Lectures 5-6: Introduction to C

- Motivation:
  - C is both a high and a low-level language
  - Very useful for systems programming
  - Faster than Java
- This intro assumes knowledge of Java
  - Focus is on differences
  - Most of the syntax is the same
  - Most statements, expressions are the same

Outline

- Major differences with Java
- A simple program; how to compile and run
- Data-types and variables
- The preprocessor
- Composite data structures
- Arrays and strings
- Pointers

Major differences with Java

- C is not object oriented
  - C programs are collections of functions, like Java methods, but not class-based.
  - No inheritance, subtyping, dynamic dispatch in C
- C is not interpreted
  - A C program is compiled into an executable machine code program, which runs directly on the processor
  - Java programs are compiled into a byte code, which is read and executed by the Java interpreter, another program

C is less "safe"

- Run-time errors are not 'caught' in C
  - The Java interpreter catches these errors before they are executed by the processor
  - C run-time errors happen for real and the program crashes
- The C compiler trusts the programmer!
  - Many mistakes go un-noticed, causing run-time errors

Memory management is different

- Memory areas
  - *Heap*: dynamically allocated storage
  - *Stack*: for function/method local variables
  - *Static*: for data living program lifetime
- In Java
  - All objects on heap
  - Unusable objects on heap recycled automatically by garbage collection
- In C
  - Data structures in all 3 areas
  - Programs must explicitly free-up heap storage that is no longer needed

C has pointers …

- Pointers are special variables that reference (or point to) another variable
  – Similar to Java references
- We have already seen pointers in assembly:

```
lw $t1,0($s2)
```

  – `$s2` is a pointer
  – C pointers are the same thing! (more later)

The hello world program

```
#include<stdio.h>
/* This is a (multi-line)
  comment */
int main(void)
{   // This is a comment too
    printf("Hello world!\n");
    return 0;
}
```

Linux/DICE shell commands

Compile: `gcc hello.c`   Run: `./a.out`

Compilation units

- Programs are divided into *compilation units*
  - Provide degree of modularity
  - Each commonly has main file for source code
  - *Header* files characterise public interfaces of units
- Each compiled separately to relocatable object code
  - Allows creation of object-code libraries
- A *linker* assembles these into an *executable*, resolving references between units
- A *loader* sets up the executable program in memory and initialises data areas, prior to program being run

Compilation units example

A.h:

```
func decls
var decls
type defs
…
```

A.c:

```
#include "A.h"

func defs
var defs
…
```

B.h:

```
func decls
var decls
type defs
…
```

B.c:

```
#include <stdio.h>
#include "A.h"
#include "B.h"

func defs
var defs
…
```

Built-in data types

- The usual basic data types are there:

char	8 bits
short	16
int	16, 32, 64 (same as machine word size)
long	32, 64
float	32
double	64

- Bit sizes are machine dependent
  – Unlike Java where an int is always 32 bits
- Normally signed, unsigned available too
- No boolean type exists
  – for any number (int, char,…): 0 false, other true

Categories of variables

- Global (*external*) variables (statically allocated)
  – Defined outside of functions
  – Have *lifetime* of program and *scope* to file end
  – `extern` declarations extend scope before definition and to other files
  – Declare `static` to hide from other files
- Local (*automatic*) variables (allocated on stack)
  – Defined inside a function (before the statements)
  – Not available outside function
  – Distinct storage for each function invocation
  – Declare `static` for same storage for all invocations

The C pre-processor: `cpp`

- Includes – imports header files
  - Declarations for variables, functions, …
- Text substitution, e.g. define constants

```
#define NAME value
```

- Macros (inline functions)

```
#define MAX(X,Y) (X>Y ? X : Y)
```

- Conditional compilation

```
#ifdef DEBUG
printf("Debugging message");
#endif
```

Composite data structures - `struct`

- Structures are like objects, but their types have no methods, unlike classes:

```
struct point {
     int x, y;
} p1;
struct point p2;
```

- Components accessed using "." operator

```
p1.x = 2;
```

- Passing structures between functions
  - In Java references always used
  - In C either all data copied or pointers used

Composite data structures - `union`

- Unions – declared and used similarly to structures:

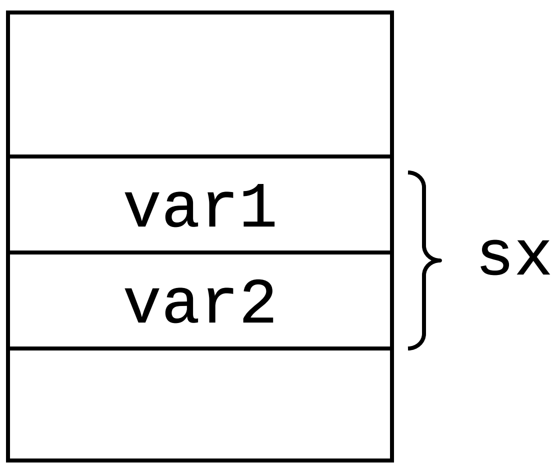
```
union geomObject {
     struct circle;
     struct rectangle;
} g_obj;
```

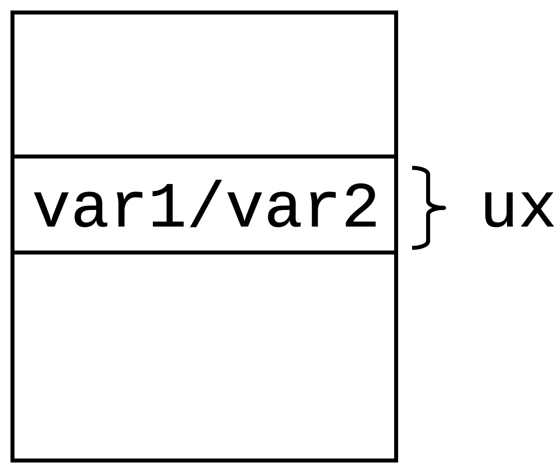
- But all variables inside a union overlap in memory,
  - Space is reserved for the largest of them, not all
  - The same memory space can be interpreted in multiple ways

In memory: structures v. unions

```
struct x {
  int var1;
  int var2;
} sx;
```

```
union x {
  int var1;
  int var2;
} ux;
```





sizeof(sx) → 8

sizeof(ux) → 4

User-defined types

- Define names for new or built-in types

```
typedef <type> <name>;
```

- Example:

```
typedef unsigned char byte;
typedef struct {
  struct point p;
  int rad;
} circle;
...
circle c1, c2;
```

Arrays

- Syntax of C arrays similar to Java
- As in Java, C arrays have fixed size
- Example declarations of array:

```
int n[] = {5, 8, 10};  // size fixed to 3
circle c[4]; // array of structs
```

- C arrays have no knowledge of their length
  - – No checking that indexes are within bounds
- In C is close relationship between arrays and pointers
  - – Pointers commonly used to pass arrays between functions

Strings

- C strings are simply arrays of type `char`
  – Encoded in 8bits using ASCII
- They end with `'\0'`, the null character

```
char s[10]; // up to 9 characters long
```

- String initialisation

```
char s[10] = “string”; // '\0‘ implied
char s1[] = “another string”;
```

- Usual C rule for arrays apply:
  – Cannot store more chars than reserved at declaration
  – But bounds are not checked!

Strings – common operations

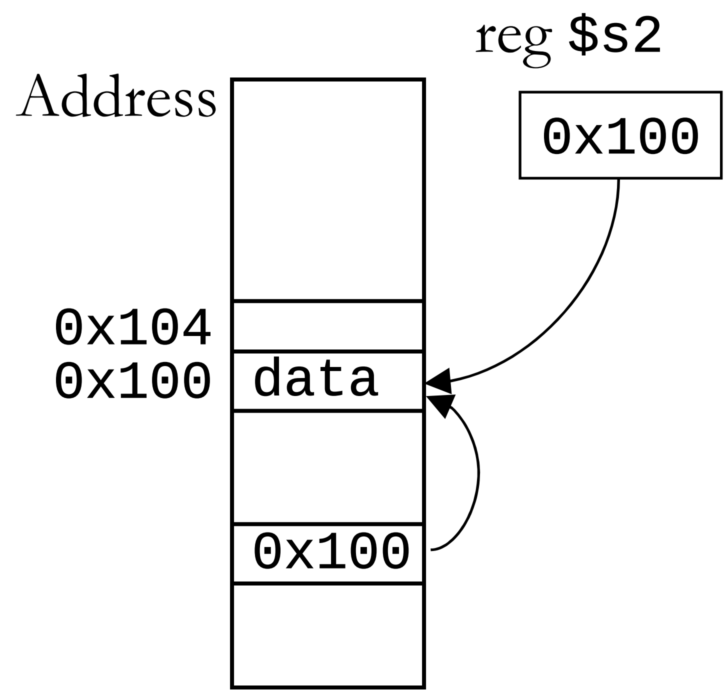
- Assignment: strcpy(s, "string");
- Length: strlen(s)
- To get the 6th character: s[5]
  - First char at position 0, as in Java arrays
- Comparison, strcmp(s1, s2) returns:
  - 0 when equal
  - Negative number when lexicographically s1 < s2
  - Positive when s1>s2
- Must #include<string.h> to call the functions
  - Type: man string to see what's available

Pointers

- We have seen pointers in assembly:

```
lw $t1,0($s2)
```

- `$s2` points to the location in memory where the "real" data is kept
- `$s2` is a register, but there's nothing stopping us to have pointers stored in memory like "normal" variables



C pointers

- A C pointer is a variable that holds the address of a piece of data
- Declaration:

```
int *p; // p is a pointer to an int
```

  – The compiler must know what data type the pointer points to
- Basic pointer usage:

```
p = &i; // p points to i now
*p = 5; // *p is another name for i
```

- & - address of, * dereference operator

Pointers as function arguments

- In Java
  - an argument with primitive type is passed by value (function gets copy of value)
  - an argument with class type is passed by reference (function gets reference to value)
- In C
  - All arguments passed by value
  - To get effect of `pass by reference', use an argument with a pointer type

Example – the swap function

```
void swap_wrong(int a, int b) {
  int t=a;
  a=b; b=t;
}
```

`swap_wrong` swaps the local variables `a,b` which are unknown outside of the function

```
void swap(int *a, int *b) {
  int t=*a;
  *a=*b; *b=t;
}
```

Function call: `swap(&x, &y);`

Pointer arithmetic and arrays

C allows arithmetic on pointers:

```
int a[10];
int *p;
p = &a[0];  // p points to a[0]
```

`p+1` points to `a[1]`

- Note that `&a[1] = &a[0]+4`
- The compiler multiplies +1 with the data type size

In general: `p+i` points to `a[i], *(p+i)` is `a[i]`

Even `*(a+i) p[i]` are allowed

- but cannot change what `a` points to. It's not a variable

More pointer arithmetic

Common expressions:

`*p++` use value pointed by `p`, make `p` point to next element

`*++p` as above, but increment `p` first

`(*p)++` increment value pointed by `p`, `p` is unchanged

- Special value NULL used to show that a pointer is not pointing to anything
  - NULL is typically 0, so statements like `if (!p)` are common
- Dereferencing a NULL pointer is a very common cause of C program crashes

Example – pointer arithmetic

Return the length of a string:

```
int strlen(char *s)
{
  char *p=s;
  while (*s++ !='\0')
    ;
  return s-p;
}
```

- Argument/variable `s` is local, so we can change it
- Pointer increment, dereference and comparison all in one! No statement in the loop body
- Note pointer subtraction at return statement

Dynamic memory allocation

- Pointers are not much use with statically allocated data
- Library function `malloc` allocates a chunk of memory at run time and returns the address

```
int *p;
if ((p = malloc(n*sizeof(int))) == NULL) {
   // Error
}
...
free(p); // release the allocated memory
```

Pointers to pointers

- Consider an array of strings:

```
char *strTable[10];
```

- The strings are dynamically allocated ⇒ any size
- But the table size is fixed to 10 strings
- How can we have both dynamically changing in size at runtime?

```
char **strTable;
```

- Since a pointer is a variable, we could have another pointer pointing to it: pointer to pointer!

Pointers to pointers - details

- Space must be allocated both for the table and the strings themselves

```
char **strTable;
strTable = malloc(n*sizeof(char *));
for (i=0; i < n; i++) {
    ...
    // s gets a string of length l
    *(strTable+i) = malloc(l*sizeof(char));
    strcpy(strTable[i], s);
}
// strTable[i][j] == *(*(strTable+i)+j)
```

That's all folks

- Not all C features have been covered, but this introduction should be enough to get you started
- Useful things to learn on your own:
  - Standard input/output: `printf, scanf, getc`, …
  - File handling: `fopen, fscanf, fprintf`, …
- Look over past exam papers for simple C programming exercises