Initialization & References

Fun times!

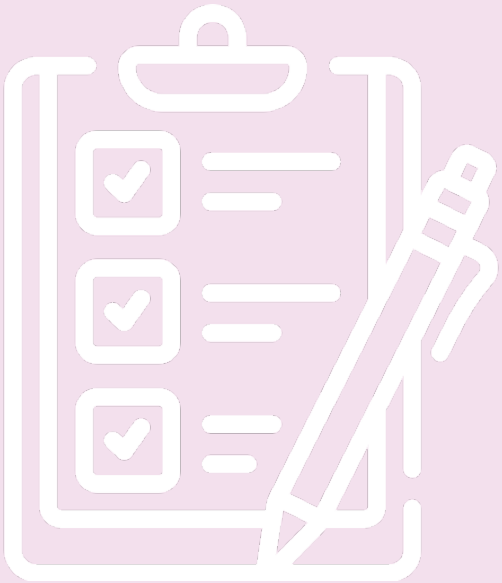
 masks strongly recommended

Attendance

bit.ly/3iyTlzk

Square Hole Video

Today



- **Initialization**
- Using auto
- References
- If time: Const

Definition

Initialization: How we provide initial values to variables

Reminder: Structs in Code

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

Student s;
s.name = "Sarah";
s.state = "CA";
s.age = 21; // use . to access fields
```

Recall: Two ways to initialize a struct

```
Student s; // initialization after we declare
s.name = "Sarah";
s.state = "CA";
s.age = 21;
//is the same as ...
Student s = {"Sarah", "CA", 21};
// initialization while we declare
```

Multiple ways to initialize a pair...

```
std::pair<int, string> numSuffix1 = {1,"st"};

std::pair<int, string> numSuffix2;

numSuffix2.first = 2;

numSuffix2.second = "nd";

std::pair<int, string> numSuffix2 =

                        std::make_pair(3, "rd");
```

Definition

Uniform initialization: curly bracket initialization. Available for all types, immediate initialization on declaration!

Uniform Initialization

```
std::vector<int> vec{1,3,5};

std::pair<int, string> numSuffix1{1,"st"};

Student s{"Sarah", "CA", 21};

// less common/nice for primitive types, but possible!

int x{5};

string f{"Sarah"};
```

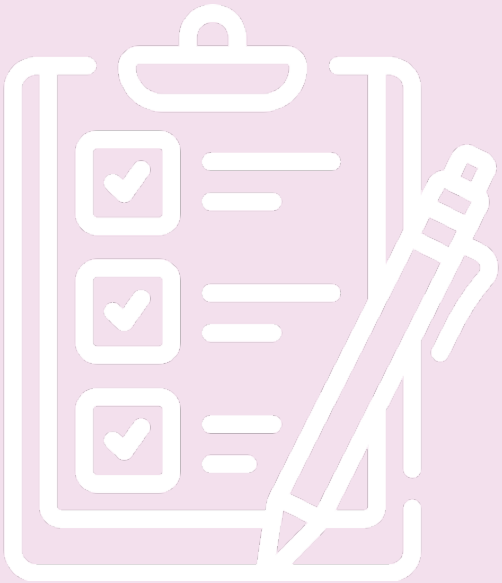
Careful with Vector initialization!

```
std::vector<int> vec1(3,5);

// makes {5, 5, 5}, not {3, 5}!

// uses a std::initializer_list (more later)

std::vector<int> vec2{3,5};

// makes {3, 5}
```

TLDR: use uniform initialization to initialize every field of your non-primitive typed variables - but be careful not to use vec(n, k)!

Questions?

Today



- ~~Initialization~~
- **Using auto**
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Recap: Type Deduction with `auto`

Definition

`auto`: Keyword used in lieu of type when declaring a variable, tells the compiler to deduce the type.

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");
```

📝 `auto` **does not mean that the variable doesn't have a type.**

It means that the type is **deduced** by the compiler.

Type Deduction using `auto`

```
// What types are these?
auto a = 3; // int
auto b = 4.3; // double
auto c = 'X'; // char
auto d = "Hello"; // char* (a C string)
auto e = std::make_pair(3, "Hello");
// 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.

‼️ `auto` **does not mean that the variable doesn’t have a type.**

It means that the type is **deduced** by the compiler.

When should we use auto?

Code Demo!

quadratic.cpp

a general quadratic equation can always be written:

$$ax^2 + bx + c = 0$$

Radical

the solutions to a general quadratic equation are:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

If Radical < 0, no real roots

Quadratic: Typing these types out is a pain...

```
int main() {
    int a, b, c;
    std::cin >> a >> b >> c;
    std::pair<bool, std::pair<double, double>> result =
                                                quadratic(a, b, c);
    bool found = result.first;
    if (found) {
        std::pair<double, double> solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << "No solutions found!" << endl;
    }
}
```

Quadratic: Typing these types out is a pain...

```
int main() {
    int a, b, c;
    std::cin >> a >> b >> c;
    auto result = quadratic(a, b, c);
    bool found = result.first;
    if (found) {
        auto solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << "No solutions found!" << endl;
    }
}
```

Cleaner! 🧼

😊

Don’t overuse `auto`

Don’t overuse auto!

```
int main() {
    auto a, b, c;
    std::cin >> a >> b >> c;
    auto result = quadratic(a, b, c);
    bool found = result.first;
    if (found) {
        auto solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << “No solutions found!” << endl;
    }
}
```

Can’t deduce the type b/c no value provided

```
int main() {
    auto a, b, c; //compile error!
    std::cin >> a >> b >> c;
    auto result = quadratic(a, b, c);
    bool found = result.first;
    if (found) {
        auto solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << “No solutions found!” << endl;
    }
}
```

ERROR!

For simple types (like bool) type it out

```
int main() {
    int a, b, c;
    std::cin >> a >> b >> c;
    auto result = quadratic(a, b, c);
    auto found = result.first; //code less clear :/
    if (found) {
        auto solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << "No solutions found!" << endl;
    }
}
```

LESS CLEAR 👎☹️

Don’t overuse `auto`

...but use it to reduce long type names

Questions?

Structured Binding

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

Before

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

After

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

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

A better way to use quadratic...

```
int main() {
    int a, b, c;
    std::cin >> a >> b >> c;
    auto result = quadratic(a, b, c);
    bool found = result.first;
    if (found) {
        auto solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << "No solutions found!" << endl;
    }
}
```

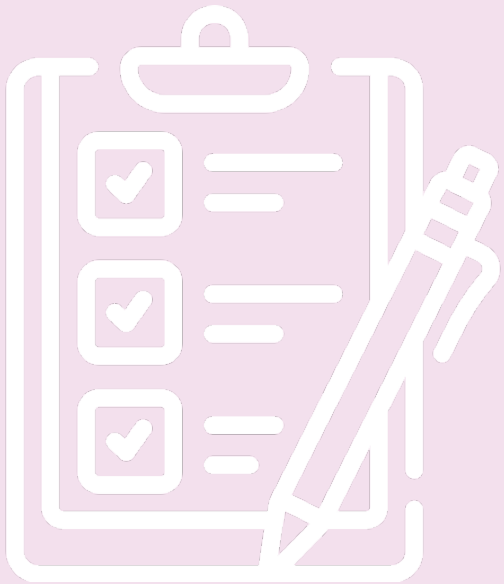
Using Structured Binding

```
int main() {
    int a, b, c;
    std::cin >> a >> b >> c;
    auto [found, solutions] = quadratic(a, b, c);
    if (found) {
        auto [x1, x2] = solutions;
        std::cout << x1 << " " << x2 << endl;
    } else {
        std::cout << "No solutions found!" << endl;
    }
}
```

📝 This is better is because it's *semantically clearer*: variables have clear names.

Questions?

Today



- ~~Initialization~~
- ~~Using auto~~
- **References**
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Definition

Reference: An alias (another name) for a named variable

References in 106B

```
void changeX(int& x){ // changes to x will persist
    x = 0;
}
void keepX(int x){
    x = 0;
}

int a = 100;
int b = 100;

changeX(a); // a becomes a reference to x
keepX(b);   // b becomes a copy of x

cout << a << endl; //0
cout << b << endl; //100
```

Standard C++ vector (intro)

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
// stay tuned
```

References in 106L: References to variables

```
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);

cout << original << endl;
cout << copy << endl;
cout << ref << endl;
```

References to variables

```
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);

cout << original << endl; // {1, 2, 3, 5}
cout << copy << endl;
cout << ref << endl;
```

References to variables

```
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);

cout << original << endl; // {1, 2, 3, 5}
cout << copy << endl;     // {1, 2, 4}
cout << ref << endl;
```

References to variables

```
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);

cout << original << endl; // {1, 2, 3, 5}
cout << copy << endl;     // {1, 2, 4}
cout << ref << endl;      // {1, 2, 3, 5}
```

References to variables

```
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);

cout << original << endl; // {1, 2, 3, 5}
cout << copy << endl;     // {1, 2, 4}
cout << ref << endl;      // {1, 2, 3, 5}
```

"=" automatically makes a copy! Must use & to avoid this.

The classic reference-copy bug 1.0:

```
void shift(vector<std::pair<int, int>>& nums) {
   for (size_t i = 0; i < nums.size(); ++i) {
      auto [num1, num2] = nums[i];
      num1++;
      num2++;
   }
}
```

The classic reference-copy bug 1.0:

```
void shift(vector<std::pair<int, int>>& nums) {
   for (size_t i = 0; i < nums.size(); ++i) {
      auto [num1, num2] = nums[i];
      num1++;
      num2++;
   }
}
```

This creates a copy of the course

This is updating that same copy!

The classic reference-copy bug 1.0: Fixed

```
void shift(vector<std::pair<int, int>>& nums) {
   for (size_t i = 0; i < nums.size(); ++i) {
      auto& [num1, num2] = nums[i];
      num1++;
      num2++;
   }
}
```

The classic reference-copy bug 2.0:

```
void shift(vector<std::pair<int, int>>& nums) {
   for (auto [num1, num2]: nums) {
      num1++;
      num2++;
   }
}
```

The classic reference-copy bug 2.0:

```
void shift(vector<std::pair<int, int>>& nums) {
    for (auto [num1, num2]: nums) {
        num1++;
        num2++;
    }
}
```

This is updating that same copy!

This creates a copy of the course

The classic reference-copy bug 2.0, fixed:

```
void shift(vector<std::pair<int, int>>& nums) {
    for (auto& [num1, num2]: nums) {
        num1++;
        num2++;
    }
}
```

Definition: l-values vs r-values

- **l-values** can appear on the **left** or **right** of an =
- `x` is an **l-value**

```
int x = 3;
int y = x;
```

l-values have names

l-values are **not temporary**

Definition: l-values vs r-values

- **l-values** can appear on the **left** or **right** of an =
- `x` is an **l-value**

```
int x = 3;
int y = x;
```

- **r-values** can ONLY appear on the **right** of an =
- `3` is an **r-value**

```
int x = 3;
int y = x;
```

l-values have names

l-values are **not temporary**

r-values don't have names

r-values are **temporary**

The classic reference-rvalue error

```
void shift(vector<std::pair<int, int>>& nums) {
   for (auto& [num1, num2]: nums) {
      num1++;
      num2++;
   }
}

shift({{1, 1}});
```

The classic reference-rvalue error

```
void shift(vector<std::pair<int, int>>& nums) {
    for (auto& [num1, num2]: nums) {
        num1++;
        num2++;
    }
}

shift({{1, 1}});
// {{1, 1}} is an rvalue, it can't be referenced
```

The classic reference-rvalue error, fixed

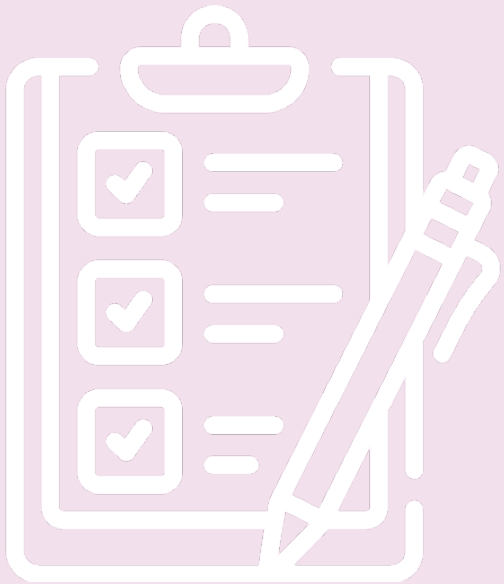
```
void shift(vector<pair<int, int>>& nums) {
   for (auto& [num1, num2]: nums) {
      num1++;
      num2++;
   }
}
auto my_nums = {{1, 1}};
shift(my_nums);
```

Note: You can only create references to variables

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

Questions?

Today



- ~~Initialization~~
- ~~Using auto~~
- ~~References~~
- **If time: Const**

BONUS: 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);
c_vec.push_back(3);
ref.push_back(3);
c_ref.push_back(3);
```

`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);
ref.push_back(3);
c_ref.push_back(3);
```

`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);
c_ref.push_back(3);
```

`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);
```

`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!

```
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 non-const reference to const variable!

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

// fixed
const std::vector<int>& bad_ref = c_vec;
```

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

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

// fixed
const std::vector<int>& bad_ref = c_vec;

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

const & subtleties

```
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.

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

You can return references as well!

```
// 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];
}
```

Questions?

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