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++:

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

This is C++:

```cpp
struct String
{
    char*   data_;  // data pointer
    size_t  size_, capacity_;  // size and capacity
};
```

Invariants (must always be true for `String` s to be valid):
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1. s.capacity_ == 0 if and only if s.data_ == nullptr
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    char* data_;  
    size_t size_, capacity_;  
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```

Invariants (must always be true for String s to be valid):

1. \( s\.capacity_ == 0 \) if and only if \( s\.data_ == \text{nullptr} \)
2. If \( s\.capacity_ > 0 \) then:
   1. \( s\.data_ \) points to a unique, free store–allocated array of \( s\.capacity \) characters
   2. \( s\.size_ + 1 \leq s\.capacity_ \)
   3. \( s\.data_[0], \ldots, s\.data_[s\.size_ - 1] \) are initialized
   4. \( s\.data_[s\.size_] == \text{"\0"} \)
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struct String {
    char* data_;  // Points to a unique, free store-allocated array of chars
    size_t size_, capacity_;  // data_[0], ..., data_[size_ - 1] are initialized
};
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       s.capacity_ chars
   2.2 s.size_ + 1 <= s.capacity_
Our own String type

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```cpp
struct String {
    char* data_;  // Pointer to the start of the string.
    size_t size_, capacity_;  // Size and capacity of the string.
};
```

Invariants (must always be true for String s to be valid):

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2. If `s.capacity_ > 0` then:
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   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`.)
The String type lifecycle

The invariant says that the data_ member variable points to an object that is *unique*—meaning that no other String’s data_ points to the same object.

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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
- Assignment operators copy or move from one initialized object to another
- The destructor frees an object’s resources

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
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Object lifecycle state diagram

Operation lifecycle:
- Uninitialized
- Valid
- Defunct

- Constructor
- Destructor
- Allocation
- Deallocation

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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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void String_construct_move(String*,
                        String* other);

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.
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

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

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

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

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

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

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

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

String_destroy(&s1); String_destroy(&s2);
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```c
const char* c_str = "hello\0world";
String s1, s2, s3, s4;

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

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

// Initialize s1 to the empty string:
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String_construct_copy(&s4, &s3);

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

```c
void String_construct_copy(String* this,
                          const String* other)
{
    String_construct_range(
        this,
        other->data_,
        other->data_ + other->size_);
}
```
void String_construct_c_str(String* this,
               const char* s)
{
    String_construct_range(this,
                          s,
                          s + std::strlen(s));
}
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:

<table>
<thead>
<tr>
<th>allocate</th>
<th>deallocate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single object:</td>
<td><strong>new</strong> T;</td>
</tr>
<tr>
<td>Array:</td>
<td><strong>new</strong> T[N];</td>
</tr>
</tbody>
</table>

(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:

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

For symmetry, `delete` calls destructors:

```cpp
void operator delete(T* ptr)
{
    T_destroy(ptr);
    free_store_free(ptr);
}
```
How new[] might work

```c
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

```cpp
void String_destroy(String* this)
{
    delete [] this->data_;  
}
```
Unlike constructors, assigners require that \texttt{this} already be initialized.

\begin{verbatim}
// 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)
\end{verbatim}
Implementing the assigners (1/2)

```cpp
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)

```cpp
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);
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

```cpp
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 —