System Software Crash Couse

Samsung Research Russia
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Block B The Basics of C

1. Introduction

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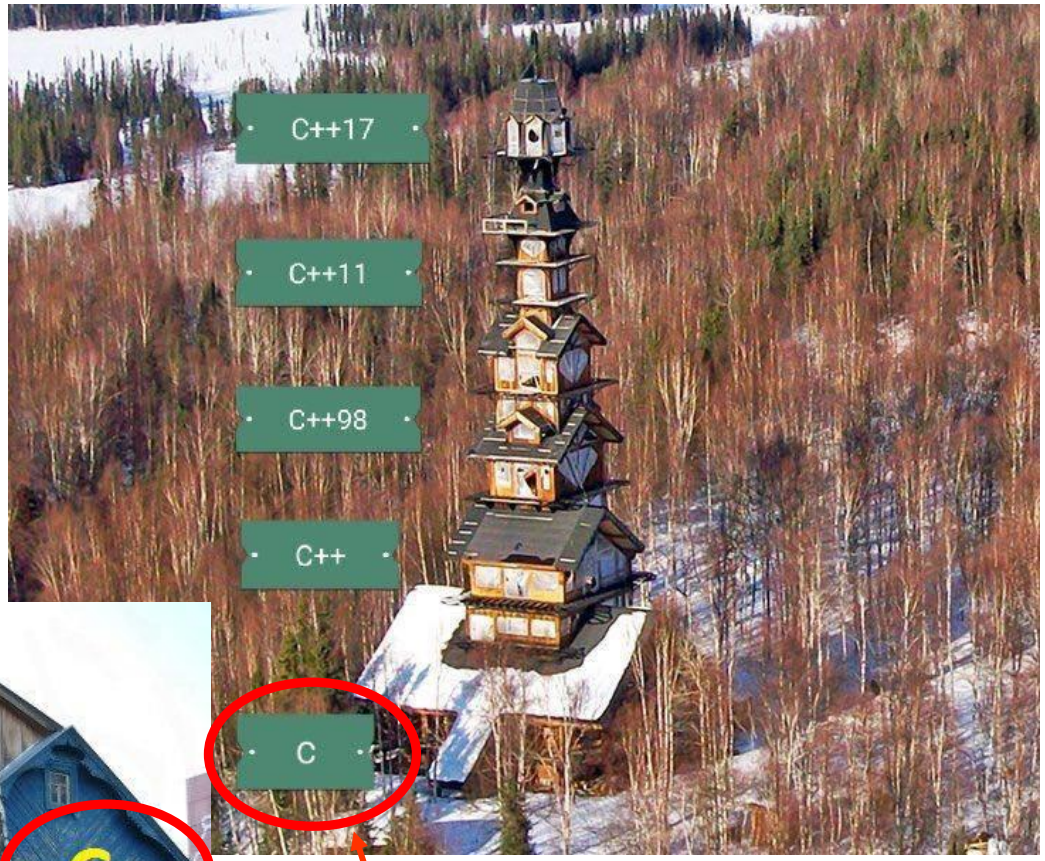
Why the Course?

- C is the most popular language for developing system software
  - See monthly TIOBE index of popularity.
- C – its semantics (and syntax) – lies in the foundation of the current software world.
  - Most of modern languages (re)use C syntax ☺.
- Each software that requires extreme efficiency with strong memory limitations is typically written in C.
  - Examples are Windows, Linux, Android, Tizen.

C & C++



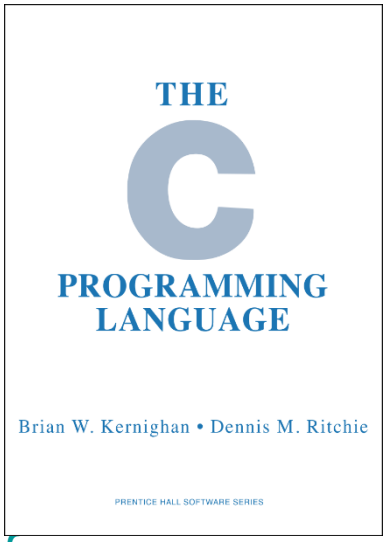
C is the predecessor
and the basis of C++

C Language Authors

Brian Kernighan

Dennis Ritchie

References



"K&R C"

- C International Standard ISO/IEC 9899:2011
  The latest publicly-available document (n1570):
  http://www.open-std.org/jtc1/sc22/wg14/www/docs/n1570.pdf
- Working group JTC1/SC22/WG14 - C
- C99 Rationale:
  http://www.open-std.org/jtc1/sc22/wg14/www/docs/C99RationaleV5.10.pdf
- Kernighan, Brian W.; Ritchie, Dennis M. (February 1978). The C Programming Language (1st ed.). Englewood Cliffs, NJ: Prentice Hall. ISBN 0-13-110163-3.
- Any modern book in C ☺.
- Online resources (many of them…)

The C Programming Language

- C is very simple & compact language. (Oh, really? ☺)
  - However, C programs can be extremely complicated and might look cryptic.
- C is complete & very powerful language.
- C is "middle-level" language.
  - No constructs with complicated semantics; no built-in system support like memory management.
- C was designed to be as close to hardware as possible.
  - Each C language construct is typically mapped to a clear machine code (or even to a single machine instruction).
- The C core language is completely independent from its standard library (see next slides).
- The C language is old.
  - It doesn't support modern programming patterns & idioms.
  - Its programming paradigm is conservative & archaic.

The C Programming Language

- C is typed language (but not strongly typed).
  - Each C object is characterized by its type;
  - No way to change object's type during program execution;
  - There are a lot of ways, however, to **convert** types.
- C assumes compilation.
  - C programs should be **compiled** into a sequence of machine instructions before running;
  - Typically, C program should also be **linked** with some other programs (libraries) before running.

The Source & Machine Code Example

Software: from C to processor instructions

C:

```
int f (int a, int b)
{
   int s = 0;

   while (s < a)
      s += b;

   return s;
}
```

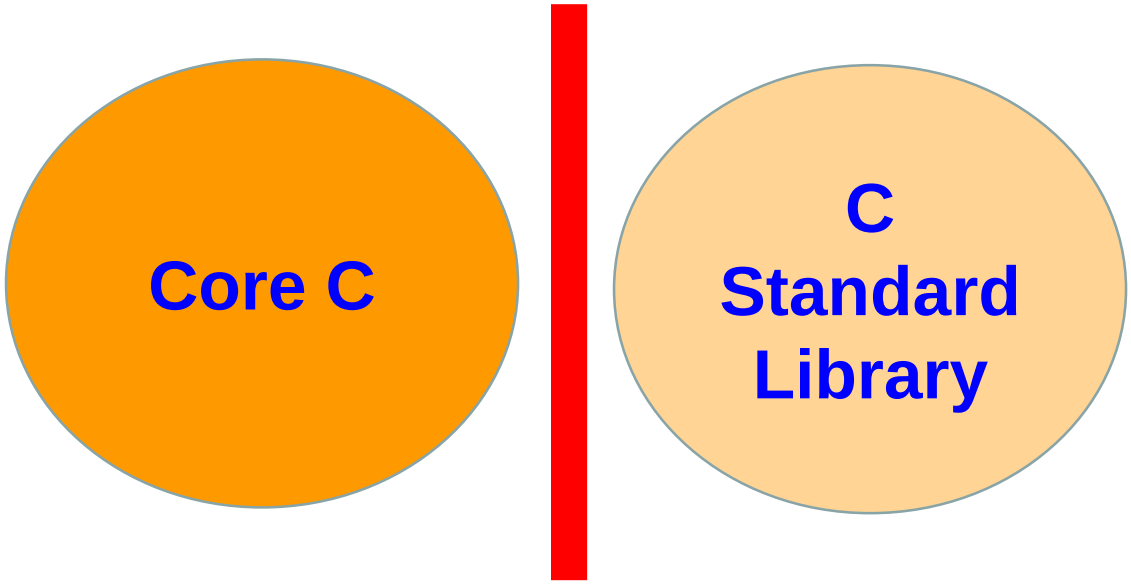
Assembly:

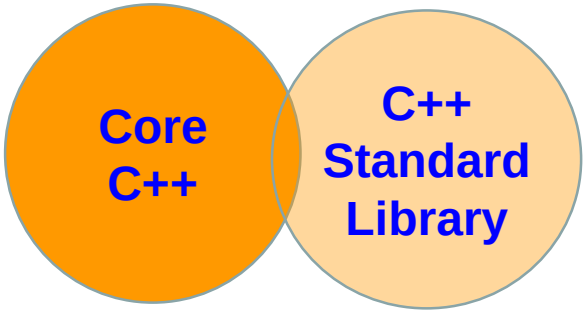
```
        .set noreorder
sum:
        blez    $4, exit
        move    $2, $0

        addu    $2, $2, $5
loop:
        slt     $3, $2, $4
        bnel    $3, $0, loop
        addu    $2, $2, $5
exit:
        jr      $31
        nop
```

Machine code

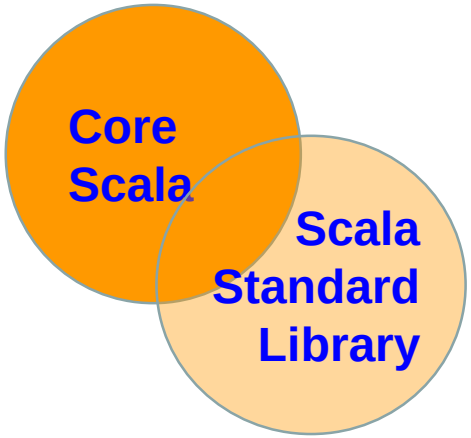
```
18800005
00001025

00451021

0044182a
5460fffe
00451021

03e00008
00000000
```

Core Language & Language Library

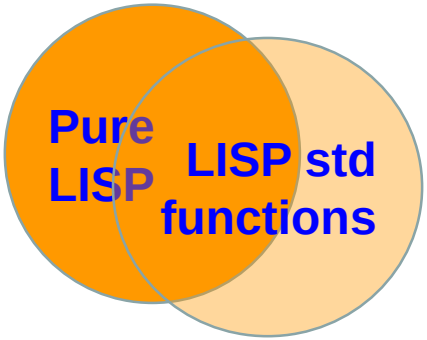




The intersection is modest
(just 4 small libraries)



The intersection is big



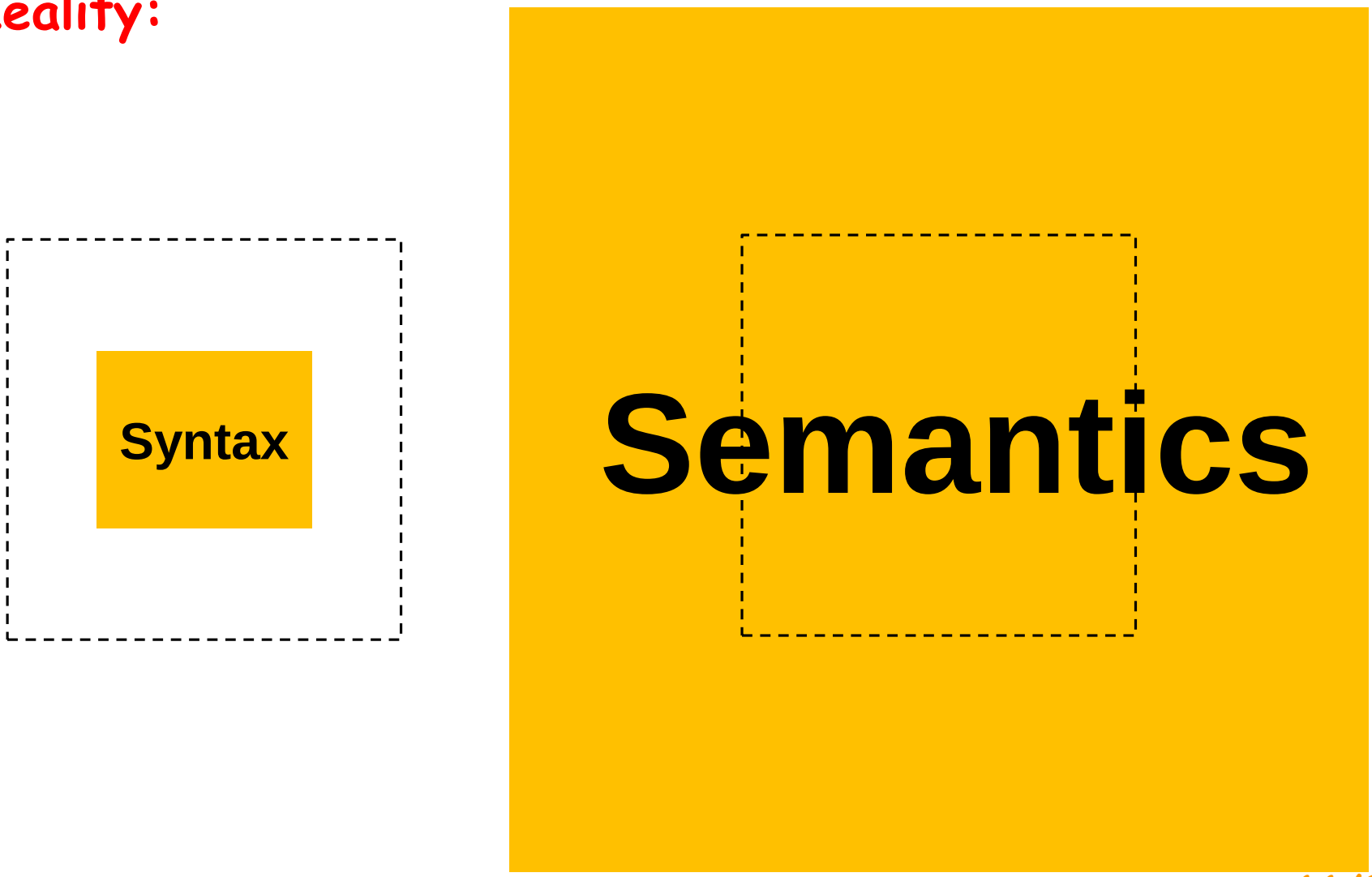
The intersection is almost a union: the LISP language has the elementary syntax/semantics and a huge library.

Languages: Syntax vs Semantics

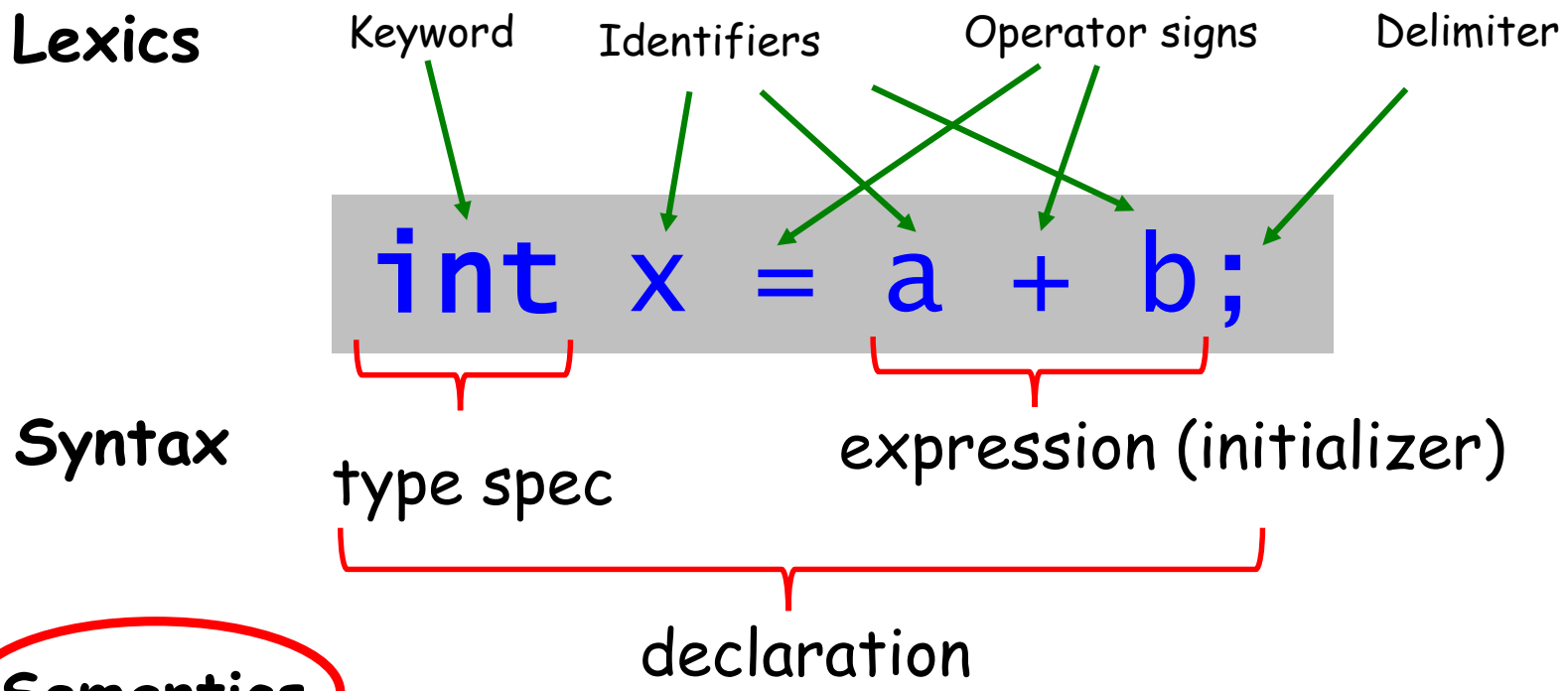
"Usual" view at a language:

Languages: Syntax vs Semantics

Reality:



C: Syntax vs Semantics



Semantics

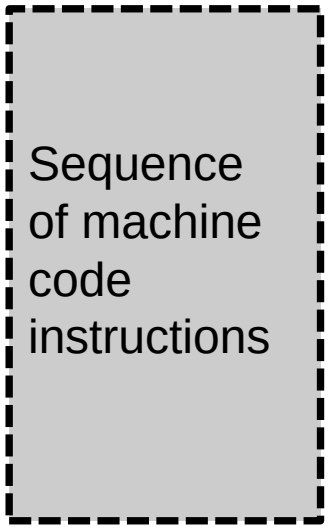
- Allocate memory for the new integer variable (in stack)
- Calculate expression from initializer
- Perform type conversion(s) to integer, if necessary
- Store the value of the expression
- Make x available in the current context

The C Memory Model

Each C program uses three kinds of memory:

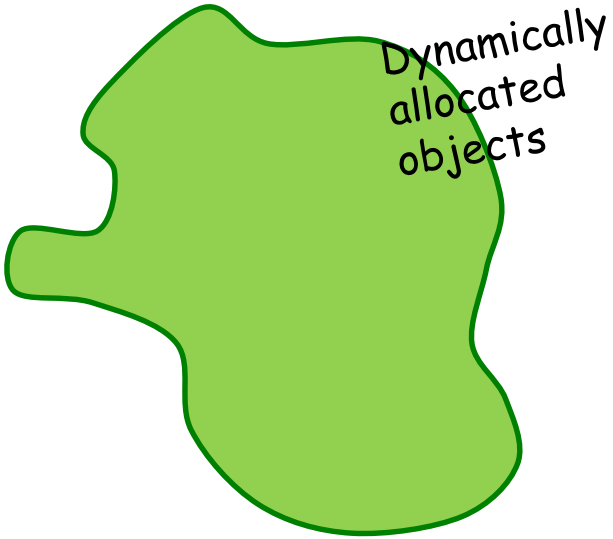
- Program
- Dynamic memory ("Heap")
- Stack

Program



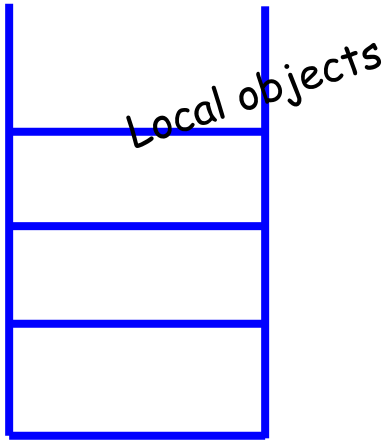
Program cannot modify this memory (self-modified programs are not allowed)

Heap



The discipline of using heap is defined by program **dynamic semantics**, i.e., at runtime (while program execution)

Stack



The discipline of using stack is defined by the (static) **program structure**

The First C Program & Structure

```
int Max(int a, int b)
{
    if ( a > b )
        return a;
    else
        return b;
}

void Input(int* x,int *y);

int main()
{
    int x, y;
    input(*x,*y);
    return Max(x,y);
}
```

Some concrete observations:

- The program contains three function declarations.
- The whole program is within the single source file.
- The execution always starts from the function called `main`.

Common rules:

- The program is a sequence of declarations.
- The whole program can be splitted into several source files (and usually does).
- All program functionality **is in functions**.

The First C Program & Structure

1. This is the function that accepts two parameters; both should be of integer type. The result of the function should be of integer type.

2. This is the function **algorithm**: what the function actually does.

3. `return` statement specifies the **result** of the function…

4. `input` is the **preliminary** function declaration – without the algorithm. The full function definition is to be provided separately (while program linking).

5. `main` is the "entry point" of the whole program.

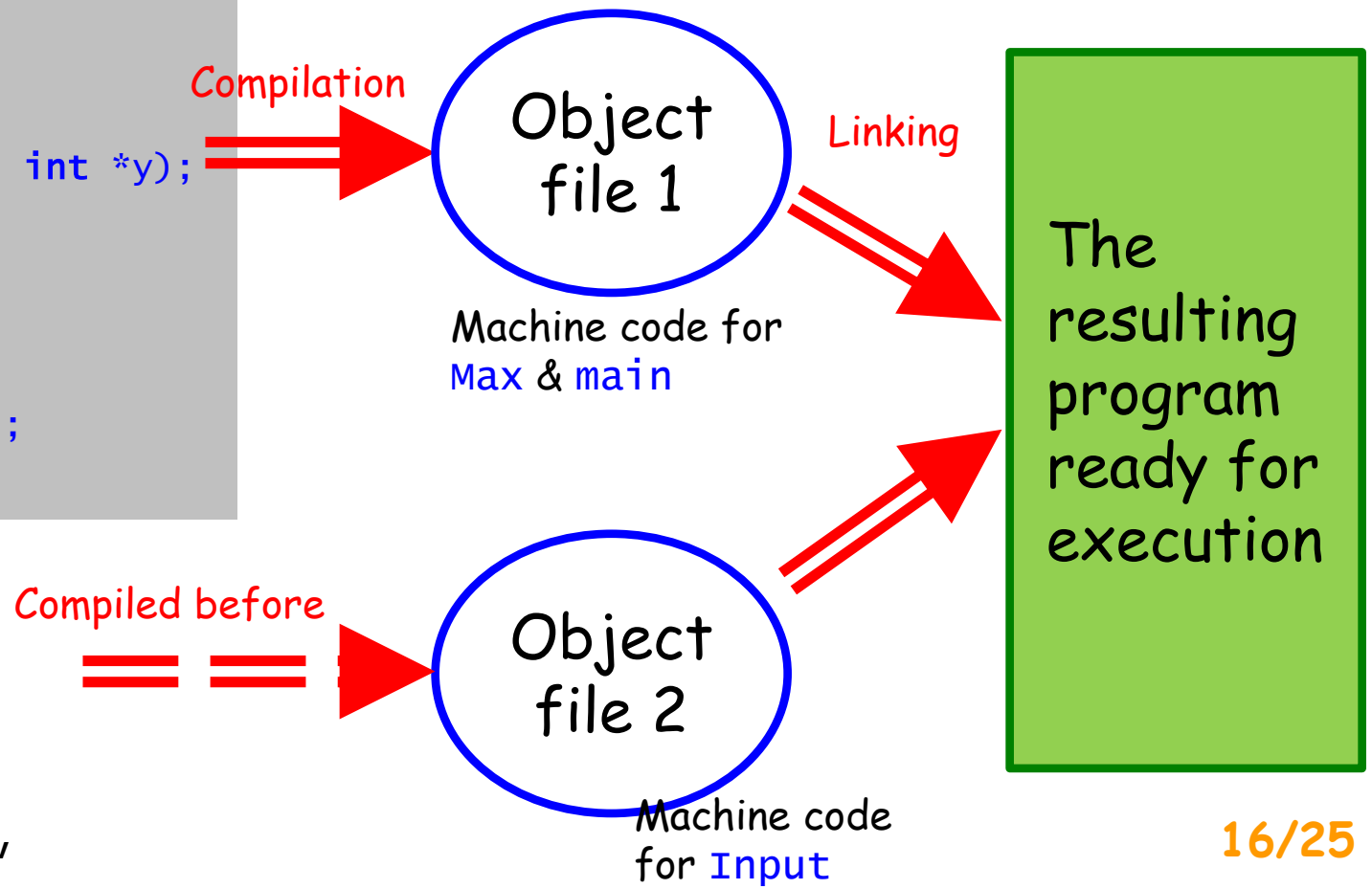
6. `main` has two **local declarations** and two **function calls**.

```
int Max(int a, int b)      *1
{*2
   if ( a > b )
        return a;
   else
        return b;          *3
}

void Input(int* x, int *y);   *4

int main()                    *5
{
   int x, y;
   Input(&x,&y);                  *6
   return Max(x,y);
}
```

How C Programs are Built

Source & object files, compilation & linking

```
int Max(int a, int b)
{
   if ( a > b )
       return a;
   else
       return b;
}

void Input(int* x, int *y);

int main()
{
   int x, y;
   Input(&x,&y);
   return Max(x,y);
}
```



How C Programs are Built

Translation units and separate compilation

Max.c

```
int Max(int a, int b)
{
   if ( a > b )
       return a;
   else
       return b;
}
```

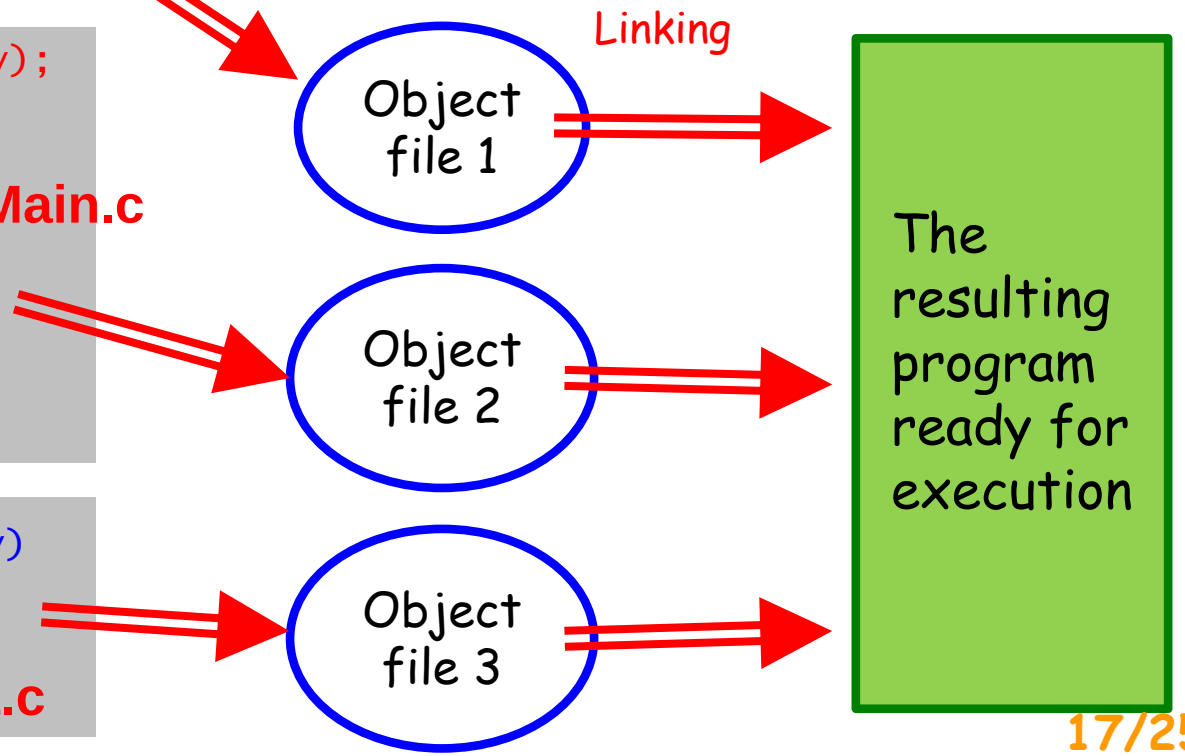
Main.c

```
void Input(int* x, int *y);
int Max(int a, int b);

int main()
{
   int x, y;
   Input(&x,&y);
   return Max(x,y);
}
```

Input.c

```
void input(int* x, int *y)
{
    ...
}
```

- Typically, any C program consists of several **translation units** each of which is located in a separate source file.
- The **separate compilation principle**; each TU gets compiled **independently** from others.



How C Programs are Built

Interface, implementation, and `#include` directive

What if `Max` and `Input` functions (from the prev slides) are used **in many translation units**?

- Instead of writing forward declaration for `Max` & `Input` in each TU where they're used, the following solution is used:

Max.h

```
int Max(int a, int b);
```

Max.c

```
int Max(int a, int b)
{
   if ( a > b )
       return a;
   else
       return b;
}
```

Each translation unit is represented **by two source files**:
- with forward declarations ("interface");
- with full declarations ("implementation").

How C Programs are Built

Interface, implementation, and #include directive

…And, instead of writing forward declarations for Max and Input again and again, we write the following:

Max.h

```
int Max(int a, int b);
```

```
int Max(int a, int b)
{
   if ( a > b )
       return a;
   else
       return b;
}
```

Max.c

```
void Input(int* x, int *y);
int Max(int a, int b);

int main()
{
   int x
   Input
   retur
}
```

```
#include "Input.h"
#include "Max.h"

int main()
{
   int x, y;
   Input(&x,&y);
   return Max(x,y);
}
```

The semantics of #include directive assumes textual inclusion of the contents of the file specified to the file where the directive is written.

C Entities & Declarations

- So, a C program consists of a sequence of **declarations**.
- Each declarations introduces an **entity**.
- What is C entity?
  - **Variable** (simple variable)
  - **Array**
    Informally: an indexed group of variables.
  - **Type**
    A user-defined type; a synonym to other type
  - **Function**
    Informally: a sequence of statements specifying the local context and some actions.

C: Variable Declarations

- x variable becomes available in the current context;
- The type of x is a default integer type;
- The initial value of x is not defined.

- y variable becomes available in the current context; its type is integer, and the initial value is 83.

```
int x;
int y = 0123;
float f1 = 0.1;
double d1, d2 = 0x555;
```

- f1 variable becomes available in the current context; its type is default float, and the initial value is 0.1.

The single declaration introduces two variables: d1 and d2; their type is **double**; the initial value for d1 is not specified, and for d2 is 1365.0.

C: Array Declarations

- A is the array consisting of 100 integer values; all elements are always **of the same type**;
- The initial values of array elements are not specified;
- The memory for the array is allocated statically: before program starts.
- Array elements are indexed using integer numbers; the first element has the index of 0.

```
int A[100];
double D[3] = { 1.2, 3.4, 5.6 };
```

- D is the array consisting of 3 values of type double each;
- The initial values of array elements are specified by means of the list of values within braces.

C Standard (Predefined) Types

```
char
```

```
_Bool
```

Signed integer types

```
signed char
short int
int
long int
long long int
```

Unsigned integer types

```
unsigned char
unsigned short int
unsigned int
unsigned long int
unsigned long long int
```

Floating types

```
float
double
long double
```

Complex types

```
float _Complex
double _Complex
long double _Complex
```

C Derived ("User-Defined") Types

- Array types
- Structure types
- Union types
- Function types
- Pointer types
- Atomic types

- There is no way to declare an array type independently from an array variable

```
int A[100];
```

This is a **variable** of array type
(The same is about function & pointer types)

- Structure & union types can be declared **separately** (as they are):

```
struct S {
   int a;
   int b;
};
```

Having such a declaration we can use it for declaring **variables** of this type:

```
struct S s;
```

C Derived ("User-Defined") Types

Some tricks & flaws with C types and declarations

```
struct S {
   int a, b;
};
```

Usual declaration of a structure type…
We can use it like as follows: `struct S s;`

```
struct S {
   int a, b;
} s1, s2;
```

The structure type declaration **together** with variable declaration!
We can still use `S` in declarations: `struct S s3;`

```
struct {
   int a, b;
} s1, s2;
```

Unnamed structure type declaration **together** with variable declaration.

```
typedef struct {
   int a, b;
} S;
```

Here, we introduce a **synonym** to the unnamed structure type.
Later, we can use the synonym:

```
S s1, s2;
```