Lectures 5-7 Inf2C - Computer Systems: Intro to C

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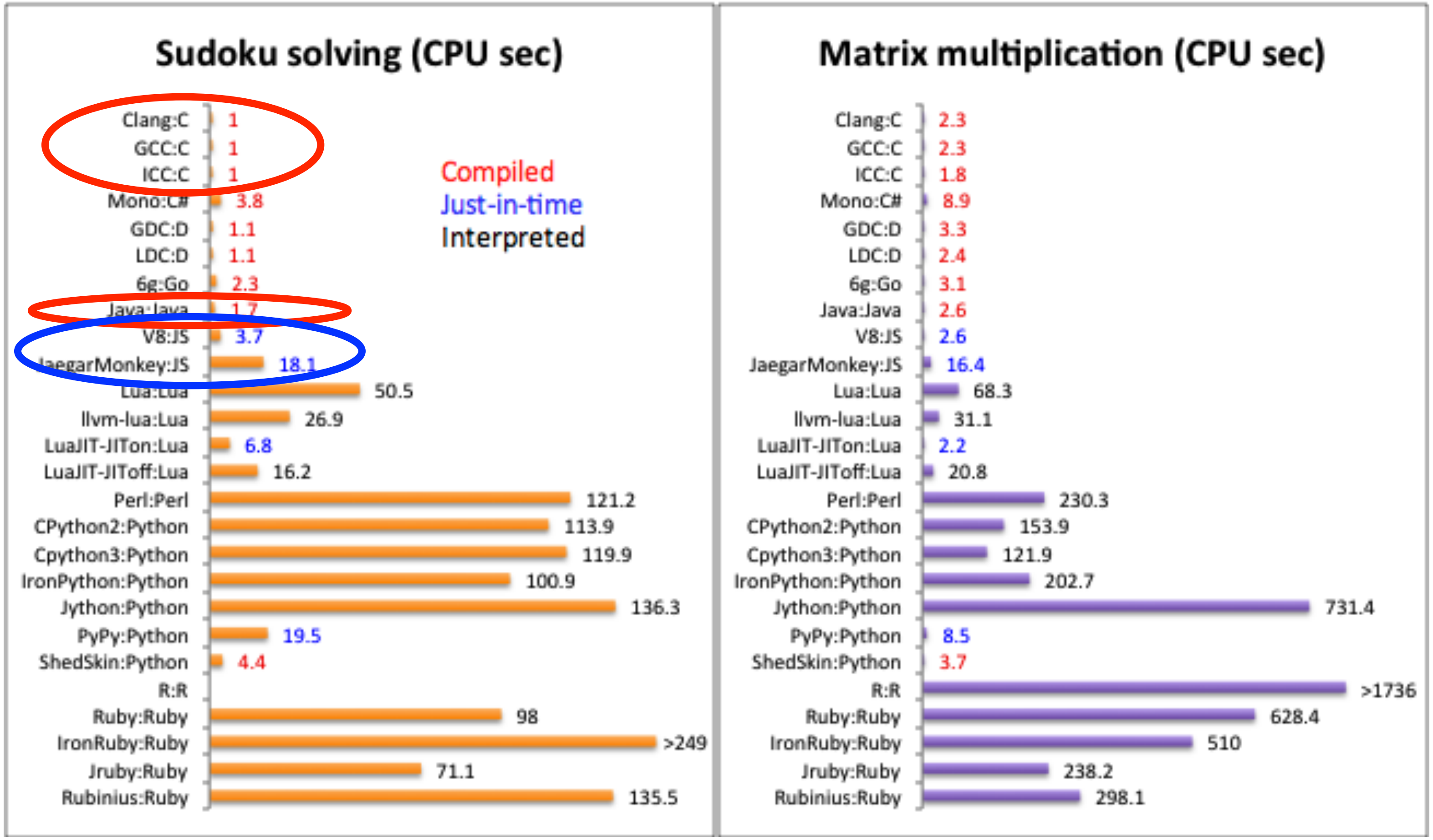
Previous lectures

- MIPS
  - Arithmetic and memory
  - Control flow: branches and jumps
  - Function calls and the stack

Lectures 5-7: Intro to C

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

Performance: C vs. the rest



Source: http://attractivechaos.github.io/plb/

Outline

- A simple program; how to compile and run
- Major differences with Java
- Data types and composite data structures
- Arrays and strings
- Pointers
- Other issues
  - Memory regions
  - C Preprocessor
  - Portability

The hello world program

```c
#include<stdio.h>

int main(void)
{   // This is a comment
    printf("Hello world!\n");
    return 0;
}
```

Linux/DICE shell commands

Compile: `gcc hello.c`

Run: `./a.out`

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 (which is just 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
    - Example: array out-of-bounds exception
  - 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 and leaving systems vulnerable to security exploits

Memory management is different

- In Java
  - All objects dynamically allocated
  - Unusable objects recycled automatically by garbage collection
- In C
  - No objects, only data structures
  - Some data structures statically allocated, others dynamically
  - Dynamically-allocated storage must be reclaimed (or freed) once the data structures there are no longer needed.
    - Major source of error, particularly when the programmer forgets to free the memory, resulting in memory leaks.

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)

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

- Data type 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

Composite data structures - `struct`

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

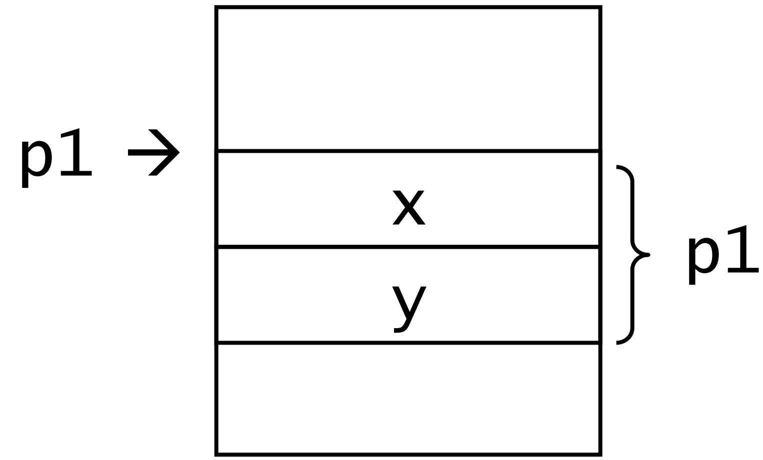
```
struct point {
     int x, y;
     // can include other structs
} p1;
struct point p2;
```

- Components accessed using "." operator

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

In memory: structures

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



`sizeof(point) = 8`

What does `p1.y` translate into in MIPS?

```
addi  $t0, $s0, 4  // $s0 points to the starting addr of p1
lw    $t4, $t0     // load p1.y into $t4
```

User-defined types

- Define names for new or built-in types

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

- Example:

```
typedef unsigned char byte;

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

Arrays

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

```
int m[] = {5, 8, 10};  // size fixed to 3
int n[2][10]; // two-dimensional array
              //  with 2 rows and 10 cols
point p[4]; // array of 4 structs
```

- C arrays have no knowledge of their length
  – No checking that indexes are within bounds
- In C, 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 8 bits 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[] = “string, too"; // length= ?
```

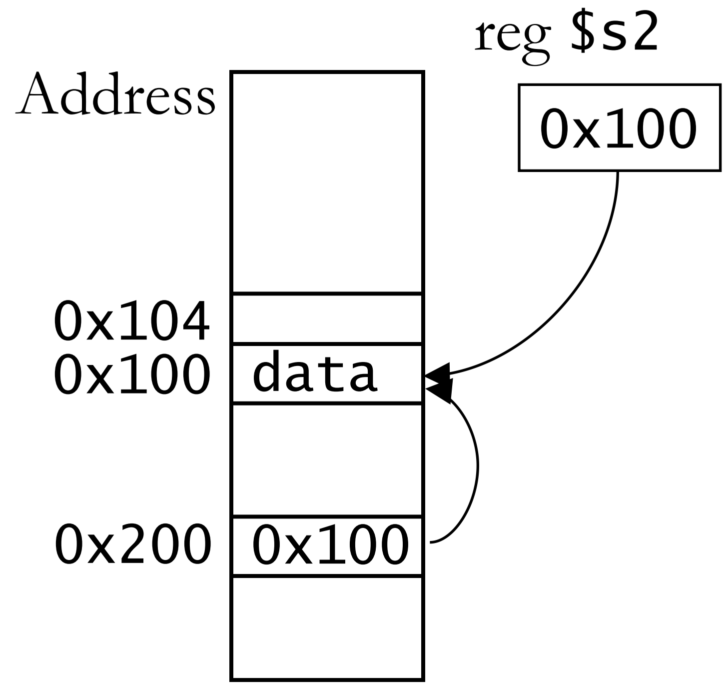
- Usual C rule for arrays apply:
  - Cannot store more chars than reserved at declaration
  - But bounds are not checked!

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* operator. * *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;  // p points to a[0]. Same as p = &a[0]
```

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

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

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

Also valid: `*(a+i)` and `p[i]`

- 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-1;
}
```

- 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

More fun with strings & pointers

```
char s1[10] = “Bob”;
char s2[10] = “Bob”;

if (s1 ==“Bob”)
  // do x
else if (s1 == s2)
  // do y
else
  // do z
```

Which statement (x, y, or z) is executed?

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
- What if we don't know the number of strings ahead of time?
  – Need to be able to provision array size on demand
  – That is, need to dynamically allocate the storage for the array of strings

```
char **strTable;
```

Pointers to pointers - details

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

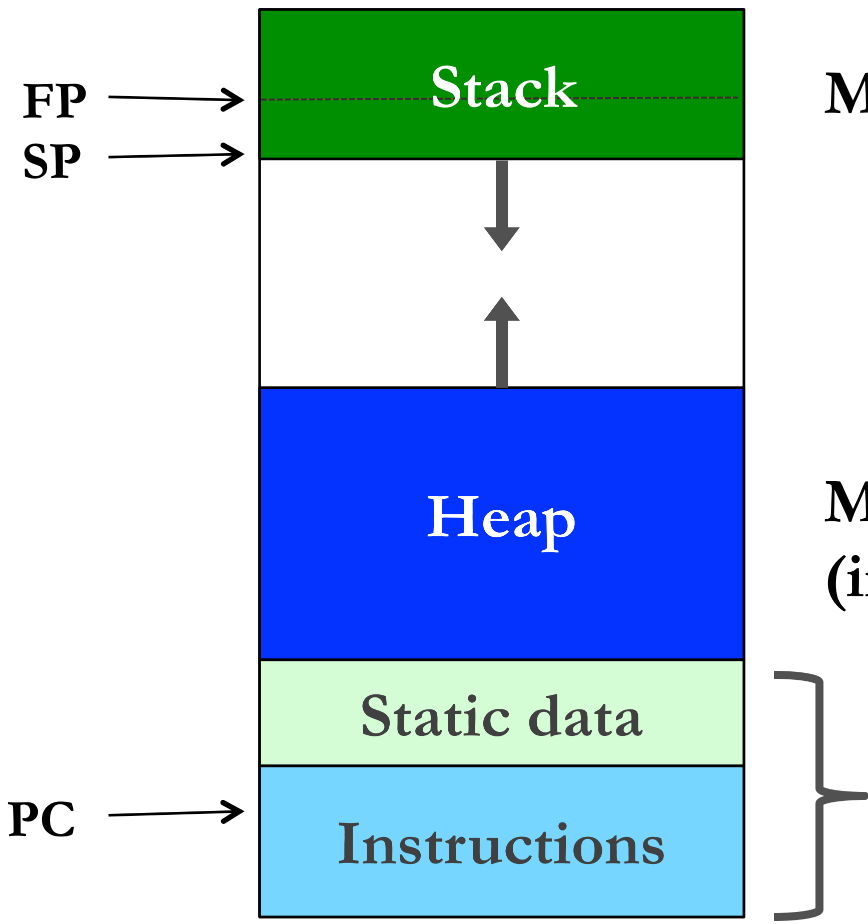
– Pointer to pointer!

```
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)
```

Memory regions and management

- 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

Memory regions in detail



Managed by the compiler

Managed by the programmer (in C) or the system (in Java)

Initialized when the process starts

Categories of variables in C

- Global 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
  - Not available outside function
  - Distinct storage for each function invocation
  - Declare `static` for same storage for all invocations

Compilation units

- Programs are divided into *compilation units*
  - Provide degree of modularity
  - Each commonly has main file (.c) for source code
  - *Header* files (.h) declare 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
  - Loader also computes addresses for Jump instructions

Declaration vs Definition

- Declaration: inform the compiler of the existence of a variable or function

```
void swap(int *a, int *b);    // in .h file
```

- Definition: provide function body; allocate memory for globals

```
void swap(int *a, int *b) {   // in .c file
     int temp = *a;
     *b = a;
     *a = temp;
}
```

Compilation units example

A.h:

```
int array_len;         // global
extern int MAX_SIZE; // global, defined elsewhere

// function declarations
void swap(int *a, int *b);
```

A.c:

```
#include "A.h"

// function definition
void swap(int *a, int *b) {
  int temp = *a;
  *a = *b;
  *b = temp;
}
```

main.c:

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

int main(void) {
  int a = 5;
  int b = 15;
  swap(a, b);
}
```

Error?

The C pre-processor: `cpp`

- Includes – imports header files

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

- 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

> gcc –DDEBUG ...
```

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

Coursework 1

- Assigned "now", due in 2 weeks
  - **Deadline: Tue, 27 Oct, 16:00h**
- Task A: split a character string into words
  - Given: a C implementation
  - Your job: convert it to MIPS
- Task B: find single-word palindromes in a string
  - Given: C and MIPS implementations of Task A
  - Your job: write C and MIPS code for Task B

Coursework 1 (con'd)

- Task A example:

```
input: The first INF2C-CS coursework
output:
The
first
INF2C
CS
coursework
```

- Task B example:

```
input: I got my Honda Civic in 2002.
output:
Civic
2002
```

A (friendly) note on plagiarism

- **Don't do it!!!!**
- We use MOSS to electronically cross-check all submissions
  - MOSS is unaffected by variable renaming, code reshuffling, etc.
- Two plagiarism instances (4 students in total) were detected and prosecuted last year.
  - Remember: if you're sharing your code, you're just as guilty as the person taking it.