Systems Engineering
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Lecture - 09
Complex Systems & System Development Process

Good Afternoon. Today, we are on the ninth lecture of the systems engineering and today our topic is Complex Systems & System Development Process. So, we are getting into the tools and now we are getting into the different components of the system and we understand the components of the systems before we understand the tools because if we know the components then knowing which tool to operate on which component is easy.

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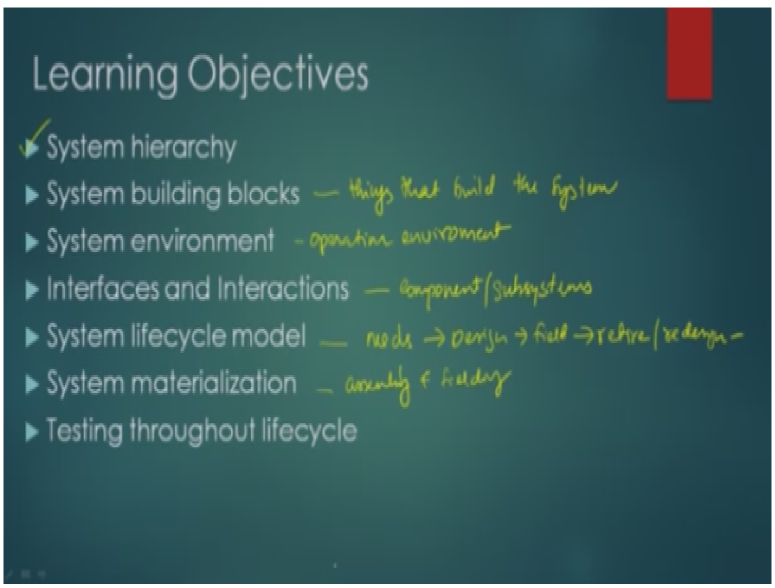

So the major learning objective today includes the system hierarchy or the order in which the different components of the system are put together. System hierarchy of it is the order in which these components are put together then the building blocks of the system or things that build the system. Then the environment the operation environment in which we are talking about the environment in which the system operates.

Then we talk about the interfaces and interaction so these are the components/sub systems. How do they interact? How do they interface with each other? Life cycle from needs to design to field to retire/ redesign like this. So, the life cycle of the system materialization which is like assembly and fielding, all those kind of thing is part of this and how do you do testings. So, we go through all these major aspects one-by-one in this todays lecture. We will get to some level and stop and then we will continue in the next lecture.

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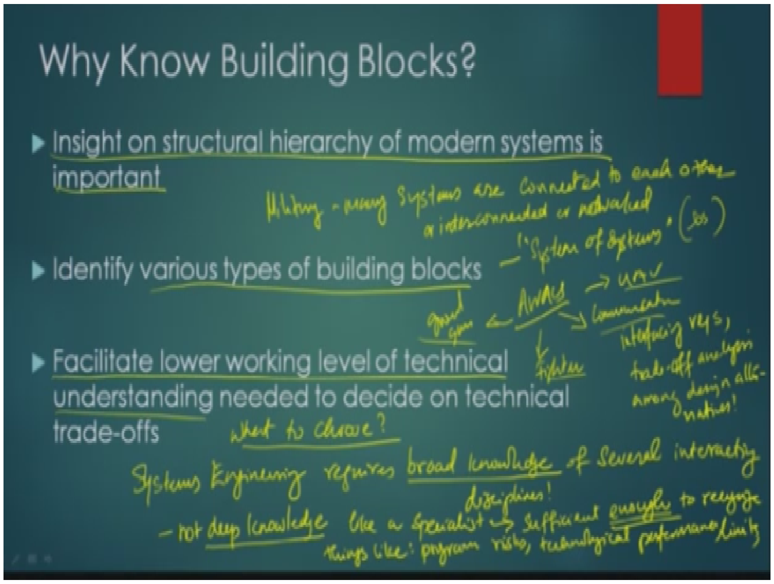

So, the first question obviously is a what do need to know the building blocks of the system and before getting into this we should understand that System Engineering requires broad knowledge of several interacting disciples. So we are talking but the concept here is the broad knowledge. Okay. We are not talking about not deep knowledge like specialist. So the system engineer is not supposed to have the deep knowledge about the specialist.

There is nothing wrong in having it but a broad knowledge is sufficient. The idea here is what is broad knowledge or how do we define it? It is sufficient enough to recognize things like many things that he need to recognize. Like program risks, technological performances and performance limits. Then I will write somewhere up here in interfacing requirements then we also talk about the trade-off analysis among design alternatives.

So, the system engineer should have enough knowledge to understand things like or recognize things like the risk of the program, technical performance limits, interfacing requirements, trade-off analysis amongst different alternative etcetera. So, with this in the system engineers should understand the building blocks because the insight of the structural hierarchy of a modern system is important. How does the modern system is structured? it is important.

There are various types of building blocks in the system even to the earlier things people use to say that system encompasses the ultimate design. But now a days, we have what we calls as in military many systems are connected to each other or interconnected or networked. This creates the new concept called “system of systems”. So a classic example of this is if you think about it if we have an AWAC system, which is called as the Advance warning airborne radar system.

So, it will have the fighter jects underneath it. It will have the communication network. It will have the UAVs underneath it. It will have the ground guns underneath it. So, many stuff like that. So, it is where different system the fighter jet system, the communication system, UAV systems, ground guns etcetera they are all interfaced together to create a system of systems which will be an advance warning system which is controlled by an airborne radar based systems.

So, using all of these so the concept of systems have arisen or SOS has arisen as well. So, it is very imperative to any system engineer that we learn the building blocks of a system. What are the various types of a building block of a system and when you know the building blocks it will result something like this. Facilitate lower working level of technical understanding so you would require the lower level of technical understanding which is necessary to desired on the technical trade off.

So what to use even if you are making what to choose? This decision requires the lower level of working knowledge and this working knowledge that we mentioned earlier. The knowledge that is sufficient enough to make multiple decisions for that the system engineer need to understand what are the different building blocks of the system?

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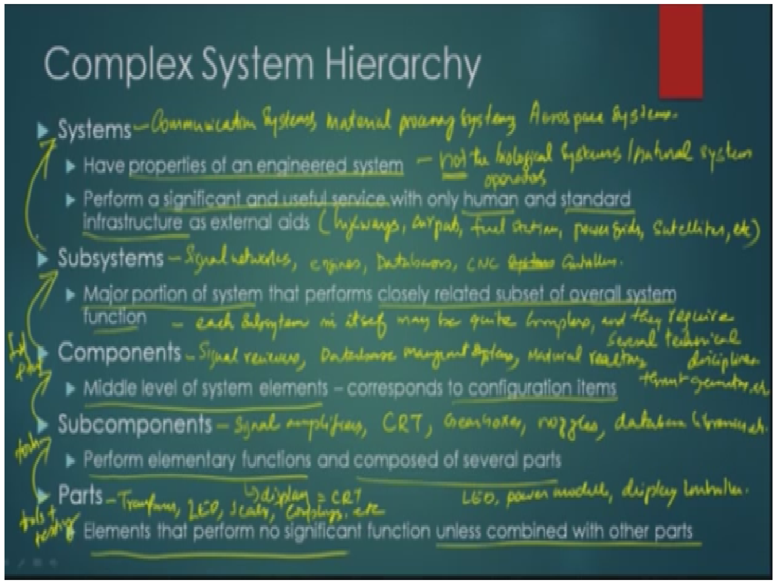

In a complex system hierarch if you think about it there is the systems then subsystems, components, subcomponents and parts. Other, many classifications are available but this classification to a larger extent givens a sufficient breadth and depth to do enough analysis into the aspects of the system. So, when we talk about the system some of the examples of the system include communication systems.

There is also we can think about it as the material processing systems or manufacturing systems. You can also think of as aerospace systems these are all examples of systems. And the major advantages of the systems are you should have properties of an engineer system. So, we are not talking about the natural systems or biological systems. Okay, not the biological systems or natural systems. We are talking about engineer systems. Not, is the key word.

And also the system should be capable of performing a significant on usual service. So it should do a significant and useful service with only human standard infrastructure as external aids. So, human an operator we can think of the human as the guide who is operating the system operator or operators plural form and standard infrastructure. So, what involves a standard infrastructure? Typically, things like highways, airports then we also we can think about it as fuel stations, power grids, lights etcetera.

So, the system might use one of these standard infrastructures. The country will always have highways, the country will have airports, countries will have power grids. So, the aerospace system would require to use airport. Similarly, like material processing system might use the power grid for powering its machines. A communication system might use satellites or it might also use the power grids as well.

So, it will depend upon the standard infrastructure and human operators to perform a significant and useful service to the user not to the mankind. So, if think about the system in that way then subsystem what are some of the examples of the subsystems will be signal networks, then you can think about it even the case of an airspace system. One example would be engines; aircraft engines, think about jet engines or turbo prop or anything you want.

You can think about data bases, then you can think about CNC systems something like this. These are all sub CNC controllers they can all be part of the subsystems. So, what do they do is it is a major portion of the system. So, subsystem do form a major portion of the system and it can perform closely related subset of overall system functions. So, each subsystem in itself may be quite complex and they require several technical disciplines.

So, they are capable of performing the major task or major portion of the system functions and what it is? It can also do a subset of the overall system function to a good possible extent. So, some example also cited earlier as signal networks engine data bases etcetera. Then we also talk about stuff called components. So the components are the middle level of the system elements. Earlier components use to be considered as equivalent to the lowest possible level.

But now in this consideration we would look at the middle level of system elements with some of the examples being let us say in the signal receivers, data based programs, data base management systems. Then we can talk about material reactors, we can talk about thrust generators etcetera. So, these are example of the components. So, they are middle level of system elements and they correspond to configuration items.

So, they kind of do some major task that is part of the subsystem. So like for example the thrust generator is, it helps the engines to generate the thrust which actually provide the propulsion main function of the system, aerospace system. So, you can think about it that way. So, the components to a large extent is a middle level of system elements and to a large extent it is still you know half.

Because, it earlier used to be very few disciples in engineering but with the advent of this interdisciplinary engineering approaches there are many aspects. So having a component as below the subsystem actually helps you to further create a functional hierarchy in the system and you can apply system engineering concept into this. Then comes the stuff, the next classification called subcomponents.

And some examples would be includes signal amplifiers on CRT or what we call as the cathode ray tubes. We can talk about it as gear boxes. We can talk about it as nozzle in the engine. We can talk about as the database libraries. So, these are examples of the subcomponents which are critical to the components to deliver the function as it requires to ensure that the subsystem can perform an overall sub set of the system functions.

And when subsystems integrate together they create systems. So, all subcomponents what do they perform? Elementary functions and they are still composed of serval parts. So, CRT the elementary function is to do display. Display equal to CRT and it would have probably an LED screen, power module, display controller something like this. So, it will have still many parts but it will do one elementary function of display.

So, finally, we talk about the parts. There are quite examples like for example will be a transformer is a part. LED is a part then seals, couplings etcetera. These can all be thought about parts which are elements that perform no significant function unless combined with other parts. So, the LED might just glow but unless you combine one LED with another LED and a controlled device then only you will be able to get a display system or a display screen.

So, elements that perform no significant function unless combined with other parts can be thought about as the basic level of the parts and then parts together become subcomponents and subcomponents together becomes components and components integrate to become subsystem and subsystem integrate to become systems. So, we think about it in system engineering at each level we apply different tools. So we have tools plus testing happening at each level.

So, we will be care tool plus test keep on going. So at each level of integration we are ensuring that the system needs the functional requirement. Each level hierarchical level meets the functional requirements of the total system.

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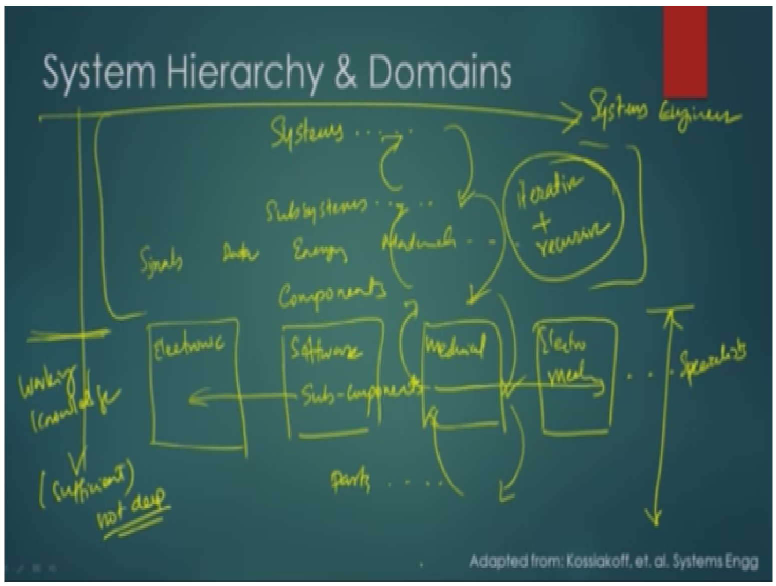

So, if you think about the hierarchical this diagram is adopted from Kossiakoff.et.al. Systems Engineering text book its very famous and well known. So, if you think about this system engineering as a discipline. So at the top level we have something called as systems. There are quite a lot of systems as part of it below that we have subsystems as we see. So, some of them will be signal as we said you will have data.

You will have energy. You have materials. All those kind of thing come along as part of it. Then you have components so this much divisions usually you can think about it as the domain of a systems engineering. Below the components there we have some subcomponents like electronic, there is the software and there is the mechanical and there is the electro mechanical stuff like this. All these things we can group them together as subcomponents, many of them will be here.

And below the subcomponents we will have parts, quite a lot of parts as we have seen. So this area from here onwards is the domain of what we call specialists. So, this is where the person would have specialized knowledge in developing these parts as well as the subcomponents where these parts integrate to. So, in this place the knowledge of the system engineer will mostly be in the form of a working knowledge or what we call as sufficient, not deep.

All this knowledges are associated with this part but in this area where this is the system engineer could write this aspect. So, this system hierarchical documentary picked up in mind is because as we drilled down from each level we moved from system to subsystem, subsystem to components, components to subcomponents, components to parts. Remember we talked about iterative plus the recursive that aspect you can actually see here and this is where we are drilling down to go into the lowest level and then building back up.

So then you integrate back up from each level do interesting another stuff to make sure that the system comes in or system gets together or get assembled in the way you wanted to do, get it done.

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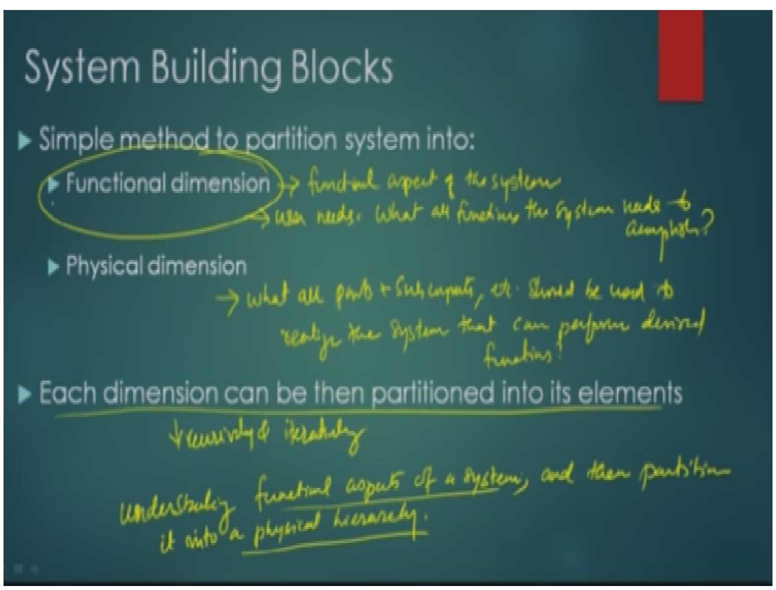

Now we will talk about these building blocks of the systems and it is necessary that we need to understand this in a simplistic aspect. The reason why we need to do or learn the system building blocks I said it earlier but it is mostly towards understanding functional aspects of a system as a first part. And then partition it into a physical hierarchy. So when you understand the system the functional aspect of the system you might not have chosen the physical aspect of the system.

But you might have just focused on the functional side, you said like okay, I need this much range you might not have specified on what engine and what fuel you are going to get the range. So, then once you decided the range and other aspects which is the functional aspect of the system how, what physical component is going to get you that realize that is where the physical hierarchy comes into picture.

So, every system can be classified into two parts, in two dimensions. The functional dimensions, where the functional aspect of the system is understood. Where does this comes from? From the user needs. What all functions the system needs to accomplish. This is the major aspect of it. Whereas the physical dimension on the other hand is what all parts plus subcomponents, etcetera should be used to realize the system that can perform desired functions.

So then once you know the functional dimension then you can choose the physical components accordingly. Once you have the physical components then all you need to do is worry to integrate them in such a way that the functional dimension met. So, each dimension can be partitioned into its elements. So the functional dimension can be partitioned down where we call as we can recursively and iteratively partition it into its elements.

So how do we do that we will actually, see this. So, let us first talk about the functional building blocks of the system and then we will take about the physical dimensions.

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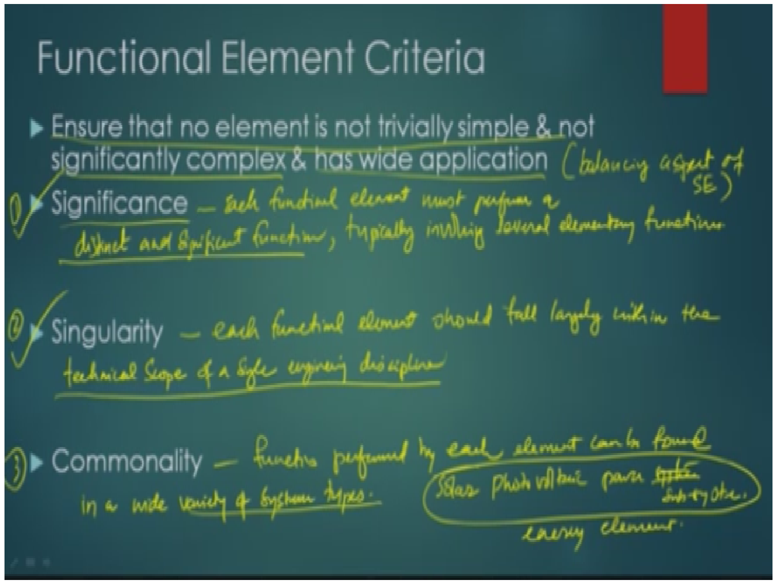

So, the functional building block of the system we can talk about it as it is basically can be classified into three major things. So, there are like three major classifications. What are those major classifications? That is information, energy and materials. Almost everything that you want to do with any system can be classified into this so the information is if you take about what is information?

Let us define information as that aspect the functional aspect that contains all knowledge and communication. And it should also be noted that it is the largest chunk in any system or portion of any system and hence further classified. What are they further classified into? They are further classified into two they are Data elements 1.1 and Signal elements 1.2. So what is the data? So let us talk about the data elements?

Data elements it basically, they are the elements, functional elements that deals with all types of stationary information. So thing that are to be stored that available stationary, not changing over time. So stationary means do not change over time as time progress the data does not change as much or their kind of stored in a hard disk or someplace where you are accessing it. Whereas the signal on the other hand is they are the elements that are related to information propagation.

So, mostly the data element is from where you use data elements to generate information and this information if you want to propagation then you use the signal elements. So, that is how the data and the signal elements are the subcomponents of the information building block which is the functional building block. If you talk about the energy then what is the energy we can define it as the it is that part that energizes the system and ensures movements of all system components.

In simplistic terms is the one that provide power. The power is a loosely time but this is a colloquial usage. Some people say that energy is the one that energy is the one that actually provide the power for the system to do the work or is capable to do the work. So, the energy elements then we talk about the energy elements are the one that provide energy and motive power anything. It could be an engine. It could be a battery.

It could be a fuel cell does not matter. Some of the aspects any aspect it could be thermo compliment or could be light source optical source. Anything that actually provides energy or motive power for the system so that it energizes the system and ensures movement of the system components that is what comes as the energy which is the second functional building block of the system. Then third we have the material which is the substance of all physical objects.

This is how you actually make the thing that it forms the skeleton of the physical system. Does not have to be skeleton it can be everything else skeleton plus others. All of those aspects are part of this. Then what are the elements material elements so they provide structure to the parts subcomponents etcetera and they also do transformation of materials. So, you might have like raw material in the form of metal but you might melt it into a molten form.

And then you cast it and create a particular part which could be used as a casing for an engine then that would be component of the material elements of the system. So, the material, energy, and information are the three functional building blocks in which the information is classified into data and signal elements and energy has only energy elements and material has material elements and we have broadly seen what are some of the aspects that constitute these functional building blocks as part of the system?

Now, we also need to talk about the functional element criteria and the functional element criteria to a large extent if you think about it, it has three aspects but the functional element criteria it ensures that no element is trivially simple. Neither, no element is not significantly complex and it has wide applications. Remember we told about that the criteria of that we use the significance, singularity and commonality these are the three criteria.

One, two and three we use this criteria to ensure what no element is not trivially simple. So, we ensure that is just not that simple because sometimes the trivially simple things you might not need to go through all this type of analysis. And we also want to ensure the same thing that they are not significantly complex either. So, as I said earlier it is the balancing. So, this is where the balancing aspect of system engineering comes into picture.

So, first we talk about it is significance. So the significance can be defined as the each functional element must perform a distinct and significant function. So, each functional element must perform a distinct and significant function typically involving several elementary functions. So, what we are interested in here is that the significance of the functional element. Each functional element must perform a distinct and significance function typically involving several elementary functions.

So, this is where you actually do the balancing. What is the distinct and significant function that we choose out that then the singularity aspect of this is each functional element what does it do should fall largely within the technical scope of a single engineering discipline. So, this is where the singularity aspect of it is you should also be functional element should be in such a way that it should be within the technical scope of a single engineering discipline.

So the interdisciplinary components we are further breaking it down into a level so that individual engineering discipline experts can actually take care of the technical scope of the functional element. Then the last one is the commonality where we basically see that the functions performed by each element can be found in a wide variety of system types. So, if somebody says I have a solar photovoltaic power system or power subsystems or you can say power components whatever you want to call it.

Then this is a functional element because it actually provides with the energy element and it is an energy element because it can be found in a wide variety of systems. It is found on the household systems. You can find it in satellites. You can find it in an automobile. You can find it even people using it for charging mobile phones. So, you can see in wide varieties or system types you could see this function being performed.

But that is just not sufficient enough that is one aspect you should also have singularity. You should also have significance. All right so we move to the next aspect.

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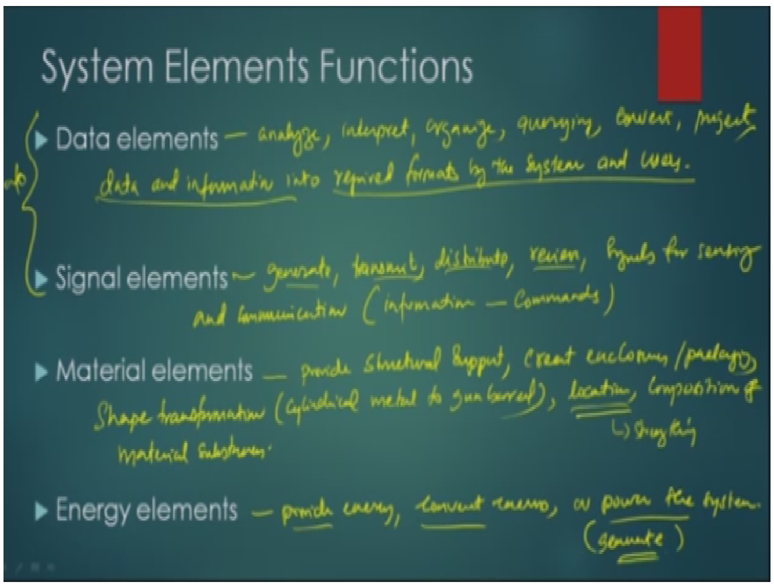

which is the system element functions. So, what are the functions of the element that we talked about? So the data elements and signal elements as we said earlier these two combined together that is part of the information and that the material elements and the energy elements are part of the material and energy functions. So, this is that classification. So, what the matter of the major function of the data elements?

So, the major functions some of them you can list it about is as analysis, interpret, organize you can also do querying. You can also do converting, convert, project what? Data and information into required formats by the system and users. So, the data elements function is to analysis, interpret, organize, query, convert, project, data and information that is the critical part into the required formate by the system and the usages.

So, that is the major aspects of major function of the system, the data element. Whereas on the other hand id the signal element the function will be to generate, transmit, distribute, receive what? Receive signals for sensing and communication. So, here it could be in sort of signals. It could also be information or it could be commands whatever.

So from the data the information can be generated or the user might have given an instruction through which when it passes through the signal element it will generate a signal, runs with the signal or distribute the signal and receive the signal so that the communication between different components of system are possible. The material elements what do they do? There function will be to provide structural support. It also creates encloses or boxes or packaging.

It can create the shape transformations like a cylindrical metal to gun barrel something like this to be an example. Then it can also talk about the location where all these strengthening are required and it also can involve the composition of material substances. These are all parts of the or function of the material elements of it. As they provide structural support. They create enclosures or create packages.

They allow for shared transformation to do for locations which is like sometimes it can also can be thought about as strengthening is also one part of it etc. like that. About energy elements what do they do? They provide energy they can convert energy of power the system. So there can be multiple ways you can prove energy or can convert energy or you can power the system. So, it can generate as well as well as –is also another way to think. It is colloquial way of thinking about.

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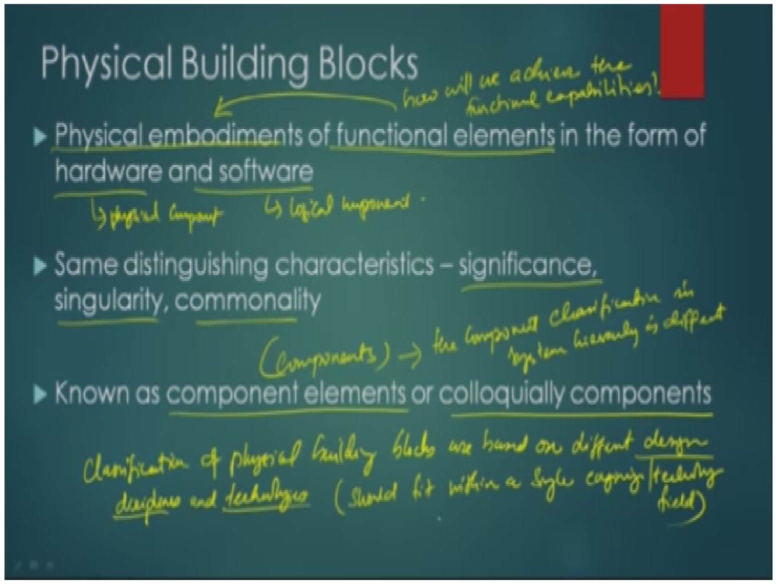

So, now we talk about the physical building blocks. So the physical building blocks to a larger extent they are the embodiments, the physical embodiments of the functional elements. So once you identified the functional elements then how will we achieve the functional capabilities? This is the where the physical embodiments of the functional elements in the form of hardware and software.

Can be hardware because here it will be physical component and software we can thought about as a logical components also. There could be other components as part of software as well. There are many distinguishing aspects okay characteristics, same distinguishing characteristic. The significant singularity and commonality that we discussed earlier in the previous slides.

So, if you think about this you talked about it here the significance singularity and commonality which are part of the functional element criteria. They are also applicable to the physical building blocks or the physical elements as part of this. They are typically called as component elements as where sometimes people use the word components and then this get confused with the components that we show in the functional, the system hierarchy.

So, they are the component classification in system hierarchy is different compared to what we talked about these component elements or this colloquially components that many of the people in the system design process use. These are two different things here we are talking about the physical stuff. There we are talking about the functional aspects of the system. So to a large extent how does this physical building blocks the classification of physical building blocks are based on, they are based on what?

On different design disciplines and technologies. So remember we said earlier that the elements one of the aspect is the singularity or should fit within a single engineering technology field. So, that aspect is also there. So, the physical building blocks classified based on different design, discipline and technologies. So, depending upon the design and disciplines we have different types of components or the technologies that are used also defines the different discipline components.

So, once you have the functional elements from there we try to create the physical elements or the physical embodiment how that will help in achieving the function.

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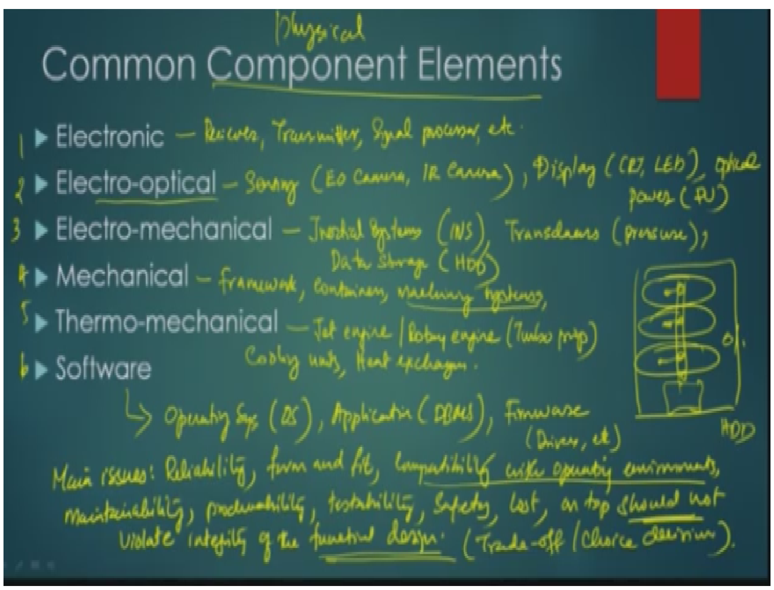

So, what are some of the common elements so the common elements are electronic, electro-optical, elector-mechanical, mechanical, thermo-mechanical and software. So, let us go through each one of them with few examples and see what are the typical functions. So, the electronic elements when we talk about it the physical elements or the component elements so here we are talking about the physical. So the electronic one it will be a receiver.

Example transmitter, another example there could be a signal processor etcetera. So these types of component elements which will achieve the electronic functional capability or it will provide the electronic functional capability is what is classified as the electronic components or the electronic physical components. On the other hand, when the elector-optical ones their major job is to do a sensing. Sense the like the electro-optical camera or the IR camera, infrared camera.

These kind of things are part of the sensing then there are lots of part of it that display like CRT, LED they are all part of that. Then we also have what we call as the optical power. So, optical power one example of this would be our photovoltaic (PV) or what we call as the solar cells. So they are all part of the electro-optical systems. Then we also have the electro-mechanical systems. So some of the electromechanical system involves, inertial systems.

So, in aerospace we actually use that as INS, National Navigation System, they are classic example of electromechanical systems. There are transducers like example pressure transducers. They use pressure or they measure pressure and convert that into an electric signal or voltage something like that. And another example of electromechanical device is the data storage or classic is HDD hard disk drive.

Because we know that there is a mechanical a hard disk is designed something like this you have a spindle on which multiple disk are created where or magnetic disk are there on which head moves and writes different types of data on that with the help of electrode depending upon the signals that is given to it different bytes zeros and once gets stored on that and there is a motor below that actually spins these spindles in which these disk actually rotate at a specified speed and they write on top of that.

So, these kind of a system so when it put into an enclosure and other things it becomes an HDD hard disk drive which would be an electromechanical component of computer system. So, another thing we talk about is the mechanical systems. So one of the mechanical systems they are examples of it like framework, there are containers, material processing machines or machining systems like lathe, drilling machine etcetera. They are all part of it.

So, there is some mechanical power or some motion happens and using which you apply a force to create, to remove material so that you can do the process the material to create something like a container of a framework or a specific part that can be used for assembling may be electro mechanical or electro-optical components and then joining them together with other things that is all part of the integration into a system stuff.

Similarly, there is a thermomechanical example also which is typically you can think about as a jet engine is an example. You can also think of a rotary engine is also an example which is a turbo prop as an example of it. There can be example of cooling units. There can be example of the heating units or the heat exchangers etcetera. These are all physical component elements of the thermomechanical which also form together to part the, to realize the functional element of the system.

And finally with the software example operating systems, which we call as OS then we have applications. One application could be DBMS. You can also have Firmware so if you have a display card then a driver that is used for this drivers and stuff like that are part of the Firmware. So, you can see that the physical components can be classified into these 1, 2, 3, 4, 5 and 6 parts or six buckets for easy understanding and study and kind of stuff.

But the system engineer, what he is more interested in these main issues. What are the main issues he is interested in? They are liability of these parts, liability form and fit. What is shape and how will they fit and the compatibility with operating environments. So where the system operates will that be able to work like for example if you are trying to create an electro-optical part which does not work in a moisture area and you are trying to design a naval system then it will not work.

So, you have to ensure that the elements, the physical component element actually would is compatible with the operating environment of the system similarly there is maintainability. How hard is to maintain it? Then there is predictability? Is it easily producible or is it available it can be mass produced? There is a testability can the component element can be tested or the physical component element can be tested and validated that it is producing, doing what it is supposed to do?

Is it safe? Safety is another example, another aspect. Cost is another aspect and more than that on top it should not is the key word. It should not violate integrity of the functional design. So you could actually create a rocket engine that could be mounted on to a unman aerial vehicle which would have sufficient thrust to take it off but then the take-off aspect it might do. But it might not provide the endurance that the UAVs expected to.

So, it is not that whether you just do the function of taking off the UAV. You should be also be able to take care of the functional design. So, I have used UAVs as an example in many times. So it should not violate the integrity of the function is assigned. So that is where you choose so this is where the trade-off of choice decisions comes out.

So, with this today we conclude our lecture and in the next class we will talk about the additional aspects of the system environments and how do we study the interfaces, integrations those aspects of the system and then we will move to various tools that will help us to realize these kind of things. Thank you very much for your patient listening.