Introduction to the C Programming Language

Accompanying Tutorial to Operating Systems Course

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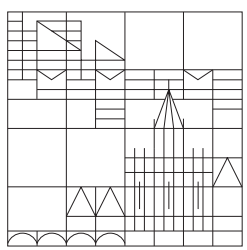


Schedule: A Guided Tour through C

- Quick introduction
- Show essential elements of the language
- No details, rules, and exceptions
- Provide examples
- Show the basics, such as
  - variables and constants
  - arithmetic
  - control flow
  - functions
  - rudiments of input and output
- Some of the (important) differences to JAVA
  - memory layout and the consequences
  - memory allocation
  - pointers
  - structures

The First Program Is Always The Same

Print the words: "Hello, world"

Not that easy, because you have to:

- Create the program text
- Compile it successfully
- Run it
- Get the output

```
1 #include <stdio.h>
2
3 int
4 main(void)
5 {
6         printf("Hello, world\n");
7         return (0);
8 }
```

Compilation On A UNIX-like OS

```
$ cc -Wall hello.c
$ ls
hello.c a.out
$ ./a.out
Hello, world
$
```

engine	filename	description
	`hello.c`	source code
preprocessor	`hello.i`	source w/ preproc. directives expanded
compiler	`hello.s`	assembler code
assembler	`hello.o`	object code ready to be linked
linker	`a.out`	executable

From Source Code To Executable Code

Translation Steps (multi-phase compilation)

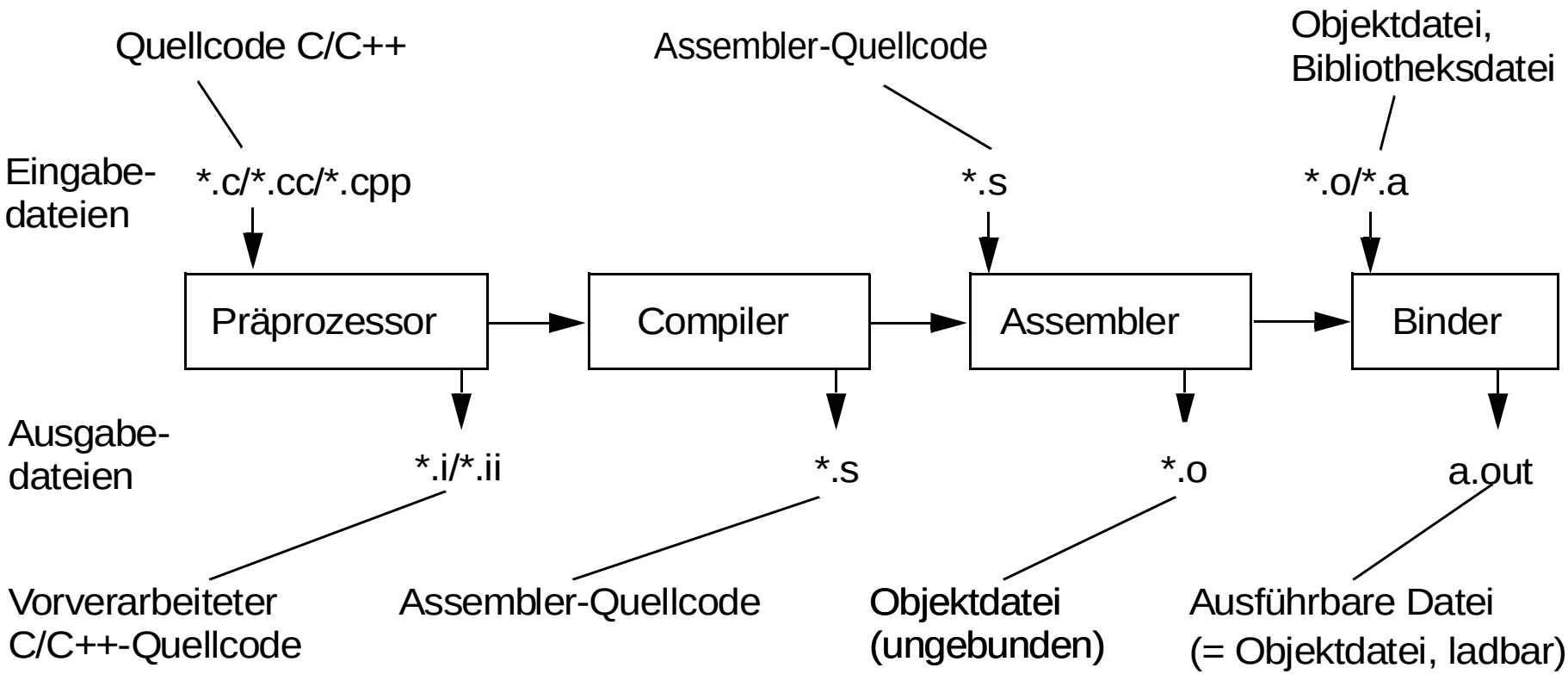
Compilation	HLL source code to assembler source code
Assembly	Assembler source code to object code
Linking	Object code to executable code

Compilers and assemblers create object files containing the generated binary code and data for a source file. Linkers combine multiple object files into one, loaders take object files and load them into memory.

Goal: An executable binary file (`a.out`)

From high-level language (HLL) *source code* to *executable code*, *i.e.*, concrete processor instructions in combination with data.

Translation Steps Using gcc(1)



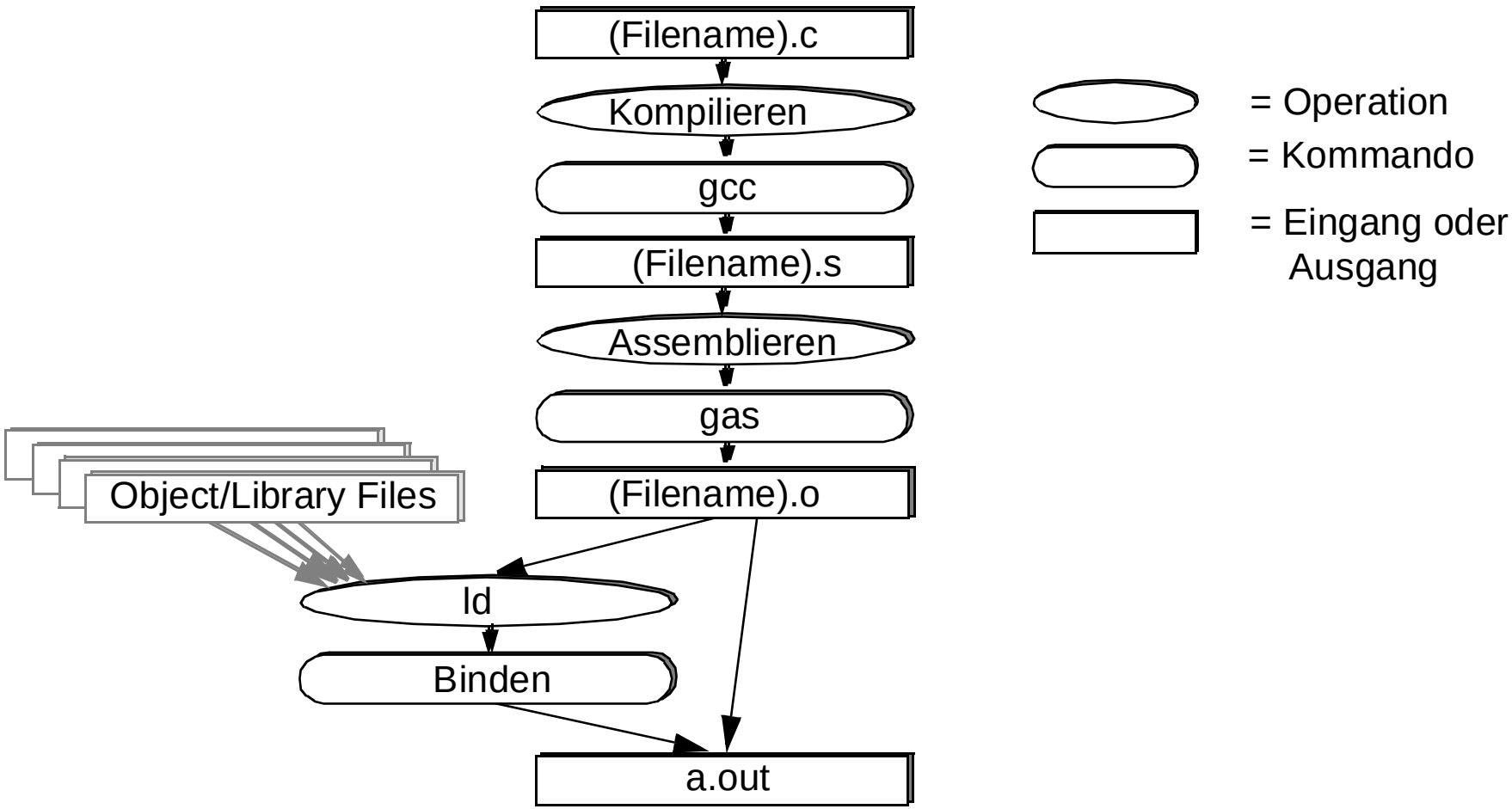
File Suffixes And Their Meaning

For any given input file, the file name suffix determines what kind of compilation is done (see `gcc(1)` for more details and suffixes):

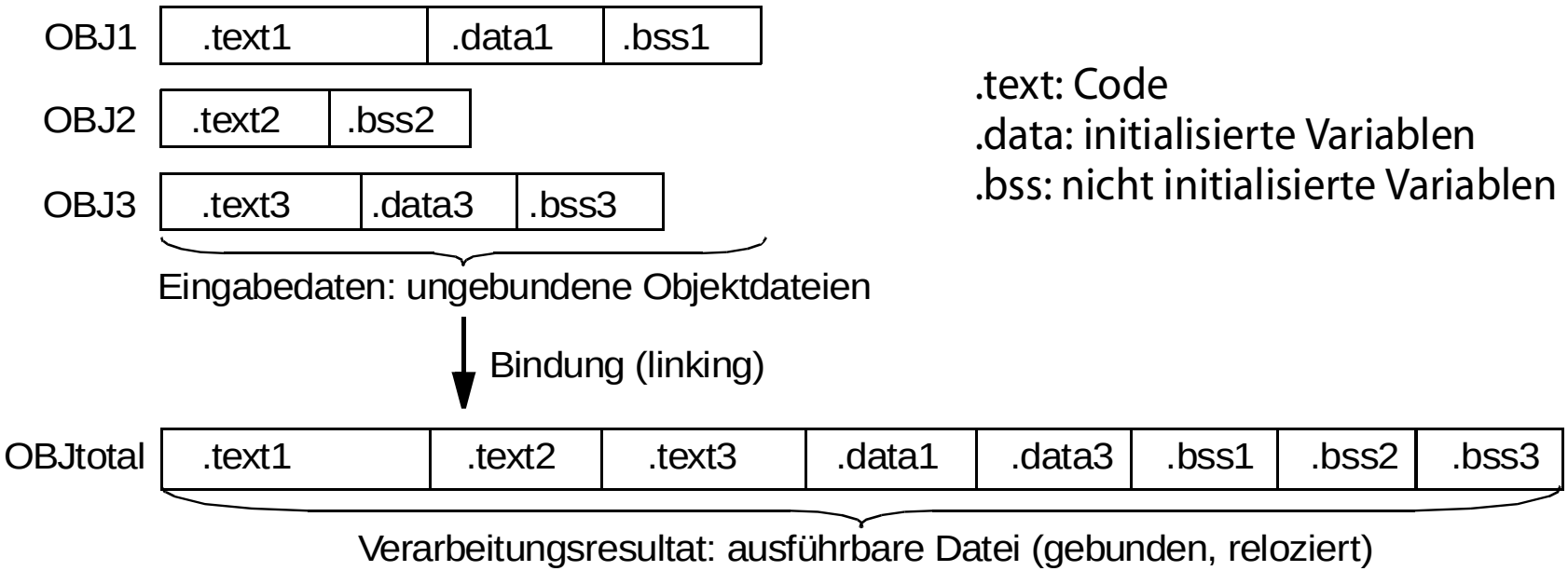
suffix	**compilation step**
`.c`	C source code which must be preprocessed
`.i`	C source code which should not be preprocessed
`.h`	Header file to be turned into a precompiled header
`.s`	Assembler code
`.o`	An object file to be fed straight into linking

- Any of this steps can be done on its own.
- You may want to try and examine the outputs.

Creation Of An Executable File



Linking An Executable Binary



.text: Code
.data: initialisierte Variablen
.bss: nicht initialisierte Variablen

- Each object code (compiled seperately) starts at address 0
- Linking them together involves
  - centralization of sections
  - relocation of adresses

Typical Program Organisation

A typical program divides naturally in sections

Code machine instructions, should be unmodifiable, size is known after compilation, does not change (`.text`)

Data

- constants
  - often placed in read-only `.text`
- static data
  - initialized (`.data`) / uninitialized (`.bss`)
  - constant address in memory
  - permanent life time
- dynamic data
  - stack or heap
  - storage space not known
  - volatile life time

Virtual Memory And Segments

Virtual Memory

- Whenever a process is created, the kernel provides a chunk of physical memory which can be located anywhere
- Through the magic of virtual memory (VM), the process believes it has all the memory on the computer

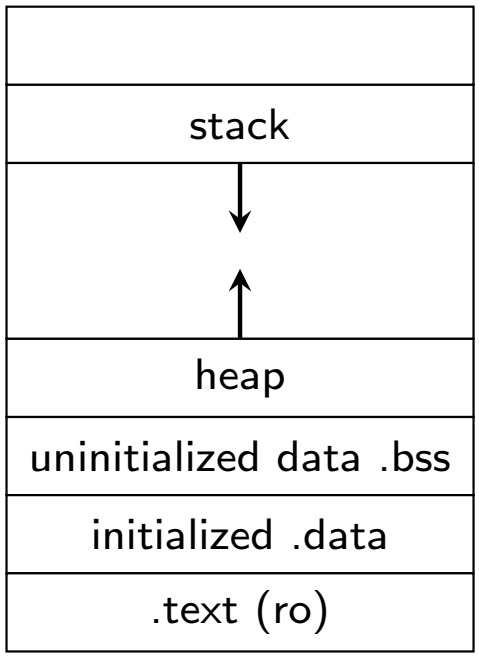
Typically the VM space is laid out in a similar manner:

- Text Segment (`.text`)
- Initialized Data Segment (`.data`)
- Uninitialized Data Segment (`.bss`)
- The Stack
- The Heap

Memory Layout Running Process

high address

low address

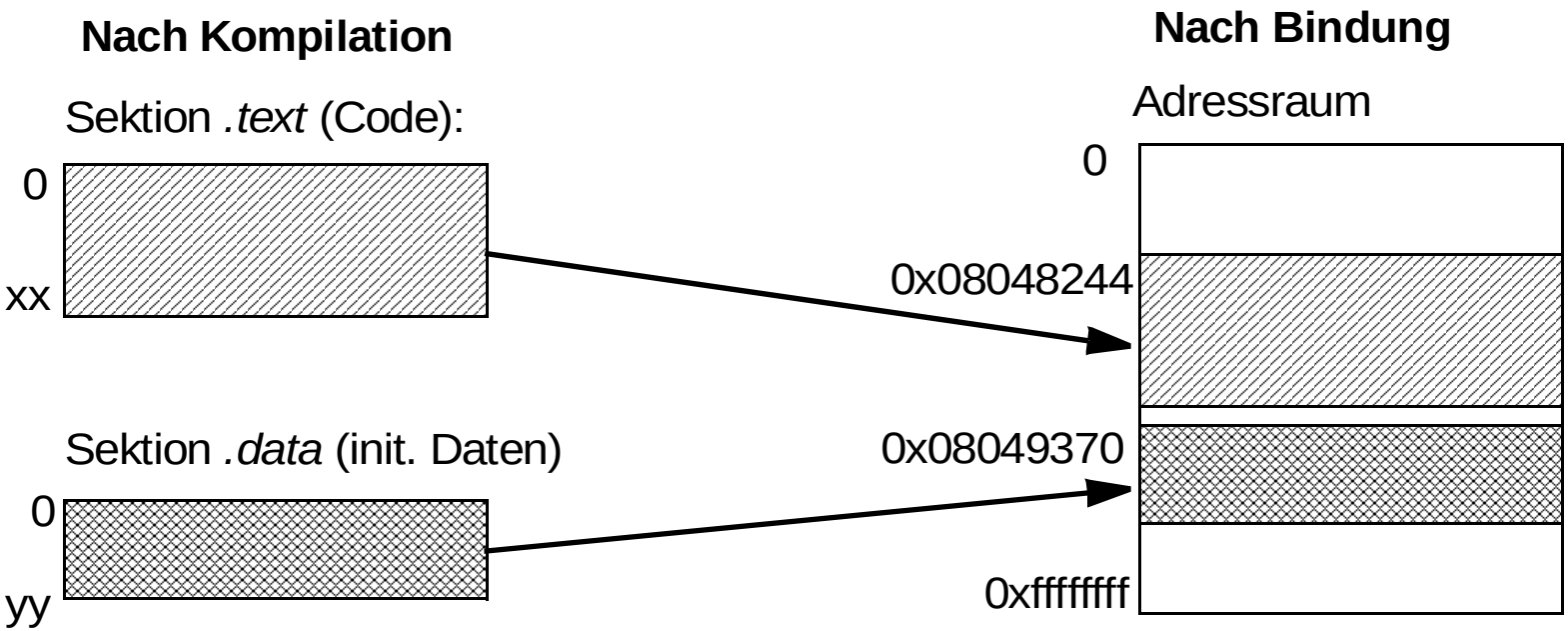


command-line args & environment variables

initialized to zero by `exec`

read from program file by `exec`

Program Section In Virtual Memory



Jede Sektion beginnt bei Adr. 0, Sektionen sind »logische. Adressräume« des Compilers

Alle Sektionen sind im Adress-raum »absolut« platziert

C Programs In (Address) Space And (Run-)time

Where is my data and why do I have to know?

- C is closely related to the machine. Before talking about pointers, storage allocation etc. some background knowledge about address space, (virtual) memory and its allocation during program execution comes in handy.
- Knowledge about the memory layout of a program is quite helpful when debugging.
- Knowledge about what is happening inside the machine on program execution is fundamental, to both, debugging programs and, in first place, writing clean code.

Storage Classes

Placement of data in memory depends on storage class

- An object, such as a variable, is a location in storage, and its interpretation depends on two main attributes: its *storage class* and its *type*.
- The *storage class* determines the lifetime of the storage associated with the identified object.
- The *types* determine the meaning of the values found in the identified object.
- In C we have two storage classes: *automatic* and *static*.
- Storage class specifiers (`auto`, `extern`, `register`, `static`) together with the context of an object's declaration, specify its storage class.

Automatic Storage Class

Automatic Objects

- `auto` and `register` give the declared objects automatic storage class, and may be used only within functions.
- They are local to a block[1], discarded on exit from the block.
- Declarations within a block create automatic objects if no storage class specification is mentioned or `auto` is used.
- Initialization of automatic objects is performed each time the block is entered at the top (if a jump into the block is executed the initializations are not performed).
- Objects declared `register` are automatic, and are (if possible) stored in fast registers of the machine
- For `register` the address operator '`&`' is not allowed.

[1] aka "compound statement", such as the body of a function

Static Storage Class

Static Objects

- May be local to a block or external to all blocks.
- In both cases, they retain their values across exit from and reentry to functions and blocks.
- Within a block, static objects are declared with `static`.
- Objects declared outside of all blocks (at the same level as function definitions) are always static.
- On the outer level, the keyword `static` makes them local to a particular translation unit (*internal linkage*).
- They are global to an entire program by omitting an explicit storage class, or by using `extern` (*external linkage*).

Storage Class And Sections

Intermediate Summary

- A program executed does not only use storage for its instructions, but additionally needs space for, *e.g.*, variables
- Variables may be temporary, dynamically allocated, or static (*i.e.*, permanent in terms of storage allocation), initialized or uninitialized, declared as constant (`const`) and thus read-only
- Placement of data in memory depends on its storage class.
- During the translation process the compiler uses *sections* to divide the address space into logical units.
- Details vary with operating systems and compiler used.

Variable Placement And Life Time (Code)

```
int a;
static int b;

void
func(void)
{
        char c;
        static int d;
}

int
main(void)
{
        int e;

        int *pi = (int*) malloc(sizeof(int));
        func();
        func();
        free(pi);
        return (0);
}
```

Variable Placement And Life Time (Code)

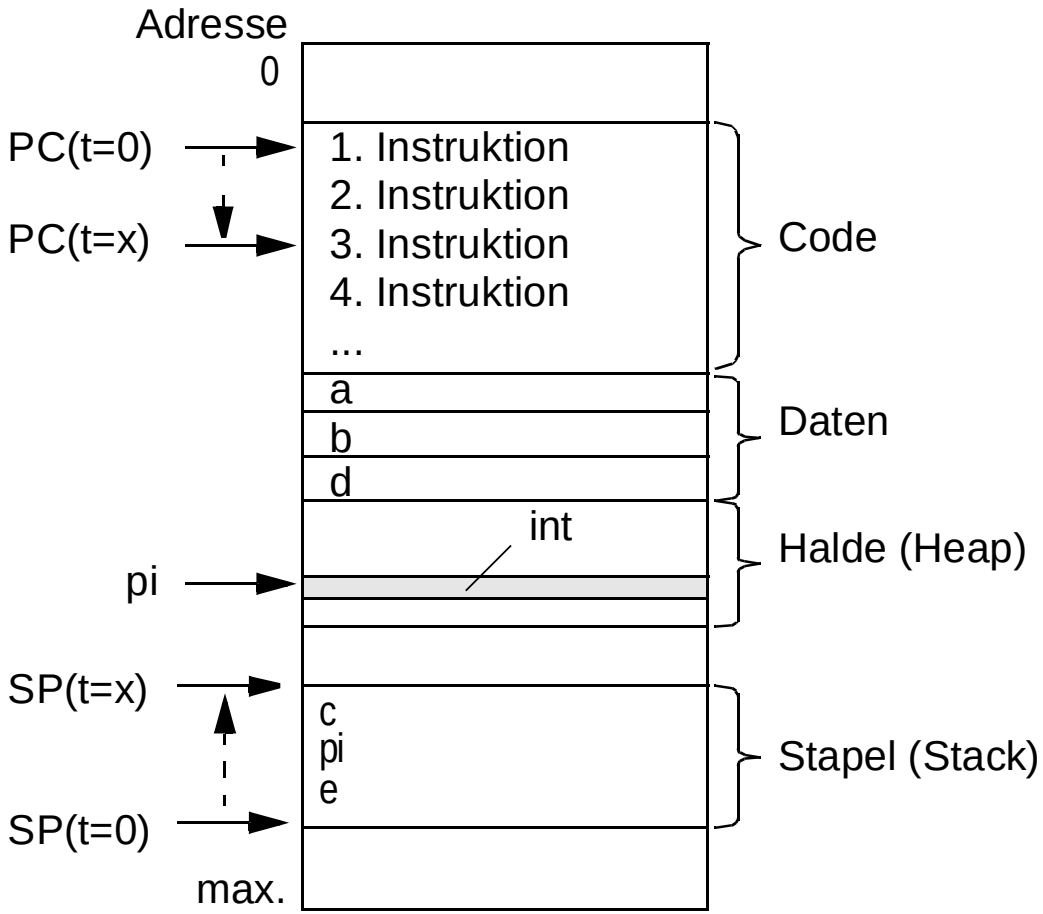
```
int a;          /* Permanent life time */
static int b; /* dito, but reduced scope */

void
func(void)
{
    char c; /* only for the life time of func() */
            /* but 2x; visible only in func()   */
    static int d; /* i'm unique, exist once at a stable */
                  /* address, visible only in func()    */
}

int
main(void)
{
    int e; /* life time of main() */

    int *pi = (int*) malloc(sizeof(int)); /* newborn */
    func();
    func();
    free(pi); /* RIP, pi points to an invalid address */
    return (0);
}
```

Variable Placement And Life Time (Diagram)



t=0: Programmausführung wird gestartet, d.h., Ausführungsumgebung ist bereits initialisiert

t=x: beliebiger Zeitpunkt während der Programmausführung

Variable Placement

Variables (outside a function) Globally declared variables go to the *Uninitialized Data Segment* if they are not initialized, to *Initialized Data Segment* otherwise. Necessary for the OS to decide if storage has to be *loaded* with initialization data from the executable binary.

Variables (inside a function) Implicit assumption of `auto`, go to *The Stack*. Declared as `static`, see above.

Constants (`const`) *Text Segment*

Function Parameters Are pushed on *The Stack* or stored in registers. If pointers are passed, data is elsewhere.

Memory Segments

Text Segment. The text segment contains the actual code (including constants) to be executed. It's usually sharable, so multiple instances of a program can share the text segment to lower memory requirements. This segment is usually marked read-only so a program can't modify its own instructions.

Initialized Data Segment. This segment contains global variables which are initialized by the programmer.

Uninitialized Data Segment. Also named `.bss` (block started by symbol) which was an operator used by an old assembler. This segment contains uninitialized global variables. All variables in this segment are initialized to `0` or `NULL` pointers before the program begins to execute.

Memory Segments (cont.)

The Stack The stack is a collection of stack frames which we will discuss later. When a new frame needs to be added (as a result of a newly called function), the stack grows downward.

The Heap Dynamic memory, where storage can be (de-)allocated via C's `free(3)`/`malloc(3)`. The C library also gets dynamic memory for its own personal workspace from the heap as well. As more memory is requested "on the fly", the heap grows upward.

The C Preprocessor

The C preprocessor performs ...

- Inclusion of named files
- Macro Substitution ($\rightarrow$ consult your favourite C book)
- Conditional Compilation ($\rightarrow$ consult your favourite C book)

File Inclusion

A control line of the form

```
#include filename
```

causes the replacement of that line by the entire contents of the file *filename*.

Note

The characters in the name *filename* must not include > or `\n`, and the effect is undefined if it contains any of ", ', \ , or /*.

Location

The named file is searched for in a sequence of implementation-dependent places (often starting in `/usr/include`).

Predefined Names

Several identifiers are predefined, and expand to produce special information. They, and also the preprocessor expression operator `defined`, may not be undefined or redefined.

`__LINE__`	A decimal constant containing the current source line number
`__FILE__`	A string literal containing the name of the file being compiled
`__DATE__`	A string literal containing the data of compilation 'Mmm dd yyyy'
`__TIME__`	A string literal containing the data of compilation 'hh:mm:ss'
`__STDC__`	The constant 1. It is intended that this identifier be defined to be 1 only in standard-conforming implementations

C Programs

Basic building blocks

- functions
- statements
- variables
- arguments

- *functions* contain *statements*
- *statements* specify computing operations to be done
- *variables* store values used during computation
- *arguments* (one way to) communicate data between functions

Building Blocks Of Our Example

- A function called `main`
- Liberty to name functions whatever you like, but . . .
- `main` is special, as any program begins execution at the beginning of `main`
- Every program must have a `main` somewhere
- `main` will usually call other functions to help perform its job
  - Functions that you wrote
  - Functions that are provided for you, *e.g.* `printf`

Some Explanations About The Program Itself

```
1 #include <stdio.h>
2
3 int
4 main(void)
5 {
6         printf("Hello, world\n");
7         return (0);
8 }
```

- line 1: tell compiler to include information about the standard input/output library
- line 3/4: define a function named `main`, which receives no arg values. Parentheses after the function name surround the argument list. Returns an `int`.
- line 5/8: statements of `main` are enclosed in braces
- line 6: `main` calls library function `printf`, which prints this sequences of characters; `\n` represents the newline character.

Line 6: Print A String

- A function is called by naming it, followed by a parenthesized list of arguments:

  ```
  printf("Hello␣world\n");
  ```

  calls the function `printf` with the argument

  ```
  "Hello␣world\n"
  ```

- `printf` is a library function that prints output

  (in this case the string of characters between the quotes)

Character String/String Constant

- A sequence of characters in double quotes is called a *character string* or *string constant*.
- Sequence `\n` stands for the *newline character*, which when printed advances the output to the left margin of the next line
- We have to use `\n` to include a newline character with `printf`

```
printf("Hello, world
");
```

```
$ cc hello.c
hello.c:6:16: missing terminating " character
hello.c:7:9: missing terminating " character
hello.c: In function ‘main’:
hello.c:8: error: syntax error before "return"
```

Printing "Hello, world"

- `printf` never supplies a newline automatically
- So several calls can build up an output line in stages
- Our first program could just as well have been written like below to produce identical output:

```
#include <stdio.h>

int
main(void)
{
        printf("Hello, ");
        printf("world");
        printf("\n");
        return(0);
}
```

Escape Sequences

- Notice that `\n` represents only a single character
- An *escape sequence* like `\n` provides a general and extensible mechanism for hard-to-type or invisible characters.

`\a`	alert (bell) character	`\\`	backslash
`\b`	backspace	`\?`	question mark
`\f`	formfeed	`\'`	single quote
`\n`	newline	`\"`	double quote
`\r`	carriage return	`\`*ooo*	octal number
`\t`	horizontal tab	`\x`*hh*	hexadecimal number
`\v`	vertical tab		

Table: The complete set of escape sequences

Fahrenheit-Celsius: $C = (5/9)(F - 32)$

```
1  #include <stdio.h>
2  /* print fahrenheit-celsius table
3     for fahrenheit = 0, 20, ..., 300 */
4  int
5  main(void)
6  {
7          int fahr, celsius;
8          int lower, upper, step;
9
10         lower = 0;    /* lower limit */
11         upper = 300;  /* upper limit */
12         step = 20;    /* step size */
13
14         fahr = lower;
15         while (fahr <= upper) {
16                 celsius = 5 * (fahr - 32) / 9;
17                 printf("%d\t%d\n", fahr, celsius);
18                 fahr = fahr + step;
19         }
20         return (0);
21 }
```

```
0       -17
20      -6
40      4
60      15
80      26
100     37
120     48
140     60
160     71
180     82
200     93
220     104
240     115
260     126
280     137
300     148
```

Declarations And Assignment Statements

A *declaration* announces the properties of variables.
Consists of *type name* and a *list of variables*, such as:

```
7           int fahr, celsius;
8           int lower, upper, step;
```

Range/size of data types depends on machine

```
10          lower = 0;    /* lower limit */
11          upper = 300;  /* upper limit */
12          step = 20;    /* step size */
```

Assignment statements set the variables to their initial values.

Basic Data Types

type	description
`char`	a single byte, capable of holding one character in the local character set
`int`	an integer, typically reflecting the natural size of integers on the host machine
`float`	single-precision floating point
`double`	double-precision floating point

`short` and `long` are qualifiers that can be applied to integers:

```
short int i;
long int f;
unsigned long d;
```

`signed` and `unsigned` can be applied to `char` and any integer.

Data Types And Sizes

Sizes are machine-dependent

- Each compiler is free to choose appropriate sizes for its own hardware. ISO C defines compile-time limits.
- `short` and `int` are *at least* 16 bit
- `long` is *at least* 32 bit
- `short` is no longer than `int`, `int` is no longer than `long`
- Numerical limits[2] are documented in `<limits.h>` and `<float.h>`. Additional limits are specified in `<stdint.h>`[3]

[2] ISO C99 : 7.10/5.2.4.2 : Numerical limits
[3] ISO C99 : 7.18 : Integer Types

The while Loop

Each line in the result table is computed the same way:

```
15          while (fahr <= upper) {
16                  celsius = 5 * (fahr - 32) / 9;
17                  printf("%d\t%d\n", fahr, celsius);
18                  fahr = fahr + step;
19          }
```

Integer Division

Why is $C = (5/9)(F - 32)$ computed as:

```
16                    celsius = 5 * (fahr - 32) / 9;
```

As in many other languages, *integer division truncates*, i.e., any fractional part is discarded. Since 5 and 9 are integers, $5/9$ would be truncated to zero and so all the Celsius temperature would be reported as zero.

printf(3) Revisited

```
#include <stdio.h>

int
printf(const char *format, ...);
```

`printf(3)` is a general-purpose output formatting function.[4]

- 1st argument is the string of characters to be printed.
  - Each **%** indicates **where** one of the other arguments
  - and **in what form** it is to be printed.
- Each % in the 1st arg is paired with the 2nd, 3rd arg etc.

```
17                    printf("%d\t%d\n", fahr, celsius);
```

- %d, for instance, specifies an integer argument, so `fahr` and `celsius` are printed with a tab (`\t`) between them.

[4] Not part of the C language, but defined in ANSI X3.159-1989 ("ANSI C")

Fahrenheit-Celsius Converter Bug List

Fixing problems

- Pretty printing: Right-justified output
- Switch from integer to floating-point arithmetic

Construct a patch for the changes using `diff(1)`

```
NAME
       diff - compare files line by line

SYNOPSIS
       diff [OPTION]... FILES

DESCRIPTION
       Compare files line by line.
       -u  -U NUM  --unified[=NUM]
           Output NUM (default 3) lines of unified context.
       -p  --show-c-function
           Show which C function each change is in.
```

```
$ diff -up fahrenheit_v1.c fahrenheit_v2.c
--- fahrenheit_v1.c     Sat Apr 19 08:58:48 2008
+++ fahrenheit_v2.c     Sat Apr 19 08:58:05 2008
@@ -4,7 +4,7 @@
 int
 main(void)
 {
-        int fahr, celsius;
+        float fahr, celsius;
         int lower, upper, step;

         lower = 0;   /* lower limit */
@@ -13,8 +13,8 @@ main(void)

         fahr = lower;
         while (fahr <= upper) {
-                celsius = 5 * (fahr - 32) / 9;
-                printf("%d\t%d\n", fahr, celsius);
+                celsius = (5.0/9.0) * (fahr - 32.0);
+                printf("%3.0f\t%6.1f\n", fahr, celsius);
                 fahr = fahr + step;
         }
         return (0);
```

Patching The First Version

Applying the patch using patch(1)

```
$ ls
fahrenheit_v1.c  fahrenheit_v1_v2.diff

$ patch < fahrenheit_v1_v2.diff
Hmm...  Looks like a unified diff to me...
The text leading up to this was:
--------------------------
|$ diff -up fahrenheit_v1.c fahrenheit_v2.c
|--- fahrenheit_v1.c    Sat Apr 19 08:58:48 2008
|+++ fahrenheit_v2.c    Sat Apr 19 08:58:05 2008
--------------------------
Patching file fahrenheit_v1.c using Plan A...
Hunk #1 succeeded at 4.
Hunk #2 succeeded at 13.
done

$ ls
fahrenheit_v1.c  fahrenheit_v1.c.orig  fahrenheit_v1_v2.diff
```

Fahrenheit-Celsius Converter v2

```
1  #include <stdio.h>
2  /* print fahrenheit-celsius table
3     for fahrenheit = 0, 20, ..., 300 */
4  int
5  main(void)
6  {
7          float fahr, celsius;
8          int lower, upper, step;
9
10         lower = 0;    /* lower limit */
11         upper = 300; /* upper limit */
12         step = 20;    /* step size */
13
14         fahr = lower;
15         while (fahr <= upper) {
16                 celsius = (5.0/9.0) * (fahr - 32.0);
17                 printf("%3.0f\t%6.1f\n", fahr, celsius);
18                 fahr = fahr + step;
19         }
20         return (0);
21 }
```

```
  0      -17.8
 20       -6.7
 40        4.4
 60       15.6
 80       26.7
100       37.8
120       48.9
140       60.0
160       71.1
180       82.2
200       93.3
220      104.4
240      115.6
...      ...
```

Printing With printf(3)

specifier	print as ...
%d	decimal integer
%6d	decimal, at least 6 characters wide
%f	floating point
%6f	floating point, at least 6 characters wide
%.2f	floating point, 2 characters after decimal point
%6.2f	floating point, at least 6 wide and 2 after decimal point

- Further `printf(3)` recognizes %o for octal, %x for hexadecimal, %c for character, %s for string, %p for address (pointer)
- ISO C : 7.19.6 : Formatted input/output functions

The for Loop, Fahrenheit-Celsius v3

```
1  #include <stdio.h>
2  /* print fahrenheit-celsius table
3     for fahrenheit = 0, 20, ..., 300 */
4  int
5  main(void)
6  {
7    int fahr;
8
9    for (fahr = 0; fahr <= 300; fahr = fahr + 20)
10     printf("%3d␣%6.1f\n", fahr, (5.0/9.0)*(fahr-32));
11
12   return (0);
13 }
```

```
  0   -17.8
 20    -6.7
 40     4.4
 60    15.6
 80    26.7
100    37.8
120    48.9
140    60.0
160    71.1
180    82.2
200    93.3
220   104.4
240   115.6
260   126.7
280   137.8
300   148.9
```

Symbolic Constants, Fahrenheit-Celsius Final

- Bad practice to bury "magic numbers" in a program
- Convey little information, hard to change in a systematic way
- A `#define` line defines a *symbolic name*

```
1  #include <stdio.h>
2
3  #define LOWER 0   /* lower limit of table */
4  #define UPPER 300 /* upper limit */
5  #define STEP  20  /* step size */
6
7  /* print fahrenheit-celsius table */
8  int
9  main(void)
10 {
11   int fahr;
12
13   for (fahr = LOWER; fahr <= UPPER; fahr += STEP)
14     printf("%3d␣%6.1f\n", fahr, (5.0/9.0)*(fahr-32));
15
16   return (0);
17 }
```

Character Input And Output

Processing character data

- Text I/O is dealt with as streams of characters
- A *text stream* is a sequence of characters divided into lines
- Each line consists of zero or more characters followed by a newline character (regardless of where the stream originates or where it goes to). The library makes each input or output stream conform to this model
- Standard library provides several functions for reading and writing one character at a time, of which `getchar(3)` and `putchar(3)` are the simplest.

getchar(3) and putchar(3)

```
#include <stdio.h>

int                     int
getchar(void);          putchar(int c);
```

- `getchar(3)` reads the next input character from a text stream
- Why does `getchar(3)` return an `int`?
  - `getchar(3)` returns a distinctive value when there is no more input. A value, called `EOF` (end of file), that cannot be confused with any real data. `EOF` is defined in `<stdio.h>`
  - The return type must be big enough to hold `EOF` in addition to any possible `char`.
- `putchar(3)` prints a character each time it is called

File Copying

Given `getchar(3)` and `putchar(3)` ...

. . . we can write a surprising amount of useful code without knowing anything more about input and output

Copying input to output one character at a time

read a character
`while` (*character is not end-of-file indicator*)
    output the character just read
    read a character

File Copying, v1

read a character
`while` (*character is not end-of-file indicator*)
    output the character just read
    read a character

```
1  #include <stdio.h>
2
3  /* copy input to output, v1 */
4  int
5  main(void)
6  {
7          int c;
8
9          c = getchar();
10         while (c != EOF) {
11                 putchar(c);
12                 c = getchar();
13         }
14
15         return (0);
16 }
```

File Copying, v2

- An assignment, such as `c = getchar()` is an expression and has a value (value of the left hand side after the assignment)
- An assignment can appear as part of a larger expression

```
1  #include <stdio.h>
2
3  /* copy input to output, v2 */
4  int
5  main(void)
6  {
7          int c;
8
9          while ((c = getchar()) != EOF)
10                 putchar(c);
11
12         return (0);
13 }
```

Character Counting, v1

```
1  #include <stdio.h>
2
3  /* count characters in input, v1 */
4  int
5  main(void)
6  {
7          long nc;
8
9          nc = 0;
10         while (getchar() != EOF)
11                 ++nc;
12         printf("%ld\n", nc);
13
14         return (0);
15 }
```

Character Counting, v2

```
1  #include <stdio.h>
2
3  /* count characters in input, v2 */
4  int
5  main(void)
6  {
7          double nc;
8
9          for (nc = 0; getchar() != EOF; ++nc)
10                 ; /* nothing */
11         printf("%.0f\n", nc);
12
13         return (0);
14 }
```

Line Counting

- Standard library ensures that an input text stream appears as a sequence of lines, each terminated by a newline

```
1  #include <stdio.h>
2
3  /* count lines in input */
4  int
5  main(void)
6  {
7          int c, nl;
8
9          nl = 0;
10         while ((c = getchar()) != EOF)
11                 if (c == '\n')
12                         ++nl;
13         printf("%d\n", nl);
14
15         return (0);
16 }
```

Word Counting

```
NAME
    wc - word, line, and byte or character count

SYNOPSIS
    wc [-c | -m] [-hlw] [file ...]

DESCRIPTION
    The wc utility reads one or more input text files, and,
    by default, writes the number of lines, words, and bytes
    contained in each input file to the standard output
```

```
$ wc /etc/services
285    1398    9732 /etc/services
$ cc count_words.c
$ cat /etc/services | ./a.out
285 1398 9732
```

```c
#include <stdio.h>

#define IN  1   /* inside a word */
#define OUT 0   /* outside a word */

/* count lines, words and, characters in input */
int
main(void)
{
        int c, nl, nw, nc, state;

        state = OUT;
        nl = nw = nc = 0;
        while ((c = getchar()) != EOF) {
                ++nc;
                if (c == '\n')
                        ++nl;
                if (c == ' ' || c == '\n' || c == '\t')
                        state = OUT;
                else if (state == OUT) {
                        state = IN;
                        ++nw;
                }
        }
        printf("%d %d %d\n", nl, nw, nc);
        return (0);
}
```

Counting Digits, White Spaces, And The Rest

Next is an artificial program, which counts the number of occurrences of each digit, of white space characters (blank, tab, newline), and all other characters.

It will help us to ...

- introduce arrays
- talk about initialization
- see that chars are, by definition, just small integers
- speak about coding conventions

The output of the program on itself is:

```
$ cat count_digits.c | ./a.out
digits = 10 3 0 0 0 0 0 0 0 1, white space=122, other=361
$ wc -m count_digits.c
497 count_digits.c
```

```c
#include <stdio.h>

/* count digits, white space, others */
int
main(void)
{
        int c, i, nwhite, nother;
        int ndigit[10];

        nwhite = nother = 0;
        for (i = 0; i < 10; ++i)
                ndigit[i] = 0;

        while ((c = getchar()) != EOF)
                if (c >= '0' && c <= '9')
                        ++ndigit[c-'0'];
                else if (c == ' ' || c == '\n' || c == '\t')
                        ++nwhite;
                else
                        ++nother;

        printf("digits =");
        for (i = 0; i < 10; ++i)
                printf(" %d", ndigit[i]);
        printf(", white space=%d, other=%d\n", nwhite, nother);

        return (0);
}
```