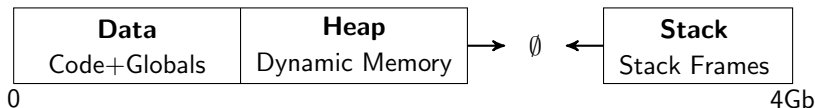
```
int n;  
scanf("%d",&n);  
int tab[n];
```

because `n` is only known at execution
- ▶ (this is not true in C99, but C99 not widely spread yet)

## Solution

- ▶ Directly request memory chunks from the system
- ▶ Manage them yourself
- ▶ And return them to the system when you're done

## Remember the Memory Layout of a Process



- ▶ The idea is to request memory from the heap

# Requesting Memory Chunks from the heap

## The several ways of doing so

- ▶ As usual, there is a high level and a low level API
- ▶ At low-level, the `brk()` syscall allows to move the heap boundary  
And you are on your own to manage its content (emacs does it)

## `malloc()` and friends

- ▶ This higher level API directly gives memory chunks in heap and deal automatically with `brk()`
- ▶ There is only 3 functions to know



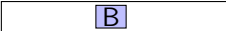


<code>#include &lt;stdlib.h&gt;</code>	
<code>void*malloc(int size)</code>	Request a new memory chunk
<code>void free(void*p)</code>	Return a memory chunk
<code>void*realloc(void*p,int size)</code>	Expend a memory chunk

# Understanding malloc and friends

## Function Semantic

- ▶ `malloc()` requests a new memory chunk and return the address of beginning  
If there is not enough free memory, it returns `NULL`

## Think of a land registry for the memory

- ▶ `void *A=malloc(12);` 
- ▶ `void *B=malloc(5);` 
- ▶ `free(A);` 
- ▶ `void *C=malloc(6);` 
- ▶ `C=realloc(C,13);` 

## As usual in C

- ▶ There is no protection mechanism here: Mess it up and you'll get a segfault
- ▶ Two surviving strategies:
  - ▶ Avoid issues through best practices
  - ▶ Solve issues through debugging tools

# Best Practices about Dynamic Memory

## Rule #1: Only access to reserved areas

- Land Registry Analogy: Only build stuff on land that you own

```
int *A;  
*A=1;  
A=malloc(sizeof(int));
```

Error! A used before malloc!

(buy it before building)

```
int *A=malloc(sizeof(int));  
free(1);  
*A=1;
```

Error! A used after free!

(forget it after selling it)

- You'll have similar symptoms in both case
  - If you are lucky, segfault (error signaled where the fault is)
  - If not, some memory pollution (probably a later segfault, harder to diagnose)



# Best Practices about Dynamic Memory

## Rule #2: To any malloc(), one and only one free()

- ▶ If you forget the free(), there is a **memory leak**
  - ▶ The system assumes that this area is used where it's not anymore
  - ▶ Ok to have a few memleaks. Too much of them will exhaust system resources
  - ▶ Slows everything down (swapping), and malloc() will eventually return NULL
- ▶ If you call free() twice (**double free**), strange things will occur

```
int *A=malloc(12);  
free(A);  
int *B=malloc(12);  
free(A);
```

~> Probably frees B ...

Unfriendly if A and B are in two separate modules

- ▶ That is why modern malloc implementations try to detect this situation
- ▶ And kill faulty program as soon as the error is detected