Programming in Modern C++
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Lecture 48
C++ 11 and beyond: General Features: Part 3

Welcome to Programming in Modern C++. We are in week 10 and we are going to discuss module 48.

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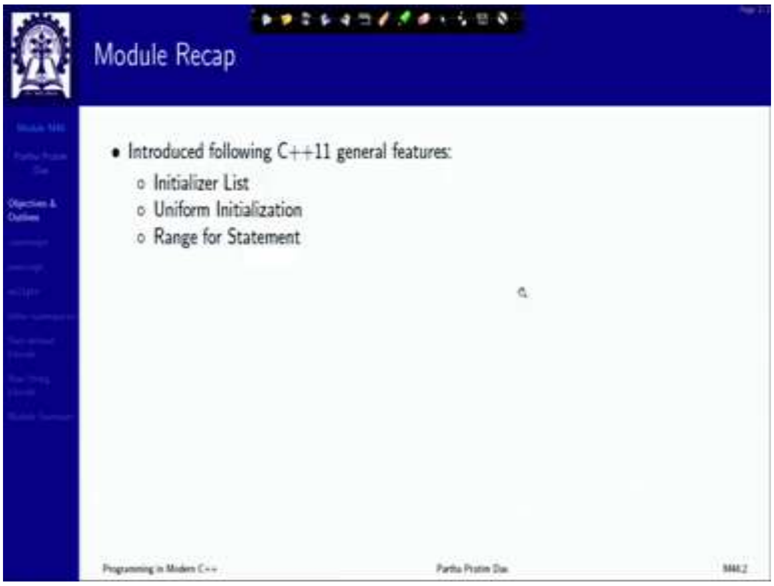

In the last module we have introduced, continued on introducing some general features of C++ 11. We have talked about initializer list, the braced initialization and its consequences and also the uniform initialization mechanism, which can be uniformly used everywhere in C++ 11. And we have also seen a convenience mechanism for iteration over an entire data structure by using the range for statement.

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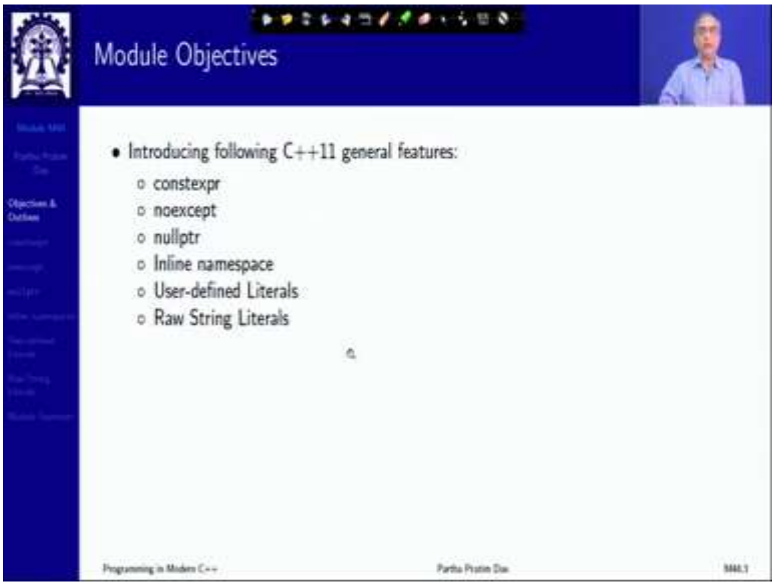

We will continue on these and introduce several of other general features of C++ 11, which are on one side for convenience, for safety, for efficiency and as well as will become important for the later important features. So, these are the six features that we are going to talk about in this module.

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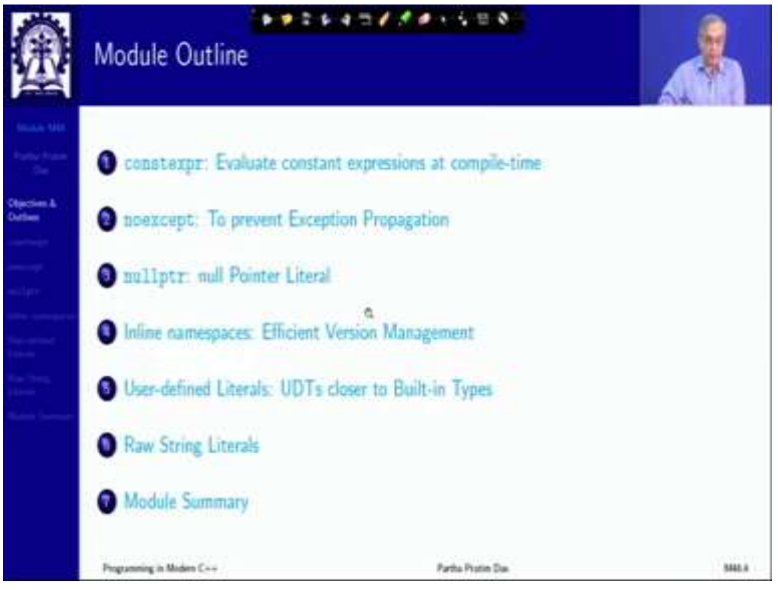

This will be our outline naturally which will be available on the left.

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So, let us start with const expression. Const expression is a feature to evaluate constant expressions at compile time.

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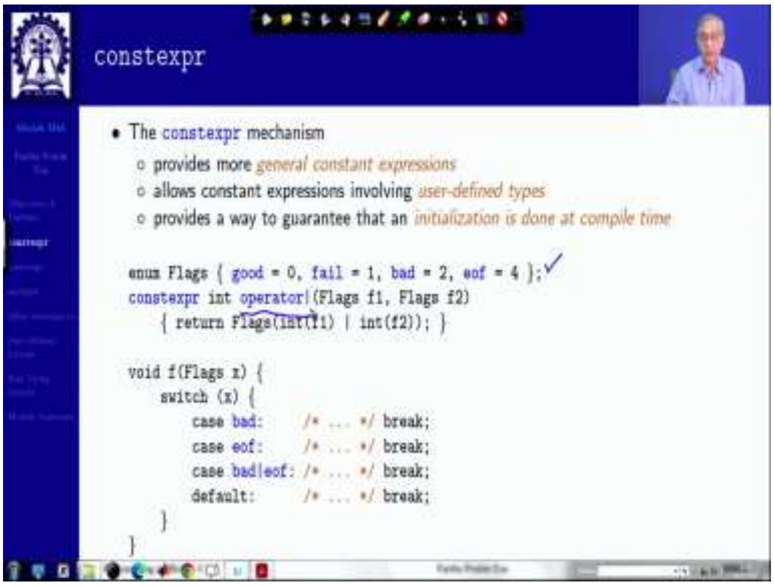
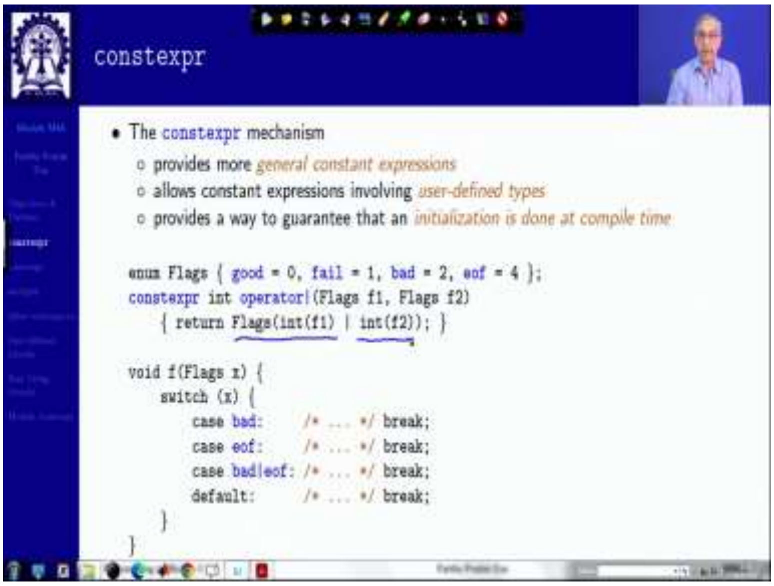
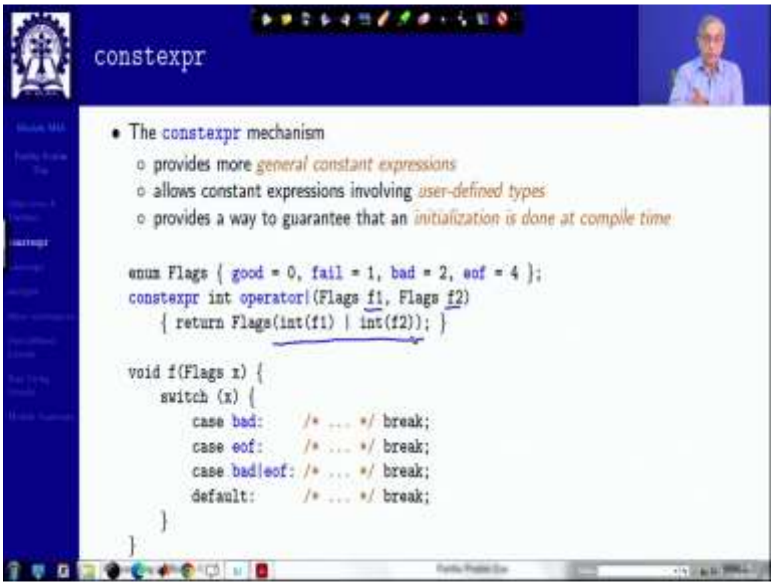



constexpr
• The constexpr mechanism
◦ provides more general constant expressions
◦ allows constant expressions involving user-defined types
◦ provides a way to guarantee that an initialization is done at compile time
enum Flags { good = 0, fail = 1, bad = 2, eof = 4 };
constexpr int operator|(Flags f1, Flags f2)
{ return Flags(int(f1) | int(f2)); }
void f(Flags x) {
switch (x) {
case bad: /* ... */ break;
case eof: /* ... */ break;
case bad|eof: /* ... */ break;
default: /* ... */ break;
}
}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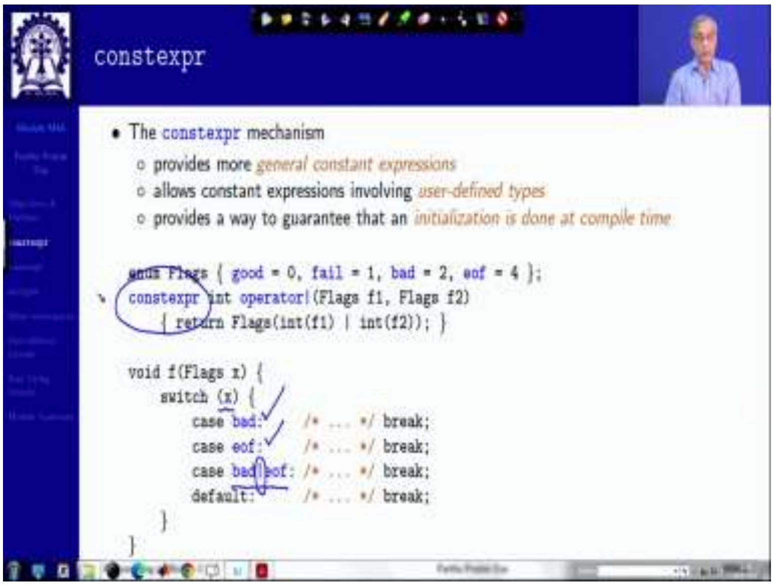
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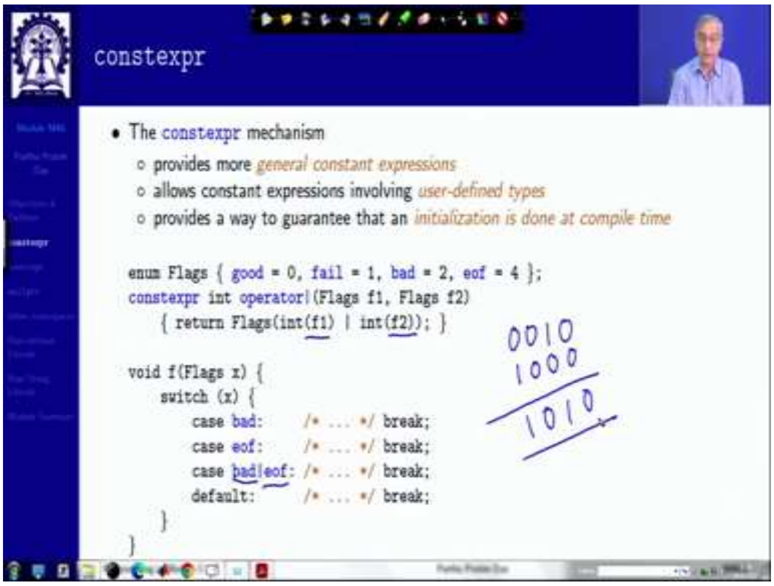

So, let us, see what it means is; const expression is in a way more, I mean. it gives us more than the general constant expressions. We have constant expression or const seen earlier, it will provide for somewhat more and with some differences. It allows constant expressions involving user defined types and provide a way to guarantee that an initialization is done at compile time for a const expression, given that you have the constants available at compile time.

So, here is a simple example of an enum of flags having four different possible innumerable values and we are defining an operator or for two flags, f1 and f2. Now, if you look at this then this is, it basically takes the flag f1 and the flag f2, converts each to int as you know normal enum can be converted to int, and then returns the value as an int value. So, that is what the flags are doing.

Now, what will you have? Since, if you know the values of the flags f1 and f2 at the time of compilation, naturally this entire expression can be evaluated at the compile time. So, as an illustration of that let us see we have a flag, we have a switch based on this flag type x. Now, as you know the cases of the switch need to be constants at the compile time, so it is quite obvious that I can have case bad which is basically case 2.

I can have case eof, which is ah case four, but I wanted to write case bad or eof. This is an operation which normally you will expect at the runtime, if you, but if that happens at the run time then this code cannot compile. This code will not compile because you will not know what is the value of bad or eof as a constant at the compile time and switch case will not allow that. So, without this const expression this code will not compile.

But what will happen with the const expression, with the const expression at the compile time f1 will be treated as bad, eof will be treated as f, I am sorry, f2 will be treated as eof and it will actually compute the o of these two and whatever is that odd value, so if I have 0 0 1 0 and eof is 4, so if I have or of that, so for this value this case will be applicable. So, this is possible because we can evaluate this expression at the constant, as a constant expression at the compiled time. So, this is the basic feature of the const expression as we have.

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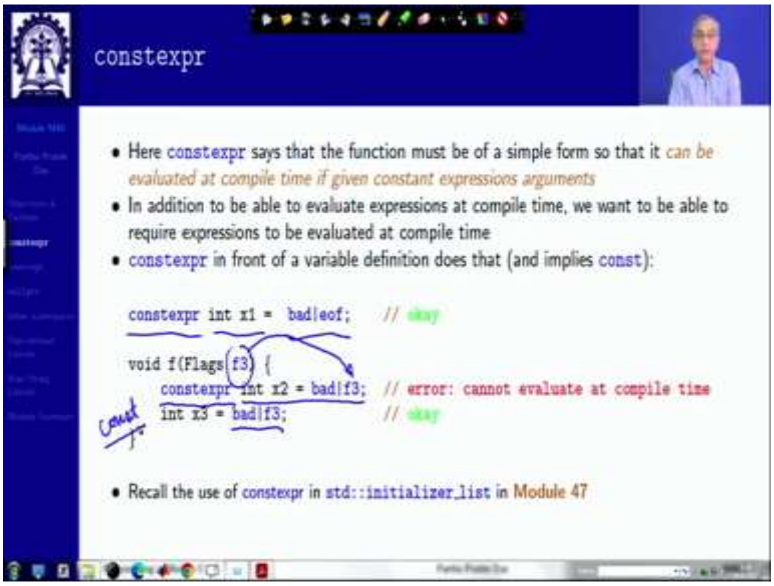

So, typically the cons expression is a function that must be of simple form that it can be evaluated at compile time given the constant expression and it is not only that it gives us an ability to evaluate expressions at compile time but we want to be able to require expressions to be evaluated at compile time, because that gives better efficiency and of the code that we have. So, const expression in the form, in front of a variable definition will does that, and will do that and will also mean what we traditionally mean by const.

So, this is a different context, so we have const expression before int x and this is an expression which can be evaluated at compile time, so it will evaluate, have a constant value and will treat this as a constant. Similarly, but if we try to do say in flags, in this function if we try to do this, see f3 is a parameter and I am using that, Now, this is, this function will get the value of f3 at the runtime and only then it will know what is bad or f3.

So, you cannot evaluate this as a const expression, but if you just do bad or f3 you will be able to do that, in fact, if you do const int x3, bad or f3 that will also be valid because const does not need the evaluation to happen at the compiled time. It only says that it has to be a constant expression. We have already seen the use of const expression in module 47 in the standard library initializer list.

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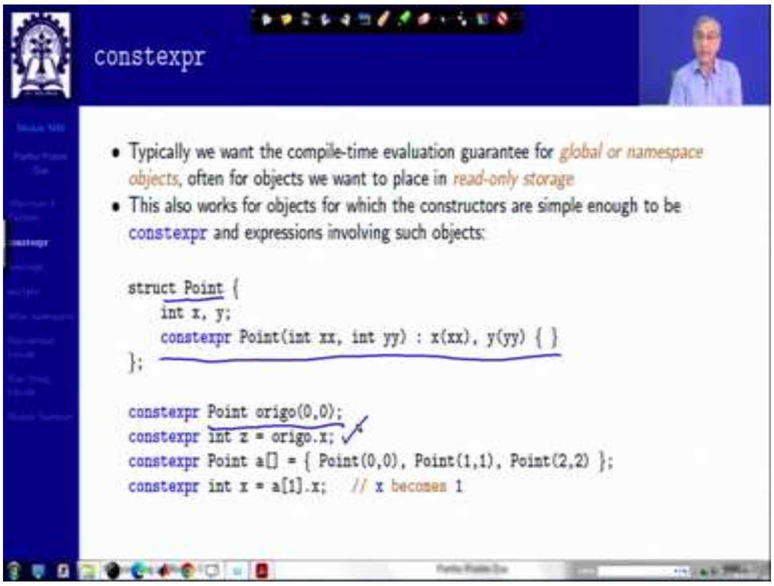

So, it can be used, const expression can be used with user defined types also. Here is an example, we have a struct point and I have specified the constructor to be const expression, so const expression point origo (0, 0) will actually at the compile time construct this object and will also set the values of x and y. Similarly, it can then set z as a const expression origo dot x which will actually get 0 and so on so forth, the arrays and so on. So, all of these different types of const expressions are possible.

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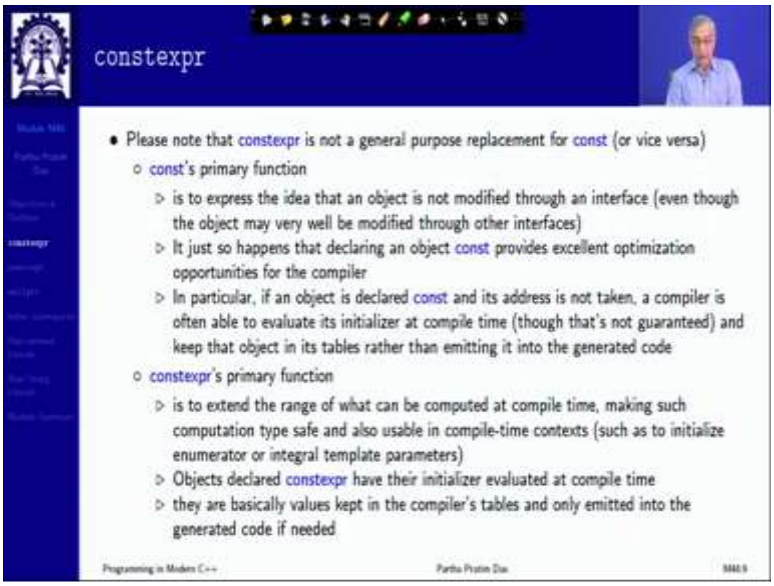

Note the difference between const and const expression. It is not in general, one is not a replacement of the other. Const's primary concern is to express the idea that the object is not modified through the const interface, though it may be modified through other means. So, it just so happens that telling that an object is const provides good opportunities for optimization for the compiler.

And for example, if an object is const and its address is not taken, then the compiler may not allocate any memory for that, it can just keep it in a read only table, whereas const expressions primary concern is to check what can be computed at compile time. So, making such computations, type safe and usable in any compile time context. For example, size of an array, initializing enumerators, passing as a int, template parameter and so on so forth. So, objects declare const expression have their initializer evaluated at the compiled time. So, that is the basic difference between these two.

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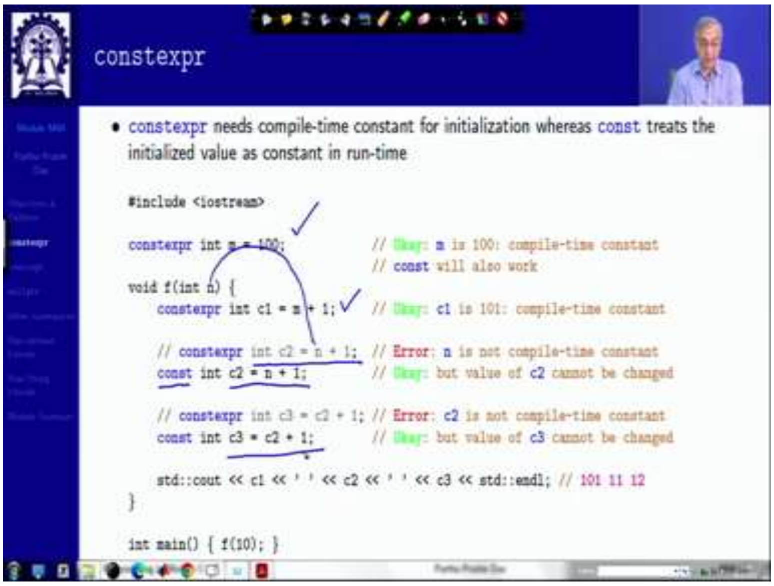

Here is another example to show the concept, so these are const expression for variable declaration m, so where const will also work actually. You can then define const expression c1 as m + 1 which will be fine because m will be const, compile time 100, so this is 101. But if you try to do say const expression int c2 of n + 1 where n is a parameter, this will not compile, because it is not known to be a constant at the compiled time.

Whereas you can do const on this, because all that it says if you say const is, it says that when this gets executed at the runtime, it is not required at the compile time, but the runtime when it gets executed whatever is the value of n + 1, will be the value with which you initialize c2 and that cannot be changed through this interface at least. So, similar thing is for c3 being defined as c2 + 1 and so on. So, that is the difference between these two const expression is a very powerful mechanism to optimize at the compile time.

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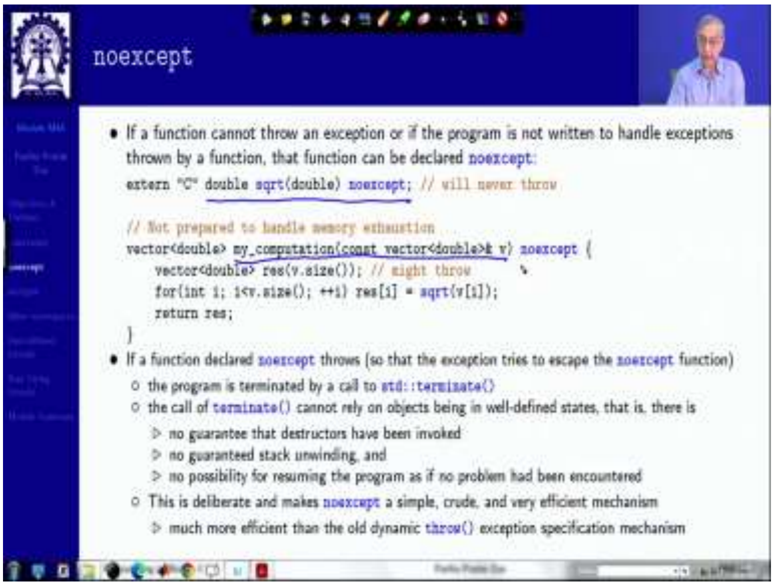
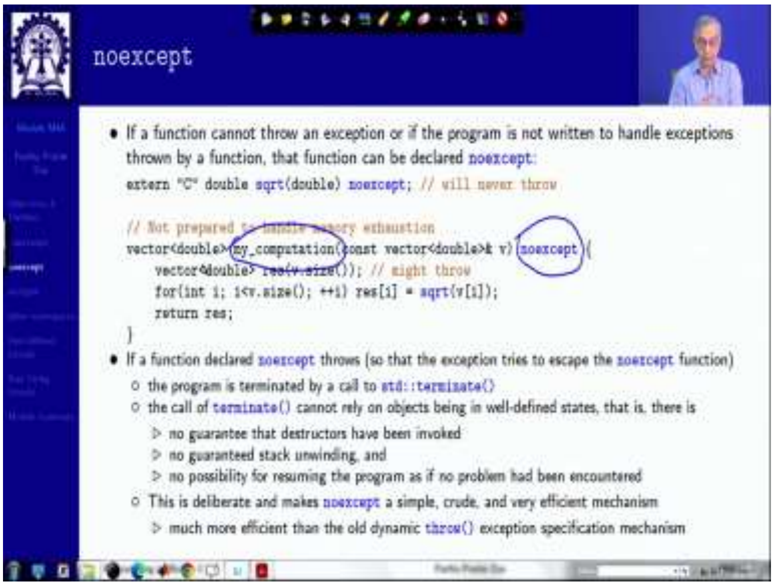
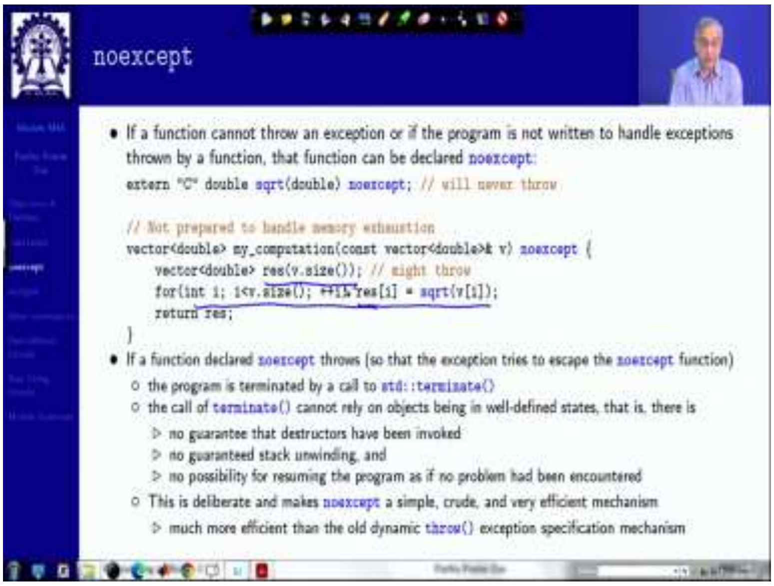



noexcept
If a function cannot throw an exception or if the program is not written to handle exceptions thrown by a function, that function can be declared noexcept:
extern "C" double sqrt(double) noexcept; // will never throw
// Not prepared to handle memory exhaustion
vector<double> my_computation(const vector<double>& v) noexcept {
vector<double> res(v.size()); // might throw
for(int i; i<v.size(); ++i) res[i] = sqrt(v[i]);
return res;
}
If a function declared noexcept throws (so that the exception tries to escape the noexcept function)
the program is terminated by a call to std::terminate()
the call of terminate() cannot rely on objects being in well-defined states, that is, there is
no guarantee that destructors have been invoked
no guaranteed stack unwinding, and
no possibility for resuming the program as if no problem had been encountered
This is deliberate and makes noexcept a simple, crude, and very efficient mechanism
much more efficient than the old dynamic throw() exception specification mechanism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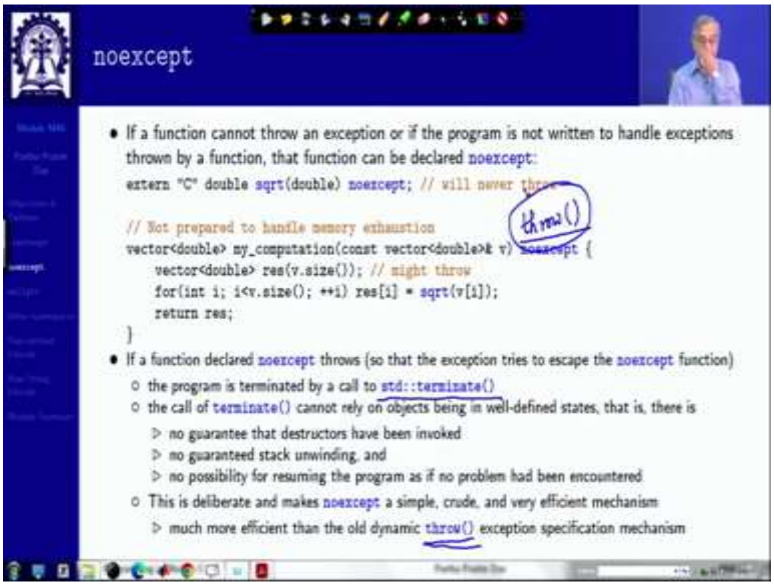
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throw()
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The second feature that we, this features are all kind of diverse because there are features on different aspects that are being talked off, so there is a feature called noexcept to declare that a function will not throw an exception or it cannot handle, it has not been written to handle exceptions thrown by functions within it. So, we are saying that let us say extern C, a C function from the standard math library, we say that sqrt function is noexcept.

Which means that the sqrt function will never throw if I call it. It will execute and give me a proper value. So, using that I am defining some function for a, my computation function for a vector, which I want to declare as noexcept. So, what it says? This noexcept says that this function my computation, either will not throw or it is not written to handle exceptions to be thrown. For example, it is using sqrt, so this will not throw.

But it is also using say v.size here, which might throw, but even if this throws, this function is not written, equipped to handle that exception. So, that is the basic idea of noexcept. So, naturally that opens the question as to what happens if a function specified to be noexept if it throws. If it throws then naturally you are violating the basic guarantee given by the code.

So, this will in turn call a function in the standard library called std::terminate, which will terminate the function, it is like, I mean close to what a bot does, you can also register your own function for terminate. Now, this function terminate does not do the typical tasks of exception handling. For example, it does not guarantee that the destructors of the objects that are getting out of context will be called.

It does not guarantee that the stack will be properly unwinded or it does not keep the provision of resuming the computation if the program has been found to have no further problem. So, you will recall that in exception also, mechanism also, we had a way to say no throw, no throw in this way, that is it specifies what does a function throws and giving an empty parameter says that it does not throw of any kind. So, which is semantically similar to noexcept, but the fact is through this throws mechanism is actually run time, so it is far less efficient in terms of the exception specification in contrast to what noexcept can do which is a compile time feature being provided.

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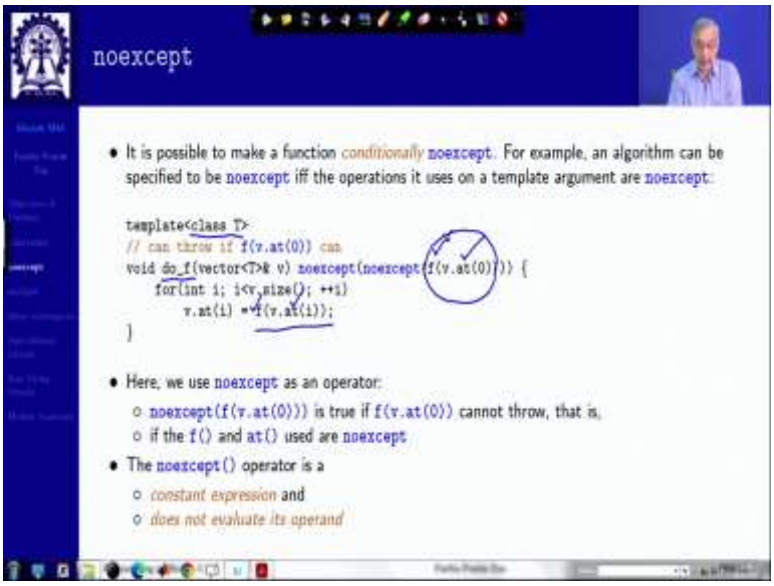

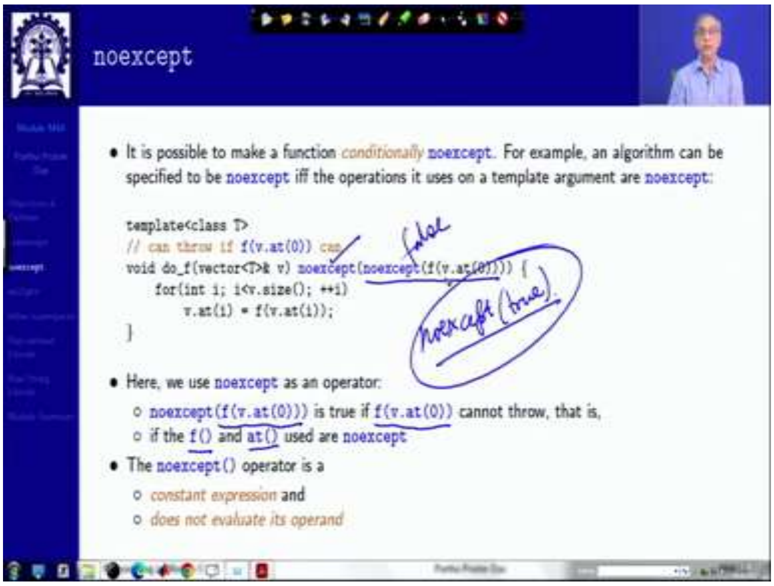

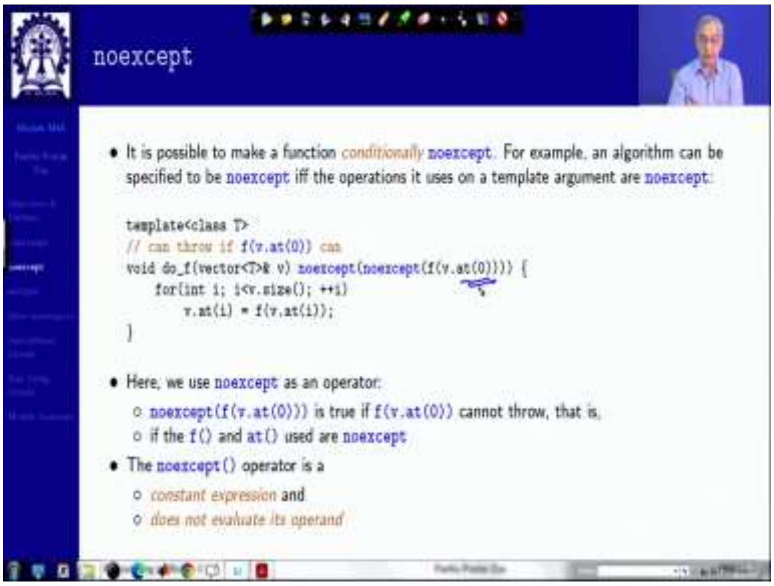

Now, the interesting fact is many a times the noexcept can be used as a conditionally and that becomes particularly useful for templates. So, what we want to say is suppose I have a function do_f templatized by the type t and that type could be kind of anything. So, what I want to say is this needs to use f(v.at(i)). At i is basically accessing a vector location and so it is accessing the ith location of the vector and then using f.

So, there are two function calls involved here, so the guarantee that we want to say, we cannot say it is noexcept, if we give noexcept then you are saying that it cannot handle anything. But what we want to say is this will be noexcept provided this expression that is the call to at and call to f, they do not throw, if they are noexcept.

So, it is kind of a conditional specification where as you can see easily that noexcept instead of just being used as a qualifying keyword it is being used kind of as a compile time operator. So, what does this operator do? It says that this will be true if f(v.at(0)) cannot throw, that is if f as well as at are used as noexcept.

So, it will check that because do not know for what f is, I do not know for that vector type what at, oe might have been. So, this will give me a conditional, so provided if this is noexcept, if this is true, then this is, then this becomes noexcept(true), that means this function is noexcept. But if this is false, then then this does not hold any good.

So, the interesting factor about noexcept is it is a constant expression, that it is evaluated at the compiled time, that is the reason I need at 0 and it does not evaluate its operand, it does not evaluate that, but it just checks the behavior, checks the specification of the corresponding functions and they are noexcept status.

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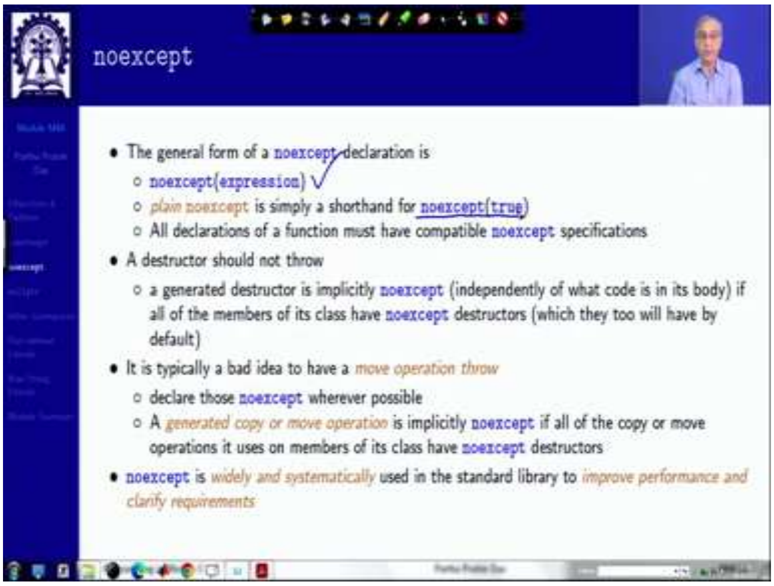

So, noexcept declaration would typically be in the form of noexcept followed by an expression and this will be true or false and the plane noexcept is just a short form of noexcept true. Now, normally destructors should not throw, because then the cleanup becomes a mess, so any destructor that is, that you write, you should write it as noexcept.

If the compiler provides the destructor, then it will be implicitly noexcept provided all objects being destroyed in that destructor, the member variables are also have destructors which are noexcept. Similarly, the move operations must not throw, they should typically be noexcept, we will talk about the move expression very soon, but not in this module. So, noexcept is widely and systematically used in the standard library to improve performance and to clarify the requirements of where do you really need to do checks for the exception handling and where you can skip those.

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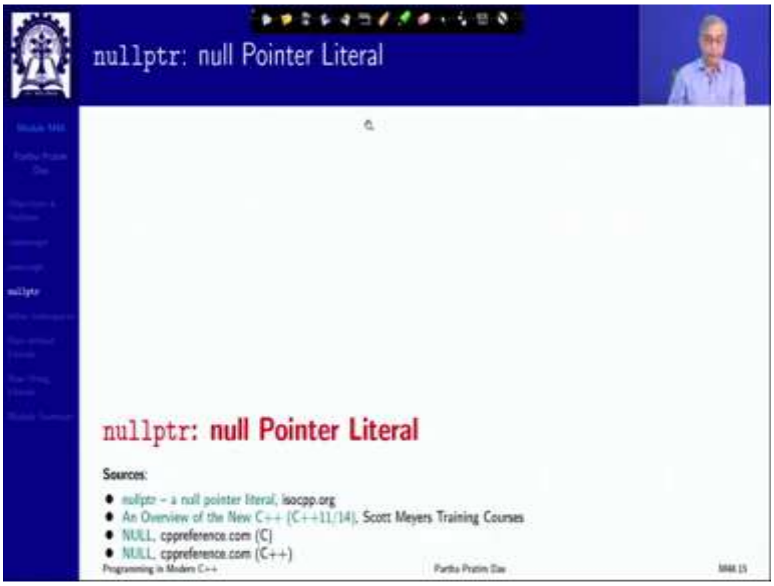

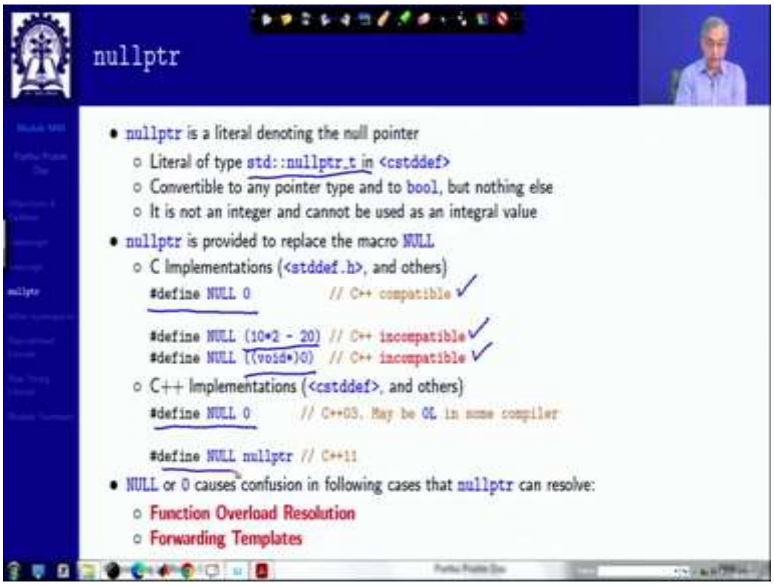

The next feature is a null pointer. You will wonder as to why do we need null pointer, we already had null pointer. So, this is a new keyword and a literal. nullptr is a new keyword and a literal of a new type called new ptr_t, and this type is defined in stddef in C standard library so cstddef is where you will get it. So, this is a literal which is convertible to any pointer type and to bool but nothing else.

Now, if you look at the typical use of capital NULL as a null pointer, you will typically have a macro somewhere in stddef.h or cstddef, which is defined as a 0. So, that basically tells you that it is an integer 0, which is defined as a null. Now, some C, so this is what how C implements it, so which is compatible to C++.

Some C plus, C compilers do some, try to do something more intelligent like specifying this as an integer expression, making sure that you get the proper integer type. Some write it as a void* null pointer and so on, note that these are not compatible to C++. C++ typically will implement this as NULL 0 or in C++ 11 NULL will be defined as nullptr. So, what is the advantage of having this nullptr? It solves basically two problems, one is a function overload resolution and one is of forwarding templates.

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So, let us look at these with through some examples. So, first let us have some examples of the nullptr. So, I have a integer pointer q initialized to nullptr. The character pointed p initialized to nullptr initialize to 0, initialize to null, p, p1, p2 all of these we will work. Now, if I check p it will compile but obviously it will fail because p is a nullptr. So, you can see that nullptr, though is of nullptr_t type it will get converted to bool for this if check.

I can compare it with another pointer, p can be equated to with p1, where p is initialized with nullptr and p one is initialized with 0, so this will compile and fail, this will compile as well as succeed because both of them are actually null. But if I try to do compare q with p2, q is int*, p2 is char*, both are null but their types are different, so that conversion will not be allowed, conversion between distinct pointer types are not allowed so therefore it will fail.

Similarly, if we have a function g which takes a parameter of type int and you try to call it with nullptr you will get an error because as we said nullptr cannot be converted to int. If you try to initialize an int value with nullptr you will also get an error, with capital NULL, both of these will actually work. Now, let us come to the function overload resolution. What is the problem? Suppose, I have a function f with two overloads, one is int, another is int*.

Now, often it becomes difficult to resolve a call to, for these overloads of the function. For example, if I write it say f(0) in C++ 11 it will call the int version, if I write it as nullptr it will write, it will get me the int* version, because 0 is a literal of int type, so f(0) is called to f(int), nullptr is of type nullptr_t, so f(nullptr) is a pointer type so it will be, give me f(int*).

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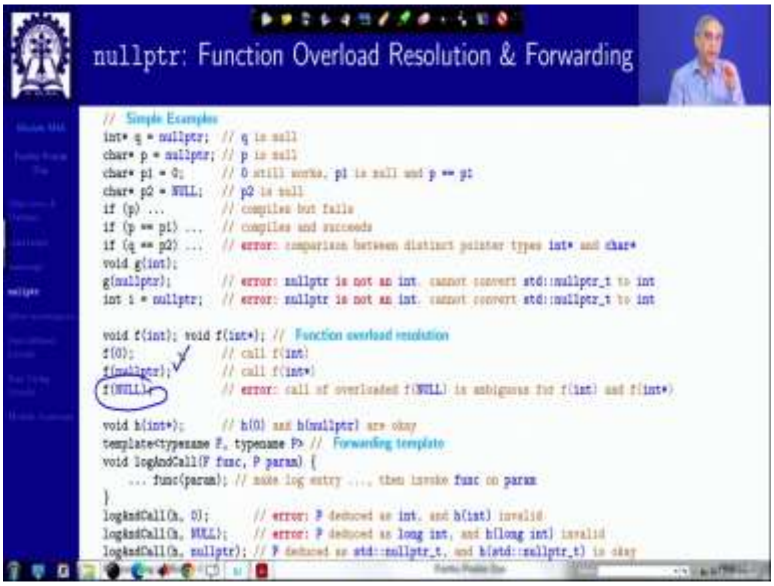
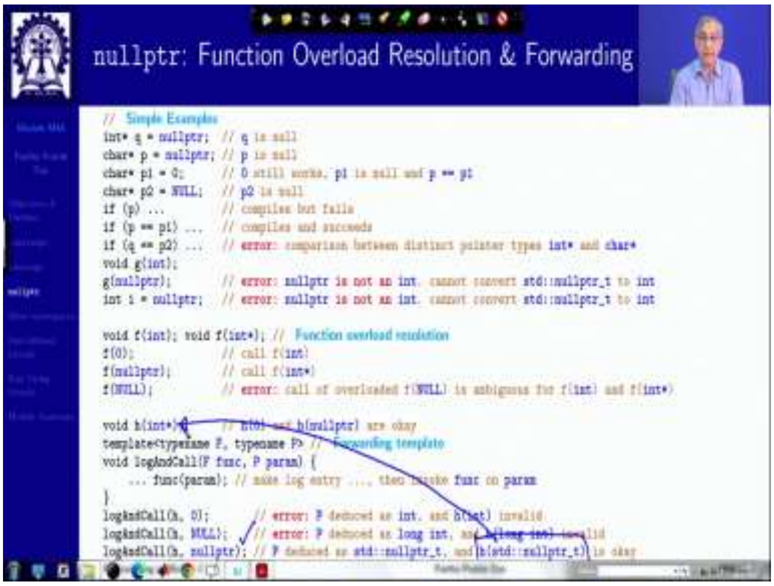



nullptr: Function Overload Resolution & Forwarding
// Simple Examples
int* q = nullptr; // q is null
char* p = nullptr; // p is null
char* p1 = 0; // 0 still works, p1 is null and p == p1
char* p2 = NULL; // p2 is null
if (p) ... // compiles but fails
if (p == p1) ... // compiles and succeeds
if (q == p2) ... // error: comparison between distinct pointer types int* and char*
void g(int);
g(nullptr); // error: nullptr is not an int, cannot convert std::nullptr_t to int
int i = nullptr; // error: nullptr is not an int, cannot convert std::nullptr_t to int
void f(int); void f(int*); // Function overload resolution
f(0); // call f(int)
f(nullptr); // call f(int*)
f(NULL); // error: call of overloaded f(NULL) is ambiguous for f(int) and f(int*)
void h(int*); // h(0) and h(nullptr) are okay
template<typename F, typename P> // Forwarding template
void logAndCall(F func, P param) {
... func(param); // make log entry .... then invoke func on param
}
logAndCall(h, 0); // error: P deduced as int, and h(int) invalid
logAndCall(h, NULL); // error: P deduced as long int, and h(long int) invalid
logAndCall(h, nullptr); // P deduced as std::nullptr_t, and h(std::nullptr_t) is okay


nullptr: Function Overload Resolution & Forwarding
// Simple Examples
int* q = nullptr; // q is null
char* p = nullptr; // p is null
char* p1 = 0; // 0 still works, p1 is null and p == p1
char* p2 = NULL; // p2 is null
if (p) ... // compiles but fails
if (p == p1) ... // compiles and succeeds
if (q == p2) ... // error: comparison between distinct pointer types int* and char*
void g(int);
g(nullptr); // error: nullptr is not an int, cannot convert std::nullptr_t to int
int i = nullptr; // error: nullptr is not an int, cannot convert std::nullptr_t to int
void f(int); void f(int*); // Function overload resolution
f(0); // call f(int)
f(nullptr); // call f(int*)
f(NULL); // error: call of overloaded f(NULL) is ambiguous for f(int) and f(int*)
void h(int*); // h(0) and h(nullptr) are okay
template<typename F, typename P> // Forwarding template
void logAndCall(F func, P param) {
... func(param); // make log entry .... then invoke func on param
}
logAndCall(h, 0); // error: P deduced as int, and h(int) invalid
logAndCall(h, NULL); // error: P deduced as long int, and h(long int) invalid
logAndCall(h, nullptr); // P deduced as std::nullptr_t, and h(std::nullptr_t) is okay


nullptr: Function Overload Resolution & Forwarding
// Simple Examples
int* q = nullptr; // q is null
char* p = nullptr; // p is null
char* p1 = 0; // 0 still works, p1 is null and p == p1
char* p2 = NULL; // p2 is null
if (p) ... // compiles but fails
if (p == p1) ... // compiles and succeeds
if (q == p2) ... // error: comparison between distinct pointer types int* and char*
void g(int);
g(nullptr); // error: nullptr is not an int, cannot convert std::nullptr_t to int
int i = nullptr; // error: nullptr is not an int, cannot convert std::nullptr_t to int
void f(int); void f(int*); // Function overload resolution
f(0); // call f(int)
f(nullptr); // call f(int*)
f(NULL); // error: call of overloaded f(NULL) is ambiguous for f(int) and f(int*)
void h(int*); // h(0) and h(nullptr) are okay
template<typename F, typename P> // Forwarding template
void logAndCall(F func, P param) {
... func(param); // make log entry .... then invoke func on param
}
logAndCall(h, 0); // error: P deduced as int, and h(int) invalid
logAndCall(h, NULL); // error: P deduced as long int, and h(long int) invalid
logAndCall(h, nullptr); // P deduced as std::nullptr_t, and h(std::nullptr_t) is okay

Now, if I had done f(null) then which function would get called? The problem is that the compiler will say I am confused, because null is actually a value 0. So, considering null to be a value 0, this function should get called, but a value 0 can also be interpreted as a null void pointer. So, this value should get called. This function should get called, so both of these overloads have equal weightage and therefore, it cannot be resolved, so using null this kind of a function overload resolution was not possible.

But with null pointer this will now be possible because you are specifically saying that I want the pointer version, when you use 0 you specifically say that I want the integer version. This gets more involved in a forwarding template. So, let us consider what it talks about. We need a function h, which takes an integer pointer. So, you can, as you can easily understand h(0) and h(null pointer) both are okay.

Now, I have a template of 2 type parameters f and p, and with that I templatize a function log and call, where f is actually a function parameter and p is the parameter to that function. So, it is kind of an application function, which takes a function pointer, it takes a parameter and applies that function on the function parameter. So, it tries to make this call. So, it is probably is doing some log entries and then it invokes this func on the parameter.

Now, what will happen if you call this with h(0)? Now, with h(0) the h is the func and the parameter is passed as 0, so you want a template deduction to happen. By template deduction this is int, 0 is int, so it will be deduced as int and you are expecting a call to h int which does not exist, h is int*, so this fails. The same thing happens with null.

If you pass it as null, then whatever is the type of #define null 0, maybe it is int, maybe it is defined as 0 l, in which case it is long end, so the compiler that I was using, the g's online gcc as I talked of, it takes it as long int the null, so p is deduced as long int and h long int is searched, it does not exist and therefore, it fails.

But if I call this with null pointer, nullptr, then it correctly succeeds because then param is deduced as nullptr_t type and therefore, h is of this std::nullptr_t type that you are trying to call and you have int* which said can automatically convert, so this function matches and the template will get forwarded easily. So, these are the two problems that nullptr, introduction of nullptr solves in terms of function overload resolution and in terms of forwarding template.

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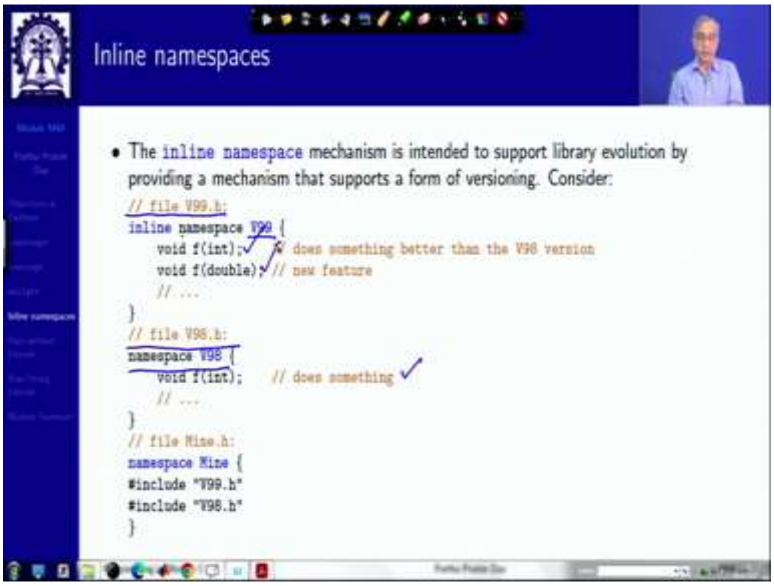

The next that we talk of is inline namespaces which is primarily for version management. Think about this, this is very simple. You have seen namespaces, so the use cases, a company is regularly releasing libraries of different versions. So, it had a version 98, say V98.h and in that it defined a name space v 98 where the function is there.

Now, what it has done? It is releasing the next version V99.h and it has defined a namespace V99 where the function f(int) has been improved possibly and another functionality f(double) has been introduced and so on. The question is in the application code how do you manage this? So, you have both of these. Now, what the company wants is, company wants you to move to V99 by default. But it, company also wants to give you the ability that if you want to stay with the older version you should be able to make small changes in your code and be with that. So, how do you take care of that?

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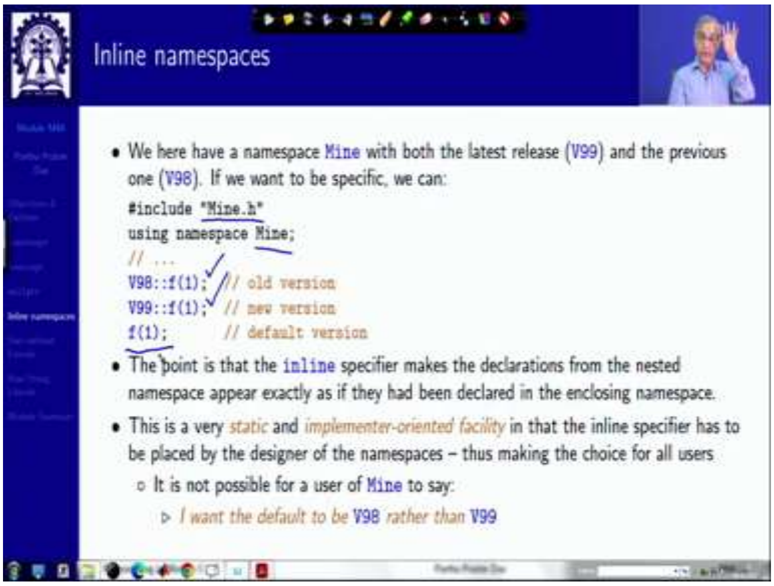

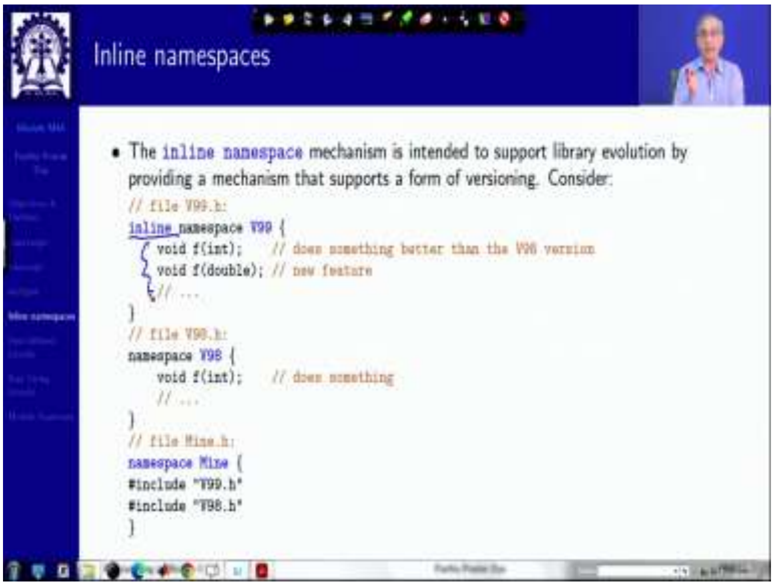

That is very simply in Mine.h, where you have included both these headers, you say you are using this Mine namespace and you say that if you want the old version you say V98::f1, if you say the new version, then you say V99::f1, no surprise till, but if you just say f1, that is if you do not make any changes, then it defaults to V99. Why? Why does it default to V99? Because V99 is inline.

So, that means that anything that is inline is available in the enclosing namespace, enclosing namespace is global, so these are available in the enclosing namespace, unless you specifically use some other namespace. So, this default behavior is what is critical of the inline namespace feature. So, the company not only can provide the versions but also can, is enforcing that if you are not consciously using the older version, then you will get automatically defaulted to the newer version.

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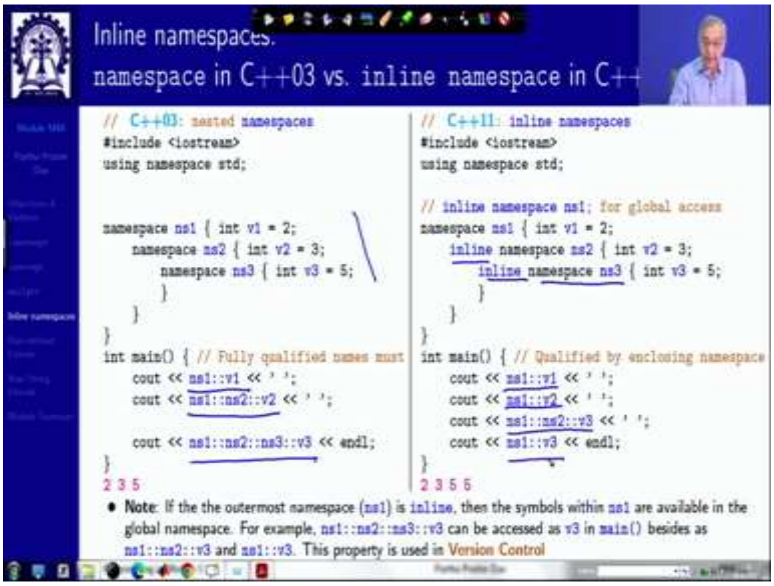

You can see the comparison of the inline namespace between C++ 03 and C++ 11. I have three namespaces with three variables and I have to give complete qualification of these variables to be accessed properly. Whereas if I inline the inner two namespaces, if I inline name space ns3, then every symbol in ns3 is automatically available in the enclosing name space ns2. If we inline ns2, all are available in ns1.

So, actually using ns1 I can use, refer any of these variables implicitly. In addition, if I had done an inline of the outermost namespace, then the symbols would be available globally also the feature that we are using in version control. The question would be could we not have done this in C++ 03 we have using.

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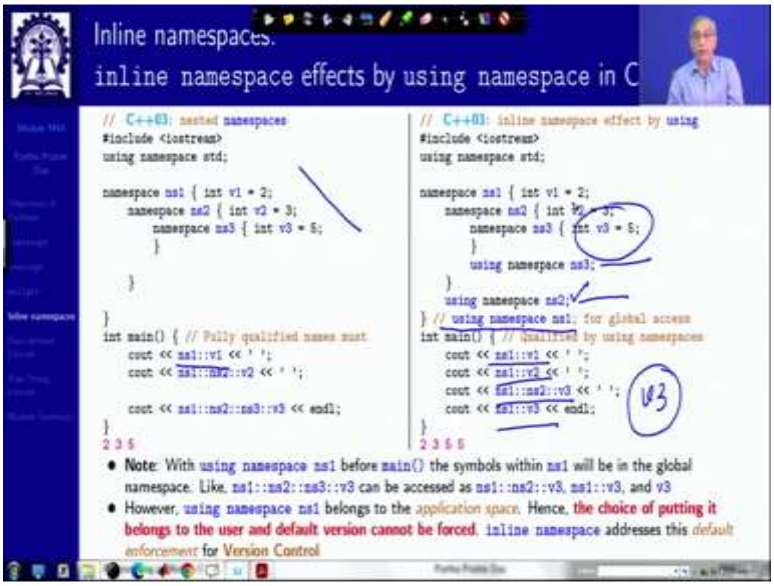

So, here is a comparison of the C++ 03 namespaces the same code as before on the left-hand side and here I have introduced two using, which gives you the same effect. You can use, like you can use everything from ns1 because using namespace ns3 as a part of ns2 says that anything in ns3 is available in ns2, and so similarly for here goes to ns1. Well, if I do that then till up to this point things are comparable.

Now, how do I make this available in global by default? What I will need to do is to put using name space ns1. If I put using name space ns1, then even simply writing v3 will mean this variable, because using, using, using everything is globally available. But that does not address the basic question, because this using namespace ns1 is in the code of the application, so it is up to the choice of the user to put it or not put it. Whereas when you do inline namespace, it is in the space of the library, so it is the choice of the library designer. That is the subtle difference for which the inline namespace feature is very important for proper version control.

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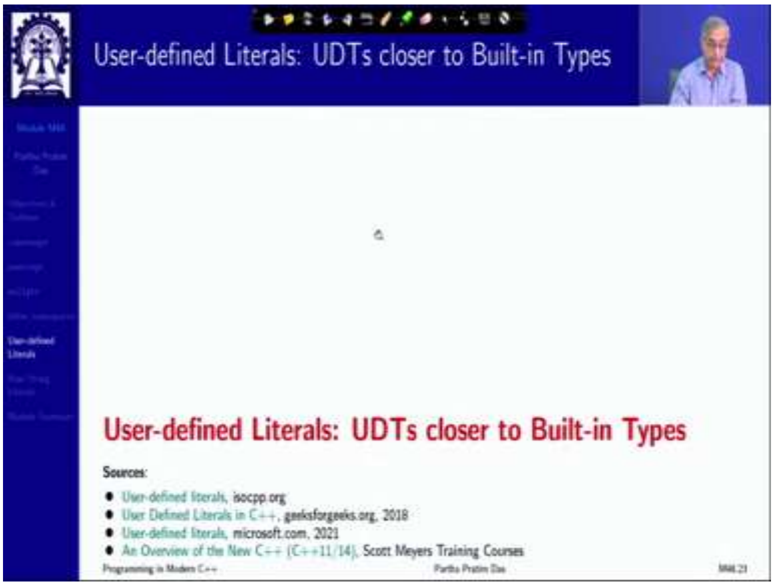

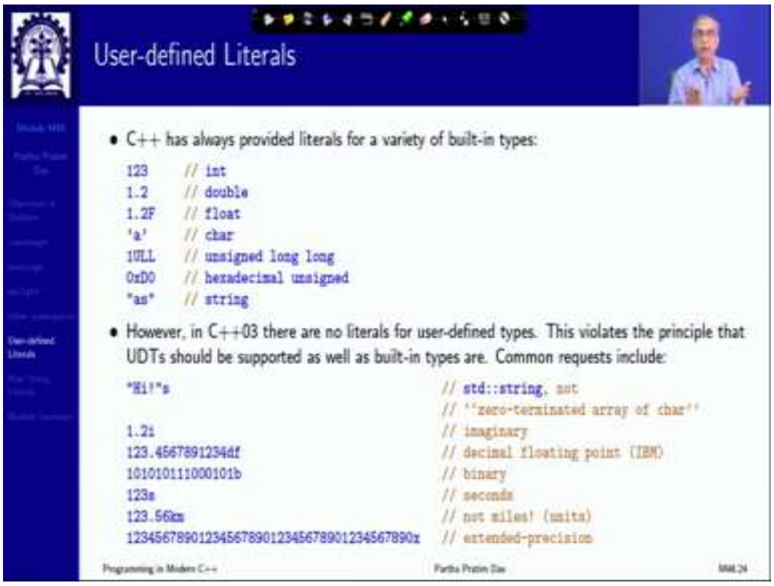

The next feature is user defined literals where the concern is very simple that we say that user defined types, I mean, in C++ we are building user defined types, but we cannot have literals of the types that we build. We can have only the literals of types that are already given, some examples are given here. Even if I want to have, take certain values and want to give them a specific meaning, say 123s, I want to mean that 123s is 123 seconds, I cannot do that.

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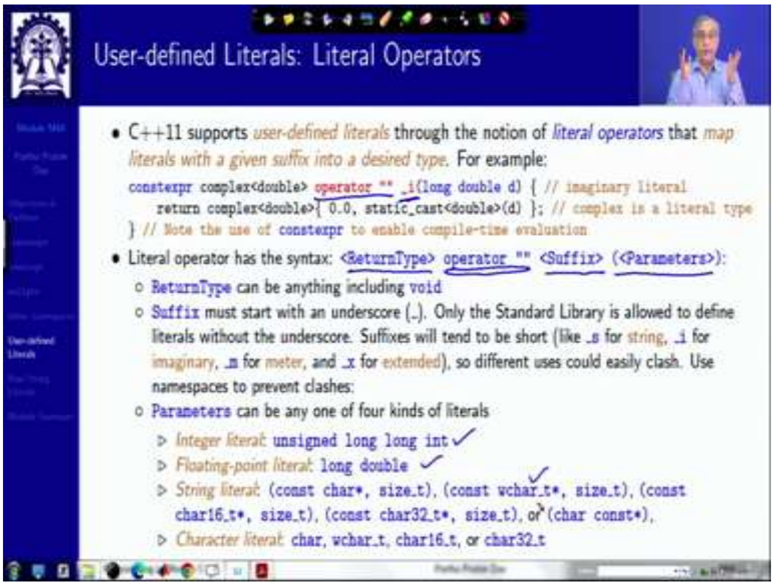

So, user defined literal does that by introducing a new literal operator, which is written in this form, that is operator keyword followed by a pair of double quotes. And then a suffix to be used with the literal conversion. So, in general this operator, so this is a computation, so this operator will have this, then a suffix to actually, which is the name of the user defined literal operator, then it will have parameters of what you are converting from and the return type.

The restrictions are that the suffix has to start with an underscore otherwise non-underscore names are reserved for the standard library and parameters can be of certain types only, either an a integer literal or a floating-point literal or a string literal or a character literal, but the return type could be anything you can take any of these and convert to a return type literal of your choice. So, let us see what it does.

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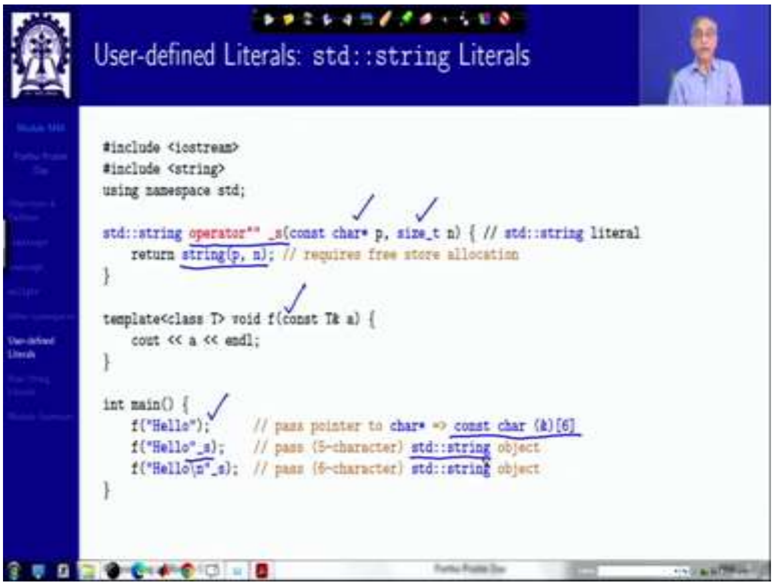

Say, I define a string, operator literal for the string, so _s, all that I do is I just construct a string and pass on. I have a pointer to the character array. I need to pass the size because otherwise I will not be able to do the conversion. So, if I do that and call this templatize function f with just the double quote, it is a pointer to character. It is an array of character, so it takes as const char reference size 6, 5, characters for hello and the terminator, but if I write it as _s, then it takes as a std::string object, it constructs an std::string object by calling this literal operator function.

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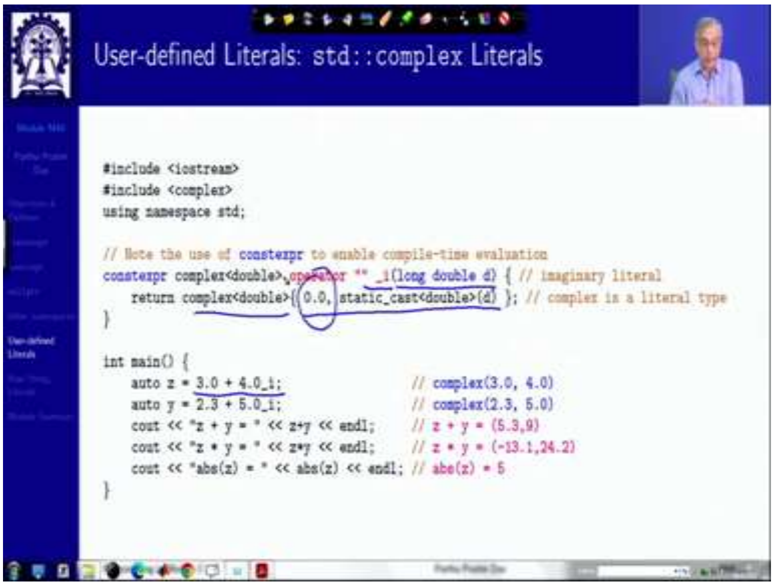

Similar thing can be done for say a complex, so I am using an _i, the value is taken as long double and I construct a complex object of the standard library, so and then I use it like this. So, I am assuming that the real part is 0 and the imaginary part is provided by this literal conversion, so this literal conversion 3 + 4.0 i gives me a complex number, 3.0 plus, 3.0, 4.0 because 4.0 _i literal gives me 0, 4.0, then that is added to 3.00, and I get that.

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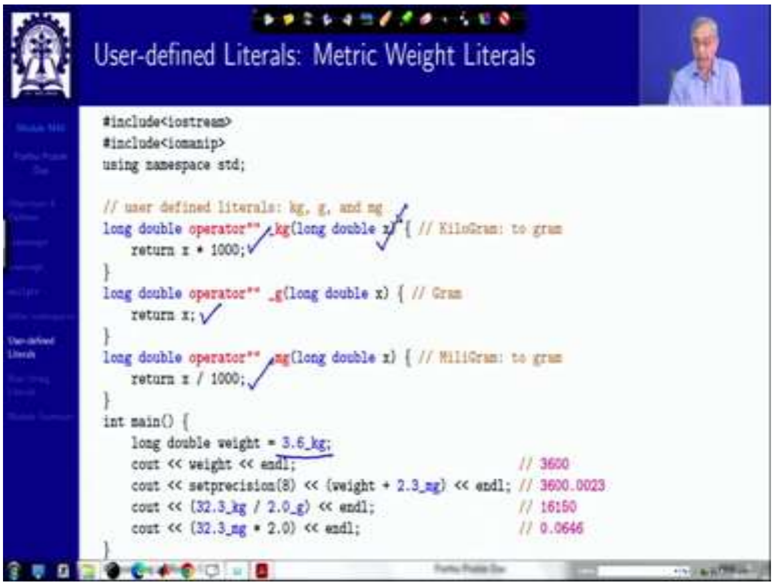

Conversions can be done with meaningful extension symbols like kg, I say okay. I have to deal with the kilogram, gram, milligram, so I have literals of every kind and I will put a value and put the literal operator. So, the basic representation is in gram. For kilogram we multiply that value by thousand, for milligram I divide it by 1000. So, I say 3.6 underscore kg is my literal, so that means 3600, because it will call this literal operator and convert into grams which is 3600 grams and similar for milligrams and all those, so this makes the code naturally lot more readable and understandable.

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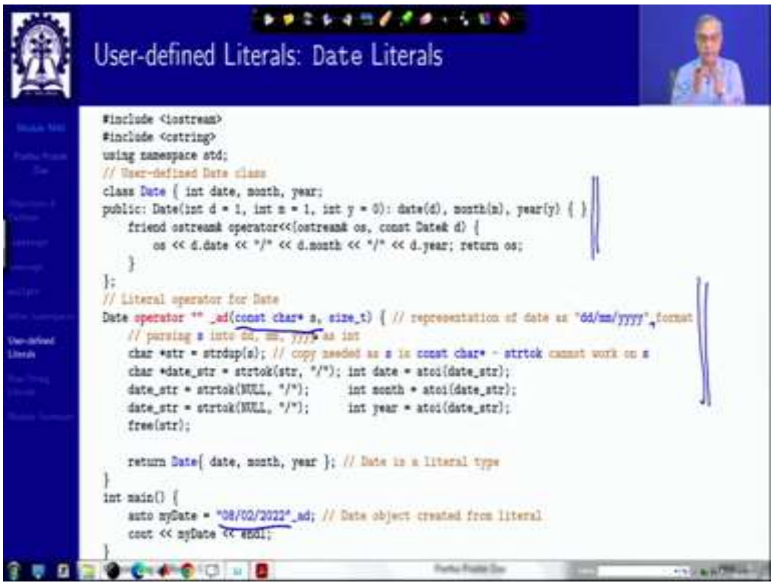

And you can actually use this to convert to user defined types like here run this example and check for yourself, I have defined a Date type, date, month, year and I want that this kind of a date literal I would have dd slash yy slash mm slash yyyy and convert it directly to date object. This conversion function, the operator literal conversion function allows me to do that. Just go through this carefully it has a lot of parsing from the string, it takes it as a string, does a parsing, take out different parts, convert them into integer and finally, it constructs the date object as a literal.

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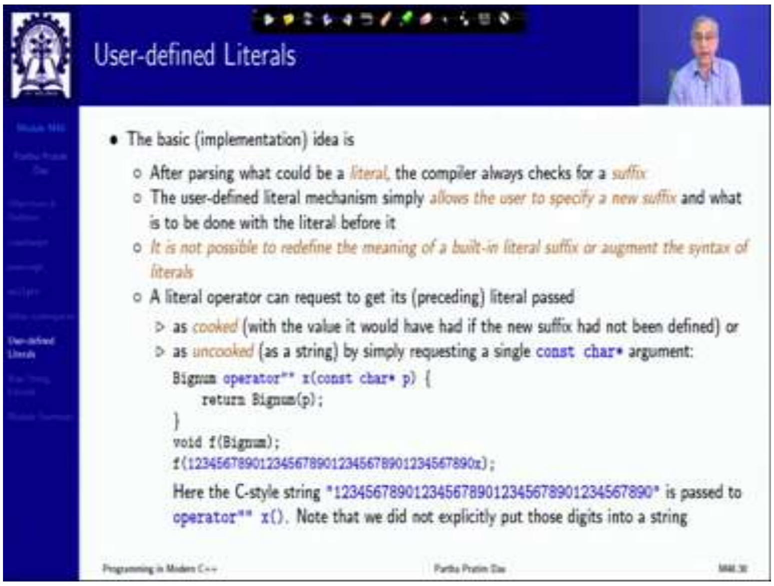

So, user defined literal is a very, very powerful mechanism, there are ways to either take the converted literal form or the raw string form in which it is provided, all of these examples are given here.

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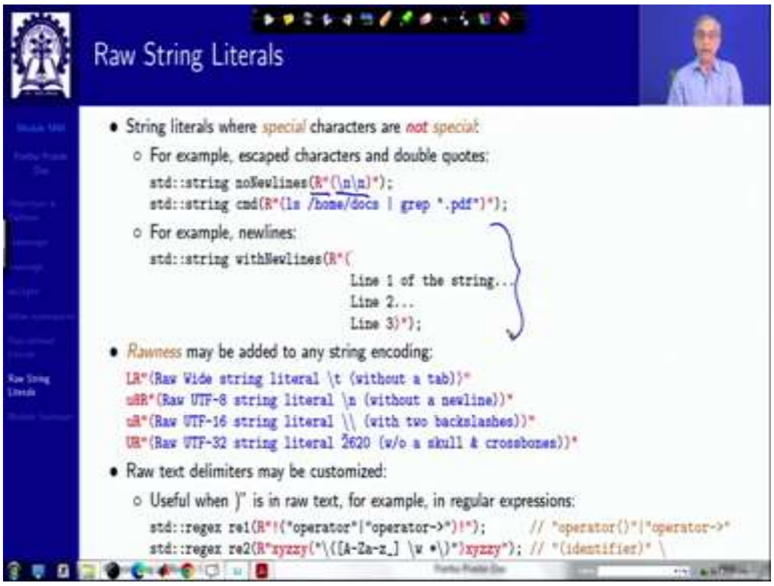

Before I end the last feature, I would like to mention is raw string, you know that c strings have lot of escape characters, like \t is written to mean tab, \n is written to mean new line, and so on. C++ allows you to define a raw string. It is written with a prefix capital R before the double quotes, which means that the escape characters will not be interpreted, they will not be treated as special.

So, this will be \n and \n not to new line. Similarly, I can write a string like this, which spreads over multiple lines. There are new lines inside. If you try to do this in a normal string you will have error, but here you will be able to do that because everything is being taken just as the character is without any special interpretation being given to that. So, this becomes useful in some of the standard library features as we will see later on.

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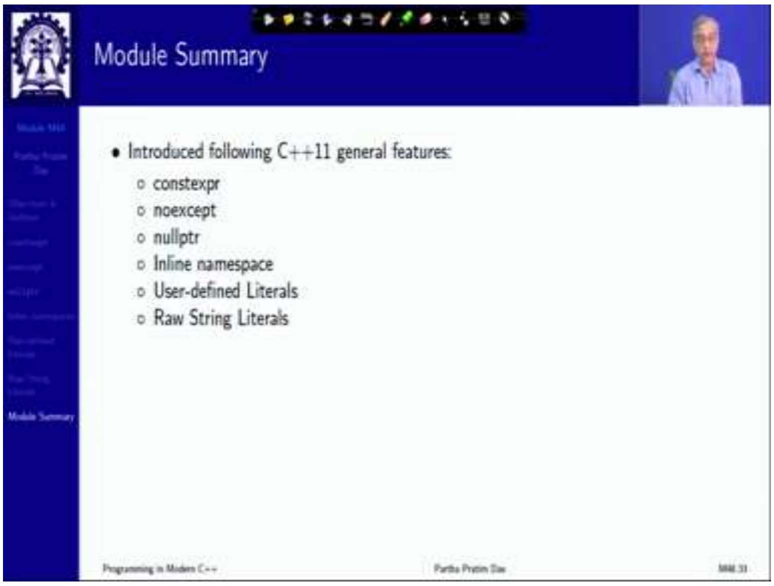

So, we have introduced a number of general features, these six, so please practice them through programming. Thank you very much for your attention and we will meet in the next module.