The C++ Object Lifecycle

EECS 211

Winter 2019

Initial code setup

```
$ cd eecs211
$ curl $URL211/lec/09lifecycle.tgz | tar zx
…
$ cd 09lifecycle
```

Road map

- Owned string type concept
- Faking it

An owned string type

Our own String type

This is C++:

```
struct String
{
    char*  data_;
    size_t size_, capacity_;
};
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Our own `String` type

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- `size_` is the actual number of characters in our string (we don't rely on `'\0'` termination anymore)
- `capacity_` is the allocated size of `data_`, which might exceed `size_`, giving us space to grow
- (We `'\0'`-terminate anyway to facilitate interaction with C—but note also that internal `'\0'`s will make C not see the whole string)

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   - 2.3 `s.data_[0]`, …, `s.data_[s.size_ - 1]` are initialized
   - 2.4 `s.data_[s.size_] == '\0'`

Some C++ stuff from the previous slide

- `struct` declarations create a type, so we can use `String` as a type, not just `struct String`
- The null pointer is named `nullptr` instead of `NULL`
- The C++ version of the heap is called the *free store* (and we will manage it using `new` and `delete` instead of `malloc` and `free`)

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(The old C ways still work, but we won't use them in C++. For example, we will see later why `nullptr` is better than `NULL`.)

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C++ can do the above automatically for us, but we'll do it manually first

Faking it

Special functions

C++ manages the lifecycle of an object with three kinds of special functions:

- Constructors initialize an uninitialized object
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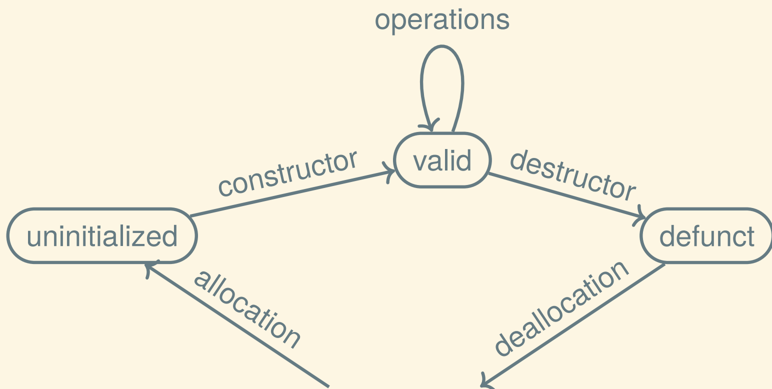
Our process for faking it:

1. Define an object
2. Call one constructor, once
3. Use the object for whatever
4. Call the destructor once
5. Don't use the object again after that

Object lifecycle state diagram



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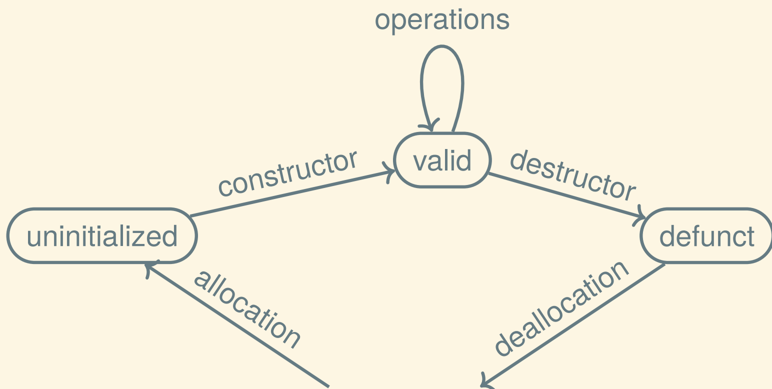

C++ automatically constructs after allocation and destroys before deallocation, but first we're going to do it ourselves

DIY `String` constructors (1/2)

```
// Constructs an empty string:
void String_construct_default(String*);

// Constructs by copying another String:
void String_construct_copy(String*,
                           const String* other);

// Constructs by moving (stealing the resources
// of) another String:
void String_construct_move(String*,
                           String* other);
```

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In C++ these three constructors will be special, in the sense that it uses them in particular places; for example, it uses the copy constructor every time you initialize a `String` from another `String`, which includes passing or returning by value.

DIY String constructors (2/2)

We also want constructors that are specific to our String type:

```
// Constructs from a C string:
void String_construct_c_str(String*,
                            const char* s);

// Constructs from the range [begin, end):
void String_construct_range(String*,
                            const char* begin,
                            const char* end);
```

DIY `String` destructor

```
// Frees any resources owned this `String`.
void String_destroy(String*);
```

Using our DIY constructors and destructor

```
const char* c_str = "hello\0world";
String s1, s2, s3, s4;

// Initialize s1 to the empty string:
String_construct_default(&s1);
```

Using our DIY constructors and destructor

```
const char* c_str = "hello\0world";
String s1, s2, s3, s4;

// Initialize s1 to the empty string:
String_construct_default(&s1);

// Initialize s2 to the string "hello":
String_construct_c_str(&s2, c_str);
```

Using our DIY constructors and destructor

```
const char* c_str = "hello\0world";
String s1, s2, s3, s4;

// Initialize s1 to the empty string:
String_construct_default(&s1);

// Initialize s2 to the string "hello":
String_construct_c_str(&s2, c_str);

// Initialize s3 to the string "hello\0world":
String_construct_range(&s3, c_str, c_str + 11)
```

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// Initialize s4 to be a copy of s3:
String_construct_copy(&s4, &s3);
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String s1, s2, s3, s4;

// Initialize s1 to the empty string:
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// Initialize s3 to the string "hello\0world":
String_construct_range(&s3, c_str, c_str + 11)

// Initialize s4 to be a copy of s3:
String_construct_copy(&s4, &s3);

String_destroy(&s1); String_destroy(&s2);
String_destroy(&s3); String_destroy(&s4);
```

DIY constructor implementations (1/5)

```
void String_construct_default(String* this)
{
    this->capacity_ = 0;
    this->size_     = 0;
    this->data_     = nullptr;
}
```

DIY constructor implementations (1/5)

```
// Never do this:
#define  this  actually_not_this

void String_construct_default(String* this)
{
    this->capacity_ = 0;
    this->size_     = 0;
    this->data_     = nullptr;
}
```

DIY constructor implementations (2/5)

```
void String_construct_move(String* this,
                           String* other)
{
    this->capacity_  = other->capacity_;
    this->size_      = other->size_;
    this->data_      = other->data_;

    other->capacity_ = 0;
    other->size_     = 0;
    other->data_     = nullptr;
}
```

DIY constructor implementations (3/5)

```
void String_construct_copy(String* this,
                           const String* other)
{
    String_construct_range(
        this,
        other->data_,
        other->data_ + other->size_);
}
```

DIY constructor implementations (4/5)

```
void String_construct_c_str(String* this,
                            const char* s)
{
    String_construct_range(this,
                           s,
                           s + std::strlen(s));
}
```

DIY constructor implementations (5/5)

```
void String_construct_range(String* this,
                            const char* begin,
                            const char* end)
{
    size_t size = end - begin;

    if (size == 0) {
        String_construct_default(this);
        return;
    }

    this->capacity_   = size + 1;
    this->size_       = size;
    this->data_       = new char[size + 1];
    this->data_[size] = '\0';
    std::memcpy(this->data_, begin, size);
}
```

Okay, so `new` and `delete`

The `new` operator allocates on the free store, and the `delete` operator deallocates `new`-allocated objects.

(What's the free store? Just like the heap, but a different place.)

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Each comes in two basic forms:

	allocate	deallocate
Single object:	`T* p = new T;`	`delete p;`
Array:	`T* p = new T[N];`	`delete [] p;`

(UB if your `delete` form doesn't match the `new` form.)

How does new differ from malloc?

It never returns nullptr and always calls constructors:

```
T* operator new()
{
    T* result = free_store_malloc(sizeof(T));
    if (! result) throw something;
    T_construct_default(result);
    return result;
}
```

How does new differ from `malloc`?

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```

For symmetry, `delete` calls destructors:

```
void operator delete(T* ptr)
{
    T_destroy(ptr);
    free_store_free(ptr);
}
```

How new[] might work

```
struct layout
{
    size_t size;
    T      data[0];
};

T* operator new[](size_t size)
{
    layout* result =
        free_store_malloc(sizeof(layout) +
                                      size * sizeof(T));
    if (! result) throw something;
    result->size = size;
    for (size_t i = 0; i < size; ++i)
        T_construct_default(result->data + i);
    return result->data;
}
```

Implementing the destructor

```
void String_destroy(String* this)
{
    delete [] this->data_;
}
```

DIY “Assigners”

Unlike constructors, assigners require that `this` already be initialized.

```
// Makes `this` a copy of `other`:
void String_assign_copy(String* this,
                        const String* other)

// Moves contents of `other` to `this`,
// leaving `other` empty:
void String_assign_move(String* this,
                        String* other)
```

Implementing the assigners (1/2)

```
void String_assign_move(String* this,
                        String* other)
{
    delete [] this->data_;

    this->capacity_  = other->capacity_;
    this->size_      = other->size_;
    this->data_      = other->data_;

    other->capacity_ = 0;
    other->size_     = 0;
    other->data_     = nullptr;
}
```

Implementing the assigners (2/2)

```
void String_assign_copy(String* this,
                        const String* other)
{
    // Reallocate only if capacity is insufficient:
    if (other->size_ > 0 &&
            other->size_ + 1 > this->capacity_) {
        char* new_data  = new char[other->size_ + 1];
        delete [] this->data_;
        this->data_     = new_data;
        this->capacity_ = other->size_ + 1;
    }

    if (this->data_ && other->data)
        std::memcpy(this->data_, other->data_,
                    other->size_ + 1);
    else if (this->data_) this->data_[0] = '\0';

    this->size_ = other->size_;
}
```

Non-lifecycle operations

```
bool String_empty(const String* this);
size_t String_size(const String* this);
char String_index(const String* this, size_t index);
char* String_index_mut(String* this, size_t index);
void String_push_back(String* this, char c);
void String_pop_back(String* this);
```

Pushing and popping

```
void String_push_back(String* this, char c)
{
    ensure_capacity(this, this->size_ + 2);
    this->data_[this->size_++] = c;
    this->data_[this->size_] = '\0';
}

void String_pop_back(String* this)
{
    this->data_[--this->size_] = '\0';
}
```

An important helper

```
static void ensure_capacity(String* this,
                            size_t min_cap)
{
    if (this->capacity_ < min_cap) {
        size_t new_cap =
            std::max(min_cap, 2 * this->capacity_);
        char* new_data = new char[new_cap];
        if (this->data_)
            std::memcpy(new_data, this->data_,
                        this->size_ + 1);
        delete [] this->data_;
        this->data_ = new_data;
        this->capacity_ = new_cap;
    }
}
```

– After the exam: Intro to GE211 —