CAD/CAM
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Lecture No. # 1
Computer Aided Design

In today's lecture we are going to learn what computer aided design is as a part of this course on CAD/CAM.

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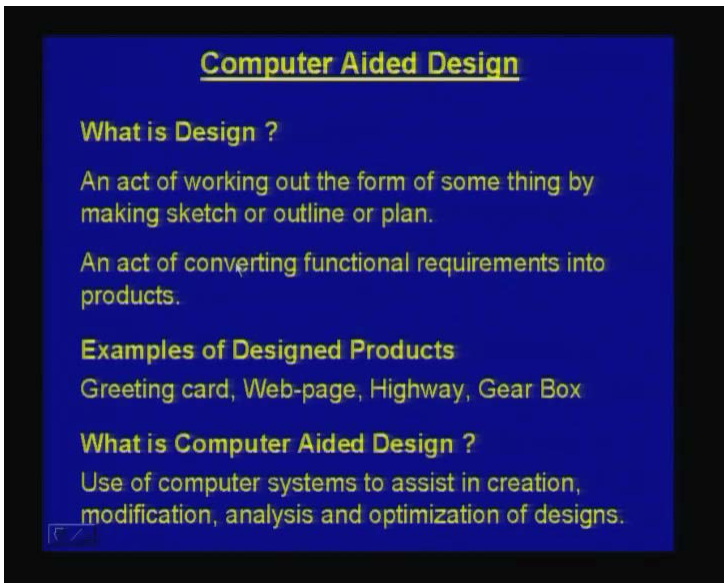

It's difficult to define the word computer aided design. In fact before I go for defining the computer aided design, I would like to look at what the design is or how do we define the word design. In fact design is something a difficult word to define. I have put down two definitions for design here. The first definition here says this is an act of working out the form of something by making sketch or outline or plan.

Now going by this particular definition, it is a very very generic definition and one thing which is common or one thing which is evident in this particular definition is that every design has something to do with a form, a geometry or a sketch which evolves as a part of a design. A more generic definition which is used particularly in engineering design, I have put down as a second definition. This particular definition says a design is an act of converting functioning requirements into products. That means every design has certain intended function which it has to do satisfactorily and the final result of design is a product which is there. Going by this particular definition we can look at some examples of design products. This is applicable to design of a greeting card or a web-page or a civil engineer would be interested in designing a highway.

Similarly a mechanical engineer would be interested in designing a gear box. So all these examples basically comply with the definition which is given here. Now coming back to computer aided design, the word is as general as that of design. So if I am using a computer system either in creation, modification, analysis or optimization of the designs, I can call it as

a computer aided design. And computers are used at various stages of design either partially or completely so all that can be termed as a computer aided design.

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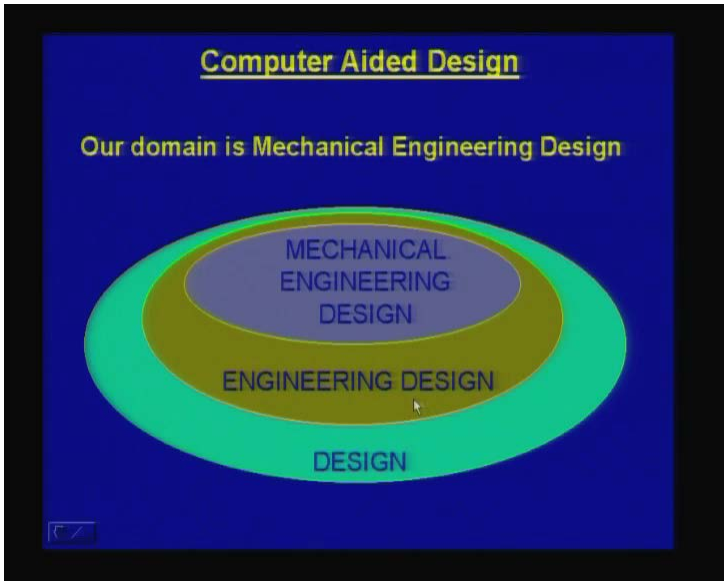

Coming back to the domain of computer aided design which we will be having here, we won't be concentrating on the word design as a very general but our focus would be on a subset which we call as a engineering design. In fact we go further and restrict our domain to mechanical engineering designs. So we would be learning about what computer aided design is particularly from the mechanical engineering products point of view.

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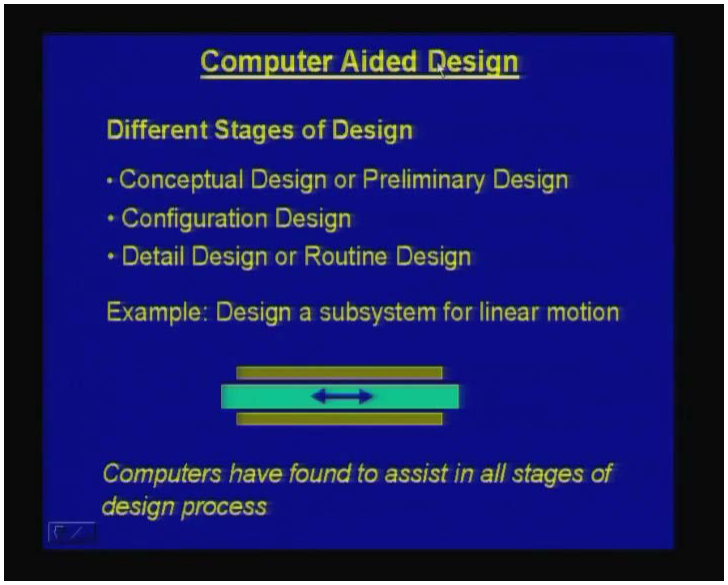

Now design is, the process of design is something which is difficult to layout or to algorithmise but it is believed that computer aided design or in general a design consist of a, it can be classified into three primary stages what is called as a first stage is a conceptual design or a preliminary design.

Second is a configuration design and third is detailed design or routine design. So as a part of a conceptual design, basically one would be looking at converting ideas into basically a feasible you can say a functional products. Most of the products geometry does not evolve as a part of a conceptual design; it evolves fully once we arrive at a detailed design. So there is some form is given to the products at the stage of a conceptual design. Configuration design basically looks at what combination of parts or components can be put together to make a complete product. And in detailed design, one basically looks at giving the exact dimensions and the exact form or geometry to the component or a product which is designed.

So if we really look at computer aided design the way it has evolved, most of the computer aided design tools were initially used in detailed design or routine design but now a days they are also being used extensively in configuration design as well as conceptual design. I would like to basically demonstrate these three stages of design just by taking an example. Here is an example of designing a sub system where I am required to achieve a linear motion for a component. So the purpose of design here or the functional requirement is a intended linear motion which has to be given to a component. Now this may involve all three stages of design. For example when it comes to a conceptual design, I would be looking at what are the different ways in which a linear motion can be achieved.

For example one can use a motor which gives me a rotary motion and then I can use a mechanism to convert rotary motion to linear motion to basically get the intended linear motion or I may use a linear motor directly and get the linear motion or I may be using a complex or a simple mechanism like a slider crank mechanism to achieve a linear motion. So there can be, a linear motion can be achieved in a number of ways. So the conceptual design stage one would be looking at which particular mechanism to select, etc as a part of this. So when it comes to a configuration design, one would be interested in what are the various components which one has to put together in order to achieve at this particular motion.

So this is like going further and where you can say product configuration evolves, some of the form of some of the component also evolve as a part of a configuration design. And it is only at the detailed design stage where the exact dimensions of all the components which are decided which is basically also called as a routine design. And as for as computers are concerned they can be used in all three stages of design, they are more and more used in a detail design stage but they also have an application in configuration and conceptual design stage.

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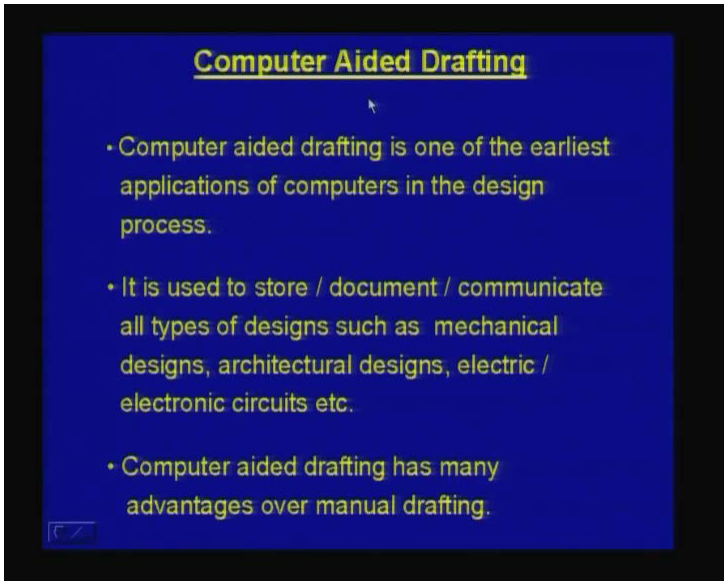

Now coming back to computer aided design, what I would like to do is to basically look at various aspects in which computers can be used in a computer aided design process, computer aided design process by taking a few examples. One of the applications of computers in design is computer aided drafting. In fact this is one of the earliest application of computers in a design process. So as a part of a computer aided drafting, one is interested to basically create, store, document and communicate a design, so this is more like a presentation tool. And this can be used for all types of design which may be a mechanical design or it may be an architectural design or it could be an electronic or electric circuit which one has designed.

So as a part of a drafting, one is trying to basically document a design as a digital design or a digital design in a computer. And this is basically replaces a manual drafting which is usually done by a designers using a drafter on let say a drawing board. And going for a computer aided drafting has many advantages because it can be used conveniently to manipulate the designs and also to store and make copies very easily compared to many of the conventional drafting which is usually done on using a drafter and drawing board. So in fact one of the first applications of computer aided computers in design is computer aided drafting.

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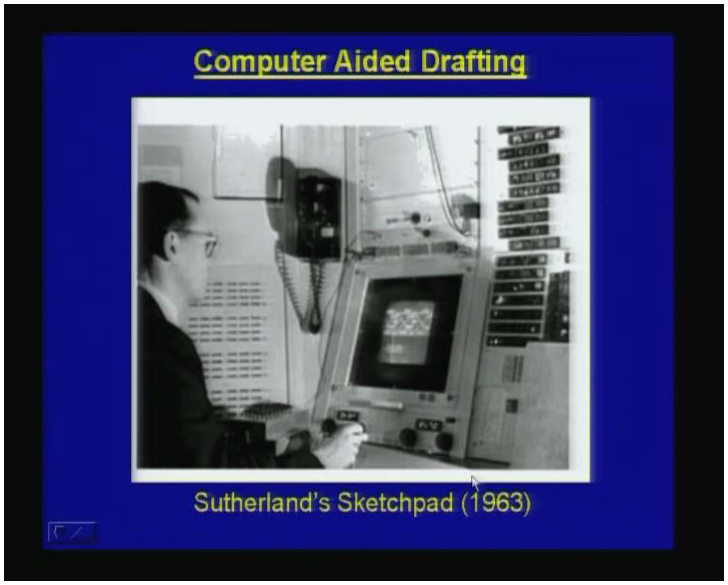

What you see here is basically one of the first computer aided drafting system which was designed in 1963. So this is called as a sketch pad which is basically, the system called sketch pad was designed by Sutherland's at MIT and this is considered to be a beginning of a computer aided design. So we can say that computer aided design is approximately about 40 years old which started with computer aided drafting and then computers where being used in other stages or other aspects of design tool.

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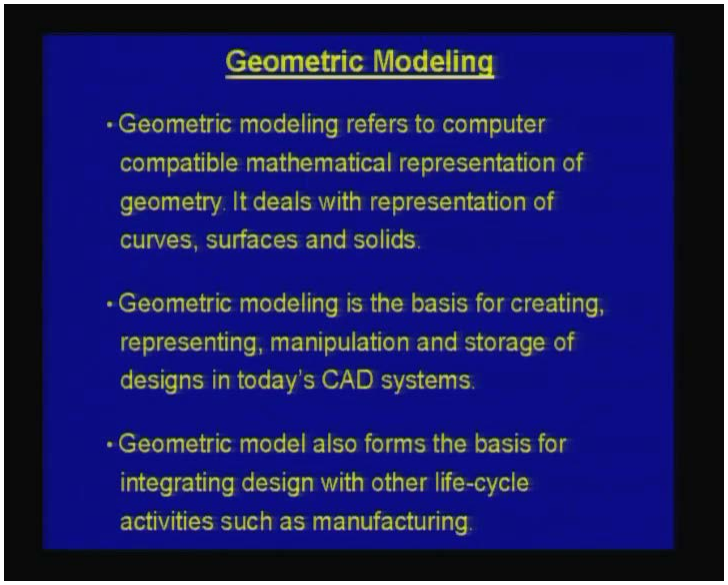

Next I will go for major applications of computers in design which basically makes use of what is called as a geometric modeling. In fact one can say that the heart of many of the CAD systems which are used today is basically a geometric modelling is considered to be a core of it. What is geometric modeling? Geometric modelling basically refers to a computer compatible mathematical representation of geometry. So the definition has two major aspects. Any definition which I am going to give it to geometry should be a computer compatible or

computer friendly and also the representation should be mathematical. If any definition which it satisfies these two requirements, I can call it as a geometric model and primarily geometric modelling deals with how to represent a different geometric entities like curves, surfaces and solids.

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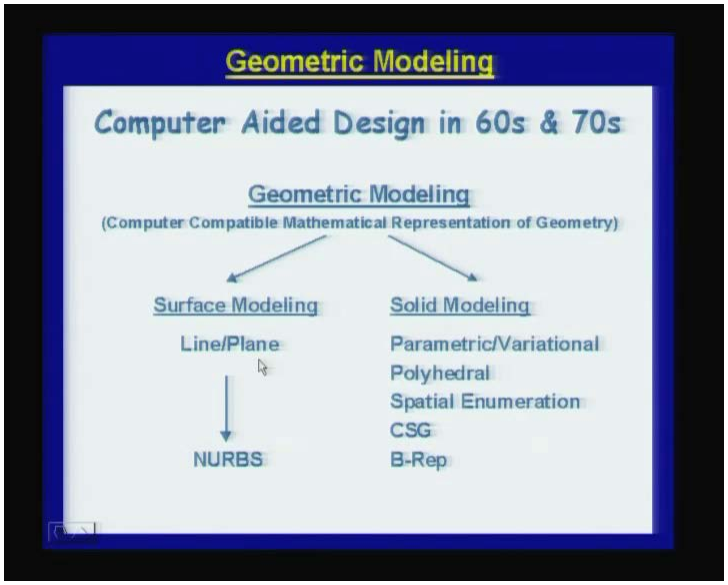

Geometric modelling is also a basis for a creating representing and manipulation and storage of designs in today's CAD systems. So most of the CAD system which are being used now both low end and high end CAD systems are based on the concept of geometric modelling where one creates geometry, manipulates, stores and communicates this particular geometry. Geometric modelling is also a basis for integrating various what we call as a products life cycle activities. For example a geometric model which is a result of design process, it stored and it can be used at a manufacturing stage when this geometry has to be realized by one of the manufacturing processes or the same geometry can be used at inspection stage where the manufactured geometry is compared with the intended design geometry for you can say an inspection check.

So a geometric modelling you can say is something which can form a basis for integrating various life cycle activities in any products design and development system. And most of the geometric modelling tools which are now being used in computer aided design evolved in 60's and 70's and there were basically two different lines of development one which we call as a surface modeling. As a part of a surface modeling, representation for curves and surfaces were developed, line and plane starting from line and plane which is a very simple which existed before a 60's and 70's and there were representations like representing curves and surfaces as Hermite curves and surfaces, Bezier curves, B-spline curves and surfaces or what we call as NURBS Non-Uniform Rational B-Splines.

Most of these representations evolved in 60's and 70's and this forms the basis for representing and a storing most of the designs as a geometry in most of the CAD systems. The second line of development which took place in 70's particularly is related to giving a mathematical representation to solids where parametric and variations models evolve then there are polyhedral and spatial enumeration models were developed.

And CSG which basically deals with constructive solid geometry and B-Rep which is boundary representation were other popular solid modelling schemes which evolved in 70's. And these concepts surface and solid modelling concepts is core of any CAD system in most of the today's high end and low end CAD systems.

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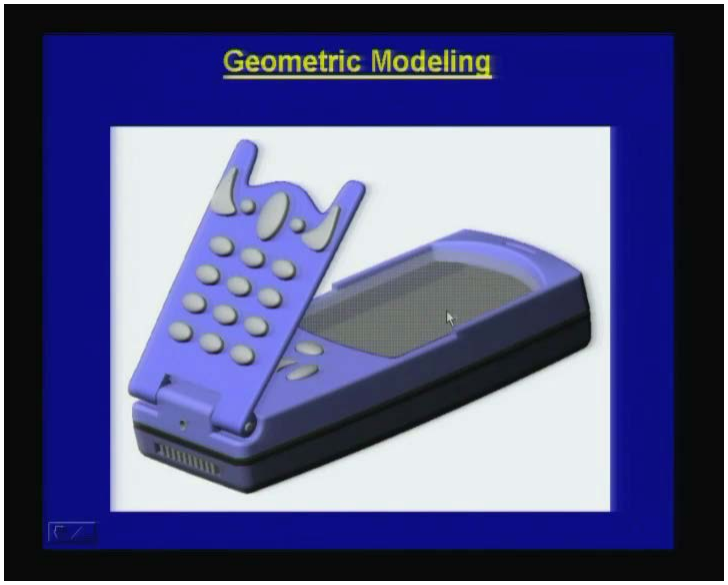

Now here is an example of basically a geometric modeling. Using a geometric modelling tools which deal with curve surface and solids, one can create let say basically a form or represent a design and this geometric model representation can be used since it's a computer compatible, it can also be used to visualize the component at various stages. It can be used as an interactive tool where the designer manipulates the geometry interactively interacting with a computer or the mathematical definition which is given to the geometry as a part of geometric model is also stored as a file and this information is available for other applications in subsequent life cycle activities.

So what we are seeing here is only basically a visual representation of a geometric model but internally it is stored as a mathematical model and hence available for various applications wherever the mathematical definition has to be used. For example if somebody would like to know what is the weight of this particular product, one can easily get because you have the entire volume information which can be easily extracted from the geometric model or the mathematical model which is stored as a file.

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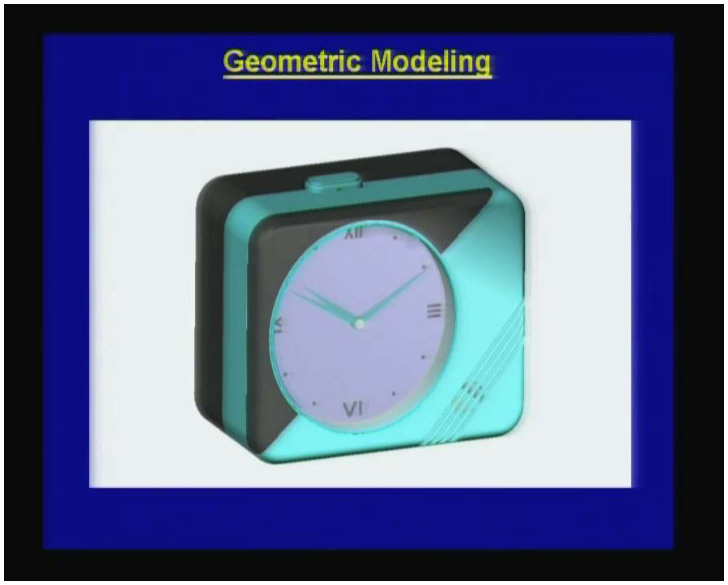

Here is another example of a geometric model and this is basically a product which consists of number of components which are put together and what you are seeing is only a one view of basically the model which is developed.

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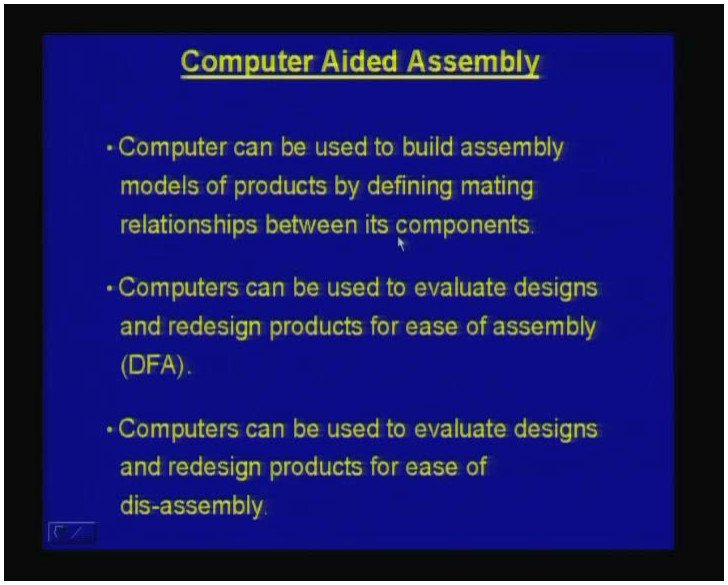

Now the computer applications are not restricted to pure representing the component geometries alone but they go one step further where products can be put, many components can be put together to represent a product assembly. So in an assembly you are not looking at a single component or a single component geometry but how various components are put together and what are the basically mating relationship between various components and how the assembly is going to look like or how assembly can be carried out can be visualized using computational tools. If you go one step further, computers can be used for what is called as design for assembly or a DFA concept.

As a part of a DFA, you are actually evaluating various designs or various configurations of designs for ease of assembly. So if I have a number of ways in which a configuration of a product can be designed then one can look or basically select or optimize from the ease of assembly point of view. And the concept of DFA is not necessarily restricted to purely an assembly, it goes one step beyond where one looks at how easy or difficult to dismantle a product or what we call as a disassembly.

As a part of disassembly, when I am designing a particular product my concentration would be that how easy or difficult to dismantle a product. Dismantling a product into various components is really necessary for different purpose. For example if I want to replace a part of this particular product or if I want to go for a maintenance of a product or let's say if I have to finally dismantle the product in terms of components for recycling once its life is over, they all deal with design for a disassembly. And basically the computer aided assembly tools can be used in all these stages.

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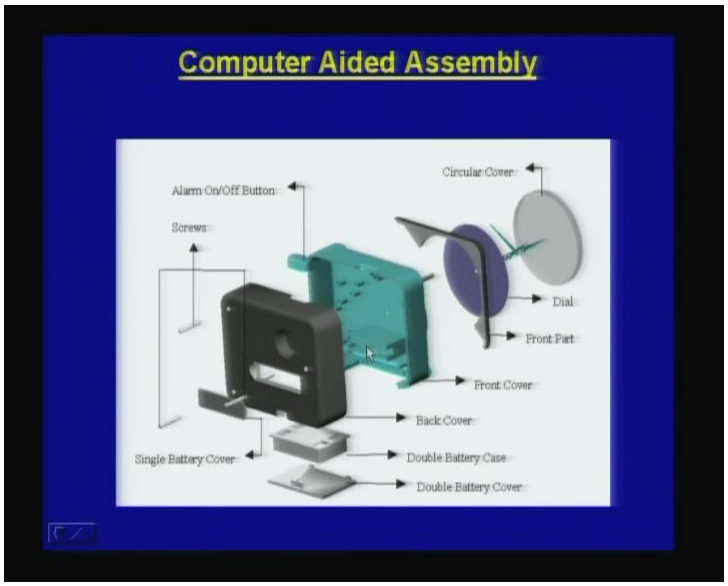

What you are going, what you are saying here is basically a simple example of an assembly which is carried out in a computer aided assembly environment. So as a part of a computer aided assembly, one basically models the components and then tries to put together these components using the mating relationship which can be defined interactively working with a computer. And one can also have analysis or we can say assembly analysis tools where the number of components can be combined and the total number of components which are required to form an assembly can be reduced or what we discussed in a DFA concept or design for assembly concept. So assembly means you can say another application of computers in the design process.

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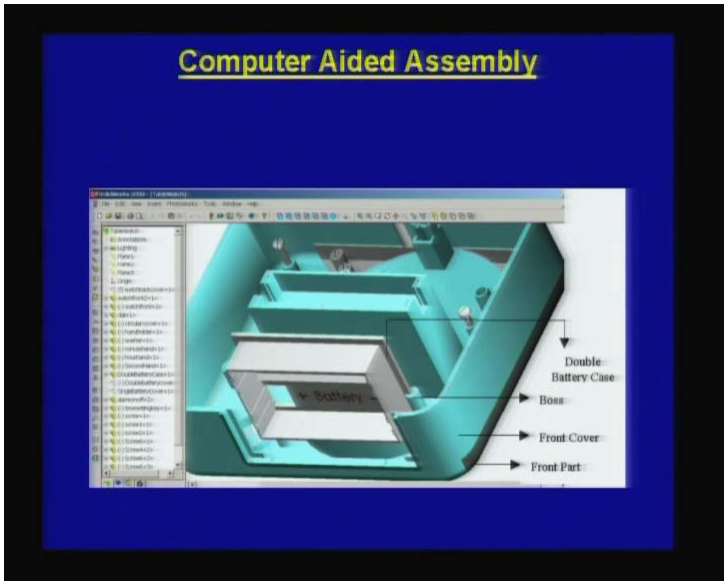

Here is a basically a view of computer aided assembly where one is trying to look at like basically the interior of a component. Suppose if I want to insert and replace battery in a product, how easy or difficult to do. If there is any problem in terms of inserting or removing battery then I can go back redesign this particular component for ease of maintenance. So computer aided assembly looks at all these aspects and many of the CAD systems now a days give you also an assembly option apart from the geometric modelling.

One of the very important applications of computers is in analysis. As a part of a design process, once designer arrives at let's say design. At various stages one is required to do analysis checks. For example suppose if I have a mechanical component and it is subjected to certain forces, I would like to know what are the kind of stresses in this particular component or what are the kind of deflections which will come in let's say a particularly component. If somebody a designer would like to have a feedback because this forms a basis for the design like designing a component for strength involves knowing what kind of stresses and deflections a component is subjected to.

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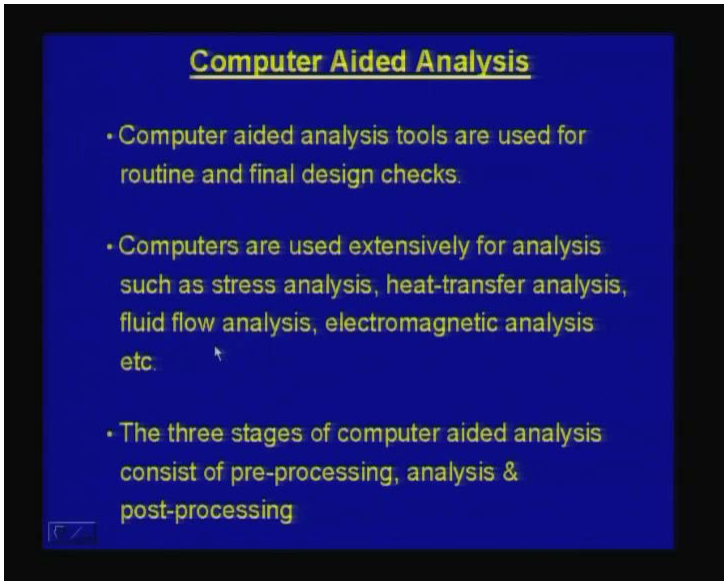

So the analysis is not restricted to purely a stress analysis. As a part of mechanical design, one may do a heat transfer analysis or there are many mechanical components where the design requires a fluid flow analysis, also a few components where one has to do an electromagnetic analysis in order to design a product. And computers have been used at all three stages of an analysis. For example if I take computing pack, computer package like a finite element analysis package which can do a stress analysis or a heat transfer analysis, the computers can be used for pre-processing analysis and post-processing. So as a part of a pre-processing, one actually prepares a model or let say a finite element model for the analysis. And once the analysis is over, the post-processing is basically used as an interactive tool to visualize the results. For example if I am carrying out a stress analysis of a component then I would like to visualize what are the stresses and deflections and strains at a various positions or various location of this particular component which gives a feedback as to how to go and redesign the component. Here is a simple example of use of computers in analysis.

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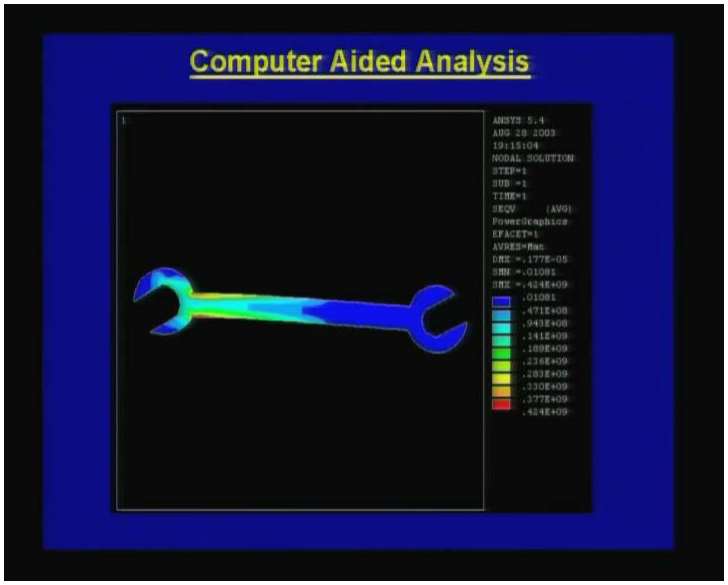

So what is shown here is basically a result of a finite element analysis which is carried out on a simple mechanical elements. And what you see here is basically a different colors which basically indicate various stress levels. And this gives enough feedback to designers as to what are the critical portions where the strengthening is required or what are the portions where the stresses are not very high or the deflections are not very high where one can go back and reduce the sections or may be remove material in some form in order to optimize the design. So analysis tools are used extensively and particularly computer aided analysis tools are commonly used in many design processes.

In the absence of computer aided analysis tools, it would be a very very difficult to carry out the analysis checks, particularly involves lot of calculations which are also error prone and particularly in today's design many of the manufacturing organizations use these tools extensively for simple power design to a complex mechanical engineering system design. One of the important aspects in any design process is related to optimization. Now when I have a number of alternatives for carrying out a design that means an intended function can be satisfactorily performed by various configurations or let say various geometries, selecting an optimum geometry based on certain criteria becomes very important. For example products can be designed for minimum cost, minimum weight or sometimes multiple criteria of cost and weight or it may be like their design for minimum surface area or maximum surface area or minimum volume or maximum volume. So, whenever I have a criteria which basically has to be maximized or minimized, one can look at the design alternatives and try to achieve what let's say an optimum design.

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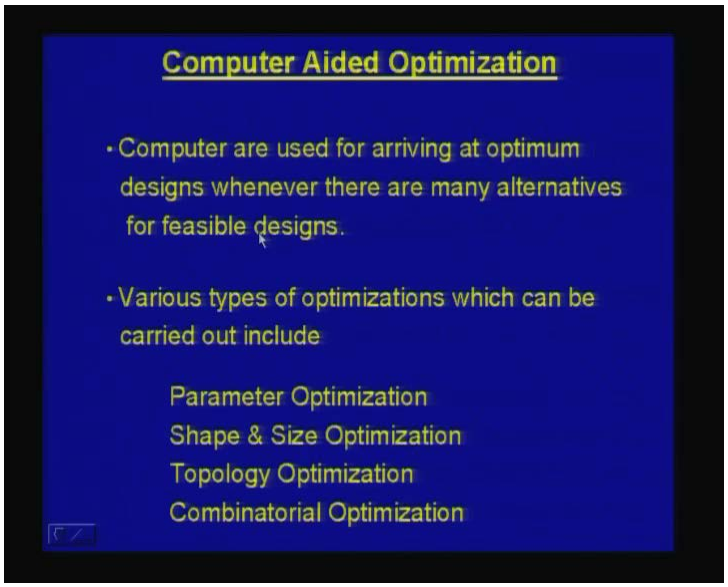

So that is what is basically accomplished in computer aided optimization. So as a part of a computer aided optimization, one is looking at the design alternatives that means all the feasible design or alternatives and searching all the feasible region to see which is the actually the optimum design which can be selected or which can be a finalized. And when it comes to design using computers for design optimization, they can be used in various ways. They are like, for example one way is to use it for parametric optimization. For example I may be designing let's say a dimensions of a component like a beam or I may be designing let's say a spring.

Now in order to arrive at the dimensions of the beam or a spring like for a given specifications, for a given functional requirements, there are number of feasible designs which are possible but suppose if I would like to design the same element for a criteria that the weight should be minimum. Suppose if the material is already selected for these then I am left with selecting the dimensions for these components such that the weight is minimum. So what one does as a part of parameter optimization is looks at all the feasible reasons for the design space and tries to arrive at let's say an optimum dimensions for the component which gives a minimum weight or minimum weight without sacrificing let say the functional requirement which it is intended to do. In many of the mechanical systems, shape and size optimization can be carried out using computers. In a shape optimization, one tries to look at optimum shape of a component or let say product which does the intended functions satisfactorily but at the same time minimizes either the weight or mass or volume, one of these.

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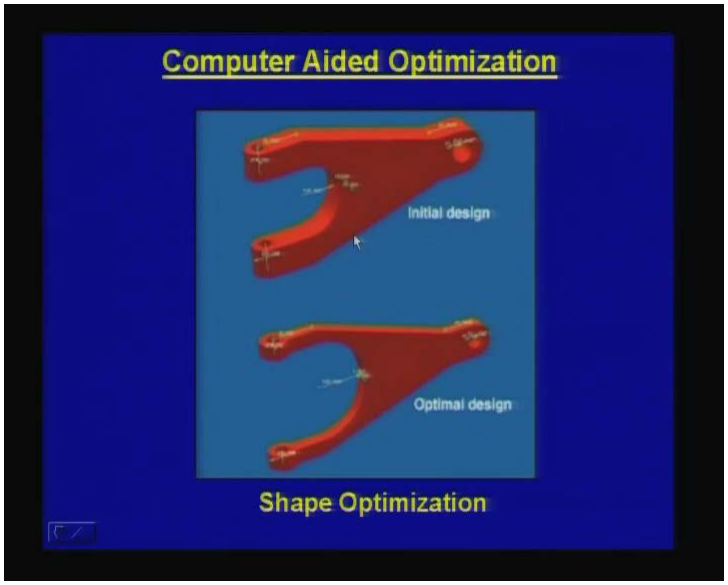

I will just show you an example. So here is basically an example where there are two designs which are depicted. One is an initial design, as a part of a design process designer has arrived at a design which is a feasible design but this may not be optimum. What is shown here is an optimal design for the same component. Now the difference is that both of them they do the intended functions satisfactorily but the optimal design weighs much less than the original design or let's say an initial design or let's say the cost of this particular manufacturing, cost of this particular component would be much less than the other one because this uses less of raw material.

So, as a part of a design optimization, one tries to look at, may be start with a feasible design and then go to optimal design which optimizes certain criteria without sacrificing the functional requirements. And computers have found to be extremely useful in carrying out this particular aspect because trying out many alternatives manually without computers to arrive at optimal design is extremely difficult or impossible in many situations.

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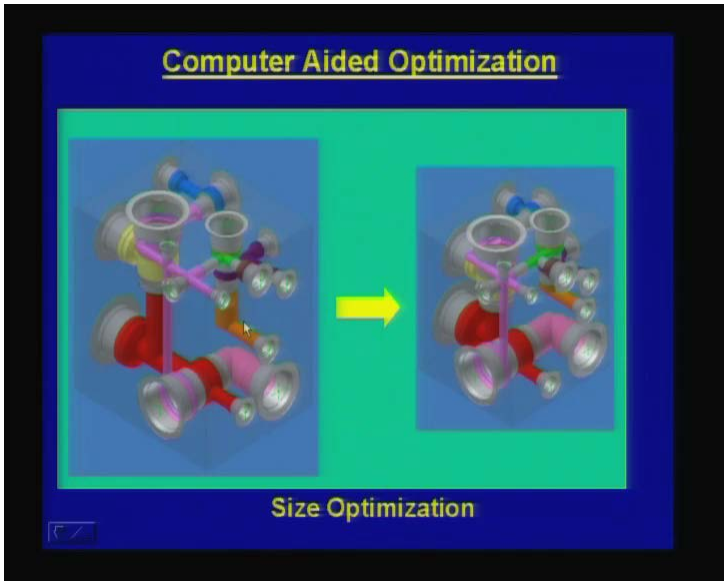

Here is another example of a basically optimization in design. What you are saying here are basically what you are saying on the left is basically hydraulic manifold. As you see this hydraulic manifold has a rectangular cross section and you see number of cavities which are interconnected in this particular manifold. And as a part of a design, the designer has arrived at a configuration for these cavities and the connections to be made and this hydraulic manifold is designed or intended to do certain function. What you see on the right is the same manifold but this is more optimal in the sense that it has a same topology like same type of connection and cavities what you see on the left but it is much more compact compared to this because a size of the manifold here is considerably less than what you see on the left.

Now as a part of optimization, before optimization a designer may arrive at a feasible design as it is shown in the left and as a part of the optimization, you start with a feasible design or initial design and may arrive at an optimal design which gives you let's say a most compact design without sacrificing some of the constraints under which this manifold is required to work. This is another we can say an example of a design optimization. Now we have looked at basically two aspects of optimization, one is a parameter optimization and then there is a shape optimization. There are situations where one is required to do a topology optimization.

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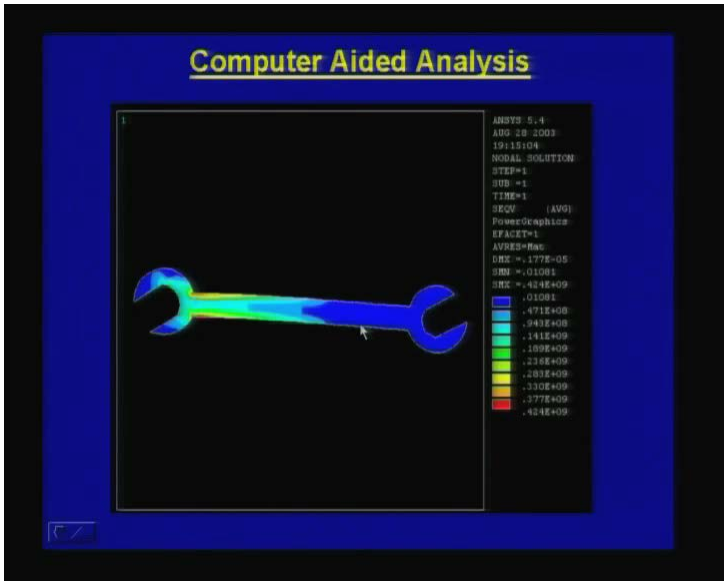

If I go back to an example of let's say designing, let's say mechanical component like a spanner now once I carry out a stress analysis, for example we know that there are certain regions which are stressed much more and then there are regions where the stresses are not as high as it is there in the other parts. So one way of redesigning a component would be that I can increase the section thickness at those places were the stresses are high and may be reduce the section thickness or the sectional dimensions at those places where the stresses are not so high. So if I carry out this, this would be an example of a parameter optimization but this can also be attempted as a topology optimization.

In a typical topology optimization, instead of reducing let's say a cross section like thickness etc at those places where it is not stressed, I may remove a material as a cut out. For example I may have for example in this particular thing a material removed somewhere in the middle in the form of let's say a cut out where by you are actually changing the geometry and also the topology to arrive at a more optimal designs. So in a typical topology optimization, one is trying to, one is not really concentrating on optimizing the geometry but arriving at a more optimum topology which can, which basically maximizes or minimizes certain criteria which is intended. There are situations where one has like one can use a computer for a combinatorial optimization.

In a combinatorial optimization you have the feasible designs is available as a fixed set either you have the number of feasible design as a set which are a few hundreds in number or may be few thousand or it may be in few millions. Now one is interested to know among the design alternatives which are available which is a fixed in number what is basically like an optimum design. So one has to basically search the design space or available set of feasible design in order to arrive at most optimum design that means which is basically an example of a combinatorial optimization. So we can see that computers, basically the computing power or the number crunching power of computers can be used in the form of an algorithm or optimization algorithm and it can be used to basically arrive at optimum designs which are otherwise very difficult to do without the use of computers. Now coming back to further applications of design, one of the stages where the computers can be used is what is called as a virtual prototyping.

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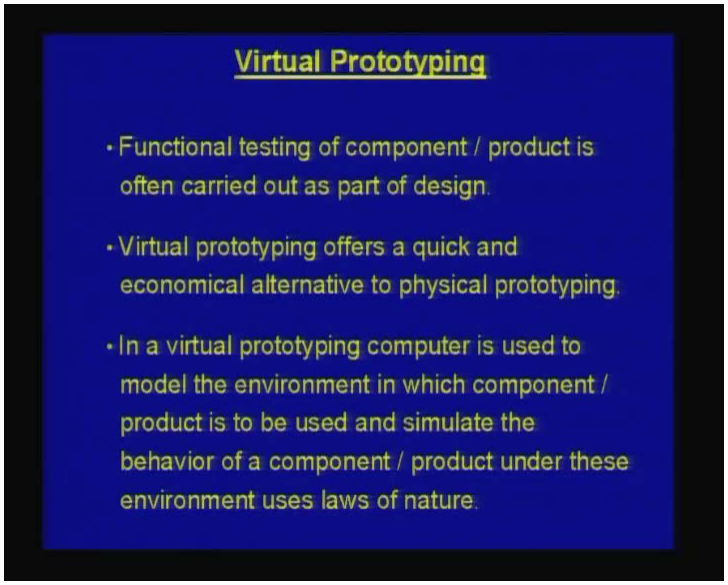

One is developing new products. One looks at like once a design is finalized, the design has to be tested whether the intended function can be satisfactorily performed or not. Now in order to do this one of the methods is that one builds a product that means one goes for a prototyping a product that means you go for a physical prototyping by some of the manufacturing methods. So one or a few copies of the product is actually fabricated or constructed and then this particular physical product is used for carrying out certain functionality test.

I can take an example of, for example one would be interested in knowing for example there is a design which has to be tested for aerodynamic efficiency. So one has come up with let say a very, a design which has a curved geometry and this curved shape has to be tested for aerodynamic efficiency as it is done in let's say automobiles or aircrafts. Now one of the ways to do this functional testing is to produce one component either of the same size and shape or a scaled version of this and then take this particular model in a wind tunnel and simulate the environment to which the component would be subjected and then look for what is the kind of aerodynamic efficiency one is getting.

Now in many situations it has been found that a physical prototyping followed by a functional testing can be replaced by a virtual prototyping. In a virtual prototyping you are actually not going for a physical fabrication of a product but the functionality can be tested by simulating the environment under which the component or product is supposed to work. So how is that done is you basically, one is trying to simulate as a part of the virtual environment the behavior of a component under the environment which it is supposed to work. And whenever there is a component which is working under certain environment then there are certain loss of physics or loss of nature which will govern. So one tries to mathematically model those loss of physics and put it as a part of a prototyping system. So I can always replace the physical prototyping followed by a functional testing with virtual prototyping in some cases. So for this purpose you have a virtual prototyping tools which are used.

A virtual prototyping is used extensively in design of complex mechanism, in design of complex geometries and then basically simulating the environment under which this component is required to work using basically computational models and simulations. So the advantage of using virtual prototyping is that it saves a lot of time and cost because a physical prototyping involves investment in terms of manufacturing and then getting product, getting the components then assembling them and then carrying out the physical test. Whereas a virtual prototyping software can replace all these effort in some of the situations and is being used extensively these days particularly in design of complex mechanical systems.

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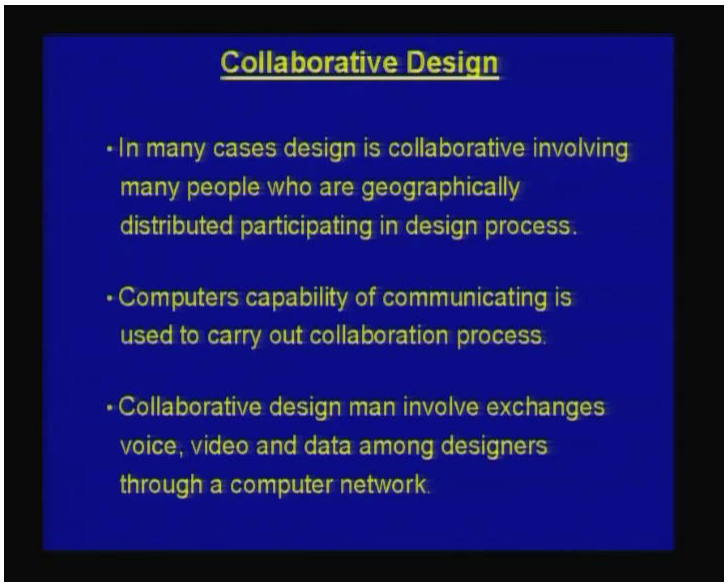

One of the aspects in which computers are used for design these days is related to collaborative design. This is particularly necessary, particularly when one is trying to design a product which is multi-disciplinary in nature. There are examples where many designers having many specialties have to come together in order to design a system. For example I may be looking at a mechanical product in order to design this, I may require a help of a physicist or I may require a person who is an expert in vacuum technology or there is a person who is expert in stress analysis, there is a person who is really good in materials.

So in these situations it is not a single person who is trying to arrive at a design but it's basically a cross functional team which is who collaborate and then arrive at a particular design and it is also seen that often the people who collaborate in order to design a product may be geographically distributed. When the people are geographically distributed, computers can be used as a collaboration medium to carry out a design process. Now we know that computers are capable of visual display and also they are also very good in number crunching but there is also a third aspect which is very very important from the design point of view is that computers can communicate. So if there are 5 or 6 people who are trying to design a system and if they are geographically distributed, if they have a computing system which they are using for a design system if these computers are connected in a network then if they have a collaboration software we can say a design collaboration software by which they can exchange the video, voice and data then a design process can be carried out by staying in their own places which may be a thousands of miles away and carrying out let say a design process.

So what one is trying to look in a collaborative design is that there are many designers who are trying to collaborate in terms of designing a particular product, exchanging the voice, video and data through a computer to arrive at a design. So in a typical collaborative design process, since there are many people involved usually one of the person takes a control of the design whereas other designers or other people who are participating in the design process, they critic on what basically one is trying to explain. And similarly the control can be passed to all the people one by one and as the new features are being added to product or as the product is being analyzed, others can critic on the design and they can come up with those products which are highly interdisciplinary or multidisciplinary in nature where it's not possible to design using single person. In fact there are many cases where human beings can be replaced with what is called as design agents.

What the design agents do is design agents are basically like you can say a piece of software which can communicate. So I may have a system of let say a collaborative design where there are 6 computers are involved and in these 6 computers there are 4 designers who are using these computers and there are two are stand-alone computers who act as a design agents and they are capable of providing certain information whenever the designer, whenever a particular person designs. So it's also possible to have basically a computer as an agent and also some of the people who are involved in the design process to come together and carry out a design process which is what is usually done in a typical collaborative design process. So this is another example of a design.

So what we basically did, in fact like what we basically studied is that computer is basically a tool which is capable of a number crunching, capable of doing a fast calculations and it has, one of the aspects of computers is that it can display and it can interact with the designer that means designer can interact with the computer in terms of creation and manipulation of the geometries visually and computers can also communicate. So a designer as a part of a design process can be benefited by all three aspects of computers either it is in the form of a presenting a design in the form of a drafting or it may be in terms of manipulating the geometry as we have seen in the geometric modelling or it may be in term of carrying out an assembly where the components are put together in terms of defining the mating relationships or it could be in the form of analysis like using a finite element analysis tools which is done for stress analysis, heat transfer analysis and other analysis checks. And computers can also be used for replacing a physical prototyping followed by a functional testing with virtual prototyping and they are also useful when one has to use particularly in a collaborative environment where people are geographically distributed and would like to carry out a design process.

So what I have given in this particular lecture are only a few examples where few, you can say a typical examples of computers in a design process otherwise the examples can be like there are many other ways a computer can be used. In fact computers can be used at a conceptual design stage, for example we have seen example of like designing a sub system where one has to look for a mechanism for achieving a linear motion. So in this situations, I can use computers as design repositories. So computers can store a large number of designs based on the previous designs or it may be from a library of patents. And if somebody is trying to know what are the different way in which rotary motion can be converted to a linear motion, so computer can search from its repository and say that here are the 35 ways in which a rotary motion can be converted to a lead motion, it may be a screw or nut, it may be rack and pinion or it may be other ways of doing that.

So even at a conceptual stage using a design repository and other aspects, computers can be used for design productivity. And another thing which is happening particularly in terms of a computer aided design is what is called as design automation. If we really look at present state of the art of in terms of using computer aided design for product design, most of the decisions are still taken by the designer whereas a computer acts or computer is basically an enabler which acts as an interactive tool where the geometry can be created, manipulated and stored. But some of the very crucial design decisions which are taken at conceptual stage can also be automated using computers. So in this case we are speaking of a computers at a conceptual design that means even the conceptual design portion can be done extensively by computers and whenever such a thing is carried out it's usually called as design automation. It's like, it's possible in some situations where a designer or a group of designer can be completely replaced by a computer for designing a specific class of products.

Suppose somebody may be trying to design let's say hydraulic manifold, so where hydraulic input is a circuit and one looks at what is the configuration of a manifold at the end of a design. So it's possible that instead of a designer sitting in front of a CAD system and carrying out a design process, I have a piece of software which is a design automation software which basically takes the input and gives a design which is a feasible design or an optimal design by completely that means the entire design process is automated and carried using a computer. And designer basically is, basically used for, basically in, the designers involvement would be more in terms of checking the design and whenever design automation is carried out where a computer has been, computing system is used along with a software to carry out a design process. It has seen that there are many situations, the actual arriving at optimum designs is possible and also the total time which is involved in design what we call as a design lead time can be considerably reduced. So we see that computer aided design is not a new anymore it's basically, it's like it's not a state of the art anymore. It's used by many people in by large industries, by smaller industries for carrying out a product design process and particularly mechanical design process.