Inf2C - Computer Systems
Lectures 7-9
Intro to C

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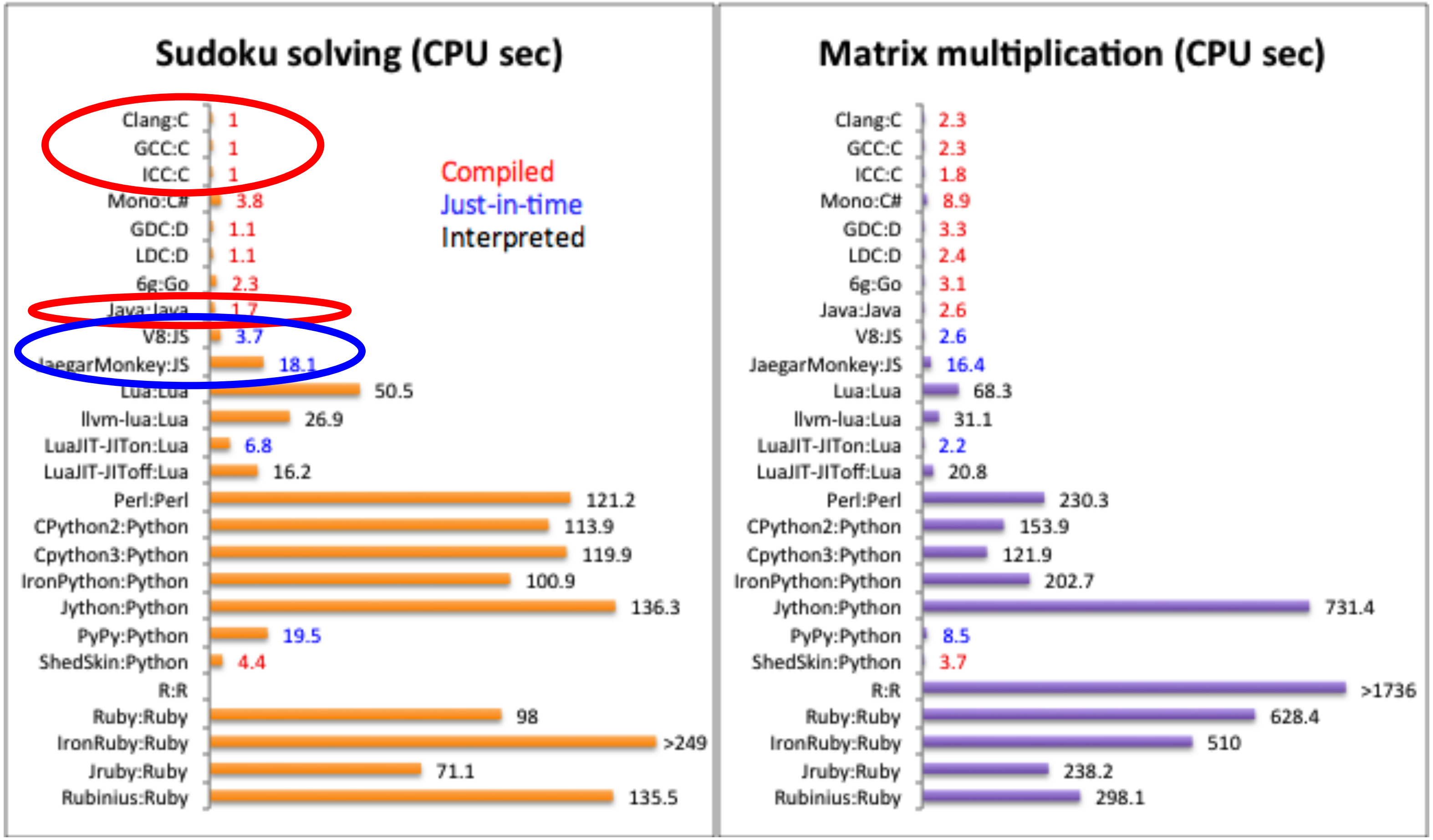
Intro to C

- Motivation:
  - C is both a high and a low-level language
  - Very useful for systems programming
  - Fast!
- 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

```
#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 (or not ☺)
- 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 through programmer-inserted directives
  - 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 numeric type (int, char,…): 0 false, other true

Composite data structures - `struct`

- Struct is like an object, but it cannot have methods, unlike classes

"point" is now a new type known to the compiler

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

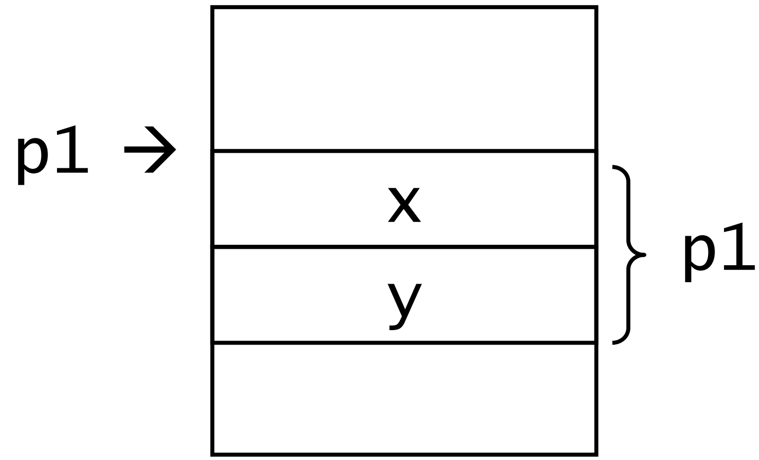
Creates an instance named p1 (optional)

- 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   $t4, 0($t0)  // load p1.y into $t4
```

User-defined types

- Define names for new or built-in types

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

- Example:

New "data type" name

```
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=12
```

why?

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

Manipulating strings

- To get the 6th character: `s[5]`
  - First char at position 0, as in Java arrays
- Assignment: `strcpy(s, "string");`
- Length: `strlen(s)`
- 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
  - On Linux, type: `man string` to see what's available

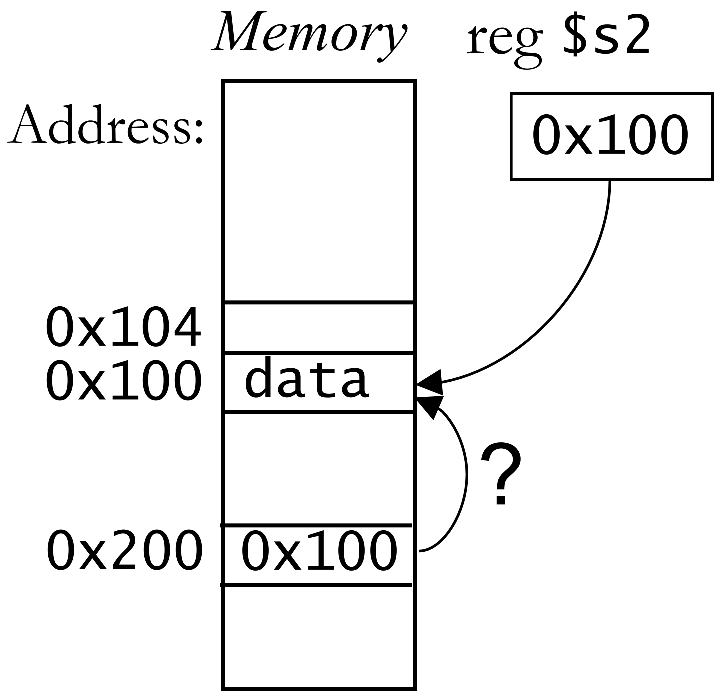
Pointers

- We have seen pointers in assembly:

  `lw $t1,0($s2)`

- `$s2` points to the location in memory where the "real" data is kept

- Pointers can also be stored in memory, like other data



C pointers

- In C, a 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_correct(int *a, int *b) {
  int t=*a;
  *a=*b; *b=t;
}
```

Function call: `swap_correct(&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]`

– The compiler multiplies +1 with the data type size

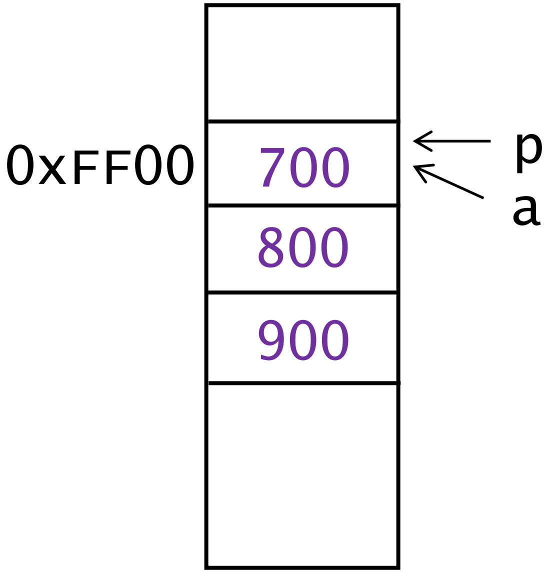
– Note that `&a[1] = &a[0]+1`

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 pointer variable

Practice questions



The following questions refer to the picture on the left. Values in memory are ints

- What is the value of `p+1` ?
- How can you get the effect of `a[2]=5` using `p` ?
- Which of these looks suspicious (i.e., likely incorrect)?

```
A.  int *p = a[2]-1
B.  int *p = &a[2]-1
```

- Would the "suspicious" expression generate a runtime error?

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 (e.g., `p=NULL`)
  - 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;
    (p = malloc(n*sizeof(int)))
```

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!

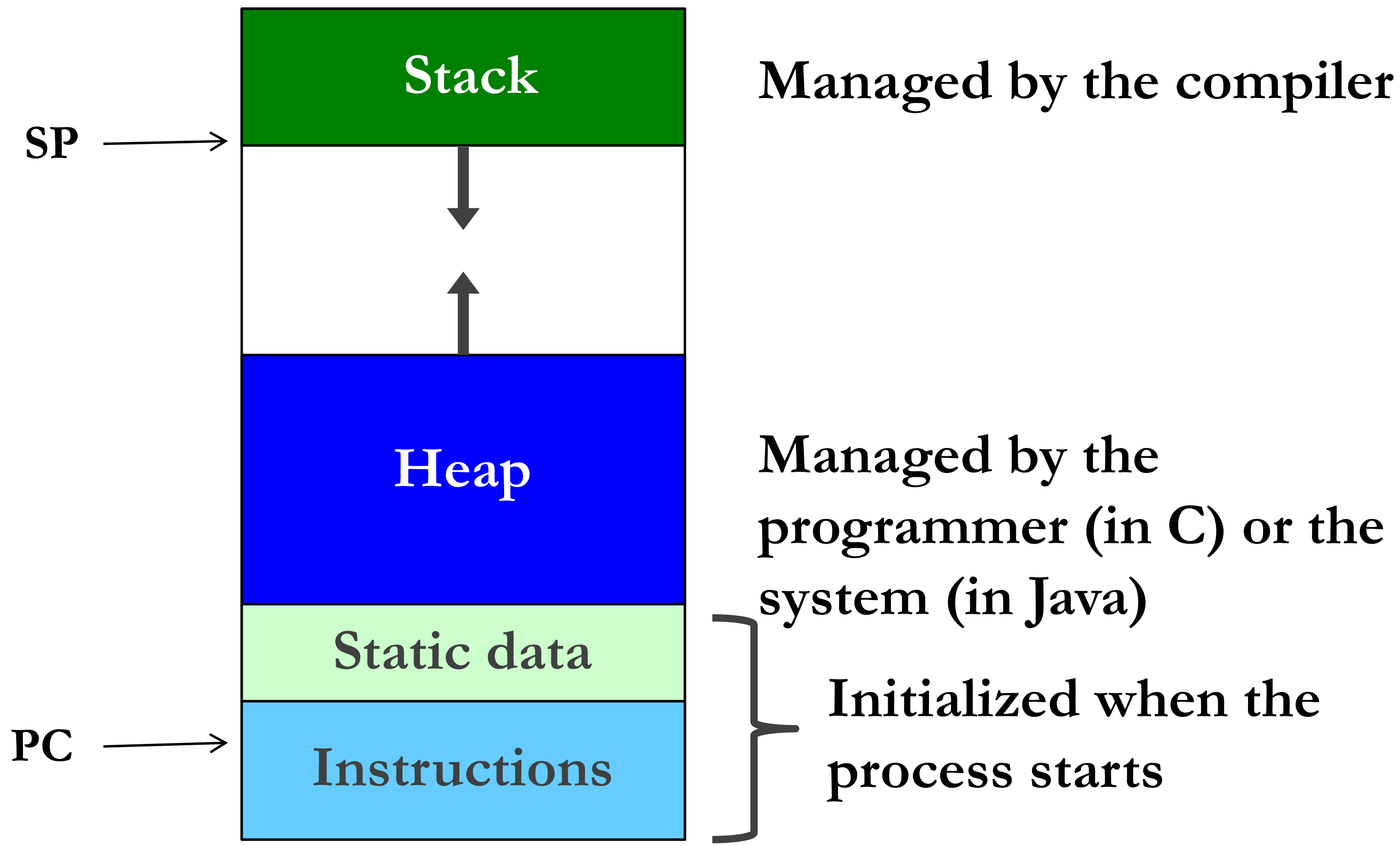
Number of strings

```
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 live during the entire 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



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

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