Intermediate Programming

Day 13

Outline

- Exercise 12
- Lifetime and scope
- `struct`s
- `typedef`
- Random numbers
- Review questions

Exercise 12

Declare and define search.

bsearch.c

```
...
int *search( int *start , int *end , int s_val );

int main( void ) {
	...
}

int *search( int *start , int *end , int s_val )
{
	if( start==end ) return NULL;
	int *mid = start + (end-start)/2;
	if( *mid==s_val ) return mid;
	else if( *mid<s_val ) return search( mid+1 , end , s_val );
	else return search( start , mid , s_val );
}
```

Exercise 12

Compute the index of the matching element

bsearch.c

```
...
int *search( int *start , int *end , int s_val );

int main( void ) {
	...
	int arr1[] = { 11, 119, 318, 518, 573, 750, 757, 809, 813, 994 };

	// example of a successful search
	pos = search(arr1, arr1 + 10, 809);
	assert(pos != NULL);
	assert(*pos == 809);
	// TODO: compute the index of the matching element
	index = pos - arr1;
	assert(7 == index);
	...
}

int *search( int *start , int *end , int s_val )
{
	if( start==end ) return NULL;
	int *mid = start + (end-start)/2;
	if( *mid==s_val ) return mid;
	else if( *mid<s_val ) return search( mid+1 , end , s_val );
	else return search( start , mid , s_val );
}
```

Exercise 12

Declare the unit array.

sudokuHelper.c

```
...
int *makeCol( int *table ) {
	int *unit = malloc( sizeof(int) * SIZE );
	if( !unit )
	{
		fprintf( stderr , "[ERROR] Failed to allocate unit\n" );
		return NULL;
	}
	...
}

int *makeCube( int *table ) {
	int *unit = malloc( sizeof(int) * SIZE );
	if( !unit )
	{
		fprintf( stderr , "[ERROR] Failed to allocate unit\n" );
		return NULL;
	}
	...
}
...
```

Exercise 12

Call **check** on current row and add to variable *good*

sudokuHelper.c

```
...
int checkRows( int table[][SIZE] ) {
        int good = 0;
        for (int r = 0; r < SIZE; r++) {
                good += check( table[r] );
        }
        return ( good==SIZE);
}
...
```

Exercise 12

Call **makeCol** on current column and assign result to variable **column**

sudokuHelper.c

```
...
int checkCols( int table[][SIZE] ) {
	int good = 0;
	int *column;
	for( int c=0 ; c<SIZE ; c++ ) {
		column = makeCol( table[0]+c );
		good += check(column);
	}
	return ( good==SIZE );
}
...
```

Exercise 12

Call **makeCube** on current cube and assign result to variable **cube**

sudokuHelper.c

```
...
int checkCubes(int table[][SIZE]) {
	int good = 0;
	int *cube;
	for( int r=0 ; r<SIZE ; r+=3)
		for( int c=0 ; c<SIZE ; c+=3 ) {
			cube = makeCube( table[r]+c );
			good += check(cube);
		}
	return (good == SIZE);
}
...
```

Exercise 12

Find and fix the memory leaks

```
>> valgrind --leak-check=full ./main puzzle1.txt
...
==3710153== HEAP SUMMARY:
==3710153==     in use at exit: 1,120 bytes in 19 blocks
==3710153==   total heap usage: 21 allocs, 2 frees, 10,336 bytes allocated
==3710153==
==3710153== 324 bytes in 9 blocks are definitely lost in loss record 1 of 3
==3710153==    at 0x484186F: malloc (vg_replace_malloc.c:381)
==3710153==    by 0x4013F9: makeCol (sudokuHelpers.c:22)
==3710153==    by 0x4015A7: checkCols (sudokuHelpers.c:85)
==3710153==    by 0x401317: main (in /home/misha/CS220/exercises/ex12/main)
```

Exercise 12

Find and fix the memory leaks

sudokuHelper.c

```c
…
21.    int* makeCol(int *table) {
22.            int *unit = malloc( sizeof(int) * SIZE );
23.            if( !unit )
24.            {
25.                    fprintf( stderr , "[ERROR] Failed to allocate unit\n" );
26.                    return NULL;
27.            }
 …
81.    int checkCols( int table[][SIZE] ) {
82.            int good = 0;
83.            int * column;
84.            for( int c=0 ; c<SIZE ; c++ ) {
85.                    column = makeCol( table[0]+c );
86.                    good += check(column);
87.            }
88.            return ( good==SIZE );
89.    }
…
```

```
>> valgrind --leak-check=full ./main puzzle1.txt
...
==3710153== HEAP SUMMARY:
==3710153==     in use at exit: 1,120 bytes in 19 blocks
==3710153==   total heap usage: 21 allocs, 2 frees, 10,336 bytes allocated
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==3710153==    by 0x401317: main (in /home/misha/CS220/exercises/ex12/main)
```

Exercise 12

Find and fix the memory leaks

sudokuHelper.c

```
...
int* makeCol(int *table) {
        int *unit = malloc( sizeof(int) * SIZE );
        if( !unit )
        {
                fprintf( stderr , "[ERROR] Failed to allocate unit\n" );
                return NULL;
        }
...
int checkCols( int table[][SIZE] ) {
        int good = 0;
        int * column;
        for( int c=0 ; c<SIZE ; c++ ) {
                column = makeCol( table[0]+c );
                good += check(column);
                free( column );
        }
        return ( good==SIZE );
}
int checkCubes(int table[][SIZE]) {
        int good = 0;
        int * cube;
        for (int r = 0; r < SIZE; r += 3)
                for (int c = 0; c < SIZE; c += 3) {
                        cube = makeCube( table[r]+c );
                        good += check(cube);
                        free( cube );
                }
        return ( good==SIZE );
}
...
```

Exercise 12

Find and fix the memory leaks

sudokuHelper.c

```
...
int* makeCol(int *table) {
        int *unit = malloc( sizeof(int) * SIZE );
        if( !unit )
        {
                fprintf( stderr , "[ERROR] Failed to allocate unit\n" );
                return NULL;
        }
...
int checkCols( int table[][SIZE] ) {
        int good = 0;
        int * column;
        for( int c=0 ; c<SIZE ; c++ ) {
                column = makeCol( table[0]+c );
                good += check(column);
                free( column );
        }
...
) {
r]+c );
```

```
>> valgrind --leak-check=full ./main puzzle1.txt
...
==3717575== HEAP SUMMARY:
==3717575==     in use at exit: 472 bytes in 1 blocks
==3717575==   total heap usage: 21 allocs, 20 frees, 10,336 bytes allocated
==3717575==
==3717575== LEAK SUMMARY:
==3717575==    definitely lost: 0 bytes in 0 blocks
==3717575==    indirectly lost: 0 bytes in 0 blocks
==3717575==      possibly lost: 0 bytes in 0 blocks
==3717575==    still reachable: 472 bytes in 1 blocks
==3717575==         suppressed: 0 bytes in 0 blocks
```

Exercise 12

Find and fix the memory leaks

sudoku.c

```
...
int main(int argc, char * argv[]) {

        if (argc < 2) {
                fprintf(stderr, "invalid program call\n");
                return 1;  // incorrect program usage
        }
        FILE* infile = fopen(argv[1], "r");
...
...     Read the board from the file
...
        if (checkRows(puzzle) && checkCols(puzzle) && checkCubes(puzzle))
                printf("puzzle is correctly solved\n");
        else
                printf("puzzle is not [correctly] solved\n");
        return 0;
}
```

```
>> valgrind --leak-check=full ./main puzzle1.txt
...
==3717575== HEAP SUMMARY:
==3717575==     in use at exit: 472 bytes in 1 blocks
==3717575==   total heap usage: 21 allocs, 20 frees, 10,336 bytes allocated
==3717575==
==3717575== LEAK SUMMARY:
==3717575==    definitely lost: 0 bytes in 0 blocks
==3717575==    indirectly lost: 0 bytes in 0 blocks
==3717575==      possibly lost: 0 bytes in 0 blocks
==3717575==    still reachable: 472 bytes in 1 blocks
==3717575==         suppressed: 0 bytes in 0 blocks
```

Exercise 12

Find and fix the memory leaks

sudoku.c

```
...
int main(int argc, char * argv[]) {

        if (argc < 2) {
                fprintf(stderr, "invalid program call\n");
                return 1;  // incorrect program usage
        }
        FILE* infile = fopen(argv[1], "r");
...
...     Read the board from the file
...
        if (checkRows(puzzle) && checkCols(puzzle) && checkCubes(puzzle))
                printf("puzzle is correctly solved\n");
        else
                printf("puzzle is not [correctly] solved\n");
        fclose( infile );
        return 0;
}
```

```
>> valgrind --leak-check=full ./main puzzle1.txt
...
==3720658== HEAP SUMMARY:
==3720658==     in use at exit: 0 bytes in 0 blocks
==3720658==   total heap usage: 21 allocs, 21 frees, 10,336 bytes allocated
==3720658==
==3720658== All heap blocks were freed -- no leaks are possible
```

Exercise 12

Find and fix the memory leaks

sudokuHelper.c

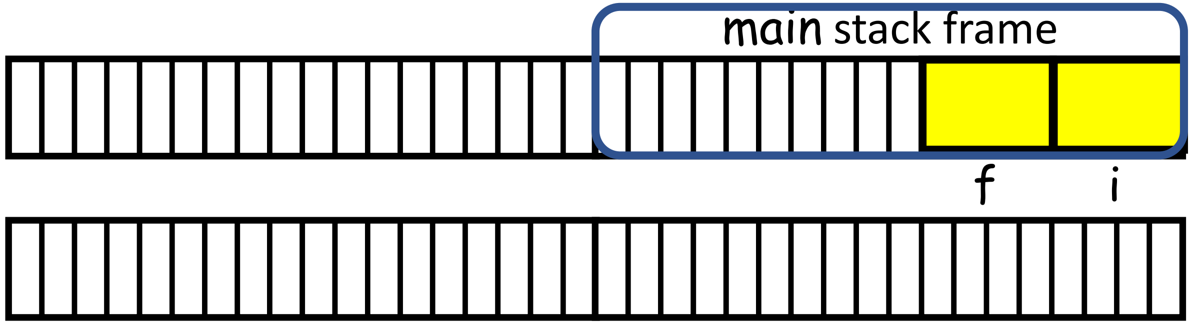
```
...
int checkCubes(int table[][SIZE]) {
	int good = 0;
	int *cube;
	for( int r=0 ; r<SIZE ; r+=3)
		for( int c=0 ; c<SIZE ; c+=3 ) {
			cube = makeCube( table[r]+c );
			good += check(cube);
			free( cube );
		}
	return (good == SIZE);
}
...
```

Outline

- Exercise 12
- Lifetime and scope
- structs
- typedef
- Random numbers
- Review questions

Variable lifetime and scope

- Variables declared in C programs have:
  - *lifetime*: How long is the variable in memory?
    - Both f and i have a lifetime equal to the duration of the main function
      (They come into existence when main's stack frame is created and disappear when it's gone)
  - *scope*: Where is the variable name accessible?
    - f is in scope from the point it is declared to the end of the main function (lines 4-7)
    - i is in scope for the for loop (lines 5-6)




```
1. #include <stdio.h>
2. int main( void )
3. {
4.         int f = 1;
5.         for( int i=2 ; i<6 ; i++ )
6.                 f*= i;
7.         printf( "%d\n" , f);
8. }
```

Variable lifetime and scope

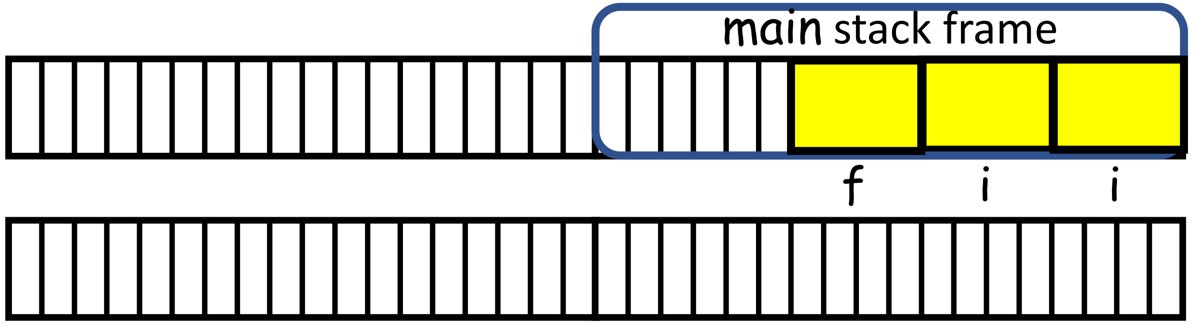
Q: What are the lifetimes of the variables `i`?

A: Both have a lifetime equal to the duration of the `main` function

Q: What are the scopes of the variables `i`?

A: The first comes into scope when it is declared, is *shadowed* / *hidden* during the `for` loop, and re-emerges after (lines 4, 7)

The second is in scope during the `for` loop (lines 5-6)




```
1. #include <stdio.h>
2. int main( void )
3. {
4.         int i,f=1;
5.         for( int i=2 ; i<6 ; i++ )
6.                 f*= i;
7.         printf( "%d\n" , f);
8. }
```

Variable lifetime and scope

- Variables declared in C programs have lifetime and scope
  - In general, local variables have lifetime / scope equal to the function's duration (assuming they aren't shadowed / hidden by an inner variable with the same name and are declared at the beginning)

```
#include <stdio.h>
void foo( int i )
{
    static int count;
    printf( "%d] foo( %d )\n" , count++ ,  i );
}
int main( void )
{
    foo( 1 ) ;
    foo( 7 );
    return 0;
}
```

Variable lifetime and scope

- Variables declared in C programs have lifetime and scope
  - In general, local variables have lifetime / scope equal to the function's duration (assuming they aren't shadowed / hidden by an inner variable with the same name and are declared at the beginning)
  - But… prefixing the variable declaration with the `static` keyword, extends the lifetime across all calls to that function
    - The variable is automatically initialized to have zero value

```
#include <stdio.h>
void foo( int i )
{
    static int count;
    printf( "%d] foo( %d )\n" , count++ ,  i );
}
int main( void )
{
    foo( 1 ) ;
    foo( 7 );
    return 0;
}
```

```
>> ./a.out
0] foo( 1 )
1] foo( 7 )
>>
```

Variable lifetime and scope

- Variables declared in C programs have lifetime and scope
  - In general, local variables have lifetime / scope equal to the function's duration (assuming they aren't shadowed / hidden by an inner variable with the same name and are declared at the beginning)
  - But… prefixing the variable declaration with the `static` keyword, extends the lifetime across all calls to that function
    - The variable is automatically initialized to have zero value
    - If you declare and assign, the assignment only happens the first time the function is called.

```
#include <stdio.h>
void foo( int i )
{
    static int count=5;
    printf( "%d] foo( %d )\n" , count++ ,  i );
}
int main( void )
{
    foo( 1 ) ;
    foo( 7 );
    return 0;
}
```

```
>> ./a.out
5] foo( 1 )
6] foo( 7 )
>>
```

Variable lifetime and scope

- Variables declared in C programs have lifetime and scope
  - In general, local variables have lifetime / scope equal to the function's duration (assuming they aren't shadowed / hidden by an inner variable with the same name and are declared at the beginning)
  - But… prefixing the variable declaration with the `static` keyword, extends the lifetime across <u>all</u> calls to that function
  - But the variable is still only scoped within the function

```
#include <stdio.h>
void foo( int i )
{
    static int count=5;
    printf( "%d] foo( %d )\n" , count++ ,  i );
}
int main( void )
{
    foo( 1 );
    printf( "%d\n" , count );
    return 0;
}
```

Variable lifetime and scope

- Variabl
  - In ge ... n's duration (ass... hidd... the same name and are declared at the beginning)
  - But… prefixing the variable declaration with the `static` keyword, extends the lifetime across all calls to that function
  - But the variable is still only scoped within the function

Note:
Because a `static` variable's lifespan extends beyond the function call, it does not reside on the stack. (`static` variables are stored in the *data segment*.)

```
{
    static int count=5;
    printf( "%d] foo( %d )\n" , count++ , i );
}
int main( void )
{
    foo( 1 );
    printf( "%d\n" , count );
    return 0;
}
```

Variable lifetime and scope

- Variables declared in C programs have lifetime and scope
  - We can also define *global* variables outside of any function
    - They have a lifetime equal to the lifetime of the program
      - They are initialized to zero
    - They are accessible to any function following the declaration

```
#include <stdio.h>
int count;
void foo( int i )
{
    printf( "%d] foo( %d )\n" , count++ ,  i );
}
int main( void )
{
    foo( 1 );
    printf( "%d\n" , count );
    return 0;
}
```

```
>> ./a.out
0] foo( 1 )
1
>>
```

Variable lifetime and scope

- Variables declared in C programs have lifetime and scope
  - We can also define *global* variables outside of any function
    - They have a lifetime equal to the lifetime of the program
      - They are initialized to zero
    - They are accessible to any function following the declaration

```
#include <stdio.h>
int count;
void foo( int i )
{
    printf( "%d] foo( %d )\n" , count++ , i );
}
main( void )

    foo( 1 );
    printf( "%d\n" , count );
    return 0;
}
```

```
>> ./a.out
0] foo( 1 )
1
>>
```

Note:
Like `static` variables, global variables do not reside on the stack.
(They too are stored in the *data segment*.)

Variable lifetime and scope

```c
int count = 3;
```

foo.c

```c
#include <stdio.h>

void incrementCount( int i )
{
    extern int count;
    count += i;
}
int main( void )
{
    extern int count;
    incrementCount( 5 );
    printf( "%d\n" , count );
    return 0;
}
```

main.c

Global variables:

- Like functions, you can define global variables in one source file and use them in another.
- At compile time, the compiler only needs to know the declaration, not the definition.
- At link time, the linker will bind the declared variables to their definitions.

Variable lifetime and scope

Global variables:

- Like functions, you can define global variables in one source file and use them in another.
- At compile time, the compiler only needs to know the declaration, not the definition.
- At link time, the linker will bind the declared variables to their definitions.
- The `extern` keyword can be used to declare global variables that are defined elsewhere (either in the same file or in other files).

```c
int count = 3;
```

foo.c

```c
#include <stdio.h>

void incrementCount( int i )
{
    extern int count;
    count += i;
}
int main( void )
{
    extern int count;
    incrementCount( 5 );
    printf( "%d\n" , count );
    return 0;
}
```

main.c

```
>> gcc main.c foo.c ...
>> ./a.out
8
>>
```

Variable lifetime and scope

```
int count = 3;
```

foo.c

```
#include <stdio.h>
extern int count;

void incrementCount( int i )
{
    count += i;
}
int main( void )
{
    incrementCount( 5 );
    printf( "%d\n" , count );
    return 0;
}
```

main.c

```
>> gcc main.c foo.c ...
>> ./a.out
8
>>
```

You can also declare the variable outside of a function call so that all (subsequent) functions calls have access to it.

needs to know the declaration, not the definition.

- At link time, the linker will bind the declared variables to their definitions.
- The extern keyword can be used to declare global variables that are defined elsewhere (either in the same file or in other files).

Beware the global variable

Usage of global variables is generally discouraged

- ✗ Debugging is harder – less clear which function changed a global variable's value (since it could be any!)
- ✗ Global variables cross boundaries between program modules, undoing benefits of modular code
  - readability
  - testability
- ✗ In general, values should be conveyed via parameter passing and return values

✓ Boolean global variables could be useful for debugging if you only want to `printf` within one function based on a condition being met in a different function.

Outline

- Exercise 12
- Lifetime and scope
- structs
- typedef
- Random numbers
- Review questions

Structures (`struct`s)

- If we have an application that stores students' ages and grades, we can represent a student's data by an array of `float` values. (E.g. by storing the data for `N` students in a `float` array of size `2N`.)

Q: What if we want to store other (non-numerical) data like names?

A: A structure is a collection of variables (often heterogeneously-typed) that are bundled together as a unit under a single name

Structures (**struct**s)

- Use the **struct** keyword to define a new type

```
struct Rec
{
    unsigned int eNum;
    const char * name;
    float salary;
};
```

Structures (**struct**s)

- Use the **struct** keyword to define a new type
  - It has a (type) name

```
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
```

Structures (**struct**s)

- Use the **struct** keyword to define a new type
  - It has a (type) name
  - And a list of variables (members)

```
struct Rec
{
    unsigned int eNum;
    const char * name;
    float salary;
};
```

Structures (**struct**s)

- Use the **struct** keyword to define a new type
  - It has a (type) name
  - And a list of variables (members)

- Variables of the type are declared using the **struct** keyword and the **struct** (type) name

```
struct Rec
{
      unsigned int eNum;
      const char * name;
      float salary;
};

struct Rec boss;
struct Rec assistant;
```

Structures (**struct**s)

- Use the **struct** keyword to define a new type
  - It has a (type) name
  - And a list of variables (members)

- Variables of the type are declared using the **struct** keyword and the **struct** (type) name
  - Can initialize members using array syntax
    - Variable order must match declaration order

```
boss = { 1 , "misha" , 0.f };
```

```
struct Rec
{
    unsigned int eNum;
    const char * name;
    float salary;
};

struct Rec boss;
struct Rec assistant;
```

Structures (**struct**s)

- Use the **struct** keyword to define a new type
  - It has a (type) name
  - And a list of variables (members)

- Variables of the type are declared using the **struct** keyword and the **struct** (type) name
  - Can initialize members using array syntax
  - Or member-by-member, using the "." operator

```
struct Rec
{
    unsigned int eNum;
    const char * name;
    float salary;
};

struct Rec boss;
struct Rec assistant;
```

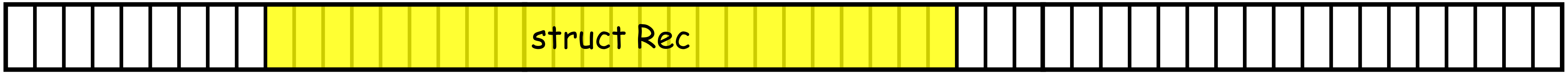
```
boss = { 1 , "misha" , 0.f };
```

```
boss.eNum = 1;
boss.name = "misha";
boss.salary = 0.f;
```

Structures (**struct**s)

- When the compiler sees a **struct** type it creates enough memory on the stack to store all of its contents

```
#include <stdio.h>
struct Rec
{
    unsigned int eNum;
    const char * name;
    float salary;
};
int main( void )
{
    struct Rec rec;
    …
    return 0;
}
```

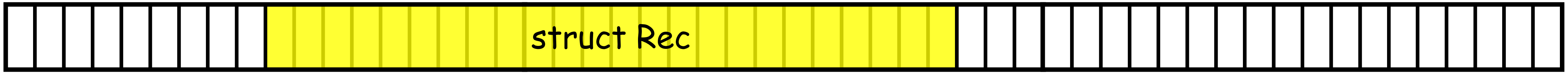


address space

Structures (**struct**s)

- When the compiler sees a **struct** type it creates enough memory on the stack to store all of its contents
  - You can get the size of the memory associated to a struct using **sizeof** …

```
#include <stdio.h>
struct Rec
{
    unsigned int eNum;
    const char * name;
    float salary;
};
int main( void )
{
    struct Rec rec;
    printf( "Size: %d\n" ,
        (int)sizeof( rec ) );
    return 0;
}
```



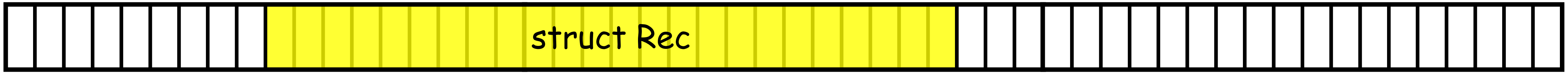
address space

Structures (**struct**s)

- When the compiler sees a **struct** type it creates enough memory on the stack to store all of its contents
  - You can get the size of the memory associated to a struct using **sizeof** … but this might be larger than the sum of its parts

```
#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
int main( void )
{
	struct Rec rec;
	printf( "Size: %d\n" ,
		(int)sizeof( rec ) );
	return 0;
}
```

```
>> ./a.out
Size: 24
>>
```



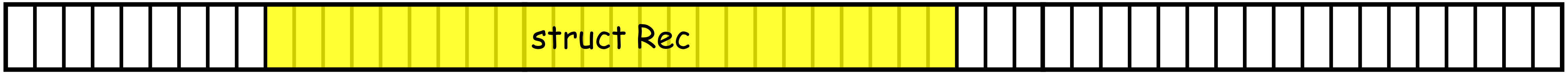
address space

Structures (**structs**)

- When the compiler sees a **struct** typ
  creates enough memory on the stack
  store all of its contents
  - You can get the size of the memory asso
    a struct using **sizeof** … but this might be
    than the sum of its parts

```c
#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
int main( void )
{
	printf( "%d + " , sizeof( unsigned int ) );
	printf( "%d + " , sizeof( const char* ) );
	printf( "%d = " , sizeof( float ) );
	printf( "%d\n" , sizeof( struct Rec ) );
	return 0;
}
```

```
>> ./a.out
4 + 8 + 4 = 24
>>
```



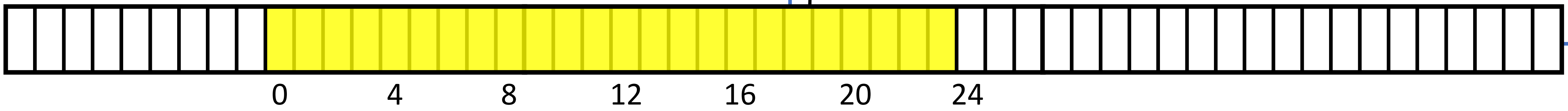
address space

Structures (**structs**)

- When the compiler sees a **struct** …
  creates enough memory on the sta…
  store all of its contents
  - You can get the size of the memory a…
    a struct using **sizeof** … but this migh…
    than the sum of its parts

```
#include <stdio.h>
struct Rec
{
    unsigned int eNum;
    const char * name;
    float salary;
};
int main( void )
{
    struct Rec r;
    void *_r = &r;
    void *_e = &(r.eNum);
    void *_n = &(r.name);
    void *_s = &(r.salary);
    printf( "Size: %d\n" , sizeof( struct Rec ) );
    printf( "eNum offset: %d\n" , _e - _r );
    printf( "name offset: %d\n" , _n - _r );
    printf( "salary offset: %d\n" , _s - _r );
    return 0;
}
```

```
>> ./a.out
Size: 24
eNum offset: 0
name offset: 8
salary offset: 16
>>
```



Structures (**structs**)

- When the compiler sees a **struct**
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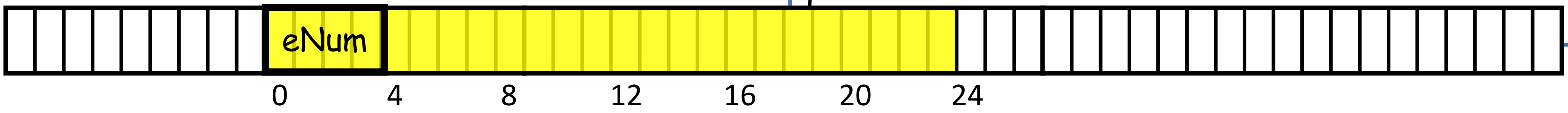
  store all of its contents
  - You can get the size of the memory a
    a struct using **sizeof** … but this migh
    than the sum of its parts

```
#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
int main( void )
{
	struct Rec r;
	void *_r = &r;
	void *_e = &(r.eNum);
	void *_n = &(r.name);
	void *_s = &(r.salary);
	printf( "Size: %d\n" , sizeof( struct Rec ) );
	printf( "eNum offset: %d\n" , _e - _r );
	printf( "name offset: %d\n" , _n - _r );
	printf( "salary offset: %d\n" , _s - _r );
	return 0;
}
```

```
>> ./a.out
Size: 24
eNum offset: 0
name offset: 8
salary offset: 16
>>
```



Structures (**structs**)

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  store all of its contents
  - You can get the size of the memory a
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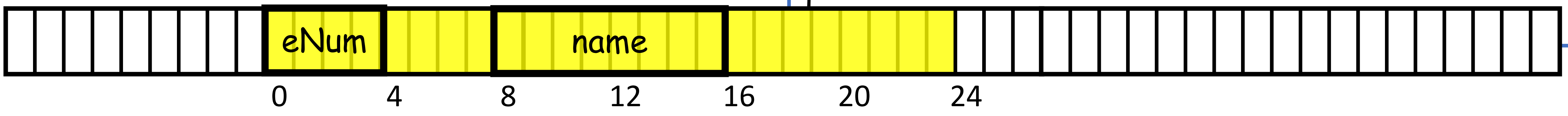
    than the sum of its parts

```c
#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
int main( void )
{
	struct Rec r;
	void *_r = &r;
	void *_e = &(r.eNum);
	void *_n = &(r.name);
	void *_s = &(r.salary);
	printf( "Size: %d\n" , sizeof( struct Rec ) );
	printf( "eNum offset: %d\n" , _e - _r );
	printf( "name offset: %d\n" , _n - _r );
	printf( "salary offset: %d\n" , _s - _r );
	return 0;
}
```

```
>> ./a.out
Size: 24
eNum offset: 0
name offset: 8
salary offset: 16
>>
```



Structures (**structs**)

- When the compiler sees a **struct** …
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#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
int main( void )
{
	struct Rec r;
	void *_r = &r;
	void *_e = &(r.eNum);
	void *_n = &(r.name);
	void *_s = &(r.salary);
	printf( "Size: %d\n" , sizeof( struct Rec ) );
	printf( "eNum offset: %d\n" , _e - _r );
	printf( "name offset: %d\n" , _n - _r );
	printf( "salary offset: %d\n" , _s - _r );
	return 0;
}
```

```
>> ./a.out
Size: 24
eNum offset: 0
name offset: 8
salary offset: 16
>>
```

Structures (**structs**)

- When the compiler sees a **struct** … creates enough memory on the sta… store all of its contents
  - You can get the size of the memory a… a struct using **sizeof** … but this migh… than the sum of its parts
  - The members are laid out in order but there may be added padding!

```
#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
int main( void )
{
	struct Rec r;
	void *_r = &r;
	void *_e = &(r.eNum);
	void *_n = &(r.name);
	void *_s = &(r.salary);
	printf( "Size: %d\n" , sizeof( struct Rec ) );
	printf( "eNum offset: %d\n" , _e - _r );
	printf( "name offset: %d\n" , _n - _r );
	printf( "salary offset: %d\n" , _s - _r );
	return 0;
}
```

```
>> ./a.out
Size: 24
eNum offset: 0
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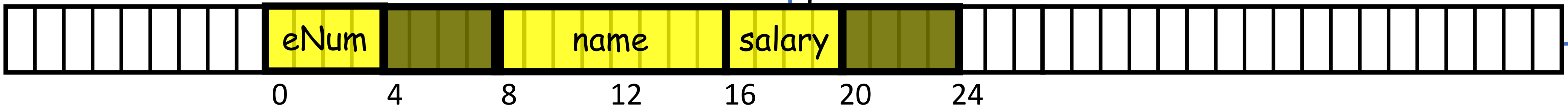
```



Structures (**structs**)

- When the compiler sees a **struct** …
  creates enough memory on the sta…
  store all of its contents
  - You can get the size of the memory a…
    a struct using **sizeof** … but this migh…
    than the sum of its parts
  - The members are laid out in order
    but there may be added padding!
    1. Start members at offsets that are multiples of their alignment

```
#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
int main( void )
{
	struct Rec r;
	void *_r = &r;
	void *_e = &(r.eNum);
	void *_n = &(r.name);
	void *_s = &(r.salary);
	printf( "Size: %d\n" , sizeof( struct Rec ) );
	printf( "eNum offset: %d\n" , _e - _r );
	printf( "name offset: %d\n" , _n - _r );
	printf( "salary offset: %d\n" , _s - _r );
	return 0;
}
```

```
>> ./a.out
Size: 24
eNum offset: 0
name offset: 8
salary offset: 16
>>
```

Structures (**structs**)

- When the compiler sees a **struct** …
  creates enough memory on the sta…
  store all of its contents
  - You can get the size of the memory a…
    a struct using **sizeof** … but this migh…
    than the sum of its parts
  - The members are laid out in order but there may be added padding!
    1. Start members at offsets that are multiples of their alignment
    2. Size should be a multiple of the size of the largest member

```c
#include <stdio.h>
struct Rec
{
        unsigned int eNum;
        const char * name;
        float salary;
};
int main( void )
{
        struct Rec r;
        void *_r = &r;
        void *_e = &(r.eNum);
        void *_n = &(r.name);
        void *_s = &(r.salary);
        printf( "Size: %d\n" , sizeof( struct Rec ) );
        printf( "eNum offset: %d\n" , _e - _r );
        printf( "name offset: %d\n" , _n - _r );
        printf( "salary offset: %d\n" , _s - _r );
        return 0;
}
```

```
>> ./a.out
Size: 24
eNum offset: 0
name offset: 8
salary offset: 16
>>
```

Structures (**structs**)

- When the compiler sees a **struct** …
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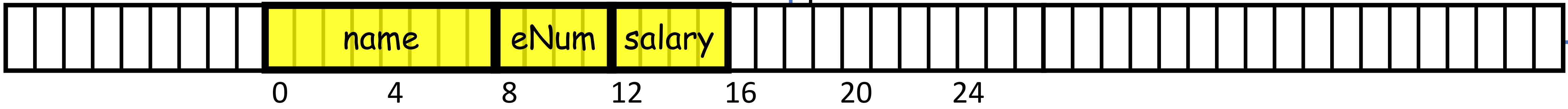
  - You can get the size of the memory a…
    a struct using **sizeof** … but this migh…
    than the sum of its parts
  - The members are laid out in order
    but there may be added padding!
    1. Start members at offsets that are multiples of their alignment
    2. Size should be a multiple of the size of the largest member

```c
#include <stdio.h>
struct Rec
{
	const char * name;
	unsigned int eNum;
	float salary;
};
int main( void )
{
	struct Rec r;
	void *_r = &r;
	void *_n = &(r.name);
	void *_e = &(r.eNum);
	void *_s = &(r.salary);
	printf( "Size: %d\n" , sizeof( struct Rec ) );
	printf( "name offset: %d\n" , _n - _r );
	printf( "eNum offset: %d\n" , _e - _r );
	printf( "salary offset: %d\n" , _s - _r );
	return 0;
}
```

```
>> ./a.out
Size: 16
name offset: 0
eNum offset: 8
salary offset: 12
>>
```



Structures (**struct**s)

- Whole **struct**s can be assigned values and copied, and/or passed into or returned from functions

```
#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
struct Rec Increase( struct Rec r , float s)
{
	r.salary += s;
	return r;
}
int main( void )
{
	struct Rec boss = { 1 , "misha" , 0.f };
	printf( "%g\t" , boss.salary );
	boss = Increase( boss , 1e6f );
	printf( "%g\n" , boss.salary );
	return 0;
}
```

```
>> ./a.out
0       1e+06
>>
```

Structures (**struct**s)

- Whole **struct**s can be assigned values and copied, and/or passed into or returned from functions
  - On return, the entire **struct** (i.e. all its contents) is copied from the stack-frame of the called function to the stack-frame of the calling function

```
#include <stdio.h>
struct Rec
{
    unsigned int eNum;
    const char * name;
    float salary;
};
struct Rec Increase( struct Rec r , float s)
{
    r.salary += s;
    return r;
}
int main( void )
{
    struct Rec boss = { 1 , "misha" , 0.f };
    printf( "%g\t" , boss.salary );
    boss = Increase( boss , 1e6f );
    printf( "%g\n" , boss.salary );
    return 0;
}
```

```
>>  ./a.out
0       1e+06
>>
```

Structures (**struct**s)

- Whole **struct**s can be assigned values and copied, and/or passed into or returned from functions
  - Arguments are passed by value so the function sees a copy of the data in the **struct**

```
#include <stdio.h>
struct Rec
{
    unsigned int eNum;
    const char * name;
    float salary;
};
void Increase( struct Rec r , float s)
{
    r.salary += s;
}
int main( void )
{
    struct Rec boss = { 1 , "misha" , 0.f };
    printf( "%g\t" , boss.salary );
    Increase( boss , 1e6f );
    printf( "%g\n" , boss.salary );
    return 0;
}
```

```
>> ./a.out
0       0
>>
```

Structures (**struct**s)

- Whole **struct**s can be assigned values and copied, and/or passed into or returned from functions
  - If you want to access the original data (or the **struct** is large and you don't want to duplicate it) you can pass a pointer
    - You can dereference the pointer and use the "." operator to access the member data

```
#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
void Increase( struct Rec * r , float s)
{
	(*r).salary += s;
}
int main( void )
{
	struct Rec boss = { 1 , "misha" , 0.f };
	printf( "%g\t" , boss.salary );
	Increase( &boss , 1e6f );
	printf( "%g\n" , boss.salary );
	return 0;
}
```

```
>> ./a.out
0       1e+06
>>
```

Structures (**struct**s)

- Whole **struct**s can be assigned values and copied, and/or passed into or returned from functions
  - If you want to access the original data (or the **struct** is large and you don't want to duplicate it) you can pass a pointer
    - You can dereference the pointer and use the "." operator to access the member data
    - Or you can use the "->" operator to access the member data directly from the pointer

```
#include <stdio.h>
struct Rec
{
    unsigned int eNum;
    const char * name;
    float salary;
};
void Increase( struct Rec * r , float s)
{
    r->salary += s;
}
int main( void )
{
    struct Rec boss = { 1 , "misha" , 0.f };
    printf( "%g\t" , boss.salary );
    Increase( &boss , 1e6f );
    printf( "%g\n" , boss.salary );
    return 0;
}
```

```
>> ./a.out
0       1e+06
>>
```

Structures (**struct**s)

- Whole **struct**s can be assigned values and copied, and/or passed into or returned from functions
  - If a **struct** contains an array, the values are stored as part of the **struct**
  - ⇒ If a function returns the **struct**, the values are copied to the calling function
  - ⇒ Wrapping arrays within a **struct**, we can have functions that effectively return arrays.

```
#include <stdio.h>
struct FourInts
{
    int ints[4];
};
struct FourInts Init( void )
{
    struct FourInts fourInts;
    for( int i=0 ; i<4 ; i++ ) fourInts.ints[i] = i;
    return fourInts;
}
int main( void )
{
    struct FourInts fi = Init();
    for( int i=0 ; i<4 ; i++ )
        printf( "%d] %d\n" , i , fi.ints[i] );
    return 0;
}
```

```
>> ./a.out
0] 0
1] 1
2] 2
3] 3
>>
```

Structures (**struct**s)

- You can nest **struct**s
  - Since both "." and "->" associate left-to-right, the employee number of the lead is:

    ```
    (mgmt.lead).eNum
    (t->lead).eNum
    mgmt.lead.eNum
    t->lead.eNum
    ```

```
#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
struct TeamRec
{
	struct Rec lead;
	struct Rec e1 , e2;
};
int main( void )
{
	…
	struct TeamRec mgmt;
	mgmt.lead = boss;
	mgmt.lead.salary *=2;
	TeamRec *t = &mgmt;
	…
}
```

Structures (**struct**s)

- You can nest **struct**s
- You can create arrays of **struct**s
  - Statically, on the stack

```
#include <stdio.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
int main( void )
{
	struct Rec staff[10];
	for( int i=0 ; i<10 ; i++ )
	{
		staff[i].eNum = i;
		…
	}
	return 0;
}
```

Structures (**struct**s)

- You can nest **struct**s
- You can create arrays of **struct**s
  - Statically, on the stack
  - Or dynamically on the heap

```
#include <stdio.h>
#include <stdlib.h>
struct Rec
{
	unsigned int eNum;
	const char * name;
	float salary;
};
int main( void )
{
	struct Rec *staff;
	staff = malloc( sizeof( struct Rec )*10 );
	for( int i=0 ; i<10 ; i++ )
	{
		staff[i].eNum = i;
		…
	}
	free( staff );
	return 0;
}
```

Structures (**struct**s)

- You can nest **struct**s
- You can create arrays of **struct**s
  - Statically, on the stack
  - Or dynamically on the heap
- You can declare a **struct** inside of a **struct**

```
#include <stdio.h>
#include <stdlib.h>
struct Pixel
{
	struct
	{
		unsigned char r , g , b;
	} color;
	struct
	{
		int x , y;
	} position;
};
int main( void )
{
	struct Pixel p;
	p.color.r = p.color.g = p.color.b = 255;
	p.position.x = p.position.y = 0;
	…
	return 0;
}
```

Structures (**structs**)

- You can nest **structs**
- You can create arrays of **structs**
  - Statically, on the stack
  - Or dynamically on the heap
- You can declare a **struct** inside of a **struct**
  - Note that these lines are simultaneously:
    - Defining an (unnamed) struct with three unsigned chars, and
    - Declaring a member color of that type.

```
#include <stdio.h>
#include <stdlib.h>
struct Pixel
{
	struct
	{
		unsigned char r , g , b;
	} color;
	struct
	{
		int x , y;
	} position;
};
int main( void )
{
	struct Pixel p;
	p.color.r = p.color.g = p.color.b = 255;
	p.position.x = p.position.y = 0;
	…
	return 0;
}
```

Outline

- Exercise 12
- Lifetime and scope
- structs
- typedef
- Random numbers
- Review questions

typedef

- Declaring / passing a `struct` requires adding the `struct` keyword

```c
#include <stdio.h>
struct Rec
{
	unsigned int emplNum;
	const char * name;
	float salary;
};
void PrintRec( struct Rec r )
{
	printf( "Number: %d\n" , r.emplNum );
	printf( "Name: %s\n" , r.name );
	printf( "Salary: %.2f\n" , r.salary );
}
int main( void )
{
	struct Rec boss = { 1 , "misha" , 0.f };
	PrintRec( boss );
	return 0;
}
```

```
>> ./a.out
Number: 1
Name: misha
Salary: 0.00
>>
```

typedef

- Declaring / passing a **struct** requires adding the **struct** keyword
- We can use the **typedef** keyword to define a new "type" that has the keyword **struct** baked in:

  typdef <type> <alias>;

```
#include <stdio.h>
struct _Rec
{
    unsigned int emplNum;
    const char * name;
    float salary;
};
typedef struct _Rec Rec;
void PrintRec( Rec r )
{
    printf( "Number: %d\n" , r.emplNum );
    printf( "Name: %s\n" , r.name );
    printf( "Salary: %.2f\n" , r.salary );
}
int main( void )
{
    Rec boss =  { 1 , "misha" , 0.f };
    PrintRec( boss );
    return 0;
}
```

typedef

- Declaring / passing a **struct** requires adding the **struct** keyword
- We can use the **typedef** keyword to define a new "type" that has the keyword **struct** baked in:

  typdef <type> <alias>;

- We can even apply it to the definition of the **struct**

```
#include <stdio.h>
typedef struct _Rec
{
    unsigned int emplNum;
    const char * name;
    float salary;
} Rec;

void PrintRec( Rec r )
{
    printf( "Number: %d\n" , r.emplNum );
    printf( "Name: %s\n" , r.name );
    printf( "Salary: %.2f\n" , r.salary );
}
int main( void )
{
    Rec boss = { 1 , "misha" , 0.f };
    PrintRec( boss );
    return 0;
}
```

typedef

- Declaring / passing a struct requires adding the struct keyword
- We can use the typedef keyword to define a new "type" that has the keyword struct baked in:

  typdef <type> <alias>;

- We can even apply it to the definition of the struct
- We can even omit the actual struct name altogether*

```
#include <stdio.h>
typedef struct
{
	unsigned int emplNum;
	const char * name;
	float salary;
} Rec;

void PrintRec( Rec r )
{
	printf( "Number: %d\n" , r.emplNum );
	printf( "Name: %s\n" , r.name );
	printf( "Salary: %.2f\n" , r.salary );
}
int main( void )
{
	Rec boss =  { 1 , "misha" , 0.f };
	PrintRec( boss );
	return 0;
}
```

*This is OK unless we need to know the struct's name within the struct.

Outline

- Exercise 12
- Lifetime and scope
- `struct`s
- typedef
- Random numbers
- Review questions

Random numbers

`stdlib.h` declares two functions for generating random numbers

```
int rand( void );
```

- Returns a random integer value between 0 and RAND_MAX
- RAND_MAX is a constant (at least 32767)
- Each call to rand creates a new random number

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

int main( void )
{
    printf( "%d < %d\n" , rand() , RAND_MAX );
    printf( "%d < %d\n" , rand() , RAND_MAX );
    return 0;
}
```

Random numbers

`stdlib.h` declares two functions for generating random numbers

```
int rand( void );
```

- Returns a random integer value between 0 and `RAND_MAX`
- `RAND_MAX` is a constant (at least 32767)
- Each call to `rand` creates a new random number

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

int main( void )
{
	printf( "%d < %d\n" , rand() , RAND_MAX );
	printf( "%d < %d\n" ,
	return 0;
}
```

```
>> ./a.out
1804289383 < 2147483647
846930886 < 2147483647
>>
```

Random numbers

`stdlib.h` declares two functions for generating random numbers

void srand(unsigned int);

- Seeds the random number generator
- Calling rand after the random number has been seeded will consistently generate the same set of random numbers.
- Useful for debugging (for consistency)
- Useful for trying different values

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

int main( void )
{
    srand( 1 );
    printf( "%d , %d\n" , rand() , rand() );
    srand( 2 );
    printf( "%d , %d\n" , rand() , rand() );
    srand( 1 );
    printf( "%d , %d\n" , rand() , rand() );
    return 0;
}
```

Random numbers

`stdlib.h` declares two functions for generating random numbers

void srand(unsigned int);

- Seeds the random number generator
- Calling rand after the random number has been seeded will consistently generate the same set of random numbers.
- Useful for debugging (for consistency)
- Useful for trying different values

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

int main( void )
{
    srand( 1 );
    printf( "%d , %d\n" , rand() , rand() );
    srand( 2 );
    printf( "%d , %d\n" , rand() , rand() );
    srand( 1 );
    printf( "%d , %
    return 0;
}
```

```
>> ./a.out
846930886 , 1804289383
1738766719 , 1505335290
846930886 , 1804289383
>>
```

Warning:
Seeding the random number with a value of 1 has a special meaning.
It re-seeds the random number generator to its original state.

On some machines the "original state" is being seeded with 0, so that srand(0) and srand(1) do the same thing.

- Seeds the random number generator
- Calling rand after the random number has been seeded will consistently generate the same set of random numbers.
- Useful for debugging (for consistency)
- Useful for trying different values

```
int main( void )
{
    srand( 1 );
    printf( "%d , %d\n" , rand() , rand() );
    srand( 2 );
    printf( "%d , %d\n" , rand() , rand() );
    srand( 1 );
    printf( "%d , %
    return 0;
}
```

```
>> ./a.out
846930886 , 1804289383
1738766719 , 1505335290
846930886 , 1804289383
>>
```

Random numbers

We can use **rand** to generate random numbers in an integer range

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

int myRand( int low , int high )
{
    return low + rand() % ( high - low );
}
int main( void )
{
    printf( "%d , %d\n" , myRand(2,6) , myRand(2,6) );
    printf( "%d , %d\n" , myRand(16,26) , myRand(16,26) );
    return 0;
}
```

```
>> ./a.out
3, 5
21, 23
>>
```

Random numbers

We

Note:
This will create random numbers in the range [low,high).

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

int myRand( int low , int high )
{
	return low + rand() % ( high - low );
}
int main( void )
{
	printf( "%d , %d\n" , myRand(2,6) , myRand(2,6) );
	printf( "%d , %d\n" , myRand(16,26) , myRand(16,26) );
	return 0;
}
```

```
>> ./a.out
3, 5
21, 23
>>
```

Random numbers

We can use **rand** to generate random numbers in a floating point range

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

float myRand( float low , float high )
{
    return low + (float)rand() / RAND_MAX * ( high - low );
}
int main( void )
{
    printf( "%f , %f\n" , myRand(2,6) , myRand(2,6) );
    printf( "%f , %f\n" , myRand(16,26) , myRand(16,26) );
    return 0;
}
```

```
>> ./a.out
3.577532 , 5.360751
23.984400 , 23.830992
>>
```

Outline

- Exercise 12
- Lifetime and scope
- `struct`s
- typedef
- Random numbers
- Review questions

Review questions

1. What is a `struct` in c?

A user defined type which is a collection of variables (often heterogeneously-typed) that are bundled together as a unit under a single name

Review questions

2. How are the fields of a `struct` passed into a function – by value or by reference?

By value

Review questions

3. What is the size of a `struct`? What is structure padding in C?

The size of a `struct` is at least the number of bytes needed to store the data. It may be padded either to align the members or to ensure that the size is a multiple of the largest member's size.

Review questions

4. What is the difference between lifetime and scope of a variable?

Lifetime describes how long the variable resides in memory.

Scope describes when it is accessible.

Review questions

5. What is variable shadowing (i.e. hiding)?

When a variable goes out of scope because another variable with the same name is brought into scope.

Review questions

6. What is the output of this program?

```
#include <stdio.h>
int foo;
void bar( void )
{
        int foo = 3;
        {
                extern int foo;
                printf( "%d; " , foo );
                foo = 2;
        }
        printf( "%d; ", foo );
}
void baz( void ) { printf( "%d; " , foo ); }
int main( void )
{
        {
                int foo = 5;
                bar();
                printf( "%d; " , foo );
        }
        baz();
        return 0;
}
```

`0; 3; 5; 2;`

(Recall that global variables are initialized to zero.)

Exercise 13

- Website -> Course Materials -> Exercise 13