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(Short) Introduction to the C programming language

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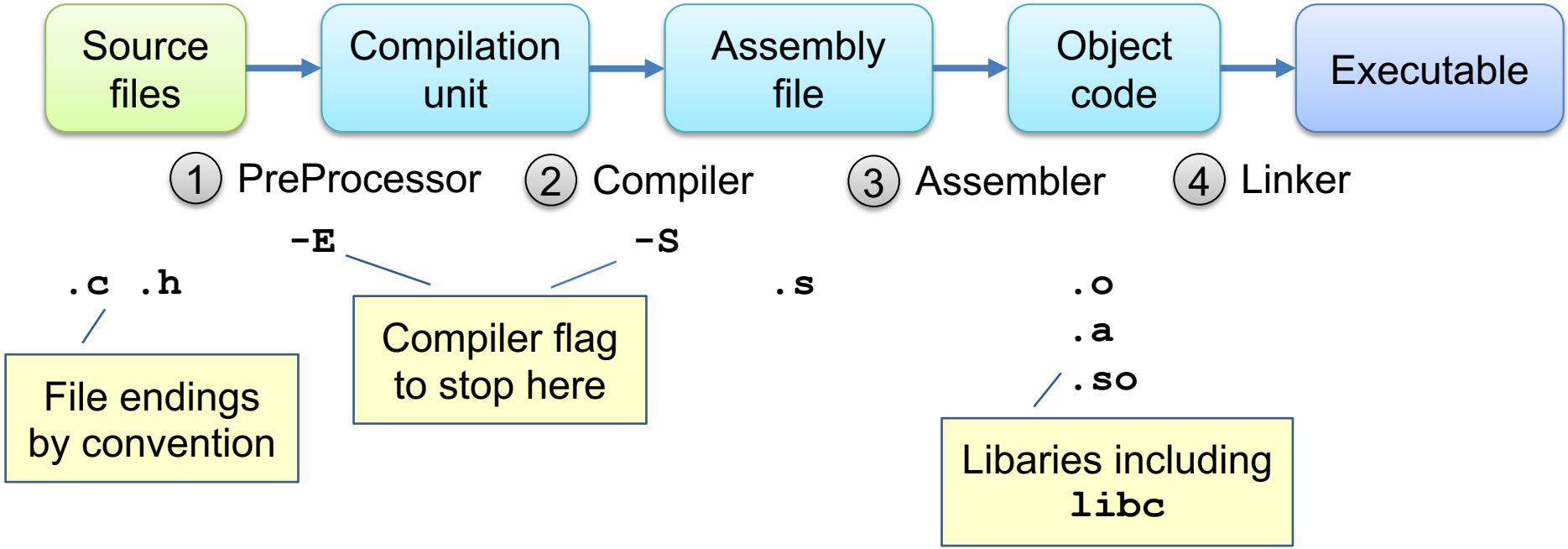
History and Background

- **Procedural** structured programming language
- **Static type system** and lexical variable scope
- **ANSI** and **ISO standard** (last stable release C17)
- Many other programming languages use a **C-like syntax**

- Developed in **1972** at **Bell labs** as part of the **UNIX OS**
- **Right level of abstraction** for **low level access** to underlying **machine architecture** while still providing support for portable **complex software**
- Still among the **most popular** programming languages (**TIOBE** 1. place)
- **Major implementations**: GCC, LLVM Clang, (Intel ICC), MS Visual C++

Getting from source code to executable

- **Multiple steps required** to get **from source to executable** (usually wrapped by cc command)



C pre-processor

Macro pre-processor directives preceded by **#**

- **File inclusion**

```
#include <stdio.h>
#include "includes/stdio.h"
```

Search in standard include paths

Also search in current directory

- **Macro expansion**

```
#define PI 3.14159
#define RADTODEG(x) ((x) * 57.29578)
```

Enforce order of operations: `RADTODEG(r + 1)`

- **Conditional compilation**

```
#ifdef __unix__
#include <unistd.h>
#else defined _WIN32
#include <windows.h>
#endif
```

Program structure and basic syntax

- **All source code** in C is contained **in subroutines**
- By convention **subroutines that return** a value **are called functions**
- The **declaration** prototype of a subroutine is also called its **signature**
- There **must be one** special subroutine called `main()` which is the **entry point** for the program

- **Higher level** program **structure** as, e.g. modular programming, is based on **symbol naming conventions**
- Source text is **free form** using a **semi-colon** as statement **terminator**
- **Curly braces** group **blocks of statements**

- **Single line comments** are beginning with `// This is a comment!`
- **Multiline comments** are enclosed in `/* comment */`

Control flow primitives (selection)

- Conditional execution

```
if (<condition>) { } else if (<condition>) { } else { }
```

C allows to omit braces.
TIP: Always use braces!

- For loops

```
for ( init; condition; increment ) { statement(s); }
```

Executed once at the beginning

Executed after every loop iteration

```
for( a = 10; a < 20; a = a + 1 ) {
  x = x + 1;
}
```

- While loops

```
while(condition) { statement(s); }
```

Basic types and variable declaration/definition

Type	Storage size	Value range
`char`	1 byte	-128 to 127
`int`	4 bytes	-2,147*10^6 to 2,147*10^6
`unsigned int`	4 bytes	0 to 4,294,967,295
`float`	4 bytes	1.2E-38 to 3.4E+38
`double`	8 bytes	2.3E-308 to 1.7E+308

`8 bits`

- All **variables** have to be **defined with** a **specific type**

```
int i, j, k;
float alpha=0.23, beta= 0.99;
extern int i;
```

Variables are initially undefined!
Tip: Always initialize ALL variables.

`extern` enforces a variable declaration

- Variables defined **inside a function** or block are **local**
- Variables defined **outside of functions** are **global**

C arithmetic and relational and logical operators

Operator	Description
+	Adds two operands
-	Subtracts second from first operand
*	Multiplies both operands
/	Divides numerator by de-numerator
%	Modulus Operator and remainder of after an integer division
++	Increment operator increases the integer value by one
--	Decrement operator decreases the integer value by one

Operator	Description
==	Equal
!=	Not equal
>	Greater than
<	Smaller than
>=	Greater than or equal
<=	Smaller than or equal
&&	Logical AND
||	Logical OR
!	Logical NOT

C types pitfalls and operator precendence

- **Statically typed** variables but **weakly enforced**!
- If the types of **two operands** do **not match** the compiler performs **implicit** arithmetic **type conversion**
- When **mixing signed with unsigned** integers both **get converted** to unsigned type! **TIP: Do not use unsigned integers!**
- **Floating point literals** are of type **double.** Use **`f`** suffix for float literals.

- Within an expression, **higher precedence** operators will be evaluated **first**

Higher **Lower**

Postfix(()[]->++--) **Unary**(+-!&) **Multiplicative**(*/%) **Additive**(+-)

TIP: Always be **explicit** and **use brackets!**

Arrays in C

```
type arrayName [ arraySize ];
```

Array size must be an integer constant greater than zero!

```
double balance[10];
```

- Initializing arrays

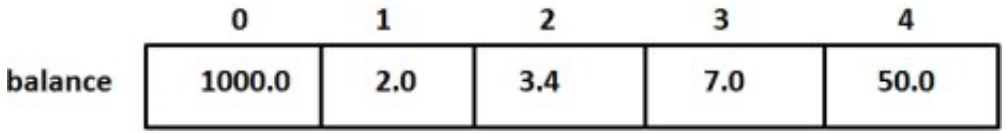
```
double balance[5] = {1000.0, 2.0, 3.4, 7.0, 50.0};
```

- Accessing array elements

```
double salary = balance[9];
```

Array indices are always zero based!

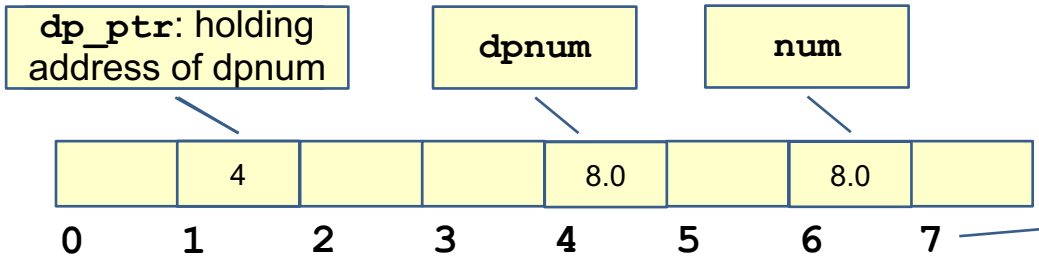
- C arrays are allocated on the stack



Pointers

- **Memory** in computers **is accessed** using **unsigned integers** (called addresses). An address is the key to a storage cell in memory.
- A **pointer** is a variable whose value is the **address of another variable**
- **Definition:** `type *var-name;` e.g. `double *dp_ptr;`
- Get address of a variable: `double dpnum = 8.0; dp_ptr = &dpnum;`
- Access value at pointer location: `double num = *dp_ptr;`

Use meaningful variable naming



Real memory is addressed bytewise!

Pointer arithmetic and square bracket notation

Interlude: Addressing modes in the X86-64 ISA

```
movaps [rdi + rax * 8], xmm3
```

BASE + INDEX * SCALE

You can perform computations with pointers: **Pointer arithmetic!**

```
double* A; double* B; double x; int i = 2;
B = A + i;
x = *(A + i);
```

Reflects addressing mode:
`B = A + i * 8b`

Get value at `A + i`

A `void*` pointer type is a generic (without type) pointer

Square bracket shorthand notation:

`x = A[i];` is equivalent to `x = *(A + i);`

For performant code always use square bracket notation!

Memory management

- **Dynamic memory allocation** (at runtime) is provided by **libc**

```
#include <stdlib.h>

int main() {
  double* A;
  A = (double*) malloc( 200 * sizeof(double) );
  // Do computations
  free(A);
}
```

Allocate memory on heap. Takes **size in bytes** as only argument and returns `void*`

Operator to get storage size of an object or type in bytes

Release memory. `A` must hold the address that was returned on allocation!

Structures and `typedef`

- A **structure** is a **user defined data type** that allows to combine data items of **different kinds**

```
struct Books {
  char title[50];
  char author[50];
  char subject[100];
  int book_id;
};
```

Less clumsy way

```
typedef struct {
…
} Books;

Books book1;
```

Pointers to structs:

```
Books *book_ptr = &book1;
```

Accessing items of ptr to struct:

```
int id = book_ptr->book_id;
```

- Declare variable of type struct Books

```
struct Books book1;
```

- Access struct items with member access operator `.`

```
int id = book1.book_id;
```

Subroutines (aka functions)

```
return_type function_name( parameter list )
{ body of the function }
```

Example for function definition:

```
int max(int num1, int num2) {
  int result;
  if (num1 > num2) { result = num1; }  else { result = num2; }
  return result;
}
```

Function parameters are default passed call by value

For call by reference you need to pass pointers as function parameters!

Pitfalls of call by value

```
void allocate_mem(double *ptr, int size){
  ptr = (double*) malloc( size * sizeof(double) );
}
```

- Using above function

```
double *my_ptr = NULL;
allocate_mem(my_ptr, 1000);
double x = my_ptr[899];
```

TIP: Always use special **NULL** value to initialize pointers!

Segmentation fault! What happened?

- Solution

```
void allocate_mem(double **ptr, int size);
allocate_mem(&my_ptr, 1000);
```

Strings and programm output

- There is **no string data type** in C!
- **Strings** are **one-dimensional arrays** of characters **terminated** by a **null character '\0'**

```
char greeting[] = "Hello";
```

String literal enclosed by "" is always zero terminated

libc provides routines for IO in **<stdio.h>**

```
#include <stdio.h>
...
printf("Greeting message: %s\n", greeting );
```

printf format string

More information on format strings:

https://en.wikipedia.org/wiki/Printf_format_string

File IO

- Opening a file

```
FILE *fopen( const char * filename, const char * mode );
```

- Writing to file

```
fprintf(FILE *fp,const char *format, ...);
```

`printf` format string

- Example

```
#include <stdio.h>
main() {
  FILE *fp;
  fp = fopen("/tmp/test.txt", "w");
  fprintf(fp, "This is testing for fprintf...\n");
  fclose(fp);
}
```

Command line arguments

- Command line arguments are passed as **arguments** to the **main routine**

Number of arguments

List of arguments. `argv[0]` holds program name!

```
int main( int argc, char **argv ) {
   if( argc == 2 ) {
      printf("The argument supplied is %s\n", argv[1]);
   } else if( argc > 2 ) {
      printf("Too many arguments supplied.\n");
   } else {
      printf("One argument expected.\n");
   }
}
```

Putting it all together

- A simple but non-trivial C example code:
  - The Bandwidth Benchmark
    `https://github.com/RRZE-HPC/TheBandwidthBenchmark`

- Further reading

`https://www.tutorialspoint.com/cprogramming/`