Advanced C Programming

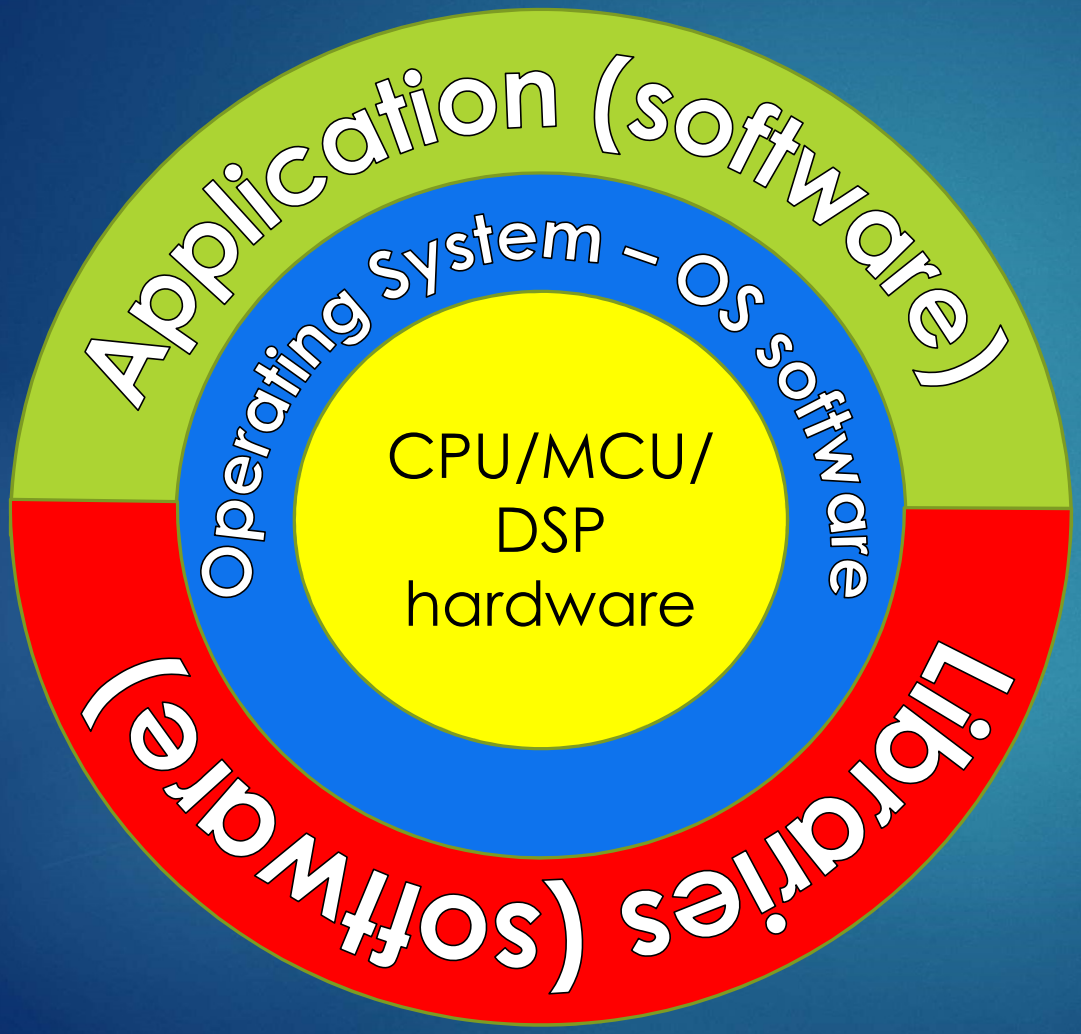
ALAIN HOUELLE

V1.9

- Compilation
- C memory mapping
- Preprocessor
- Logic operators
- Variable type & Standard data format
  - ASCII
  - UTF8
  - INT(unsigned, signed)
  - Floating point
- Array, Multidimensional array, Structure, Union, enum
- Pointers
- Pointers on functions
- Input/Output (File)
- Type modifier
- Qsort Algorithm
- Process
- Threads
- Game competition (for the most advanced coders)

C to Exe

Computer architecture



Most used software programming languages:

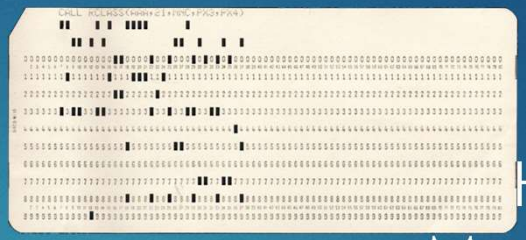
- C
- C++
- Java
- Assembler

- A lot of Micro Controlers applications don't use the OS layer.

ACP

Assembler

Assembler
Human writable/readable
Machine language



Hexadecimal
Machine language

```
clrf    PIE1
movlw   d'255'
movwf   PR2
```

Assembler

```
0x1834A733
0x907D6C88
0x4533AFC5
```

.asm

.hex

Machine language

لا يحق لك المرور

Вы не павінны праходзіць

Atmel

MicroChip (Pic)

Each µC speaks its own machine language
=> No portability

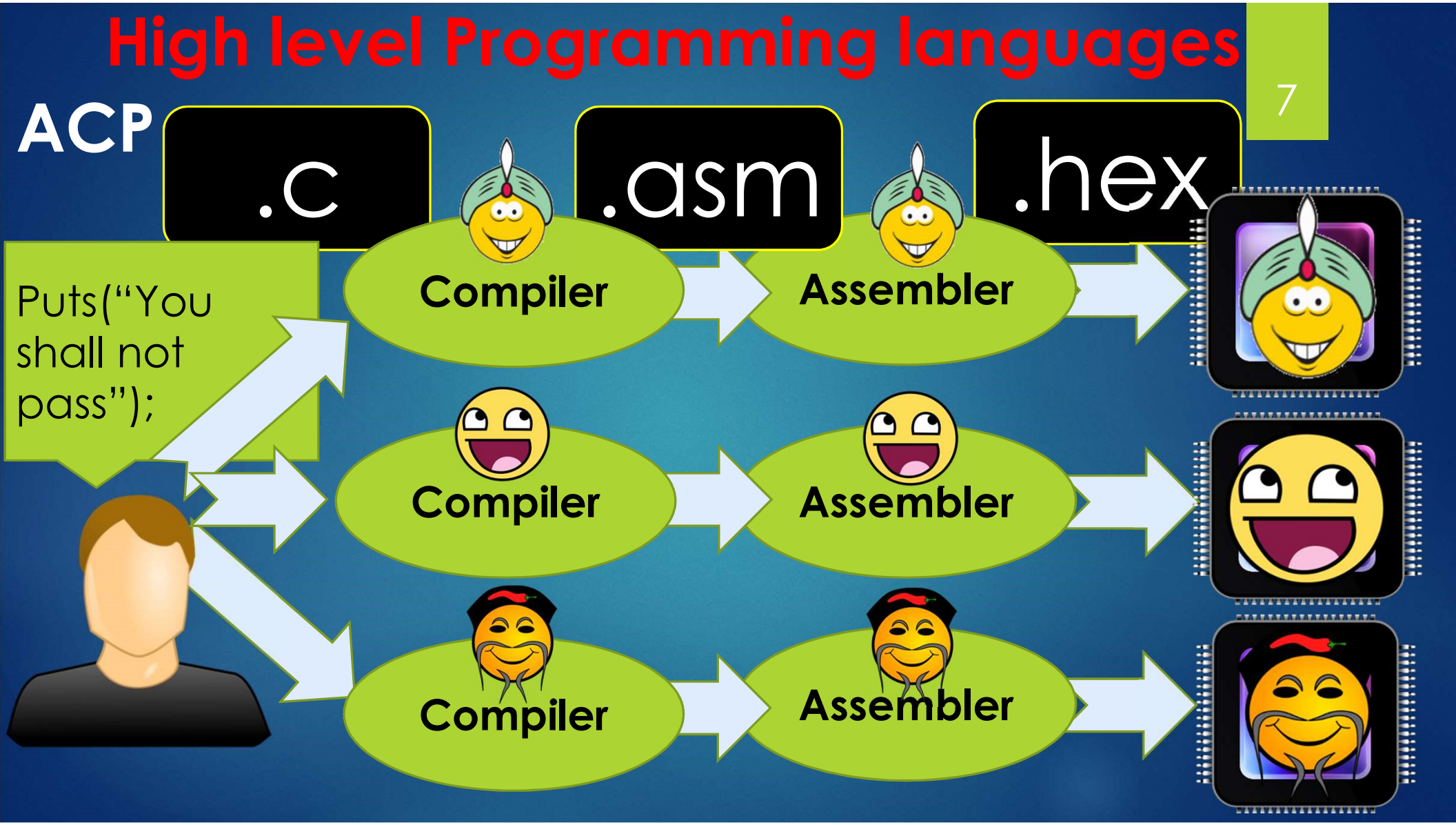
0x01010203
0x05080C15
0x22375990

Hexadecimal

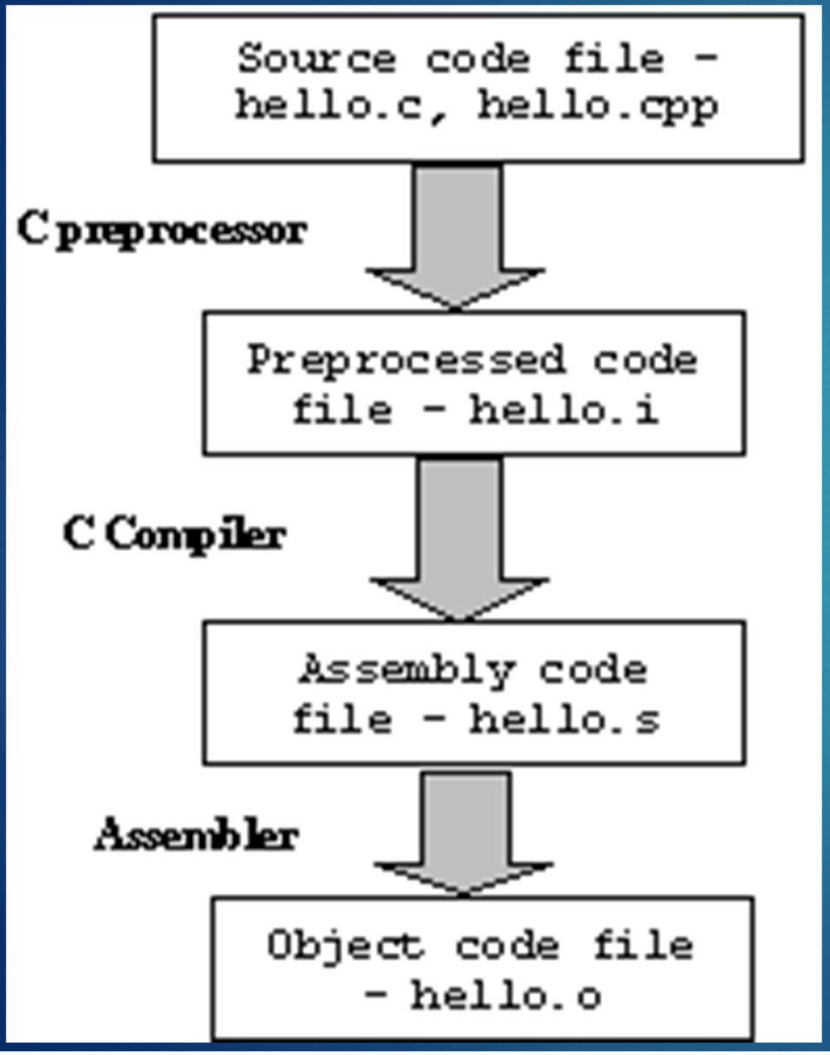
你不可以過去

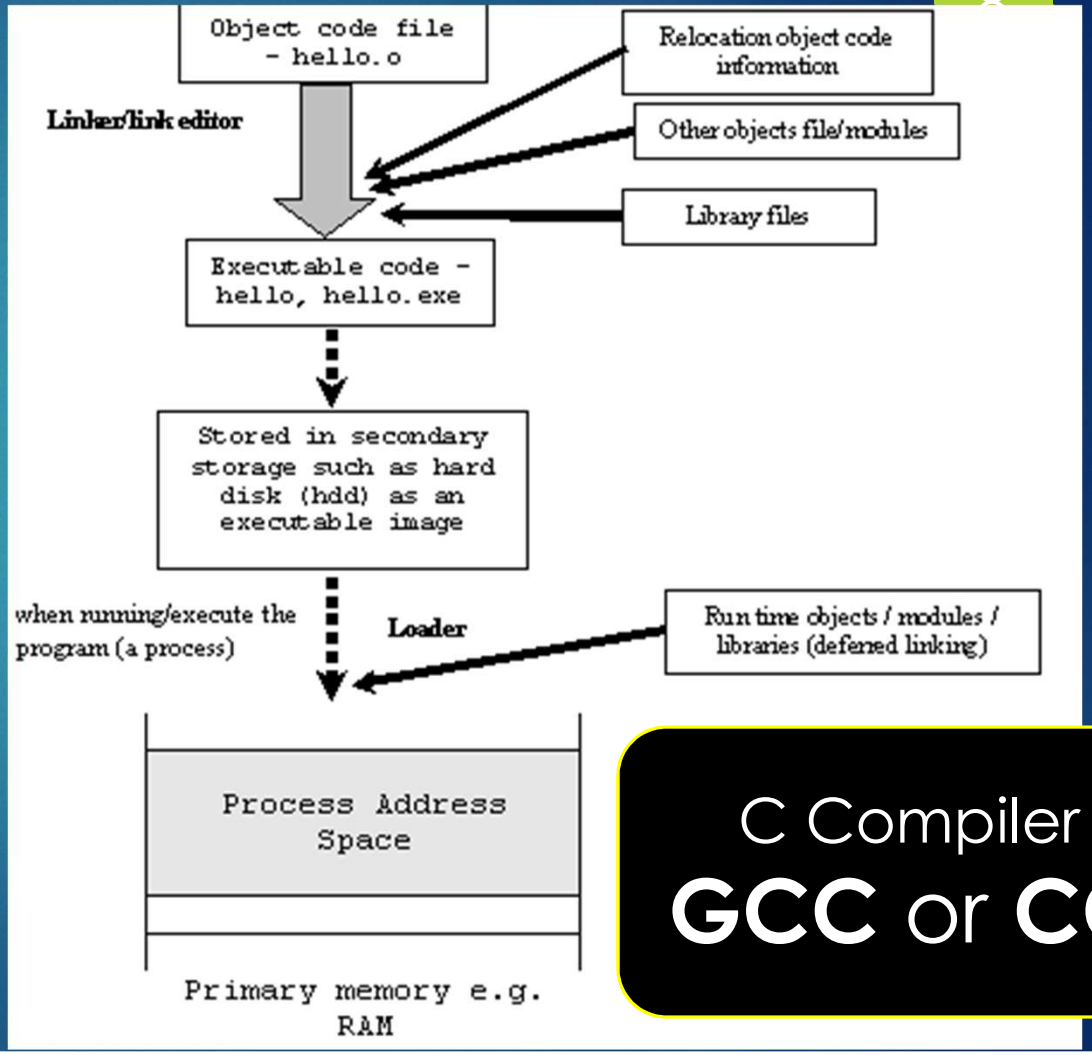
ST Micro (STM32)

High level Programming languages



Compilation Stages





C Compiler
GCC or **CC**

test.c

Stage 1: C Preprocessor


```c
#include "testinclude.c"

#define BB 32

int main() {
    int question, v=12;
    question=BB | !BB;
    question|=v;
#ifdef WHITERABBIT
    puts("white rabbit is defined");
#endif
}
```

testinclude.c

```c
int IAmNotANumberIAmAFreeMan() {
    return 6;
}
```

Preprocessor only:
gcc –E test.c

```c
# 1 "test.c"
# 1 "<built-in>"
# 1 "<command-line>"
# 1 "/usr/include/stdc-predef.h" 1 3 4
# 1 "<command-line>" 2
# 1 "test.c"
# 1 "testinclude.c" 1
int IAmNotANumberIAmAFreeMan() {
 return 6;
}
# 2 "test.c" 2

int main() {
 int question, v=12;
 question=32 | !32;
 question|=v;
}
```

ACP Stage 2 : Compiler

```
# 1 "test.c"
# 1 "<built-in>"
# 1 "<command-line>"
# 1 "/usr/include/stdc-predef.h" 1 3 4
# 1 "<command-line>" 2
# 1 "test.c"
# 1 "testinclude.c" 1
int IAmNotANumberIAmAFreeMan() {
 return 6;
}
# 2 "test.c" 2

int main() {
 int question, v=12;
 question=32 | !32;
 question|=v;
}
```

Compilation only:
gcc –S test.c
gcc –S test.i

```
    .file   "test.c"
    .text
    .globl  IAmNotANumberIAmAFreeMan
    .type   IAmNotANumberIAmAFreeMan, @function
IAmNotANumberIAmAFreeMan:
.LFB0:
    .cfi_startproc
    pushl   %ebp
    .cfi_def_cfa_offset 8
    .cfi_offset 5, -8
    movl    %esp, %ebp
    .cfi_def_cfa_register 5
    movl    $6, %eax
    popl    %ebp
    .cfi_restore 5
    .cfi_def_cfa 4, 4
    ret
    .cfi_endproc
.LFE0:
    .size   IAmNotANumberIAmAFreeMan, .-IAmNotANumberIAmAFreeMan
    .globl  main
    .type   main, @function
main:
.LFB1:
    .cfi_startproc
    pushl   %ebp
    .cfi_def_cfa_offset 8
    .cfi_offset 5, -8
    movl    %esp, %ebp
    .cfi_def_cfa_register 5
    subl    $16, %esp
    movl    $12, -8(%ebp)
    movl    $32, -4(%ebp)
    movl    -8(%ebp), %eax
    orl %eax, -4(%ebp)
    leave
    .cfi_restore 5
    .cfi_def_cfa 4, 4
    ret
    .cfi_endproc
```

ACP

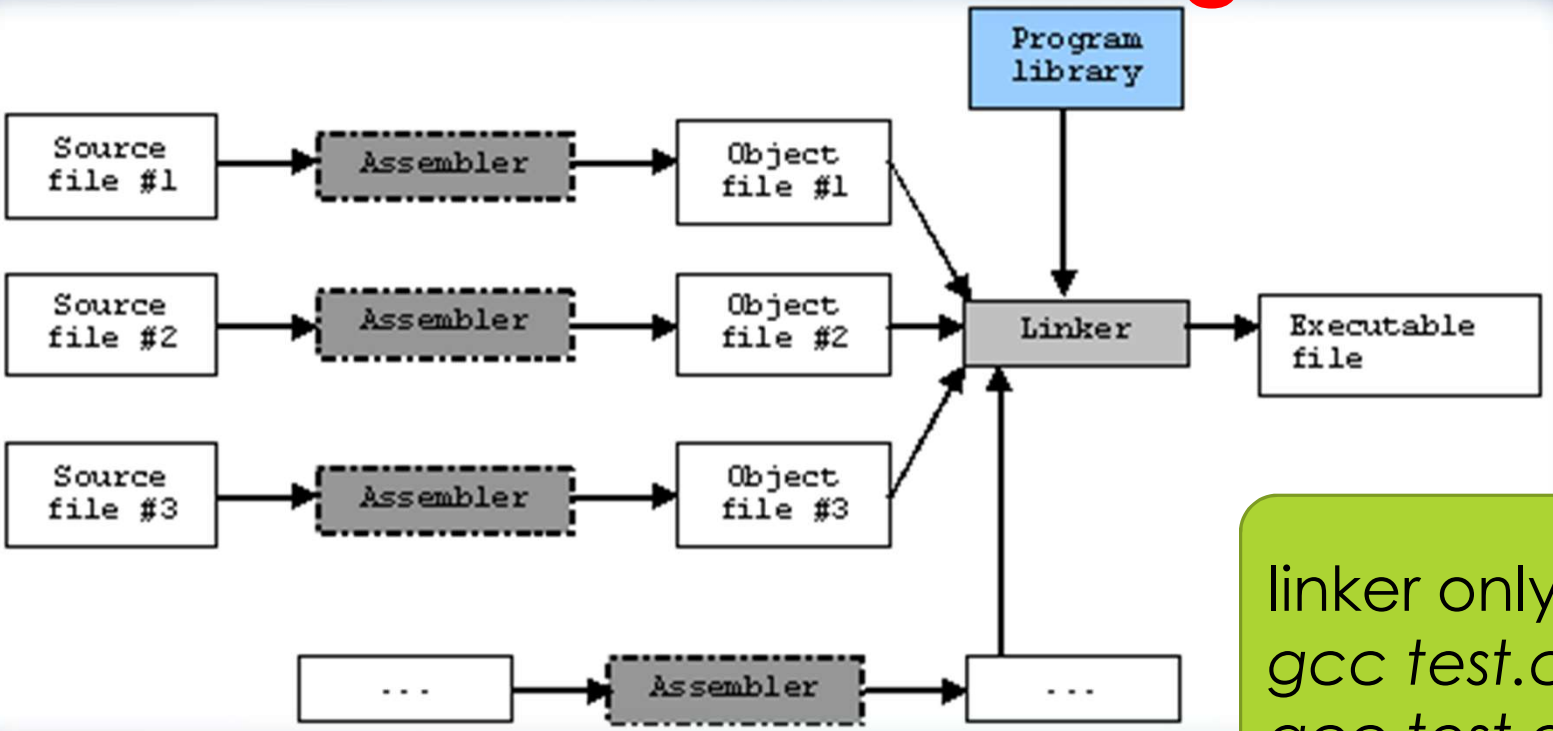
Stage 3 : Assembler

Assembler only:
gcc –c test.c
gcc –c test.i

Gives binary file : test.o
To dump it:
Hexdump test.o

```
0000000 457f 464c 0101 0001 0000 0000 0000 0000
0000010 0001 0003 0001 0000 0000 0000 0000 0000
0000020 0134 0000 0000 0000 0034 0000 0000 0028
0000030 000b 0008 8955 b8e5 0006 0000 c35d 8955
0000040 83e5 10ec 45c7 0cf8 0000 c700 fc45 0020
0000050 0000 458b 09f8 fc45 c3c9 4700 4343 203a
0000060 5528 7562 746e 2075 2e34 2e38 2d34 7532
0000070 7562 746e 3175 317e 2e34 3430 312e 2029
0000080 2e34 2e38 0034 0000 0014 0000 0000 0000
0000090 7a01 0052 7c01 0108 0c1b 0404 0188 0000
00000a0 001c 0000 001c 0000 0000 0000 000a 0000
00000b0 4100 080e 0285 0d42 4605 0cc5 0404 0000
00000c0 001c 0000 003c 0000 000a 0000 001c 0000
00000d0 4100 080e 0285 0d42 5805 0cc5 0404 0000
00000e0 2e00 7973 746d 6261 2e00 7473 7472 6261
00000f0 2e00 6873 7473 7472 6261 2e00 6574 7478
0000100 2e00 6164 6174 2e00 7362 0073 632e 6d6f
0000110 656d 746e 2e00 6f6e 6574 472e 554e 732d
0000120 6174 6b63 2e00 6572 2e6c 6865 665f 6172
0000130 656d 0000 0000 0000 0000 0000 0000 0000
```

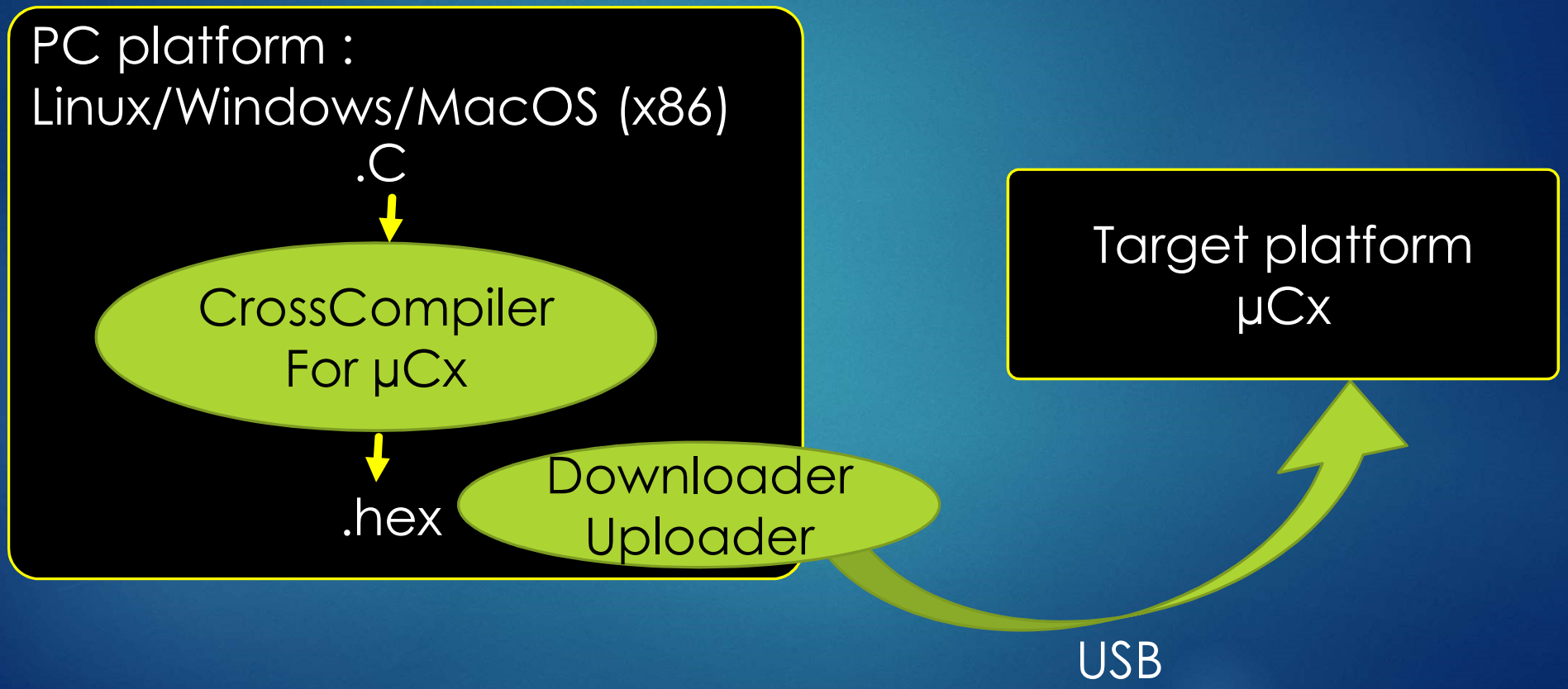
Stage 4 : linker



linker only:
gcc test.c –o test
gcc test.o –o test

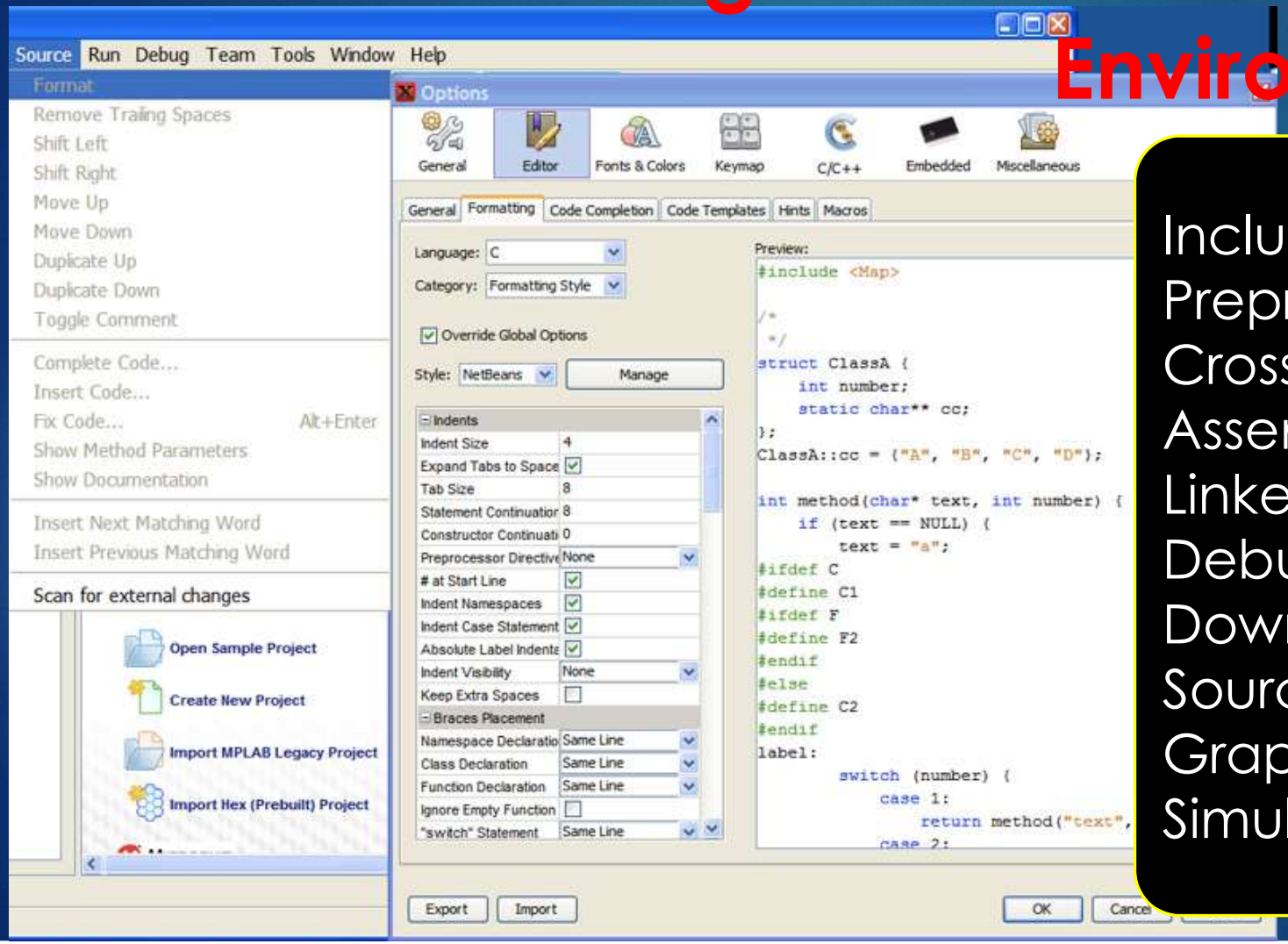
Gives executable file.
.exe on windows

Cross Compilers Downloader



ACP

IDE : Integrated Development Environment



Includes:
Preprocessor
CrossCompiler
Assembler
Linker
Debugger
Downloader
Source Editor
Graphical Environment
Simulator

C

Overview

Inventors

Ken Thompson

Dennis Ritchie
1941-2011

C created in 1970 to (re)write Unix kernel on a PDP 11 (DECsystem)

Called “C” because it was the next version of “B” language

ACP Global Structure of a C Program

- Preprocessor directives
- Global Declarations
- Functions
- main() {…}

#include
#define
#ifdef

Variable which can be reached by any functions of the program

Any function needed by the application

Main function. The program will start here

Global Structure of a C Program function

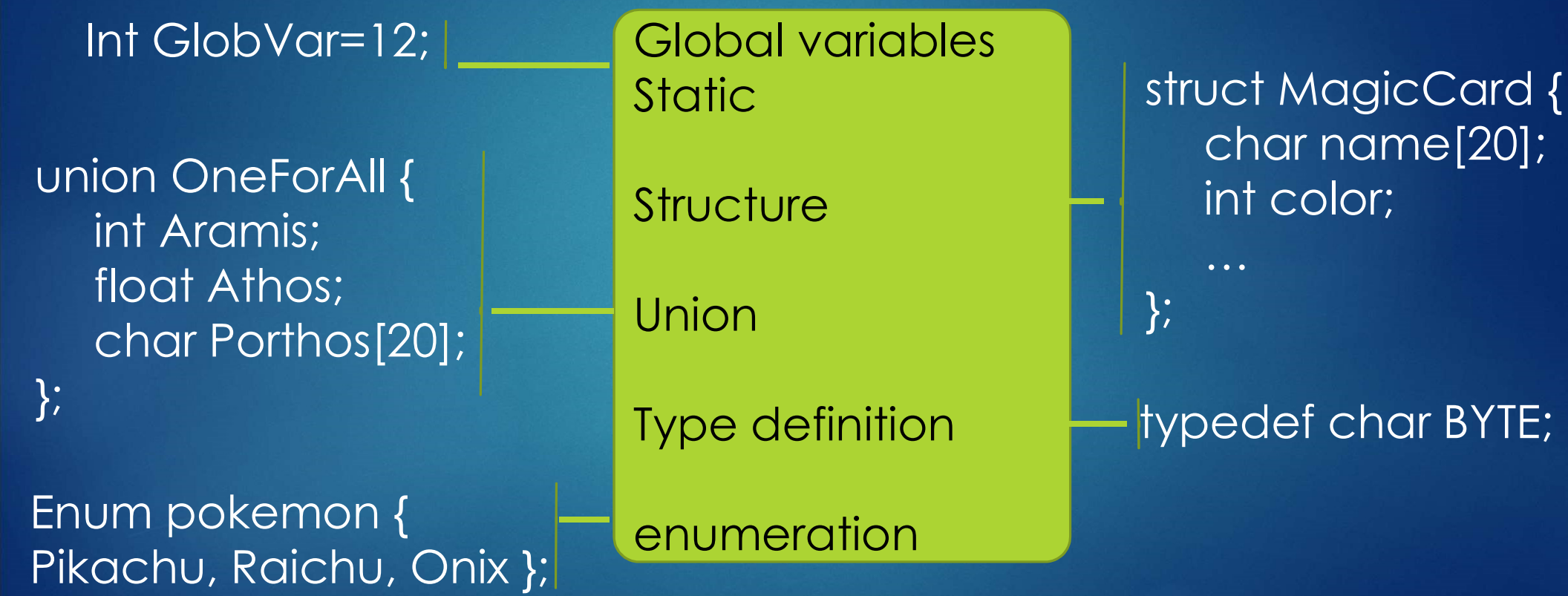

```
return type function(parameters) {
    local declaration

    source code
    return value
}
```

Local declaration only available for the function

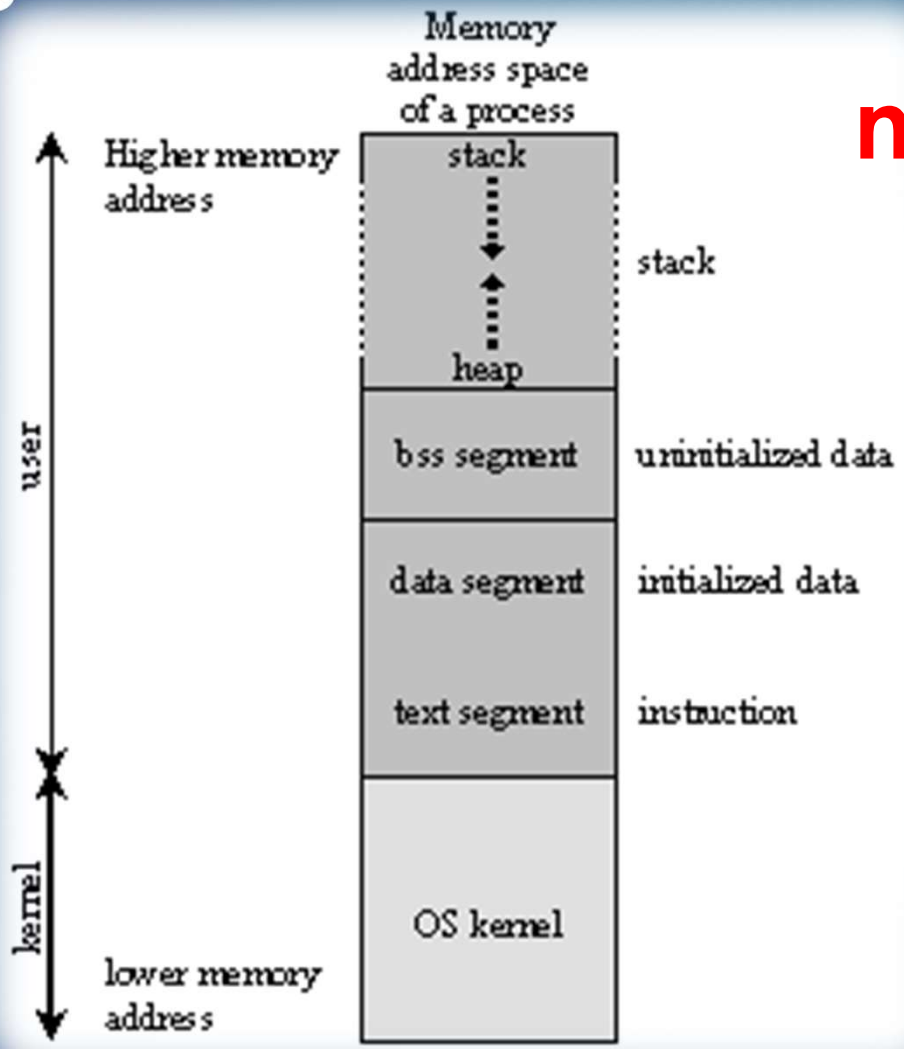
Local variable=dynamic variable :
it exists only when the function is running

=> Stored in stack

Global Structure of a C Program
Global declaration



Unix Process memory space



Global (static) declaration
Are stored in data segment

Dynamic allocations (malloc)
Are stored in heap

Dynamic variables:
Function parameters,
Function local declaration,
Function return value,
Are stored in the stack

Stack & recursivity


```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal= test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma= test(3);
}
```

Stack & recursivity


```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal= test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma= test(3);
}
```

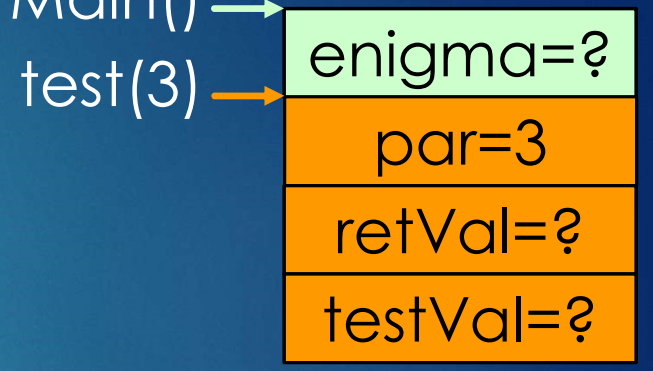
Stack & recursivity

test(3)

```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal= test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma= test(3);
}
```

Main()

stack

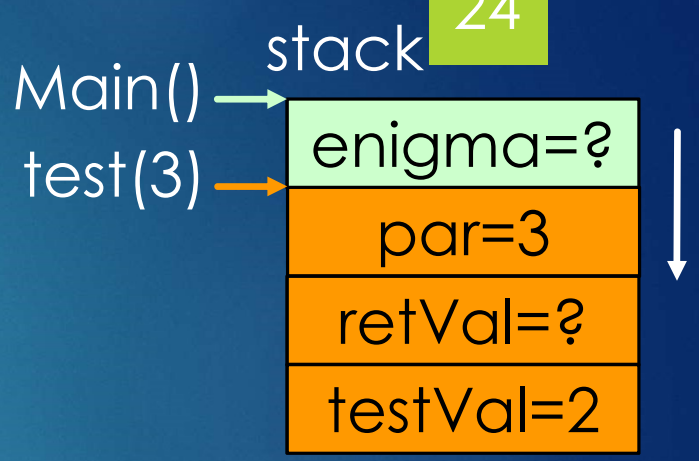


Stack & recursivity


```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal= test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma= test(3);
}
```

test(3)

Main()



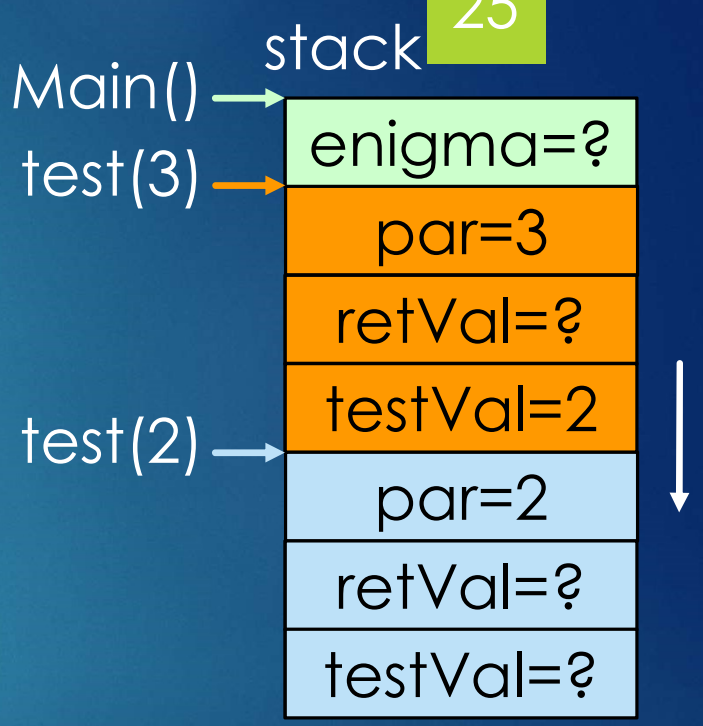
Stack & recursivity

test(2)

test(3)

Main()

```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal= test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma= test(3);
}
```



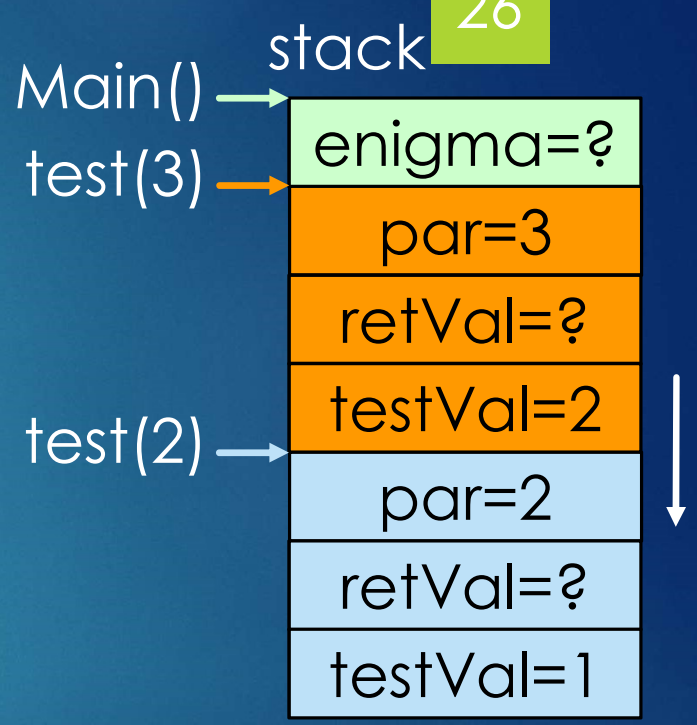
Stack & recursivity


```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal= test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma= test(3);
}
```

test(2)

test(3)

Main()



Stack & recursivity

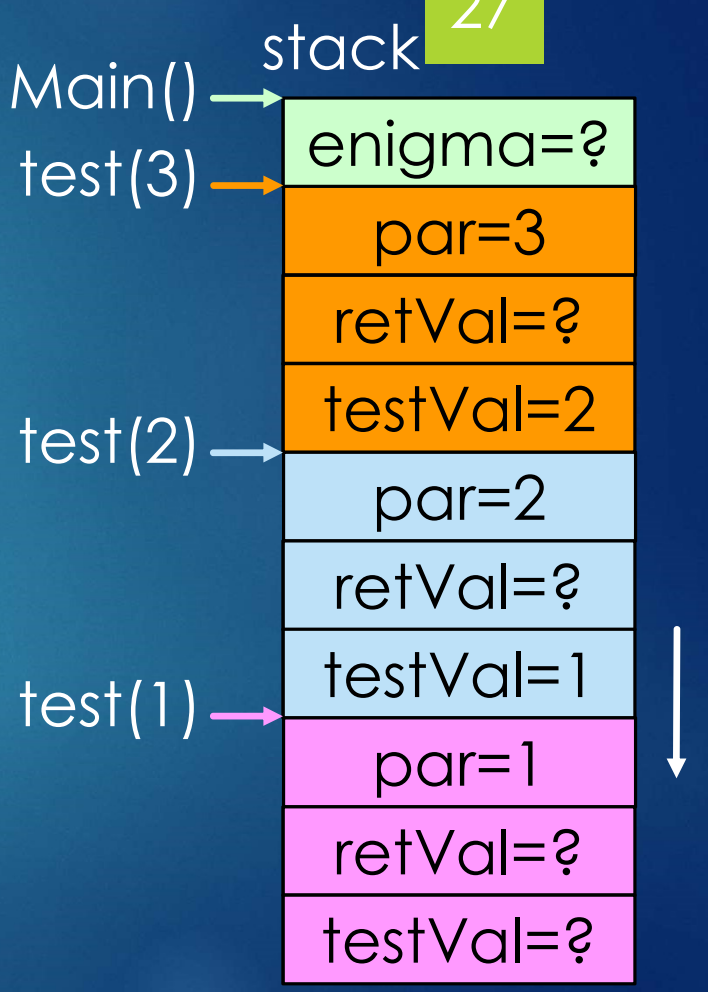

```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal=test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma=test(3);
}
```

test(1)

test(2)

test(3)

Main()



Stack & recursivity

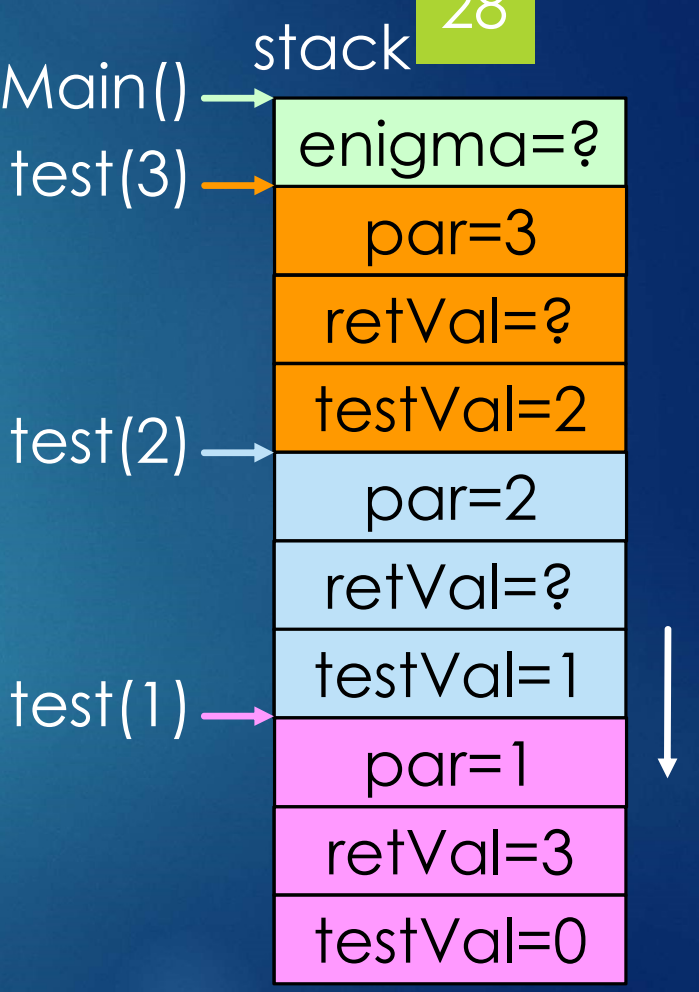

```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal=test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma=test(3);
}
```

test(1)

test(2)

test(3)

Main()



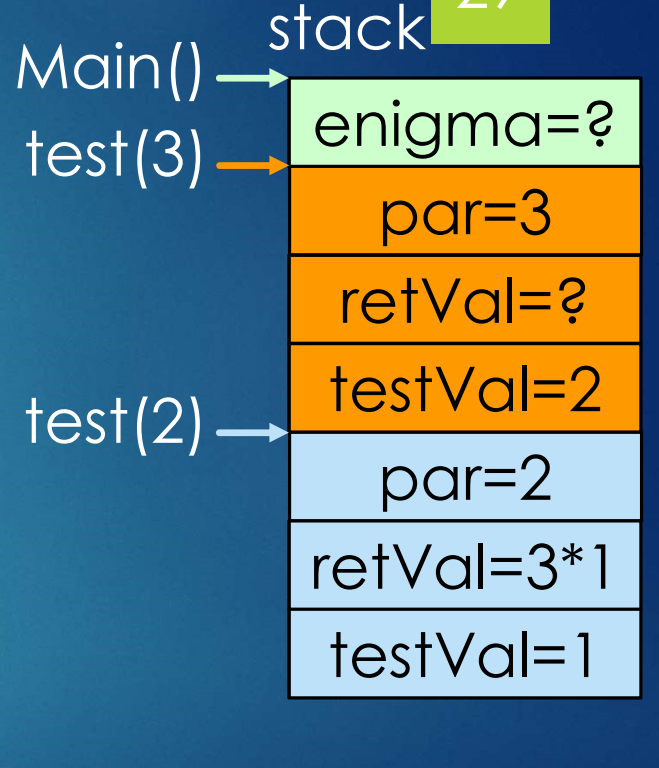
Stack & recursivity


```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal=test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma=test(3);
}
```

test(2)

test(3)

Main()



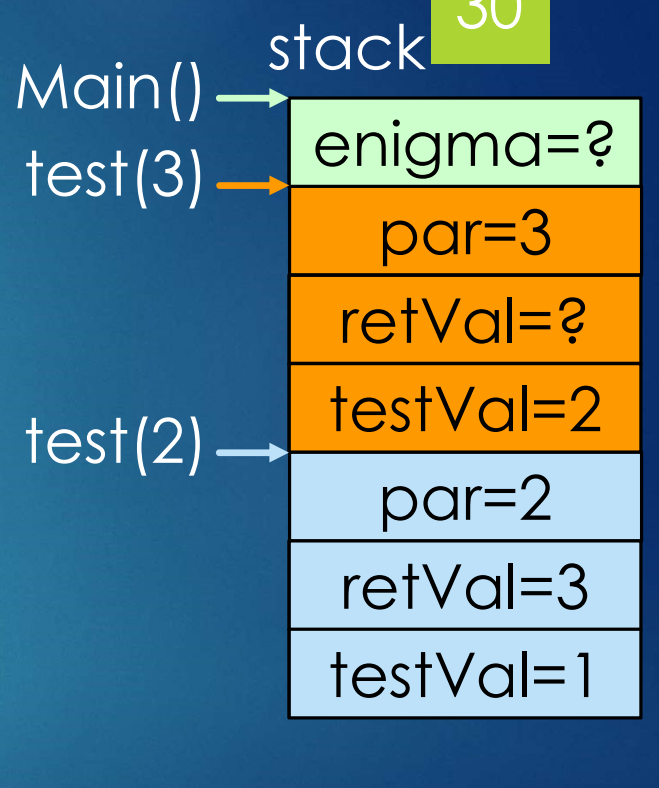
Stack & recursivity


```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal=test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma=test(3);
}
```

test(3)

test(2)

Main()

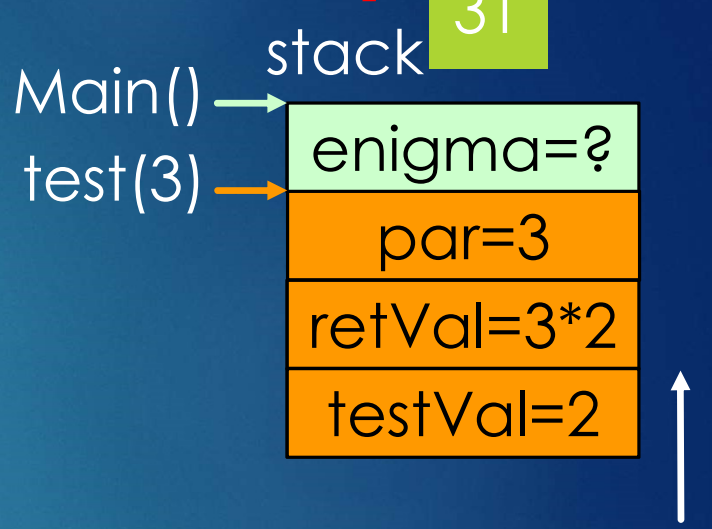


Stack & recursivity


```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal=test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma=test(3);
}
```

test(3)

Main()

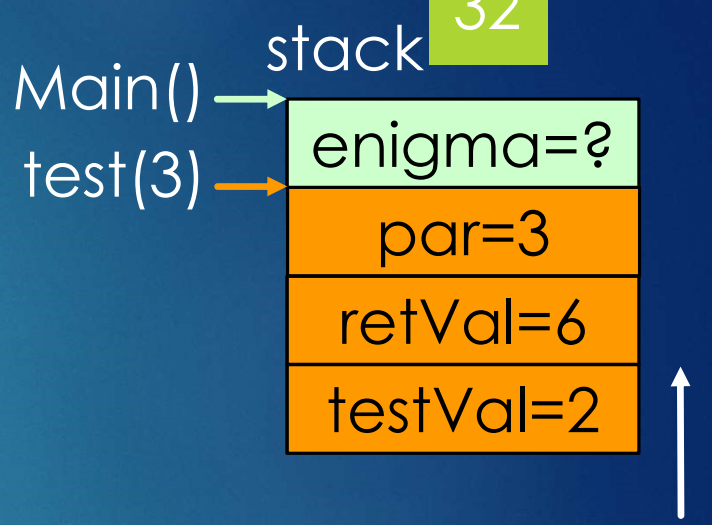


Stack & recursivity


```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal=test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma=test(3);
}
```

test(3)

Main()



Stack & recursivity


```
void test(int par) {
    int testVal,retVal;

    testVal=par-1;
    if(testVal==0) {
        retVal=3;
        return retVal;
    }

    retVal=test(testVal)*testVal;
    return retVal;
}

Main() {
    int enigma;
    enigma=test(3);
}
```

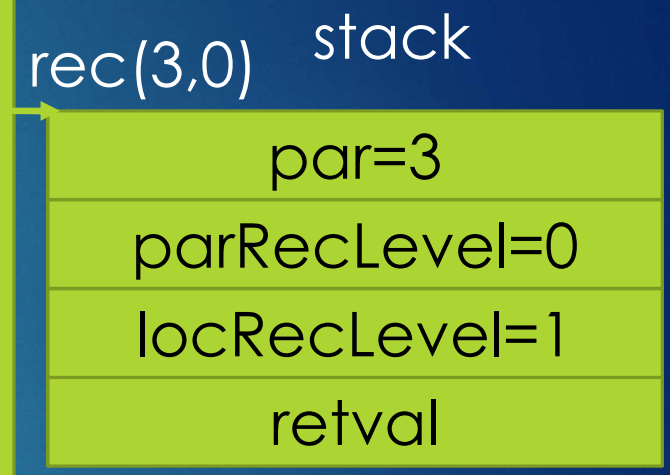
Main()

stack

Main() → enigma=6

Stack & recursivity (ex.)


```
Int rec(int par, int parRecLevel) {
      int locRecLevel, retVal;

      locRecLevel=parRecLevel++; // this one
      locRecLevel=++parRecLevel;//or this one?
      if(locRecLevel>=par) return par;
      retVal=rec(par, locRecLevel)*locRecLevel;
      return retVal;
}

Main() {
      int v;
      v=rec(3,0);
}
```



C Preprocessor

Preprocessor directives 1


```
#include <file>   // include a file from the library directory
#include "file"   // include a file from the default directory (default directory is the current directory or
                  // can be defined with –D gcc command line option)

#define PI   3.14159  // every variable PI in the program will be replaced by 3.14159
#define ab  CD        // every ab variable will be replaced by CD

#ifdef   foobar  // if foobar has been defined "…" will be included in the source code, else "…" will be
…                // skipped
#endif

#define ab CD  // define ab as CD
…1             // for this part of code ab will be replaced by CD
#undef ab      // undefine ab
…2             // for this part of code ab will not be replaced
```

Preprocessor directives 2

Macro Functions:

```
#define myMacro(x) printf("Value of X=%d\n",x)
```

C code example:

```
....
int number;
myMacro(number);
....
```

After preprocessing (gcc –E):

```
....
int number;
printf("Value of X=%d\n",number);
....
```

C

Variable types
Standard variable types

Signed integers:

$$v = -u_{N-1} 2^{N-1} + \sum_{i=0}^{N-2} u_i 2^i$$

$-(2^3)$	2^2	2^1	2^0	
0	1	1	1	= 7
0	0	1	0	= 2
0	0	0	1	= 1
0	0	0	0	= 0
1	1	1	1	= -1
1	1	1	0	= -2
1	0	0	0	= -8

int : signed integer number on 8/16/32/64 bits depending on the CPU (size of the CPU register)

long : signed integer number on 64 bits

short : signed integer number on 16 bits

char : signed integer number on 8 bits

integers

$$v = \sum_{i=0}^{N-1} u_i 2^i$$

2^3	2^2	2^1	2^0	
0	1	1	1	= 7
0	0	1	0	= 2
0	0	0	1	= 1
0	0	0	0	= 0
1	1	1	1	= 15
1	1	1	0	= 14
1	0	0	0	= 8

unsigned int : unsigned integer number on 8/16/32/64 bits depending on the CPU (size of the CPU register)

unsigned long : unsigned integer number on 64 bits

unsigned short : unsigned integer number on 16 bits

unsigned char : unsigned integer number on 8 bits

To initialise an integer:

```
#include <stdio.h>

void main() {
   int spart=300;       // decimal value
   spart=0x12C;         // hexadecimal value
}
```

To display an integer:

```
#include <stdio.h>

void main() {
   int tnotb=666;
   printf("tnotb(decimal)=%d\n",tnotb);
   printf("tnotb(hexadecimal)=%x\n",tnotb);
}
```

integer (ex.)

Considering :
int are on 32 bits, char/8, short/16, long/64

What is the minimum value of unsigned char?
What is the maximum value of a short?
What is the minimum value of a long?
What is the maximum value of a unsigned long?

If you want to know the size of a variable use

sizeof

Example:

```
int varInt;
long varLong;
Printf("sizeof(varInt)=%d\n",sizeof(varInt));
Printf("sizeof(varLong)=%d\n",sizeof(varLong));
```

Logic operators (AND)

AND (&): intersection of two operands

0 & 0 =0
0 & 1= 0
1 & 0=0
1 & 1=1

Example on 4 bits operands:

0011
& 1010
= 0010

Masks can be used to reset some bits.
Ex: 0011 wil reset the two first bits.

Logic operators (OR)

OR (|): union of two operands

0 | 0 =0
0 | 1= 1
1 | 0=1
1 | 1=1

Example on 4 bits operands:

```
  0011
| 1010
= 1011
```

Masks can be used to set some bits.
Ex: 0011 wil set the two last bits.

Logic operators (XOR)

XOR (^): Exclusive OR of two operands

0 ^ 0 =0

0 ^ 1= 1

1 ^ 0=1

1 ^ 1=0

Example on 4 bits operands:

0011

^ 1010

= 1001

Logic operators (right shift)

Right shift (>>):
op >> shiftVal : shift operand op of shiftVal bits to the right

Arithmetic:
op >> shiftVal= op / $2^{shiftVal}$

Example on 4 bits operands:

1011 >> 1= 0101
1011 >> 2 = 0010
1011 >> 3 = 0001
1011 >> 4 = 0000

Logic operators (left shift)

Left shift (<<):
op << shiftVal : shift operand op of shiftVal bits to the left

Arithmetic:
op << shiftVal=
op x $2^{shiftVal}$

Example on 4 bits operands:

1011 << 1= 0110
1011 << 2 = 1100
1011 << 3 = 1000
1011 << 4 = 0000

Logic operators (ex.)

Multiply two integers (a x b) without using the multiply operator (*).

Hint:
Start by trying on fixed simple values.

ACP

char : 8 bits integer usually used to store ASCII characters.

Standard ASCII table

char

00	nul	10	dle	20	sp	30	0	40	@	50	P	60	`	70	p
01	soh	11	dc1	21	!	31	1	41	A	51	Q	61	a	71	q
02	stx	12	dc2	22	"	32	2	42	B	52	R	62	b	72	r
03	etx	13	dc3	23	#	33	3	43	C	53	S	63	c	73	s
04	eot	14	dc4	24	$	34	4	44	D	54	T	64	d	74	t
05	enq	15	nak	25	%	35	5	45	E	55	U	65	e	75	u
06	ack	16	syn	26	&	36	6	46	F	56	V	66	f	76	v
07	bel	17	etb	27	'	37	7	47	G	57	W	67	g	77	w
08	bs	18	can	28	(	38	8	48	H	58	X	68	h	78	x
09	ht	19	em	29	)	39	9	49	I	59	Y	69	i	79	y
0a	nl	1a	sub	2a	*	3a	:	4a	J	5a	Z	6a	j	7a	z
0b	vt	1b	esc	2b	+	3b	;	4b	K	5b	[	6b	k	7b	{
0c	np	1c	fs	2c	,	3c	<	4c	L	5c	₩	6c	l	7c	|
0d	cr	1d	gs	2d	-	3d	=	4d	M	5d	]	6d	m	7d	}
0e	so	1e	rs	2e	.	3e	>	4e	N	5e	^	6e	n	7e	~
0f	si	1f	us	2f	/	3f	?	4f	O	5f	_	6f	o	7f	del

Utf8:Universal Character Set Transformation Format

0xxxxxxx	
110xxxxx	10xxxxxx
1110*0000*	10*1*xxxxx 10xxxxxx
1110*0001*	10xxxxxx 10xxxxxx
1110*001x*	10xxxxxx 10xxxxxx
1110*01xx*	10xxxxxx 10xxxxxx
1110*10xx*	10xxxxxx 10xxxxxx
1110*1100*	10xxxxxx 10xxxxxx
1110*1101*	10*0*xxxxx 10xxxxxx
1110*111x*	10xxxxxx 10xxxxxx
11110*000*	10*01*xxxx 10xxxxxx 10xxxxxx
11110*000*	10*1*xxxxx 10xxxxxx 10xxxxxx
11110*001*	10xxxxxx 10xxxxxx 10xxxxxx
11110*01x*	10xxxxxx 10xxxxxx 10xxxxxx
11110*100*	10*00*xxxx 10xxxxxx 10xxxxxx

ACP

Utf8:Universal Character Set Transformation Format

A=65=0x41=b(100 0001)= Utf8(b**0**100 0001)

~ = 128 = b(1000 0000) = Utf8(**110**0 0010 **10**00 0000)

2048=0x800=b(1000 0000 0000)=Utf8(**1110** 0000 **10**10 0000 **10**00 0000)

To display a char :

```
#include <stdio.h>
void main() {
char myChar='A';
printf("myChar(decimal)=%d\n",myChar);
printf("myChar(hexadecimal)=%x\n",myChar);
printf("myChar(character)=%c\n",myChar);
}
```

char (ex.)

Translate in ASCII the String: “HAL9000”

How to transform this string in lowercase?

How to compare the alphabetical order of two strings : ex. “Dupond”&”Dupont”?

How to transform an ASCII number in “int”?

ACP

Utf8:Universal Character Set Transformation Format (ex.)

Decode this UTF8 encoded string (hexadecimal code) :
0XE1 0x88 0xB4 0xE5 0x99 0xB8

Answer: 0x1234 0x5678

Utf8:Universal Character Set Transformation Format (ex.)

Encode these numbers in UTF8 String (hexadecimal code) :
0XCAFE 0xBABE

Answer: 0xEC 0xAB 0xBE 0xEB 0xAA 0xBE

Floating point

Floating Point IEEE754 standard :

$$(-1)^{sign} \times (1+mantissa) \times 2^{(exponent-bias)}$$

Mantissa (significand) = accuracy
Exponent = range
How to code 1? 2? 3? 0.25? 0?

Floating point

float : real number on 32 bits :
1 sign bit, 8 exponent bits, 23 mantissa bits, bias=127

double : real number on 64 bits
1 sign bit, 11 exponent bits, 52 mantissa bits, bias=1023

Floating point (ex.)

Put 7558963.25 in a float variable.
Print it : printf("num=%f\n",floatVar);

What happens?

Why?

How to solve the problem?

Array []


```
// declaration
int myArray[11]; // array of 11 integers (from 0 to 10)
// use
myArray[0]=12;
myArray[i]=98;
// error
myArray[11]=90; // one of the most current error
```

```
// declaration with initialisation
int myArray[5]={10,20,30,40,50};
```

Array [] (ex.)

Create a static (global) array of ints.
Print the content of the array.

Create a dynamic (local) array of ints.
Print the content of the array.

Create a static array of 5 ints.
Read the 6^{th} element. What happens?
Write the 6^{th} element. What happens?

Strings are arrays of char:

```
char myString[100];

Initialisation:
myString[0]='A';
myString[1]='B';
myString[2]=(char)0;
myString[3]='C';
```

```
// to display a String
Printf("string is %s\n",myString);

// The display will end when the
// first 'null' (0) occurs. The result
will be:

String is AB
```

Strings 2

Standard library <string.h> includes several functions to manipulate strings:

#include <string.h>

int strlen(string); // return the length of string (without the null character)

int strcpy(stringDst, stringSrc); // copy the stringSrc into stringDst.

int strcmp(string1, string2); // compare two strings.

Strings (ex.)

- What happens if:

```
char foo[3];
strcpy(foo, "weiner");
printf("foo=%s\n",foo);
```

- Write a code which gives the index of the first difference.

```
char string1[]="DUPOND";
char string2[]="DUPONT";
```

Multidimensional Array []


```
// initialisation
int myMatrix[11][30]; // array of 11x30 integers

// use
myMatrix[0][0]=12;
myMatrix[i][ j ]=98;
```

```
// declaration with initialisation
int myMatrix[2][3]={   {1, 2, 3},
                       {4, 5, 6}  };
```

Multidimensional Array (ex.)

Try to find how is stored a multidimensional array.

Hint:

Create a [3][2] matrix.

Initialise elements:

[0][0], [0][1], [0][2], [0][3], [0][4], [0][5]

Visualise the content of:

[0][0], [0][1], [1][0], [1][1], [2][0], [2][1]

Explain

Enumeration 1


```
// declaration:
enum enumColor { RED, GREEN, BLUE};
// => RED=0, GREEN=1, BLUE=2
// variable declaration:
enum enumColor myColor;
// use
myColor=BLUE;
```

Enumeration 2


```
// declaration:
enum enumColor { RED, GREEN=4, BLUE};
// => RED=0, GREEN=4, BLUE=5
// variable declaration and initialisation:
enum enumColor myColor=GREEN;
```

Enumeration 3

// enum declaration; variable declaration;
// variable initialisation :

```
enum enumColor { RED, GREEN, BLUE} myColor=BLUE;
```

Enumeration (ex.)

What happens when:

```
enum enumTest { FOO=3, BAR=2, MYSTERY };
```

Structure 1


```
// declaration
struct date {
    int day;
    int month;
    int year;
};

// declaration of one variable
struct date yesterday;
```

```
// use
yesterday.day=10;
yesterday.month=1;
yesterday.year=2099;
```

Structure 2


```
// struct declaration; variable declaration;
// variable initialisation
struct date {
    int day;
    int month;
    int year;
} yesterday={ 10, 1, 2099};

struct date foo[10];
```

Structure 3


```
// structure imbrication
struct event {
   struct date eDate;
   char name[32];
} testEvent= {{ 10, 1, 2099},
                {“JPO”} };

// use
testEvent.eDate.day=12;
```

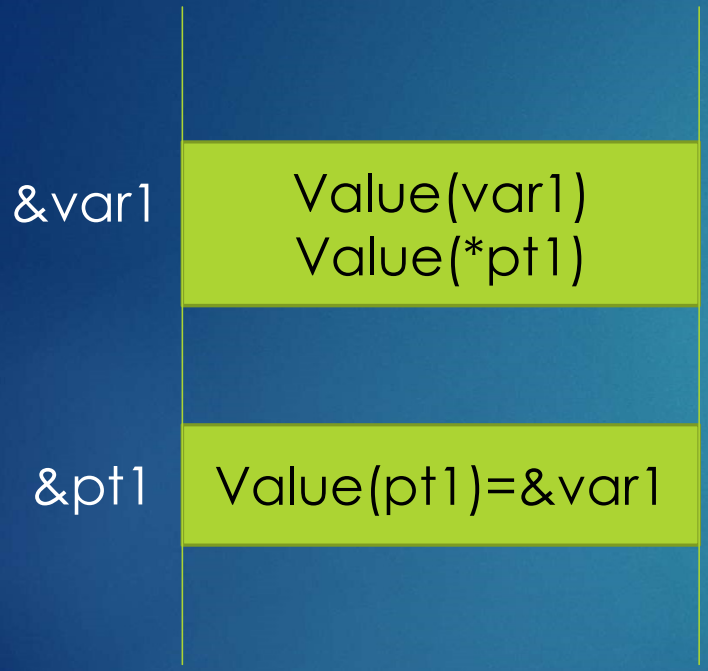
Union


```
// Union declaration
union oneElement {
   float floatVal;
   int intVal;
   char charVal[10];
};

union oneElement foo;
foo.floatVal=3.14;
```

Foo will able to take only one of the Three available element:
foo.floatVal OR
foo. intVal OR
foo.charVal

The size of foo will be equal to the longer field. In this case the size of foo will be 10 bytes.

Pointers 1




```
int var1;
int *pt1;   // declare pt1 as a pointer on ints

pt1=&var1;  // put the address of var1 in pt1
*pt1=12;    // put 12 in the memory pointed
            // by pt1. As pt1 "points" on var1
            // it is the same as var1=12;
printf("var1=%d\n",var1); // will give var1=12

var1=6;     // modify the content of var1
printf("*pt1=%d\n",*pt1); // will give *pt1=6
```

Pointers 2


```
int arrayInt[5]={1,2,3,4,5};
int *ptInt; // declare ptInt as a pointer on ints
char arrayChar[5]={"JPO"};
char *ptChar;

ptInt=&arrayInt[0];      // same as ptInt=&arrayInt
ptChar=&arrayChar[0];
printf("%d %c\n",*ptInt, *ptChar); // output : 1 J
ptInt=ptInt+1; ptChar=ptChar+1;
printf("%d %c\n",*ptInt, *ptChar); // output : 2 P
```

Operation on pointers depends on their types:

+1 on on int will be +4 bytes

+1 on a char will be +1 byte

It is possible to use operator [] (array) on pointers:

```
int arrayInt[5]={1,2,3,4,5};
int *ptInt; // declare ptInt as a pointer on ints
char arrayChar[5]={"JPO"};
char *ptChar;

ptInt=&arrayInt[0];      // same as ptInt=&arrayInt
ptChar=&arrayChar[0];
printf("%d %c\n",ptInt[0], ptChar[0]);  // output : 1 J
printf("%d %c\n",ptInt[1], ptChar[1]);  // output : 2 P
```

pt[n]
is equivalent to
*(pt+n)

Endianness

0x12345678

Big endian:

0x12	@n
0x34	@n+1
0x56	@n+2
0x78	@n+3

Little endian:

0x78	@n
0x56	@n+1
0x34	@n+2
0x12	@n+3

Cast on pointers


```
int var=0x12345678;
char *pt;

pt=(char *)&var;
printf("v1=%x v2=%x v3=%x v4=%x\n",pt[0], pt[1], pt[2], pt[3]);
```

=> Ouput???

Pointers (ex.)

Find the coding of <type> on your machine:
Long (is it little or big endian?)
float, double (where is the sign/mantissa/exponent?)

Is it possible to visualize the stack?
(hint: use recurse function)

Dynamic Allocation : malloc

#include <malloc.h>

void *malloc(int size);

Allocate *size* bytes in heap space and return a pointer to this reserved space.

Example:

```
int *pt;
pt=(int *)malloc(sizeof(int));
```

Always cast to the right type

Use sizeof to get the right size

Dynamic desallocation : free


```
#include <malloc.h>
void free(void *foo);
```

Desallocate (free) the space reserved in heap space pointed by *foo*.

Example:

```
int *pt;
pt=(int *)malloc(sizeof(int));
free(pt);
```

Dynamic Allocation (ex.)

Allocate an array of 32 characters.

Initialise it with the String "Run to the hills"

Display it with a printf

Free it

Pointers on structures 1


```
struct student {
char *name;
int *notes;
}

struct student *singleStudent;
struct student studentStatArray[100];

int main() {
    singleStudent=(struct student *)malloc(sizeof(struct student));
    singleStudent->name=(char *)malloc(100);
    singleStudent->notes=(int *)malloc(sizeof(int)*10);

    studentStatArray[0].name=(char *)malloc(100);
    studentStatArray[0].notes=(int *)malloc(sizeof(int)*10);
}
```

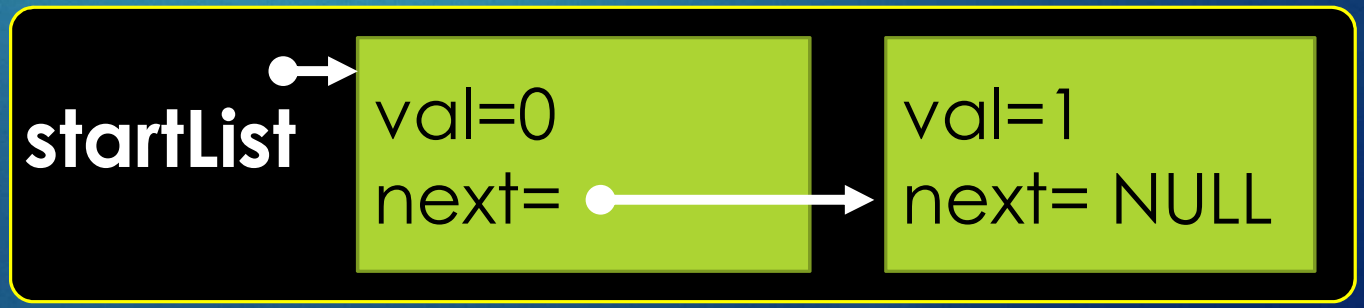
Pointers on structures 2

Pointer used as an array

```
struct student {
char *name;
int *notes;
}

struct student *studentDynArray;

int main() {
    studentDynArray=(struct student *)malloc(sizeof(structDynArray)*10);

    studentDynArray[0].name=(char *)malloc(100);
    studentDynArray[0].notes=(int *)malloc(sizeof(int)*10);
}
```

Chained lists

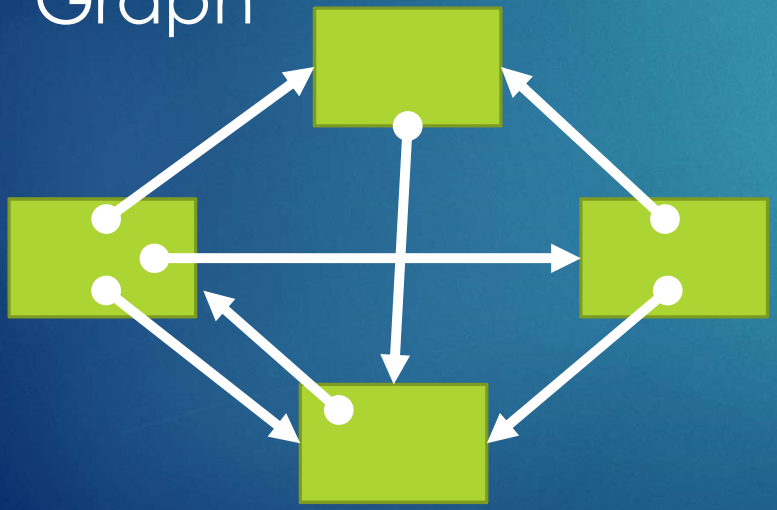

```
struct chainList {
    int val;
    struct chainList *next;
};
int main() {
    struct chainList *startList, *lastElm, *newElm;

    startList=(struct chainList *)malloc(sizeof(struct chainList));
    startList->val=0;
    lastElm=startList;
    newElm=(struct chainList *)malloc(sizeof(struct chainList));
    newElm->val=1;
    newElm->next=NULL;
    lastElm->next=newElm;
    lastElm=newElm;
}
```



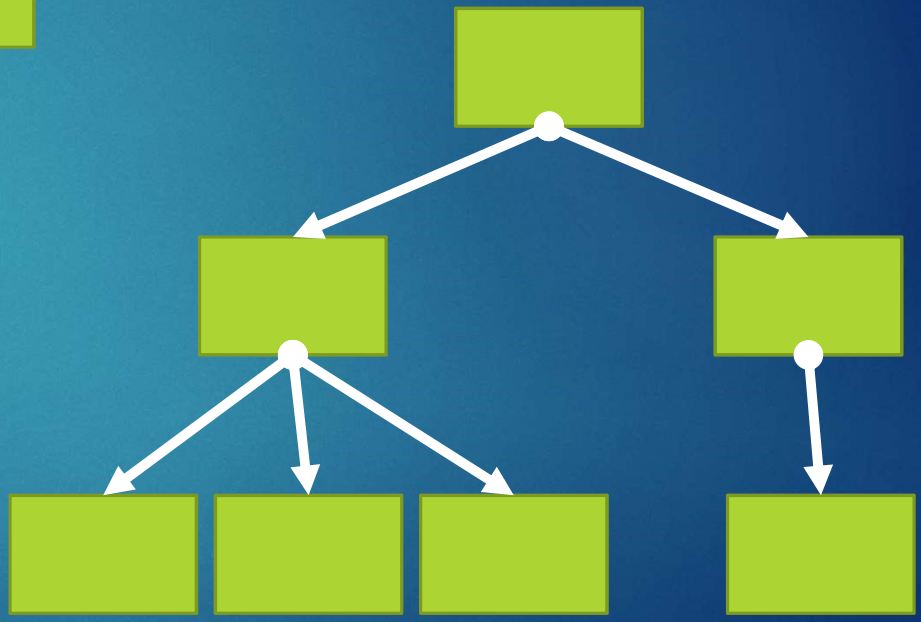
Different kinds of chained lists

2 ways Chained list

Graph



Tree

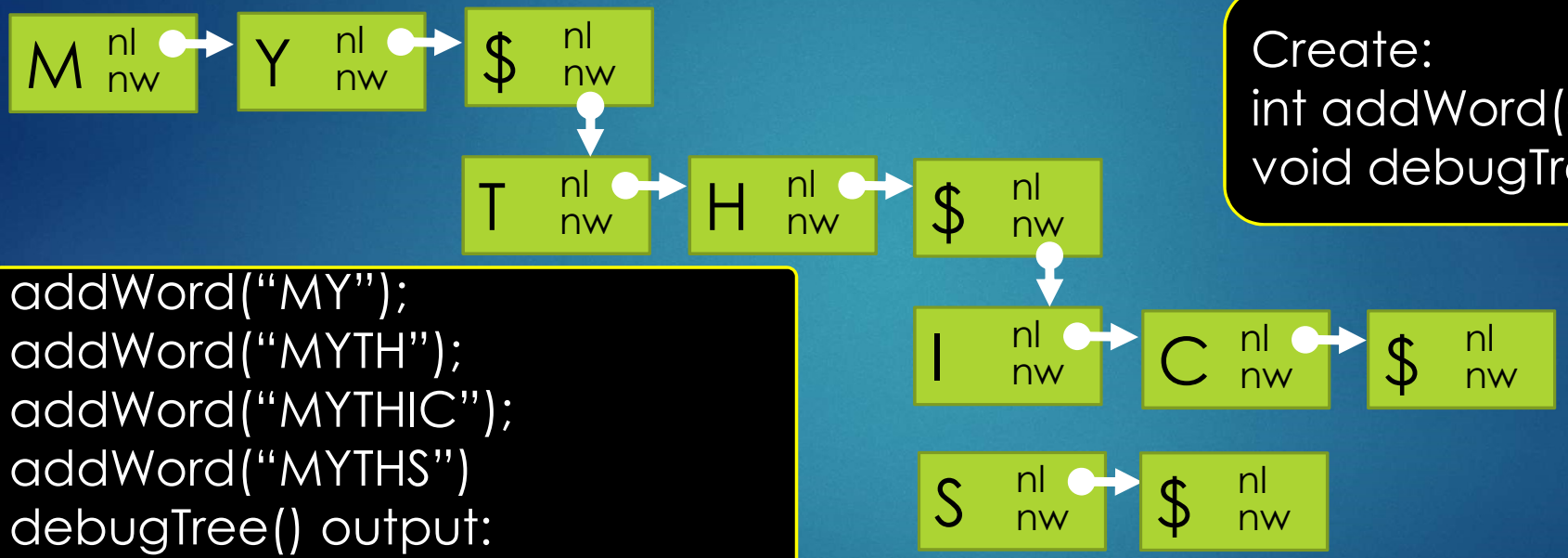


Chain list (ex.)

- Write a "2 ways chain list" : each element will store a number from 0 to 19. Read list from right to left and left to right.

Chain list (ex.)

- Write a completion dictionnary



Create:
int addWord(char *string)
void debugTree();

addWord("MY");
addWord("MYTH");
addWord("MYTHIC");
addWord("MYTHS")
debugTree() output:
MY
MYTH
MYTHIC
MYTHS

Order can be different

Pointers on functions


```
int originalFunc(int x, int y) {
    printf("x=%d, y=%d\n", x, y);
    return 0;
}
int main() {
    int (*ptFunc)(int x, int y)=NULL;
    ptFunc=originalFunc;
    ptFunc(2, 3);
    return 0;
}
```

Pointers on functions (ex.)

Object Oriented Approach

- Write a single chained list of heterogenous elements: rectangle(left, top, width, height), circle(radius), triangle(x1,y1,x2,y2,x3,y3).
- Each elements will have a function "display" which will write to the screens the parameters of the matching element.

Pointers on functions (ex.)

Object Oriented Approach : hints


```
struct object {
        struct object *next;
        void (*display)(struct object *object);
};
struct rectangle {
        struct object *next;
        void (*display)(struct rectangle *pt);
        int left, top, right, left;
}
struct circle {
        struct object *next;
        void (*display)(struct circle *pt);
        int radius
};
struct triangle {
        struct object *next;
        void (*display)(struct triangle *pt);
        int x1, y1, x2, y2, x3, y3;
}
```

```
struct circle *createCircle(int radius);
struct rectangle *createRectangle(int left, int top, int right, int
left);
struct triangle *createTriangle(int x1, int y1, int x2, int y2, int x3, int
y3);

void displayTriangle(struct triangle *pt);
void displayCircle(struct circle *pt);
void displayRectangle(struct rectangle *pt);

void addObject(struct object *pt);
void displayList();
```

Function parameters

By value :

```
void resetAB(int a, int b) {
    a=0; b=0;
}

int a=1,b=2;
resetAB(a,b);
Printf("a=%d b=%d\n",a,b);
```

=> Output : a=1 b=2

Function parameters

By reference (or address):

```
void resetAB(int *a, int *b) {
   *a=0; *b=0;
}

int a=1,b=2;
resetAB(&a, &b);
Printf("a=%d b=%d\n",a,b);
```

=> Output : a=0 b=0

File manipulation: open

open()

#include <fcntl.h>
*int open(char *filename, int access, int permission);*
The available access modes are
O_RDONLY O_WRONLY O_RDWR O_APPEND O_BINARY O_TEXT
The permissions are
S_IWRITE S_IREAD S_IWRITE | S_IREAD
The *open()* function returns an integer value, which is used to refer to the file. If un- successful, it returns -1, and sets the global variable *errno* to indicate the error type.

File manipulation: read

read()

#include <fcntl.h>

*int read(int handle, void *buffer, int nbyte);*

The *read()* function attempts to read nbytes from the file associated with handle, and places the characters read into *buffer*. If the file is opened using O_TEXT, it removes carriage returns and detects the end of the file.

The function returns the number of bytes read. On end-of-file, 0 is returned, on error it returns -1, setting errno to indicate the type of error that occurred.

File manipulation: write

write()

#include <fcntl.h>
*int write(int handle, void *buffer, int nbyte);*

The *write()* function attempts to write nbytes from *buffer* to the file associated with handle. On text files, it expands each LF to a CR/LF.

The function returns the number of bytes written to the file. A return value of -1 indicates an error, with errno set appropriately.

File manipulation: close

close()

#include <fcntl.h>
int close(int handle);

The *close()* function closes the file associated with handle. The function returns 0 if successful, -1 to indicate an error, with errno set appropriately.

ACP File manipulation & pointers (ex.)

- Open the file student.txt
- Create an array of all student elements.
- Sort students by alphabetical order
- Write a file student_order.txt with all students sorted by alphabetical order.

Qsort algorithm

Bias=3

3	1	4	1	5	9	2	6	5	3

3	1	3	1	2	9	5	6	5	4

Bias=3 Bias=6

3	1	3	1	2	9	5	6	5	4

Bias=2

2	1	1	3	3	4	5	5	6	9

1	1	2	3	3	4	5	5	6	9

Choose a bias (a random value between array min and max). Here 3

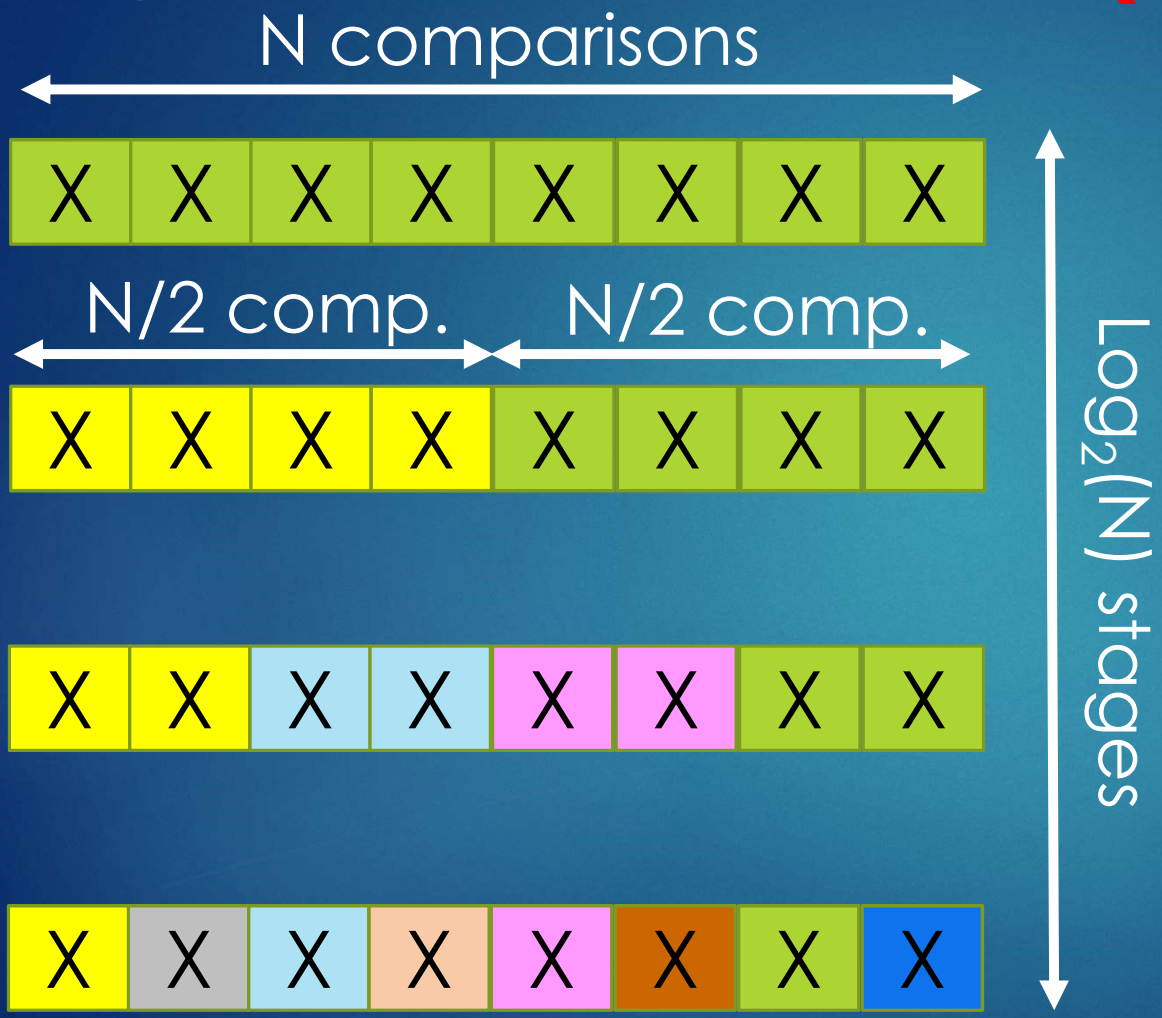
Sort in two arrays: less to bias (left) and greater or equal to bias (right)

Restart the same operation on the two subarrays.

Etc…

Advantage :
No insertion
Only swap

Qsort algorithm



Advantages of Qsort:

Complexity:
$O(N \times \log_2(N))$

Use only swap (no insertion): array can be used (faster than chained list)

Can be parallelized

Qsort (ex.)

- Generate an array of 1000000 random ints
- Sort the array by using YOUR qsort algorithm (not the one included in C)
- Write a function which verifies the array is correctly sorted

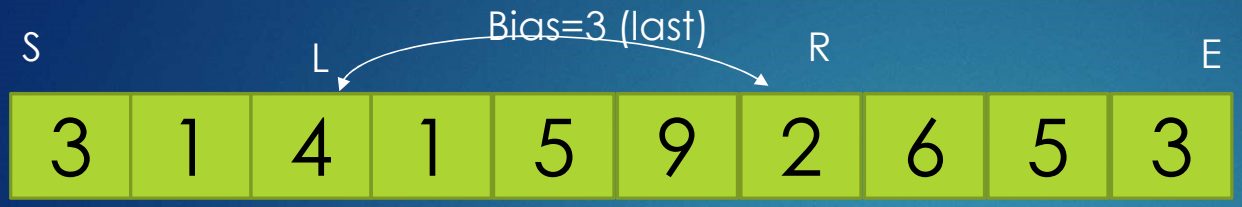
Qsort (ex.)


```
void swap(int array[], int a, int b) {
        int temp = array[a];
        array[a] = array[b];
        array[b] = temp;
}

void quickSort(int array[], int start, int end) {
        int left = start-1;
        int right = end+1;
        const int bias = array[start];
        /* if array length is null, nothing to do */
        if(start >= end) return;
        /* else, we read the array, one time from right
        to left and one time from left to right to search
        for element which are on the wrong place.
        Once found, we swap them. When right index
        reaches left index we stop.*/
        while(1) {
                do right--; while(array[right] > bias);
                do left++; while(array[left] < bias);
                if(left < right) swap(array, left, right);
                else break;
        }
        /* Now, all elements lesser than bias are on the
        left side and all elements greater than bias are
        on the right side. Thus, we have 2 groups to
        sort. We launch quicksort on these 2 groups!
        That's what we call recursivity ! */
        quickSort(array, start, right);
        quickSort(array, right+1, end);
}
```

Qsort (ex.)

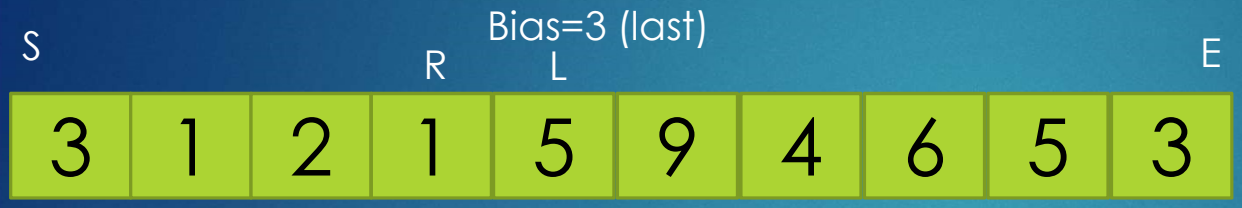

```
void echanger(int tableau[], int a, int b)
{
int temp = tableau[a];
tableau[a] = tableau[b];
tableau[b] = temp;
}
void quickSort(int tableau[], int debut, int fin)
{
int gauche = debut-1;
int droite = fin+1;
const int pivot = tableau[debut];
/* Si le tableau est de longueur nulle, il n'y a rien à
faire. */
if(debut >= fin)
return;
/* Sinon, on parcourt le tableau, une fois de droite à
gauche, et une
autre de gauche à droite, à la recherche d'éléments
mal placés,
que l'on permute. Si les deux parcours se croisent,
on arrête. */
while(1)
{
do droite--; while(tableau[droite] > pivot);
do gauche++; while(tableau[gauche] < pivot);
if(gauche < droite)
echanger(tableau, gauche, droite);
else break;
}
/* Maintenant, tous les éléments inférieurs au pivot
sont avant ceux
supérieurs au pivot. On a donc deux groupes de
cases à trier. On utilise
pour cela... la méthode quickSort elle-même ! */
quickSort(tableau, debut, droite);
quickSort(tableau, droite+1, fin);
}
```

Qsort algorithm

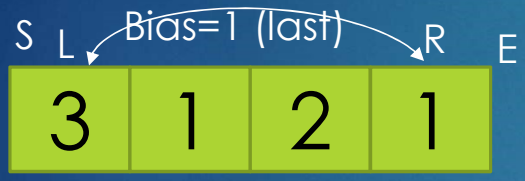


S=start E=end
L=Left R=Right

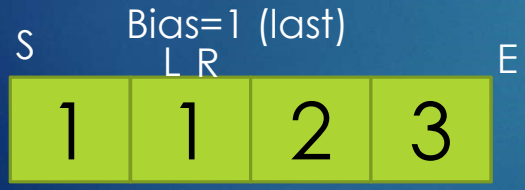
R>L
*R<bias *L>bias
Xchange(*L, *R)



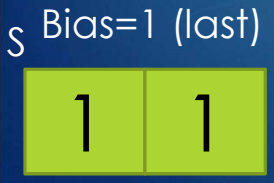
R<L
Qsort(S,R); Qsort(R+1,E)



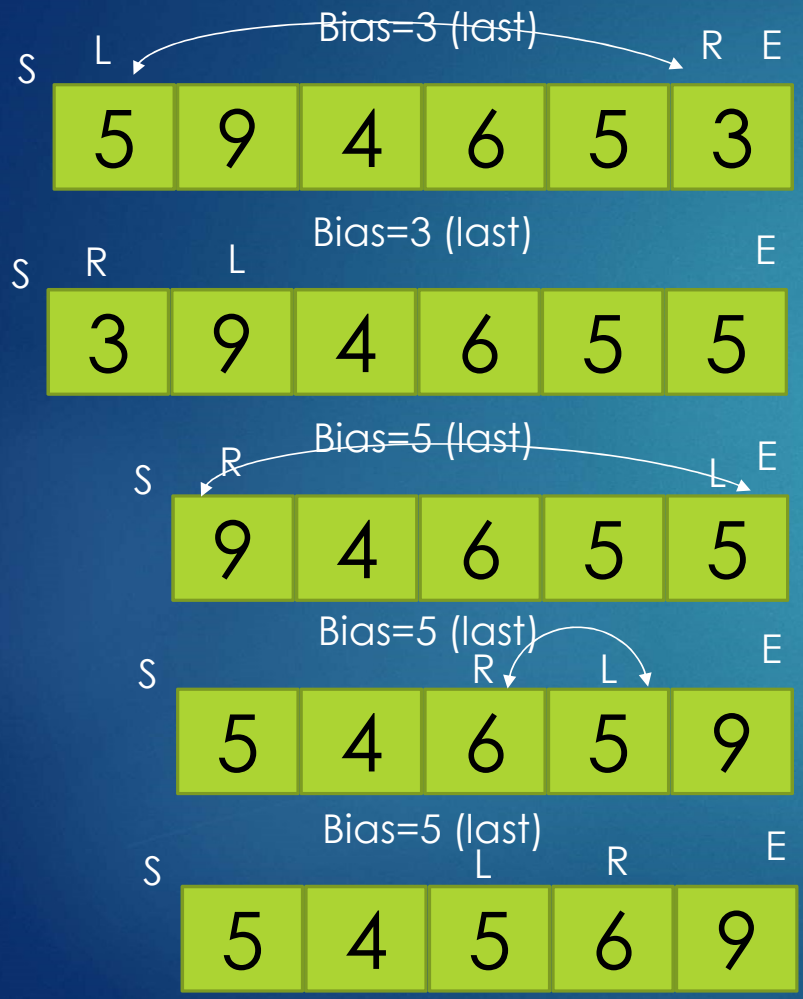
R>L
*R<bias *L>bias
Xchange(*L, *R)



R==L
Qsort(S,R); Qsort(R+1,E)



Qsort algorithm



S=start E=end
L=Left R=Right

R>L
*R<bias *L>bias
Xchange(*L, *R)

R<L
Qsort(S,R); Qsort(R+1,E)

R>L
*R<bias *L>bias
Xchange(*L, *R)

R>L
*R<bias *L>bias
Xchange(*L, *R)

R<L
Qsort(S,R); Qsort(R+1,E)

Qsort (ex.)

Hint: to generate random numbers:

PseudoRandom:

```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
int main(void){
  int i = 0;
  int random_number = 0;
  for(i=0; i<5; i++)  {
    random_number = rand();
    printf("%d ",random_number);
  }
  return 0;
}
```

Random:

```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
int main(void) {
  int i = 0;
  int random_number = 0;
  srand(time(NULL));
  for(i=0; i<5; i++){
    random_number = rand();
    printf("%d ",random_number);
  }
  return 0;
}
```

Type modifier

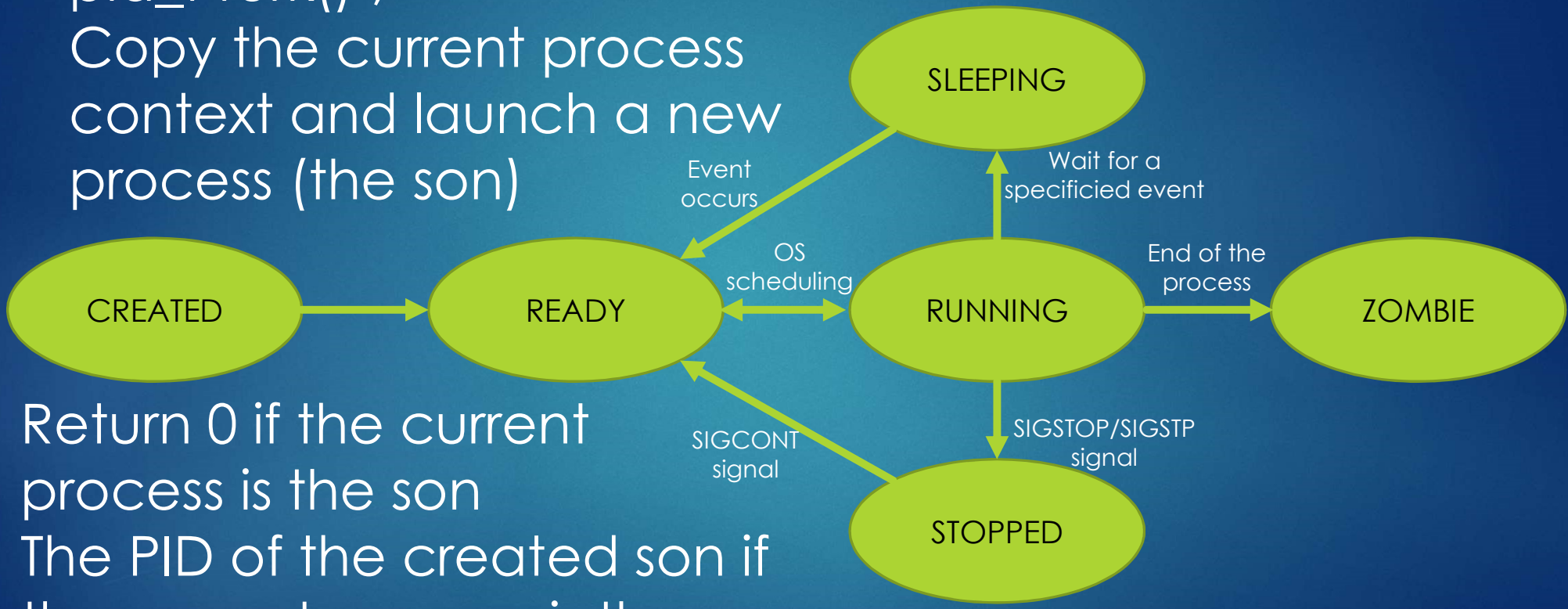
register May be applied to local variables.
It specify to the compiler to use the variable in a processor register .

static May be applied to local variables.
It specify to the compiler to store the variable in heap instead stack.

volatile May be applied to all variables.
It specify to the compiler to avoid code optimization on the variable. The variable may change without code instruction (hardware, thread, etc…)

Process
(fork)

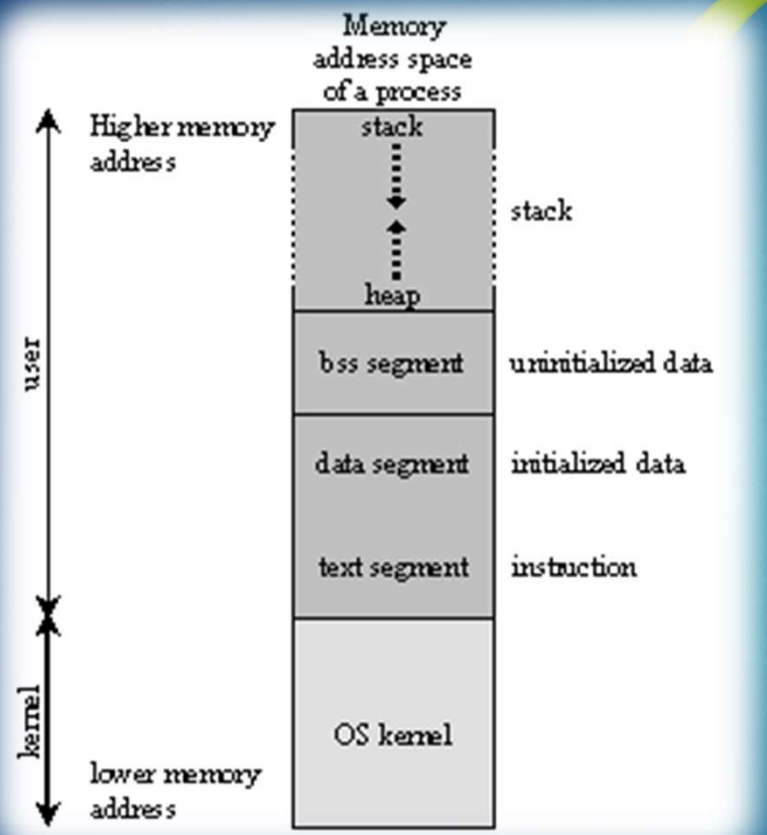
#include <unistd.h>
pid_t fork() ;
Copy the current process context and launch a new process (the son)



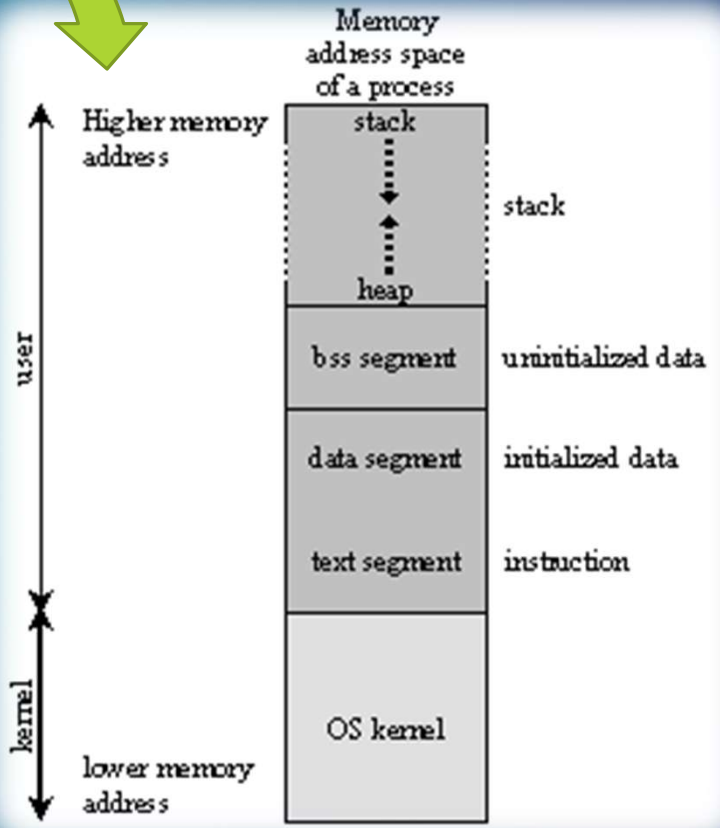
Return 0 if the current process is the son
The PID of the created son if the current process is the parent

Process

Fork
Memory copy



Parent (father)



Child (son)

Getpid : get the current process ID
Getppid : get the parent (father) process ID

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
int main (void) {
    pid_t pid ;
    printf(« Before the fork ;I'm the process %d my
    father is %d\n\n",getpid(), getppid()) ;
    pid = fork() ;
    printf("fork result %d\n",pid) ;
    printf("After the fork ; I'm the process %d my
    father is %d\n\n",getpid(), getppid()) ;
    return 0 ;
}
```

Output:
Before the fork; I'm the process 11383 my father is 1258
Fork result 11384
After the fork; I'm the process 11383 my father is 1258
Fork result 0
After the fork; I'm the process 11384 my father is 1

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
#include <stdlib.h>
#include <string.h>
int main(void){
int     fd[2], nbytes, windex;
pid_t   childpid;
char    string[] = "Luke I'm your father!\n";
char    string2[] = "Damned\n";
char    readbuffer[80];
pipe(fd);
if((childpid = fork()) == -1) {
      perror("fork"); exit(1);
}
if(childpid == 0) {
      // lUke is born
      // wait for full string
      windex=-1;
      do {
            windex++;
            // read is blocking it will be released when the
character will be received
            nbytes = read(fd[0], &readbuffer[windex], 1);      }
            while(readbuffer[windex]!=0);
            printf("Son Received string: %s\n", readbuffer);
            write(fd[1], string2, (strlen(string2)+1));
      } else {
            /* Send "string" through the output side of pipe */
            write(fd[1], string, (strlen(string)+1));
            sleep(1);      // avoid reading before son
            // wait for full string
            windex=-1;
            do {
                  windex++; // read is blocking it will be released
when the character will be received
                  nbytes = read(fd[0], &readbuffer[windex], 1);
            } while(readbuffer[windex]!=0);
            printf("Father: Received string: %s\n", readbuffer);
      }
}
```

Pthreads

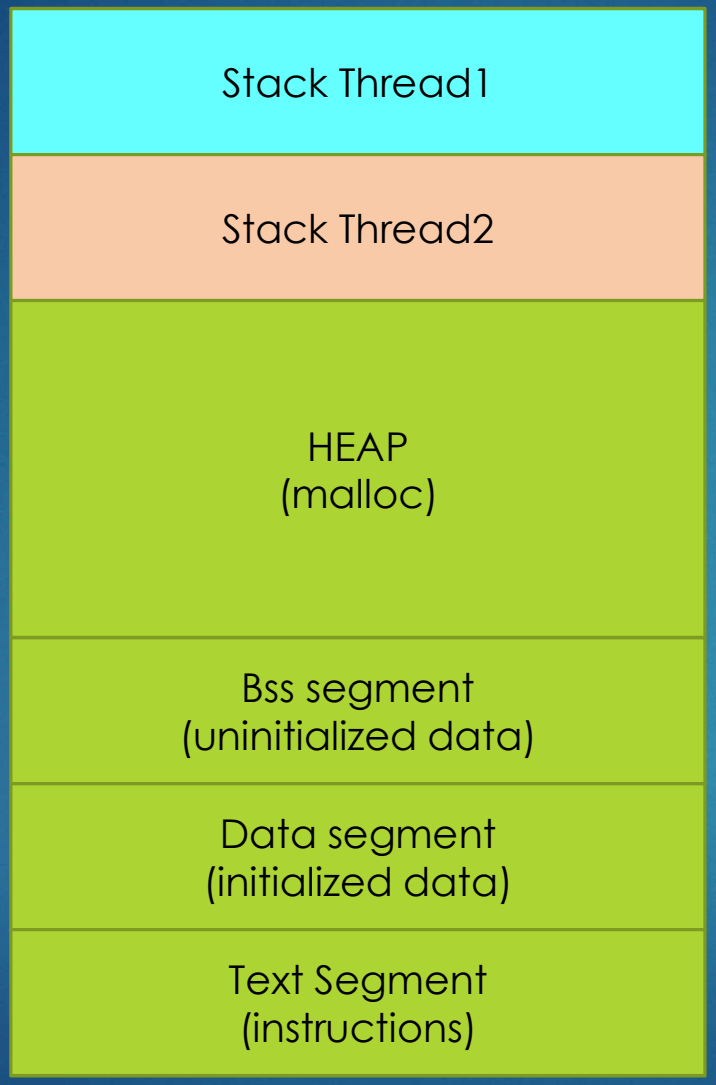
A thread is a process (stream of instruction)

A program can create several threads

Threads share the same memory heap

Thread are scheduled by the OS (preemptive threads)

Very light compared to processes


Stack Thread1
Stack Thread2
HEAP
(malloc)
Bss segment
(uninitialized data)
Data segment
(initialized data)
Text Segment
(instructions)

Pthread

#include <pthread.h>

int pthread_create (pthread_t *thread, pthread_attr_t *attr, void *(*start_routine) (void *), void *arg);

```
pthread_t pthread1;

Int main() {
      int ret, i=2;
      ret=pthread_create(&pthread1, NULL, pthread1Func, (void *)i);
      if(ret!=0) {
            printf (stderr, "%s", strerror (ret));
      }
}

Void *pthread1Func(void *par) {
      int i=(int)par;
      …
      return NULL;
}
```

#include <pthread.h>

int pthread_join (pthread_t th, void **thread_return);

```
pthread_t pthread1;

Int main() {
      int ret;
      ret=pthread_create(&pthread1, NULL, pthread1Func, NULL);
      if(ret!=0) {
            printf (stderr, "%s", strerror (ret));
      }
      pthread_join(pthread1, NULL);
}

Void *pthread1Func(void *) {
      …
      return NULL;
}
```

The calling thread sleeps until the end of the specified thread.
Returns :
0 if OK
ESRCH if no thread match with the specified thread
EINVAL if another thread is alredy waiting for the end of **th**
EDEADLK if **th** is the current thread

Pthread (ex.)

- Write a program which creates ten threads (stored in a pthread array or a chain list).
- Each thread will loop n times. “n” is an integer which will be given as a parameter to the created pthread (using the parameter of pthread_create).
- The main program will wait the end of all threads in order to finish.
- You will use printf in order to display when the threads start and when the threads end.

Pthread (ex.)

- Write a program which creates ten threads (stored in a pthread array or a chain list).
- Each thread will increment 1000000 times a shared global variable.
- The main program will wait the end of all threads in order to finish and will print the shared global variable.
- Did you expect this result?

int pthread_mutex_lock (pthread_mutex_t * mutex);

Lock a mutex (mutual exclusion)
If the mutex is free (=0): the current thread takes the mutex (=1).
If the current thread is already the owner of the mutext is incremented (+1).
If the mutex is already used by another thread, the current thread is set in a sleeping state. It takes no more CPU (passive wait). The thread will be awaken when the mutex will be freed.
return 0 if OK

int pthread_mutex_unlock (pthread_mutex_t * mutex);

Unlock a mutex
Decrement the mutext counter (-1).
If the counter is equal 0 the mutex is freed and the next thread waiting (sleeping) for this mutex is awaken.
The algorithm may be system (OS) dependent.

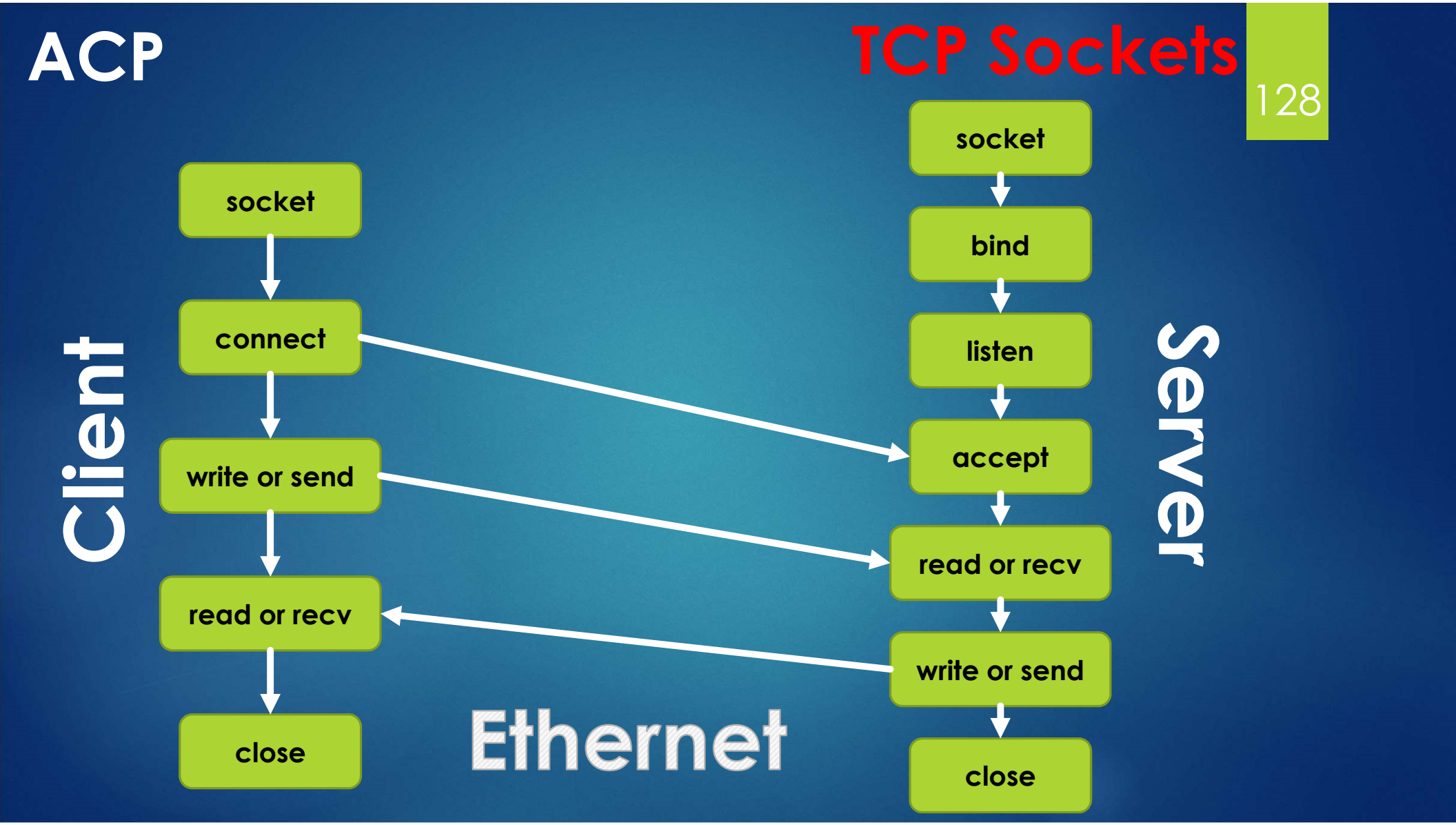
return 0 if OK

```
pthread_mutex_t
pmutext_var1=PTHREAD_MUTEX_INITIA
LIZER;
Int var1

void thread1Func(void *) {
    while(1){
    pthead_mutex_lock(&pmutex_var1
);
    var1++;
    pthead_mutex_unlock(&pmutex_v
ar1);
    }
}
```

```
void thread2Func(void *) {
    while(1){
    pthead_mutex_lock(&pmutex_var1
);
    var1++;
    pthead_mutex_unlock(&pmutex_v
ar1);
    }
}
```

Sockets

TCP Sockets


Client
socket
connect
write or send
read or recv
close
Ethernet
Server
socket
bind
listen
accept
read or recv
write or send
close

TCP Client


```c
/*
    C ECHO client example using sockets
*/
#include<stdio.h> //printf
#include<string.h>    //strlen
#include<sys/socket.h>    //socket
#include<arpa/inet.h> //inet_addr

 int main(int argc , char *argv[]) {
    int sock;
    struct sockaddr_in server;
    char message[1000] , server_reply[2000];

    //Create socket
    sock = socket(AF_INET , SOCK_STREAM , 0);
    if (sock == -1) {  printf("Could not create socket"); }
    puts("Socket created");

    // Define the socket remote address : 127.0.0.1:8888
    server.sin_addr.s_addr = inet_addr("127.0.0.1");
    server.sin_family = AF_INET;
    server.sin_port = htons( 8888 );

     //Connect to remote server
    if (connect(sock , (struct sockaddr *)&server , sizeof(server)) < 0) {
        perror("connect failed. Error");
        return 1;
    }
    puts("Connected\n");
```

```c
  //keep communicating with server
    while(1)    {
        printf("Enter message : ");
        scanf("%s" , message);

        //Send some data
        if( write(sock , message , strlen(message) , 0) < 0)  {
            puts("write failed");
            return 1;
        }

        //Receive a reply from the server
        if( read(sock , server_reply , 2000 ) < 0)  {
            puts("read failed");
            break;
        }

        puts("Server reply :");
        puts(server_reply);
    }

    close(sock);
    return 0;
}
```

TCP Client

Sock=socket(AF_INET, SOCK_STREAM, 0);
Arg1 :
AF_INET : Ethernet Socket
AF_UNIX : Unix Socket
Arg2:
SOCK_STREAM : TCP Socket (safe/slow)
SOCK_DGRAM : UDP Socket (unsafe/fast)

server.sin_addr.s_addr = inet_addr("127.0.0.1");
"127.0.0.1" : local address (loopback (lo))
"www.google.com"

server.sin_port = htons(8888);
8888 : port number. 2 bytes : 0 – 16535
80 : html port

write(sock , message , strlen(message))
sock : socket used to write data
message: buffer containing data to send
strlen(message) : number of bytes to send

read(sock , server_reply , 10)
sock : socket used to read data
server_reply: buffer used to put data coming from socket
10 : number of bytes to read from the socket

Read will block until all bytes have been read

TCP Server


```c
/*    C socket server example */
 #include<stdio.h>
#include<string.h>    //strlen
#include<sys/socket.h>
#include<arpa/inet.h> //inet_addr
#include<unistd.h>    //write

int main(int argc , char *argv[]) {
    int socket_desc , client_sock , c , read_size;
    struct sockaddr_in server , client;
    char client_message[2000];

    //Create socket
    socket_desc = socket(AF_INET , SOCK_STREAM , 0);
    if (socket_desc == -1) {
        printf("Could not create socket");
    }
    puts("Socket created");

    //Prepare the sockaddr_in structure
    server.sin_family = AF_INET;
    server.sin_addr.s_addr = INADDR_ANY;
    server.sin_port = htons( 8888 );

    //Bind
    if( bind(socket_desc,(struct sockaddr *)&server , sizeof(server)) < 0) {
        //print the error message
        perror("bind failed. Error");
        return 1;
    }
    puts("bind done");
```

```c
    //Listen
    listen(socket_desc , 3);

    //Accept and incoming connection
    puts("Waiting for incoming connections...");
    c = sizeof(struct sockaddr_in);

    //accept connection from an incoming client
    client_sock = accept(socket_desc, (struct sockaddr *)&client,
(socklen_t*)&c);
    if (client_sock < 0) {
        perror("accept failed");
        return 1;
    }
    puts("Connection accepted");

    //Receive a message from client
    while( (read_size = read(client_sock , client_message , 2000)) > 0 ) {
        //Send the message back to client
        write(client_sock , client_message , strlen(client_message));
    }

    if(read_size == 0) {
        puts("Client disconnected");
        fflush(stdout);
    } else if(read_size == -1) {
        perror("recv failed");
    }
    return 0;
}
```

TCP Server

server.sin_family = AF_INET;
server.sin_addr.s_addr = INADDR_ANY;
server.sin_port = htons(8888);
bind(socket_desc,(struct sockaddr *)&server , sizeof(server))
⇒ Set the socket parameter and affect them to the socket descriptor

listen(socket_desc , 3);
⇒ Wait for incoming sockets (clients). 3 sockets can be opened simultaneously

Listen will block until a client incoming connection occurs

client_sock = accept(socket_desc, (struct sockaddr *)&client, (socklen_t*)&c);
⇒ Accept the incoming connection and affect it to the new descriptor « client_sock ». « client_sock » will be used to communicate with the new client. « server » can be used to wait another incoming connection.