Object-Oriented Analysis and Design

Prof. Partha Pratim Das
Department of Computer science and Engineering
Indian Institute of Technology, Kharagpur

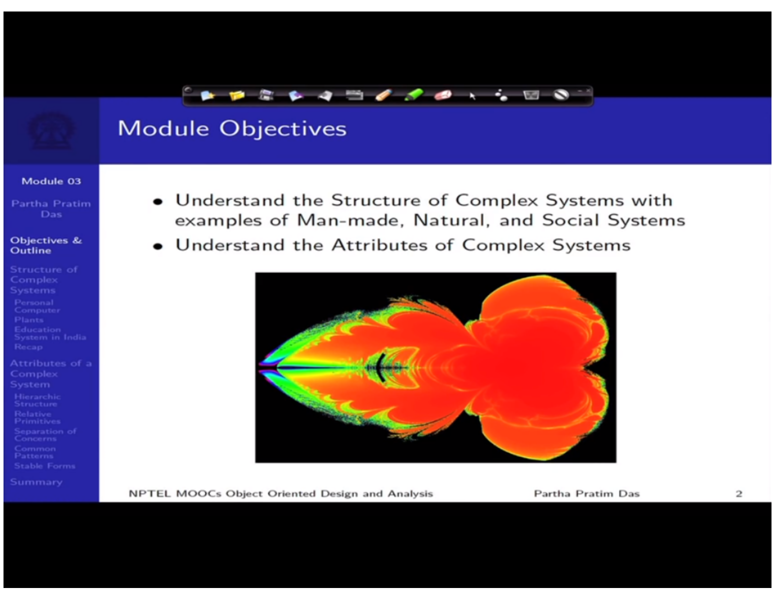
Lecture – 04
Structure and Attributes of a Complex System

Welcome to module 3 of object-oriented analysis and design. In the earlier modules we have taken a look at some of the big challenges that are faced by software engineering. Software projects having a high percentage of failure and based on that in the last module we tried to look at some of the typical complexities that face software development, the issues that arise from the problem domain, the external complexity, the difficulty of managing groups.

And the issues arising from discrete system behavior and flexibility and so on. So now we slowly start getting into how to handle how to manage this complexity. So in the module the current module and the subsequent ones we will slowly start characterizing how to handle this complexity. So first what we do in this module here is we take a look into a variety of complex systems and try to observe what is the inherent structure.

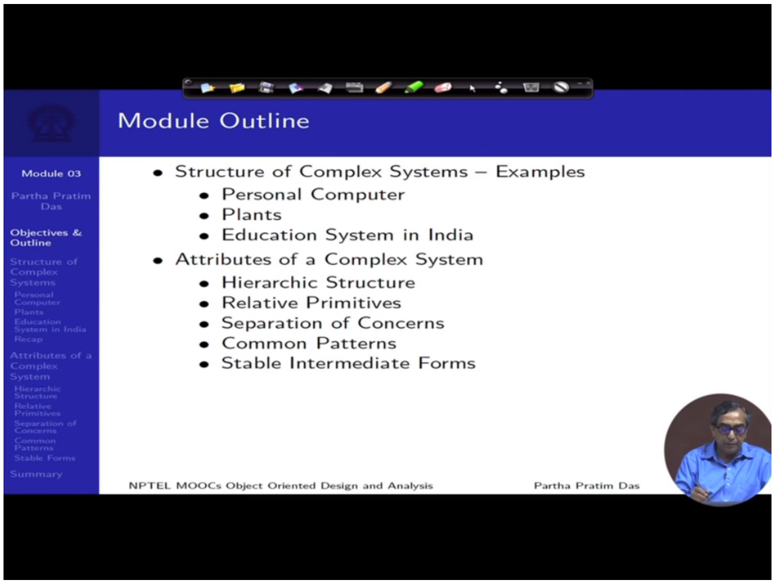
What is the inherent behavior and through that process, we will try to extract some commonality that we can canonicalize at a later point of time and then find out a strategy to handle the design, to handle the complexity.

(Refer Slide Time: 01:53)



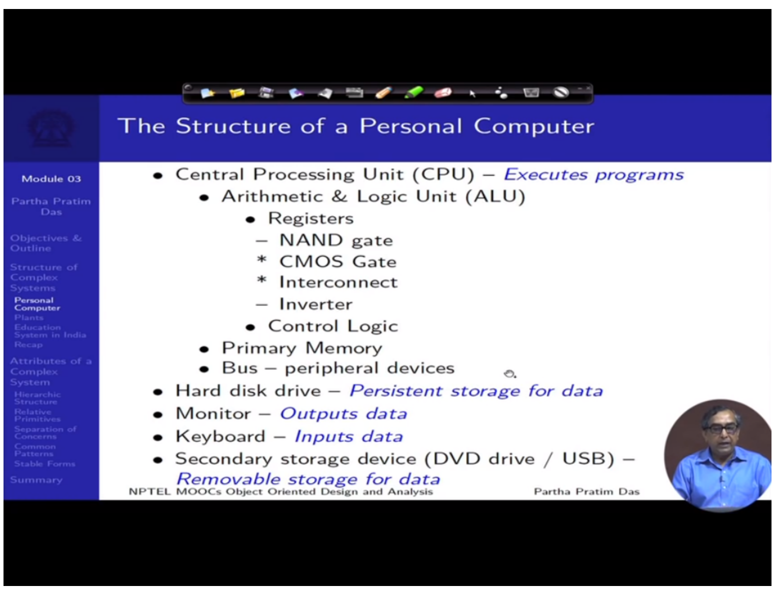
So this current module will specifically focus to understand the structure of complex systems and we take 3 examples, 1 manmade, 1 natural and 1 social system and from that we try to understand attributes of a complex system.

(Refer Slide Time: 02:10)



The module outline as you already know is presented also on the left bar of every slide.

(Refer Slide Time: 02:18)



So the first system we take a look at is a man made system. We try to understand what is an outline of a personal computer. all of us know personal computer. So you will know that there are some a personal computer of whatever capacity you talk of, am not talking about any specific personal computer, even this will include laptop and so on will comprise of a cpu which is a basic component which executes programs.

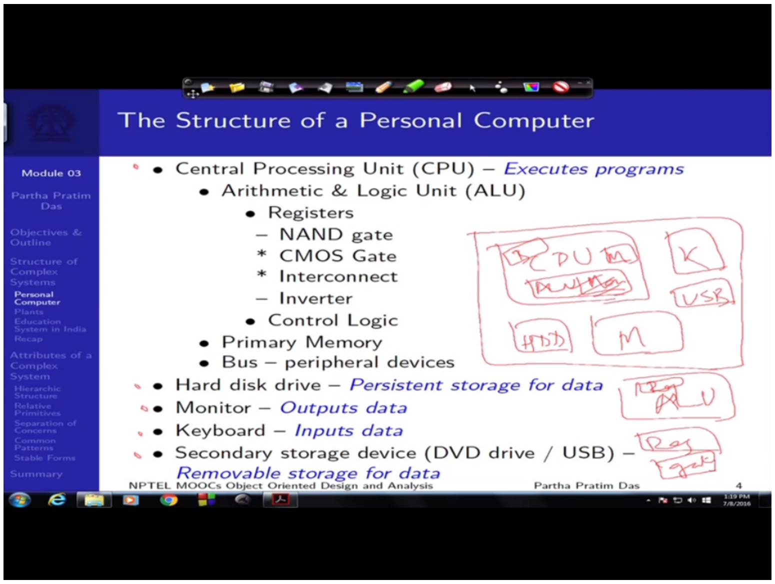
It must have the hard disk to store the programs, store the data on a persistent basis, it must have a monitor to display interact with us the output device, it must have a keyboard as an input device and typically it will have a removable storage, secondary storage like usb or DVD. At least at a, these are the minimum components which will define personal computer. Now if I take each one of these components, say just as an example I take the CPU.

Then I can say that the CPU actually comprise a number of sub components or sub systems. It must have an arithmetic and logical unit which is a core unit which does the mathematical computation, the condition checking and so on. The CPU must have primary memory, the fast memory through which we operate and it has busses that will connect to the peripheral external devices of the CPU. Now in turn, again if you look at the ALU.

The arithmetic and logical unit, then we can decompose and find the other sub systems that alus must have registers, it will have control logic, it will have other say floating point unit, integer unit, branch unit all these different components will be there. All are not listed here is not possible that will comprise and make the arithmetic and logic unit. Now again if you go deeper, look specifically into register.

We know that typically today the registers are built with digital logic of NAND gates inverters and other different kinds of gates. Now if you look into a particular NAND gate typically a NAND gate will be realized in terms of a cmos technology so it will have cmos gates and interconnects. So if we specifically look into so this was the the highest level of decomposition so a personal computer.

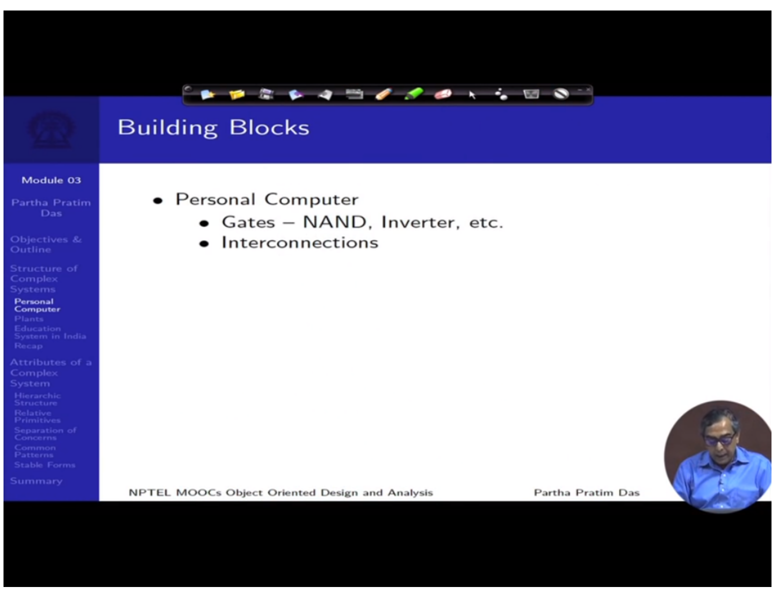
(Refer Slide Time: 04:53)



If I look at it this way, we have a cpu, I have hard disk, I have monitor, I have keyboard, I have usb then the cpu in turn has ALU, it has memory, another component as lets say it's a memory here, then it has bars all these different components. Now if I take ALU, then again I have registers in them. If I take registers, I have gates in them and so on. So if we if we just keep on going on this hierarchy.

You will find that the whole system can be described as a collection of hierarchical components, hierarchical subsystems where every ss system has certain subcomponents, subsystems in that and is a part of the higher level of systems.

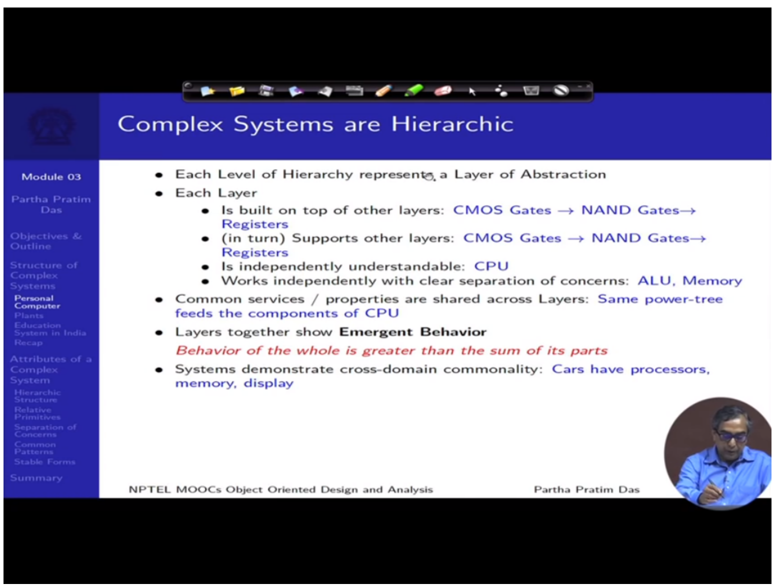
(Refer Slide Time: 06:02)



Now this is what we observe in case of a personal computer so but at a basic level we can see that the building block of a personal computer is something very generic. it is, these are basically gates, NAND gate, inverter so whether you talk about ALU or you talk about say the memory or you talk about hard disk (())(06:22) fundamentally these are collection I mean built with several primitive gates.

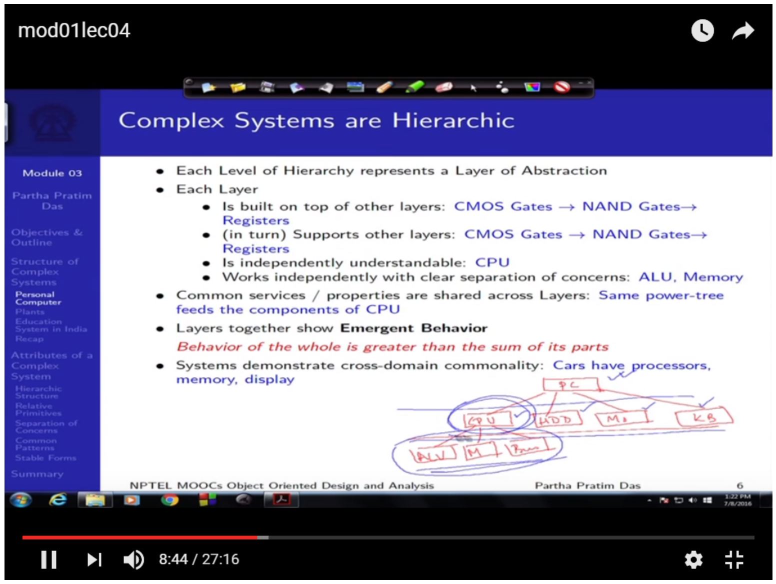
And on other side we have different interconnects to define the buses that exist on the CPU, the buses that connect from one CPU to the hard disk and so on. So while on one side, the personal computer has several other systems and subsystems of complexities on the other side, there are few primitive elements through which these computers are built up.

(Refer Slide Time: 06:54)



Now with this, with this observation about personal computer, we can try to make some generic properties and we will slowly build up on those properties. First thing we observe is each level of hierarchy represents a layer of abstraction which you mean is if I talk about a personal computer itself is an abstraction, is a concept and so I can say that the at this is at the top level of hierarchy, this is the personal computer.

(Refer Slide Time: 07:35)



Now I say that this is comprising a number of other levels hierarchically of HDD of monitor, of keyboard and so on. Now the CPU in turn has ALU, it has memory; it has bars and so on actually. So what am trying to point out is, if you look into every say if you look into this layer, if I loo if I look into this layer, then these different components of this layer together buildup the higher layer in turn if you look into any specific component here, that again is built up by other subcomponents.

So each layer is built on top of other layer. This layer of CPU is built on top of this layer. In CPU, hdd, memory, monitor, keyboard all makes up the next layer. So these are just examples shown here of these multi layered structure like CMOS gates build NAND gates, NAND gates build registers and so on. But in spite of all of that, the major property is that every layer can be independently understood. I can study CPU independent of any other layer anything else.

I can they work independently with what you call is a clear separation of concerns that is when I look into the functioning of an ALU, I just assume that there is a memory through which I can send a data and keep it as long as I want. But I do not really need to know how the drams in the memory, the flip-flops in the memory really work to make that happen and when I concentrate on organizing the memory, what are the different ports, how the address to be decoded and so on.

Am really not concerned with how numbers are added in ALU. All that I know is ALU might ask, the CPU might ask for some value to be stored or retrieve from the memory and at that point of time, we can just respond to that request. So this individuality, this individuality is as will see can be sort of is called the separation of concerns that is different systems within themselves can function independently.

And across systems there is an interconnection there is an interlink which has to be clearly which is clearly specified. Further we can make some more observations that in addition to this hierarchy and this independence of components in subsystems, there are some common services and properties that are shared across layers. For examples many of you who have having background of electrical sciences would know that.

If I have a CPU, then the CPU needs power. all components of the cpu, the memory needs power, bus needs power, the ALU needs power, the registers needs power and each of the component separately do not get a power tree which kind of distribute the power to different components. This power tree is there for a common facility, common service that is shared by different components.

And in every many systems we will see that this particular concept will be applicable. Given all this, what we observe is we have several subsystem of every system and when we look at the system and the subsystem separately we find interesting observation that if we just take the subsystems as a collection and then we put them together, then the system we get actually more than just the collection of subsystem.

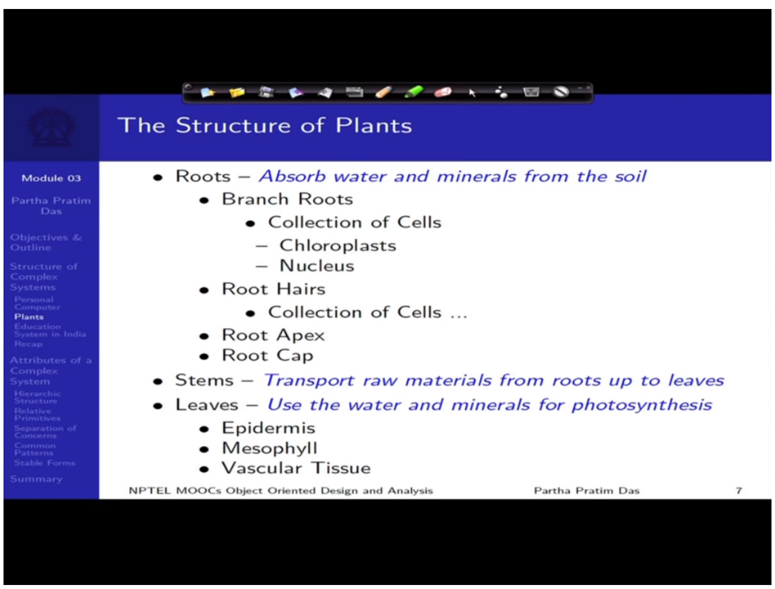
ALU by itself can only add 2 numbers in a register and so on. Primary memory by itself can store some values, retrieve those values, the bus can only take a value from one point to another. But when you put them together into a CPU, it can execute a program and this principle is known as a emergent behavior principle. The behavior when you say that the behavior of the whole is greater than the sum of its parts.

So behavior of the CPU is more than the behavior of the ALU plus the behavior of the memory plus the behavior of the bus and so on. Together when they are put or put together, properly interlinked then they build the whole system which has a high emergent behavior. Finally we will observe that the systems complex systems often demonstrate cross-domain commonality that is all this different hierarchy.

And commonality that am discussing in terms of personal computer if I just go to one of the modern day cars and try to look into different subsystems of steering control, break control, air condition control, the wind control and so on, we will find simpler processors there having similar, very similar kind of functionalities so if I understand the functionality of a cpu kind of or a personal computer kind of complex system, and there the same logic would apply.

For understanding mobile phone understanding air craft controls and so on. So there is a lot of cross-domain commonality that can be found so these are some of the generic observations that we are making from our example of personal computers.

(Refer Slide Time: 13:47)



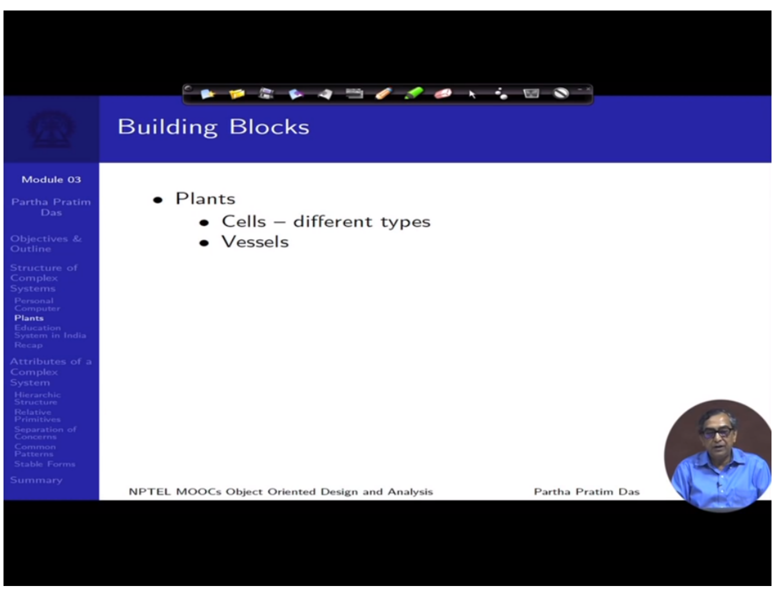
Now let’s move on to take up the next system which is the natural system and we look at the structure of plants. am not a botanist um exactly I don’t expect whole lot of knowledge of botany but all of us understand this much which we studied in school that a plant comprise of primarily few parts. There has to be roots that go into the ground usually there are stem and there are leaves. Roots observe the nutrition, the water, minerals from the soil.

Stem carry those from the root to the leaves and the leaves use water, minerals and the sun rays to do photosynthesis so that food can be prepared. These are the basics. So if I look at the plant as a system then these are the main 3 subsystems with their functionalities. Now again like in the case of personal computers we can start decomposing and look into subsystems. The roots have branch roots, they branch through the soil.

They are find at the end there are root hairs, at the end of the hair there is a root apex and a root cap. So any roots can be typically thought of to be comprising of four different subsystems as listed. In turn branch roots will be comprising a collection of cells. Every cell will comprise of chloroplast and nucleus and so and so forth. Am just expanded few few places only to give you a representative idea if I expand it all then it will really become an essay in botany.

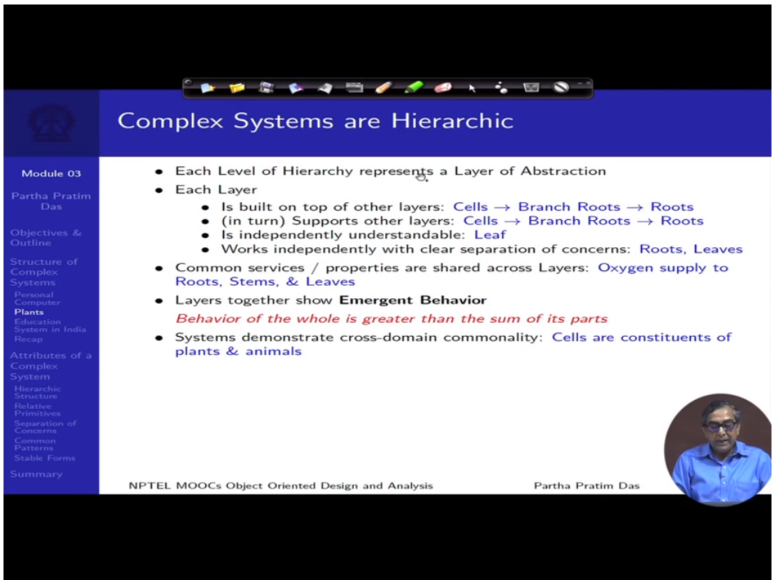
Similarly if we look at leaves they are formed of subsystems defining epidermis, mesophyll and the vascular tissues. Similar decomposition is possible for stems and multilayers. So this is what we find in a natural system and again if we look at how this is implemented we say that the building blocks are few.

(Refer Slide Time: 15:43)



The cells of different types and there are vessels to carry a fluid carry information from one part of the subsystem to another, something that we should note is is kind of very common with what we saw in personal computer that such a complex system that personal computer has very few building blocks like interconnects and gates and so on. Similarly such complex systems as plants has very few building blocks fundamentally in terms of vessels and so on.

(Refer Slide Time: 16:19)



Now I take you back to the same characterization chart that I discussed in terms of a personal computer the same set of points but I just read these points now in the context of a plant system. Again we have seen that it is hierarchy it has different levels of abstraction the plant being in the highest level, then you have roots, stems and leaves roots have branch roots and so on. So each layer again is been build on top of the other.

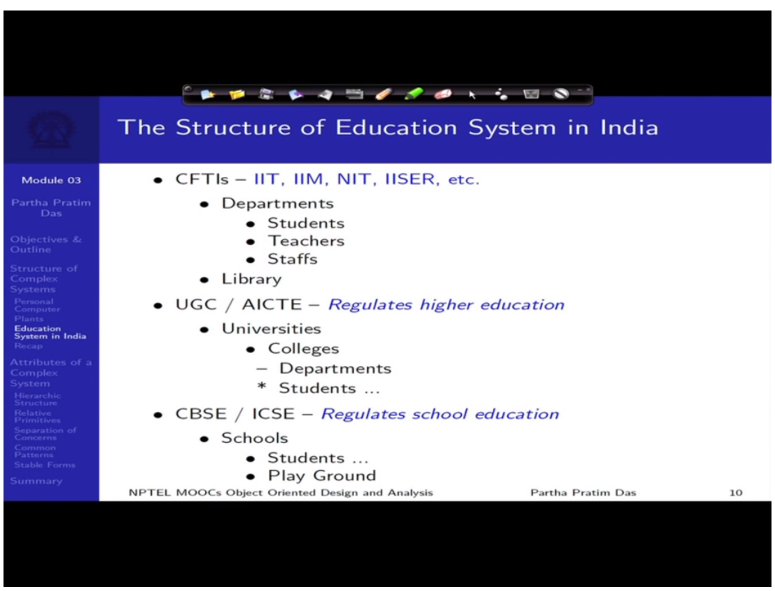
You can see that cells form branch roots, branch roots going to forming roots and so on. So if you look at branch roots, it has to use cells. It is build on top of that. If you look at branch roots, they help to build up roots and e a each one of them each one of these subsystems can be independently understand like a leaf and they work independently with a clear separation of concern. The way the roots function we does not need to know photosynthesis happens in the leaf.

And when the le when we study the leaf, we do not really need to understand the osmosis that happens to observe water and minerals to the roots. Again together we can take up a leaf we can pick up a stem, we can uproot a plant, but when you put them together in the system is properly interlinked, you find the budge and behavior of a plant which is certainly bigger than the independent behavior of these components.

And very interestingly the natural world show a significant amount of a cross-domain commonality. For example in parallel to plant systems if we just study animal systems, we find very similar hierarchy of different plot systems like digestive systems, like reproductive systems, like respiratory systems and so on. We can keep on decomposing that but when we go to the basic building blocks they are again cells. So the cells differ.

They are they are different kind of cells, animal cells have certain properties, plant cells have different properties, but fundamental part is they are undeniably these are cells. Those are the consequence of plants and animals both. So across domain, we find commonality here as again as we saw in case of the personal computer.

(Refer Slide Time: 18:37)

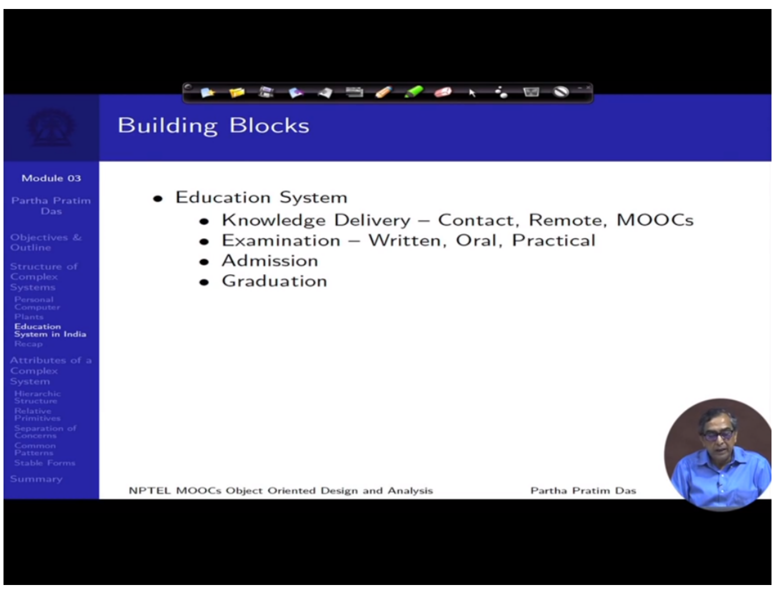


So let us move on and take a third example which is kind of a social administrative system and since we all are in in India and related to education and so I take an example of education system in India. So I we look at the education system in India if you take that as a whole system and try to analyze you will find that they are significantly divided in terms of centrally funded technical institutes like CFTIs.

Then there are organizations like university grants commission or aicte who regulates higher education and there are cbse, icse and so on who regulates school education. Now if you look into any any one of this particularly CFTI you will find that CFTI, IIT is like a CFTI, is a CFTI. You will find different departments, libraries, stadium auditorium and so on. Every department will have students, teachers, staff.

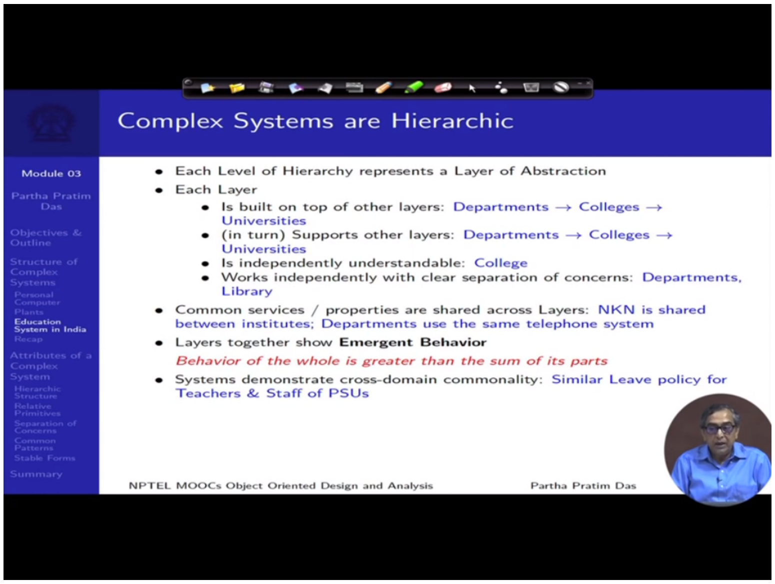
Similarly if you go to uGu and start decomposing that you will find universities. Universities will have colleges, colleges have departments, departments have students and so on. Cbse has schools, schools has students, play grounds and so on. So again we see that in a system of social political administrative nature we again see on one side we do see it's a really complex system again but it again shows a same kind of hierarchy, same kind of uhh system subsystem decomposition that exist.

(Refer Slide Time: 20:07)



Building blocks there are very, in the education system there are few building blocks one is the knowledge delivery that is how people teach, one is examination how knowledge acquired is checked and how people joined this institutes and how they graduate and go out of this institute. If you look at all of this institutes and educational system that this is based on defining our our ah specializing this specific building blocks on which then you add different variabilitys, conditions in terms to buildup these systems.

(Refer Slide Time: 20:44)



So will be back to our characterization of complex systems in the sense like now you are interpreting this in terms of the education system. So again the highest level of abstraction is the education system in India, below that we have CFTI and UGC and all those and then the appropriate ones. For example if we look into this particular that departments build up colleges, colleges build up universities.

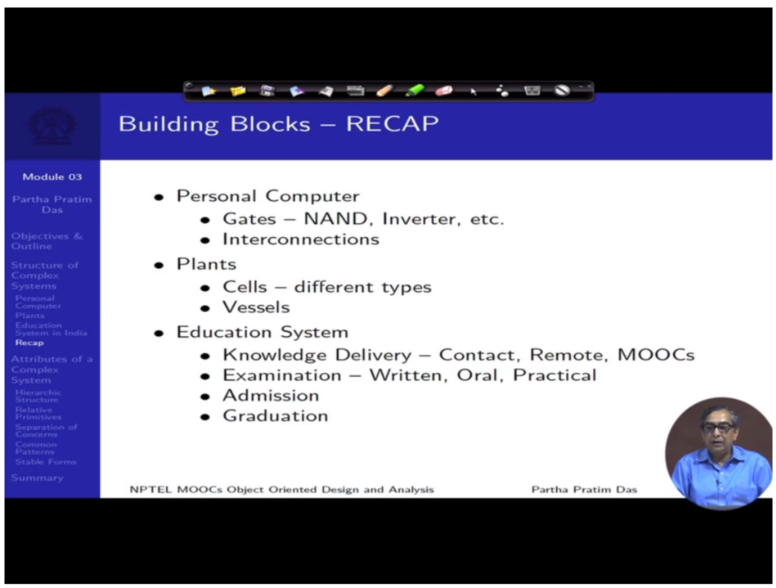
So if you look at colleges, then it is built in terms of the layer of departments and colleges go in terms of building the university layer. So the similar kind of the structure that we had seen for a personal computer and system and the plant system we do see here. We do see that this systems, many of this systems can be independently understood, there is separation of concern the department and library has to function together.

But how a department functions and it conducts its classes and examinations and all that is not required to be understood by a library system which has requirement of books, issue of books and so on and vice versa. So they enjoy a whole lot of common services like nkn is available between institutes dep the many departments but they have the same, they use the same telephone system and finally they should demonstrate the emergent behavior.

When we just take the library separately, the department separately or the play ground separately, we have certain functionalities but when you put to them together then we have a college which has a bigger functionality. When you put 100 colleges together under a university we have a traditional behavior and certainly also in terms of cross-domain functionality, we find that different practices different properties that are held in the education system are also enjoyed by several other.

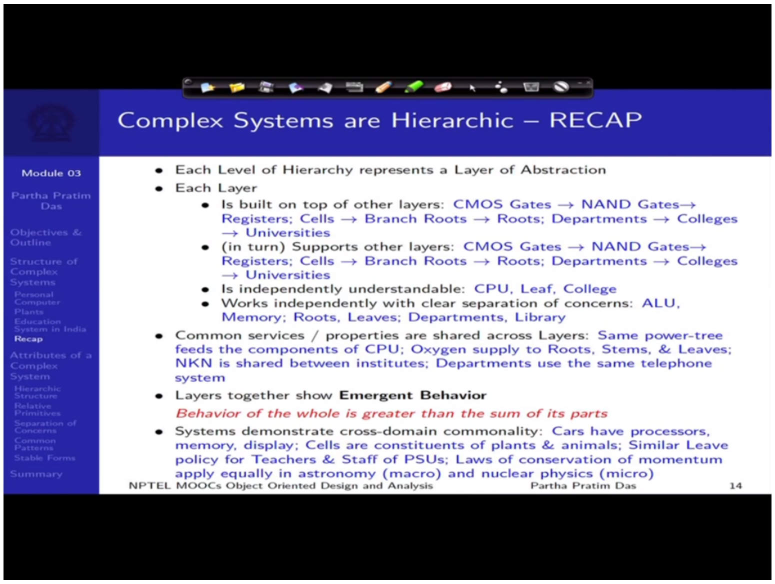
For example the leave policy of teachers and staff will be lot similar to the leave policy of teacher and staff in the public sector units psus.

(Refer Slide Time: 23:10)



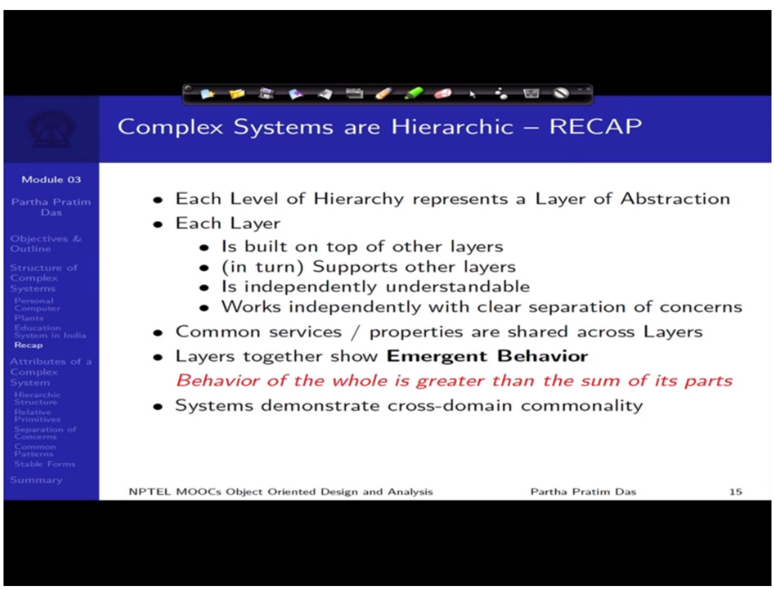
So in short what we want to conclude from these examples is that here is whole lot of similarities between all these different kind of system irrespective of whether they are manmade they are natural they are social or (())(23:13). So just recap that we saw that every system has a few primitive building blocks, personal computer, plant education system all of that.

(Refer Slide Time: 23:28)



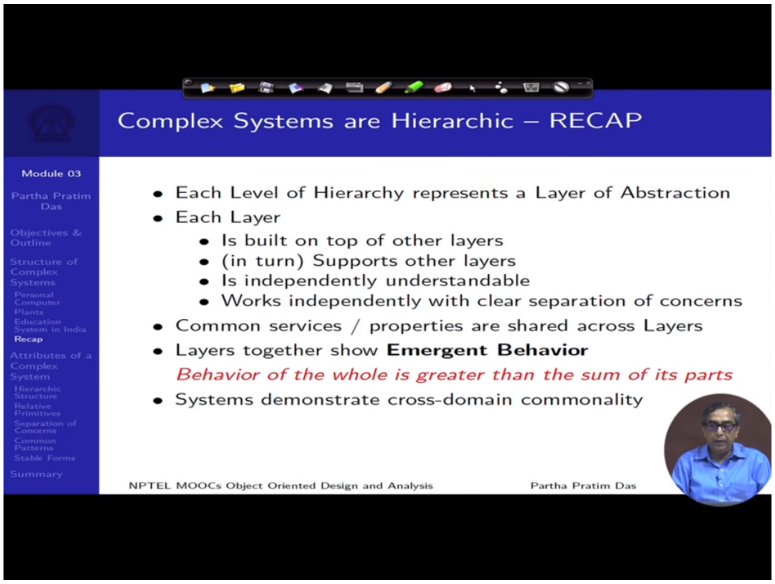
And just putting everything together that complex systems are hierarchical and they demonstrate a whole lot of properties which are independent of whether it is a manmade system, it's a natural system or whatever kind of system, complex system typically show these properties. So these are collection of all the instantiation for your easy reference and I have some additional ones also included here. But I will just clean up and show you.

(Refer Slide Time: 23:57)



This is the take back we want to do from this short study of structure of different complex systems that to summarize complex systems are hierarchical. This is the major observation we are making and it has multiple layers of levels of abstraction and abs levels of abstractions are interrelated. Every level supports the higher level and is supported by the lower level. Every level can be understood on its one.

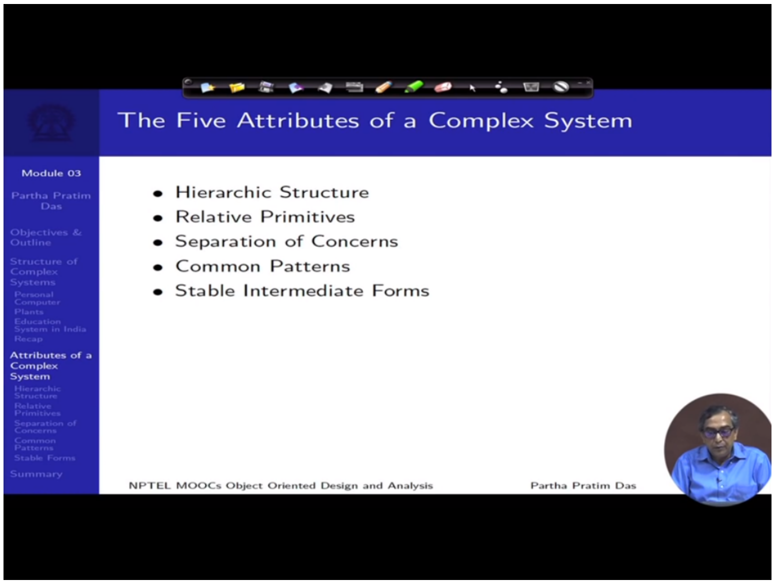
(Refer Slide Time: 24:24)



The different components in a level have separate concerns which can be independently studied put together every level build up a bigger functionality for the next level and there are lot of cross-domain commonality in terms of these systems. So we started with the issue of how we actually handle complexity and this was our first step to go forward analyzing the complex system and through some examples we analyze and come to the conclusion that while the complex systems are indeed complex but they do show a lot common properties.

So if we build up strategies, if we build up further analysis based on these properties, based on these characteristics, then we hope to be able to analyze a new complex system lot more effectively.

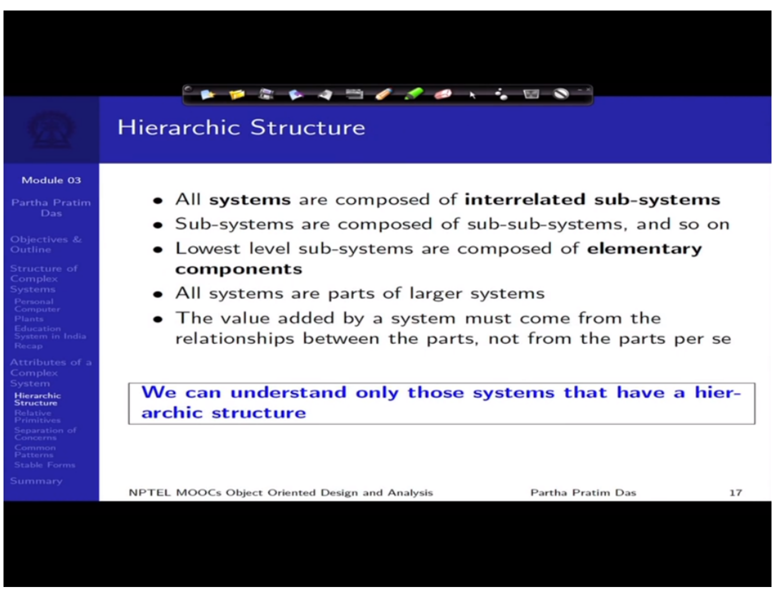
(Refer Slide Time: 25:17)



So with this intention we go forward to just put all these observations in a very crisp forms and this is typically called the 5 attributes of complex systems. That every complex system will have hierarchic structure and this hierarchy will terminate in a primitive which is directly defined. Now what is a primitive and what is not a primitive is kind of a subjective decision. There will be strong separation of concerns between these components

Across domains there are similarities so there are common patterns that happen across domains and the whole development of such complex systems has to happen through a reted iterative refinement process. So at every stage we need to have certain intermediate forms.

(Refer Slide Time: 26:14)



So just to quickly illustrate a hierarchical system we have talked we have been talking from the beginning of this module, we have been talking about this systems. So they are composed of interrelated subsystems, sub-subsystems and so on and at the bottom they have the elementary components. And we can understand now you can question that it is it necessary that all complex systems be hierarchic in nature and show these behavior.

The reality is that the complex subsystems that we study do show this behavior or we can put this differently that only those complex systems we can study and you know try to think of putting up a software system on where this hierarchy exist. So it is kind of our basic assumption is hierarchy is the kind of base line, is kind of the foundational part of the complex system on which the remaining 4 attributes are built up.