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Tutorial 1: Introduction to C

Computer Architecture and
Systems Programming
(252-0061-00)

Herbstsemester 2012

Goal

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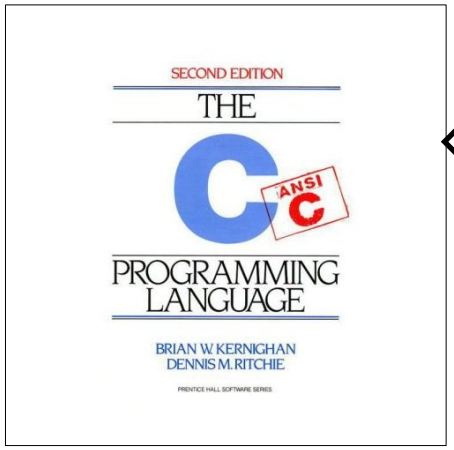
- Quick introduction to C
  - Enough to program assignments
  - Background for lectures
- Assume you know Java or C#
  - E.g. from Parallel Programming
- Non-goal:
  - Teach details and strict definition of C
  - Teach advanced features/idioms/techniques in C

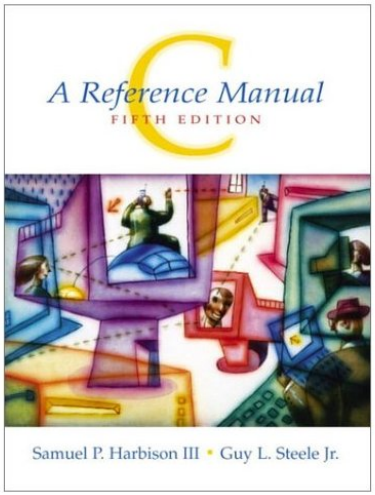
Further reading

Online: http://www.iu.hio.no/~mark/CTutorial/CTutorial.html

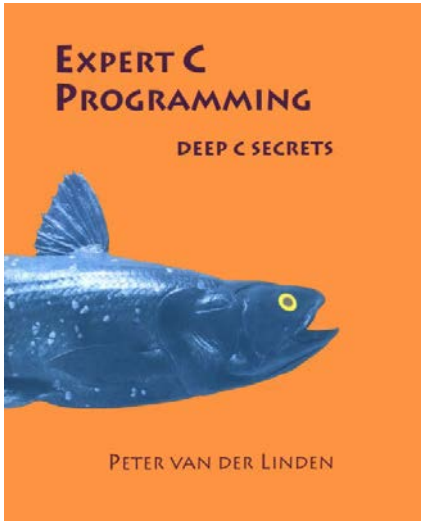


Old, but a great tutorial (how I learned C)

Very advanced: all the stuff you *never* wanted to know about C ☺



Definitive.



Compared to Java or C#

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- No objects, classes, features, methods, or interfaces
  - Only functions/procedures
  - Function pointers will be met later…
- No memory management
  - Lots of things on the stack
  - Heap structures must be explicitly created and freed
- No fancy built-in types
  - Mostly just what the hardware provides
  - Type constructors to build structured types
- No exceptions
  - convention is to use integer *return codes*

Compared to Java or C#

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- Powerful macro pre-processor (cpp)
- Very fast
  - Almost impossible to write assembly as fast as a good C compiler
  - Pretty much impossible to compile Java to run as fast as C
- Pointers: real machine addresses
- Close to the metal: you can *know* what the code is doing to the hardware
  $\Rightarrow$ Language of choice for
  - Operating System developers
  - Embedded systems
  - People who *really* care about speed
  - Authors of security exploits

A feel of C programs

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- A C program is characterized by:
  - Functions, grouped by header files and libraries
  - Data structures built using structs and pointers
  - Created dynamically using malloc and free
  - Symbolic constants defined with cpp macros
- More advanced features:
  - Polymorphism and object dispatch with *function pointers*

Syntax: the good news

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- Similar to Java or C#
  - Java or C# syntax almost entirely lifted from C
  - Comments (/*...*/, //) the same
  - Identifiers the same as in Java (C# allows more characters in identifiers)
  - Block structure using { … }
  - Many other constructs the same or similar
- Main differences
  - List of reserved words is different
  - C is run through a *macro preprocessor*
    - String and file substitution
    - Conditional compilation
    - Although C# has preprocessor directives, it does not have a separate preprocessor. Moreover there are no macros.

Hello World

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```
#include <stdio.h>

int main(int argc, char *argv[])
{
        printf("hello, world\n");
        return 0;
}
```

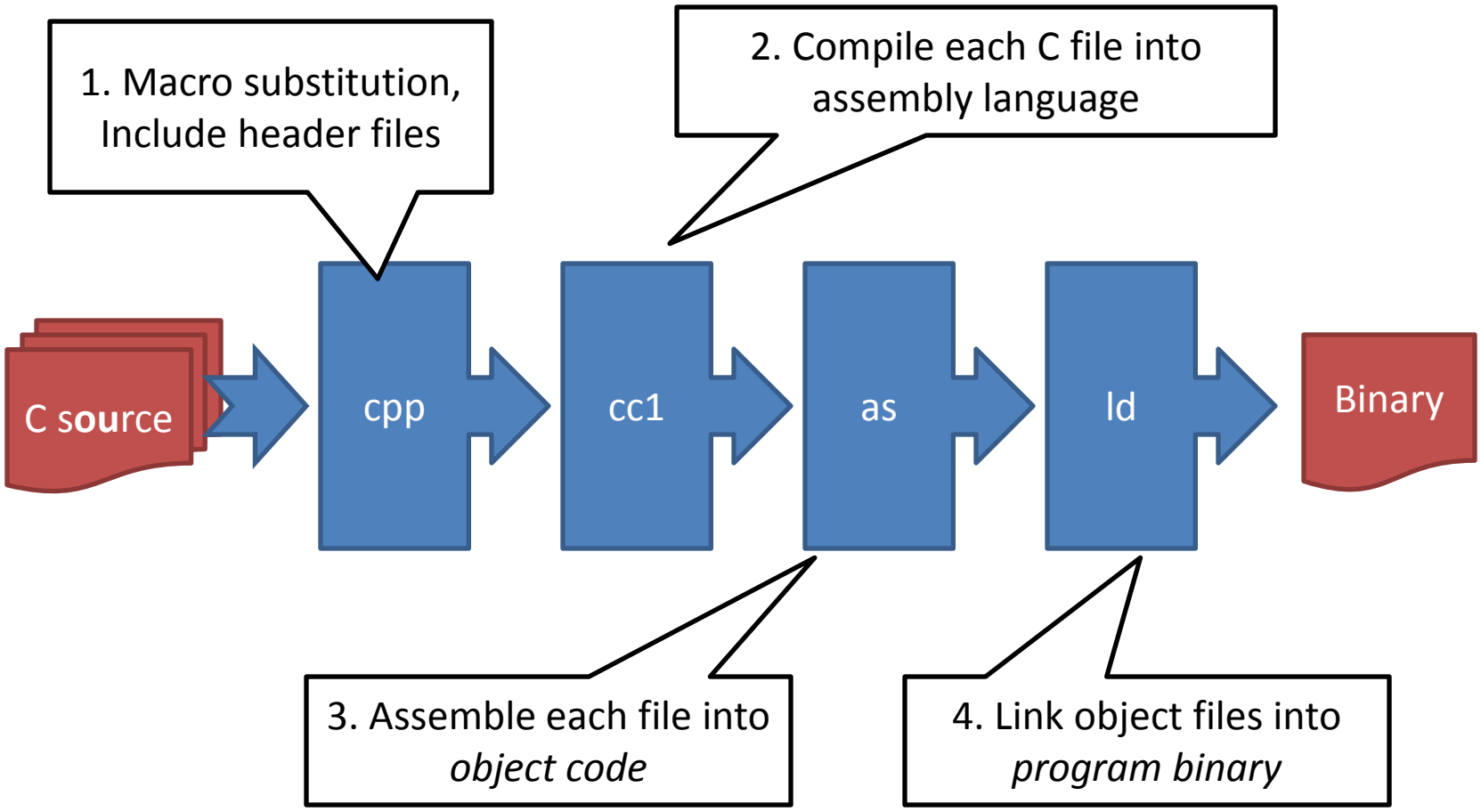
"header file" – bit like an interface file in Java or C#

Every program has to have a "main" function, which takes a list of *command line arguments.*

Generic function for printing formatted strings. The "newline" is not included automatically!

Returning 0 indicates everything is OK – C has no exceptions.

Workflow


1. Macro substitution, Include header files
2. Compile each C file into assembly language
C source
cpp
cc1
as
ld
Binary
3. Assemble each file into *object code*
4. Link object files into *program binary*

The C Preprocessor

```
#include <file1.h>

#include “file2.h”
```

- Include the “header” file inline in the source code
- Basic mechanism for defining APIs
- Use of <> or “” determines where to look for the file
  - Use <> for system headers
  - Use “” for your own headers
- Included files can include other files
  - Beware of including files twice!

The C Preprocessor

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```
#define FOO BAZ
#define BAR(x) (x+3)

…

#undef FOO
```

- Token-based macro substitution
- Any subsequent occurrence of **FOO** is replaced with **BAZ**
  - Until a **#undef FOO**
- **BAR(4)** is replaced with **(4+3)**
  - Not 7!
- **BAR(hello)** is replaced with **(hello+3)**

The C Preprocessor

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```
#ifdef FOO
… (text 1)
#else
… (text 2)
#endif

#ifndef BAR
… (text 1)
#else
… (text 2)
#endif
```

- Text 1 is used if a macro **FOO** is defined, otherwise Text 2
- Opposite for **BAR**
- **#else** is optional
- Idiom for header files:

```
#ifndef __FILE_H
  #define __FILE_H
… (contents of file.h)
#endif // __FILE_H
```

- Ensures file contents only appear once!

Types in C

Declarations

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- Are like Java or C#:

```
int my_int;
double some_floating_point = 0.123;
```

- Inside a block:
  - Scope is just the block
  - **`static`** → value *persists* between calls
- Outside a block:
  - Scope is the *entire program!*
  - **`static`** → scope limited to the file (compilation unit)

Integers and floats

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- Types and sizes:

C data type	Typical 32-bit	ia32	Intel x86-64
`char`	1	1	1
`short`	2	2	2
`int`	4	4	4
`long`	4	4	8
`long long`	8	8	8
`float`	4	4	4
`double`	8	8	8
`long double`	8	10/12	10/16

- Integers are signed by default
  - use **`signed`** or **`unsigned`** to clarify

Integers and floats

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- Rules for arithmetic on integers and floats are complex
  - Implicit conversions between integer types
  - Implicit conversions between floating point types
  - Explicit conversions between anything (casts)

- Behavior is either:
  - Determined by the hardware
  - Was decided by hardware, a long time ago
- We'll cover this more in lectures

Booleans

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- Boolean values are just integers
  - False → zero
  - True → anything non-zero
  - Negation (“!”) turns zero into non-zero, and vice-versa

- Any statement in C is also an expression, hence idioms like:

```
int rc;
if (!(rc = call_some_fn())) {
   printf(“Failed with return code %d\n”, rc);
   exit(1);
}
// Carry on: call succeeded.
```

Casting

- Most C types can be *cast* to another:

```
unsigned int ui = 0xFFEEDDCC;
signed int i    = (signed int)ui;
```

⇒ **`i`** has value -1122868.

Name of type in parentheses functions like an operator.

- Bit-representation does not change!
- Frequently used with pointer types…

Arrays

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- Finite set of variables, all the same type
- For an N-element array a:
  - First element is a[0]
  - last element is a[N-1]
- C compiler does not check the array bounds!
  - Very typical bug!
  - Always check array bounds!

```
#include <stdio.h>
float data[5];  /* data to average and total */
float total;    /* total of the data items */
float average;  /* average of the items */

int main() {
    data[0] = 34.0;
    data[1] = 27.0;
    data[2] = 45.0;
    data[3] = 82.0;
    data[4] = 22.0;

    total = data[0] + data[1] + data[2] +
          data[3] + data[4];
    average =  total / 5.0;
    printf("Total %f Average %f\n", total,
          average);
    return (0);
}
```

Multi-dimensional arrays

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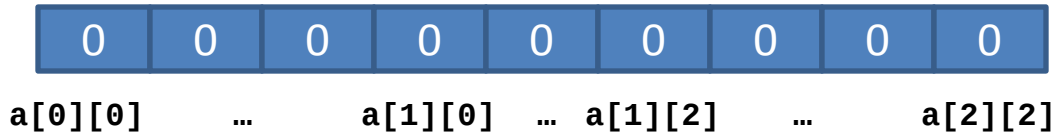
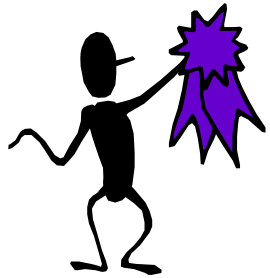
```
int a[3][3];
```



```
int a = 1;
for (i=0; i < 3; i++)
      for (j=0; j < 3; j++)
            matrix[i][j] = a++;
```



```
int a = 1;
for (i=0; i < 3; i++)
      for (j=0; j < 3; j++)
            matrix[j][i] = a++;
```

More on arrays

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- Arrays can be initialized when they are defined:

```
/* a[0] = 3,
   a[1] = 7,
   a[2] = 9 */
int a[3] = {3, 7, 9};

/* list[0]=0.0, …,
   list[99]=0.0 */
float list[100] = {};

int a[3][3] = {
  { 1, 2, 3},
  { 4, 5, 6},
  { 7, 8, 9},
};
```

- Strings are arrays of characters terminated with the null character \0:

```
char str[6] =
   {'h','e','l','l','o','\0'}
```

… is the same as:

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

- Secretly, arrays are (almost) the same as pointers

Example string library

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

int main(int argc, char *argv[]) {
  char name1[12], name2[12], mixed[25];
  char title[20];

  strcpy(name1, "Rosalinda");
  strcpy(name2, "Zeke");
  strcpy(title, "This is the title.");

  printf("    %s\n\n", title);
  printf("Name 1 is %s\n", name1);
  printf("Name 2 is %s\n", name2);

  if(strcmp(name1, name2) > 0)
              /* returns 1 if name1 > name2 */
    strcpy(mixed, name1);
  else
    strcpy(mixed, name2);

  printf("The biggest name alphabetically is %s\n",
      mixed);

  strcpy(mixed, name1);
  strcat(mixed, "  ");
  strcat(mixed, name2);
  printf("Both names are %s\n", mixed);
  return 0;
}
```

```
This is the title.

Name1 is Rosalinda
Name2 is Zeke
The biggest name alphabetically is Zeke
Both names are Rosalinda  Zeke
```

Sizes

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- How much memory does a value take up?
- Depends on machine and compiler!
- Use:

  `sizeof(`type**`)`** or **`sizeof(`**value**`)`**

- Evaluates at compile time to size in bytes
- e.g.

```
int nr = 1919;
int size = sizeof(nr);
```

void

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- There is a type called **`void`**.
- It has no value.
- Used for:
  - Untyped pointers (to raw memory): "**`void *`**"
  - Declaring functions with no return value (procedures)

- **`sizeof(void)`** shouldn't work
  - Why?
  - (Non-standard) GCC allows **`sizeof(void)==1`**
  - Why?

Operators

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Decreasing precendence

Operator	Associativity
`() [] -> .`	Left-to-right
`! ~ ++ -- + - * & (type) sizeof`	Right-to-left
`* / %`	Left-to-right
`+ -`	Left-to-right
`<< >>`	Left-to-right
`< <= > >=`	Left-to-right
`== !=`	Left-to-right
`&`	Left-to-right
`^`	Left-to-right
`|`	Left-to-right
`&&`	Left-to-right
`||`	Left-to-right
`?:`	Right-to-left
`= += -= *= /= %= &= ^= |= <<= >>=`	Right-to-left
`,`	Left-to-right

- `()` is a function call
- `->` means struct pointer indirection

- Unary `+, -, *`
- `*` here is pointer indirection

- Ternary if-else operator

Control flow

Control flow statements (like Java or C#)

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```
if (Expression) Statement_when_true
        else  Statement_when_false
```

```
switch (Expression) {
        case Constant_1 : Statement; break;
        case Constant_2 : Statement; break;
        …
        case Constant_n: Statement; break;
        default: Statement; break;
}
```

```
return (Expression)
```

Control flow statements (just like Java)

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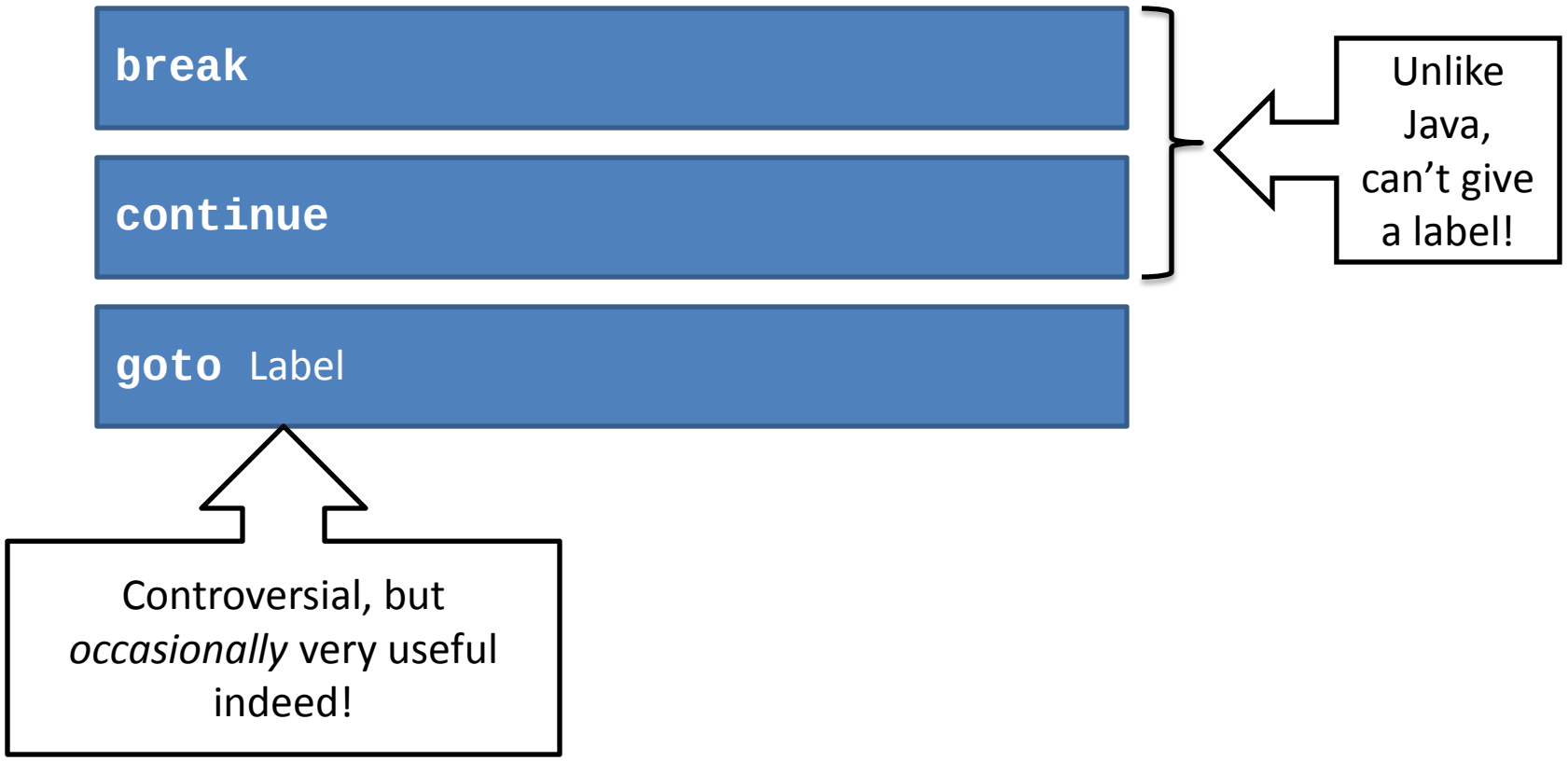
```
for (initial; Test; Increment) Statement
```

```
while (Expression) Statement
```

```
do Statement while (Expression)
```

Control flow statements (not like Java, same as C#)



Functions

- Main unit of composition for programs
  - **Return type**: type of the value returned by the function when it terminates
  - **Name**: identifies the function
  - **Arguments** of defined types: parameters to pass to the function
- Arguments *passed by value*
  - function gets copy of the value of the parameters but cannot modify the actual parameters
  - Values can be passed by reference using *pointers to the values* instead

General syntax:

```
returntype function_name(def of parameters) {
    localvariables
    functioncode
}
```

Example:

```
float findavg(float a, float b)
{
   float average;
   average=(a+b)/2;
   return(average);
}
```

Must be declared as prototypes *before* they are defined:

```
float findavg(float a, float b );
```

Example

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```
/* Compute factorial function */
/* fact(n) = n * (n-1) * … * 2 * 1 */

#include <stdio.h>

int fact(int n)
{
        if (n == 0) {
                return(1);
        } else {
                return(n * fact(n-1));
        }
}

int main(int argc, char *argv[])
{
        int n, m;

        printf("Enter a number: ");
        scanf("%d", &n);
        m = fact(n);
        printf("Factorial of %d is %d.\n", n, m);
        return 0;
}
```

main() is also a function

```
/* program to print arguments from
   command line */
#include <stdio.h>

int main(int argc, char **argv) {
     int i;

     printf("argc = %d\n\n",argc);
     for (i=0;i<argc;++i)
           printf("argv[%d]: %s\n",i,
   argv[i]);
   return 0;
}
```

- **argc**: argument count.
  Number arguments passed in the command line
- **argv**: argument vector (array).
  All the arguments as strings
- **argc** is always at least 1 since **argv[0]** is the name of the program

```
/* append one file to the another */
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char **argv) {
    int c;
    FILE *from, *to;
    if (argc != 3) {   /* Check the arguments. */
        fprintf(stderr, "Usage: %s from-file to-file\n",
     *argv);
        exit(1);
    }
    if ((from = fopen(argv[1], "r")) == NULL) {
        perror(argv[1]);          /* Open the from-file
     */
        exit(1);
    }
    if ((to = fopen(argv[2], "a")) == NULL) {
        perror(argv[2]);     /* Open the to-file */
        exit(1);
    }
 /* Read one file and append to the other until EOF */
    while ((c = getc(from)) != EOF)
        putc(c, to);
    /*close the files */
    fclose(from);
    fclose(to);
    exit(0);
}
```

printf

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- Just another function, but very useful!

```
#include <stdio.h>
int i = 79;
const char *s=“Mothy”;
printf(“My name is %s and I work in CAB F %d\n”, s, i);
```

- First argument is format string
  - see “man 3 printf” for all the (many) options
- Remaining arguments are arbitrary
  - but must match the format
- You will see other “printf-like” functions