

# Assignment Operator Overloading and Class Templates: Overloading C++ syntactic operators and class templates for user defined data types

COSC 2336: Data Structures and Algorithms

Summer 2021

## Objectives

- Gaining more experience with the concept of an Abstract Data Type (ADT) and how user defined data types are like adding a new type to the language.
- More practice with classes and arrays in C++.
- Practice writing member functions of C++ classes.
- Introduction to operator overloading, and extending the idea of a user defined type as a new type by adding basic support in the language for syntactic operators on the new type.
- More practice with dynamic memory management in order to support list types that can grow and shrink dynamically.
- Experience working with and defining class templates, which are important mechanisms in C++ and other languages for writing generic container data types.

## Description

We have two related but separate goals in this assignment. First of all in this assignment we will be emphasizing the idea that defining a class is like adding a new user defined data type to the C++ language. One way this can be incredibly powerful is when we define operator so that user defined classes can be used in similar ways as built in data types. This gives ways of much more naturally and expressively being able to work with classes you define to use in your code, as hopefully you will better understand by doing this assignment. We have actually already seen some examples of operator overloading in previous assignments, before we talked about it in this weeks unit. For example, you have been using the overloaded `operator[]` a lot which defined an indexing operator into our user defined `List` data type. This week you will continue adding onto the `List` data type some other operators that will allow us to append and prepend items on lists, and concatenate lists together to make other lists.

In addition another goal of this assignment is to get some experience with defining class templates. Class templates are used extensively by C++ (see the Standard Template Library or STL) to provide generic container data types. For example, in previous assignments you have been given a `List` user defined class that initially held lists of `int` integer values. This was kind of boring, so we switched it up a bit and defined basically the same `List` but one that held and managed lists of `string` values. It is very common to want to have powerful data types that can hold and manage different types of values, floats, ints, strings, even other user defined data types. So far, the only solution you would have if you wanted to have our `List` that could sometime manage lists of `int` values, and have some others to manage lists of `string` values, would be to define two mostly identical classes with different names, say `ListInt` and `ListString` to hold lists of integers and lists of strings respectively. Class templates allow us to parameterize the type of data being held in a container, so that we can define the operations of the container separate from the type of data we want to be able to put into and manage with the container.

So in this assignment, you will start again with the `List` of strings container, and add some additional overloaded operators to it. Then we will attempt to ‘templiatize’ your `List` class, so that you can use it to hold and manage lists of any desired data type.

## Overview and Setup

For this assignment you will be given the following files that you will be using and adding code to for this assignment.

File Name	Description
<code>src/test-List.cpp</code>	Unit tests for the overloaded operators you are to implement.
<code>include/List.hpp</code>	Header file for the declarations of the <code>List</code> class you will be modifying and its defined API.
<code>src/List.cpp</code>	Implementation file for the <code>List</code> member functions that implement the API and class functionality.

This week you will be adding in several new member functions to the `List` class. So all of your work will be to add in code into the `List`.`[hpp|cpp]` header and implementation files.

As usual, before starting on the assignment tasks proper, you should make sure you have completed the following setup steps.

1. Copy the assignment repository on GitHub using the provided assignment invitation link for ‘Assignment Recursion’ for our current class semester and section.
2. Clone the repository using the SSH URL to your local class DevBox development environment.
3. Configure the project by running the `configure` script from a terminal.
4. Confirm that the project builds and runs, though no tests will be defined or run initially. If the project does not build on the first checkout, please inform the instructor.
5. You should create the issue for Task 1 and/or for all tasks for the assignment now before beginning the first task. On your GitHub account, go to issues, and create it/them from the issue templates for the assignment. Make sure that you link the issues to the `Feedback` pull request.

## Assignment Tasks

Notice before beginning the assignment that there are 3 overloaded operators already defined for the `List`: `operator[]()`, `operator==()` and `operator<<()`. You used these in previous assignments, especially the indexing `operator[]`, though we mostly took them for granted as working at the time. Notice how they work. For example, the `operator==()` allows us to test two `List` items to see if they contain all of the exact same values:

```
int values2[] = {1, 3, -2, -4, 7};
List l2(5, values2);

int values3[] = {1, 3, -2, -4, -7};
List l3(5, values3);

l2 == l3;
```

This should return `false` because while the lists are both of the same size, and most values are equal, the last value of the two lists differ. But the point is that, given the overloaded boolean comparison operator for our `List` class, we can perform boolean comparisons that yield `true` / `false` results just like the built in data types like `int` or `float`. If you wanted, you could add in other boolean comparison operators for the `List` class, like `<`, `>=`, etc. Question: how would you define `<` for our `List` class? We will not be adding in more boolean operators in this assignment, but doing something different.

Notice also the overloading of the `operator[]` which allows us to index `List` instances as if they were regular C/C++ arrays. This is powerful, as it allows us a way to look into our lists, iterate over them, and even modify our list contents. But also notice, recall that this is powerful because it allows us to add in some bounds checking on index requests, so that we can throw an exception if someone tries and access a value beyond the end of our list, instead of causing memory corruption which is what will happen if you make bounds errors when accessing regular C/C++ arrays.

As was discussed in this weeks unit, the `operator<<` to overload the output stream operator is a bit different from the previous two operators. It is actually a `friend` function rather than a member function. There are technical reasons

why this is necessary, which were discussed in some of this weeks learning materials. Basically we need the instance of the class we want to send to send to the output stream on the right hand side of the output stream operator:

```
List l1;  
  
cout << l1;
```

Here the output stream object `cout` is on the left hand side, and the `List` object `l1` is on the right hand side of the `operator<<()` stream operator. Because the `List` needs to be on the right hand side for stream output, it cannot be handled as a regular member overloaded operator, as that requires the object to be on the left hand side of the operator.

Also before starting to implement this weeks assignment, note the new `growListIfNeeded()` private member function. This week we are enhancing the `List` to be able to dynamically grow and shrink, but being able to add and remove items from the list. Because of this requirement, the memory management of our list of `values` is a bit more complicated now. We need to be able to grow the size of the dynamically allocated array of `values` if it is currently full. This is where the new `growListIfNeeded()` function comes in. There is also a new member variable named `allocationSize`.

For this implementation of the `List` user defined type, the `size` of the list will not necessarily be the same as the amount of memory we have allocated to hold values, the `allocationSize`. The memory allocation can be larger than is currently being used. The strategy is that, whenever the list of values becomes full (e.g. `size == allocationSize`), we will grow the list. We do this by doubling the current memory allocation, and copying all of the values from the original array into the newly allocated array. So the `growListIfNeeded()` function will be useful for the methods you will implement where you need to add in a value and the list is currently full.

We double the new allocation of memory by default in this class. This is a common trade off between performance and memory size/usage. It is a very expensive operation to have to grow the list size, we have to allocate the new memory, and copy all of the values from the old allocation to the new allocation. This is a  $\mathcal{O}(n)$  complexity operation, which will take an amount of time roughly proportional to the current number of items  $n$  or `size` that are in the `List`. But adding an item or items to the end of the list can be done in constant  $\mathcal{O}(1)$  time whenever the new value or values will fit into the current allocation, we just add them to the end of the `values` array and increase the `List size` by 1. So insertion at the end can usually be done fast, but sometimes when we need to grow the list it will be slow. Doubling the size when we need to grow the list usually ensures that we won't have to grow too soon, and by doubling we ensure we only need to perform the growth  $\log_2 n$  times for a final large size of  $n$  of values that might be managed by the `List`.

## Task 1: Implement `append()` and Overload `operator>>()`

As usual make sure that you create Task 1 issue on GitHub and have linked the issue with the 'Feedback' Pull request in this assignment repository before beginning.

For the first task you will implement the ability to append a new value onto the end of our `List` of values. You will first do this by implementing a regular member function named `append()`. This function takes an `int` value as input, which is the value to append to the end of the list. This function should actually return a reference to a `List` as its result. You will not be creating a new `List` to return, but you will simply be returning a reference to the instance from the member function. The reason for this will become apparent when you implement the overloaded operator. To return a reference to this instance, simply do a

```
return *this;
```

at the end of your member function. The result of calling this function is that the new value will be appended to the end of the list, and the list may have grown if it was full when the append was attempted.

As usual it is recommended that you start by adding the member function signature to the `List` class header file, and a stub function to the implementation file, uncommenting the second set of unit tests, and ensuring that your project can compile and run the tests before proceeding with the implementation.

It is required that you use the `growListIfNeeded()` private member function to implement your append and prepend operations. If you call this function before attempting to add the item to the list of `values`, it will grow the list if needed, so that you have enough room to append on the new value.

Once the `append()` member function is working, you should then add in an overloaded operator for the `List` class to allow appending of values to the list. The next set of unit tests will test the overloading of the operator for appending values. We chose to reuse the `operator>>()` operator to denote appending values to the list. The `>>` operator normally performs input stream operations in C/C++. There is no real operator that means something like ‘append’ for the built in basic data types. It is not uncommon when doing operator overloading to do something like this, to re-purpose an existing syntactic operation to mean something useful for your own user defined data type. Overloading this operator to mean appending a value allows us to write code like the following:

```
List l1;
```

```
l1 >> 5;
```

This will append the new value of 5 onto the end of the initially empty `l1` list. Likewise, because we return a reference to the `List` object from the append operator, it allows us to chain append operations, for example:

```
l1 >> 5 >> 3 >> 7;
```

This will first append 5 to `l1` and it returns `l1` back as its result. Then `l1 >> 3` would be performed which appends 3 to the end now, and so on.

Your `operator>>()` will have the same signature as the `append()` function you just completed. And in fact, this method is trivial, as you should simply reuse and call the `append()` implementation you already have to implement this overloaded operator.

Once you are satisfied with your implementation of the overloaded append operator perform the usual actions. Commit your changes and push them to the `Feedback` pull request of your repository.

## Task 2: Implement `prepend()` and Overload `operator<<()`

As usual make sure that you create the Task 2 issue on GitHub and are linking with your Pull request for work on this task.

Your `List` user defined data type you are creating uses a regular, though dynamically allocated, array as the actual storage of the data values being managed by the `List`. If your append operation is working correctly, it most of the time only takes  $\mathcal{O}(1)$  time to append a new item onto the end of the list, though at times when the list needs to grow you need  $\mathcal{O}(n)$  time to allocate the new memory and copy the  $n$  values from the old memory to the new memory.

What if we want the ability to be able to push items onto the front of the list? Can we do that with our current data structure? The only way we can do this is to first shift all of the current items up 1 index to make room at index 0 of the array to prepend the new value. This means that the prepend operation will always be at least  $\mathcal{O}(n)$  in time, though you also still need to grow the array before shifting if it is full, so that time can double if the array first needs to grow. Keep in mind the performance of append and prepend in our next unit where we talk about Linked Lists, which give a way to allow  $\mathcal{O}(1)$  constant time performance to append and prepend items to the list.

Besides the need to first shift all items up 1 index for the prepend to index 0, this task will end up being pretty similar to Task 1. You will first create a `prepend()` member function. It will have the same signature as `append()` and will return the same reference to `this` `List` instance as its result. Of course after checking if the list needs to grow, you first need to shift all items up by 1 index before putting the new value into index 0 of the `values` array.

Then likewise the `operator<<()` which we have chosen to overload for the prepend operation can be defined, and its implementation is simply to call the `prepend()` function you implemented first.

NOTE: it would probably syntactically make more sense to specify prepend as

```
5 << l1;
```

with the value to prepend on the left hand side of the operator. But in order to do this, we would instead have to create a friend function that expects an `int` value as the first parameter and a `List` as the second, similar to the `operator<<()` friend function. We leave this as an exercise for the interested student.

As usual it is recommended that you first create the signature for the `append()` method and a stub function, uncomment the first test case testing the `append()` and make sure you project compiles and runs the tests before you start implementing. It is also suggested you complete `append()` first, and then work on defining the overloaded `operator<<()`.

Once you are satisfied with your implementation of the append operation for the `List` class, commit your changes and push them to the `Feedback` pull request of your repository.

### Task 3: Implement `concatenate()` and Overload `operator+()`

Make sure that you create the Task 3 issue on GitHub and are updating your Pull request with work for this assignment, and that the previous tasks have appropriate commits to document them before proceeding.

We would like to support the concatenation of two lists together to create a new list. For example, if we have

```
List l1;  
l1 >> 1 >> 2 >> 3;  
  
List l2;  
l2 >> 4 >> 5 >> 6;  
  
List l3 = l1 + l2;
```

We would like the result to be that `List l3` has the values 1, 2, 3, 4, 5, 6 in it. This is the concatenation of the two lists to create a new third list. Also notice the above implies that `l1` and `l2` should not be modified as a result of this operation, they are still both lists with 3 values after the concatenation. This further implies that a new list needs to be dynamically created and returned in the `operator+()` that holds the result of the concatenation.

There are some subtle difficulties with memory management that we must take into consideration here. We could try using, for example, the copy constructor and the append or prepend methods, but these approaches will end up being more difficult than they might at first seem.

First of all, the above example indicates that your `concatenate()` function should take a `const` reference to another `List`. This would be the right hand side `l2` list that is passed into your `concatenate()` function in the previous example. Also we said that `l1` should not be modified by doing the concatenate, so your `concatenate()` function should be declared as a `const` member function as well. The function should return a reference to a new `List` that will need to be created dynamically.

So the approach you should use for `concatenate` is as follows.

1. Start by allocating a new array of `int` values that is large enough to hold both `this` size plus the right hand side `size` values once you concatenate them together. Then
2. Copy all of the values of `this` from its array of `values` to the beginning of this new array of values.
3. Likewise copy all of the values from the right hand side list after these in the new array.
4. Then it is important to dynamically create a new `List` of values that is initialized with this array of the concatenated values you just created.
5. Once you have dynamically allocated your new `List` you don't need the array from step 1 anymore, so `delete` it.
6. You should return the newly dynamically allocated `List` object as a reference from your function.

For step 5, let's say you created an array of integers named `concatenatedValues` that has is of size `concatenatedSize`. Then you would dynamically allocate a new list using the array based constructor, like

```
List* concatenatedList = new List(concatenatedSize, concatenatedValues);
```

The result as shown here, as always, is a pointer to the newly allocated `List` that is now on the heap. You can return this dynamically allocated reference by dereferencing the pointer

```
return *concatenatedList;
```

Once you have the `concatenate()` member function working, overloading the `operator+()` for list concatenation should be relatively simple and basically the same as you did in the previous 2 tasks. You should be able to define the overloaded operator and simply call your working `concatenate()` function to actually perform the concatenation of the lists into a new list that you return.

Once you are satisfied with your implementation of the `concatenate()` member function and overloaded operator, commit your work and push this commit to the `Feedback` pull request of your repository.

## Task 4: Templatize List Class

With task 4 we will be shifting gears and turn our attention to making your List class into a template class, so that we can manage lists of types other than `int` as we have now.

We will also be getting some practice using git and GitHub in this assignment, as we are going to perform the templatzation of the `List` class in a new branch. So don't start task 4 until you have all of the previous tasks committed and their tests passing through task 3.

Once the tasks 1-3 are passing the GitHub actions/tests, and you have all of the work recorded and pushed as commits into the `Feedback` pull request, then you can turn your attention to working on task 4. We are going to put all work to templatzate the function into a new branch. We would like to start this branch back before you started adding in commits for the tasks 1-3. We want to end up with the non-template version of the code on the main and feedback branch of your repository, which are already created. We want to create a new branch called `template` that branches from the initial commit of your repository, and records all of your commits to templatzate the `List` class for task 4.

You first need to checkout the commit in you DevBox that happened before your first commit for task 1. Unfortunately it seems like VSCode has a bug that makes it difficult to checkout specific commits, a task that is easy to do from the git command line. So you will need to open up a terminal and do something like the following:

```
$ vagrant@devbox:~/sync/assg/assg05-test-team$ git checkout 8e543b45
Note: switching to '8e543b45'.
```

You are in 'detached HEAD' state. You can look around, make experimental changes and commit them, and you can discard any commits you make in this state without impacting any branches by switching back to a branch.

If you want to create a new branch to retain commits you create, you may do so (now or later) by using `-c` with the switch command. Example:

```
git switch -c <new-branch-name>
```

Or undo this operation with:

```
git switch -
```

Turn off this advice by setting config variable `advice.detachedHead` to `false`

HEAD is now at 8e543b4 Initial commit

Notice that you should run this command from your assignment repository directory for this assignment. Also notice you need to specify a funny looking number for the checkout command. This is the git commit hash for the commit I wanted to checkout and switch to. These hashes are really long, you only need to specify the first 8 digits or so if typing them in by hand. But the git hash id you need will be different for you, you will need to look through the history of your commits and find the commit id that corresponds to the commit just before your first task 1 commit.

Once you have checked out this commit, if you go back and look at the code you added, you will see it is now gone. This is because you have moved back in time in your commit history, and you should be at the place just before you started doing your work. This is what we want. We want to branch off from this point in time and add the code again, but this time first turing the class into a template class. As the message indicated from the checkout, we should create and switch to the new branch we want to begin work on. So again from the terminal, do as it says and create a template branch:

```
vagrant@devbox:~/sync/assg/assg05-test-team$ git switch -c template
Switched to a new branch 'template'
```

Once on the template branch, you will be able to add in new work, and stage, commit and push changes as you have been doing. These changes will be pushed directly to the new `template` branch you are working on at your GitHub classroom repository.

We need to modify and add additional tests in order to make `List` into a template class, so that we can test not just a `List` of `int` values, as you currently have, but create lists of any type, e.g. `List<int>`, `List<string>`, `List<char>`,

or `List<MyOwnClass>`. I have created and updated a set of tests and the build system for you in order to start templating your `List` class. There is a subdirectory called `template` in your project that contains some files. Copy the files named `test-int-template.cpp` and `test-string-template.cpp` to your `src` subdirectory. These files will be replacing the old `tests-List.cpp` file that was testing the nontemplated version of `List` that only managed `int` values. There is also a new `Makefile` that will use these 2 tests files to build the test executable, copy this new `Makefile` from the `template` subdirectory and replace the current `Makefile` you have at the root of the directory. You will also see there are files named `List.hpp` and `List.cpp` in the `template` subdirectory. Copy these files to `include` and `src` respectively. I have gotten you started on turning `List` into a template class, but have only templated the class declaration and the class constructors and destructor.

Once you copy over all of the files from the `template` subdirectory, your project should now build and run the unit tests. You should check that this is true at this point by building and running the tests. Most all of the tests are commented out again, so not much will be tested yet, but you should be back to a compilable and runnable state.

If you get the copied tests and templated `List` to compile and run the tests, you should make a commit with these changes and push it to the `template` branch of your repository. Take a moment to examine the new branch in your repository, and the history of the commits now along your `template` branch. Also, let's create a new pull request called `Template`, that will be tracking all changes of the `template` branch for merge back into the `main` branch. We will not ultimately merge this work into the `main` branch, as we want to keep the `template` work separate from the `main` nontemplate work. But having a `Template` pull request that tracks the `template` branch will be a convenient way to gather all work and commits while templating the `List` class.

After committing and pushing, you should examine how the `List` class has been turned into a template class. In the `List.hpp` file, there are just a few subtle changes. The declaration of the `List` class is now preceded by the template specifier keyword:

```
template <class T>
class List
{
    ...
}
```

As we talked about in this unit, this declares that `List` is a template class, templated on a generic type or class we have called `T` here. The `List` class will be able to hold and manage type `T` objects, where `T` can be replaced by actual types in our code.

**NOTICE:** one other important change here. The type of the `values` array/pointer is now:

```
T* values;
```

This reflects the fact that we are templating our list, so we need it to now hold an array of some generic type `T` instead of concrete `int` types. Also notice that not all `int` types change. We are holding values of some generic type `T` in our list, but the current `size` and the current `allocationSize` of the list are still integer types.

Also notice the standard and copy constructors. The standard constructor used to take an array of `int` values in order to construct a list with:

```
List(int size, int values[]); // standard constructor
```

but now we say instead that we expect an array of some type `T` for this constructor:

```
List(int size, T values[]); // standard constructor now expects generic type T values
```

Likewise the copy constructor used to expect a `List` as the parameter to copy into a new list. But now we no longer have nontemplate `List` classes, instead the class must always be templated:

```
List(const List<T>& list); // copy constructor expects a List<T> containing type T values
```

You should also examine the implementations of these constructors and destructor in the `List.cpp` implementation file. First of all, now that the `List` class is a template class, all member functions of `List` must become template functions, even constructors and destructors. So you will see that all of the constructors and the destructor that were templated for you now contain the `template <class T>` modifier before them.

Likewise, all of these class methods / constructors / destructors are now members of `List<T>`, so they all have



`List<T>::` before the name of the constructor function. All regular member functions are also now members of the `List<T>` class instead of just of a `List`, so all member functions you modify likewise need the `template` preamble before them, and need to be changed to be members of the `List<T>::` class namespace.

These are not the only changes that were done to turn these constructors into template member functions. Examine more closely the two constructors we discussed before. For example, the standard and copy constructors now dynamically create an array of `T` values rather than of `int` values:

```
this->values = new T[allocationSize];
```

In general you will have to make similar changes in the member methods you templatize. Not all `int` types become a generic `T` type. But anytime you are passing in a or referring to a value that will be managed by the `List<T>`, it will need to be turned into a generic type `T` instead of the `int` it currently is.

The tests in the two new testing files have mostly been commented out again. You will find the first two `TEST_CASE` sections are uncommented in both `test-int-template.cpp` and `test-string-template.cpp`. As the names hopefully suggest, the `int` tests are testing `List<int>`, a list of `int` values, and the `string` tests are testing `List<string>` list containers. While the second test case is uncommented, most of the checks are actually commented out. Only the invocation of the constructors for the class are actually currently executing.

To begin templatizing the whole class, start by uncommenting the first `CHECK` that calls the `getSize()` member method. You want to add back in `getSize()` to the `List` class, converting it into a template member function. There are ways to use git to stash files, and switch between commits to pull out code from other commits into your current work. However, for simplicity, I suggest you simply open up your GitHub assignment classroom, make sure you are looking at your `main` branch, and then copy the `getSize()` nontemplate method from there back into your work. Then convert this member method into a template member method. The methods `getSize()`, `getAllocationSize()` and `str()` should all be relatively easy, you only need to change them into template functions, none of them create or refer to any values in the container that need to be changed from `int` to type `T` declarations. Templatize these 3 member methods first. Uncomment any tests in the first 2 test cases calling `getSize()`, `getAllocationSize()` or `str()`. Don't forget to uncomment both in the `int` tests as well as in the `string` tests. The `test-string-template.cpp` testing file is testing that your changes work when the `List` holds `string` type values in the list. Once the tests pass for these 3 functions in both testing files, create a new commit and push it to your `template` branch of your GitHub classroom repository.

Once you get these working, you next need to templatize the `operator[]` indexing operator, and the `operator==` boolean comparison operator. These again do not actually create any local variables that are values of the `List`, so you should be able to simply convert them into template functions without having to do much more, though the indexing `operator[]` does return an `int&`, but now for a template `List`, it should be returning a generic `T&` reference, and the `operator==` will be expecting a `List<T>` now as the right hand side list to compare with.

If you convert those functions to template member functions, then that should be enough to allow you to pass all of the tests in the second `TEST_CASE` of the `List<int>` tests. But also, after or while you are doing this, you could and should uncomment the same tests of these function in the `List<string>` test file as well. If you templatize these functions correctly, you should be able to pass the tests both when using lists of `int` values and when using lists of `string` values.

Once you get the first two test cases in both of the testing files to pass, I suggest you next templatize the `growListIfNeeded()` member function. This is another function that was given to you, but you should be using it in the operators you implemented in tasks 1-3 before. This member function does require you to templatize some of the local member declarations to be of generic type `T` instead of `int`. Specifically, the grow list function creates a new array of values if it needs to, and of course this array needs to be of generic type `T` now. You should modify this function and make sure your code still compiles and passes the first two test cases after making your modifications. There are no explicit tests of the private `growListIfNeeded()`, but if your code compiles and runs it would be good to push a commit of this work to the `template` branch of your repository now.

At this point, if you have templatized `growListIfNeeded()` and the other accessor and operator methods, you can begin templatizing the functions and operators you added in tasks 1-3. With practice you may be able to go faster, but it is still recommended to do these 1 at a time, as it is very easy to get lost in a sea of compiler error messages when working with class templates. Start by uncommenting the tests of the `List<int>` of your `append()` member method, and then add and templatize this method. As a hint, remember that the value being passed into `append()` is being added into the list, so it is no longer just an `int` but it needs to be a generic template class `T` now.



If the test passes for the `List<int>`, try uncommenting it in `List<string>` as well. Then you can proceed to uncomment each test, and templatized your other overloaded operators and member functions you added in tasks 1-3.

Once you are done with that, you should be able to now pass all of the tests with all of them now uncommented. If you want, you can now delete the `template` subdirectory and you can delete the old `test-List.cpp` testing file if you didn't already. You should make a new commit with the unnecessary files removed and push it to the `template` branch, though make sure everything still compiles and runs before and after pushing these changes.

You should have done these changes in a new branch called `template`, as stated at the start of this task. Once you are satisfied, commit your changes to templatize the class to the `template` branch, and push your changes to your repository. Hopefully you will now be able to pass all of the GitHub test actions. The `Template` pull request you created should show all of the commits you made to templatize your `List` class. We will not be merging this pull request back to the `main` branch. We want to leave it open to keep separate branches of development possible for the nontemplate and templatized versions of this code.

## Assignment Submission

For this class, the submission process is to correctly create pull request(s) with changes committed and pushed to your copied repository for grading and evaluation. For the assignments, you may not be able to complete all tasks and have all of the tests successfully finishing. This is ok. However, you should endeavor to have as many of the tasks completed before the deadline for the assignment as possible. Also, try and make sure that you only push commits that are building and able to run the tests. You may loose points for pushing a broken build, especially if the last build you submit is not properly compiling and running the tests.

In this problem, up to 20 points will be given for having at least 1 commit that compiles and runs the tests (and at least some attempt was made to work on the first task). Thereafter 20 points are awarded for completing each of the 4 tasks. However you should note that the autograder awards either all point for passing all tests, or no points if any test is failing for one of the tasks. Also note that even if you pass all tests, when the instructor evaluates your assignment, they may remove points if you don't follow the requirements for implementing the code (e.g. must reuse functions here as described, need to correctly declare parameters or member functions as `const` where needed, must have function documentation correct). You may also loose points for style issues. The instructor may give back comments in pull requests and/or create new issues for you if you have issues such as these, so it is good to have work committed early before the due date, so that the instructor may give feedback requesting you to fix issues with your current submission.

## Program Style

At some point you will be required to follow class style and formatting guidelines. The VSCode environment has been set up to try and format your code for some of these guidelines automatically to conform to class style requirements. But not all style issues can be enforced by the IDE/Editor. The instructor may give you feedback in your pull comments and/or create issues for you for the assignment that you need to address and fix. You should address those if asked, and push a new commit that fixes the issue (or ask for clarification if you don't understand the request). In general the following style/formatting issues will be required for programs for this class:

1. All programs must be properly indented. All indentation must be consistent and lined up correctly. Class style requires 2 spaces with no embedded tabs for all code indentation levels. The editor style checker should properly indent your code when you save it, but if not you may need to check or correct this if code is misaligned or not properly indented.
2. Variable and function names must use **camelCaseNameingNotation**. All variable and function names must begin with a lowercase letter. Do not use underscores between words in the variable or function name. Often function names will be given to you, but you will need to create variables, and maybe some functions, that conform to the naming conventions.
  - Global constants should be used instead of magic numbers. Global constants are identified using **ALL\_CAPS\_UNDERLINE\_NAMING**.
  - User defined types, such as classes, structures and enumerated types should use camel case notation, but should begin with an initial upper case letter, thus **MyUserDefinedClass**.
3. You are required to use meaningful variable and function names. Choosing good names for code items is an important skill. The code examples and starting code tries to give examples of good and meaningful names. In general, do not use abbreviations. Single variable names should be avoided, except maybe for generic loop

index variables `i`, `j`, etc. Make your code readable, think of it as writing a document to communicate with other developers (and with your instructor who will be evaluating your code).

4. There are certain white space requirements. In general there should usually never be more than 1 blank line in a row in your code. Likewise there should usually not be more than 1 blank space on a line. There should be 1 blank space before and after all binary operators like `+`, `*`, `=`, `or`.
5. Function documentation is required for all regular functions and all class member functions. You need to follow the correctly formatted Doxygen function documentation format. We will use function documentation generation, and you should be sure your documentation can be built without emitting warnings or errors. Likewise all files should have a file header documentation at the top. You should edit the file header of files where you add in new code (not simply uncommenting existing code). Make sure the information has your correct name, dates, and other information.
6. Practice using proper Git commit messages. You should refer to issues and tasks correctly in commit messages.

## Additional Information

The following are suggested online materials you may use to help you understand the tools and topics we have introduced in this assignment.

- [Lecture U07-1 Object Inheritance and Composition](#)
- [Lecture U07-2 Overloading](#)
- [Lecture U07-3 Templates](#)
- [C++ Classes and Objects](#)
- [C++ Inheritance](#)
- [C++ Overloading](#)
- [C++ Templates](#)