Review: Arrays

- Arrays are (almost) identical to pointers
  - char *string and char string[] are nearly identical declarations
    - They differ in subtle ways: incrementing, declaration of filled arrays
    - Key Difference: an array variable is a CONSTANT pointer to the first element.

```c
char *ar = string;
char string[] = "Hello World!";
```

Review: Arrays and Pointers

- Array size n; want to access from 0 to n - 1:

<table>
<thead>
<tr>
<th>Array Indexing Versions</th>
<th>Pointer Indexing Version</th>
</tr>
</thead>
</table>
| #define ARSIZE 10 int ar[ARSIZE];
int i = 0, sum = 0;
... |
| #define ARSIZE 10 int ar[ARSIZE];
int *p = ar, *q = &ar[10];
int sum = 0;
... |
| while (i < ARSIZE) sum += ar[i++]; |
| while (p < q) sum += *p++;
 |
- * C allows 1 past end of array!

Review: Common C Errors

- There is a difference between assignment and equality
  - `a = b` is assignment
  - `a == b` is an equality test

- This is one of the most common errors for beginning C programmers!

- Precedence Rules
  - int **a = {{1, 2}, {3, 4}}
  - "a[1]++; (([ ] > )

Topic Outline

- Strings
- Handles
- Structs
- Heap Allocation Intro
- Linked List Example

C Strings (1/3)

- A string in C is just an array of characters.
  ```c
  char string[] = "abc";
  ```

- How do you tell how long a string is?
  - Last character is followed by a 0 byte (null terminator)
  ```c
  int strlen(char s[])
  {
    int n = 0;
    while (s[n] != 0) n++;
    return n;
  }
  ```
C Strings Headaches (2/3)

- One common mistake is to forget to allocate an extra byte for the null terminator.
- More generally, C requires the programmer to manage memory manually (unlike Java or C++).
  - When creating a long string by concatenating several smaller strings, the programmer must ensure there is enough space to store the full string!
  - What if you don’t know ahead of time how big your string will be?
- String constants are immutable:
  - char f[] = "abc": f[0]++; /* illegal */
    - Because section of mem where "abc" lives is immutable.
  - char f[] = "abc"; f[0]++; /* Works! */
    - Because, in declaration, C copies abc into space allocated for f.

C String Standard Functions (3/3)

- int strlen(char *string);
  - compute the length of string
- int strcmp(char *str1, char *str2);
  - return 0 if str1 and str2 are identical (how is this different from str1 == str2?)
- char *strcpy(char *dst, char *src);
  - copy the contents of string src to the memory at dst and return dst. The caller must ensure that dst has enough memory to hold the data to be copied.

Pointers to pointers (1/4) ...review...

- Sometimes you want to have a procedure increment a variable?
- What gets printed?

```c
void AddOne(int x) { x = x + 1; }
int y = 5;
AddOne( y);
printf("y = %d\n", y);
```

Pointers to pointers (2/4) ...review...

- Solved by passing in a pointer to our subroutine.
- Now what gets printed?

```c
void AddOne(int *p) { *p = *p + 1; }
int y = 5;
AddOne( &y);
printf("y = %d\n", y);
```

Pointers to pointers (3/4)

- But what if what you want changed is a pointer?
- What gets printed?

```c
void IncrementPtr(int *p) { *p = *p + 1; }
int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr( q);
printf("*q = %d\n", *q);
```

Pointers to pointers (4/4)

- Solution! Pass a pointer to a pointer, called a handle, declared as **h
- Now what gets printed?

```c
void IncrementPtr(int **h) { *h = *h + 1; }
int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr( &q);
printf("*q = %d\n", *q);
```
C structures: Overview (1/3)

• A struct is a data structure composed of simpler data types.
  • Like a class in Java/C++ but without methods or inheritance. Don’t get hung up on this comparison.
  
```c
struct point {
  int x;
  int y;
};
void PrintPoint(struct point p) {
  printf("(%d,%d)\n", p.x, p.y);
}
```

C structures: Pointers to them (2/3)

• The C arrow operator (->) dereferences and extracts a structure field with a single operator.

```c
struct point *p;
printf("x is %d\n", (*p).x);
printf("x is %d\n", p->x);
```

How big are structs? (3/3)

• Recall C operator sizeof() which gives size in bytes (of type or variable)
• How big is sizeof(p)?

```c
struct p {
  char x;
  int y;
};
```

5 bytes? 8 bytes?
Compiler may word align integer y

Dynamic Memory Allocation (1/4)

• C has operator sizeof() which gives size in bytes (of type or variable)
• Assume size of objects can be misleading & is bad style, so use sizeof(type)
  • Many years ago an int was 16 bits, and programs assumed it was 2 bytes

Dynamic Memory Allocation (2/4)

• To allocate room for something new to point to, use malloc() (with the help of a typecast and sizeof):

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

  • Now, ptr points to a space somewhere in memory of size sizeof(int) in bytes.
  • (int *) simply tells the compiler what will go into that space (called a typecast).

  • malloc is almost never used for 1 var

  ```c
  ptr = (int *) malloc(n*sizeof(int));
  ```

  • This allocates an array of n integers.

Dynamic Memory Allocation (3/4)

• Once malloc() is called, the memory location might contain anything, so don’t use it until you’ve set its value.

  • After dynamically allocating space, we must dynamically free it:
    ```c
    free(ptr);
    ```

  • Use this command to clean up.
  • OS keeps track of size to free.
Dynamic Memory Allocation (4/4)

- Malloc does not always succeed.
  - System could be out of memory
  - An error occurred during the memory request
  - Operating system just doesn’t like you today...

- Always check the pointer you get back to make sure it is not NULL.
  ```c
  int *p;
  if ((p = (int*) malloc(10 * sizeof(int))) == NULL) {
    /*do something to recover*/
  }
  ```

Linked List Example

- Let’s look at an example of using structures, pointers, malloc(), and free() to implement a linked list of strings.

```c
struct Node {
  char *value;
  struct Node *next;
};
typedef Node *List;

/* Create a new (empty) list */
List ListNew(void) {
  return NULL;
}
```

```c
/* add a string to an existing list */
List list_add(List list, char *string) {
  struct Node *node = (struct Node*) malloc(sizeof(struct Node));
  node->value = (char*) malloc(strlen(string) + 1);
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```

```c
node:
  list:
  string:
  "abc"
```

Binky Pointer Video (thanks to NP @ SU)

Linked List Example

```c
/* add a string to an existing list */
List list_add(List list, char *string) {
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}
```

```c
node:
  list:
  string:
  "abc"
```
Linked List Example

/* add a string to an existing list */
List list_add(List list, char *string)
{
    struct Node *node = (struct Node*) malloc(sizeof(struct Node));
    node->value = (char*) malloc(strlen(string) + 1);
    strcpy(node->value, string);
    node->next = list;
    return node;
}

node: ?
list: ...
string: "abc"

“And in Conclusion...”

- Use handles to change pointers
- Create abstractions with structures
- Dynamically allocated heap memory must be manually deallocated in C.
  - Use malloc() and free() to allocate and deallocate memory from heap.