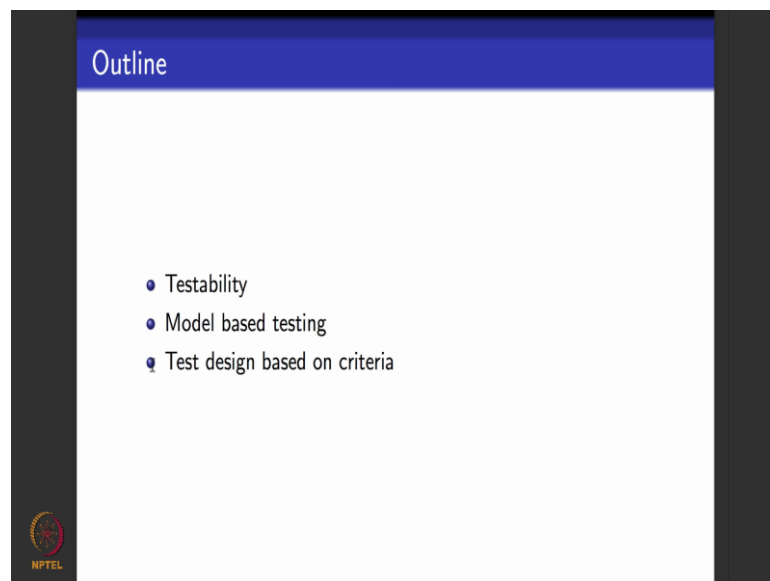


Software Testing
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Lecture - 03
Software Testing: Testing based on models and criteria

Hello everyone. This is the lecture on the second module of first week. So, what will be seeing in today's lecture? We will look at it what it means to test the software.

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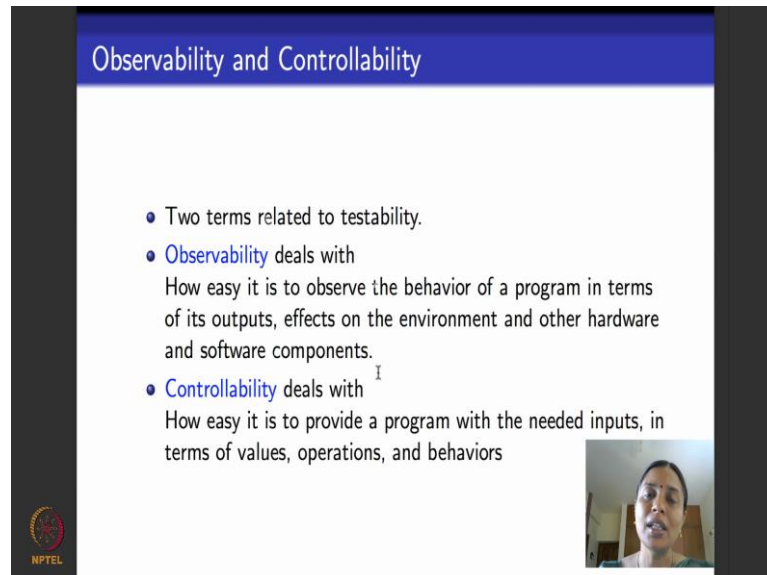


What is testability; we will also look at what is model based testing as its commonly perceive in the testing world, and how we will use model based testing when we design algorithms for test cases. As I told you lot of this course is going to be on algorithms and methodologies for test case design. And in fact we will be looking at what is call criteria based test case design. So, we will formally define what is criteria, and look at the various artifacts on which we will be defining these criteria to design test cases for.

So, I begin with introducing what is testability. So, what is testability? If you look at it in simple English terms it simply answers the question--- is the software testable or not. So now, if I ask the same question again in term what is it mean for the software to be testable, right? So, we say can I give inputs to the software; inputs a test cases to software? After giving the test cases to the software can I execute the software an observe the outputs. You might think it is a very obvious question--- when I write a piece

of core what is the difficulty about giving inputs to the software, executing the software and observing its outputs.

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The slide is titled "Observability and Controllability" in a blue header. It contains a bulleted list of two terms related to testability. The first bullet point is "Observability" which deals with how easy it is to observe the behavior of a program in terms of its outputs, effects on the environment and other hardware and software components. The second bullet point is "Controllability" which deals with how easy it is to provide a program with the needed inputs, in terms of values, operations, and behaviors. In the bottom right corner of the slide, there is a small video inset showing a person speaking.

- Two terms related to testability.
- **Observability** deals with
How easy it is to observe the behavior of a program in terms of its outputs, effects on the environment and other hardware and software components.
- **Controllability** deals with
How easy it is to provide a program with the needed inputs, in terms of values, operations, and behaviors

So, we will see what are the particular hiccups that can arise while doing this. Two related notions of testability are what are called observability and controllability. So, what is observability mean? Observability it tries to answer the following question. So, it says the suppose you give a software certain kinds of inputs and execute it, how observable is its behaviour,? How observable are the outputs that the software produces?

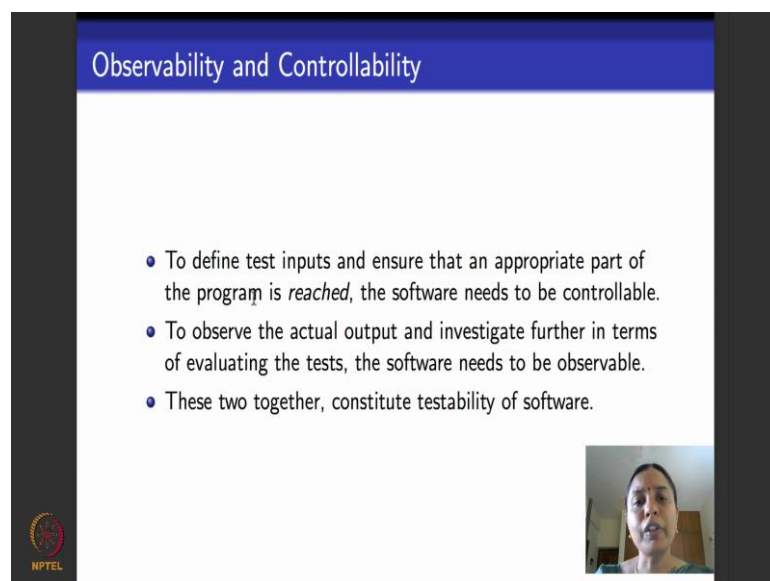
It could do we doing a lot of things silently and producing only the final output, whereas as a tester you might be interested in some intermediate outputs that the software produces. So, observability tries to answer this question about how observable the outputs produced by the software are and how much we can tweak the outputs that we want the software to produce towards testing it.

So, when I test the software I might want to observe a little more about its outputs, not actually the actual outputs of software. But I might want to know the values of specific internal variables, specific call and return values. Observability deals with all this. Another related term for testability is what is called controllability. What is controllability? Controllability says if a software controllable by giving it in some input and actually executing the software.

Again this might seem like a trivial question you might ask why is it so difficult to give inputs to a software. Let us take a particular case for example, where piece of software runs for some time and then at particular point and code it calls a particular function. So, I want to be able to let us say “integrate test” this function call. So, what I am interested in controllability is the fact that I should be able to give inputs to the softwares such that I can ensure that the particular function of procedure that is embedded deep inside the code is actually called for the values of the inputs. And not only is the function called, I now want to be able to observe what the function returns in turn.

So, controllability and observability help you to answer these questions and software. And, they are one of the several different quality attributes broadly call “ilities”, that the people worry about while testing and writing software.

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The slide is titled "Observability and Controllability" in a blue header. It contains a bulleted list with three points. In the bottom right corner, there is a small video inset showing a woman speaking. The NPTEL logo is in the bottom left corner.

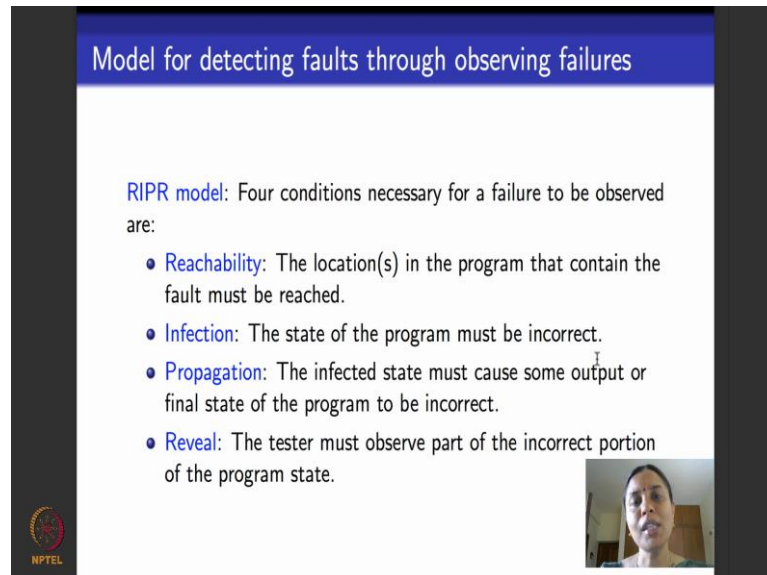
- To define test inputs and ensure that an appropriate part of the program is *reached*, the software needs to be controllable.
- To observe the actual output and investigate further in terms of evaluating the tests, the software needs to be observable.
- These two together, constitute testability of software.

So, to define test inputs and to ensure that in appropriate part of the code is reached, like I told you an appropriate function is called and I will be able to in turn observe the value return by the function I say that the software needs to be controllable. When I want to observe the value that is return by the function and see how it gets passed on to the main callee program then I say that the software needs to be observable. Observability and controllability put together constitute testability of a software.

Obviously, for a software to be testable, its testability quotient must be very high; it should be observable, it should be controllable. So, we will little more in detail

understand what this notion are; when people say a software is testable they usually talk about four parameters for observability and controllability put together.

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Model for detecting faults through observing failures

RIPR model: Four conditions necessary for a failure to be observed are:

- **Reachability:** The location(s) in the program that contain the fault must be reached.
- **Infection:** The state of the program must be incorrect.
- **Propagation:** The infected state must cause some output or final state of the program to be incorrect.
- **Reveal:** The tester must observe part of the incorrect portion of the program state.

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So, these four parameters are what are called RIPR model. So, what is R? R stands for reachability. Reachability mean suppose I am testing, white box testing, a piece of software and I want to check whether a particular statement is reached, whether a particular function call is reached, whether a particular code segment is reached; I should be able to give test inputs that guarantee the execution of software in such a way that this particular target place in the software of goal is reached.

Now the next important thing is I: I stands for infection, what do we mean by infection? Not only do I want to reach that place I want to be able to execute those statements in the software. And suppose there is an error that is observed I want the error to be exercised or I want the error to be reached; I want the software to reach its faulty state. And I want to be able to give inputs in such a way that I can infect that particular statement in the software and actually pull out the error or the faulty states the software was in. Suppose I manage to do that, but the software still manages to run fine and execute such that it acts normally, then even though the software is erroneous I, as a tester have not really observed the error.

So, the next parameter that I am looking for is P which stands for propagation. So, I say not only much particular statement be reached and the error be revealed as infected; the

error should also be propagated to output, observable output, such that I know that there is an error that has occurred in the software. And it could be propagated and for some simple reason like you might just forgotten to write a print statement or forgotten to track this particular values the propagated error might not actually get revealed to the tester. So, at the last parameter in this RIPR model that I am looking for is for the error to be revealed; this tester will be able to observe the incorrect part in the program and correctly isolate and identify which part of the code was the error in.

So, to summarise we say that if I am targeting a particular a piece of code that I suspect to be erroneous or that I want coverage to be achieved; somebody told me you please test this piece the code thoroughly. You please test this function and the function called thoroughly. So, I am looking for four properties the software should satisfy for it to be observable and controllable.

The first one is that the particular target code fragment or segment should be reachable. The particular target code fragment or segment, if it has an error should infect and the particular test case that I give should make sure that the error state has actually occurred. This occurred error, in turn, should propagated to the software producing a different kind of output that reveals the error. And the revealed error should, in turn, help the tester to be able to identify and isolate the error as having occurred in that piece of software. So, software that needs this RIPR model property is supposed to be highly testable.



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RIPR example

Consider the code segment below:

```
input x,y;  
if (x < 10)  
{ z = x+1;  
  if (y < z)  
    --- error ---;  
}
```

- Reachability: True, any value of x can reach the first if statement. $x < 10$ will reach the second if statement.
- Infection: $x \neq 10$ will test the first if statement. $y < x+1$ will test the second if statement.
- Propagation: $x < 10$ and $y < z$ will result in reaching the error statement.



So, here is an example of an RIPR model: you consider the small code fragment that is given here I am not given the full piece of code here, I have just given a small fragment of the code. In this small fragment of the code there are two inputs x and y , and then they could be other statements lot of other commands and the software. But let us focus on this particular thing fragment of the code which says that for there are two nested if statements here. The first statement checks if x is less than 10 that it sets the value of z to be x plus 1. And then there is one more if inside that which says that if y is less than z then there is an error in the software. I haven't actually written what the error could be, I have just written it like a stub which marked it out as error.

So, suppose I want to actually; my goal is to be able to be actually reach this error statement and reveal the fact that this error as occurred. So, what does RIPR parameters do for this? So, let us look at reachability first. So, what is it mean for the first if statement to be reachable; any value of x will reach that statement assuming that there are no code fragments that change the value of x , any value of x that is given here will reach the first statement which is x less than 10. So, reachability can be thought of as being true, always true, there is nothing specific that I need to do.

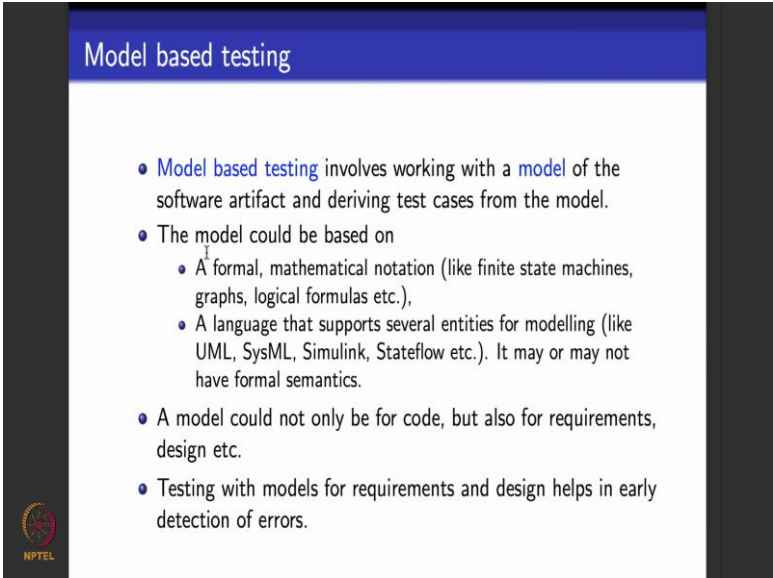
But to be able to reach the second nested if statement; suppose the first if statement test negative in the sense suppose I give a value of x that is not less than 10. So, this if statement, this predicate will written false and the code will exist this if statement it will never enter this if statement. If it does not enter this if statement it is not going to be able to test the second if make it positive and then reach the error statement. So, reachability for the second if statement will happen only if the first if statement returns true and the first if statement will return true if I give a value of x that is less than 10.

So, the predicate x less than 10 should be true for me to be able to reach the second if statement. So, what is infection? Infection means I not only reach the statement, I manage to execute that statement and make it true or false. So, again an infection for the first if statement is any value of x less than 10 like for example, or any value of x greater than 10 or even x is equal to 10 will manage to infect this first statement. For the second statement remember z is set to x plus 1. So, you must give a value of y that is less then x plus 1 to be able to test the second if statement. Now moving on, when it comes to propagation I should be able to go past the first if statement makes it true, go past the second if statement make that also true, and then only I will reach the error statement.

So, both these predicates x less than 10 and y less than z will have to be true for me to be able to reach the error statement.

I hope what reachability infection and propagation is very clear. So, in this piece of the example it is quite small, so it easy to be able to do what are the conditions for reachability, infection and propagation and so on. But for large fragments of code, where I have thousands of lines of code it is not an easy problem to be able to come up with less list of predicate for reachability for infection and propagation and to be able to solve them. In later modules when we look at testing criteria we will see how what it means to solve the predicate or a particular piece of code for reachability, for infection, and for propagation in detail.

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The slide is titled "Model based testing" in a blue header. It contains a bulleted list of points. The first point states that model based testing involves working with a model of the software artifact and deriving test cases from the model. The second point states that the model could be based on two sub-points: a formal, mathematical notation (like finite state machines, graphs, logical formulas etc.), and a language that supports several entities for modelling (like UML, SysML, Simulink, Stateflow etc.). It may or may not have formal semantics. The third point states that a model could not only be for code, but also for requirements, design etc. The fourth point states that testing with models for requirements and design helps in early detection of errors. In the bottom left corner, there is a small NPTEL logo.

- Model based testing involves working with a model of the software artifact and deriving test cases from the model.
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- A model could not only be for code, but also for requirements, design etc.
- Testing with models for requirements and design helps in early detection of errors.

I will now move on to looking at model based testing. What is model based testing mean? In the English sense of the term, model based testing means that you have a model of the software artefact; the artifact could be requirements it could be design, it could be architecture, it could be code, and then you design test cases by looking at the model. There are of course, several other uses of the models for software, well done models could be used to auto generate codes they could be used to early validate the system. There are several other uses for model based design and model based testing.

There are broadly two kinds of models: the model could be based on a formal, mathematical notation. Here are some popular modelling languages: finite state

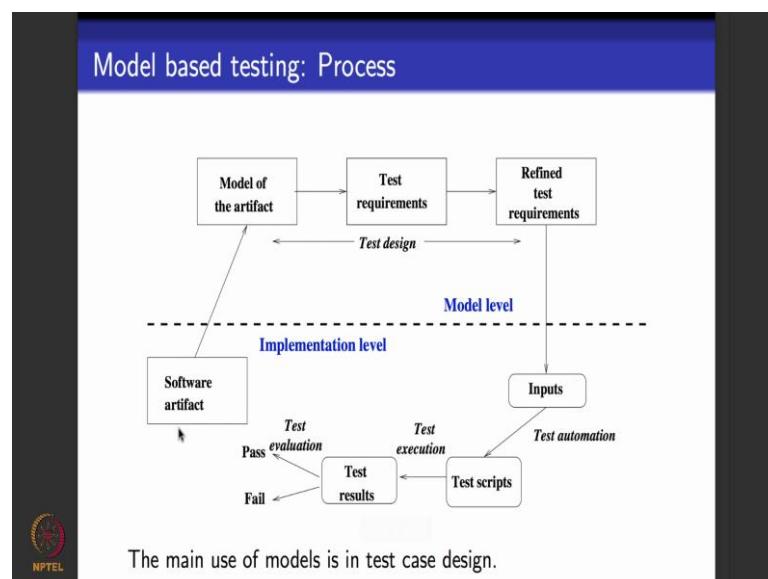
machines, graphs, logical formulae. As I told you in the last module there are several different verification techniques, like model checking theorem proving, they all use mathematical models of software artifacts to be able to verify a software.

Models it could also mean a particular domain language or specifically designed language that specifies all the artifacts that particular software is concerned. You might have heard popular modelling language like UML which stands for unified modelling language, SysML which is systems modelling language, Simulink, Stateflow which are modelling languages that are proprietary to a company called Mathworks which makes a popular tool called MATLAB.

So, these modelling languages support several diagrammatic notations for me to be able to module various software artifacts like use cases requirements design, control laws and so on. They may or may not have formal semantics. So, it is to be noted as I told you that the model need not be only for code; it could be for requirements, it could be for design, and so on. Testing with models for requirements and design: suppose I manage to have good, well defined models for requirements and design and I am able to design test cases for them, then remember that I am doing this kind of testing right at the requirements level or design level, before I write code.

So, if I find an error I find it early on in the life cycle and that is considered to have lots of benefits. So, what is the process of model based testing, how does it work?

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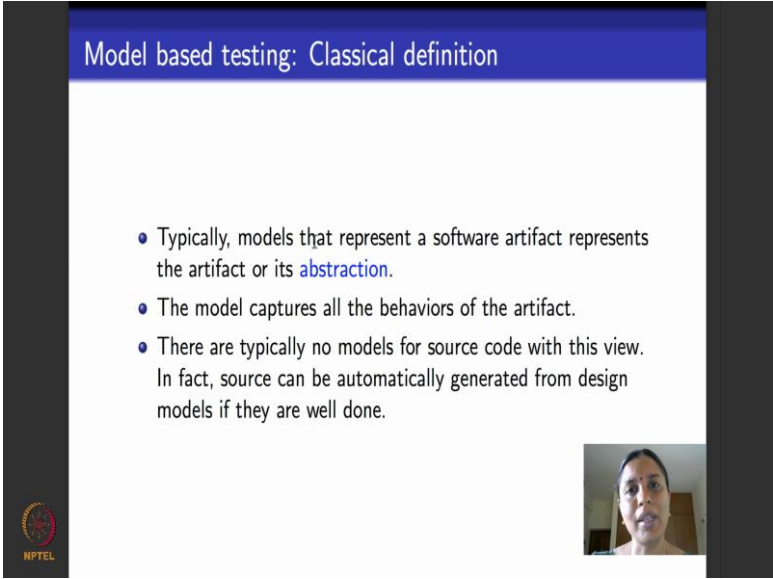
Let us begin here with this part: I have a software artifact with me under consideration that would be code that could be a requirements document that could be a design document. Code is typically executable, but many software companies have requirements of design document written in English. So, English documents cannot act as models. So, I take the software artifact and come up with the model of the artifact. The model of an artifacts is designed in a language that I have predisposal decided as suitable for the class of software that I am working with.

Once I have the model of this software artifacts I do what is called model based design and I can subject this model to several different uses, but what we will focus on today, is in this particular slide, is the use of the model when it comes to designing test cases. So, I take this model of the artifacts and then I also have a set of test requirements that have been given to me. Test requirements could say something like--- there are some highly critical requirements you please design test cases to exhaustively test for all the requirements. Test requirement could say something, like you cover this particular fragment of the model or a piece of code.

So, I take these test requirements and refine them with reference to the model that I have in mind. After I refine the test requirements I have done my test case design and I am ready to give my test case as inputs. Remember once I have a test case that has to be actually executed in code. So, I assume that I have an implementation ready and I move on to the implementation of the software. Once I have given my test case design I pass these inputs, make it ready for execution; make it ready for execution you remember in the last module we saw this step called test automation. So, I do test automation and get that test scripts which are ready for execution then I use the tool to execute this test scripts and observe the results. And then I conclude the test cases have passed or failed.

So, this is the normal process of testing that we saw the only difference here is that while doing designing of test cases I have a particular model of the software and hand and I design test cases for a set of test requirements on that specific model of the software. Here my main use of models is to be able to do test case design.

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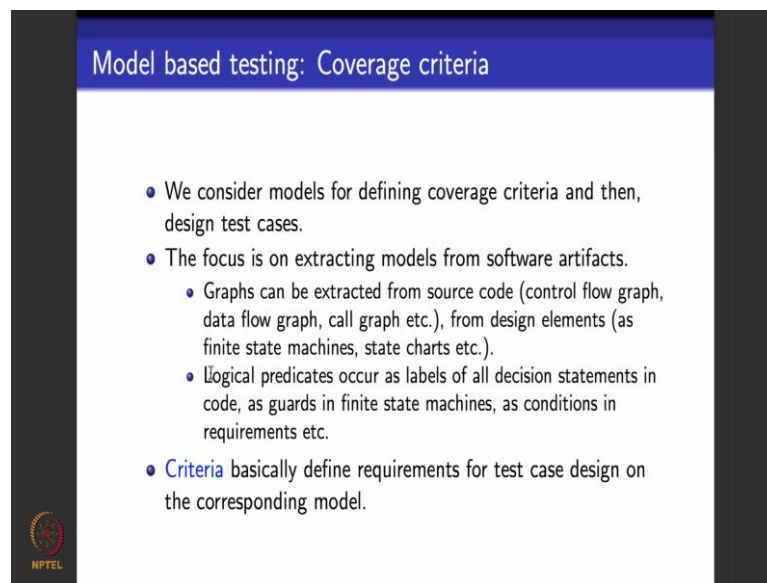
The slide has a blue header with the text "Model based testing: Classical definition". Below the header, there is a bulleted list of three points. In the bottom right corner of the slide, there is a small video inset showing a person speaking. In the bottom left corner, there is a small logo for NPTEL.

- Typically, models that represent a software artifact represents the artifact or its **abstraction**.
- The model captures all the behaviors of the artifact.
- There are typically no models for source code with this view. In fact, source can be automatically generated from design models if they are well done.

So, the classical view of model based testing or model based design is to say that models could represent a very high level abstraction of the software, it need not represent the actual code. In fact, code is almost always never represented as a model. Code is represented in the programming language of your choice and is always an executable entity. Models may or may not be executed, they could be static artifacts that represent the code. Typically a model is supposed to capture all the behaviours of the particular software artifacts and it is for the user to ensure that the model of the software is accurate and good enough to meet the required expectations of the model. If the model that you do of the software artifacts is itself wrong, then obviously the test case and everything else that you do with the model is also going to be wrong.

So, is up to the user to ensure that he or she knows the modelling notation well and is modelled software well enough to be able to design all the test cases. So, we do not view the classical view of model checking in this particular course, we will view model based testing for doing coverage criteria based design in this course.

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The slide is titled "Model based testing: Coverage criteria" in a blue header. It contains a bulleted list of four points. The first point states that models are considered for defining coverage criteria and then design test cases. The second point states that the focus is on extracting models from software artifacts, with sub-bullets indicating that graphs can be extracted from source code (control flow graph, data flow graph, call graph etc.), from design elements (as finite state machines, state charts etc.), and that logical predicates occur as labels of all decision statements in code, as guards in finite state machines, as conditions in requirements etc. The third point states that criteria basically define requirements for test case design on the corresponding model. In the bottom left corner, there is a small NPTEL logo.

- We consider models for defining coverage criteria and then, design test cases.
- The focus is on extracting models from software artifacts.
 - Graphs can be extracted from source code (control flow graph, data flow graph, call graph etc.), from design elements (as finite state machines, state charts etc.).
 - Logical predicates occur as labels of all decision statements in code, as guards in finite state machines, as conditions in requirements etc.
- **Criteria** basically define requirements for test case design on the corresponding model.

So, what do we do? We first focus and represent the software artifacts as models, we typically work with several different models. So, where do these models come from? So, graphs are one kind of models that I want to work with. Where do I get graphs from? I can get graphs from source code. You might have heard of control flow graph or a flowchart corresponding to a piece of code. In fact, there is something called data flow graph which represents the control flow along with tracking of the variables that are involved at a particular piece of statement in the code.

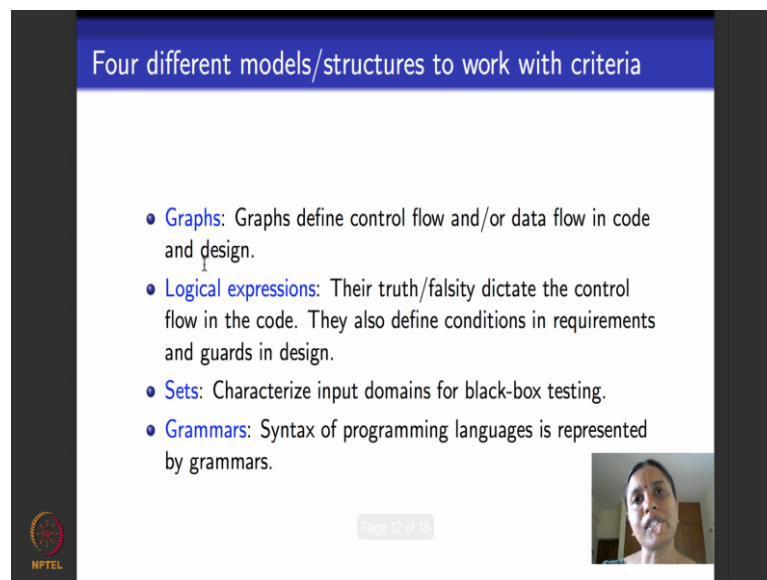
And then there is an notion of call graph in an inter procedural call graph when the code is modularized into several functions or procedures or method. I can also get graph from design; lots of designs these days are represented using UML notations which are basically finite state machines, state charts, all these are some specific kinds of graph. They have several different specific parameters to each of them, but they are all basically graphs.

Another class of models that we will be working with what are called logical predicates. Where do logical predicates come? If you see a typical code or an implementation is studded with them, at every decision point in the code. What is the decision point in the code? It could be an if statement, a while statement, a for statement which says that there is going to be some kind of the branching in the execution of a code, some kind of the choice in the execution of code. At every decision point in the code there is a predicate.

Based on whether the predicate is true or false the code execution takes one path or the other.

So, what we will try to do is we will try to work with graphs, logical predicates and a few other things is a models of software and design test cases based on these models, based on certain criteria.

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The slide is titled "Four different models/structures to work with criteria". It contains a bulleted list of four items:

- **Graphs:** Graphs define control flow and/or data flow in code and design.
- **Logical expressions:** Their truth/falsity dictate the control flow in the code. They also define conditions in requirements and guards in design.
- **Sets:** Characterize input domains for black-box testing.
- **Grammars:** Syntax of programming languages is represented by grammars.

The slide also features the NPTEL logo in the bottom left corner, a page number "Page 12 of 18" in the bottom center, and a small video feed of a man in the bottom right corner.

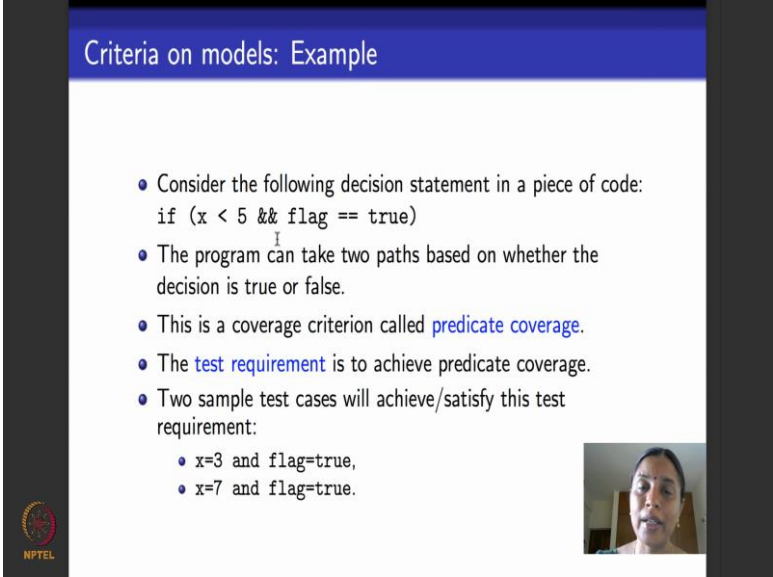
So, what are the four different model structures is that we will be working with as a part of this course. We will first begin with graphs next week. So, graphs typically in software define control flow, they also define data flow and as I told you little earlier they also could be graphs that depict calls of procedures, one procedure calling the other. So, we look at graphs as models representing such entities about a piece of software and then we will define criteria based on that and understand how to design test cases based on criteria.

Then we will look at logical expressions as they occur software, as they occur code, as they occur guards in design that represented as finite state machines, as they occur in requirements. And we will design test cases that check when a logical predicate could be true or when a logical predicate could be false. We will also, for the point of view of black box testing, look at sets of inputs that are given to a software and design test cases based on partitioning of those sets. So, sets would be another structures that we would be working with in this course.

And finally, when we look at coverage criteria we will also look at the underline syntax of programming language. So, every programming language as you know it could be C, it could be Java, it could be Python as an underlining grammar which tells you what is allowed in terms of writing in that programming language, how to write programs in the programming language. And when I compile a piece of software in the process of compiling I also check at the particular program adheres to the underline syntax or not. So, you can do mutation testing which exploits the syntax of a particular piece of programming language and designs test cases by manipulating inputs that adhere to the underline syntax or grammar of that particular language.

So, to summarise this slide, what we will do is we will look at software artifacts as four different structures or models: we will first consider them as graphs, and then will consider the logical predicates that occur in the code, then we will look at sets of inputs and outputs, and finally we will look at the grammar or the syntax of the programming languages. For each of these, we will design what are called testing criteria and also see algorithms on how to design test cases to test for these criteria.

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The slide is titled "Criteria on models: Example" in a blue header. It contains a list of bullet points explaining predicate coverage. The first bullet point shows a code snippet: `if (x < 5 && flag == true)`. The second bullet point states that the program can take two paths based on whether the decision is true or false. The third bullet point identifies this as a coverage criterion called "predicate coverage". The fourth bullet point states that the "test requirement" is to achieve predicate coverage. The fifth bullet point lists two sample test cases that will achieve/satisfy this test requirement: `x=3 and flag=true,` and `x=7 and flag=true.` In the bottom right corner of the slide, there is a small video inset showing a woman speaking. The NPTEL logo is visible in the bottom left corner of the slide.

- Consider the following decision statement in a piece of code:
`if (x < 5 && flag == true)`
- The program can take two paths based on whether the decision is true or false.
- This is a coverage criterion called **predicate coverage**.
- The **test requirement** is to achieve predicate coverage.
- Two sample test cases will achieve/satisfy this test requirement:
 - `x=3 and flag=true,`
 - `x=7 and flag=true.`

So, here is a simple example to understand what criteria means. Let us say somewhere in your piece of code there is this following decision statement. How does this read? It says if x is less than 5 and a Boolean variable called flag is true then you do something. We are not interested in what we do, I just want to focus on this particular if statement.

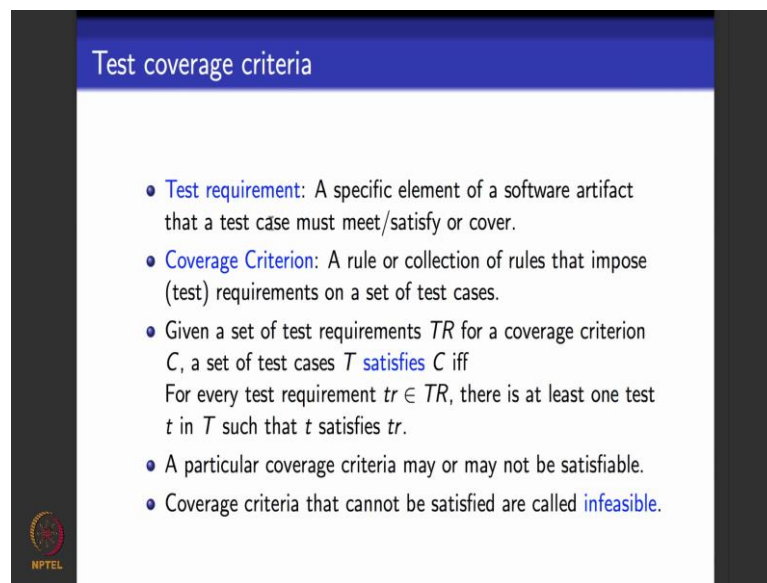
Now, what is the label of this if statement? The label of the statement is this particular thing right $x < 5$ and $\text{flag} == \text{true}$. It involves two kinds of variables: it involves, maybe, an integer variable x whose values compared to 5, and it involves a Boolean variable flag which is tested to be equivalent to true. So, this whole thing is what we call a predicate. So, let's suppose this predicate turns out to be true that is x is indeed less than 5 and flag is also equal to true then you say that the if statement takes the then branch of the code. And suppose this predicate is false then you say that the if statement takes what is called the else branch of the code.

So, how will I make this predicate true? I say, you write two kinds of test cases one that makes this predicate true and one that makes this predicate false; that way I would have exercised this if statement for predicate coverage or branch coverage. When I cover a predicate I also cover then branch of the if statement and predicate is true and I cover the else branch of the if statement when the predicate is false.

So, for this particular if statement: suppose I set x to be equal to 3 and the value of the variable flag to be equal to true then the whole predicate with this and operator evaluates to be true. So, this would exercise the then part of the if statement. And suppose I give a value of x to be 7 and let's say I set the Boolean variable flag to be true, then this predicate would evaluate to be false, because this first condition will evaluate to be false. So, then this will mean that this whole if statement will have to exercise the else part of the code that is present after the if statement.


So, I say this is my test requirement; my test requirement is to be able to achieve predicate coverage on this if statement and these are the two test cases that achieve this test requirement. We will see how to define such coverage criteria based on graph, based on predicates, based on sets of inputs and how to automatically design test cases that will tell you whether the particular coverage criteria is achieved or not, and if it is achieved how is it achieved.

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The slide is titled "Test coverage criteria" in a blue header. It contains a bulleted list of definitions and a logo in the bottom left corner.

- **Test requirement:** A specific element of a software artifact that a test case must meet/satisfy or cover.
- **Coverage Criterion:** A rule or collection of rules that impose (test) requirements on a set of test cases.
- Given a set of test requirements TR for a coverage criterion C , a set of test cases T **satisfies** C iff
For every test requirement $tr \in TR$, there is at least one test t in T such that t satisfies tr .
- A particular coverage criteria may or may not be satisfiable.
- Coverage criteria that cannot be satisfied are called **infeasible**.



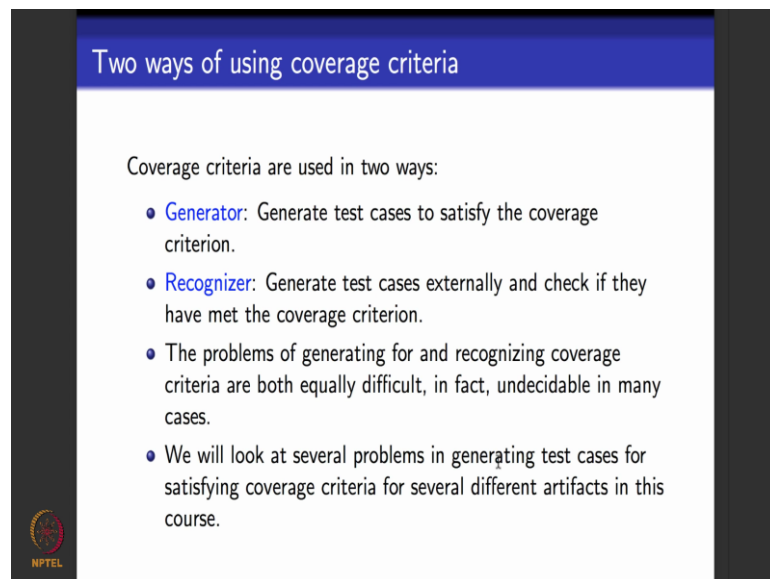
So, here are some definitions. What is the test requirement? A test requirement is basically a requirement that you say about a test case. You gave a thing like please design a test case to cover this if statement, to execute this if statement once for the then part once for the else part. You might say, please design a test case that will execute this while statement at least three times. You know these are all test requirements. They basically give you requirements on how to design test cases.

What is a criterion? A criterion is a rule or a set of rules that impose certain requirements on a set of test cases. Like in the previous slide if you say my test requirements is to test this if statement to be true once and to be false once then the criteria is what we call as predicate coverage. So, given a set of test requirements for a coverage criteria C , we say that a set of test cases satisfies the coverage criteria C if every test case in that set of test requirements satisfies the coverage criteria C ; there is nothing more to it.

So, it is to be noted that a particular coverage criteria may or may not be feasible. Like for example: you take an if statement that occurs in something like this, let us say this if statement is labelled by a predicate that can never be made false. For example right, it could be labelled by a predicate that is always true or a tautology. In which case I say that predicate coverage criteria on this if statement becomes infeasible, because predicate coverage says that you make this predicate that labels an if statement true once and false once.

The predicate is such that it can never be made false. If it can never be made false then I cannot achieve predicate coverage. When I cannot achieve predicate coverage then I say that the particular coverage criteria that I cannot achieve are what is called infeasible. So, it is undecidable problem to check or an arbitrary coverage criterion whether it is feasible or not. What we will see several heuristic or techniques that will let you decide implicitly whether particular coverage criteria is feasible or not; and if it is feasible to be able to design test cases that will satisfy the coverage criteria.

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Two ways of using coverage criteria

Coverage criteria are used in two ways:

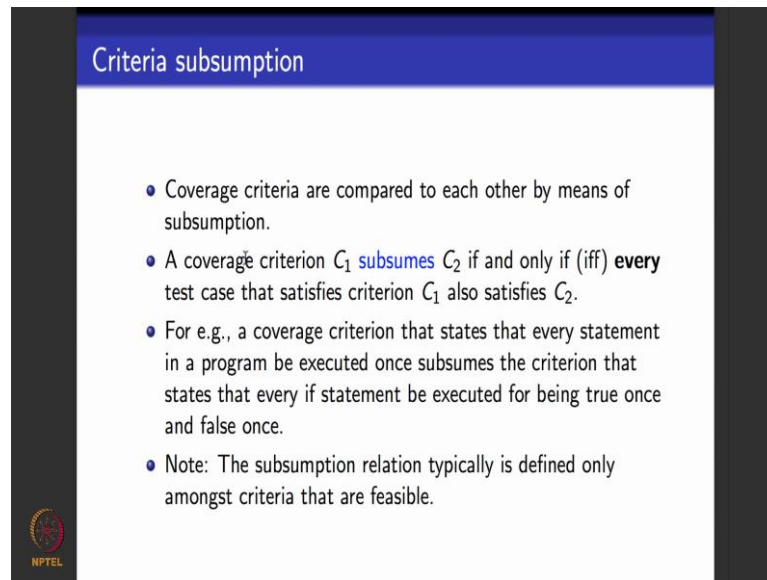
- **Generator:** Generate test cases to satisfy the coverage criterion.
- **Recognizer:** Generate test cases externally and check if they have met the coverage criterion.
- The problems of generating for and recognizing coverage criteria are both equally difficult, in fact, undecidable in many cases.
- We will look at several problems in generating test cases for satisfying coverage criteria for several different artifacts in this course.

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So, how do we design test cases that satisfy the coverage criteria? There are two base to do it: one is to automatically generate test cases that satisfy the coverage criteria, and the next one is to generate test cases externally; externally means you generated arbitrarily and then somebody gives you the coverage criteria. Now you take this set of generate test cases and the coverage criteria and you check if these test cases meet those coverage criteria so that is done by what is called a recognizer. And directly given a coverage criteria generating test cases for that coverage criteria is done by what is called generator.

Both generator and recognizer for testing based on coverage criteria are in their most generality, undecidable problems. In fact several times the algorithms for decidable fragments also have high complexity, but we will look at algorithms, nonetheless, without worrying about what the complexities and see how to use them to be able to generate test cases.

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The slide is titled "Criteria subsumption" in a blue header. It contains a bulleted list of four points. The first point states that coverage criteria are compared by means of subsumption. The second point defines subsumption: a coverage criterion C_1 subsumes C_2 if and only if every test case that satisfies C_1 also satisfies C_2 . The third point provides an example: a coverage criterion that states that every statement in a program be executed once subsumes the criterion that states that every if statement be executed for being true once and false once. The fourth point is a note: The subsumption relation typically is defined only amongst criteria that are feasible. In the bottom left corner, there is a small circular logo with the text "NPTEL" below it.

- Coverage criteria are compared to each other by means of subsumption.
- A coverage criterion C_1 subsumes C_2 if and only if (iff) every test case that satisfies criterion C_1 also satisfies C_2 .
- For e.g., a coverage criterion that states that every statement in a program be executed once subsumes the criterion that states that every if statement be executed for being true once and false once.
- Note: The subsumption relation typically is defined only amongst criteria that are feasible.

Now, suppose I have a particular thing and I define several different coverage criteria on a particular test requirement. So, I should know how do each of these coverage criteria compare to each other. Like for example, I in a piece of code I could have two different coverage criteria: one coverage criterion says that- you design a set of test cases that will execute every statement once. Another coverage criterion says that- you design a set of test cases which will execute every branch for the then part and for the else part once.

So, how do I know which of this is better and the work that I do for achieving one coverage criteria, implicitly also meets another coverage criteria. So, the notion of subsumption comes to our rescue here. So, we say that a particular coverage criteria C_1 subsumes another coverage criteria C_2 if every test case that satisfies criterion C_1 also satisfies criterion C_2 . Like for example, suppose I told you there was a criteria with says executive every statement once right, which means executive every statement in the program. And let us say there was another other criteria which says that is executed in every branch that you encounter, execute the true part executive the false part.

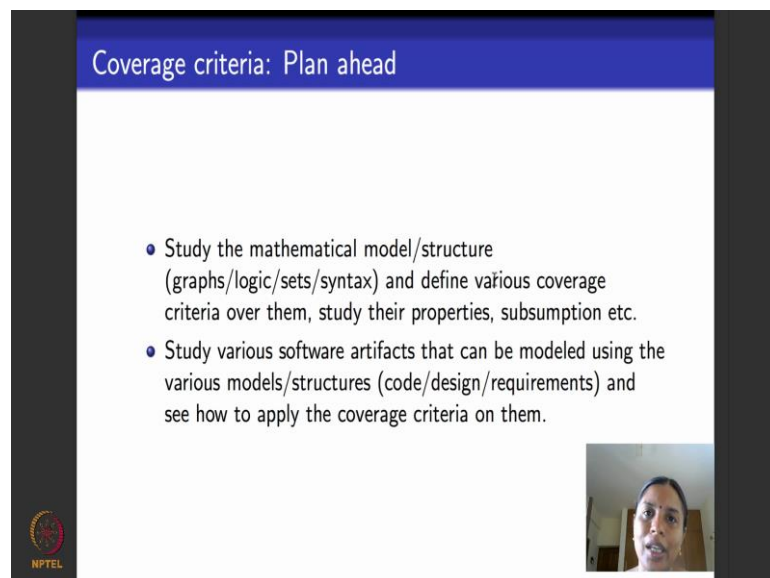
It is obvious that the first coverage criteria with says executive every statement one subsumes the second coverage criteria, because if I execute every statement once I would also be executing the statements of the then branch and the statements of the else branch.

So, this is how I use the notion of subsumption to be able to compare coverage criteria. It is important to be able to compare coverage criteria to reduce the burden on you

repeatedly generating test cases for different coverage criteria that are actually subsumed by the other coverage criteria. So, it is important to know if I generate test cases for one kind of coverage criteria what other parts of other different coverage criteria I have already achieved because of this. So, the notion of subsumption will help you to answer these kinds of questions.

One important note to observe that is that suppose a particular coverage criteria is infeasible then I really do not look at what subsumption for that coverage criteria, I define subsumption only for feasible coverage criteria.

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The slide has a blue header with the text "Coverage criteria: Plan ahead". Below the header, there are two bullet points:

- Study the mathematical model/structure (graphs/logic/sets/syntax) and define various coverage criteria over them, study their properties, subsumption etc.
- Study various software artifacts that can be modeled using the various models/structures (code/design/requirements) and see how to apply the coverage criteria on them.

In the bottom right corner, there is a small video inset showing a person speaking. In the bottom left corner, there is a small logo with the text "NPTEL" below it.

So, what is the plan ahead for the next weeks? What we will do is that we will consider software as various mathematical models or structures. So, what are the four structures that I said we will look at? We will look at graphs as model software artifacts, we look at logical predicate that occur in software artifacts, we will look at sets of inputs and outputs that are given to the software, and finally we will look at the underlining grammar or the syntax of software.

So, each of these models as structures we will define coverage criteria and discuss algorithms that will let us you design test cases to achieve coverage criteria. Of course, we look at subsumptions of coverage criteria and so on and so forth. So, what we will do first is we look at the model at an abstract level. Just as a graph, as a predicate, and then define algorithms for coverage criteria. Post that we will look at various software

artifacts; so we will see how to take code and model it as a graph, and what are the coverage criteria that we look at the graphs and how do those help to test various aspects of the code. Then we will take design and model it as a graph, and then we will see what are the coverage criteria that we looked at for graphs that will be relevant to design test cases for these designs.

So, similarly when we go to logical predicates, we look at logical predicates as they occur in code, look at coverage criteria and then see how these coverage criteria means testing which parts of the code. So, we look at these mathematical structures look at coverage criteria separately, then we look at how to model software artifacts using these structures and what do the various define coverage criteria mean for these structures.

So, next week when I begin my first module we will look at graph as models of software artifacts and define coverage criteria based on graphs so that will be the next lecture.

Thank you.