

Data Structures in C and C++

CS 214, Fall 2019

Structs

Structs in DSSL2

```
struct posn:  
  let x: num?  
  let y: num?  
  
struct circle:  
  let center: posn?  
  let radius: num?
```

Structs in DSSL2

```
struct posn:
```

```
  let x: num?
```

```
  let y: num?
```

```
struct circle:
```

```
  let center: posn?
```

```
  let radius: num?
```

```
def scale_circle(circ, factor):
```

```
  circ.radius = factor * circ.radius
```

Structs in DSSL2

```
struct posn:
```

```
  let x: num?
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```
  let y: num?
```

```
struct circle:
```

```
  let center: posn?
```

```
  let radius: num?
```

```
def scale_circle(circ, factor):
```

```
  circ.radius = factor * circ.radius
```

```
test 'parameter passing creates sharing':
```

```
  let c = circle(posn(3, 4), 6)
```

```
  scale_circle(c, 2)
```

```
  assert_eq c.radius, 12
```

Structs in DSSL2

```
struct posn:
```

```
  let x: num?
```

```
  let y: num?
```

```
struct circle:
```

```
  let center: posn?
```

```
  let radius: num?
```

```
test 'assignment creates sharing':
```

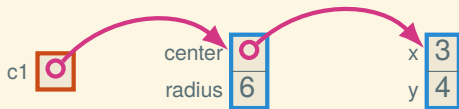
```
  let c1 = circle(posn(3, 4), 6)
```

```
  let c2 = c1
```

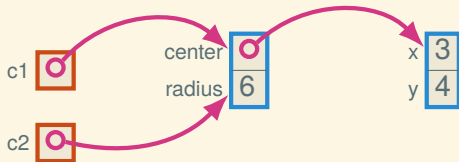
```
  c2.radius = 12
```

```
  assert_eq c1.radius, 12
```

What is happening in memory (in DSSL2)

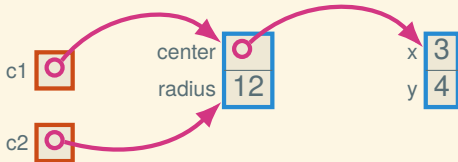


What is happening in memory (in DSSL2)



```
let c2 = c1
```


What is happening in memory (in DSSL2)



```
let c2 = c1
```

```
c2.radius = 12
```

Comparison between DSSL2 and C (and C++)

| | DSSL2 | C(++) |
|-------------------|-----------------|---------------------|
| size of variables | always the same | depends on type |
| pointers | to every struct | only when requested |

Comparison between DSSL2 and C (and C++)

| | DSSL2 | C(++) |
|-------------------|-----------------|---------------------|
| size of variables | always the same | depends on type |
| pointers | to every struct | only when requested |

Other languages like C and C++:

- C# (sort of)
- Swift (sort of)
- Rust

Other languages like DSSL2:

- Java
- Python
- JavaScript

The circle example in C

```
struct posn
{
    double x, y;
};

struct circle
{
    struct posn center;
    double radius;
};
```

The circle example in C

```
struct posn
{
    double x, y;
};

struct circle
{
    struct posn center;
    double radius;
};

void scale_circle(struct circle c2, double factor)
{
    c2.radius *= factor;
}
```

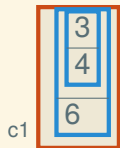
The circle example in C

```
struct posn
{
    double x, y;
};

struct circle
{
    struct posn center;
    double radius;
};

int main()
{
    struct circle c1 = { .center = { .x = 3, .y = 4 },
                        .radius = 6 };
    struct circle c2 = c1;
    c2.radius = 12;
}
```

What is happening in memory (in C)



What is happening in memory (in C)



```
struct circle c2 = c1;
```


What is happening in memory (in C)



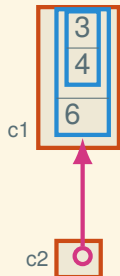
```
struct circle c2 = c1;
```

```
c2.radius = 12
```

Getting the address of a variable

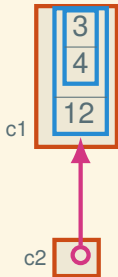


Getting the address of a variable



```
struct circle* c2p = &c1;
```

Getting the address of a variable



```
struct circle* c2p = &c1;
```

```
c2p->radius = 12;
```

Passing a pointer

```
void scale_circle(struct circle* cp, double factor)
{
    cp->radius *= factor;
}

int main()
{
    struct circle c = {
        .center = { .x = 3, .y = 4 },
        .radius = 6
    };

    scale_circle(&c);
}
```

Stack allocation



```
struct circle* bad()
{
    struct circle c = { .center = { .x = 3, .y = 4 },
                       .radius = 6 };
    return &c;
}
```

Stack allocation



```
struct circle* bad()
{
    struct circle c = { .center = { .x = 3, .y = 4 },
                       .radius = 6 };
    return &c;
}

int main()
{
    struct circle* cp = bad();
}
```

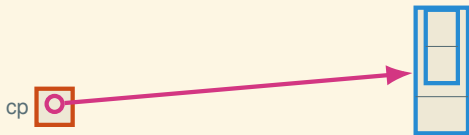
Heap allocation

```
int main()
{
    struct circle* cp = malloc(sizeof(struct circle));
    if (cp == NULL) return 1;
    cp->center.x = 3; cp->center.y = 4; cp->radius = 6;

    scale_circle(cp, 2);

    free(cp);
}
```


Heap allocation



```
int main()
{
    struct circle* cp = malloc(sizeof(struct circle));
    if (cp == NULL) return 1;
    cp->center.x = 3; cp->center.y = 4; cp->radius = 6;

    scale_circle(cp, 2);

    free(cp);
}
```

Heap allocation

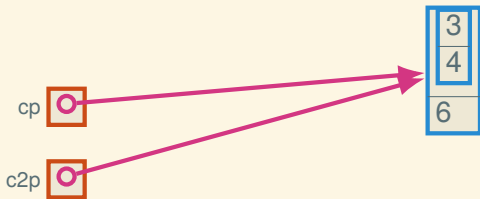


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    if (cp == NULL) return 1;
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    scale_circle(cp, 2);

    free(cp);
}
```

Heap allocation

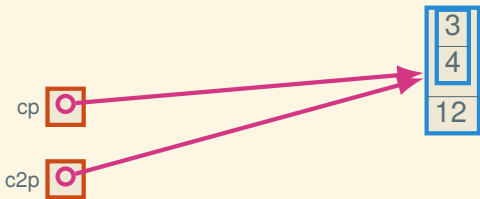


```
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    if (cp == NULL) return 1;
    cp->center.x = 3; cp->center.y = 4; cp->radius = 6;

    scale_circle(cp, 2);

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Heap allocation



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Heap allocation



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int main()
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Heap allocation



```
int main()
{
    struct circle* cp = malloc(sizeof(struct circle));
    if (cp == NULL) return 1;
    cp->center.x = 3; cp->center.y = 4; cp->radius = 6;

    scale_circle(cp, 2);

    free(cp);
}
```

Arrays

Fixed-sized arrays

Global (statically allocated):

```
int array[10];
```

```
void f(size_t i)
{
    array[i] = 7;
}
```


Fixed-sized arrays

Global (statically allocated):

```
int array[10];  
  
void f(size_t i)  
{  
    array[i] = 7;  
}
```

Local (stack allocated):

```
void g(size_t i)  
{  
    int array[10];  
    array[i] = 7;  
}
```

Returning an array

This function returns a dangling pointer:

```
int* bad(size_t i)
{
    int array[10];
    array[i] = 7;
    return array;
}
```

Returning an array

This function returns a dangling pointer:

```
int* bad(size_t i)
{
    int array[10];
    array[i] = 7;
    return array;
}
```

But you can malloc up a heap array:

```
int* good(size_t i)
{
    int* array = malloc(10 * sizeof(int));
    if (array == NULL) out_of_memory();
    array[i] = 7;
    return array;
}
```

Be careful!

```
int* f(size_t i)
{
    int* array = malloc(10 * sizeof(int));
    if (array == NULL) out_of_memory();
    array[i] = 7;
    return array;
}
```

```
void g()
{
    int* array = f(5);

    // prints "7\n"
    printf("%d\n", array[5]);

    free(array);
}
```

Be careful!

```
int* f(size_t i)
{
    int* array = malloc(10 * sizeof(int));
    if (array == NULL) out_of_memory();
    array[i] = 7;
    return array;
}
```

```
void g()
{
    int* array = f(5);

    // UNDEFINED BEHAVIOR!
    printf("%d\n", array[6]);

    free(array);
}
```

Be careful!

```
int* f(size_t i)
{
    int* array = malloc(10 * sizeof(int));
    if (array == NULL) out_of_memory();
    array[i] = 7;
    return array;
}
```

```
void g()
{
    int* array = f(5);

    // prints "12\n"
    array[6] = 12;
    printf("%d\n", array[6]);

    free(array);
}
```

Be careful!

```
int* f(size_t i)
{
    int* array = malloc(10 * sizeof(int));
    if (array == NULL) out_of_memory();
    array[i] = 7;
    return array;
}
```

```
void g()
{
    int* array = f(5);

    // UNDEFINED BEHAVIOR!
    array[10] = 17;

    free(array);
}
```

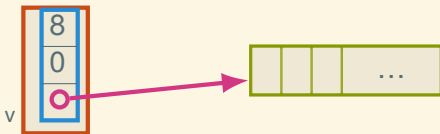
Representing dynamic arrays in C



```
struct int_da
{
    size_t capacity;
    size_t size;
    int* data;
};
```

```
struct int_da v;
```


Representing dynamic arrays in C



```
struct int_da
{
    size_t capacity;
    size_t size;
    int* data;
};
```

```
struct int_da v;
```

```
v.capacity = 8;
v.size     = 0;
v.data     = malloc(v.capacity * sizeof(int));
```

The pimpl pattern

```
// int_da.h  
typedef struct int_da* int_da_t;  
int_da_t int_da_create(size_t capacity);
```

The pimpl pattern

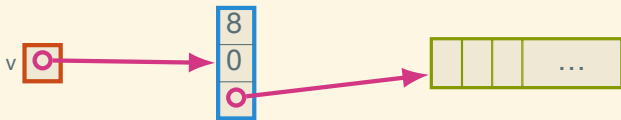
```
// int_da.h  
typedef struct int_da* int_da_t;  
int_da_t int_da_create(size_t capacity);
```

```
// int_da.c  
struct int_da  
{  
    size_t capacity;  
    size_t size;  
    int* data;  
};
```

The pimpl pattern

```
// int_da.h
typedef struct int_da* int_da_t;
int_da_t int_da_create(size_t capacity);
```

```
// int_da.c
struct int_da
{
    size_t capacity;
    size_t size;
    int* data;
};
```



```
int_da_t v = int_da_create(8);
```

To `int_da.h`, `int_da.c`, `str_da.h`,
`str_da.c`, ...

Moving to C++

Why C++?

- Generics
- Privacy
- Stuff happens automatically

C++ generics

```
struct int_da  
{  
    size_t capacity, size;  
    int* data;  
};
```

```
struct str_da  
{  
    size_t capacity, size;  
    char** data;  
};
```


C++ generics

```
struct int_da
{
    size_t capacity, size;
    int* data;
};
```

```
struct str_da
{
    size_t capacity, size;
    char** data;
};
```

```
template <class T>
struct Dyn_array
{
    size_t capacity, size;
    T* data;
}
```

C++ privacy

```
template <class T>
class Dyn_array
{
public:
    Dyn_array();

    size_t size() const;
    void push_back(T const&);
    T& operator[](size_t);

    // ...

private:
    size_t capacity_, size_;
    T* data_;
}
```

C++ stuff that happens automatically

```
template <class T>
class Dyn_array
{
public:
    // ...

    ~Dyn_array();
    Dyn_array(Dyn_array const&);
    Dyn_array& operator=(Dyn_array const&);

    // ...
}
```

To `raii.cpp`, `Dyn_array.hpp`,
`Hash_map.hpp`, ...

STL: The C++ Standard Template Library

```
#include <vector>           // dynamic array
```

```
std::vector<size_t> v1;  
std::vector<std::string> v2;  
std::vector<std::vector<bool>> v3;
```

STL: The C++ Standard Template Library

```
#include <vector>           // dynamic array

std::vector<size_t> v1;
std::vector<std::string> v2;
std::vector<std::vector<bool>> v3;

#include <unordered_map>    // hash table dictionary
#include <set>               // BST set

template <class T>
class Graph
{
    std::unordered_map<T, std::set<T>> adj_sets_;

    // ...
};
```

A less silly way to represent a graph

```
#include <unordered_map>
#include <set>

template <class T>
class Graph
{
public:
    // ...
    size_t new_node(T const& name);

private:
    std::unordered_map<T, size_t> name_to_index_;
    std::vector<T*> index_to_name_;
    std::vector<std::set<size_t>> adj_sets_;
};
```

Adding a node

```
template <class T>
size_t Graph<T>::new_node(T const& name)
{
    size_t index = index_to_name_.size();

    auto pair = name_to_index_.insert({name, index});
    if (!pair.second)
        throw name_already_exists(name);

    index_to_name.push_back(&pair.first->first);
    adj_sets_.emplace_back();

    return index;
}
```


Next time: Bloom filters