Lecture 3: Initialization and References

CS 106L, Fall ‘20

Today's Agenda

- Recap: **Structures**
- Standard C++ Vector (Intro)
- Uniform Initialization
- Announcements
- References
- Const and Const References

Recap: Structures and Types

A struct is a group of named variables

each with their own type

Struct Example

```
struct Student {
    string name;          // these are called fields
    string state;         // separate these by semicolons
    int age;
}

Student s;
s.name = “Ethan”;         // use the . operator to access fields
s.state = “CA”;
s.age = 20;
```

A pair is a struct with two fields.

```
int main() {
    std::pair<bool, Student> query_result;
    query_result.first = true;
    Report current = query_result.second;
}
```

📝 **std::pair is a template.** You can use any type inside it; type goes in the <>.
(We'll learn more about templates in a future lecture.)

Type Deduction using auto

```
// What types are these?
auto a = 3;
auto b = 4.3;
auto c = 'X';
auto d = "Hello";
auto e = std::make_pair(3, "Hello");
```

Answers: int, double, char, char* (a C string), std::pair<int, char*>

📝 **`auto` does not mean that the variable doesn't have a type.**
It means that the type is **deduced** by the compiler.

Structured binding lets you initialize directly from the contents of a struct

Before

```
auto p = std::make_pair("s", 5);
string a = s.first;
int b = s.second;
```

After

```
auto p = std::make_pair("s", 5);
auto [a, b] = p;
// a is of type string
// b is of type int

// auto [a, b] = std::make_pair(...);
```

📝 This works for regular structs, too. Also, no nested structured binding.

Standard C++ `vector` (intro)

Stanford `Vector` review

```
Vector<int> v;
Vector<int> v(n, k);
v.add(k);
v[i] = k;
auto k = v[i];

v.isEmpty();
v.size();
v.clear();
v.insert(i, k);
v.remove(i);
```

Stanford `Vector` vs. Standard `std::vector`

```
Vector<int> v;
Vector<int> v(n, k);
v.add(k);
v[i] = k;
auto k = v[i];

v.isEmpty();
v.size();
v.clear();
v.insert(i, k);
v.remove(i);
```

```
std::vector<int> v;
std::vector<int> v(n, k);
v.push_back(k);
v[i] = k;
auto k = v[i];

v.empty();
v.size();
v.clear();
// stay tuned for a future lecture
// stay tuned for a future lecture
```


Questions?

Uniform Initialization

What’s initialization?

Initialization is how we provide initial values to variables

Initialization examples

```
int x = 5; // initializing while we declare

int y;
y = 6; // initializing after we declare
```

In C++, initialization used to be tricky, and varied substantially depending upon the type

Examples of complicated initialization

```
std::pair<bool, int> some_pair = std::make_pair(false, 6);

// Student is a struct from last time
// with name, state, and age fields
Student s;
s.name = “Ethan”;
s.state = “CA”;
s.age = 20;
```

That's why uniform initialization is useful

Uniform initialization provides a way for us to use **brackets** to initialize anything succinctly

Uniform Initialization to the Rescue!

Before

```
std::pair<bool, int> some_pair =
     std::make_pair(false, 6);

Student s;
s.name = “Ethan”;
s.state = “CA”;
s.age = 20;
```

After

```
std::pair<bool, int>
     some_pair{false, 6};

Student s{"Ethan", "CA", 20};
```

We can also set our variable equal to the curly brackets chunk

Before

```
std::pair<bool, int> some_pair =
     std::make_pair(false, 6);

Student s;
s.name = “Ethan”;
s.state = “CA”;
s.age = 20;
```

After

```
std::pair<bool, int>
     some_pair = {false, 6};

Student s = {"Ethan", "CA", 20};
```

Uniform initialization examples

```
int x{3}; // Uniform initialization not super needed here
int y = {3};

// Both of these are vectors with elements {3, 5, 7}
std::vector<int> a_vector{3, 5, 7};
std::vector<int> another_vector = {3, 5, 7};

// Later, when we get to classes, we can use uniform
// initialization to invoke our constructors, which dictate
// how we initialize our variable
```

A “gotcha” with uniform initialization

Remember this way to initialize a `std::vector`?

```
int n = 3;
int k = 5;

std::vector<int> v(n, k); // {5, 5, 5}
```

A “gotcha” with uniform initialization (cont.)

This initialization uses a constructor (which 106B will talk more about soon)

```
int n = 3;
int k = 5;

std::vector<int> v(n, k); // {5, 5, 5}
```

A “gotcha” with uniform initialization (cont.)

Normally, we can replace the () with {} to use uniform initialization--not here!

```
int n = 3;
int k = 5;

std::vector<int> v(n, k); // {5, 5, 5}
std::vector<int> v2{n, k}; // {3, 5} -- not the same!!
```

Using {} for vector creates an initializer_list

When we create a std::initializer_list, we actually end up invoking a different constructor!

```
auto list_init{3, 5}; // type is std::initializer_list
```

Moral of the story:

Make sure you’re completely clear what constructor you’re invoking when using uniform initialization

Complicated uniform initialization example

Say we wanted to represent Stanford courses as structs

```
struct Course {
    string code;
    pair<Time, Time> time;
    vector<string> instructors;
};

struct Time {
    int hour, minute;
}

...

Course now{“CS106L”, { {16, 30}, {17, 50} }, {“Raghuraman”, “Chi”} };
```


Questions?

Summary of Uniform Initialization

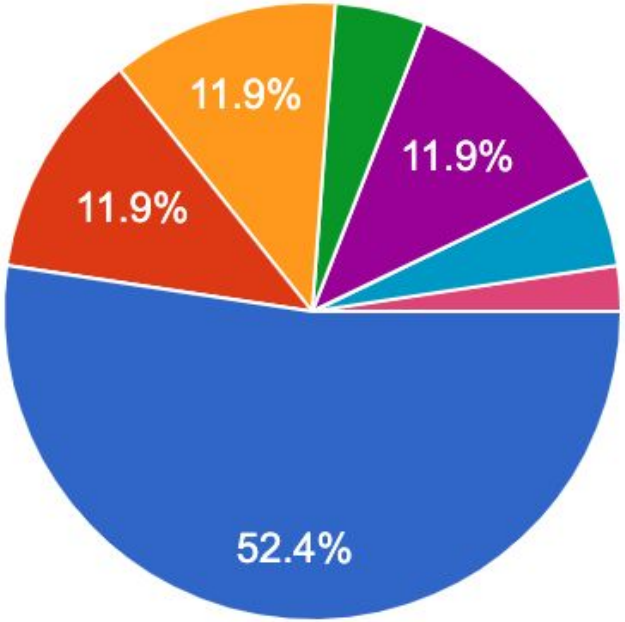
- You can use uniform initialization to initialize anything
- Be careful of ambiguities with `std::initializer_list`

Announcements

Announcements

- Office hours have been set up and will start on Friday:
  - Nikhil: 7-8 AM PDT on Fridays
  - Ethan: 6-7 PM PDT on Mondays

Survey Results!



- Freshman
- Sophomore
- Junior
- Senior
- Master's
- PhD
- 3rd year, 4 quarters completed

Examples of Majors

- MCS
- Physics
- SymSys
- CS
- Chemistry
- English
- Product Design
- EE
- Math

References

A coding problem

Write a function to shift all courses in a `std::vector` over by 1 hour

```
struct Course {
    string code;
    pair<Time, Time> time;
    vector<string> instructors;
};

struct Time {
    int hour, minute;
}

...

void shift(vector<Course>& courses) {
    // TODO
}
```

Live Code Demo:
Courses

This is buggy!

```
void shift(vector<Course>& courses) {
    for (size_t i = 0; i < courses.size(); ++i) {
        auto [code, time, instructors] = courses[i];

        time.first.hour++;
        time.second.hour++;
    }
}
```

This creates a copy of the course

This is updating that same copy!

This also doesn't work!

```
void shift(vector<Course>& courses) {
    for (auto [code, time, instructors] : courses) {
        time.first.hour++;
        time.second.hour++;
    }
}
```

This creates a copy of the course

This is updating that same copy!

We need more information on reference parameters!

What we've learned in 106B

```
int doubleValue(int& x) {
    x *= 2;
    return x;
}

int main() {
    int myValue = 5;
    int result = doubleValue(myValue);
    cout << myValue << endl; // 10
    cout << result << endl;  // 10
}
```

The variable `myValue` is passed by reference into `doubleValue`.

`x` inside `doubleValue` is an **alias** for `myValue` in `main`. This means it's another name for the same variable!

A change to `x` is a change to `myValue`.

References in variable assignment

Notice the ampersand -- `ref` is an alias for `original`!

```
std::vector<int> original{1, 2};
std::vector<int> copy = original;
std::vector<int>& ref = original;

original.push_back(3);
copy.push_back(4);
ref.push_back(5);

// original (and also ref!) = {1, 2, 3, 5}
// copy = {1, 2, 4}
```

Practice Problem (try afterward if you'd like)

Read through the code below and think through the questions! (answers on next slide)

```
std::vector<int> original{1, 2};
std::vector<int> copy = original;
std::vector<int>& ref = original;

original.push_back(3);
copy.push_back(4);
ref.push_back(5);

// original (and also ref!) = {1, 2, 3, 5}
// copy = {1, 2, 4}
ref = copy;
copy.push_back(6);
ref.push_back(7);
// Q1: what are contents of original?
// Q2: what are contents of copy?
```

A reference is always an alias to the same variable!

This means setting `ref` equal to a new value is exactly the same as setting `original` equal to that value! We can't change what variable `ref` aliases

```
vector<int> original{1, 2};
vector<int> copy = original;
vector<int>& ref = original;

original.push_back(3);
copy.push_back(4);
ref.push_back(5);

// original (and also ref!) = {1, 2, 3, 5}
// copy = {1, 2, 4}
ref = copy;
copy.push_back(6);
ref.push_back(7);
// original = {1, 2, 4, 7}
// copy = {1, 2, 4, 6}
```

Live Code Demo:
References pitfall

Note: You can only create references to variables

This has to do with something called l-values (as we saw in our error message), which we'll discuss later in the course!

```
int& thisWontWork = 5; // This doesn't work!
```


Questions?

Const and Const References

`const` indicates a variable can't be modified!

`const` variables can be references or not!

```
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};  // a const variable
std::vector<int>& ref = vec;         // a regular reference
const std::vector<int>& c_ref = vec;  // a const reference

vec.push_back(3);    // OKAY
c_vec.push_back(3);  // BAD - const
ref.push_back(3);   // OKAY
c_ref.push_back(3); // BAD - const
```

Can’t declare non-const reference to const variable!

The below example isn’t permitted!

```
const std::vector<int> c_vec{7, 8};  // a const variable

// BAD - can't declare non-const ref to const vector
std::vector<int>& bad_ref = c_vec
```

Can’t declare a non-const ref to a const ref!

The below is also not permitted!

```
std::vector<int> vec{1, 2, 3};

const std::vector<int>& c_ref = vec;  // a const reference

// BAD - Can't declare a non-const reference as equal
// to a const reference!
std::vector<int>& ref = c_ref;
```

If you don't write &, C++ will make a copy by default!

```
std::vector<int> vec{1, 2, 3};
const std::vector<int>& c_ref =  vec;          // a const reference

// This is a non-const copy of vec, even though we're setting
// it equal to a const reference! Remember that ref is just an
// alias (aka another name) for vec
std::vector<int> copy = c_ref;

copy.push_back(4);
// vec = {1, 2, 3}
// copy = {1, 2, 3, 4}
```

Need to explicitly specify const and & with auto!

```
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};
std::vector<int>& ref = vec;
const std::vector<int>& c_ref = vec;

auto copy = c_ref;          // a non-const copy
const auto copy = c_ref;    // a const copy
auto& a_ref = ref;          // a non-const reference
const auto& c_aref = ref;   // a const reference
```

Remember: C++, by default, makes copies when we do variable assignment! We need to use `&` if we need references instead.


Questions?

More about References

You can return references as well!

This is something that the C++ Standard Library frequently makes use of.

```
// Note that the parameter must be a non-const reference to return
// a non-const reference to one of its elements!
int& front(std::vector<int>& vec) {
    // assuming vec.size() > 0
    return vec[0];
}

int main() {
    std::vector<int> numbers{1, 2, 3};
    front(numbers) = 4; // vec = {4, 2, 3}
    return 0;
}
```

Can also return const references

```
const int& front(std::vector<int>& vec) {
    // assuming vec.size() > 0
    return vec[0];
}
```

Dangling references: references to out-of-scope vars

Never return a reference to a local variable! They'll go out of scope.

```
int& front(const std::string& file) {
    std::vector<int> vec = readFile(file);
    return vec[0];
}

int main() {
    front("text.txt") = 4; // undefined behavior
    return 0;
}
```

Return to example: How could we fix this code? (chat)

```
void shift(vector<Course>& courses) {
    for (size_t i = 0; i < courses.size(); ++i) {
        auto [code, time, instructors] = courses[i];

        time.first.hour++;
        time.second.hour++;
    }
}
```

Return to example: How could we fix this code?

This is one option.

```
void shift(vector<Course>& courses) {
    for (size_t i = 0; i < courses.size(); ++i) {
        auto& [code, time, instructors] = courses[i];

        time.first.hour++;
        time.second.hour++;
    }
}
```

This creates a reference to the course

This updates that reference!

Return to example: How could we fix this code?

This is another option.

```
void shift(vector<Course>& courses) {
    for (auto& [code, time, instructors] : courses) {
        time.first.hour++;
        time.second.hour++;
    }
}
```

This updates that reference!

This creates a reference to the course

When do we use references/const references?

- If we're working with a variable that takes up little space in memory (e.g. `int`, `double`), we don't need to use a reference and can just copy the variable
- If we need to **alias** the variable to modify it, we can use references
- If we don't need to modify the variable, but it's a big variable (e.g. `std::vector`), we can use const references

Recap

- **Uniform initialization**
  - A “uniform” way to initialize variables of different types!
- **References**
  - Allow us to alias variables
- **Const**
  - Allow us to specify that a variable can’t be modified

Next time:

Streams