



 <http://web.stanford.edu/class/cs106l/>



Template Functions

What else in C++ can be generalized? What is the philosophy behind generalization?

CS106L - Spring 23



Attendance!

<https://bit.ly/3Vq0jFR>





Agenda



01. Recap: Iterators & Template Classes



02. Template Functions

Type deduction, lvalues and rvalues

03. Template metaprogramming

Gaming the system

04. Introduction to Algorithms

Prepping for Thursday!



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Review: Iterators

Containers all implement something called an iterator to do this!

- Iterators let you access **all** data in **all** containers programmatically!
- An iterator has a certain **order**; it “knows” what element will come next
 - Not necessarily the same each time you iterate!

Review: Iterators

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing → `iter = s.begin();`
 - Incrementing → `++iter;`
 - Dereferencing → `*iter;`
 - Comparing → `iter != s.end();`
 - Copying → `new_iter = iter;`

Review: Iterators

```
for ( auto iter=set.begin() ; iter != set.end(); ++iter ) {
```

Now we can access each element individually!

If we want the element and not just a reference to it, we dereference (*iter).

```
const auto& elem = *iter;
```

Review: Template Classes

- Add `template<typename T1, typename T2...>` before class definition in .h
- Add `template<typename T1, typename T2...>` before all function signature in .cpp
- When returning nested types (like iterator types), put `typename ClassName<T1, T2...>::member_type` as return type, not just `member_type`
- Templates don't emit code until instantiated, so `#include` the .cpp file in the .h file, not the other way around!

Review: Const and Const Correctness

- Use const parameters and variables wherever you can in application code
- Every member function of a class that doesn't change its member variables should be marked `const`
- `auto` will drop all const and `&`, so be sure to specify
- Make iterators and `const_iterators` for all your classes!
 - `const_iterator` = cannot increment the iterator, can dereference and change underlying value
 - `const_iterator` = can increment the iterator, cannot dereference and change underlying value
 - `const const_iterator` = cannot increment iterator, cannot change underlying value



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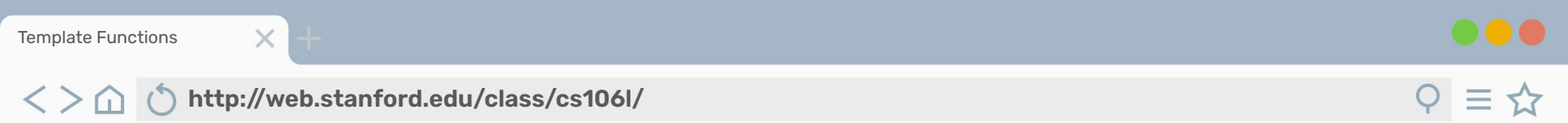
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- Ex. variable return type or input in a class (template classes)

Can we parametrize even more?

Can we write a function that works on **any data type**?



Why not!

Let's say we want a function to return the min of two ints!



Why not!

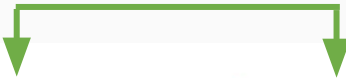
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int myMin(int a, int b) {  
    return a < b ? a : b;  
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We take in two
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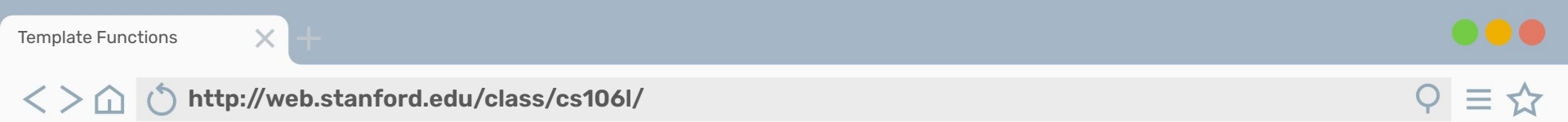
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```

What about doubles? Floats? Longs?



What about function overloading?

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```
int myMin(int a, int b) {  
    return a < b ? a : b;  
}  
  
// exactly the same except for types  
std::string my_min(std::string a, std::string b) {  
    return a < b ? a : b;  
}  
  
int main() {  
    auto min_int = myMin(1, 2);           // 1  
    auto min_name = myMin("Sarah", "Haven"); // Haven  
}
```

What about function overloading?

Sure, we
could...

**What about
other types?**

```
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int main() {  
    auto min_int = myMin(1, 2);           // 1  
    auto min_name = myMin("Sarah", "Haven"); // Haven  
}
```

Template functions:

Functions whose functionality can be adapted to more than one type or class without repeating the entire code for each type.

Template functions are completely generic functions!

Just like classes, they work regardless of type!

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Let's break it down:

```
template <typename Type>
Type myMin(Type a, Type b) {
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}
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Let's break it down:

Indicating this
function is a template

Specifies that
Type is generic

List of your
template
variables

```
template <typename Type>
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Just like classes, they work regardless of type!

Let's break it down:

Indicating this
function is a template

The class keyword is
interchangeable!

List of your
template
variables

```
template <class Type>
Type myMin(Type a, Type b) {
    return a < b ? a : b;
}
```

Default Types

We can define default parameter types!

```
template <typename Type=int>
Type myMin(Type a, Type b) {
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If a type isn't specified, it will default to int if possible!

Aside: Constraints and Concepts

As of C++20, we can limit the acceptable types in:

- template classes
- template functions
- non-template member functions of a template class

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These limits or requirements on are called **constraints**.

A named set of constraints is a **concept**.

Aside: Constraints and Concepts

Constraints can be simple:

```
template<typename T>
concept Addable = requires (T a, T b)
{
    a + b; // "the expression a+b is a valid expression that will compile"
};

template<typename T> requires Addable<T> // requires-clause
T add(T a, T b) { return a + b; }
```

Source: cppreference.com

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template<typename T> requires Addable<T> // requires-clause
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**Can also appear at the end of
a function declaration (ex.
forward declarations)**

Source: cppreference.com

Default Types

We can define default parameter types!

```
template <typename Type=int>
Type myMin(Type a, Type b) {
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What does it look like to use a template function?

Calling template functions

We can explicitly define what type we will pass, like this:

```
template <typename Type>
Type myMin(Type a, Type b) {
    return a < b ? a : b;
}
```

```
// int main() {} will be omitted from future examples
// we'll instead show the code that'd go inside it
cout << myMin<int>(3, 4) << endl; // 3
```

Calling template functions

We can **explicitly** define what type we will pass, like this:

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**Just like in
template classes!**

Calling template functions

We can also **implicitly** leave it for the compiler to deduce!

```
template <typename T, typename U>  
auto smarterMyMin(T a, U b) {  
    return a < b ? a : b;  
}
```

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// int main() {} will be omitted from future examples  
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cout << myMin(3.2, 4) << endl; // 3.2
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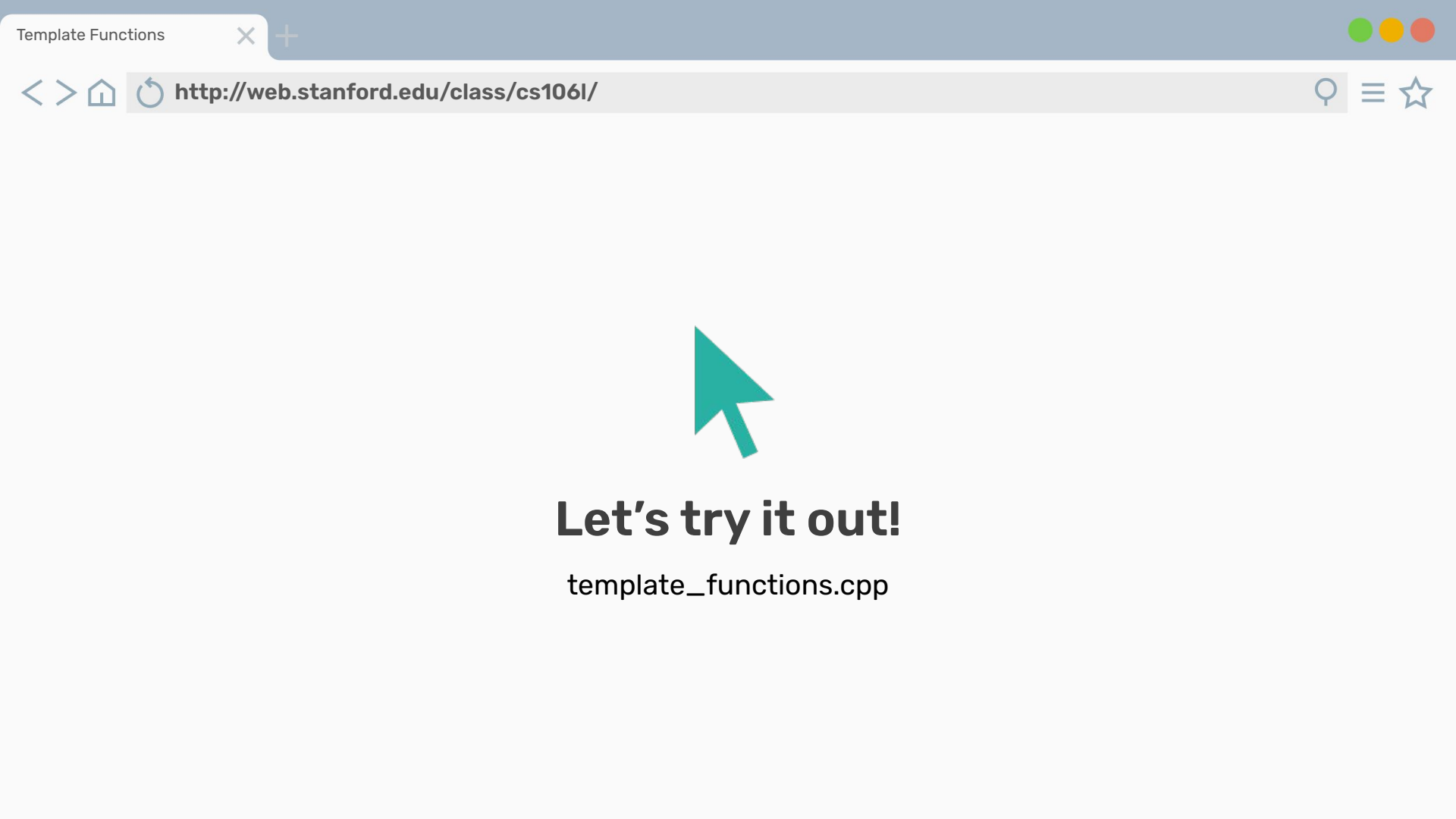
We might like explicit calling of a template function to specify number types if passed in as literals!

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Let's try it out!

template_functions.cpp



Behind the Instantiation Scenes

Remember: like in template classes, **template functions are not compiled until used!**

Behind the Instantiation Scenes

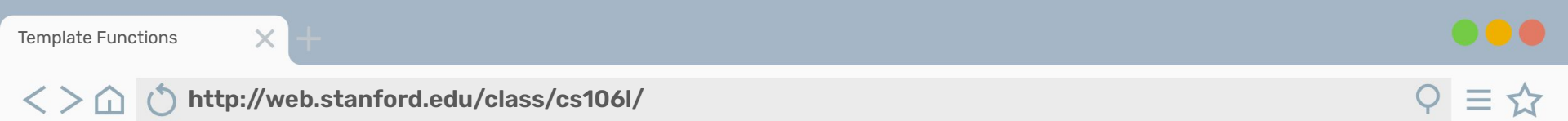
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Behind the Instantiation Scenes

Remember: like in template classes, **template functions are not compiled until used!**

- For each instantiation with different parameters, the compiler generates a new specific version of your template
- After compilation, it will look like you wrote each version yourself



Wait a minute...

The code doesn't exist until you instantiate it, which runs quicker.

Can we take advantage of this behavior?

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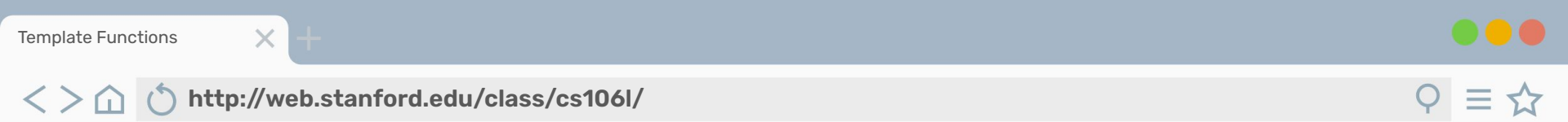
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template<unsigned n>
struct Factorial {
    enum { value = n * Factorial<n - 1>::value };
};

template<> // template class "specialization"
struct Factorial<0> {
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std::cout << Factorial<10>::value << endl; // prints 3628800, but run during compile time!
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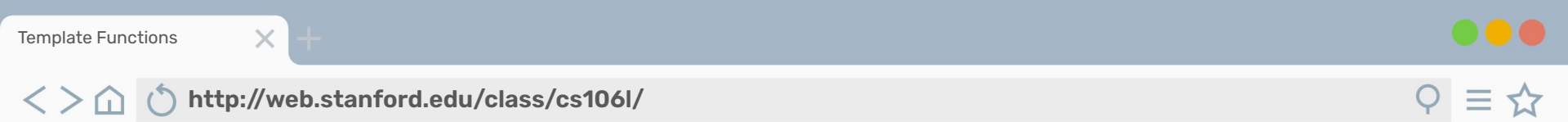
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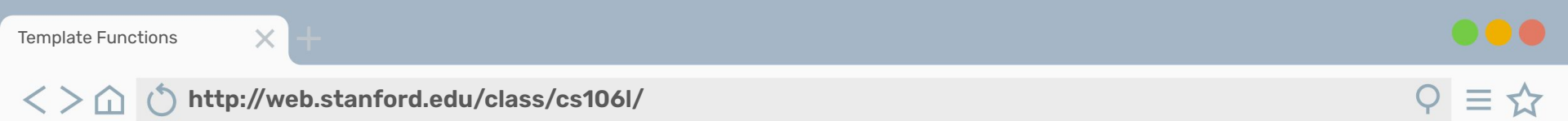
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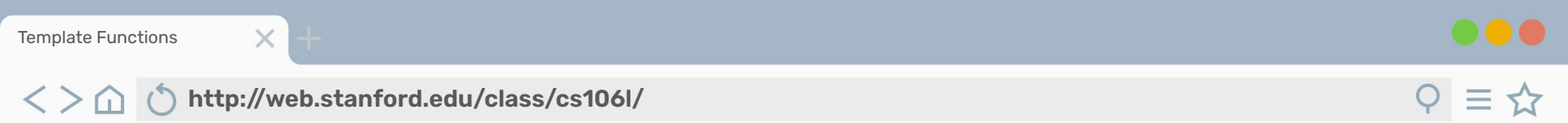
Variables can also be declared as **constexpr** !

Aside: constexpr

We could also compute the same example in compile time using `constexpr` instead of template metaprogramming!

```
constexpr double fib(int n) { // function declared as constexpr
    if (n == 1) return 1;
    return fib(n-1) * n;
}

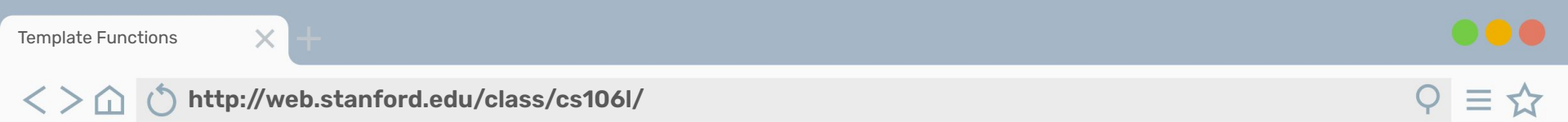
int main() {
    const long long bigval = fib(20);
    std::cout << bigval << std::endl;
}
```



Why?

Overall, can increase performance for these pieces!

- Compiled code ends up being smaller



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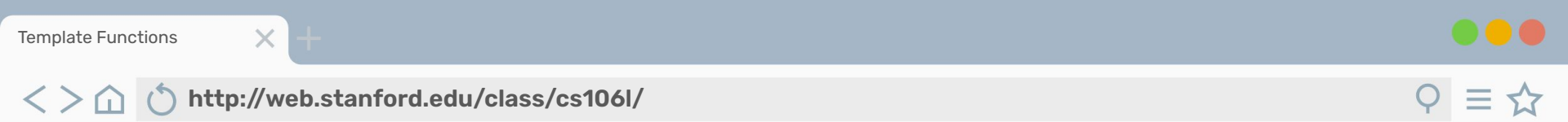


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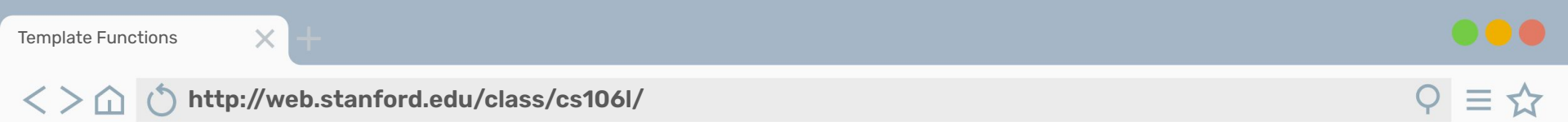
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TMP was an accident; it was discovered, not invented!



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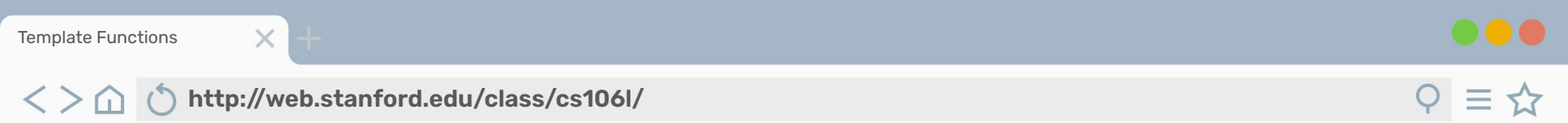
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Or a word in a stream?

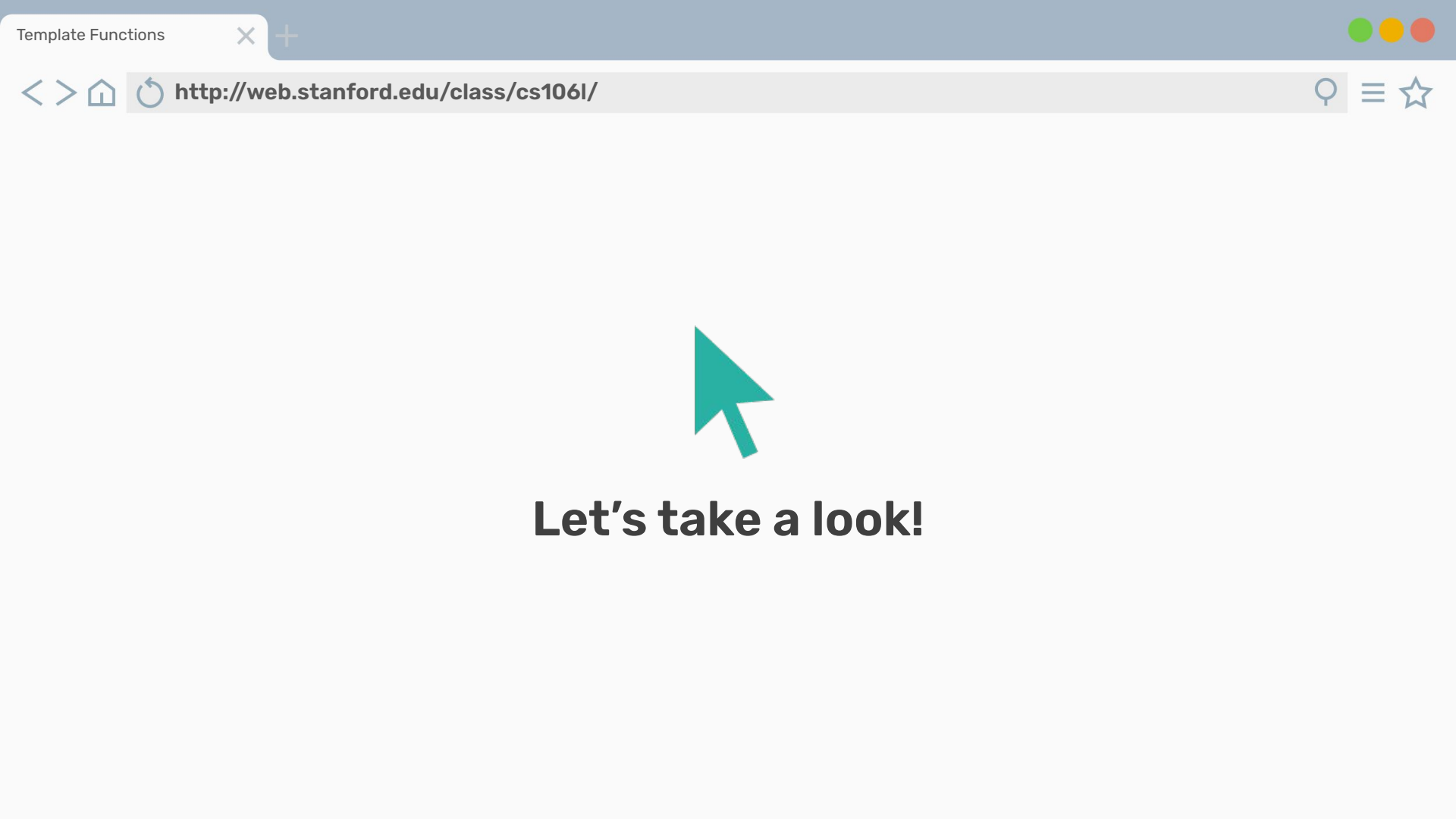
Solving problems with generics

What if we wanted to count all the occurrences of a character in a string?

Or a number in a vector?

Or a word in a stream?

These are all the same problem!



Let's take a look!

Summary

- Template functions allow you to parametrize the type of a function to be anything without changing functionality
- Generic programming can solve a complicated conceptual problem for any specifics – powerful and flexible!
- Template code is instantiated at compile time; template metaprogramming takes advantage of this to run code at compile time



<http://web.stanford.edu/class/cs106l/>



Thanks!

Next up: Functions and Lambdas!