

C – Structs and Dynamic Memory Allocation

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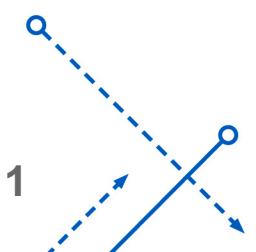
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Portions of this lecture are borrowed from the U-W CSE 333 course slides



Administrivia

- Some students used forbidden functions in lab
You will lose points for that portion of the lab exam
Pay attention to instructions
- Fix your SENS accounts
- PA1 due this weekend
- Lab 03 is on testing
- Repsect your Tas
Regardless of gender, ethnicity, major, what dorm they are in etc.
Each of them was handpicked by us for a reason

Practice

- Which lines have errors?

```
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char** argv) {
    int a[2];
    int* b = malloc(2*sizeof(int));
    int* c;

    1    a[2] = 5;
    2    b[0] += 2;
    3    c = b+3;
    4    free(&(a[0]));
    5    free(b);
    6    free(b);
    7    b[0] = 5;

    return EXIT_SUCCESS;
}
```

Memory Corruption

- There are all sorts of ways to corrupt memory in C

```
#include <stdio.h>
#include <stdlib.h>

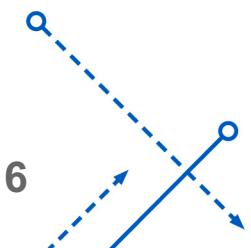
int main(int argc, char** argv) {
    int a[2];
    int* b = malloc(2*sizeof(int));
    int* c;

    a[2] = 5;    // assign past the end of an array
    b[0] += 2;   // assume malloc zeros out memory
    c = b+3;     // mess up your pointer arithmetic
    free(&(a[0])); // free something not malloc'ed
    free(b);
    free(b);     // double-free the same block
    b[0] = 5;    // use a freed pointer

    // any many more!
    return EXIT_SUCCESS;
}
```

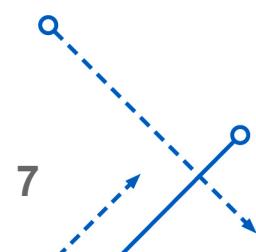
Memory Leak

- A **memory leak** occurs when code fails to deallocate dynamically-allocated memory that is no longer used
e.g. forget to **free** malloc-ed block, lose/change pointer to malloc-ed block
- What happens: program's VM footprint will keep growing
This might be OK for *short-lived* program, since all memory is deallocated when program ends
Usually has bad repercussions for *long-lived* programs
 - Might slow down over time (e.g. lead to VM thrashing)
 - Might exhaust all available memory and crash
 - Other programs might get starved of memory



Derived Data Types

- Arrays require all elements to be of the same data type
- Many times, we want to group items of different types in a structure
- E.g., `grade_roster = {Name (char *), UBID (int) , Active (bool) , Lab1 (float), PA0 (float), ..}`
- `struct`: Derived data type composed of members that are basic or other derived data types



Structured Data

- A **struct** is a C datatype that contains a set of fields

Similar to a Java class, but with no methods or constructors

Useful for defining new structured types of data

Behave similarly to primitive variables

- Generic declaration:

```
struct tagname {  
    type1 name1;  
    ...  
    typeN nameN;  
};
```

```
// the following defines a new  
// structured datatype called  
// a "struct Point"  
struct Point {  
    float x, y;  
};  
  
// declare and initialize a  
// struct Point variable  
struct Point origin = {0.0,0.0};
```

Declaring structs

Just specify the struct
(no space reserved)

```
// the following defines a new
// structured datatype called
// a "struct Point"
struct Point {
    float x, y;
};
```

specify the struct and
declare a variable
(space reserved)

```
// the following defines a new
// structured datatype called
// a "struct Point" and declares
// a variable "origin" of type
// struct Point
struct Point {
    float x, y;
} origin;
```

Using structs

- Use “.” to refer to a field in a struct
- Use “->” to refer to a field from a struct pointer

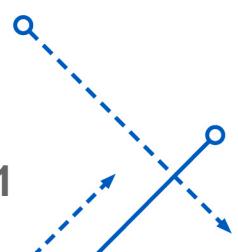
Dereferences pointer first, then accesses field

```
struct Point {  
    float x, y;  
};  
  
int main(int argc, char** argv) {  
    struct Point p1 = {0.0, 0.0}; // p1 is stack allocated  
    struct Point* p1_ptr = &p1;  
  
    p1.x = 1.0;  
    p1_ptr->y = 2.0; // equivalent to (*p1_ptr).y = 2.0;  
    return EXIT_SUCCESS;  
}
```

Copy by Assignment

- You can assign the value of a struct from a struct of the same type – *this copies the entire contents!*

```
struct Point {  
    float x, y;  
};  
  
int main(int argc, char** argv) {  
    struct Point p1 = {0.0, 2.0};  
    struct Point p2 = {4.0, 6.0};  
  
    printf("p1: {%f, %f}  p2: {%f, %f}\n", p1.x, p1.y, p2.x, p2.y);  
    p2 = p1;  
    printf("p1: {%f, %f}  p2: {%f, %f}\n", p1.x, p1.y, p2.x, p2.y);  
    return EXIT_SUCCESS;  
}
```



typedef

- Generic format: `typedef type name;`
- Allows you to define new data type *names/synonyms*
Both `type` and `name` are usable and refer to the same type
Be careful with pointers – * before name is part of type!

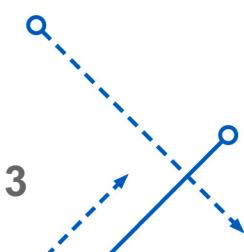
```
// make "superlong" a synonym for "unsigned long long"  
typedef unsigned long long superlong;  
  
// make "str" a synonym for "char*"  
typedef char *str;  
  
// make "Point" a synonym for "struct point_st { ... }"  
// make "PointPtr" a synonym for "struct point_st*"  
typedef struct point_st {  
    superlong x;  
    superlong y;  
} Point, *PointPtr; // similar syntax to "int n, *p;"  
  
Point origin = {0, 0};
```

Dynamically-allocated Structs

- You can **malloc** and **free** structs, just like other data type
sizeof is particularly helpful here

```
// a complex number is a + bi
typedef struct complex_st {
    double real;    // real component
    double imag;    // imaginary component
} Complex, *ComplexPtr;

// note that ComplexPtr is equivalent to Complex*
ComplexPtr AllocComplex(double real, double imag) {
    Complex* retval = (Complex*) malloc(sizeof(Complex));
    if (retval != NULL) {
        retval->real = real;
        retval->imag = imag;
    }
    return retval;
}
```



Aside: Arguments in C

- In most languages, arguments can be
 - Passed by value
 - Passed by reference
- C uses pass-by-value
- Example

```
before swap a = 1
before swap b = 2
after swap a = 1
after swap b = 2
```

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

int main() {
    int a = 1;
    int b = 2;

    printf("a before swap=%d\n",a);
    printf("b before swap=%d\n",b);
    swap(a,b);
    printf("a after swap=%d\n",a);
    printf("b after swap=%d\n",b);

    return 0;
}
```

<https://denniskubesh.com/2012/08/20/is-c-pass-by-value-or-reference/>

Aside: Arguments in C

- FIX: pass a pointer to the variables

```
before swap a = 1
before swap b = 2
after swap a = 2
after swap b = 1
```

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

int main() {
    int a = 1;
    int b = 2;

    printf("a before swap=%d\n", a);
    printf("b before swap=%d\n", b);
    swap(&a, &b);
    printf("a after swap=%d\n", a);
    printf("b after swap=%d\n", b);

    return 0;
}
```

<https://denniskubesh.com/2012/08/20/is-c-pass-by-value-or-reference/>

Structs as Arguments

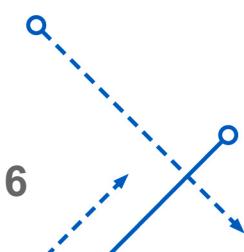
- Structs are passed by value, like everything else in C
Entire struct is copied
To manipulate a struct argument, pass a pointer instead

```
typedef struct point_st {
    int x, y;
} Point, *PointPtr;

void DoubleXBroken(Point p) { p.x *= 2; }

void DoubleXWorks(PointPtr p) { p->x *= 2; }

int main(int argc, char** argv) {
    Point a = {1,1};
    DoubleXBroken(a);
    printf("(%.d,%.d)\n", a.x, a.y); // prints: ( , )
    DoubleXWorks(&a);
    printf("(%.d,%.d)\n", a.x, a.y); // prints: ( , )
    return EXIT_SUCCESS;
}
```



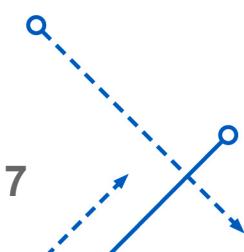
Returning Structs

- Exact method of return depends on calling conventions
Often returned in memory for larger structs

```
// a complex number is a + bi
typedef struct complex_st {
    double real;      // real component
    double imag;      // imaginary component
} Complex, *ComplexPtr;

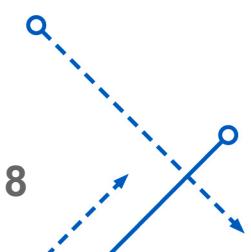
Complex MultiplyComplex(Complex x, Complex y) {
    Complex retval;

    retval.real = (x.real * y.real) - (x.imag * y.imag);
    retval.imag = (x.imag * y.real) - (x.real * y.imag);
    return retval; // returns a copy of retval
}
```



Pass Copy of Struct or Pointer?

- Value passed: passing a pointer is cheaper and takes less space unless struct is small
- Field access: indirect accesses through pointers are a bit more expensive and can be harder for compiler to optimize
- For small structs (like `struct complex_st`), passing a copy of the struct can be faster and often preferred if function only reads data; for large structs use pointers



Exercise #1

- Write a program that defines:

A new structured type Point

Represent it with `floats` for the x and y coordinates

A new structured type Rectangle

Assume its sides are parallel to the x-axis and y-axis

Represent it with the bottom-left and top-right Points

A function that computes and returns the area of a Rectangle

A function that tests whether a Point is inside of a Rectangle

Extra: Exercise #2

- Implement AllocSet() and FreeSet()

AllocSet() needs to use malloc twice: once to allocate a new ComplexSet and once to allocate the “points” field inside it

FreeSet() needs to use free twice

```
typedef struct complex_st {
    double real;      // real component
    double imag;      // imaginary component
} Complex;

typedef struct complex_set_st {
    double num_points_in_set;
    Complex* points;           // an array of Complex
} ComplexSet;

ComplexSet* AllocSet(Complex c_arr[], int size);
void FreeSet(ComplexSet* set);
```



Required Reading

- K&R 6.1-6.4, 7.8.5

