Programming in Modern C++
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Lecture: 43
C++ Standard Library: Part 1 (Generic Programming)

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Welcome to programming in modern C++. We are in week 9 and we are going to discuss module 43.

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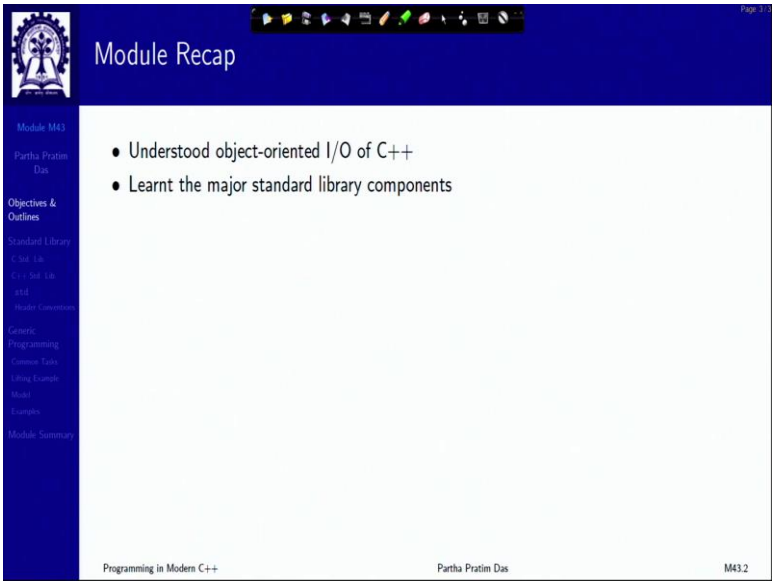

In the last module, we understood the object-oriented I/O of C++, the iostream, fstream and other headers and learned some of the major standard library components. We will actually

go further in that to get an overview of the overall standard library components of C++ and understand the generic programming what is generic programming for STL.

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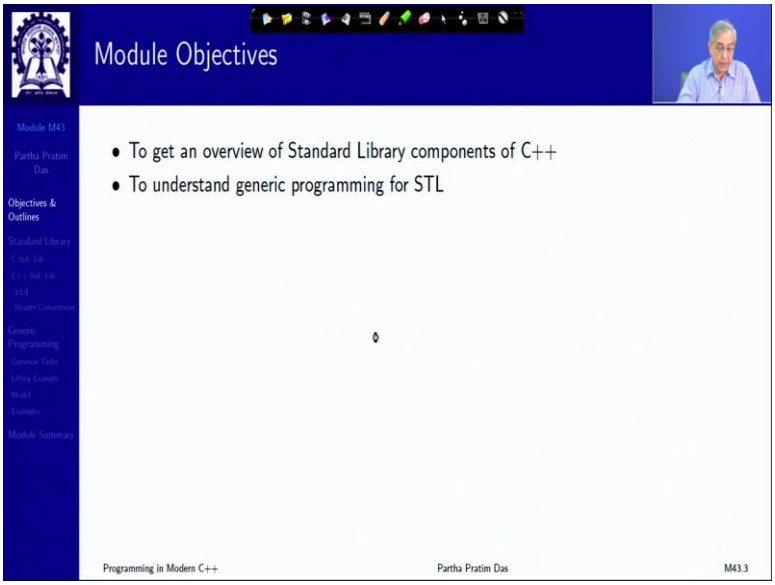

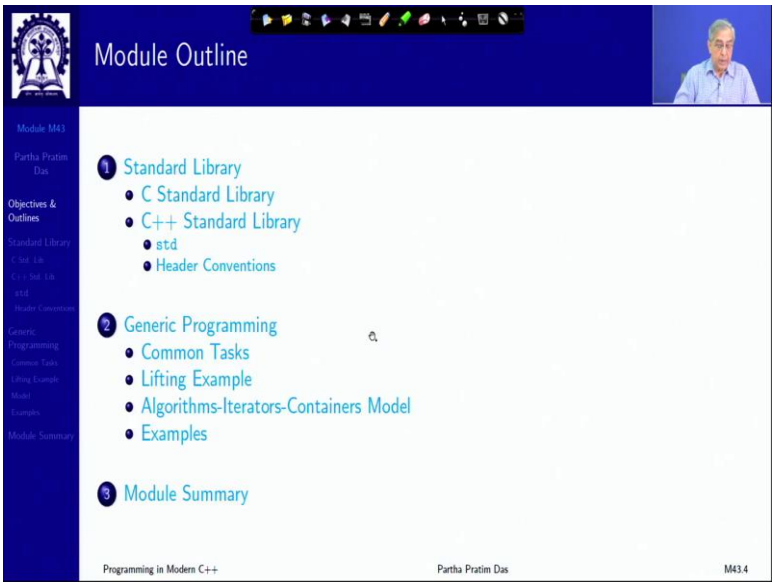

This is the outline of points on standard library and generic programming which will be available on the left panel.

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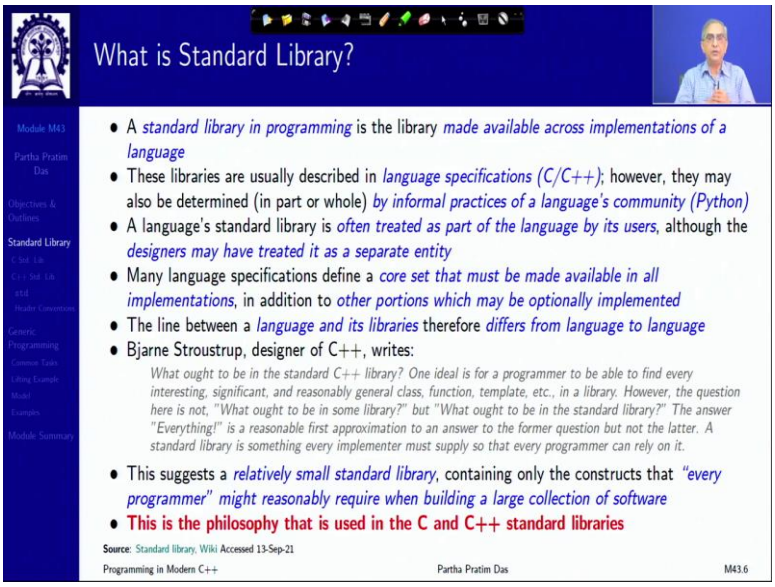

So, just to quickly recap, what is the standard library? A standard library is a collection of functions or classes typically templatized which are made available in addition to the core language. So, the core language has a lot of features as we have already studied at least, all major features of C++98, C++03 we have already studied. Will do some more for C++11.

But in order to facilitate the programming the development work for the software developers in an easy manner languages do provide a standard library which is also, specified in the language standard. So, C had a standard library much of which we have seen through practice and C++ has a significant standard library which is designed keeping, relatively small size in mind though that small size itself is not small enough. And it is useful for every programmer who needs to do programming in C++.

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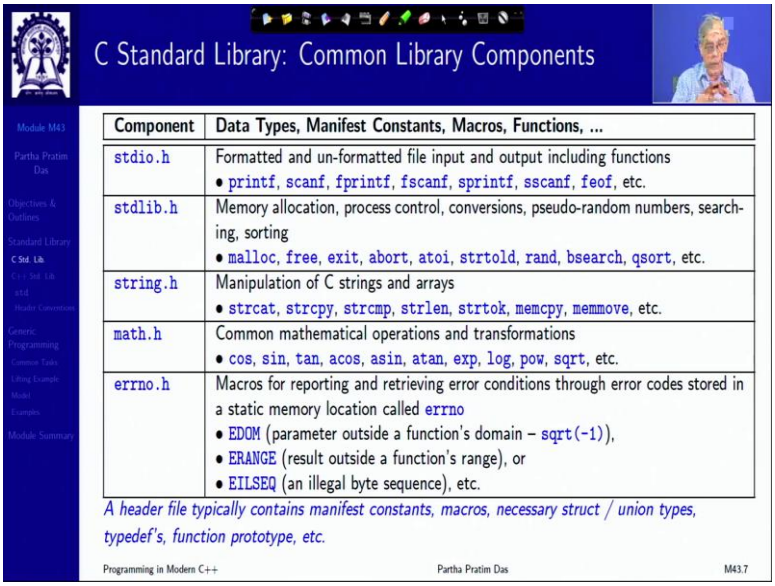

So, quick look at some of the major common library components of C which we are regularly using stdio.h, stdlib.h, string.h, math.h, are 4 that almost every time we need.

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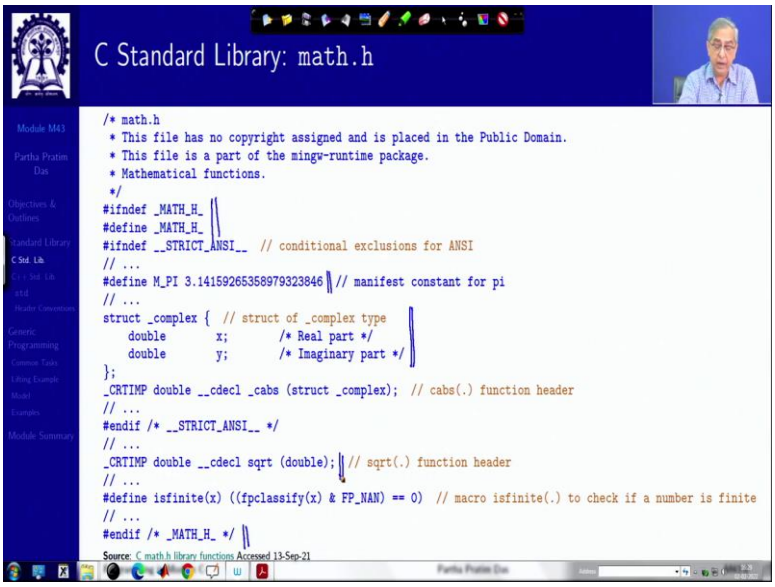

This is how a typical header would look like if you just go into your system and dig out a header I have dugout math.h. So, this is the compilation multiple inclusion guard present here which we learned about here are some constants defined as manifest constants because it is C. So, if you need the value of PI in a language, the developer can use M_PI, here is a complex structure defined with _complex name. This is the addition in C++ at a later point.

Here is a signature for the function square root that we regularly use and So, on. Of course, a lot of the code here I have just hidden just to give you a glimpse of the kinds of things that the standard library headers will have. Headers in C++ will, in addition, have classes and templatized definitions.

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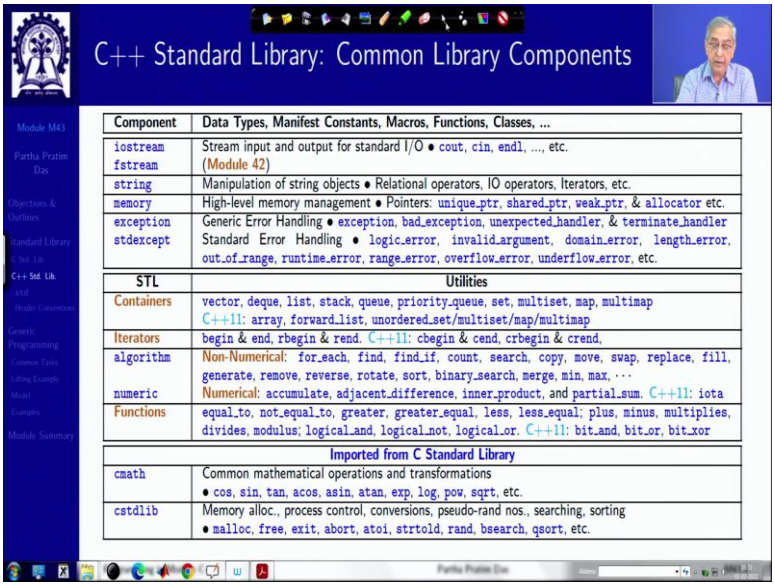

Now, in C++ standard library if we want to take a look then some of the components which we have already done well is iostream, fstream all those I/O libraries which we have done in the last module itself, we have been using the string component very heavily we will make use of memory component we have not discussed that yet we have made use of the exception components and so on. So, there are a number of components which are very useful for us. What is special in C++ standard library is the support for STL. STL stands for Standard Template Library. STL is neither the full of the library.

It is kind of a subset by of the standard library, but it does provide support for quite a very few important and interesting features of this standard C++ library. The most useful of them include containers, like in C, you did not have a support for data structure only array is available as a language feature. Using pointer, we had to build up linked lists of every kind.

But anything beyond that, whether it is stack or it is a queue or a priority queue or if I want to do a HashMap anything, the programmer had to create his or her own library for that. So, that has been strongly facilitated in C++ by providing a number of containers, almost a complete set of what you will need, I mean, this kind of is resonates with what you have in Python, where you have five basic data structure given as a part of the Python language itself.

So, in terms of the containers, we have vectors, which we have already been using quite extensively in place of array, it is an array of flexible size, but the same efficiency, you have doubly linked list, you have stack queue, priority queue or heap data structure, you also have Set, Map, which is basically kind of hashing and So, on.

And C++11 has added a lot more components in that. So, each one of these container components are a header by itself and has a complete functionality for that data structure. So, using C++ the need for doing any basic data structure is almost not there, the standard library will help that. To support that containers we have a number of iterators which can go over the container and check at different elements, will understand what iterators are in more depth. We have components for common algorithms like find, copy for doing something for each element of a data structure and so on.

We have some numeric very useful flexible numeric algorithms, given numeric components given these are not the numerical computation that we know, but these are like simple numeric operations like summing the elements of a vector and those kind of. And we have something which is very, very special in terms of the different functions that are provided.

So, there are, we have studied about functors in module 40. So, using functors using function objects, a number of very useful functions are provided, which are in turn used in the algorithms component and the container components. So, this is the main chunk of C++ standard library to specially learn and that is what we will be focusing in this module and in the next two.

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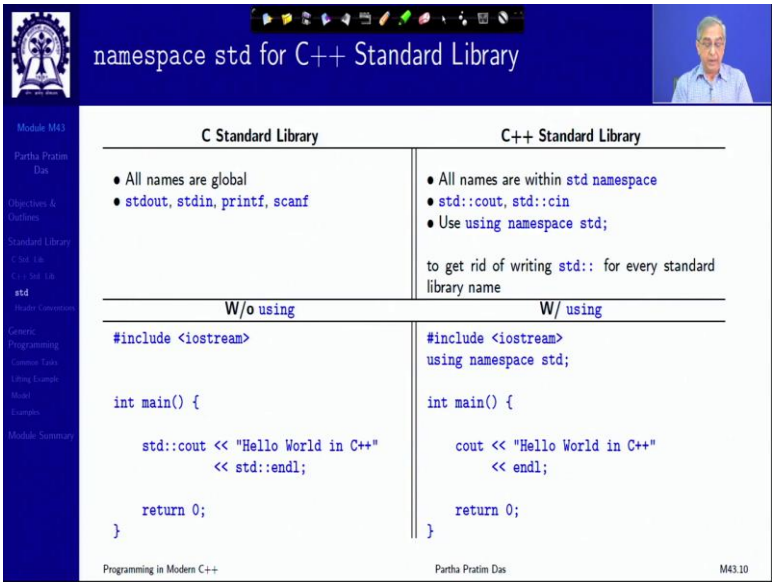

Now, coming to besides that, obviously, we know that C standard library headers can also be used in C++ by prefixing the word the letters c with it and you have the entire C standard library functionality available though in C++, they may differ a little bit differently at times. Just a quick recap that in C every name is in a namespace is which is global, because C does not have the concept of separate namespaces.

So, all functions standard library functions are in the global namespace. So, you cannot have your own functions by the same name. Whereas C++ puts all standard library components under a namespace std, which you have to prefix before the standard library symbols or you can use the mean have the flexibility of doing the using command as we have seen earlier.

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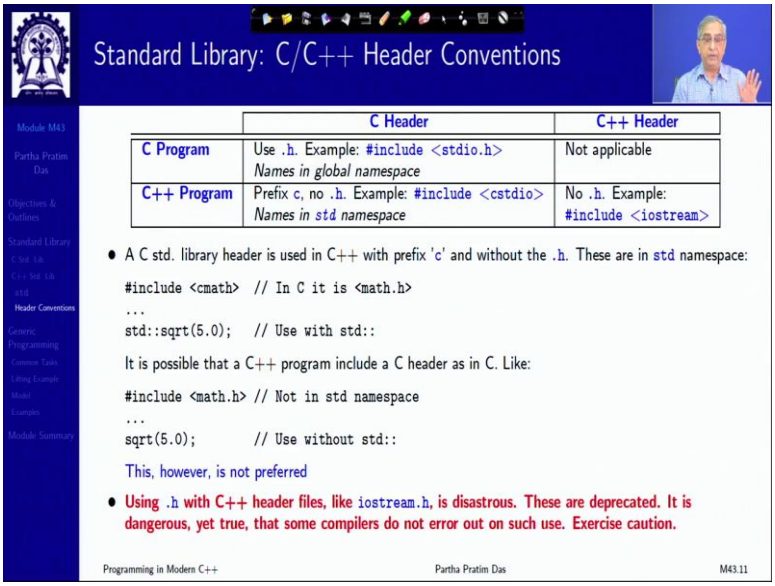

In terms of header names, all headers in C has an extension .h in the standard library, stdio.h whereas in C++, the standard library headers do not have this .h extension. If their standard library headers borrowed from the C standard library, then there named in the C standard library it is prefixed with c and the .h is dropped. So, stdio.h to be used in a C++ program must be included as cstdio.

Do not put that .h and the the pure C++ standard library headers do not have a .h, So, it is iostream simply not iostream .h, be very careful about this because in the older versions of C, the .h extension was there in the standard library. So, if you are using a little bit old system then it might have somewhere in the corner, some iostream.h header available. So, if you use that .h that wrong old file will be used. So, remember, in C standard library will always have .h in C++ standard library headers will never have .h.

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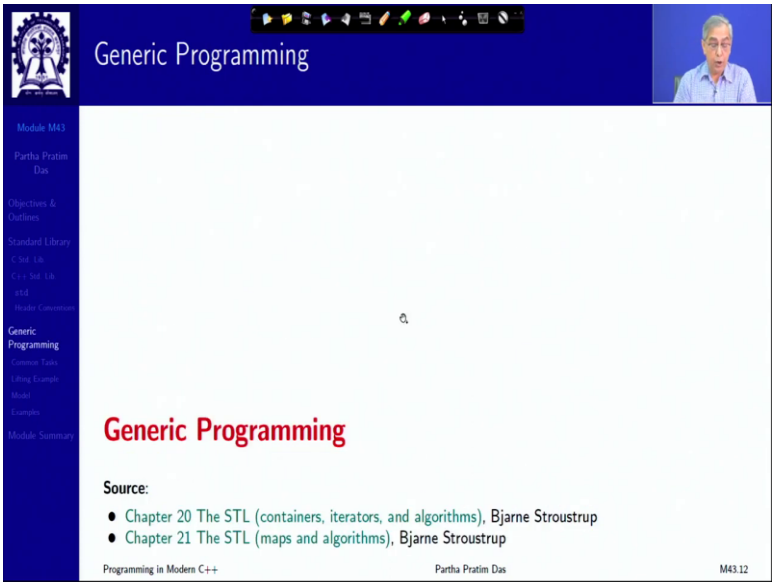

With these few words. Let me go over to discussing what is generic programming. Before we can get into the containers, iterators, algorithms, functions of the C++ standard library, we need to understand this concept of generic programming.

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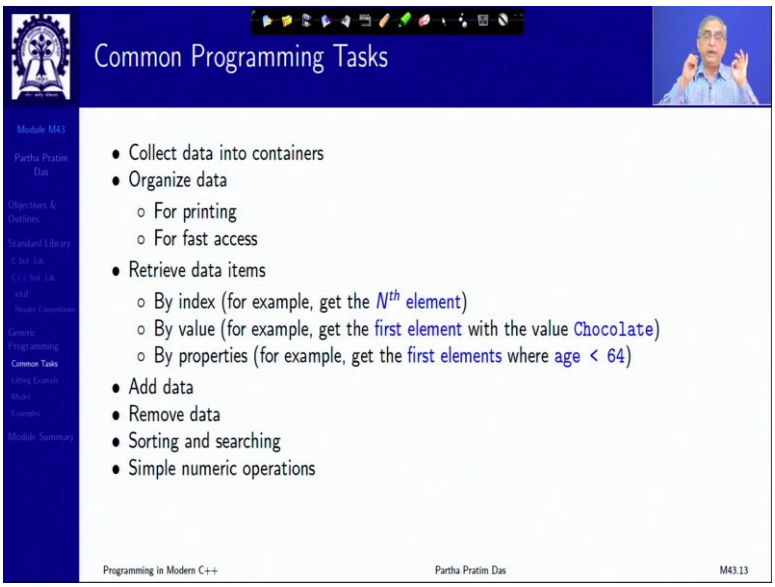

We mentioned about this earlier too. And in the context of C++, this is often also referred to as template metaprogramming. Because that is the mechanism through which generic programming is realized in C++. So, what is the purpose of generic programming? Consider the common programming tasks that we often have to do. What do we do, we think in a very

abstract way, we collect the data into containers, containers are nothing but data structures, which contain data.

And we organize them for different purposes like I might want to print the data or I might want to access the data at a very high speed, I may want to retrieve data items by different criterion, for example, I may want to retrieve a data item by an index or the position have the data in the data structure, or I might want to access that data by value that I want the value first element in my list, which has a value chocolate.

Or I might want to access a data by a property, you can say that well, from the collection of stood say person records, get me that record the first record where the age is less than 64. So, there could be several such but generically, we want to retrieve data items based on certain criteria, we want to add data, remove data, sort data, search data and so on, and do some simple arithmetic, numeric computation. So, these are things which, irrespective of which software project you are doing, you would be doing these or requiring to do this quite often.

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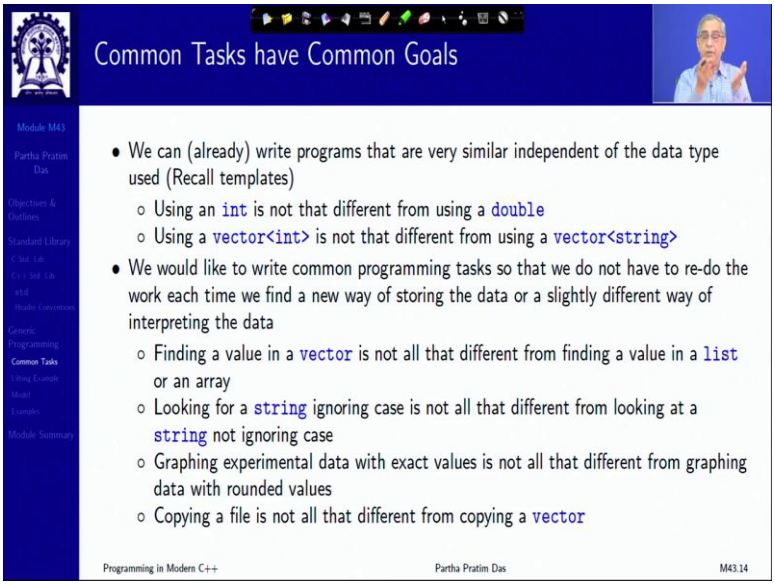

So, what we saw earlier is to facilitate these kinds of repeated tasks, we saw the use of templates, we have understood templates. So, we know that using an int is not very different from using a double or using a vector of int, is not very different from using a vector of string and so on. And so, we have seen that if we needed a stack of int or of char or of string or of a user defined data type, unlike C, I do not need to write the stack code, every time in C++.

I can use the stack component from the C++ standard library, set the data element type to be of the appropriate type, whether it is int or char, and the template automatically sets the type for the container underlying container element of the stack, it sets the type for the different push pop operations and so on.

So, using template, we have been able to generalize the different data structure different classes based on certain templatized type parameters. So, this is one level of generalization that we have been able to do. But still there is more that is possible. For example, suppose I want to find a value in a data structure. Now, I that data structure could be a vector, the data structure could be a list, naturally, the code typically would be different.

The same code cannot do this, of the kind of programming we know So, far. But conceptually, if you think is it significantly different as to whether I am finding the value in a vector or in a list, it is a collection. So, I want to find the value in that collection. So, the use of template first gave us the liberty I mean liberation from the underlying element, data type and so on.

But I want more liberty that conceptually, if an operation is applicable for multiple different containers, multiple different data structures, I should not be able to write a common code to do that operation. I want to I am looking for strings in a collection. Now, whether I look for strings with case sensitivity or in a case insensitive manner, will mean certain difference in the code. But conceptually, it is not very different. Conceptually, I am looking for strings, that is all.

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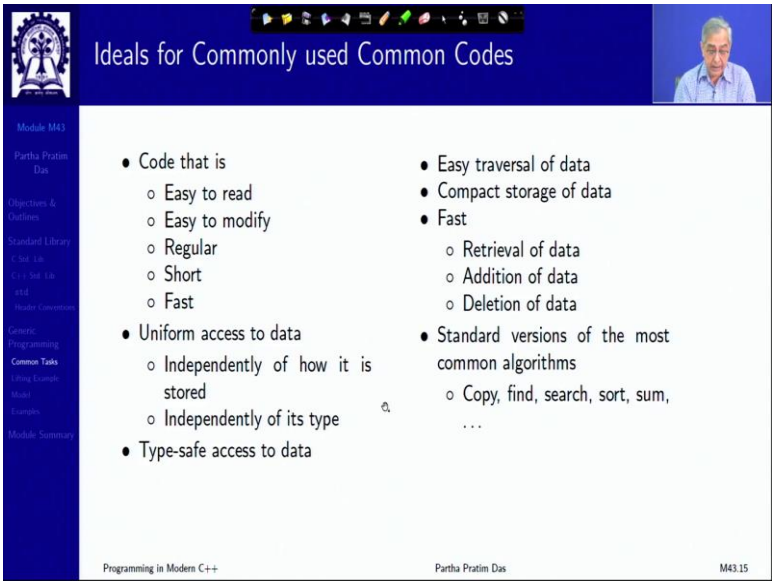

So, generic programming or commonly tries to find the common code with certain characteristics. So, what it should be? The characteristics that are desirable is ideals we say is the code should be easy to read, easy to modify, it should be more or less regular, short, fast and so on. The access to the data should be uniform independent of how it is stored, I am working with a stack I should not be bothered about whether the elements are stored in an array or in a linked list.

It should be independent of that, I am doing a search on a data structure, I should not be bothered about whether the data is in a vector or is in a list, whether the list is a single linked list or is a doubly linked list and so on. And of course, it should be independent of its type. C++ is strongly typed. So, access must be typesafe it should be easy to traverse the data the storage must be compact retrieval, addition, deletion, everything should be fast.

And there should be standard versions of common tasks like copying, search, finding, sorting and so on so forth. Can we write algorithms or codes in that level of generality? If we can and that is what is called generic programming.

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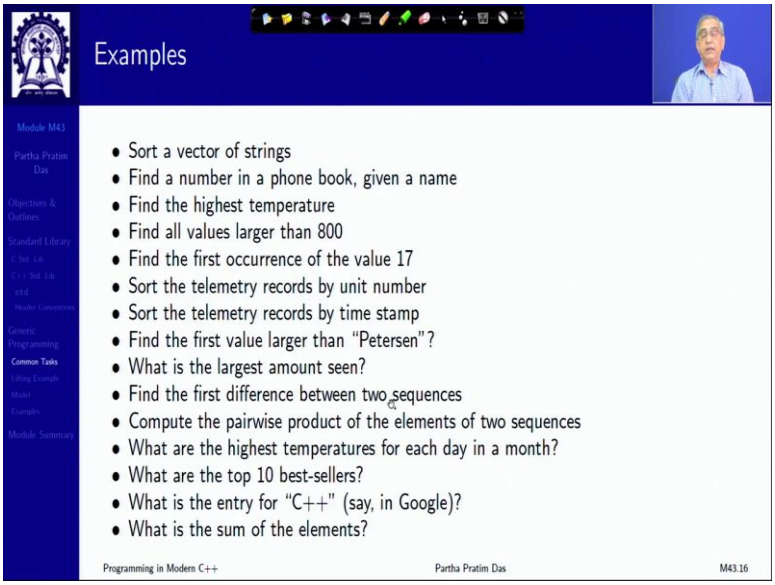

So, here, just a jumble list of some common tasks like sorting a vector of strings, finding the first value larger than “Peterson” and what is the entity for C++ say, when you search in Google and so on so forth, which are generic in nature, but comes from a wide variety of domains, for a wide variety of types, for a wide variety of possible values and So, on.

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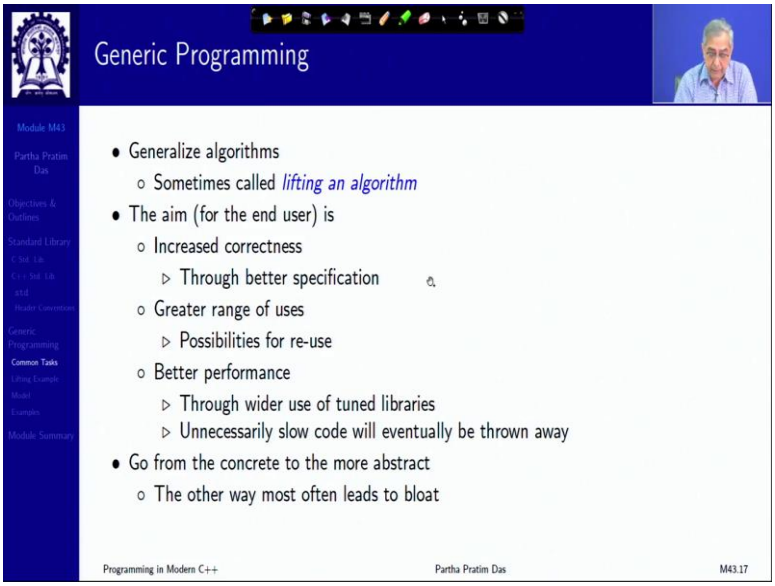

So, instead of having to write separate specific code for these tasks, can we generalize? That is the basic question that we are trying to answer in the generic programming. So, generic programming tries to generalize the algorithm it is also, called lifting an algorithm. So, that its correctness can be increased, because you are generalizing you are specifying it in a very compact form, and possibly once to be used a million times afterwards.

So, a better specification must be possible, there should be greater range of use, that is the basic purpose and the performance must be wisely usable for tuned libraries. So, for doing this, we try to go from concrete algorithms that we write down in terms of C or C++ code, to more abstract forms of algorithms.

So, as you come to concrete, things start bloating up, the code for stack, for input, for stack, for a double, bloated up, we made an abstraction to made it a, made the element type to be a type parameter in the template, it became compact. Now, it still can bloat if it is a stack of vector. Stack, realized by a vector or a stack realized by a doubly linked list. Can I abstract it by just saying that it is a container, where I can put an element take out an element, check if the container is empty, and so on so forth.

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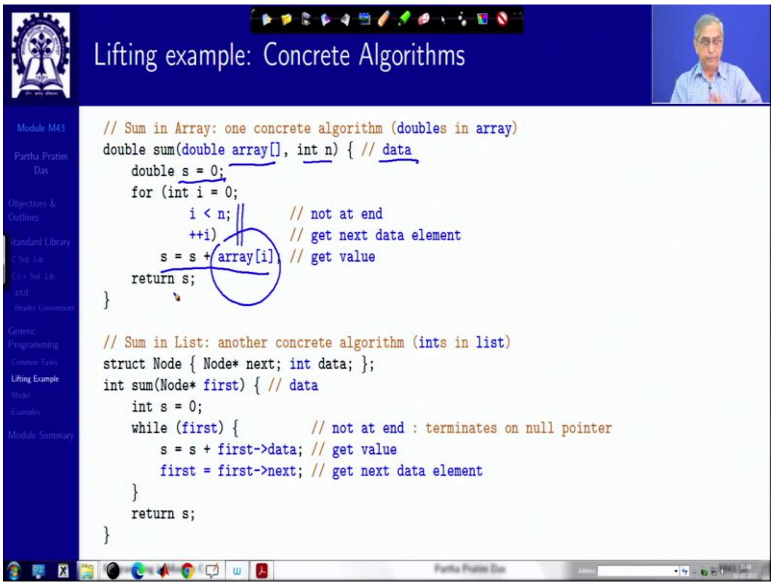

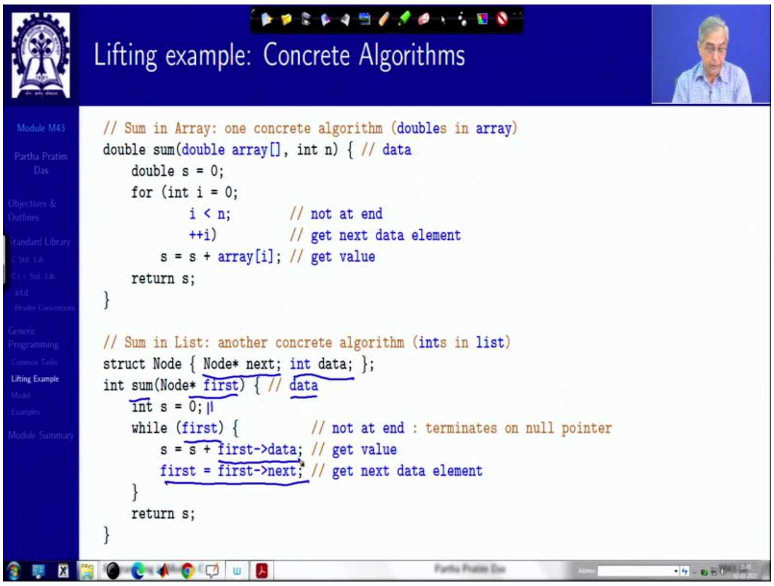

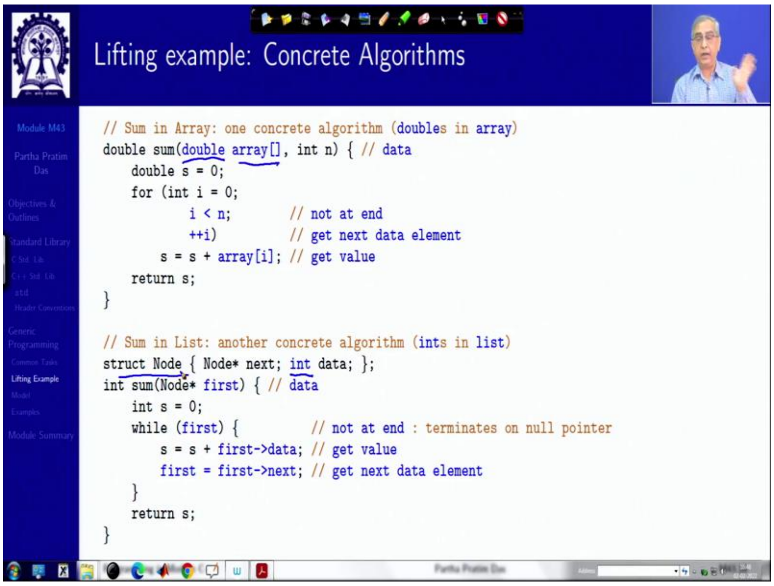

So, that is the basic, lifting the algorithm is a basic idea, and I give you an example. Suppose we are trying to do, we are trying to add the numbers in a data structure, let the data structure be an array. So, that is the data given to us. And, well, since it is an array, I need to also tell what is the size of the array, I tell that and then how do I add the elements, I will have an accumulating variable s, says where I keep the sum, which I initialized to 0, and then I keep on traversing on the array.

And there are two steps one is i < n, which checks if I have reached the end of the array, because there are n elements, I can go up to n - 1. And there is ++i, which takes me from the current index to the next index. That is it gets the next element. And as I have got the next element, I add it to the accumulated variable s, the sample code, C code. All of us have seen this a number of times.

Think about an equivalent code, equivalent way of doing this for a list. Let us say it is a Singly Linked List, which has a node which points to the next node contains the data and you write a similar function some passing the header of the node. So, which is the marker of the data. Now you have a similar accumulator for, for s which will have the sum. Now, you start with the first header and you keep on traversing the linked list we know.

So, what we have the header, we go to the next pointer, get the next value, go to the next pointer, get the next value till we are at the end of the list where typically customarily we will have a null value assigned to mean that the list has ended. So, we can go to the next element by doing this operation, changing first from first to first point and next.

And any when at a certain point, then the value that I need to access is first pointer data. Now, if you compare these two, then you see there are differences in terms of the first underlying type of data, double and int. There is differences in terms of the data structure. One is a list and other is an array.

But if you look at the loop in general, you can see that it is almost similar requiring three basic operation that to be able to check that you are not at the end, to be able to start at the beginning and then check that you are not at the end. And this has to be a way to go to the next element. And there has to be a way to access that element and get that value to do that accumulation.

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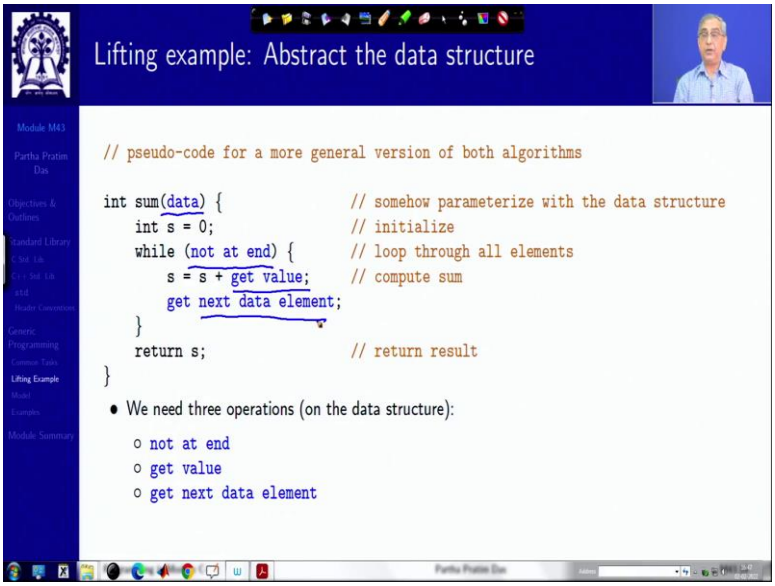

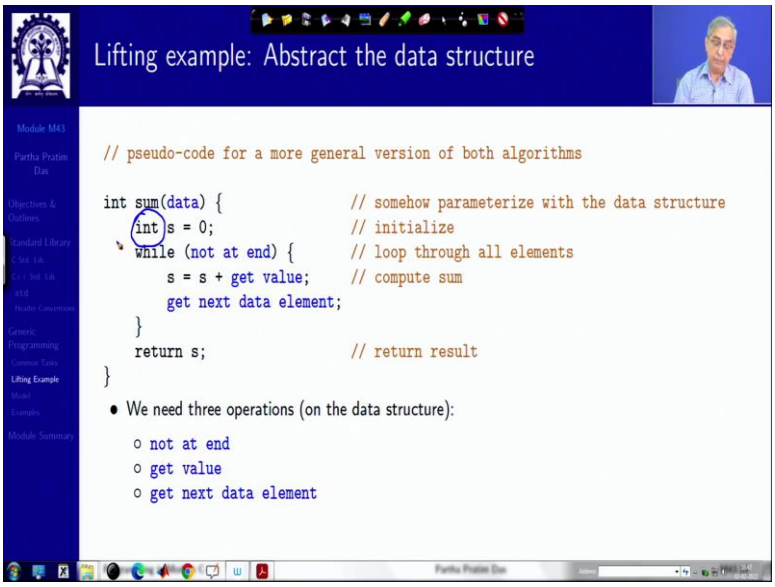

So, we can lift these two concrete algorithms into an abstract algorithm to write it in a in terms of a pseudo code, we say okay, given the data, which could be array or list whatever, it is a while loop, which continues till the end is reached every time I check the current value-added to s and then go to the next element. If we can do that, if we can do these three steps, then we will be able to easily, generalize both these concrete algorithms into an abstraction and that is what we are trying to do here a specific element type has been used, which, can be very easily liberated by using a templatized type.

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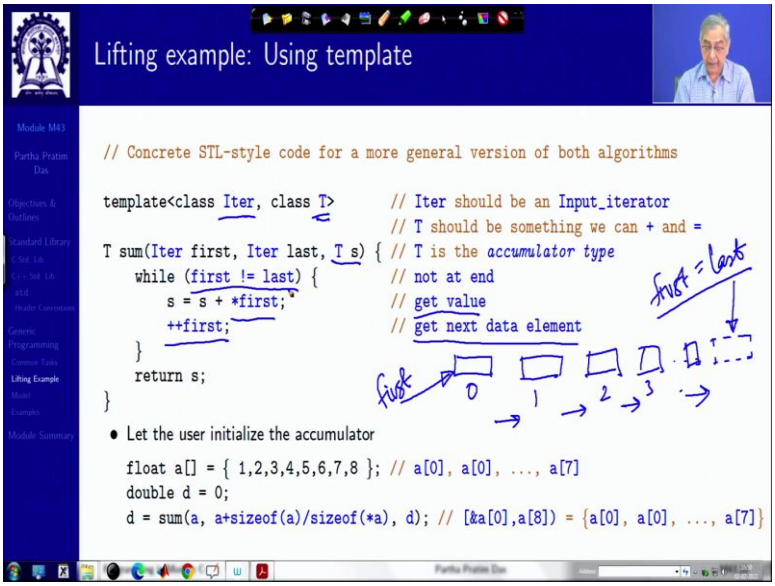

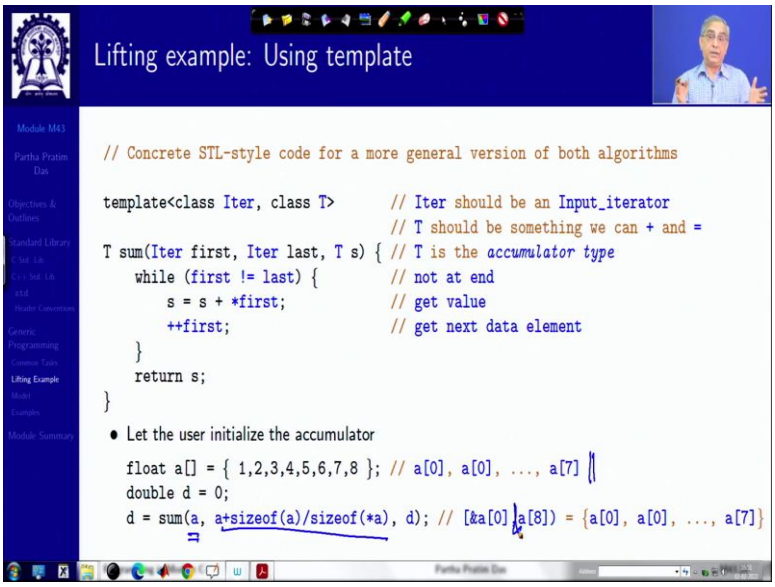

So, if I try to write this in the form of a template, I can say that, well, I will have something like, like a pointer to the data, which I called Iter, or iterator. So, I will have a class iterator which can point to any data element. Now, mind you, this pointing mechanism would be maybe different between an array and a linked list. Because the way I go to the next element in an array, and the way I go to the next element in a linked list are different.

But I can generically think that there is a pointer like thing, which say, if I have these data elements, So far I am talking about a linear data structure. So, I can there is a sequencing order in this, I am not saying whether they are indexed like this or whether they are linked like this either that is possible. And I say that I have a iterator, which points to the first. So, it is for the array it is a[0] for the list, it is a header.

And then I say that I have something like a node which is beyond my last element one beyond my last element. So, for an array of size n it is the location a[n]. For a linked list, it is a value null, which is where the next element should have been. So, I call this as my first and I call this as my last. This is a basic process of iteration.

And then I have a template parameter T which tells me the element type of which the sum type will have to be the same. So, what I do is I would say that I have an operator++, if you think about pointer, you will understand is very immediately. I have an operator++ which takes my pointer, the iterator from the current position to the next, then again current that position to the next So, that takes me to the to get the next data element.

I have a * operator thinking in terms of as if it is a pointer, it is again similar it is basically dereferencing whatever that iterator is pointing to I can get that element. So, that is get value. And how long do I continue? I will continue till from the first is going till it becomes equal to last, when this becomes equal to last the when first becomes equal to last I know that have gone past the last element because it is one beyond the last element.

So, I will continue till first is not equal to last. So, I should be there should be a way to compare these two iterators leads to values of the iterators and this like comparing pointers as you can think. So, with that a this becomes a generic code which can work in different contexts provided I can support this, ++, * and != operators in a proper manner I show it use in in case of a of a concrete array where there is an array of 8 elements.

So, this is my begin Iter which actually a is nothing but address of a 0. This is the size the number of elements which is I know there are 8 elements. So, it is 1 beyond a[8], is the address of a[8], sorry there should be address of, is the address of a[8], but it just does not go there goes one before that, and I will go up to that this is my end last Iter.

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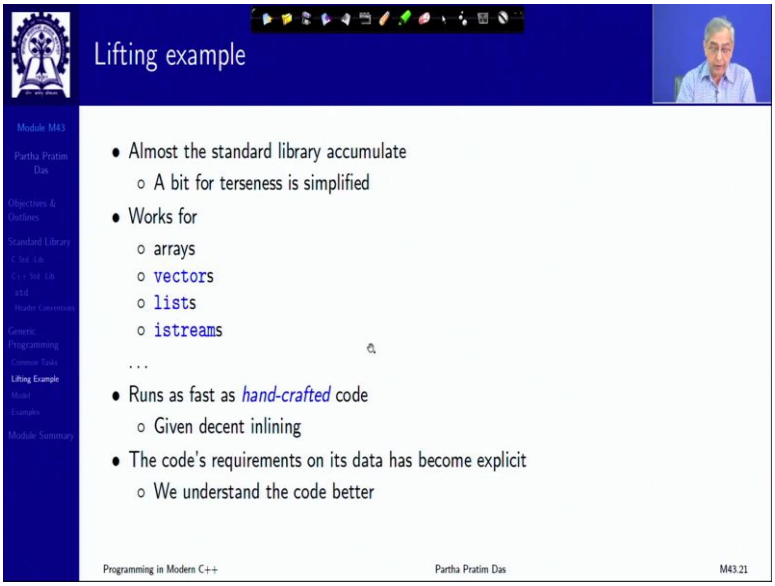

So, with this generalization, now, I can easily do things uniformly for arrays, for vectors, for lists, and so on.

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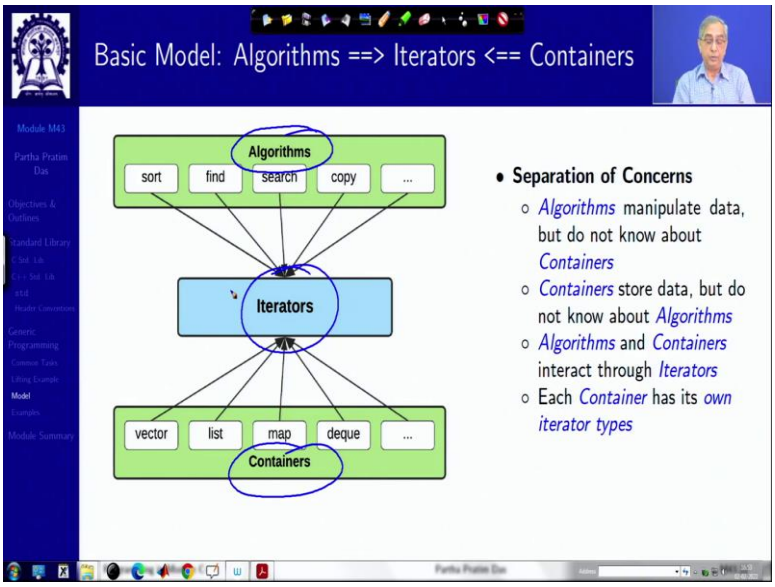

And that will be as efficient as doing it in the handcrafted code. So, for this C++ standard library provides a generic model, which say that, well, what are the things that I need to do? I will have to do different I will have different containers as in here, these are the different data structures, I can have a vector of a list, as a map and so on. I have different algorithms to perform, I want to do a search, I want to do a find, I want to do a copy, I want to do a sort and so on. So, these are different algorithms.

If I look in the C way then for every data type, for every data structure, I have to implement every algorithm. So, if there are 60 10 containers that C++ standard library has another 60 algorithms roughly, then there are 600 implementations you need which is humongously large, I get rid of that by introducing the iterators.

Iterators are as I explained, simply, it tells you the way to get start from the beginning of the data structure go over till the end at every point gives you the data. So, if the algorithm does not assume that it knows the container, if it knows that there is somebody called iterator, which will give you the elements 1 by 1, then the algorithm can be written even without knowing the container.

The containers can be implemented without knowing what the algorithm will do with them, because all that they need to provide, is the implementation of the iterator. That is the current, the beginning, the end the current position, how to go to the next position and how to give the next element.

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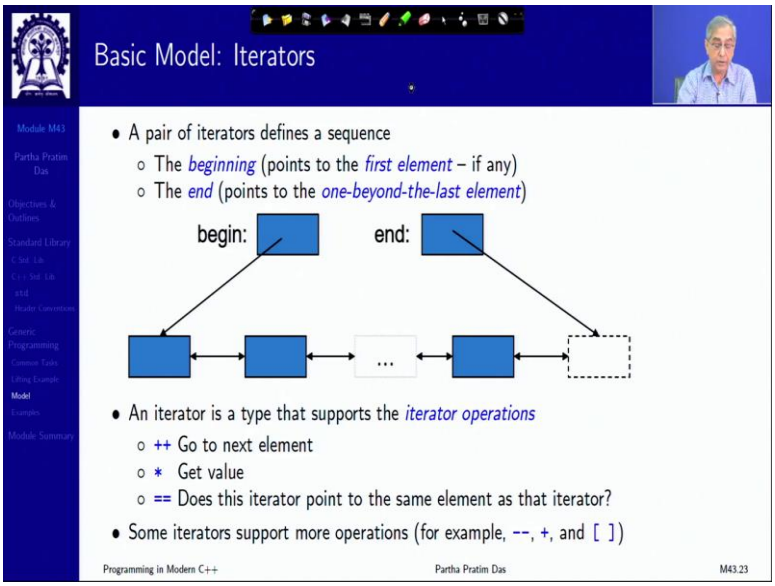

So, this is the basic model that is used. So, this is the better diagram of the iterator that I was drawing earlier. So, it is typically the initial is called begin, one pass the last one beyond the last element is called end. And there are three operators++ to go to the next element start with the value and equality to check if two iterator values are equal or not.

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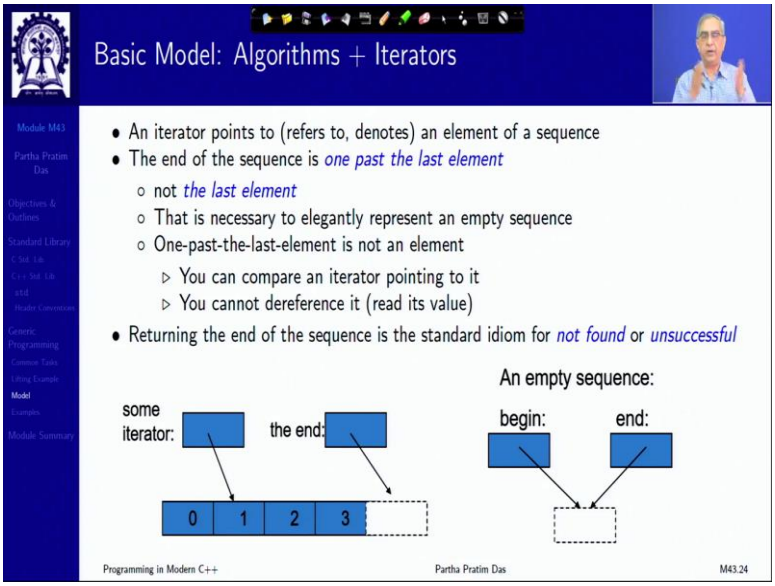

So, algorithms can now be written just thinking of the iterators. So, whatever you need to do, you just do not have to think whether you are going over an array or a list or a set or anything, you just think that the iterator, call the iterator operation, and that will give you the next element to work with. You can work simply with that.

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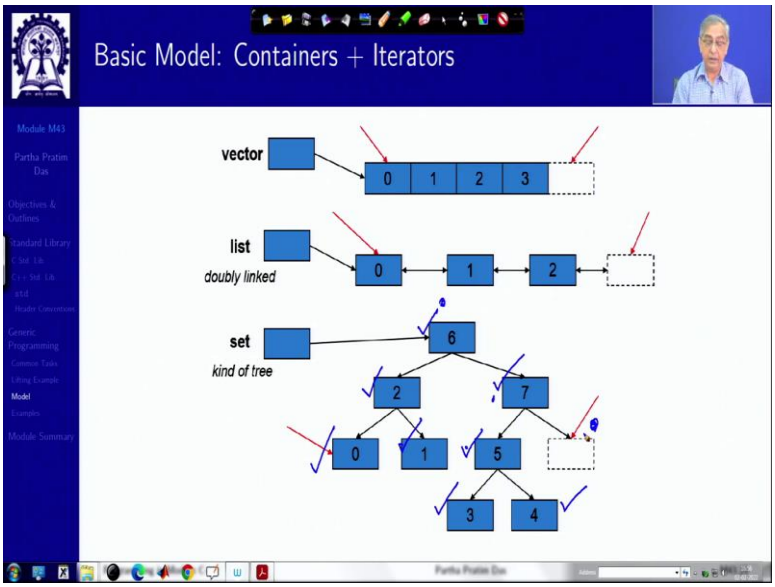

Similarly, containers do not need to think about the algorithms all that they need to support the iterator and here we show that the support can be provided not only for the sequence iterators sequence containers like vector, which is kind of an array or a list, which is linked

singly or doubly. But it can be provided for a nonlinear data structure like set. Set is a collection of unique elements. So, it is typically kept in the form of a binary search tree.

So, in that binary search tree, if we do a in order traversal, then naturally the nodes are traversed in a certain way left, then parent then right, if we do that. So, the traversal order here would be I will start from here, I will call left left left until I get to a lift node, this is the first iteration value this is the first element I will get, these are first of the iterator.

Then I will have this element on ++, this element on ++, next ++ is here, next ++ is this this this this call, because it keeps on going down, then it is this element then it is this element, then it is this element and then it does not have anything where it should. So, that is my end of the iteration. So, you can see that even when a data structure is nonlinear, it can be linearized through this process of iteration very simply.

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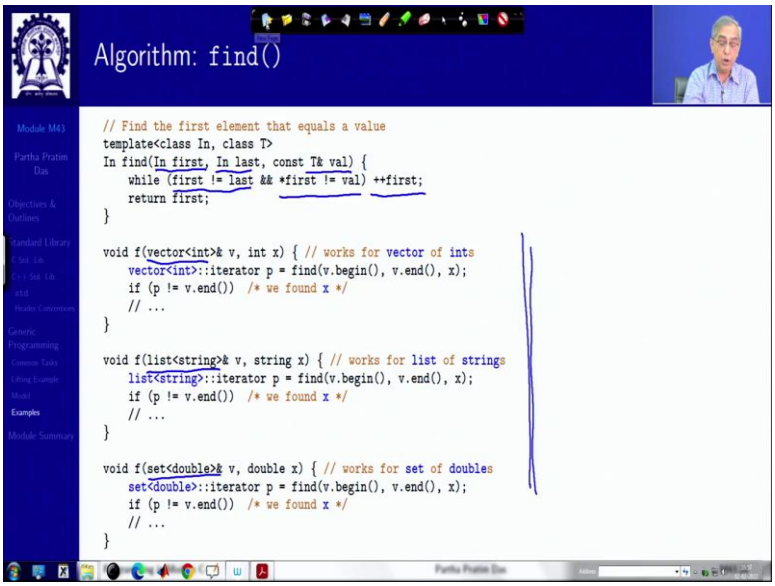

So, using that we can have very nice algorithms written for example, if you compare these codes to find it is one is for vector of int, one is for list of strings, and one is for set of doubles, you can see that the code is practically identical, because all that it needs to know is the first and last of the iterator and the type of the value it has to look for, which is all templatized and all that you are doing is you are checking that you are covering the entire data structure. You are checking if the current iteration value, which is start first equals the value given. If it does not, then you go to the next one. And you keep on doing that you can see that all this code are perfectly identical.

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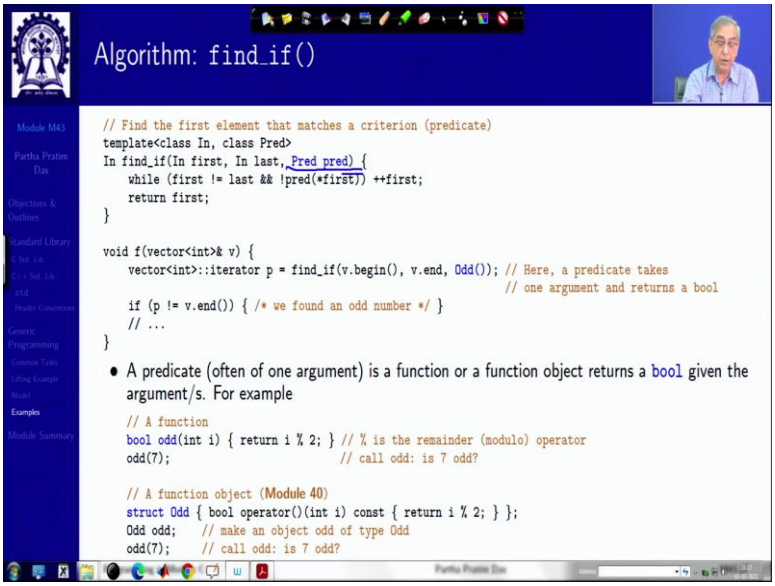

So, that is a big advantage that we get by doing this kind of generic programming this is another where if you are doing find and you can even generalize it further saying that find finds the element which is equal to the given element, but I can say that I do not just want to find "PPD", I want to find the person who is teaching programming in modern C++.

So, I can provide a condition statement predicate for that, which can be provided as a as a functor. As you can see here, the function object as you can see here, we will talk more about this as we go forward.

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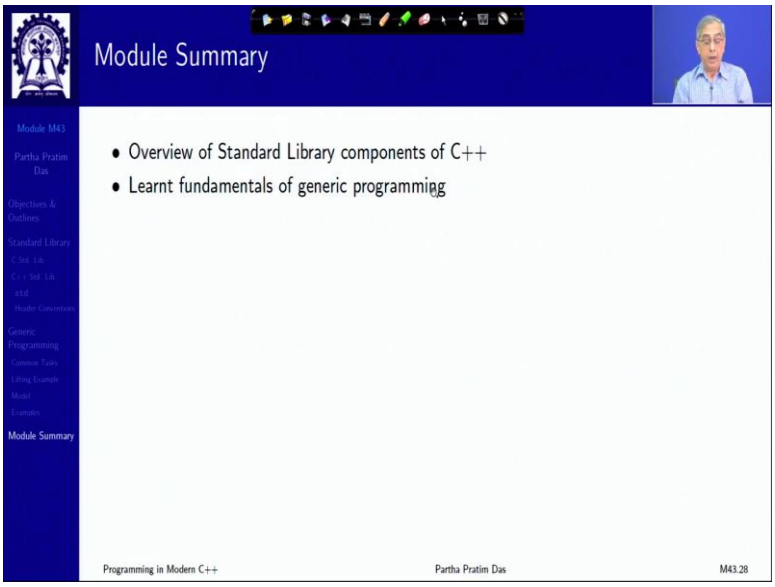

So, this was a basic introduction to standard library component, particularly the generic programming side of it. So, that we can subsequently discuss the actual STL which will be the topic for the next module. Thank you very much for your attention and see you in the next module.