Pointers and Indirection

By the end of this lecture, you will be able to describe the memory model of a C program.

You will also be able to use pointers in a C program to control what happens in memory.

Lecture 04 Summary

- Process Memory
- Pointers
  - Declaring
  - Dereferencing
  - Pointer Arithmetic
- Dynamic Memory Allocation
- Passing Parameters by Reference

How do you break a problem down in order to solve it using a computer program?

Process Memory

- One (good) approach:
  - Find *entities* which exhibit *state*
  - Analyze how the state of each entity changes
  - Create *variables* (or data structures) to hold the state of the entities
  - Create *code* that describes how to change the state of the entities

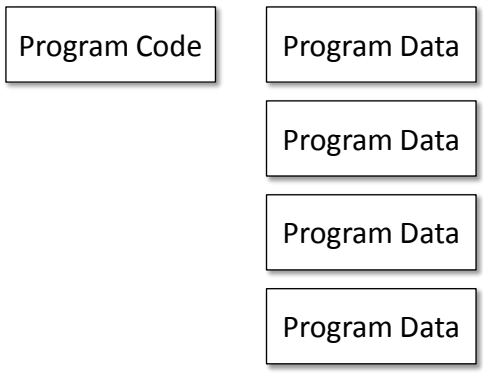
Process Memory

- Program Data
  - the variables which hold the entities' states
- Program Code
  - the instructions which say what to do with the program data

Program Data & Program Code

- How many times can a program be run?
- How many copies of the program can be running at once?
- How many copies of the program data are needed?
- How many copies of the program code are needed?

Program Data & Program Code



Terminology

- *Program* = program code
- *Process* = execution of a program

- Each process has:
  - a program to execute
  - all of the program data for that execution

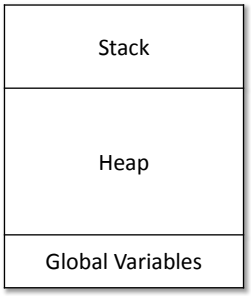
Program Data

- Contains many segments

- Different for each operating system
  - Linux/Mac OS
  - Windows

- Some segments appear in most OSs

Program Data



Global Variables

- All variables global to the program are stored here.
- Once created, they are never destroyed

How do we create a global variable in C?

Stack

- All variables local to functions are stored here.
- Last-in first-out (LIFO)

- Once the function returns, these variables are destroyed

How do we create a variable on the stack?

Creating a variable on the stack is called *static memory allocation* and all such variables are called *automatic variables*.

Heap

- Reserved for *dynamic memory management*
- The programmer must explicitly create and destroy these variables

How do we create a variable on the heap?

Where is the stack?

Where is the heap?

What happens if they meet?

What might cause them to meet?

Pointers

Pointer Gotchas

- Two parts to think about
  - the *value* of a variable
  - the *address* of a variable
- Each variable has both (even pointers themselves)!
- The value of a pointer is another variable's address

Example

```
main()
{
    int x = 100;

    printf("The value of x is %d\n", x);
    printf("The address of x is %u\n", &x);
}
```

Declaring a Pointer

```
main()
{
  char *charPointer;
  short *shortPointer;
  int *intPointer;
  long *longPointer;
  long long *longLongPointer;
  float *floatPointer;
  double *doublePointer;
  unsigned char *uCharPointer;
  unsigned short *uShortPointer;
  unsigned int *uIntPointer;
  unsigned long *uLongPointer;
  unsigned long long *uLongLongPointer;
}
```


What type is charPointer?

```
  char *charPointer;
```

What can its contents be?

```
char *charPointer;
```


Where would it be allocated?

```
char *charPointer;
```

Example

```
main()
{
     int x = 100;
     int *y = &x;

     printf("The value of x is %d\n", x);
     printf("The address of x is %u\n", y);
}
```

- How do we make use of y?

Dereferencing Pointers

```
main()
{
    int x = 100;
    int *y = &x;

    printf(" x = %d\n", x);
    printf("*y = %d\n", *y);

    x = x + 1;

    printf(" x = %d\n", x);
    printf("*y = %d\n", *y);

    *y = *y + 5;

    printf(" x = %d\n", x);
    printf("*y = %d\n", *y);
}
```

- x is an integer
- y is a pointer to an integer

- x is initialized to 100
- y is initialized to the address of x

- the place in memory called "x" can be accessed in two ways
  - by using the variable name "x"
  - by dereferencing the variable "y"

- *y can be used to read/write from where y points to

What is the output?

```
main()
{
     int *x;

     printf("%d\n", *x);
}
```


What is the output?

```
main()
{
     int *x = 0;

     printf("%d\n", *x);
}
```

What is the output?

```
void function1()
{
     int x = 100;
     int *y = &x;

     printf("*y = %u\n", y);
}

void function2()
{
     function1();
}

main()
{
     function1();
     function1();
     function2();
}
```


Pointer Arithmetic

```
main()
{
    int x = 100;
    int *y = &x;

    printf("x = %d\n", x);
    x++;
    printf("x = %d\n", x);
    x++;
    printf("x = %d\n", x);
    x++;
    printf("x = %d\n", x);

    printf("y = %u\n", y);
    y++;
    printf("y = %u\n", y);
    y++;
    printf("y = %u\n", y);
    y++;
    printf("y = %u\n", y);
}
```

Output:

```
x = 100
x = 101
x = 102
x = 103
y = 3219634196
y = 3219634200
y = 3219634204
y = 3219634208
```

- Why does `y` go up by 4?

Pointer Arithmetic

- Adding *n* to a pointer makes it point *n* spots "to the right"
- Subtracting *n* makes it point *n* "to the left"
- Using ++ makes it point one "to the right"
- Using -- makes it point one "to the left"

Recall the equation from yesterday's exercise for calculating the address of an array element given its index.

Given a pointer to the first element, use pointer arithmetic to obtain a pointer to the i^{th} element.

Exercise

```
main()
{
     int array[100];
     int *start = &array[0];
     int *element;
     int i;

     for (i = 0; i < 100; i++)
     {
          element = ?
     }
}
```


Consider this code

```
main()
{
     int array[100];
     int *element;
     int i;

     for (i = 0; i < 100; i++)
     {
          element = array + i;
          ...
     }
}
```

Pointers and Arrays

- In C, arrays are very closely related to pointers
- In fact, these two statements do the exact same thing:

```
array[5] = 20;
*(array + 5) = 20;
```

- Both could be written more explicitly as:

```
int *elem = &array[0] + 5;
*elem = 20;
```


What type of variable is `s`?

```
char *s;
```

Possible answers

- Pointer to a character
- An array of characters
- A string
  - Most advanced C programmers would think of this answer first (or even call it a C string)

Consider the following code

```
char *createName(char *first, char *middle, char *last)
{
    char name[100];
    name[0] = '\0';
    strcat(name, first);
    strcat(name, " ");
    strcat(name, middle);
    strcat(name, " ");
    strcat(name, last);

    return name;
}

main()
{
    char *name = createName("Alfredo", "H.", "Pasqualie");
}
```

Dynamic Memory Allocation

- To add a variable to the heap, we need to manually *allocate* the space.
- To remove a variable from the heap, we need to manually *free* up that space.

`malloc` and `free` (Example)

```
main()
{
    int *intPointer;

    intPointer = (int *)malloc( sizeof(int) );
    *intPointer = 20;

    free(intPointer);
}
```

malloc and free

```
void *malloc(int nbytes); /* must cast result */

void free(void *ptr);
```


Contrast

```
char *createName(char *first,
   char *middle, char *last)
{
    char name[100];
    name[0] = '\0';
    strcat(name, first);
    strcat(name, " ");
    strcat(name, middle);
    strcat(name, " ");
    strcat(name, last);

    return name;
}
```

```
char *createName(char *first,
   char *middle, char *last)
{
    int size = strlen(first)
        + strlen(middle)
        + strlen(last) + 3;

    char *name =
        (char *) malloc(size);
    *name = '\0';

    strcat(name, first);
    strcat(name, " ");
    strcat(name, middle);
    strcat(name, " ");
    strcat(name, last);

    return name;
}
```

Pass by Reference

- Using pointers, we have the ability to access pretty much any memory location.
- Most parameters are passed by value in C
- How would we pass by reference?

Example

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

main()
{
    int x = 100;
    int y = 200;

    printf("x = %d\n", x);
    printf("y = %d\n", y);

    swap(&x, &y);

    printf("x = %d\n", x);
    printf("y = %d\n", y);
}
```

Double Indirection

- What does this mean?

```
char **stringList;
```


Lecture 04 Summary

- Process Memory
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  - Dereferencing
  - Pointer Arithmetic
- Dynamic Memory Allocation
- Passing Parameters by Reference

Next Class

- Abstract Data Types