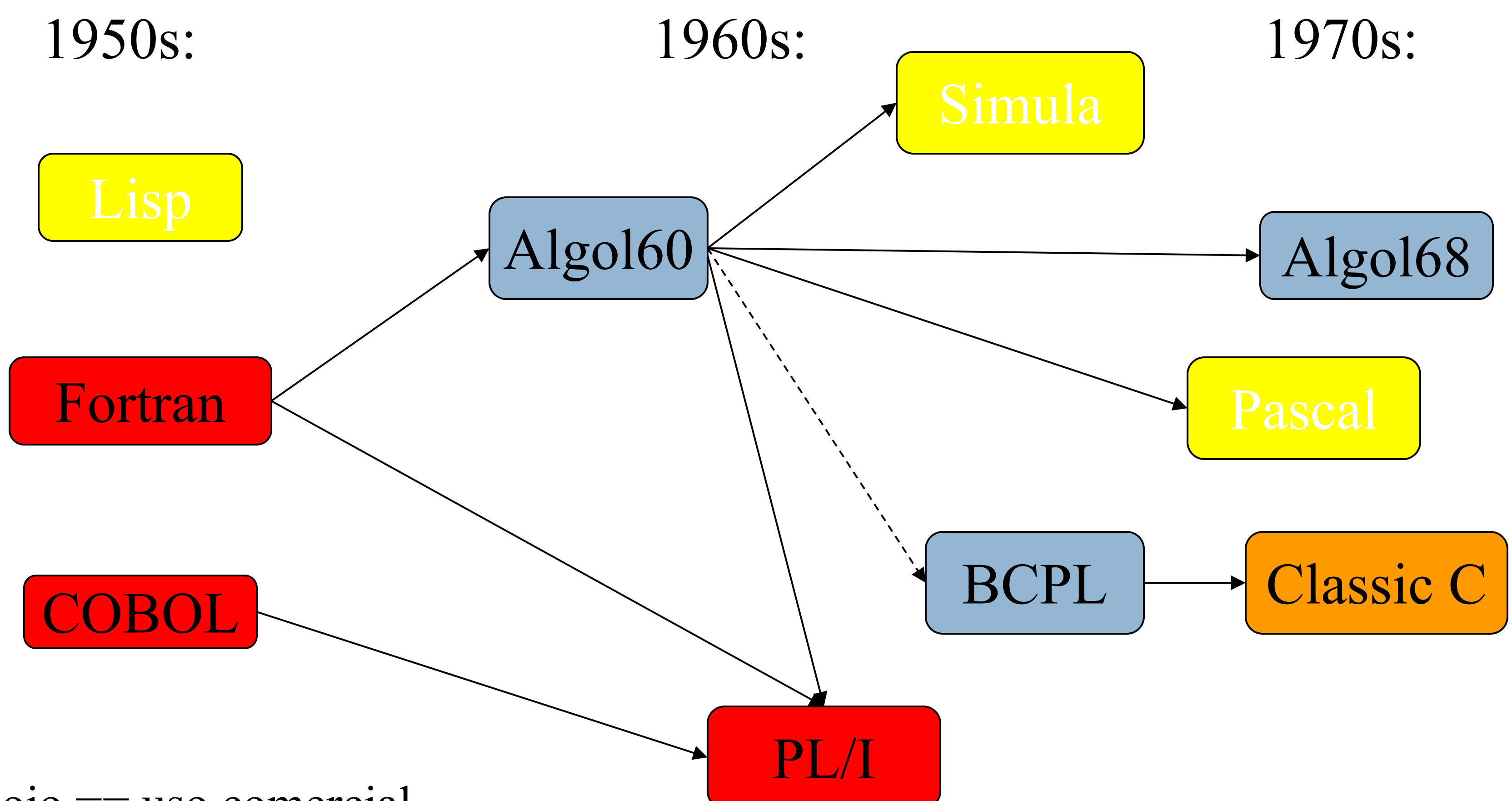
BACHELOR'S DEGREE IN COMPUTER SCIENCE AND ENGINEERING

OPERATING SYSTEMS

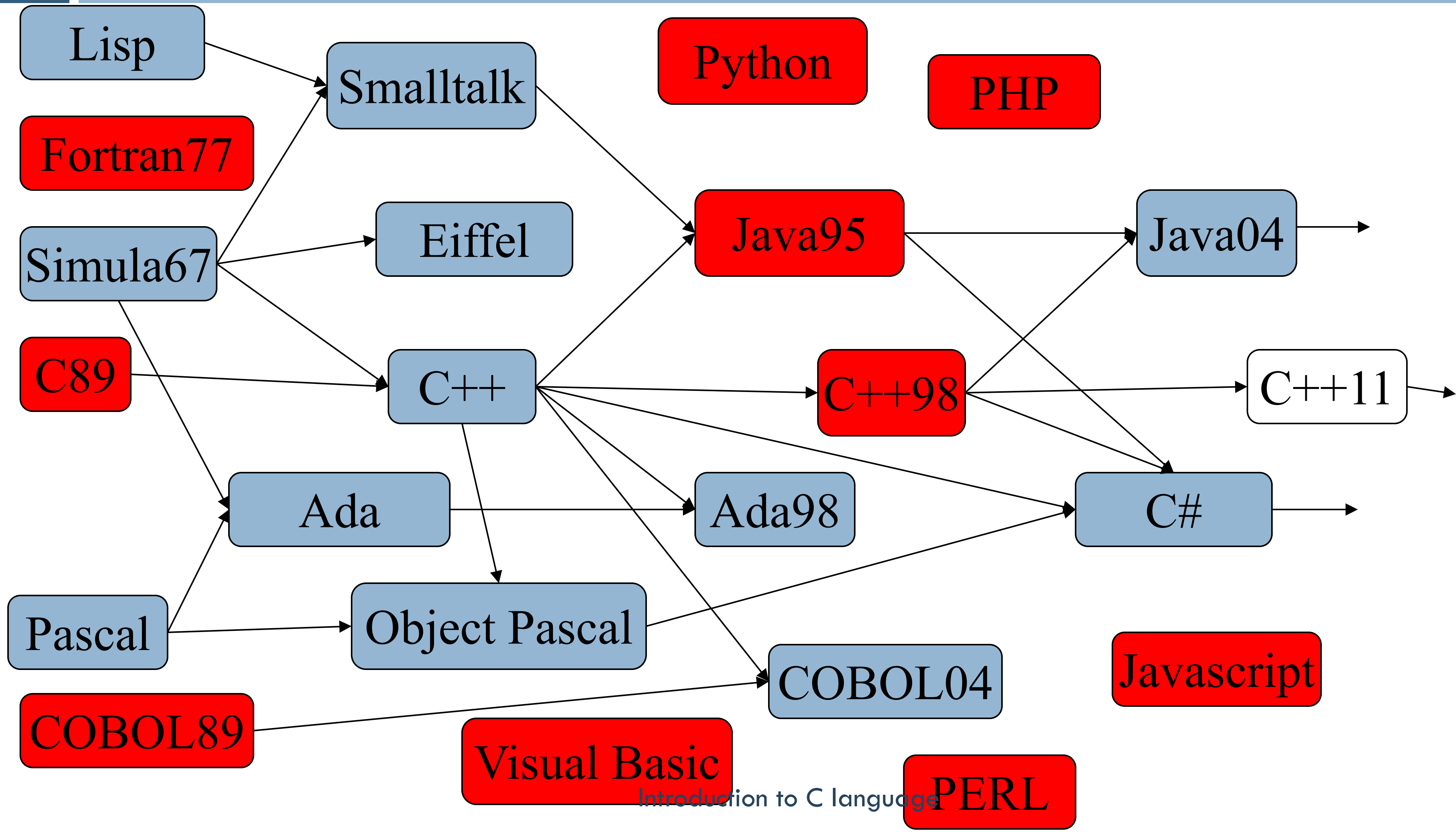
Introduction to C language

Pioneer programming languages



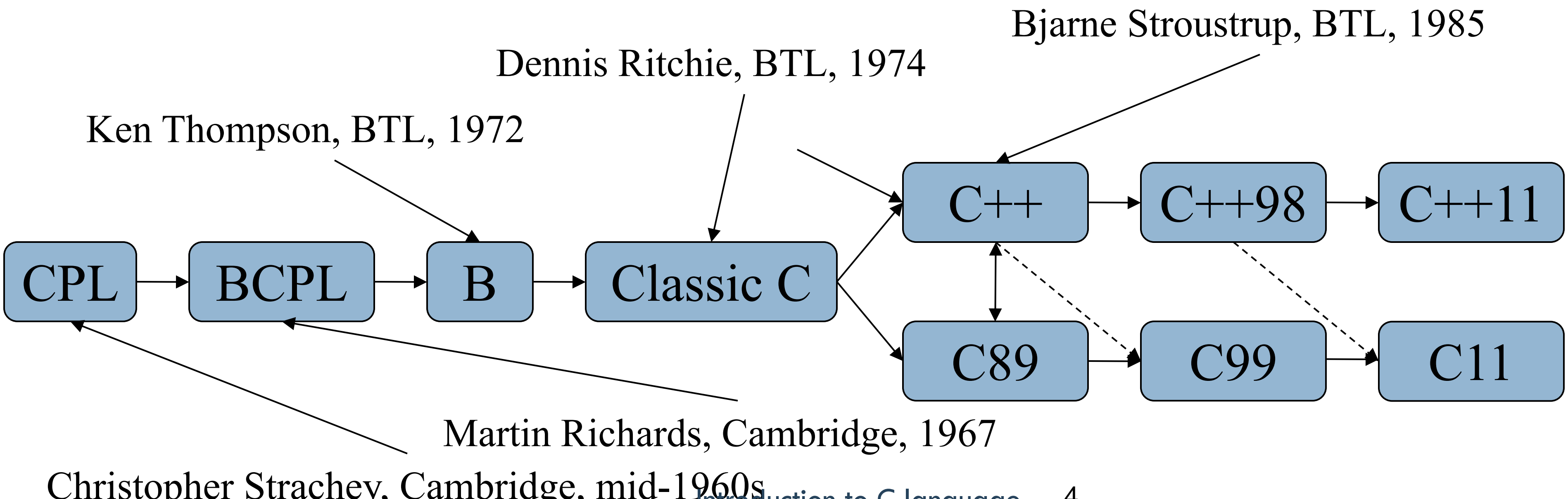
Rojo == uso comercial
Amarillo == producirán una descendencia significativa

Modern programming languages



C – 1978

- High level programming language
  - Related to Unix/Linux and opensource
  - Low-level lenguage
  - Performance is now portable
  - Designed and implemented by Dennis Ritchie 1974-78



C book

Kernighan, Ritchie

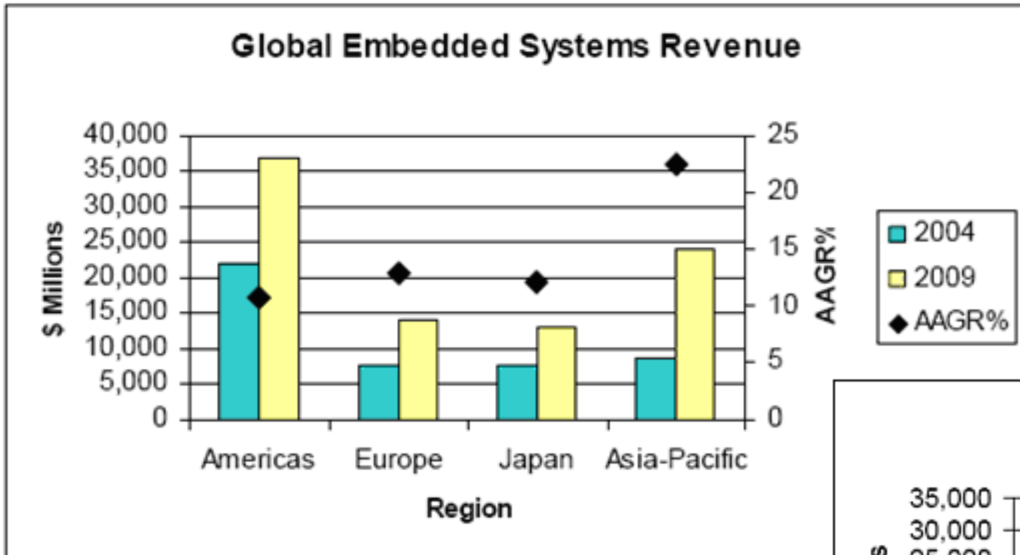
The C Programming Language (2^{nd} ed.)

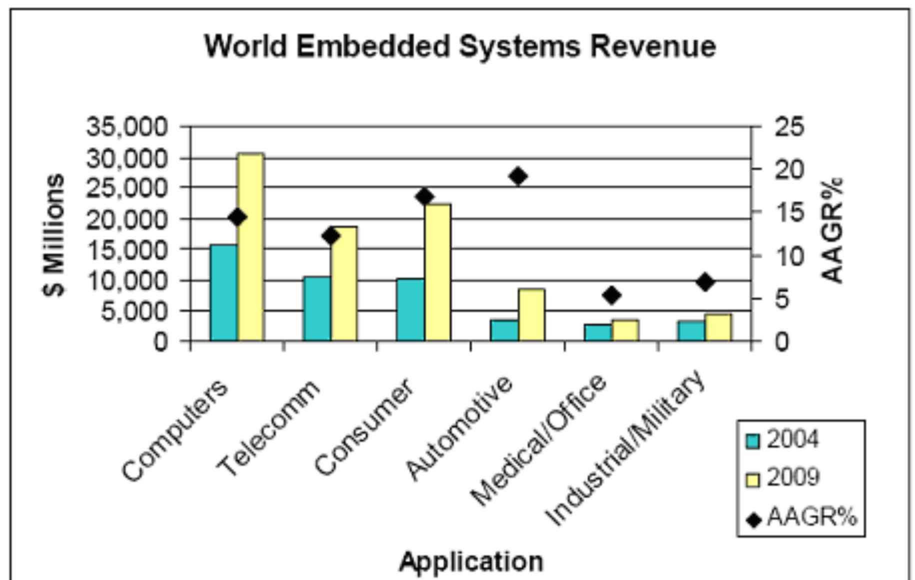
Prentice Hall, March 1988.

ISBN 0-13-110362-8.

Motivation

- *The Programming Languages Beacon*





Application software expert

Study of Worldwide Trends and R&D Programm*es* in Embedded Systems in View of Maximising the Impact of a Technology Platform in the Area
Final Report 18.11.2005

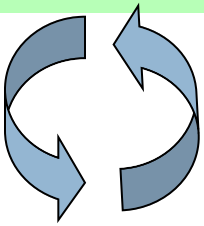
What programming languages/environments are currently used in your organisation for the development of Embedded Systems?	
AWL / IL	6%
C	97%
C++	83%
Java	66%
Assembler	33%

Content

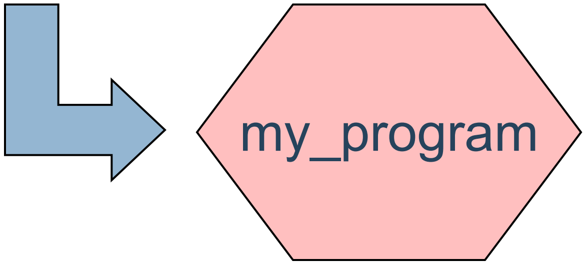
- Writing, compiling, running C programs
- Syntax
- Functions
- Memory
- Variables
- Lexical scoping
- Expressions
- Pointers
- Structures
- Arrays
- Dynamic memory
- Common errors
- Macros

Writing and Running C Programs


```
#include <stdio.h>
/* The simplest C Program */
int main(int argc, char **argv)
{
  printf("Hello World\n");
  return 0;
}
```



```
$ gcc -Wall -g my_program.c -o my_program
tt.c: In function `main':
tt.c:6: parse error before `x'
tt.c:5: parm types given both in parmlist and separately
tt.c:8: `x' undeclared (first use in this function)
tt.c:8: (Each undeclared identifier is reported only once
tt.c:8: for each function it appears in.)
tt.c:10: warning: control reaches end of non-void function
tt.c: At top level:
tt.c:11: parse error before `return'
```



1. Write text of program (source code) using an editor such as emacs, save as file e.g. my_program.c

2. Run the compiler to convert program from source to an "executable" or "binary":

    $ gcc –Wall –g my_program.c –o my_program

-Wall –g ?

3-N. Compiler gives errors and warnings; edit source file, fix it, and re-compile

N. Run it and see if it works ☺

    $ ./my_program
    Hello World
    $ ▌

. / ?

What if it doesn't work?

C Syntax and Hello World

What does the < > mean?

#include inserts another file. “.h” files are called “header” files. They contain stuff needed to interface to libraries and code in other “.c” files.

Can your program have more than one .c file?

This is a comment. The compiler ignores this.

```
#include <stdio.h>
/* The simplest C Program */
int main(int argc, char **argv)
{
  printf(“Hello World\n”);
  return 0;
}
```

The main() function is always where your program starts running.

Blocks of code (“lexical scopes”) are marked by { … }

Print out a message. ‘\n’ means “new line”.

Return ‘0’ from this function

A Quick Digression About the Compiler


```
#include <stdio.h>
/* The simplest C Program */
int main(int argc, char **argv)
{
  printf("Hello World\n");
  return 0;
}
```

Preprocess

```
__extension__ typedef  unsigned long long int   __dev_t;
__extension__ typedef  unsigned int   __uid_t;
__extension__ typedef  unsigned int   __gid_t;
__extension__ typedef  unsigned long int   __ino_t;
__extension__ typedef  unsigned long long int   __ino64_t;
__extension__ typedef  unsigned int   __nlink_t;
__extension__ typedef  long int   __off_t;
__extension__ typedef  long long int   __off64_t;
extern void flockfile (FILE *__stream)  ;
extern int ftrylockfile (FILE *__stream)  ;
extern void funlockfile (FILE *__stream)  ;
int main(int argc, char **argv)
{
  printf("Hello World\n");
  return 0;
}
```

Compile

my_program

Compilation occurs in two steps: "Preprocessing" and "Compiling"

Why ?

In Preprocessing, source code is "expanded" into a larger form that is simpler for the compiler to understand. Any line that starts with '#' is a line that is interpreted by the Preprocessor.

- Include files are "pasted in" (#include)
- Macros are "expanded" (#define)
- Comments are stripped out (/* */ , //)
- Continued lines are joined (\ )

\ ?

The compiler then converts the resulting text into binary code the CPU can run directly.

OK, We're Back.. What is a Function?

A Function is a series of instructions to run. You pass Arguments to a function and it returns a Value.

"main()" is a Function. It's only special because it always gets called first when you run your program.

Return type, or void

Function Arguments

```
#include <stdio.h>
/* The simplest C Program */
int main(int argc, char **argv)
{
  printf("Hello World\n");
  return 0;
}
```

Calling a Function: "printf()" is just another function, like main(). It's defined for you in a "library", a collection of functions you can call from your program.

Returning a value

What is “Memory”?

Memory is like a big table of numbered slots where bytes can be stored.

The number of a slot is its Address.
One byte Value can be stored in each slot.

Some “logical” data values span more than one slot, like the character string “Hello\n”

A Type names a logical meaning to a span of memory. Some simple types are:

`char`	a single character (1 slot)
`char [10]`	an array of 10 characters
`int`	signed 4 byte integer
`float`	4 byte floating point
`int64_t`	signed 8 byte integer

not always…

Signed?…

Addr	Value
0	
1	
2	
3	
4	‘H’ (72)
5	‘e’ (101)
6	‘l’ (108)
7	‘l’ (108)
8	‘o’ (111)
9	‘\n’ (10)
10	‘\0’ (0)
11	
12	

72?

What is a Variable?

A Variable names a place in memory where you store a Value of a certain Type.

You first Define a variable by giving it a name and specifying the type, and optionally an initial value

declare vs define?

```
char x;
char y='e';
```

Initial value of x is undefined

Initial value

Name

What names are legal?

Type is single character (char)

extern? static? const?

symbol table?

Symbol	Addr	Value
	0	
	1	
	2	
	3	
x	4	?
y	5	'e' (101)
	6	
	7	
	8	
	9	
	10	
	11	
	12	

The compiler puts them somewhere in memory.

Multi-byte Variables

Different types consume different amounts of memory. Most architectures store data on "word boundaries", or even multiples of the size of a primitive data type (int, char)

```
char x;
char y='e';
int z = 0x01020304;
```

0x means the constant is written in hex

padding

An int consumes 4 bytes

Symbol	Addr	Value
	0	
	1	
	2	
	3	
x	4	?
y	5	'e' (101)
	6	
	7	
z	8	4
	9	3
	10	2
	11	1
	12	

Lexical Scoping

(Returns nothing)

Every Variable is Defined within some scope. A Variable cannot be referenced by name (a.k.a. Symbol) from outside of that scope.

Lexical scopes are defined with curly braces { }.

- The scope of Function Arguments is the complete body of the function.
- The scope of Variables defined inside a function starts at the definition and ends at the closing brace of the containing block
- The scope of Variables defined outside a function starts at the definition and ends at the end of the file. Called "Global" Vars.

```
void p(char x)
{
                /* p,x */
  char y;
                /* p,x,y */
  char z;
                /* p,x,y,z */
}
                /* p */
char z;
                /* p,z */

void q(char a)
{
  char b;
                /* p,z,q,a,b */

  {
    char b,c;
                /* p,z,q,a,b,c */
  }

  char d;
  /* p,z,q,a,b,d (not c) */
}

/* p,z,q */
```

char b?

legal?

Expressions and Evaluation

Expressions combine Values using Operators, according to precedence.

```
1 + 2 * 2        → 1 + 4        → 5
(1 + 2) * 2      → 3 * 2        → 6
```

Symbols are evaluated to their Values before being combined.

```
int x=1;
int y=2;
x + y * y        → x + 2 * 2        → x + 4        → 1 + 4        → 5
```

Comparison operators are used to compare values.
In C, 0 means "false", and *any other value* means "true".

```
int x=4;
(x < 5)                  → (4 < 5)                  → <true>
(x < 4)                  → (4 < 4)                  → 0
((x < 5) || (x < 4))     → (<true> || (x < 4))      → <true>
```

Not evaluated because first clause was true

Comparison and Mathematical Operators


```
== equal to
<  less than
<= less than or equal
>  greater than
>= greater than or equal
!= not equal
&& logical and
|| logical or
!  logical not
```

```
+  plus
-  minus
*  mult
/  divide
%  modulo
```

```
&  bitwise and
|  bitwise or
^  bitwise xor
~  bitwise not
<< shift left
>> shift right
```

The rules of precedence are clearly defined but often difficult to remember or non-intuitive. When in doubt, add parentheses to make it explicit. For oft-confused cases, the compiler will give you a warning "Suggest parens around …" – do it!

Beware division:

- If second argument is integer, the result will be integer (rounded):
  5 / 10 → 0 *whereas* 5 / 10.0 → 0.5
- Division by 0 will cause a FPE

Don't confuse & and &&..
1 & 2 → 0 *whereas* 1 && 2 → <true>

Assignment Operators


```
x = y     assign y to x
x++       post-increment x
++x       pre-increment x
x--       post-decrement x
--x       pre-decrement x
```

```
x += y   assign (x+y) to x
x -= y   assign (x-y) to x
x *= y   assign (x*y) to x
x /= y   assign (x/y) to x
x %= y   assign (x%y) to x
```

Note the difference between ++x and x++:

```
int x=5;
int y;
y = ++x;
/* x == 6, y == 6 */
```

```
int x=5;
int y;
y = x++;
/* x == 6, y == 5 */
```

Don’t confuse = and ==! The compiler will warn “suggest parens”.

```
int x=5;
if (x==6)   /* false */
{
  /* ... */
}
/* x is still 5 */
```

```
int x=5;
if (x=6)   /* always true */
{
  /* x is now 6 */
}
/* ... */
```

recommendation

A More Complex Program: pow

“if” statement

```
/* if evaluated expression is not 0 */
if (expression) {
  /* then execute this block */
}
else {
  /* otherwise execute this block */
}
```

Need braces?

X ? Y : Z

Short-circuit eval?

detecting brace errors

Tracing “pow()”:
- What does pow(5,0) do?
- What about pow(5,1)?
- “Induction”

```
#include <stdio.h>
#include <inttypes.h>

float pow(float x, uint32_t exp)
{
  /* base case */
  if (exp == 0) {
    return 1.0;
  }

  /* “recursive” case */
  return x*pow(x, exp – 1);
}

int main(int argc, char **argv)
{
  float p;
  p = pow(10.0, 5);
  printf(“p = %f\n”, p);
  return 0;
}
```

Challenge: write pow() so it requires log(exp) iterations

The "Stack"

Recall lexical scoping. If a variable is valid "within the scope of a function", what happens when you call that function recursively? Is there more than one "exp"?

Yes. Each function call allocates a "stack frame" where Variables within that function's scope will reside.

float x	5.0	
uint32_t exp	0	Return 1.0
float x	5.0	
uint32_t exp	1	Return 5.0
int argc	1	
char **argv	0x2342	
float p	5.0	

Grows

```
#include <stdio.h>
#include <inttypes.h>

float pow(float x, uint32_t exp)
{
  /* base case */
  if (exp == 0) {
    return 1.0;
  }

  /* "recursive" case */
  return x*pow(x, exp - 1);
}

int main(int argc, char **argv)
{
  float p;
  p = pow(5.0, 1);
  printf("p = %f\n", p);
  return 0;
}
```

static

Java?

Iterative pow(): the "while" loop

Problem: "recursion" eats stack space (in C). Each loop must allocate space for arguments and local variables, because each new call creates a new "scope".

Solution: "while" loop.

```
loop:
  if (condition) {
    statements;
    goto loop;
  }
```

⇨

```
while (condition) {
  statements;
}
```

```
float pow(float x, uint exp)
{
  int i=0;
  float result=1.0;
  while (i < exp) {
    result = result * x;
    i++;
  }
  return result;
}

int main(int argc, char **argv)
{
  float p;
  p = pow(10.0, 5);
  printf("p = %f\n", p);
  return 0;
}
```

The “for” loop

The “for” loop is just shorthand for this “while” loop structure.

```
float pow(float x, uint exp)
{
  float result=1.0;
  int i;
  i=0;
  while (i < exp) {
    result = result * x;
    i++;
  }
  return result;
}

int main(int argc, char **argv)
{
  float p;
  p = pow(10.0, 5);
  printf(“p = %f\n”, p);
  return 0;
}
```

```
float pow(float x, uint exp)
{
  float result=1.0;
  int i;
  for (i=0; (i < exp); i++) {
    result = result * x;
  }
  return result;
}

int main(int argc, char **argv)
{
  float p;
  p = pow(10.0, 5);
  printf(“p = %f\n”, p);
  return 0;
}
```

Referencing Data from Other Scopes

So far, all of our examples all of the data values we have used have been defined in our lexical scope

```
float pow(float x, uint exp)
{
  float result=1.0;
  int i;
  for (i=0; (i < exp); i++) {
    result = result * x;
  }
  return result;
}

int main(int argc, char **argv)
{
  float p;
  p = pow(10.0, 5);
  printf("p = %f\n", p);
  return 0;
}
```

Nothing in this scope

Uses any of these variables

Can a function modify its arguments?

What if we wanted to implement a function pow_assign() that *modified* its argument, so that these are equivalent:

```
float p = 2.0;
/* p is 2.0 here */
p = pow(p, 5);
/* p is 32.0 here */
```

```
float p = 2.0;
/* p is 2.0 here */
pow_assign(p, 5);
/* p is 32.0 here */
```

Would this work?

```
void pow_assign(float x, uint exp)
{
  float result=1.0;
  int i;
  for (i=0; (i < exp); i++) {
    result = result * x;
  }
  x = result;
}
```

NO!

Remember the stack!

```
void pow_assign(float x, uint exp)
{
  float result=1.0;
  int i;
  for (i=0; (i < exp); i++) {
    result = result * x;
  }
  x = result;
}

{
  float p=2.0;
  pow_assign(p, 5);
}
```

float x	32.0
uint32_t exp	5
float result	32.0
float p	2.0

Grows

Java/C++?

In C, all arguments are passed as values

But, what if the argument is the *address* of a variable?

Passing Addresses

Recall our model for variables stored in memory

What if we had a way to find out the address of a symbol, and a way to reference that memory location by address?

```
address_of(y) == 5
memory_at[5] == 101
```

```
void f(address_of_char p)
{
  memory_at[p] = memory_at[p] - 32;
}
```

```
char y = 101;       /* y is 101 */
f(address_of(y));   /* i.e. f(5) */
/* y is now 101-32 = 69 */
```

Symbol	Addr	Value
	0	
	1	
	2	
	3	
char x	4	‘H’ (72)
char y	5	‘e’ (101)
	6	
	7	
	8	
	9	
	10	
	11	
	12	

“Pointers”

This is exactly how “pointers” work.

```
“address of” or reference operator:  &
“memory_at” or dereference operator: *
```

A “pointer type”: pointer to char

```
void f(address_of_char p)
{
  memory_at[p] = memory_at[p] - 32;
}
```

```
void f(char * p)
{
  *p = *p - 32;
}
```

```
char y = 101;       /* y is 101 */
f(address_of(y));   /* i.e. f(5) */
/* y is now 101-32 = 69 */
```

```
char y = 101;       /* y is 101 */
f(&y);              /* i.e. f(5) */
/* y is now 101-32 = 69 */
```

Pointers are used in C for many other purposes:

- Passing large objects without copying them
- Accessing dynamically allocated memory
- Referring to functions

Pointer Validity

A Valid pointer is one that points to memory that your program controls. Using invalid pointers will cause non-deterministic behavior, and will often cause Linux to kill your process (SEGV or Segmentation Fault).

How should pointers be initialized?

There are two general causes for these errors:
- Program errors that set the pointer value to a strange number
- Use of a pointer that was at one time valid, but later became invalid

Will ptr be valid or invalid?

```
char * get_pointer()
{
  char x=0;
  return &x;
}

{
  char * ptr = get_pointer();
  *ptr = 12;  /* valid? */
}
```

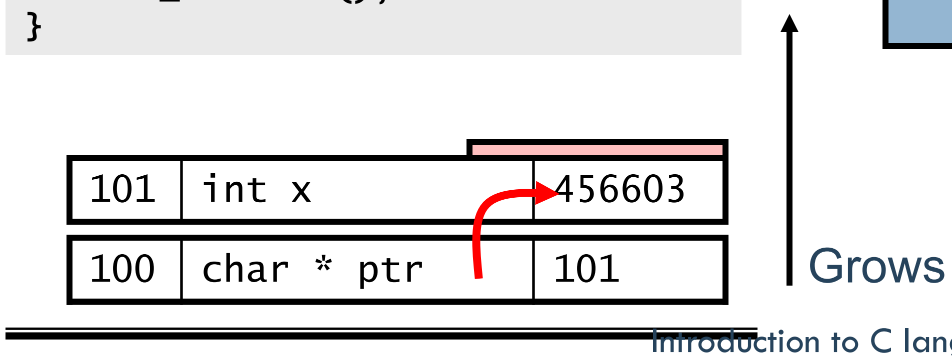
Answer: Invalid!

A pointer to a variable allocated on the stack becomes invalid when that variable goes out of scope and the stack frame is "popped". The pointer will point to an area of the memory that may later get reused and rewritten.

```
char * get_pointer()
{
  char x=0;
  return &x;
}

{
  char * ptr = get_pointer();
  *ptr = 12;  /* valid? */
  other_function();
}
```

But now, `ptr` points to a location that's no longer in use, and will be reused the next time a function is called!



More on Types

We' ve seen a few types at this point: char, int, float, char *

Types are important because:
- They allow your program to impose logical structure on memory
- They help the compiler tell when you' re making a mistake

In the next slides we will discuss:
- How to create logical layouts of different types (structs)
- How to use arrays
- How to parse C type names (there is a logic to it!)
- How to create new types using typedef

Arrays

Arrays in C are composed of a particular type, laid out in memory in a repeating pattern. Array elements are accessed by stepping forward in memory from the base of the array by a multiple of the element size.

```
/* define an array of 10 chars */
char x[5] = {'t','e','s','t','\0'};

/* accessing element 0 */
x[0] = 'T';

/* pointer arithmetic to get elt 3 */
char elt3 = *(x+3);  /* x[3] */

/* x[0] evaluates to the first element;
 * x evaluates to the address of the
 * first element, or &(x[0]) */

/* 0-indexed for loop idiom */
#define COUNT 10
char y[COUNT];
int i;
for (i=0; i<COUNT; i++) {
  /* process y[i] */
  printf("%c\n", y[i]);
}
```

Brackets specify the count of elements. Initial values optionally set in braces.

Arrays in C are 0-indexed (here, 0..9)

x[3] == *(x+3) == 't'   (*NOT* 's'!)

What's the difference between char x[] and char *x?

For loop that iterates from 0 to COUNT-1.

Symbol	Addr	Value
char x [0]	100	't'
char x [1]	101	'e'
char x [2]	102	's'
char x [3]	103	't'
char x [4]	104	'\0'

How to Parse and Define C Types

At this point we have seen a few basic types, arrays, pointer types, and structures. So far we've glossed over how types are named.

```
int x;          /* int;                     */  typedef int T;
int *x;         /* pointer to int;          */  typedef int *T;
int x[10];      /* array of ints;           */  typedef int T[10];
int *x[10];     /* array of pointers to int; */ typedef int *T[10];
int (*x)[10];   /* pointer to array of ints; */ typedef int (*T)[10];
```

typedef defines a new type

C type names are parsed by starting at the type name and working outwards according to the rules of precedence:

```
int *x[10];
```

```
x is
an array of
pointers to
int
```

```
int (*x)[10];
```

```
x is
a pointer to
an array of
int
```

Arrays are the primary source of confusion. When in doubt, use extra parenthesis clarify the expression.

Structures

struct: a way to compose existing types into a structure

Packing?

```
#include <sys/time.h>

/* declare the struct */
struct my_struct {
  int counter;
  float average;
  struct timeval timestamp;
  uint in_use:1;
  uint8_t data[0];
};

/* define an instance of my_struct */
struct my_struct x = {
  in_use: 1,
  timestamp: {
    tv_sec: 200
  }
};
x.counter = 1;
x.average = sum / (float)(x.counter);

struct my_struct * ptr = &x;
ptr->counter = 2;
(*ptr).counter = 3;  /* equiv. */
```

struct timeval is defined in this header

structs define a layout of typed fields

structs can contain other structs

fields can specify specific bit widths

Why?

A newly-defined structure is initialized using this syntax. All unset fields are 0.

Fields are accessed using '.' notation.

A pointer to a struct. Fields are accessed using '->' notation, or (*ptr).counter

Dynamic Memory Allocation

So far all of our examples have allocated variables statically by defining them in our program. This allocates them in the stack.

But, what if we want to allocate variables based on user input or other dynamic inputs, at run-time? This requires dynamic allocation.

sizeof() reports the size of a type in bytes

For details:
$ man calloc

calloc() allocates memory for N elements of size k

Returns NULL if can't alloc

```
int * alloc_ints(size_t requested_count)
{
  int * big_array;
  big_array = (int *)calloc(requested_count, sizeof(int));
  if (big_array == NULL) {
    printf("can't allocate %d ints: %m\n", requested_count);
    return NULL;
  }

  /* now big_array[0] .. big_array[requested_count-1] are
   * valid and zeroed. */
  return big_array;
}
```

%m ?

It's OK to return this pointer. It will remain valid until it is freed with free()

Caveats with Dynamic Memory

Dynamic memory is useful. But it has several caveats:

Whereas the stack is automatically reclaimed, dynamic allocations must be tracked and free()'d when they are no longer needed. With every allocation, be sure to plan how that memory will get freed. Losing track of memory is called a "memory leak".

Reference counting

Whereas the compiler enforces that reclaimed stack space can no longer be reached, it is easy to accidentally keep a pointer to dynamic memory that has been freed. Whenever you free memory you must be certain that you will not try to use it again. It is safest to erase any pointers to it.

Because dynamic memory always uses pointers, there is generally no way for the compiler to statically verify usage of dynamic memory. This means that errors that are detectable with static allocation are not with dynamic

Some Common Errors and Hints

sizeof() can take a variable reference in place of a type name. This gurantees the right allocation, but don't accidentally allocate the sizeof() the *pointer* instead of the *object*!

malloc() allocates n bytes

Why?

Always check for NULL.. Even if you just exit(1).

malloc() does not zero the memory, so you should memset() it to 0.

```
/* allocating a struct with malloc() */
struct my_struct *s = NULL;
s = (struct my_struct *)malloc(sizeof(*s));  /* NOT sizeof(s)!! */
if (s == NULL) {
  printf(stderr, "no memory!");
  exit(1);
}

memset(s, 0, sizeof(*s));

/* another way to initialize an alloc'd structure: */
struct my_struct init = {
  counter: 1,
  average: 2.5,
  in_use: 1
};

/* memmove(dst, src, size) (note, arg order like assignment) */
memmove(s, &init, sizeof(init));

/* when you are done with it, free it! */
free(s);
s = NULL;
```

memmove is preferred because it is safe for shifting buffers

Why?

Use pointers as implied in-use flags!

Macros

Macros can be a useful way to customize your interface to C and make your code easier to read and less redundant. However, when possible, use a static inline function instead.

What's the difference between a macro and a static inline function?

Macros and static inline functions must be included in any file that uses them, usually via a header file. Common uses for macros:

More on C constants?

```
/* Macros are used to define constants */
#define FUDGE_FACTOR   45.6
#define MSEC_PER_SEC   1000
#define INPUT_FILENAME "my_input_file"

/* Macros are used to do constant arithmetic */
#define TIMER_VAL      (2*MSEC_PER_SEC)

/* Macros are used to capture information from the compiler */
#define DBG(args...) \
  do { \
    fprintf(stderr, "%s:%s:%d: ", \
      __FUNCTION__, __FILE__, __LINENO__); \
    fprintf(stderr, args...); \
  } while (0)

/* ex. DBG("error: %d", errno); */
```

Float constants must have a decimal point, else they are type int

enums

Put expressions in parenthesis.

Why?

Multi-line macros need \

args… grabs rest of args

Why?

Enclose multi-statement macros in do{}while(0)

Macros and Readability

Sometimes macros can be used to improve code readability… but make sure what’s going on is obvious.

```
/* often best to define these types of macro right where they are used */
#define CASE(str) if (strncasecmp(arg, str, strlen(str)) == 0)

void parse_command(char *arg)
{
  CASE(“help”) {
    /* print help */
  }
  CASE(“quit”) {
    exit(0);
  }
}

/* and un-define them after use */
#undef CASE
```

```
void parse_command(char *arg)
{
  if (strncasecmp(arg, “help”, strlen(“help”)) {
    /* print help */
  }
  if (strncasecmp(arg, “quit”, strlen(“quit”)) {
    exit(0);
  }
}
```

Macros can be used to generate static inline functions. This is like a C version of a C++ template. See emstar/libmisc/include/queue.h for an example of this technique.