Introduction

HISTORY, BASIC SYNTAX

What is C?

- C is a *general-purpose* programming language initially developed by Dennis Ritchie between 1969 and 1973 at AT&T Bell Labs
- It is an imperative procedural language intended for system software
  – Strong ties with UNIX operating system
- It has influenced many other programming languages
  – C++, C#, ObjC, Java, JavaScript, Go, csh, ...

Why C?

- It's still popular and widely used
  – Available on almost all platforms
  – Lots of libraries for different tasks
- Provides a relatively low-level (or mid-level) access to the operating system and hardware
  – System-level programming, embedded systems
  – Can lead to better performance

Standards

- First standard by ANSI in 1989, known as “ANSI C” or C89
  - Still the best choice when portability is important!
  - ISO adopted the same standard in 1990 (C90)
- Next revision in 1999, C99
  - New datatypes, complex numbers, variable length arrays,...
  - Not fully backwards compatible with C90
- Current standard is C11
  - Improved Unicode support, atomic operations, multi-threading, bounds-checked functions, ...

Look and feel

```
/* Computing the factorial of an specified (by the user) number */
#include <stdio.h>
int fact(int n);
int main(void){
   int current;
   printf("Enter some POSITIVE integer (non-positive to finish): ");
   scanf("%d", &current);
   while (current > 0) {
      printf("Factorial of %d is %d\n", current, fact(current));
      printf("Enter a POSITIVE integer (non-positive to finish): ");
      scanf("%d", &current);
   }
   return 0;
}

/* This function returns the factorial of the specified integer (n) */
int fact(int n) {
 ...
```


Basic syntax

- Code is case sensitive
- *Statements* terminate with ;
- {} enclose *blocks*
- There are two ways to comment:

```
/* Single or
   Multiple lines */

// Single line (C99)
```

```
/* example function */
float foo(int bar) {
   int i, c = 0;
   float x;

   x = 0.1;
   for (i = 0; i < bar; i++) {
      x += i*3.14 + c;
      c = i + 2;
   }
   return x;
}
```


Formatting

- Free format
  - Whitespace, newlines, layout etc. do not matter ...

to the computer !

```
/* same example function? */
float
foo(/*float f,*/int
bar) { int   i,c=0; float x;
x=0.1;for  (/*i=10
; i<2*bar*/  i=
0;i<bar;i++){x+=i*3.1/*1.2+
     */4+c;c=i+2;}return x;}
```

```
/* example function */
float foo(int bar) {
   int i, c=0;
   float x;

   x = 0.1;
   for (i=0; i<bar; i++) {
      x += i*3.14 + c;
      c = i + 2;
   }
   return x;
}
```

DATATYPES, VARIABLES, ASSIGNMENT AND OPERATORS

Basic data types

- Basic datatypes in C are:

`char`	character
`int`	integer number
`long`	long integer number
`float`	floating point number
`double`	double precision float

- Integers can be signed (default) or **`unsigned`**
- C has also *pointer* types
- There is also a special type **`void`**

Variables

- Variable data types are static
- Declare variables before using them
  - C90 requires that the declarations are before any other statements
- Valid variable names in C:
  - Upper and lower case letters, underline and numbers are allowed

```
// variable declaration
int i;
float f, g;
double total = 1.9;

// valid names
int i3, myINT, I_o;
float o3Gf_ry9;

// invalid names
int 33, 9a, i-o;
float o3.Gf;

// data type matters
char c;
float f;

f = 1.234;
c = f;      // ERROR!
            // wrong data type
```


Variable assignment

- Assign a value to a variable:
  `variable = value;`
- Both should have the same data type
  - Implicit conversion between compatible types
  - Explicit conversion (typecast) syntax:
    `(type) var`

```
// examples of assignment
count = 10;
i = j = 0;
k = i*j + 1;

// assign at declaration
int i = 4;

// typecast from int to float
int i;
float f;

i = 5 * 21;
f = (float) i;

// watch out for operator order
(float) i/5 != (float) (i/5)
```

Arithmetics

- Operators:

+	addition
-	subtraction
*	multiplication
/	division
%	modulus

- Operator precedence

```
1) % * /
2) + -
```

- Parentheses can be used to group operations () and change evaluation order

Compound assignment

- C has a short-hand notation for combined arithmetic operation and assignment
- Given an operator **`<op>`** and values **a** and **b**, the syntax is **`a<op>=b`** and the result is **`a=a<op>b`**
- For special cases **`a+=1`** and **`a-=1`** there are special operators **`++`** and **`--`**

```
// example of compound assignment
int count = 10;
count += 5;  // now count is 15
count /= 3;  // and now count is 5

// Adding one to count
count++;

// This is also valid!
++count;
```


Arithmetics and assignment examples

```
// addition, substraction
i = 5 + 2;
i = 5 - 2;
i += 1;       // i = i + 1
f -= 3.4;
i++;          // i = i + 1
i--;

// multiplication, division
i = 5 * 2;
i = 5 / 2;      // integer division
f *= 3.0 / 4.2;

// modulus
m = 25 % 3;
```

```
// grouping with ()s
b = a * (1.3 + (25%3));

// watch out for precedence!
f = 1 + q / (1 - q);
f = (1 + q) / (1 - q);

// also function calls use ()
f = r * sin(theta);
f = (r + p)*sin(theta);
```


Other operators

- Logical operators

`&&`	AND
`||`	OR
`>`	larger than
`<`	less than
`>=`	larger or equal
`<=`	less or equal
`==`	equal
`!=`	unequal
`!`	negation

- Bit-wise operators

`>>`	shift right
`<<`	shift left
`&`	AND
`|`	OR
`^`	XOR
`~`	complement

BASIC I/O

Basic I/O

- **`printf`** prints formatted text to the screen
- Format of **`printf`** call is

```
printf(<template> {, <variables>})
```

where

`<template>`	arbitrary string with optional *placeholders* for data from variables
`<variables>`	(optional) list of variables or values

Basic I/O

- Special characters that can be used in the template string:

`\n`	newline	**`\t`**	horizontal tab
`\"`	double quote	**`\\`**	literal backslash

- Placeholders are marked with **%** followed by formatting and type information
  - For now, we will just use the following formattings:

`%d`	integer value
`%f`	float value
`%s`	string

Basic I/O example

```c
#include <stdio.h>

int main(int argc, char *argv[]) {
   printf("The answer is %d.\n", 42);
   printf("Pi equals to %.2f", 3.14159265);
   printf(" ...at least to the %dnd decimal.\n", 2);
   return 0;
}

//output:
// The answer is 42.
// Pi equals to 3.14 ...at least to the 2nd decimal.
```

Summary

- Short history and different standards
- Basic syntax
- Variables and their type, assignment of values
- Arithmetic operations
- Basic IO (printf)

Getting started

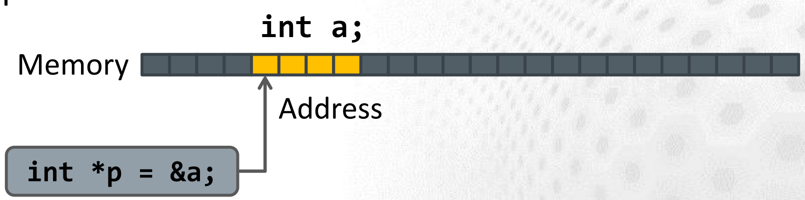
POINTERS, ARRAYS AND FUNCTIONS

Pointers

- On the hardware level a variable is actually a reference to a memory location
- The contents of the memory block determine the value of a variable
  - The size of the memory block depends on the type of the variable
- Memory *addresses* can be stored (and manipulated) using *pointers*
- Pointer variables can be considered as variables that hold the address of a element with given datatype (**int**, **char**, ...)

Pointers

- Pointer variables are defined by adding ***** into the definition, for example a pointer named **ptr** of type **int** is defined as **int *ptr;**
- The address of a variable can be obtained using **&** operator



Arrays

- Static arrays can be introduced using **[]**:

char str[20];	Array of 20 characters
double values[10];	Array of 10 doubles

- Elements of array can be accessed using the same **[]** operator. The value inside brackets is interpreted as an offset from the beginning of the array
  - Indices always start from 0
  - Last element of an array **A** of size **n** is **A[n-1]**

Array examples

```
// int array of size 10
int array[10];

// Set value of third element to 1
array[2] = 1;

// Print the value
printf("a[2]=%d\n", array[2]);

// type of array is equivalent to
// type (int*)
int *ptr;

array[0] = 3;
ptr = array;
printf("*ptr=%d\n", *ptr);
```


FUNCTIONS

Functions

- Functions are the only subroutine type in C
  - But functions do not have to return anything
- Function definitions are of form

```
type func-name(param-list)
{
   /* body of function */
}
```

- Here **type** is the return type of the function
  - **void** means that function does not return anything

main function

- Every C program has the main function with definition

```
int main(int argc, char *argv[])
{
   /* body of function */
}
```

- Command line arguments are passed to the program using **argc** and **argv**
- main should always return integer
  - zero means success, non-zero values are errors

Function example

- This function returns the sum of two integer arguments:

```
#include <stdio.h>
int add(int a, int b) {
   return a + b;
}

int main(void) {
   int val;
   val = add(3, 6);
   printf("Sum is %d\n", val);
   return 0;
}
```


Variable scoping

- Variable scoping in C is local unless defined otherwise
  - Variables declared in the function definition are only visible inside the function body
  - Variables of calling scope are not visible inside function body

```
void funcB(float a) {
   int counter;
   ...
}
int funcA(void) {
   float value_1, value2;
   funcB(value_1);
   ...
}
```

Not accessible from **funcA**

Not accessible from **funcB**

Arguments

- All arguments are passed as *values*
  - Copy of the value is passed to the function
  - Functions can not change the value of a variable in the *calling scope*
- Pointers can be used to pass a reference to a variable as an argument!

```
void funcB(int a) {
   a += 10;
}

int funcA(void) {
   int var = 0;
   funcB(var);
   // var is still 0!
   ...
}
```

csc

PREPROCESSOR

C preprocessor

csc

- The line **`#include <stdio.h>`** in the previous example is a *preprocessor directive*
  – It directs the preprocessor to literally read in the file `stdio.h` before the source is passed to the compiler
  – `stdio.h` has several definitions related to standard input and output, including the definition of the printf function

Preprocessor macros and #define

csc

- **`#define`** can be used to define "objects" or macros
- It has the form of
  `#define` ***`identifier replacement-list`*** **`new-line`**
- After the definition, all instances of ***`identifier`*** are replaced with ***`replacement-list`***

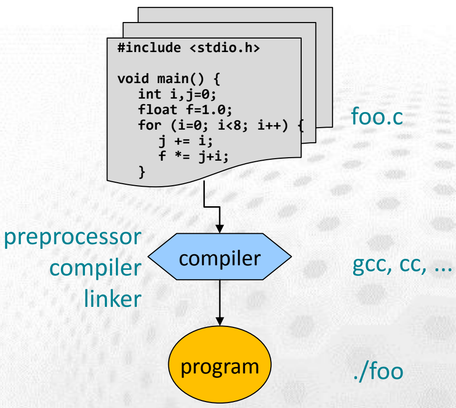
```
// Example
#define ONE 1
printf("Value is %d\n", ONE);
// Result: Value is 1
```


csc

COMPILING AND LINKING, MATH ROUTINES

Transition from source code to program

- Compiling:
  - Transforming the C source code to machine language
- Linker:
  - Combines object files generated by the compiler into a single executable program
- The result is an executable binary file



Let's try it out!

- Write the classic first program in C:

```
#include <stdio.h>
int main(int argc, char *argv[]) {
    printf("Hello, World!\n");
    return 0;
}
```

- Compile your code:

```
$ gcc -o hello hello.c
```

- Test your program:

```
$ ./hello
Hello, World!
```


Math routines library

- Math routines are defined in a *library* that is not linked in by default
- It includes the most common mathematical functions, e.g. `sin()`, `pow()`, `log()`, etc.
- Header `math.h` also has definitions for constants such as `M_PI` for **π**
- For power operation function `pow()` is used (^ is bitwise operator in C)

```
#include <math.h>

float r, theta;
double area, y;

// radius and an angle
r = 1.2;
theta = 0.456;

// calculate something
area = M_PI * pow(r,2);
y = sin(theta)
  + cos(theta/2.0);
y += exp(-3.1 * area);

// echo results
printf("area is %f\n", area);
printf("y=%.18e\n", y);
```


Compiler flags

- Compiler flags provide a way to control how the program code is processed
- For example following (and many other) options can be used with gcc:

  -o name of the output file
  -c generate an object file, do not link executable
  -lname link in library **name**, for example -lm
  -O optimize the program code (also -O2, -O3, ...)

- For more comprehensive list of options, see the man page of gcc ("man gcc")

Linking objects and libraries

- In complex projects:
  - Compile each source code file (.c) into an object file (.o)

```
$ gcc -c main.c
$ gcc -c sub.c
```

  - Link object files into a binary and execute the binary

```
$ gcc -o foo main.o sub.o -lm
$ ./foo
```

Link with math routines library!

Summary

- Functions
- Pointers
- Compiling
- Arrays
- Scoping

Control structures

LOGICAL COMPARISONS, BRANCHING

Boolean datatype

- C90 does not have a logical datatype
  - Comparison operators (**>**,**>=**,...) return integer 0 for FALSE and 1 for TRUE
- C99 has boolean type **`bool`** defined in header `stdbool.h`
  - Also defines constants **`true`** and **`false`** as integers with values 1 and 0 respectively
  - Backwards compatible with C90 definition

Recap: logical operators

- Operators

`>`	`larger than`
`<`	`less than`
`>=`	`larger or equal`
`<=`	`less or equal`
`==`	`equal`
`!=`	`unequal`
`&&`	AND
`||`	OR
`!`	NOT

- Precedence (high to low)

```
* / % + -
< <= > >=
== !=
&&
||
= += -= *= /= %=
```

Control structures // if – else

- Code execution can be branched according to a logical test using **`if`** statement:

```
if (...) {...} else {...}
```

conditional TRUE FALSE

- **TRUE** block is executed if the **conditional** evaluates to *non zero*, otherwise the (optional) **FALSE** block is executed

Control structures // if – else

```
// simple if-else
if (x > 1.2) {
   y = 4 * x * r;  // TRUE
} else {
   y = 0.0;         // FALSE
}

// else is optional
if (x || y) {
   z += x + y;
}
```

```
// complex if-elseif-else
if ((x > 1.2) && (i != 0))
{
   y = x * i;  // 1st TRUE
} else if ((x < 1.0) && c)
{
   y = -x;     // 1st FALSE
               // 2nd TRUE
} else {
   y = 0.0; // 1st, 2nd
FALSE
}
```


Control structures // switch

- **`switch (...) {`**
  `case ... : ...`
  `break;`
  `default: ... }`

condition

test value

end of branch

default branch executed if nothing else matches

- Condition:
  - single variable or expression
- Branch(=case) with matching value chosen
- **`break`** stops branch

Control structures // switch

```
// Simple switch based on the
// value of integer i
switch (i) {
    case 1:
        printf("one\n");
        break;
    case 2:
        printf("two\n");
        break;
    default:
        printf("many\n");
        break;
}
```

good style to break even the last branch!

Control structures // switch

A

```
switch (i) {
    case 1:
        printf("one\n");
        break;
    case 2:
        printf("two\n");
        break;
    default:
        printf("many\n");
}
```

B

```
switch (i) {
    default:
        printf("many\n");
    case 1:
        printf("one\n");
        break;
    case 2:
        printf("two\n");
        break;
}
```

C

```
switch (i) {
    case 1:
        printf("one\n");
    case 2:
        printf("two\n");
    default:
        printf("many\n");
}
```

In each case, what would be printed on the screen if i is 1, 2, or 3?

Ternary operator

- Ternary conditional is an expression that can be used as a short-hand if-else in assignments:

```
(conditional) ? value-if-true : value-if-false
```

```
// ternary conditional in use
total += found ? count : 0

// is equal to this
if (found)
   total += count;
else
   total += 0;
```


LOOPS

Loops // for

- Looping over a block of code can be accomplished using for statement:

```
for (<initial>;
     <condition>;
     <post-iteration>) {...}
```

`<initial>`	executed once before entering the loop
`<condition>`	stop loop when condition is FALSE
`<post-iteration>`	execute after each iteration

Loops // while

- **`while (...) {...}`**

  condition (→ `(...)`), code block (→ `{...}`)

- Code block executes repeatedly as long as condition is TRUE
- Condition evaluated before iteration

Loops // while

```c
// loop using a for-statement
//   i is incremented after each iteration
for (i = 0; i < bar; i++) {
    x += i*3.14 + c;
    c = i + 2;
}

// the same loop but with a while-statement
i = 0;
while (i < bar) {
    x += i*3.14 + c;
    c = i + 2;
    i++;
}
```


do while

- The condition for while is evaluated before the block is executed
  - Sometimes it is desirable to start the loop first and then check the condition
- This can be done using **`do {...} while ()`** loop

```c
// Execute the loop at least
// one time
counter = 0;

do {
    printf("in loop");
} while (counter != 0)
```


Special for loops

- All statements in the **`for`** loop construct are optional
- So all following loops are valid C code (with variables correctly defined):

```c
for (; a < treshold; a += 1e-3) {...}
for (; still_valid;) {...}
for (;;) {...}
```

- Try to avoid using these – use the **`while`** instead

Jump statements

- **break**
  - end a loop (for, while, do) or a switch statement
- **continue**
  - continue with the next iteration of a loop
- Note that these apply to the smallest enclosing iteration statement

```
// jump out of a loop
// at first iteration
for (i = 0; i < 10; i++) {
    break;
    printf("in loop");
}
printf("i=%d ", i);
// output: i=0


// jump to the next loop
// iteration
for (i = 0; i < 10; i++) {
    continue;
    printf("in loop");
}
printf("i=%d", i);
// output: i=10
```


Summary

- Boolean values, comparisons
- if-then-else
- switch-case
- Loops

Pointers and dynamic memory

USING POINTERS

Recap

- Pointer variables hold a reference to a memory location
- Pointers have type (**`int`**, **`float`**, ...)
- Pointer variables are defined with **`*`**, for example

```
int *a;    double *d;
```

- Address of a variable can be obtained using address operator **&** (same symbol as bit-wise AND)

Address operator &

- Operator **&** returns the reference to the operand
- Type of the pointer matches with the type of the operand
  - That is, reference to an **`int`** is of type pointer to an integer, **`(int *)`**

```
int i_value = 0;
double d_value;
int *ptr;

// This is ok
ptr = &i_value;

// Types have to match!
ptr = &d_value;
```

Dereferencing pointers with *

- Dereferencing means accessing the value from the address that pointer points to
- Dereferencing is done using ***** operator
- Precedence can be changed with parentheses ()

```
int a = 10;
int *ptr;

// ptr points to a
ptr = &a;

// Let's do some arithmetics
(*ptr)++;

// and print the value of a
printf("a=%d\n", a);

// Result: a=11
```


Functions with pointer arguments

- All function arguments are passed "by value"
  - When function changes the values of arguments the changes are not visible to the caller (no side effects)
- When a pointer is passed as a function argument the function can not change the value of the pointer itself, but it *can* modify the referenced value

Pointer arguments example

```
#include<stdio.h>

void demo(int a, int *b) {
    a += 1;
    *b += 1;
    printf("In demo function: a=%d, b=%d\n", a, *b);
}

int main(void) {
    int a = 0, b = 0;
    demo(a, &b);
    printf("In main after call: a=%d, b=%d\n", a, b);
    return 0;
}
// Result:
// In demo function: a=1, b=1
// In main after call: a=0, b=1
```


Pointer arithmetics

- Pointer variables can also be modified using arithmetic operations
- Can lead to bugs that are very difficult to find and fix
- Can be useful in some cases when manipulating arrays
- Try to avoid when possible!

```
#include<stdio.h>
#include<stddef.h>
int main(void) {
    int a = 0, b = 0;
    int *ptr;
    ptrdiff_t diff;
    diff = &a - &b;
    ptr = &a;
    *(ptr - diff) = 10;
    printf("a=%d,b=%d\n",a,b);
    return 0;
}
// Result: a=0,b=10
```

Dereferencing pointers with []

- For arrays it is more convenient to derefence the values using `[ ]` operator
  - This was already used with static sized arrays
- Definition of the `[ ]` operator is that `E1[E2]` equals to `(*(E1+(E2))`, for example

`b=3*arr[n+1]` is same as `b=3*(*(arr+(n+1)))`

Special pointers

- Pointers to type **void** can be cast back and forth to any other type
  - Provides a mechanism to implement type generic routines
  - Several standard library routines use void pointers
- Pointers of any type can be assigned to value **NULL**
  - Can be used to check if a pointer is associated or not
  - Pointers are not initialized to **NULL** by default

Pointers to pointers

- It is possible to have pointer references to pointers
  - This is very useful when functions have to manipulate values of arguments of pointer type
  - Multidimensional arrays are also naturally mapped into pointers of pointers

Pointer to a pointer example

```
#include<stdio.h>

int main(void) {
    int a = 5;
    int *int_ptr;
    int **int_ptr_ptr;

    int_ptr_ptr = &int_ptr;
    int_ptr = &a;

    printf("a=%d\n", **int_ptr_ptr);
    return 0;
}

// Result: a=5
```

MALLOC, REALLOC AND FREE

Memory management in C

- C manages memory statically, automatically and dynamically
  - Static allocations are determined during compile time and required memory allocation is done when execution starts
  - Automatic memory management is done for e.g. variables defined inside a function body
  - Dynamic memory management is controlled by the program logic at runtime

Dynamic memory management

- In most cases the exact size of all data structures is not known at compile time because they depend on the input data
- Dynamic memory management is accomplished by using pointers and controlling memory (de)allocation manually
- Relevant functions are **`malloc()`**, **`realloc()`**, **`free()`**

malloc

- **`malloc`** function is defined in header file `stdlib.h`:

```
void *malloc(size_t size);
```

- **`malloc`** returns a pointer of type **`void`** to a memory location with allocated space of size **`size`** bytes
  - If allocation fails, **`malloc`** returns **`NULL`**!
- The memory area returned by the malloc is uninitialized!

How to determine the size for allocation?

- The only argument for **malloc** function is the size of the object in bytes
- The sizes of different objects can be determined using **sizeof** operator which returns the size of the argument in bytes
  - Return type of the **sizeof** operator is **size_t**
- Example:

```
int *ptr = (int *) malloc(sizeof(int));
float **ptr = (float **) malloc(sizeof(float *));
```


realloc

- **realloc** function changes the size of allocation, its definition is

```
void *realloc(void *ptr, size_t size);
```

- The argument **ptr** has to point to a previously allocated object
  - If ptr is **NULL**, **realloc** is equivalent to **malloc**
- Contents of the allocated memory area returned by **realloc** is equal up to the lesser of old and new sizes

free

- **free** deallocates previous allocated object

```
void free(void *ptr);
```

- After freeing you should not try to access any part of the allocation
- Calling free with a pointer that does not point to a allocated memory can crash the code
  - Calling free twice is a common mistake!

Summary

- Pointers are references to memory locations
- Operators *****, **&** and **[]**
- Functions with pointer arguments can manipulate the values of arguments
- Pointers to pointers
- Dynamic memory management
  - malloc and free

Structures and strings

STRINGS

Strings

- Strings in C are arrays of type char that end with value 0 (not character 0!)
  - This definition is problematic and has caused many critical bugs especially in operating systems
- String manipulation routines are defined in header `<string.h>`
  - There are routines with both **`str`** and **`mem`** prefixes
    - Different behavior when the array is not NULL terminated

String manipulation

- Concatenate:

```
char *strncat(char *s1, char *s2, size_t n);
```

- Compare:

```
int strncmp(char *s1, char *s2, size_t n);
```

- Copy:

```
char *strncpy(char *s1, char *s2, size_t n);
```

- Search a character:

```
void *memchr(void *s, int c; size_t n);
```

- String length:

```
size_t strlen(char *s);
```

Character manipulation

- Defined in header **<ctype.h>**

`int isspace(int c)`	test for space
`int isalpha(int c)`	test for alphabetic letter
`int isdigit(int c)`	test for decimal digit
`int isalnum(int c)`	test for letter or digit
`int iscntrl(int c)`	test for control character
`int tolower(int c)`	convert to lower case
`int toupper(int c)`	convert to upper case

String examples

```
// two string buffers
char str1[256], str2[256];

// initialize the strings
strncpy(str1, "abc", 256);
strncpy(str2, "def", 256);

// add str2 to the end of str1
strncat(str1, str2, 3);

printf("len(str1)=%d\n", strlen(str1));
// output: 6

printf("%s, %s\n", str1, str2);
// output: abcdef, def

printf("tolower(A) = %c\n", tolower('A'));
// output: tolower(A) = a
```


STRUCTURES

Defining a structure

- Structures are defined using **struct** keyword:

```
struct tag_name {
    type member1;
    type member2;
    …
};
```

- Example:

```
struct book {
    char author[100];
    char title[100];
    char publisher[100];
    int year;
};
```

Declaring a structure variable

- Structure declarations are usually given at the beginning of the file before function definitions
  – Accessible by all functions in the same file
- Variables of a given structure type are declared using the struct keyword, for example

```
struct book item;
```

declares a variable **item** of type **struct book**

Structures - why?

- Structures can be considered as a collection of variables with (possibly) different datatypes
- Code can be made more readable when all related information is passed between function using just a one argument of relevant structure
  – For example the information of a book in a library
- Also implementing abstract datatypes, such as lists and binary trees, is much more convenient with structures

Accessing structure members

- Structure members can be accessed using **.**, for example setting the year and printing the title for a book defined previously:

```
struct book item;
...
item.year = 1984;
...
printf("Author: %s\n", item.author);
```


Pointer to structure

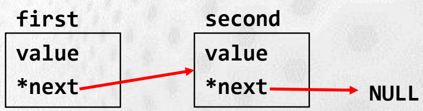
- There is a short-hand notation **->** for accessing elements of a pointer to a structure:

```
struct book item;
struct book *ptr;
ptr = &item;
(*ptr).year = 2015;
ptr->year = 2015;
```

Pointer to structure

- Structures can have other structures as members
  - Also a pointer to the structure itself!
  - Abstract datatypes can be nicely defined using structures with pointers

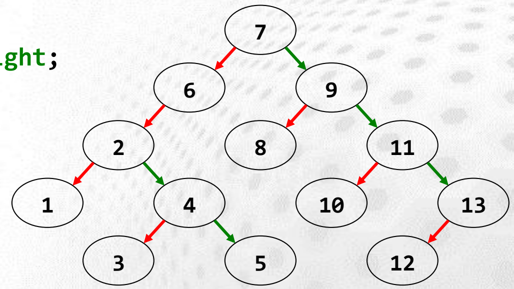
```
struct node {
  int value;
  struct node *next;
};

struct node first, second;
first.next = &second;
second.next = NULL;
```



Pointer to structure

- Example of ADT: binary tree

```
struct node {
  integer value;
  struct node *left, *right;
};
```



Summary

- Strings in C always end with 0
  - Remember the safety implications of string operations
- Structure is datatype that is a collection of members
  - Packing relevant data to a single unit
  - Abstract data types

Dynamic memory management

Dynamic arrays

- **`malloc`** can be used to allocate space for arrays too
- When allocating an array just multiply the size of each element in the array by the number of elements
  - **`malloc`** returns a pointer to the beginning of the array
  - Elements can be accessed with normal pointer syntax

Dynamic arrays

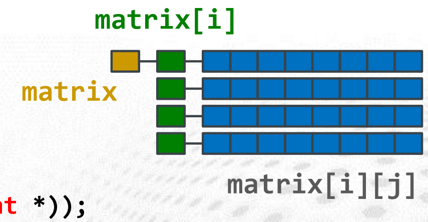
```c
int n_elems = 32;
float *prices;

// allocate memory for the required amount of floats
prices = malloc(n_elems*sizeof(float));
for (i = 0; i < n_elems; i++) {
   prices[i] = i*1.23;
}
// add space for one more float
prices = realloc(prices, sizeof(float)*(n_elems+1));
prices[n_elems] = 0.91;
// de-allocate the memory block
free(prices);
```


Dynamic multi-dimensional arrays

- Doable, but becomes complicated
- No real multi-dimensional arrays in C, so really just arrays of arrays
  - Two dimensional array maps to a variable that is a pointer to a pointer
- Memory management by hand
  - There are at least two different ways to do the allocation
  - Easy to make mistakes, beware here lieth dragons!

Allocating row-by-row, not recommended

```c
int i;
int rows = 4, cols = 8;
float **matrix;

/* allocate memory */
matrix = malloc(rows * sizeof(float *));
for (i = 0; i < rows; i++)
    matrix[i] = malloc(cols * sizeof(float));

// start using the 2D array
matrix[0][2] = 3.14;
```



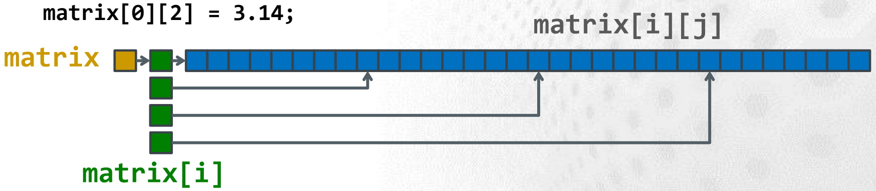
Dynamic multi-dimensional arrays

Dynamic 2D array in *contiguous* memory:

- First, allocate memory for pointers to the first element of each row
- Second, allocate memory for all elements
- Third, point each row at the first element of that row

Dynamic multi-dimensional arrays

```c
/* allocate memory */
matrix = malloc(rows * sizeof(float *));
matrix[0] = malloc(rows * cols * sizeof(float));

/* point the beginning of each row at the correct address
*/
for (i = 1; i < rows; i++)
    matrix[i] = matrix[0] + i * cols;

// start using the 2D array
matrix[0][2] = 3.14;
```



Memory layout

- Allocating space for the whole array using a single malloc call is the recommended way
  - Number of expensive malloc calls is minimized
  - Array is represented as one contiguous block in memory
  - It can be copied without looping over rows
  - Most IO and numerical libraries assume contiguous storage

Freeing multi-dimensional arrays

```
/* free each row first */
for (i = 0; i < rows; i++) {
    free(matrix[i]);
}
/* only after that, we can free the
main matrix */
free(matrix);

OR

/* alternatively, when using contiguous
memory */
free(matrix[0]);
free(matrix);
```

- After using a dynamic multi-dimensional array, remember to free each array inside the main array

Summary

- Multidimensional arrays are a bit tricky and there are several different implementations
  - Malloc are usually time consuming
  - Memory layout matters

I/O

I/O – Introduction

- Common I/O design alternatives
  - databases
  - data format libraries
  - standard C libraries
- Standard C library `stdio.h`
  - Reading from keyboard and writing to display
  - Reading and writing files

I/O – Standard C library stdio.h

To use:

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

1. Do a web search for “stdio.h reference” to see what functions are in the library.
2. Do a web search for “stdio.h printf” to get a detailed description of the printf function.
3. Type “man stdio” and “man printf” on a Linux workstation

I/O – Reading from keyboard and writing to display

`printf()`	Print formatted data to stdout.
`scanf()`	Read formatted data from stdin.
`putchar()`	Print a single character to stdout.
`getchar()`	Read a single character from stdin.
`puts()`	Print a string to stdout.
`fgets()`	Read a string from stdin (or file).

stdin = keyboard
stdout = display

I/O – Reading from keyboard and writing to display

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

```
printf("The answer is %d.\n", 42);
printf("Pi equals to %.2f", 3.14159265);
printf("...at least to the %dnd decimal.\n", 2);

/* output:
 * The answer is 42.
 * Pi equals to 3.14 ...at least to the 2nd decimal.
 */
```


I/O – printf

\a	alarm (beep) character	\0NN	character code in octal
\p	backspace	\xNN	character code in hex
\f	formfeed	\0	null character
\n	**newline**		
\r	carriage return		
\t	horizontal tab		
\v	vertical tab		
****	**backslash**		
\?	question mark		
\’	single quote		
\”	**double quote**		

I/O – printf

%d	decimal integer	%g	use %e or %f, whichever is shorter
%c	character	%u	unsigned decimal integer
%s	string	%o	unsigned octal integer
%e	floating-point number in exponential notation	%x	unsigned hex integer
%f	floating-point number in decimal notation		

I/O – printf

- The format specifier:

`%[parameter][flags][width][.precision][length]type`

n$: which parameter

```
[0-9] : left-pad w/ spaces
    + : always show +/-
    - : left-align
    # : alternate form
    0 : pad w/ zeros
```

```
[0-9] : min. width / precision
    * : width / precision given
        as a parameter
```

```
l L : long int / float
 ll : long long int
```

- type:

d, i	int	x	hexadecimal
f, e, g	float / double	o	octal
s	string	c	char
%	literal %		

I/O – Reading from keyboard and writing to display

- `int scanf(const char *format, ...)`

```
printf("Enter a number: ");
scanf("%d", &number);
printf("You entered %d.\n", number);

/* output:
 * Enter a number: 9
 * You entered 9.
 */
```


I/O – scanf

- When can you assume that the input is well-formatted? Never.
- Good article :"Things to Avoid in C/C++" at www.gidnetwork.com for discussion about gets() and scanf().

I/O – Reading from keyboard and writing to display

`printf()`	Print formatted data to stdout.
~~**`scanf()`**~~	~~Read formatted data from stdin.~~
`putchar()`	Print a single character to stdout.
`getchar()`	Read a single character from stdin.
`puts()`	Print a string to stdout.
`fgets()`	Read a string from stdin or a file.

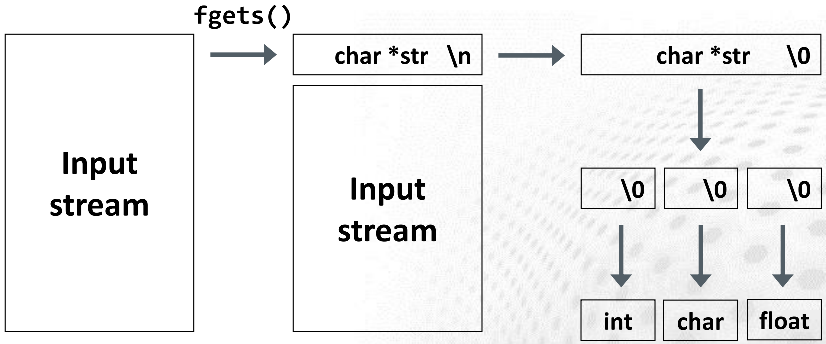
stdin = keyboard
stdout = display

I/O – Reading from keyboard and writing to display

- `char *fgets(char *str, int num, FILE *stream)`

```
printf("Enter some text\n");
fgets(string, 100, stdin);
printf("You entered:\n");
printf("%s", string);

/* output:
 * Enter some text:
 * Reading and validating input is difficult.
 * You entered:
 * Reading and validating input is difficult.
 */
```

I/O – fgets



I/O – Reading and writing files

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

`r, w, a`	`read, write, append`
`r+, w+, a+`	`read+write`
`rb, wb, ...`	`binary mode`

- `int fclose(FILE *stream)`
- `int fflush(FILE *stream)`

I/O – fopen, fclose

```
char filename[] = "file.txt";
FILE *myfile;
myfile = fopen(filename, "r");
if (myfile == NULL) {
  printf("Can't open %s. Check that it ", filename);
  printf("exists and the permissions.\n");
  return EXIT_FAILURE;
}
fclose(myfile);

/* output (on error):
 * Can't open file.txt. Check that it exists and the
 * permissions.
 */
```


I/O – Reading and writing files

`fprintf()`	Print formatted data to file.
~~`fscanf()`~~	~~Read formatted data from file.~~
`fputc()`	Print a single character to file.
`fgetc()`	Read a single character from file.
`fputs()`	Print a string to file.
`fgets()`	Read a string from file.
`fwrite()`	Write binary data to file
`fread()`	Read binary data from file

I/O – Reading and writing files

- `int fgetc(FILE *stream)`

```
int c;
char filename[] = "file.txt";
FILE *myfile;
myfile = fopen(filename, "r");
c = fgetc(myfile);
while (c != EOF) {
  printf("%c", (char)c);
  c = fgetc(myfile);
}
fclose(myfile);
```


I/O – Reading and writing files

- `size_t fwrite(const void *ptr, size_t size, size_t count, FILE *stream)`

```
char filename[] = "file.dat";
FILE *mybinary;
mybinary = fopen(filename, "wb");
fwrite(&number, sizeof(int), 1, mybinary);
fwrite(array, sizeof(float), 1000, mybinary);
```


I/O – Reading and writing files

- `size_t fread(const void *ptr, size_t size, size_t count, FILE *stream)`

```
char filename[] = "file.dat";
FILE *mybinary;
mybinary = fopen(filename, "rb");
fread(&number, sizeof(int), 1, mybinary);
fread(array, sizeof(float), 1000, mybinary);
```


I/O – Final words

- Standard C libraries
  - text or binary?
- Alternative solutions
  - databases
  - data format libraries

Code structuring

C PREPROCESSOR

Preprocessing directives

- C preprocessor is a part of the compiler that does initial text substitution, manipulation, inclusion and other activities before the actual translation is done
  - We have already used **#include**, which includes a file and **#define** for macros
- C relies heavily on preprocessor to accomplish
  - Portability of code
  - Source code control
  - Debugging

Directives

- Preprocessor directives start with **#**, which has to be first token on a line
- Directives are limited to one line
  - Line can be continued using ****
- Directives are not statements, do not end the line with **;**

```
// These are ok
#define one
  #define two
// Not the first token - WRONG!
int i; #define one
```

Conditional inclusion with #if

- Conditionals can be used to control if part of the code is included (and compiled) or not
- Conditional part begins with **#if/#ifdef/#ifndef** and ends with **#endif**:

```
#if constant-exp
  text section
#elif constant-exp
  text section
#else
  text section
#endif
```

```
#ifdef identifier
  text section
#else
  text section
#endif
```

```
#ifndef identifier
  text section
#else
  text section
#endif
```


Example

```
#include <stdio.h>
#define PRINT_GREETINGS
#define PRINT_VALUE 3
int main(void) {
#ifdef PRINT_GREETINGS
  printf("Hello, World!\n");
#endif
#if PRINT_VALUE == 3
  printf("Value is %d\n", PRINT_VALUE);
#endif
  return 0;
}
```


Definitions on compiler command line

- It is also possible to set preprocessor definitions on the compiler command line
- Most compilers accept option **-D** for this purpose:

```
gcc -DONE=1 -DUSE_FEATURE
```

is equivalent with

```
#define ONE 1
#define USE_FEATURE
```


COMPILING WITH SEVERAL FILES

Compilation: working with several files

- Advantages:
  - Code structure is easier to understand when related parts are in same file
    - *Scoping* of variables can be controlled more strictly
  - Changing a file, only that file needs to be re-compiled to rebuild the program
- UNIX 'make' can be very useful tool for this!
  - Most IDEs also provide a tools for building this kind of compilation

Function prototypes

- Functions, like variables, have to be defined (declared) before use
- Program execution starts from **`main()`**
  - If function definitions are in the same file and definitions are always before usage then compiler can find everything it needs
  - Otherwise we have to introduce the functions using *function prototypes*

Function prototypes

- Function prototypes are like variable declarations: they introduce the name of the function, its arguments and return value
- Note that only types of arguments are needed
- Function prototype declaration is a statement so you have to finish it with **;**

```
// Function prototype
int funcA(int, int);
// Function can now be used
int main(void) {
   ...
   val = funcA(arg1, arg2);
   ...
}
// Function definition
int funcA(int a, int b)
{
   return a * b;
}
```


Working with several files

- We can use header files to define functions that we can use later
- Making **.h** files for your functions allows you to 'include' them in your code

```
// we implement the function 'add'
int add(int first, int second)
{
    return first + second;
}
```

File: add.c

```
// we define the function 'add'
#ifndef ADD_H
#define ADD_H
int add(int first, int second);
#endif
```

File: add.h

Compilation: working with several files

- Another .c file can then use the function **`add()`** by including the header file:

```
// If we use #include "", the file is searched from
// current directory
#include "add.h"

int example(int x)
{
    return add(x, add(x,x));
}
```


Compilation: working with several files

- So, this is how headers work:
  - **`main()`** would be in one file, the others will contain functions
  - Headers usually only contain definitions of data types, function prototypes and C preprocessor commands
  - We include the header into the C files
  - We compile the different files and the compiler calls the header file

Global variables, extern

- Scoping of variables depend on the place where the variable is declared
  - Variables declared inside a function are visible only in the scope of that function
- Variables defined in a file have a scope of that file
- If a truly global value is needed (not generally recommended practice), one has to use **`extern`** keyword
  - Only one definition in file scope
  - Other files refer this value with **`extern`**

Example

file main.c:

```
...
// File scope variable for
// status
struct status global_status;
...
int main(void) {
   ...
```

file utilities.c:

```
...
// We want to use the same
// structure in this file
extern struct status global_status;
...
int set_error_status(int stat) {
   ...
   global_status.error_code = stat;
   ...
}
```

Summary

- C preprocessor
  - Macros, conditional compiling
- Working with several files
  - Function prototypes
  - Compiling and linking

Programming practices

BACKGROUND

What and why?

- Coding practices are an informal set of rules that community has learned by experience
  - Purpose is to help improve the quality of software
- Some practices may seem unimportant if you are just starting to write a small ad-hoc application for yourself
  - Software lifetime is hard to predict—small application can grow and become important
  - Wrong choices are much harder to fix when project grows and more developers start to contribute

Software quality

- Several definitions and metrics, but some common desirable attributes are
  - Maintainability
    - How easy the code is to modify and extend?
  - Reliability
    - Does program work correctly with different inputs?
  - Efficiency
    - Is the program fast enough for the purpose it was made for?
  - Correctness
    - Does the program implement the given specifications correctly?

CODING STANDARDS

Keep it simple

- Code should be simple, do not use complicated logic to implement simple things
  – Complicated algoritms are of course difficult, but individual parts of code should not be!
- Complicated code filled with tricks is difficult to understand, fix and modify
  – After couple of years it will be hard even for the person who wrote it

Comments

- Easily overlooked, but very important for new developers working on old code
- Comment at least the purpose of different data structures and things that use complicated logic

```
// Do not comment like this

// Increment i by one
i++;

// This is more useful

// Increment i so that
// the residual will be
// computed correctly
i++;
```


Code formatting

- As mentioned already in the beginning the C code formatting is very flexible
  – There are many common styles: K&R, GNU, Linux, ...
- Rule of thumb: *be consistent!*
  – It is much easier to read code that has all blocks formatted similarly
- Use automatic tools: **indent**

```
// GNU
for (i = 0; i < n; i++)
  {
    printf("Hi!\n");
  }
print("Finished\n");
// Linux
for (i = 0; i < n; i++) {
        printf("Hi!\n");
}
print("Finished\n");
```

Naming conventions

- There are several conventions on naming, but again, choose one and use it
- In any case the name of variables and fuctions should be descriptive
- Preprocessor macros and definitions should always be uppercase!

```
// This
d = s * t;
// ... or this
distance = speed * time_interval;
```


Version control

- If you do any development you should already be using version control
  - It is helpful even in projects with just one developer
  - ... but it is critical tool for projects with larger teams
- Without VCS tracking bug fixes and changes becomes almost impossible
- Common version control systems include git, svn, mercurial, cvs, perforce,...

Build tools

- When the size of the software project grows compiling becomes more and more complicated
  - Recompiling everything from the beginning becomes too slow and handling the dependencies can be complicated
- Build tools handle the dependencies
- Most common tool in UNIX-like systems is Make
- IDEs also provide build tools

DEBUGGING

Debuggers

- Debuggers are tools that are used to examine the program execution
  - Check the values of variables during execution without adding any extra I/O calls
  - Execute the program code step-by-step
  - Stop the program execution when a given condition is met
  - Examine the call tree and function call arguments

Debugging demo

- Demo on tracking down the cause of segmentation fault

COMMON PITFALLS

Common pitfalls 1

- Segmentation faults
- Arrays in C are not protected
  - Trying to access a wrong element can in principle have any effect
  - Most difficult cases to debug are the ones where value of some other variable is modified by accident
  - Segmentation faults are usually easier to find
  - Some compilers have memory debugging tools integrated (e.g. address sanitizer in Clang and gcc)

Common pitfalls 2

- Using = in comparison in stead of ==

```
int val = 2;
if (val = 1)
   printf("val is equal to one");
```

- This will print that the value is one!
  - The assignment operator returns the assigned value 1 which is nonzero and interpreted as true
- One way to avoid this is to use the constant on left, compiler will complain about the invalid assignment

Common pitfalls 3

- Manual memory management is error prone
- Make sure that the allocations are always done before trying to dereference pointers
- Memory leak:
  - Releasing the pointer to an allocation before free

Common pitfalls 4

- Remember the implicit type conversions
- For example integer division:

```
double third = 1/3;
```

- This will set the value of third to zero
  - Result of the integer division is 0 and that value is then casted into double precision 0.0

Summary

- Coding standards help to develop programs
  - Based on long time experience
- Debuggers help when you track down errors in your programs