

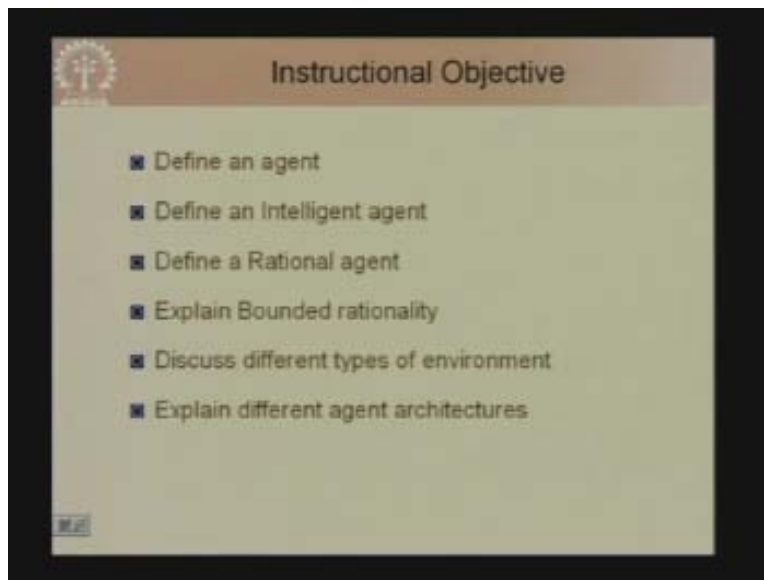
Artificial Intelligence
Prof. Sudeshna Sarkar
Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur
Lecture - 2
Intelligent Agents

Today we will start our second lecture of artificial intelligence. In the first lecture we introduced certain things namely what artificial intelligence is all about, the definition of intelligence and we looked at several examples of AI systems and we also traced the history of AI. Today we will go to the second part of this introduction where we will talk about intelligent agents.

In a major part of this course we will talk about the various aspects of an intelligent agent. Today we will introduce what an intelligent is and how we look at intelligent agents. Now, to describe the instructional objective of today's lecture we would like to define an intelligent agent as to what we mean by intelligence as an agent, define a rational agent.

In the last class we talked about rationality. We will talk about what we mean by a rational agent. Then we will explain the concept of rationality as we see or the concept of bounded rationality which we will deal with. We will discuss the different characteristics of the environment in which the agent operates and we will explain different agent architectures.

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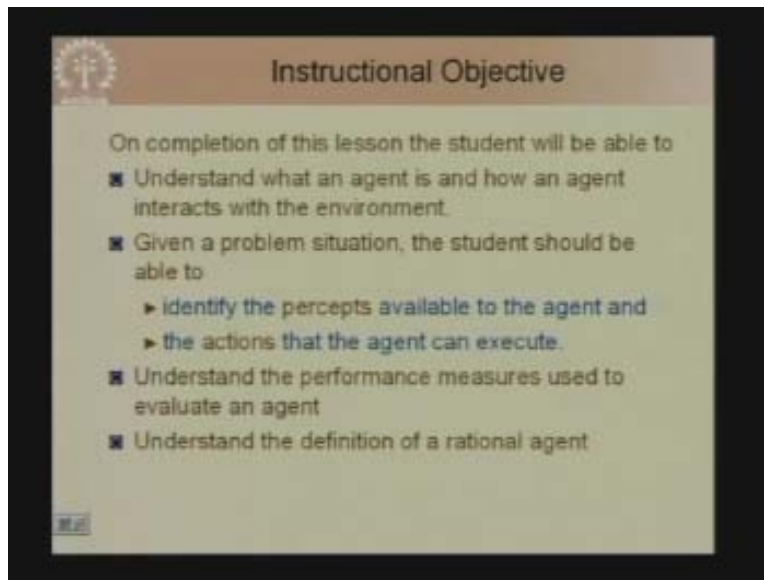


On completing this lesson you will be able to understand what an agent is and how an agent interacts with the environment. As we will see in the course of this lecture the environment is an important component of the agent design and the agent should be

designed so that it can work properly in its environment. After you have taken today's lecture you should be able to do the following:

When you are given a problem situation, you should be able to identify which are the percepts available to the agent or what the agent can sense and how the agent should act to optimize its performance. We should also look at what are the performance measures by which we should evaluate an agent to try to see if the agent design has been successful and we hope to understand what we mean by the definition of what a rational agent is.

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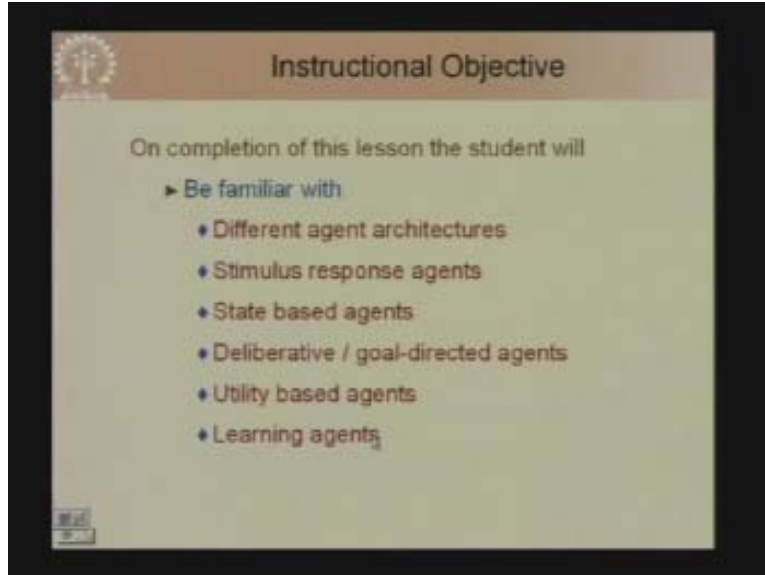
The slide is titled "Instructional Objective" and contains the following text:

On completion of this lesson the student will be able to

- Understand what an agent is and how an agent interacts with the environment.
- Given a problem situation, the student should be able to
 - ▶ identify the percepts available to the agent and
 - ▶ the actions that the agent can execute.
- Understand the performance measures used to evaluate an agent
- Understand the definition of a rational agent

We will also look at the concept of bounded rationality which is the rationality that we will deal with. In summary we will be familiar with different agent architectures including stimulus response agents, state based agents, deliberative or goal directed agents, utility based agents as well as learning agents.

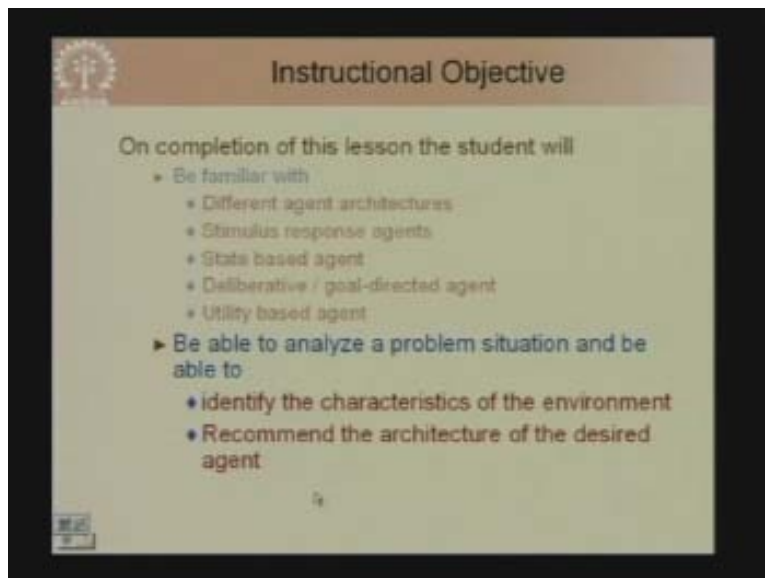
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The slide is titled "Instructional Objective" and features a logo in the top left corner. The main text reads: "On completion of this lesson the student will". Below this, there is a primary bullet point: "► Be familiar with". Underneath this primary point, there are six secondary bullet points, each preceded by a diamond symbol: "◆ Different agent architectures", "◆ Stimulus response agents", "◆ State based agents", "◆ Deliberative / goal-directed agents", "◆ Utility based agents", and "◆ Learning agents".

And we should also be able to identify given a problem situation the characteristics of the environment and recommend what the architecture of the desired agent should be in this environment.

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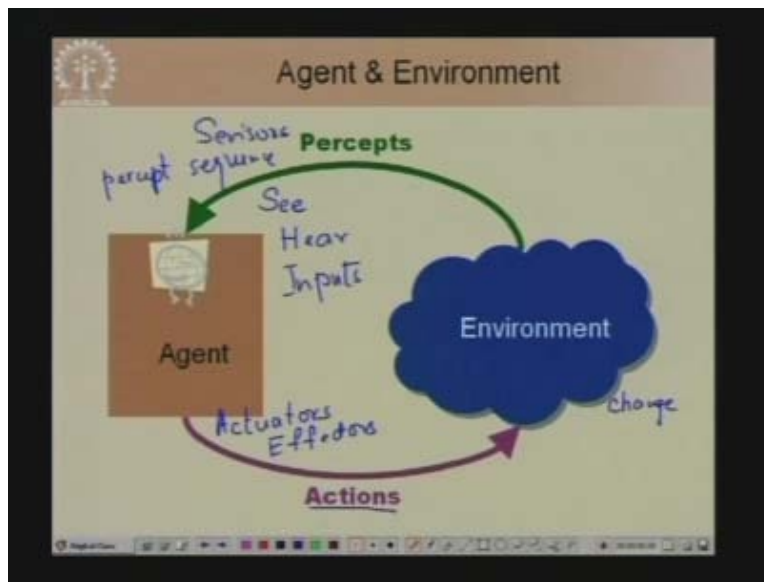
The slide is titled "Instructional Objective" and features a logo in the top left corner. The main text reads: "On completion of this lesson the student will". Below this, there are two primary bullet points, each preceded by a right-pointing triangle: "► Be familiar with" and "► Be able to analyze a problem situation and be able to". Under the first primary point, there are five secondary bullet points, each preceded by a diamond symbol: "◆ Different agent architectures", "◆ Stimulus response agents", "◆ State based agent", "◆ Deliberative / goal-directed agent", and "◆ Utility based agent". Under the second primary point, there are two secondary bullet points, each preceded by a diamond symbol: "◆ identify the characteristics of the environment" and "◆ Recommend the architecture of the desired agent".

So this is our agent. The agent operates in an environment. The agent receives percepts from the environment and the agent acts and its actions can change the environment. The agent uses its various sensory organs so depending upon the sensors that the agent has for example the agent may be able to see if the agent has a camera, the agent may be able to

hear if it has a sonar sensor and so agent can see or hear or accept different inputs from the environment.

Inside the agent there is an agent program which decides on the basis of the current percept or the percept sequence it has received till date to decide what should be the good action to take in the current situation. So the agent has actuators or effectors to take actions. These actions can potentially change the environment and the agent can use its sensors to sense the changed environment.

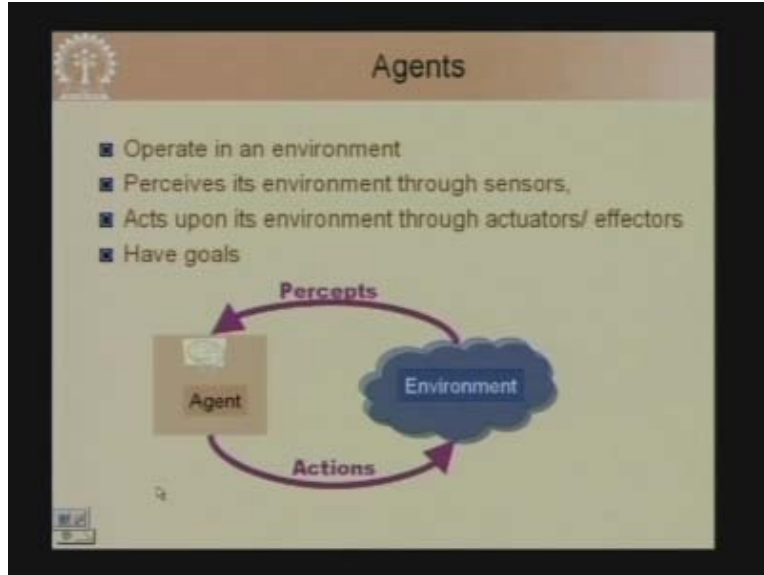
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The agent does the following things:

The agent operates in an environment. The agent perceives its environment through its sensors. The agent acts upon the environment through actuators or effectors and also the agent has goals.

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Goals are the objectives which the agent has to satisfy and the actions that the agent will take will depend upon the goal it wants to achieve.

What is a percept?

The complete set of inputs at a given time the agent gets is called its percept. The input can be from the keyboard or through its various sensors. The sequence of percepts may be the current percept or may be all the percepts that the agent has perceived so far can influence the actions of an agent. The agent can change the environment through effectors or actuators. An operation which involves an actuator is called an action. So, agent can take action in an environment through the output device or through the different actuators that it might be having. These actions can be grouped into action sequences.

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Sensors and effectors

- An agent perceives its environment through sensors
 - ▶ The complete set of inputs at a given time is called a percept
 - ▶ The current percept, or a sequence of percepts can influence the actions of an agent *actuators*
- It can change the environment through effectors
 - ▶ An operation involving an actuator is called an action
 - ▶ Actions can be grouped into action sequences

We have already seen that the agent has sensors and actuators and has goals. And the agent program implements a mapping from percept sequences to actions.

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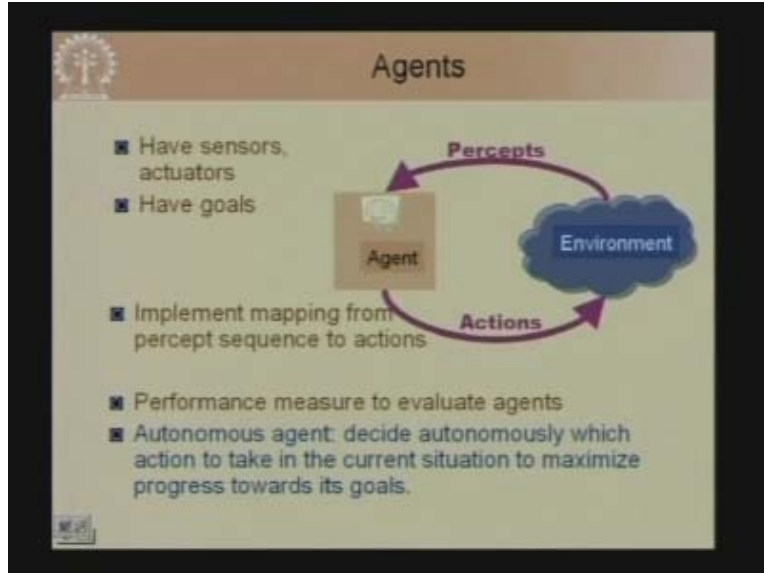
Agents

- Have sensors, actuators
- Have goals
- Agent program*
- Implement mapping from percept sequence to actions

The diagram shows an **Agent** (represented by a box with a gear icon) and an **Environment** (represented by a cloud). A purple arrow labeled **Percepts** points from the Environment to the Agent. A purple arrow labeled **Actions** points from the Agent to the Environment.

We also have to talk about a performance measure by which we will evaluate an agent, evaluate how successful the agent design has been. And finally we will like to talk about autonomous agents.

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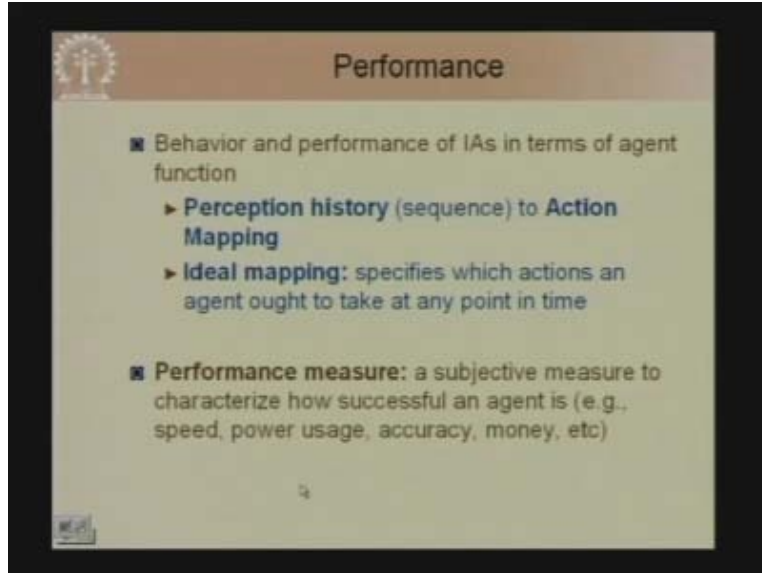


In artificial intelligence artificial intelligent agent's autonomy is extremely important. The agent should be able to decide autonomously which action it should take in the current situation. So an autonomous agent decides autonomously what action to take in its current situation in order to maximize its progress towards its goals. So, if the agent has a goal the agent should try to maximize its goal too so that its performance measure is at maximum. The behavior and performance of intelligent agents we will look at in terms of the agent function. An agent function as we have already talked about is a mapping from perception history to action.

Now what is the mapping that the agent should implement?

Obviously the mapping the agent should implement is the one which maximizes its performance measure. The ideal mapping of an agent specifies which action an agent should take at any point of time. We will talk presently about how the agent should achieve this maximization. The performance measure is in fact a subjective measure which characterizes how successful an agent is. And how the performance measure is characterized can vary.

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The performance measure could be the amount of how rich the agent will become if the agent behaves in a particular way or how quickly the problem can be solved or how precise or how good the solution is, what is the quality of the solution that the agent has been able to achieve, the amount of power the agent's objective may be to minimize the amount of power consumed or the performance measure could be a combinations of several of these factors.

Actually an agent could be anything. We can look upon a human being as an agent, we can look upon a calculator as an agent. So, in order to characterize something as an agent we have to look at the different characteristics in terms of the different mappings the agent performs such as its percepts, its actions, the environment it operates, the entire characteristics of the environment and certain other things. So let us look at some common things that we are familiar with and look at what are the characteristics associated with such agents.

We are all familiar agents, so what are our sensory organs?

We can see with our eyes, we can hear with our ears, we can smell, we can touch, we can taste so these are the five primary input mechanisms we possess.

What are the actuators we possess?

We have our hands with which we can take some action, we have our fingers, we have our legs and several other things including the mouth with which we can take our actions.

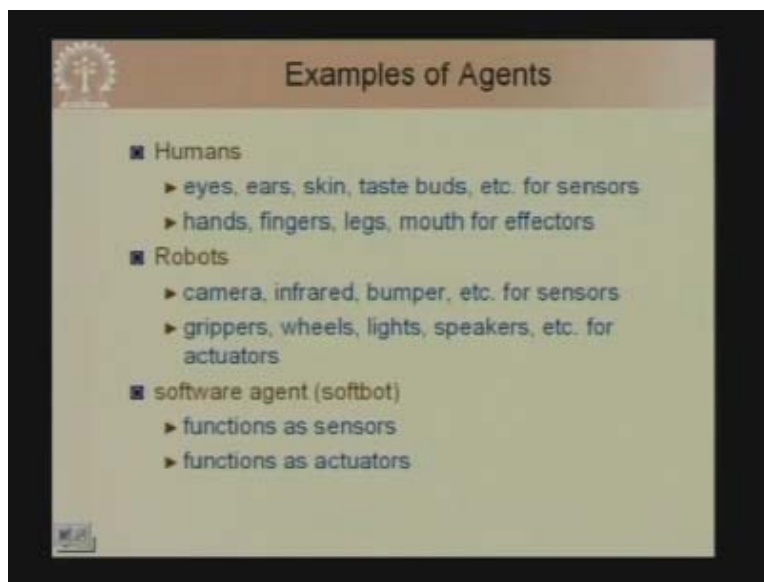
Now, if we design a robot what are the percepts, what are the different sensory organs we can give to the robot that we can build into a robot?

We can have a camera with a robot, a camera with which it can take pictures of what is in front of the robot and the robot function or the robot program can analyze that image and find out salient characteristics of the environment which will decide the way it should act.

Then the robot can use other types of sensors like sonar sensors, infra red sensors etc. And the type of actuators we can have or we can build into a robot are wheels, speakers, lights, grippers and any other output device that we may want to. And then we can look at a software agent.

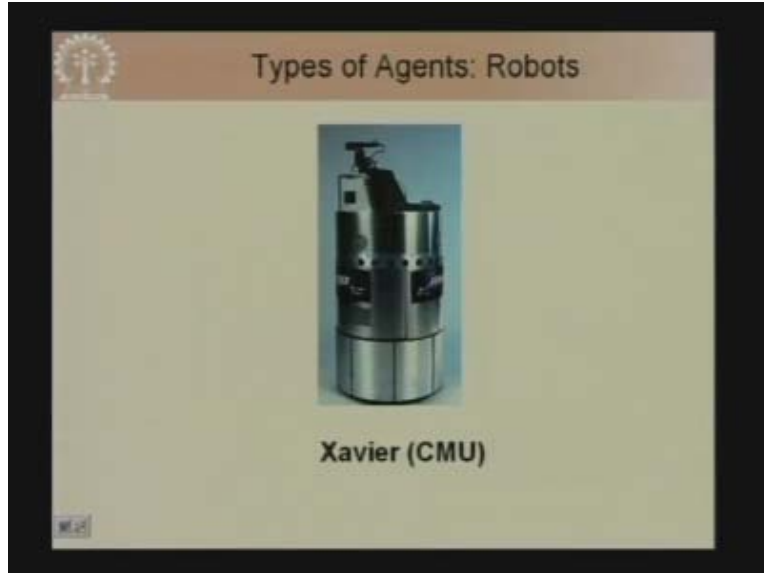
The software agent is becoming increasingly common now-a-days. So many people call them softbots. These softbots have some functions as sensors. They compute a function of the input. So they have some functions as sensors and some functions as actuators. We will later look at some specific software agents to look at the sort of function which they take as the input and the sort of function they compute to give the output.

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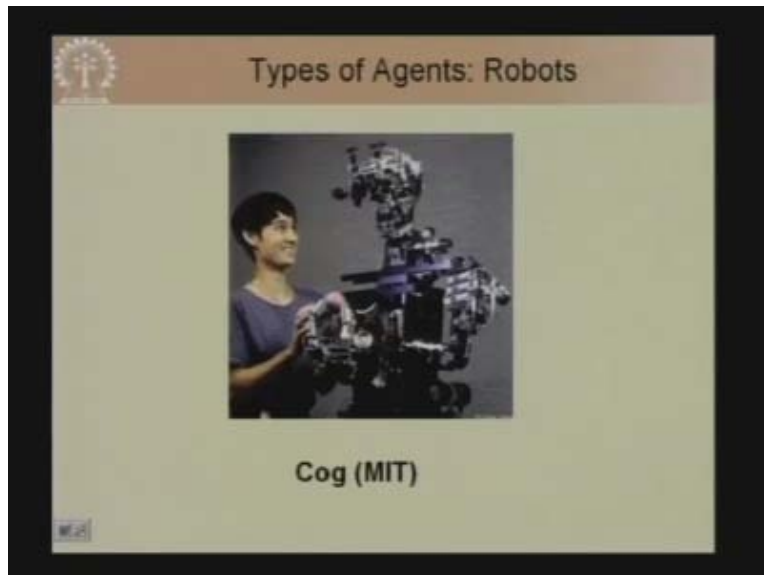
This is a picture of a robot. This is the Xavier robot developed at CMU it was one of the earlier robots that was developed at CMU.

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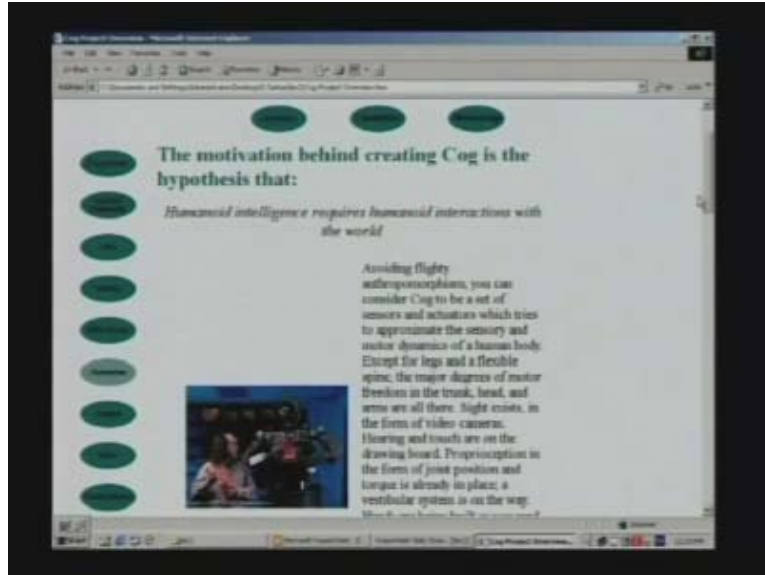
Then this is a robot called the Cog robot which was developed by Rodney Brooks group at MIT.

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We will have an occasion to talk more about Rodney Brooks' activity in the course of today's lecture. So the basic motivation behind creating Cog is the hypothesis that they wanted to build a humanoid robot a robot having intelligence like a human being. This picture shows professor Rodney Brooks with the robot Cog.

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And thirdly we have this entertainment robot. This Aibo robot is sold by Sony. This robot is claimed to be autonomous, sensitive to its environment, it can learn, it has different stages of its life and it can be personalized according to the environment in which it grows up in.

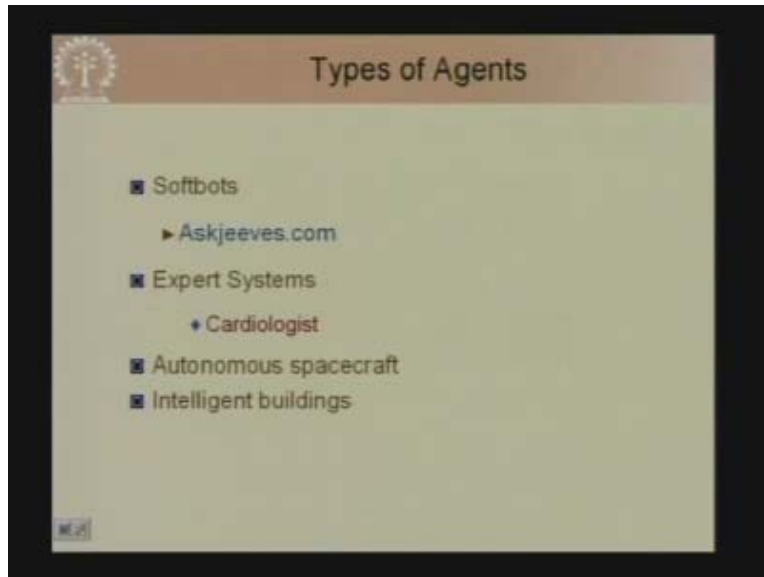
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Then there are other types of agents like softbots or software agents. For example, there are sites like askjeeves dot com which you can consider as an example of a software agent. There are various expert systems including the medical expert systems for example, the cardiologist which are also software agents. Other than software agents we

have other types of robots for example, the autonomous spacecrafts like the Mars Rover and then there are other types of robots like intelligent buildings which have intelligence built into them to decide the lighting condition, air conditioning etc.

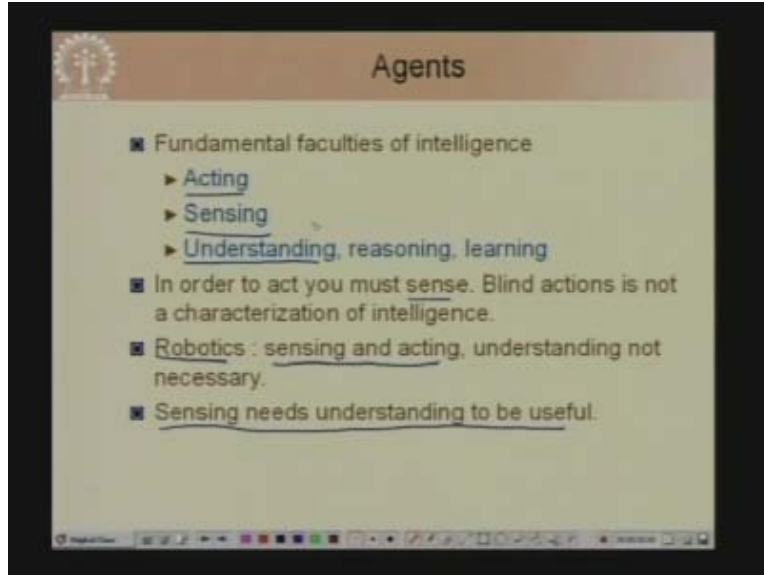
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So an intelligent agent must have certain fundamental faculties. It should be able to act. An intelligent agent must act. The intelligent agent must sense its environment. An agent must sense its environment. If the agent acts without sensing, it is a blind action and blind action cannot be intelligent. So there are certain types of architectures where the agents can sense and act and the agents do not do, do not perform any deeper deliberative action. In fact robotics is about sensing and acting only. At the outside we only require the agent to act appropriately. Understanding is not necessary. Understanding may be important for choosing proper actions but understanding by itself may not be necessary.

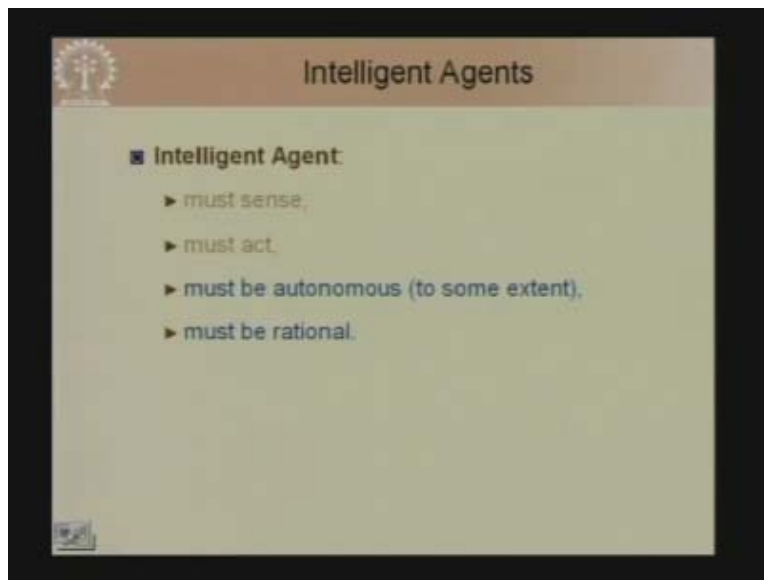
However, we must realize that sensing really needs understanding to be useful. So an intelligent agent who possesses complete intelligence must be able to do the following: It must be able to understand or interpret what it senses, it should be able to reason and finally the agent should also be able to learn so that the agent can operate in an unknown environment. In fact learning is a prerequisite for the agent to be autonomous. An autonomous agent which can adjust to a changing environment must have some learning component.

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Also, intelligent agents must be rational.

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In artificial intelligence we will talk about building rational agents and we will talk about different aspects the rational agent has and look at the

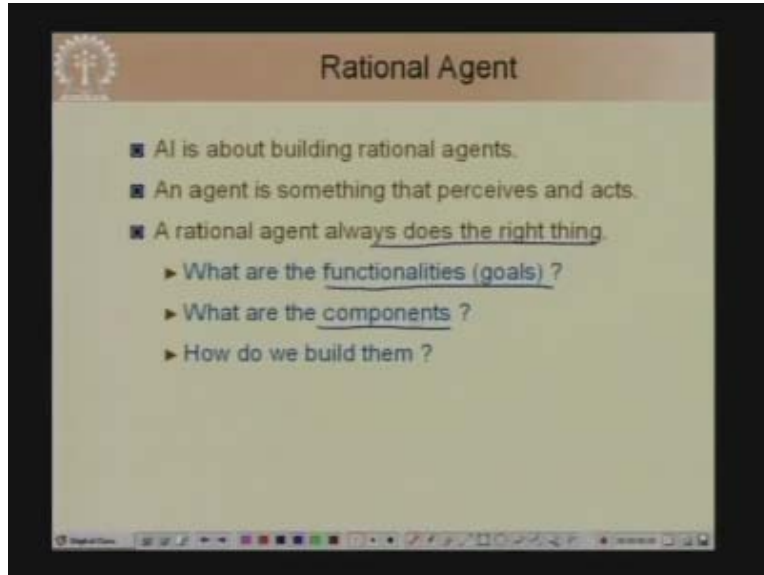
Now, what is a rational agent?

A rational agent is an agent which always does the right thing.

Now what is the right thing?

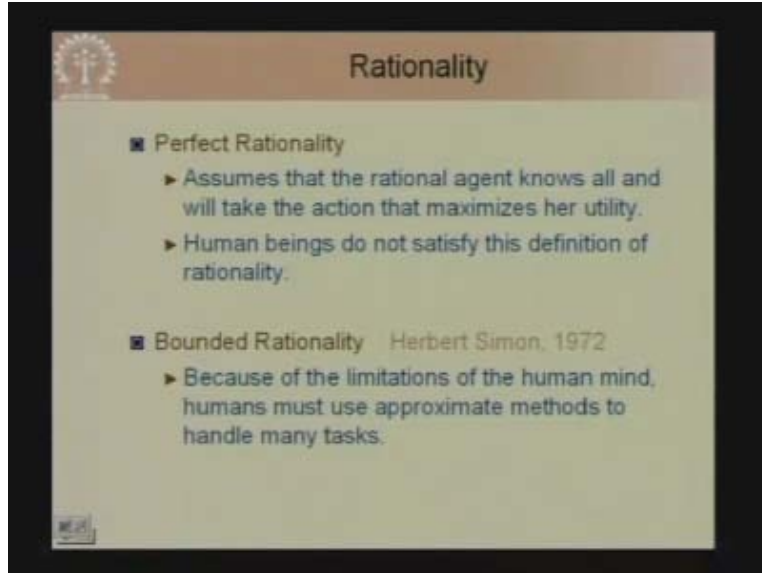
So in order to understand that we must understand what are the functionalities or the goals of the agent. What are the components of the agent and we must look at how we should build these agents.

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Perfect rationality assumes that the rational agent knows everything and will take that action which maximizes her utility. So, perfect rationality is prevalent to demanding that the agent is omniscient or all knowing. If the agent knows everything and the agent can reason extremely fast then the agent is a perfect rational agent. However, a perfect rationality is something which is not within the scope of even human beings. We do not satisfy the definition of perfect rationality. We are not omniscient; there are many things which we do not know, there are many things which we cannot reason in a reasonable time frame given what we know. The concept of bounded rationality was introduced by Herbert Simon of CMU in 1972 in his theory of Economics. So, bounded rationality says that because of the limitations of the human mind humans must use approximate methods to handle many tasks.

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Hence, bounded rationality does not aim at maximizing the absolute utility of the agent because that is something which may not be achievable given a realistic agent given realistic resource path. So, instead rationality as we will look at we will concentrate on using approximate methods where appropriate so that the agent can take the best action given its resource limitation and given what it already knows.

Rational action is the action that maximizes the expected value of the performance given the percept sequence to date. When an agent takes an action the action may not always have the same outcome. Sometimes the outcome of the action may be good, sometimes it may be bad. So, when we talk about rationality we must look at the expected value of the performance measure and not always the absolute value of the performance measure.

Also, we must evaluate an agent not on the basis of how it should behave in a perfect case but how it can behave based on what it can sense. So something that the agent cannot sense or foresee we cannot hold the agent responsible for those things. Therefore rational action in the light of bounded rationality talks about maximizing the expected value of the performance measure given the percept sequence which is available to the agent.

Therefore does rational action means the best action?

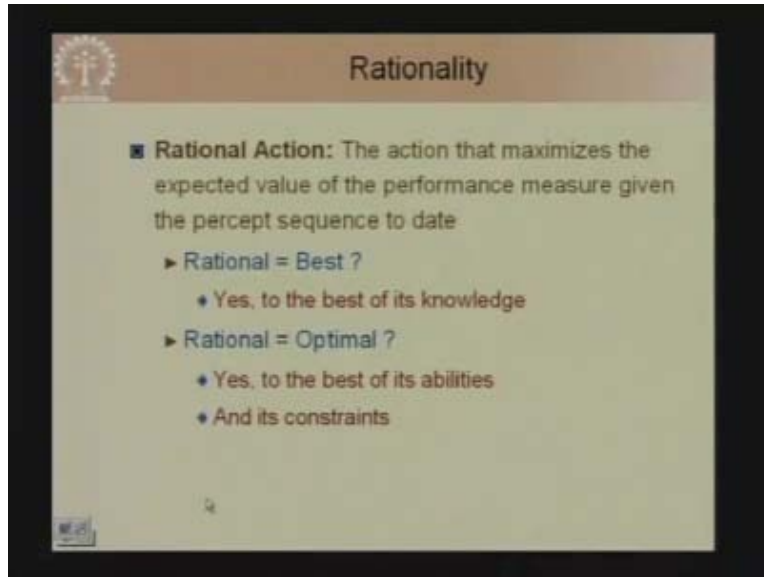
The answer is yes but to the best of the agent's knowledge based on what percepts the agent already has access to.

Does rational mean optimum?

Yes, but to the best of the abilities of the agent and subject to the resource constraints. The agent may have limitations in the way it can act. The agent may have limitations in terms of the resources that it has access to. There could be time limitations, there could be space limitations. So, given these constraints given its abilities the agent should take the

best action that is expected to maximize its utility. That is the rationality we will talk about.

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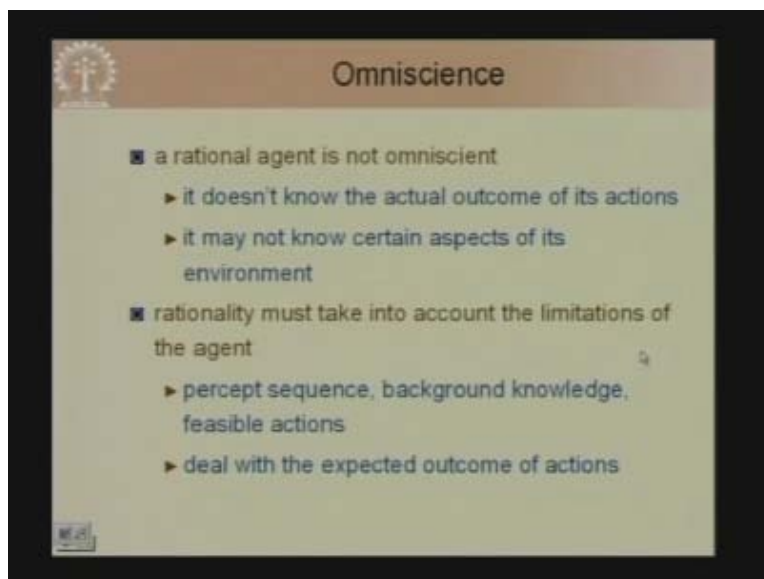


Rationality

- **Rational Action:** The action that maximizes the expected value of the performance measure given the percept sequence to date
 - ▶ Rational = Best ?
 - ◆ Yes, to the best of its knowledge
 - ▶ Rational = Optimal ?
 - ◆ Yes, to the best of its abilities
 - ◆ And its constraints

We must understand that a rational agent need not be omniscient because it does not know the actual outcome of its actions. And certain aspects of the environment may be unknown to the agent. So rationality takes into account the limitations of the agent, the percept sequence that it has access to, the background knowledge the agent has and the actions that the agent can take. And we only deal with the expected outcome of actions.

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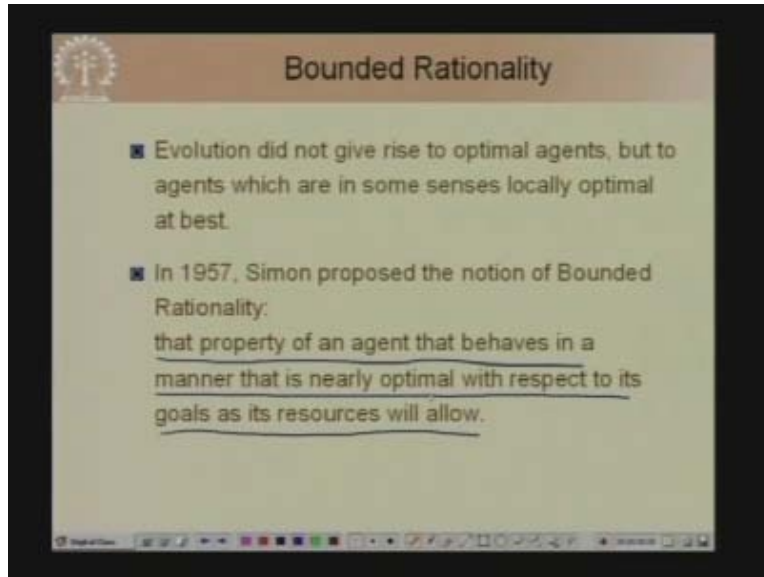


Omniscience

- a rational agent is not omniscient
 - ▶ it doesn't know the actual outcome of its actions
 - ▶ it may not know certain aspects of its environment
- rationality must take into account the limitations of the agent
 - ▶ percept sequence, background knowledge, feasible actions
 - ▶ deal with the expected outcome of actions

As we have already talked about, in 1957 Herbert Simon proposed the notion of bounded rationality. Formally if we define bounded rationality, It is that property of an agent that behaves in a manner that is nearly optimal with respect to its goal as its resources will allow as nearly optimal as its resources will allow.

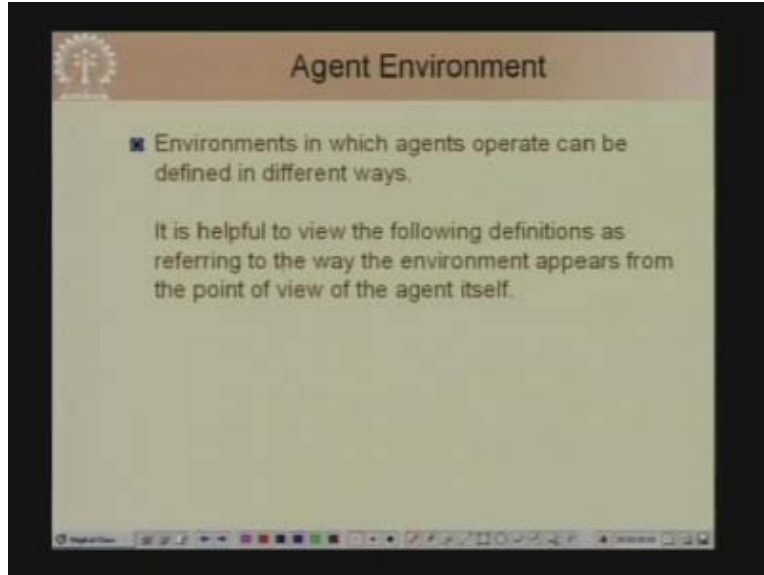
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Now we come to another very important component of an agent. Actually the design of the agent depends a lot on the environment in which the agent operates. And the task environment of the agent can be defined in different ways. So we will look at several ways of characterizing the environment. There are two ways of characterizing an environment. One way of characterizing the environment is in the absolute sense and another is from the point of view of the agent.

For example, when we want to talk about whether an environment is deterministic or stochastic we must not look at whether the environment is deterministic from an absolute point of view but rather whether the agent appears, whether the environment appears deterministic to the agent based on what it can perceive.

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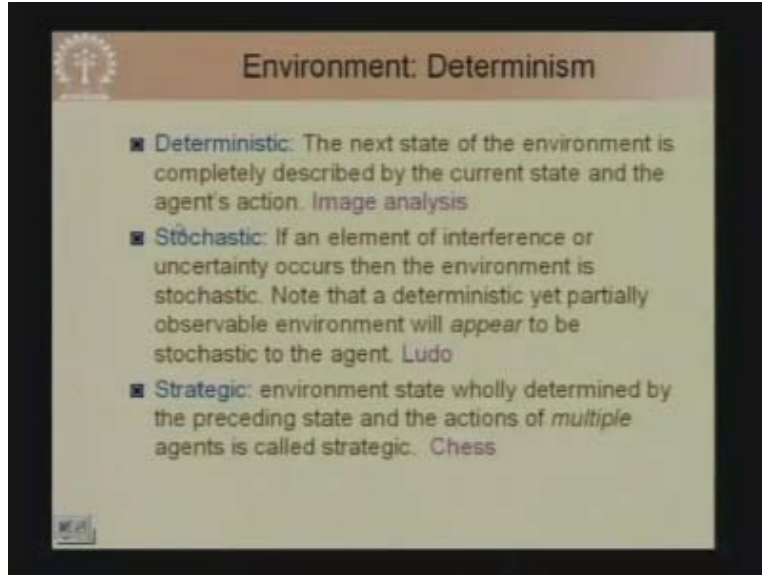


Environments can be divided into two types based on the observability of the environment. An environment may be fully observable or it may be partially observable. If the environment is fully observable the entire environment which is relevant to the action being considered is observable. All the relevant portions of the environment are observable.

On the other hand, in the case of partially observable environments not all the relevant portions may be observed. The relevant features of the environment are only partially observable. For example, consider an agent playing chess like the deep blue chess playing program. The agent has complete knowledge of the board. So everything about the environment is accessible to the agent. So the chess environment is a fully observable environment.

Consider again the environment where the agent is playing pokers where the agent cannot see the hand of the opponent. So the environment in this case is only partially observable to the agent. So, if the environment is fully observable the agent need not keep track of how the environment is changing and deliberating about the environment. So, if the environment is partially observable the agent in order to behave successfully in such an environment has an added task of keeping track of the environment and reasoning about the properties of the environment.

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Then, if you look at the aspect of determinism again environments can be divided into two or three types.

Deterministic environments: In deterministic environments the next state of the environment is completely described by the current state and the agent's action. When we looked at diagram of agent environment we have already seen that the agent's action changes the environment. Now, in a deterministic environment given the agent's action how the environment change is deterministic. There is no other unknown thing which comes into the picture to decide how the environment changes.

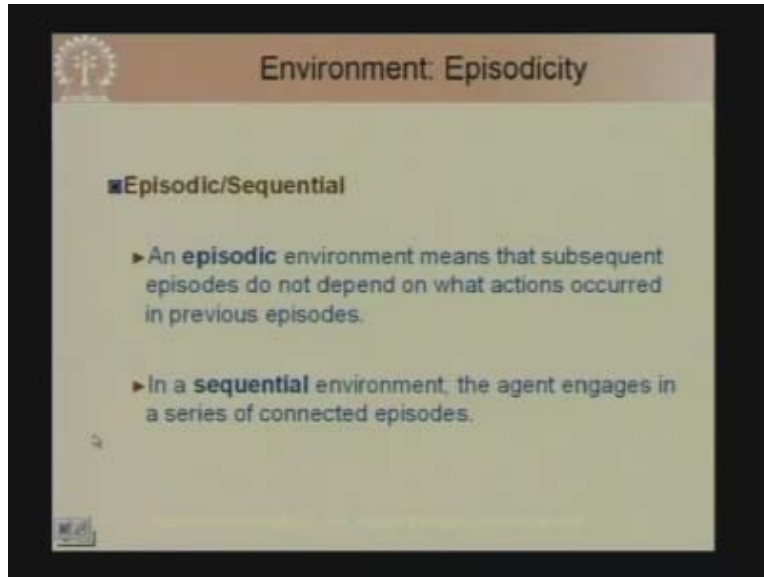
In stochastic environments, on the other hand, there is some element of uncertainty. Therefore how the environment changes depends not just on the action that the agent takes. So, whether an environment is deterministic or stochastic depends on how you look at the environment. If you cannot observe the environment fully the environment may appear stochastic to you whereas it is actually deterministic if you have access to the entire environment.

For example, take the example of pokers again. If the agent did have access to both the players' hands and all the cards which are there then the environment actually behaves in a deterministic way. However when it is partially observable it appears to be a stochastic environment. So this is an environment which appears to be stochastic because of partial **observability**. If you look at the game of Ludo it is a stochastic environment because how the environment evolves depend on the value which the **die** has rolled. So whether the die has rolled 1 or 2 or 6 depending on that the agent can decide its actions. Therefore this is a truly stochastic environment.

A strategic environment is an environment state which is wholly determined by the preceding state and the actions of multiple agents. In a strategic environment apart from

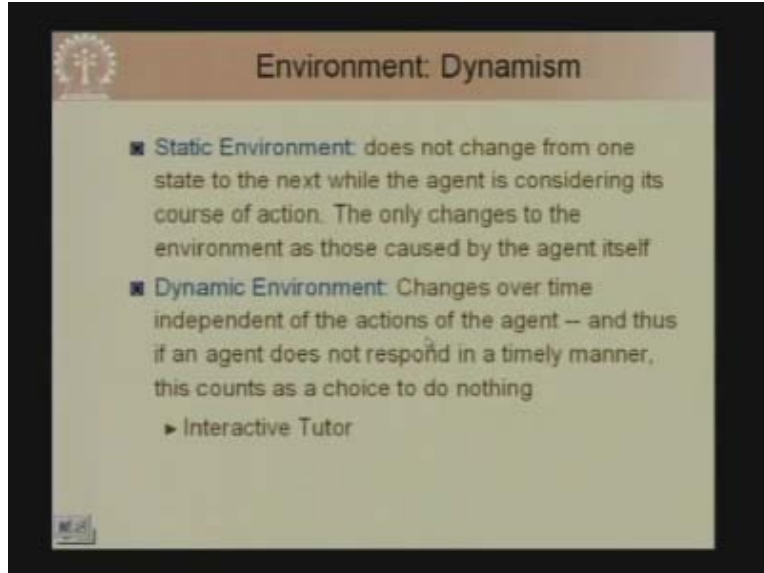
the current agent itself there are other agents around and the actions of all these agents influence the environment. A strategic environment is one where the environment is only changed by the actions of the agent itself and other agents. For example, a chess playing agent operates in a strategic environment.

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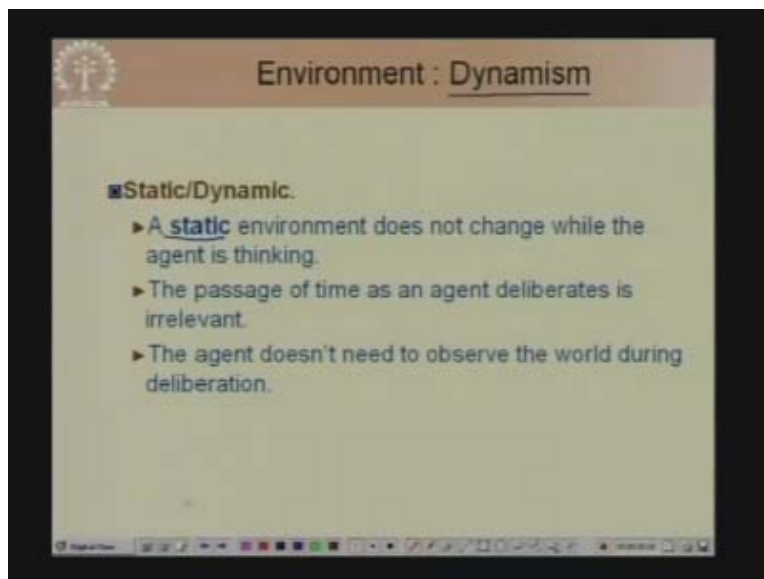
Then if we look at the **episodicity** of the environment an environment may be episodic or sequential. An episodic environment is one where subsequent episodes do not depend on what actions occurred in previous episodes. First of all sometimes certain tasks can be divided into different phases or different episodes. In such episodic environments the one episode may or may not influence the subsequent episode. So, if one episode does not influence the subsequent episode such an environment is called an episodic environment. Therefore in such an environment an agent did not plan beyond episodes. In a sequential environment, on the other hand, the agent engages in a series of connected episodes. So subsequent episodes are dependent on what happened in the previous episodes. Hence, in this case the agent may need to plan ahead or base its action upon what happened in the previous episodes.

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Then if you look at another characteristic of the environment is its dynamism. Environments may be static or dynamic. A static environment does not change by itself. So an advantage is that a static environment does not change when the agent is deliberating. The agent does not need to observe the world during its thinking process. A dynamic environment changes by itself that is apart from the action that the agent takes.

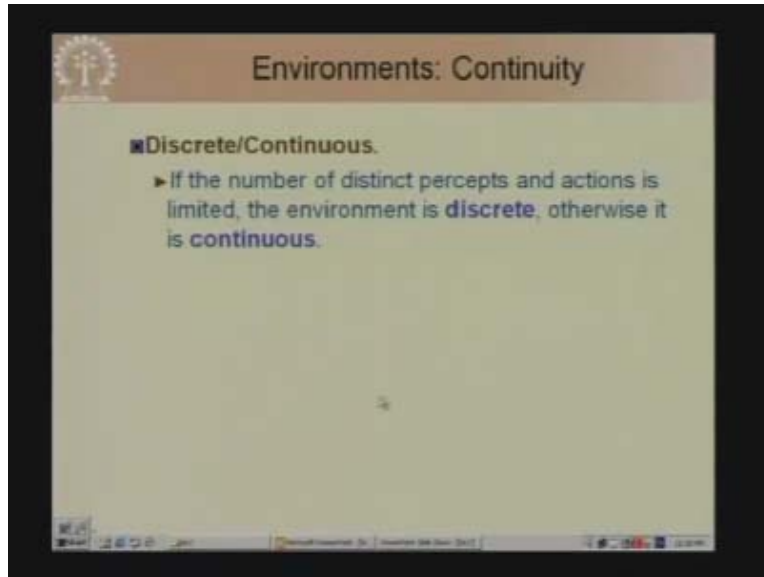
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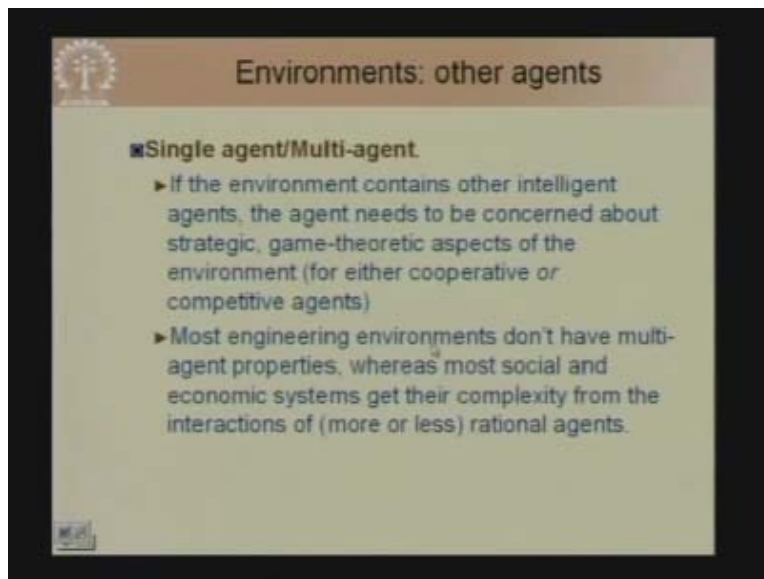
Also, another dimension by which we can characterize environments is by its continuity. An environment is discrete or continuous. An environment is discrete if the number of distinct percepts and actions are limited and the number of states is limited. If the number

of states is discrete then that environment is a discrete environment. And the environment is a continuous environment if the range of percepts is continuous or the range of actions that it can take is many or the number of states is either continuous or too many so that we treat them as continuous.

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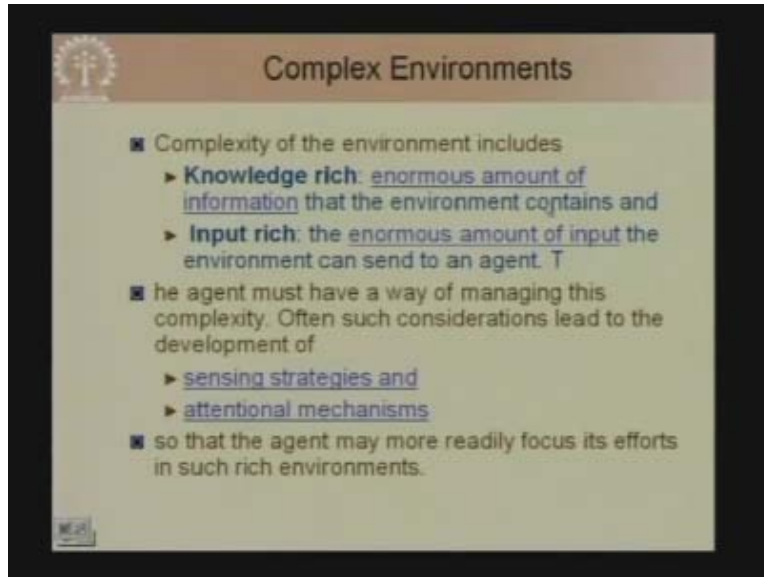
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And finally we can also characterize the environment according to whether there is one agent whom we are talking about in the environment or whether there are other multiple regions in the environment. That is, if the environment contains other agents then it is a multi agent environment. In games when we look at two person games we usually talk

about one opponent agent. There are environments where there is a single agent but for many tasks that the agent does usually we talk about a single agent environment but there are many situations which require distributed agents or with social and economic systems we deal with multiple agent systems.

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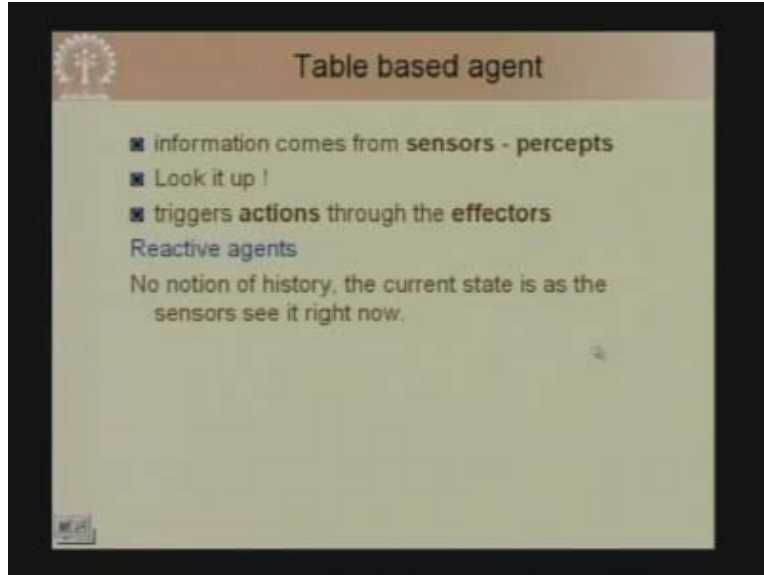


The slide is titled "Complex Environments" and features a list of characteristics and requirements for agents in such environments. The text is as follows:

- Complexity of the environment includes
 - ▶ **Knowledge rich:** enormous amount of information that the environment contains and
 - ▶ **Input rich:** the enormous amount of input the environment can send to an agent. T
- The agent must have a way of managing this complexity. Often such considerations lead to the development of
 - ▶ sensing strategies and
 - ▶ attentional mechanisms
- so that the agent may more readily focus its efforts in such rich environments.

Therefore the complexity of the environment includes knowledge rich environments and input rich environments. In knowledge rich environments there is enormous amount of information the environment contains. Knowledge rich environments contain lots of information. And input rich environment is one where there is enormous amount of input, enormous amount of percept that the agent can get. And in such environments which are complex, which are either knowledge rich or which are percept rich the agent must have a way of managing this complexity. So, such considerations in the environment are complex. The agent must develop its strategies for sensing or its strategies of attentional mechanisms. The agent must decide selectively what to sense, what is more relevant and what it should give its attention to rather than deal with the entire complexity of the full environment. Thus, an agent needs to focus its effort in such rich environments.

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Now we will look at the different types of agent architectures. Table based agents, stimulus response agents, goal based agents, and utility based agents and learning agents. We will briefly talk about these agent architectures. A table base agent is a very simple agent. An agent has to take actions given its sense given what it senses, given its percepts.

Now, in a table based agent the mapping from percepts to actions is stored in the form of a table. Therefore, on the left side we have the percepts and on the right side we have actions. And the agent program is extremely simple. Hence, given the percept the agent looks at the table and decides what action to take. Therefore based on this mechanism we can develop what we call reactive agents which can take the action depending on the percept. Unfortunately the best action for the agent it depends not only on the current percept but on the percept sequence.

Now the number of possible percept sequence can be very large. In fact it can be infinite till the agent acts over many time steps, many unbounded time steps then it can become infinite. So this table can become very large if you have a mapping from percept sequence to action. In simple tasks where the action only depends on the current percept it may be easy to develop a table based agent but it is infeasible when the correct action or the best action depends on the past and not only what the agent sees or perceives at the current time step.

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Table based agent

- information comes from **sensors** - **percepts**
- Look it up !
- triggers **actions** through the **effectors**

Reactive agents
No notion of history, the current state is as the sensors see it right now.

Agent ← Percepts
→ actions
Percept sequence

Percept	Act.
—	—
—	—
—	—
—	—

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Table based agent

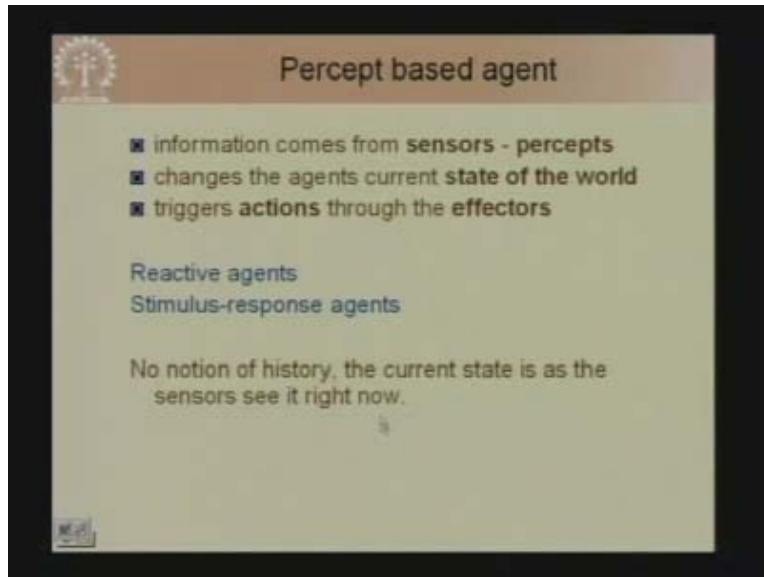
- a table is simple way to specify a mapping from percepts to actions
 - ▶ tables may become very large
 - ▶ all work done by the designer
 - ▶ no autonomy, all actions are predetermined
 - ▶ learning might take a very long time
- mapping is implicitly defined by a program
 - ▶ rule based
 - ▶ neural networks
 - ▶ algorithm

So, a table is a very simple way to specify a mapping from percepts to actions but tables may become very large. And in a table based agent there is no intelligence in the agent itself and the entire work is done by the designer in designing the table. So the designer makes the table and the agent just looks it up to decide how to act. So such agents have no autonomy. All actions, all behaviors are predetermined and there is really no concept of learning.

Now, the mapping from percept to action may be done in different ways. It may be in terms of a natural table, it may be in terms of a production system or rules. This mapping

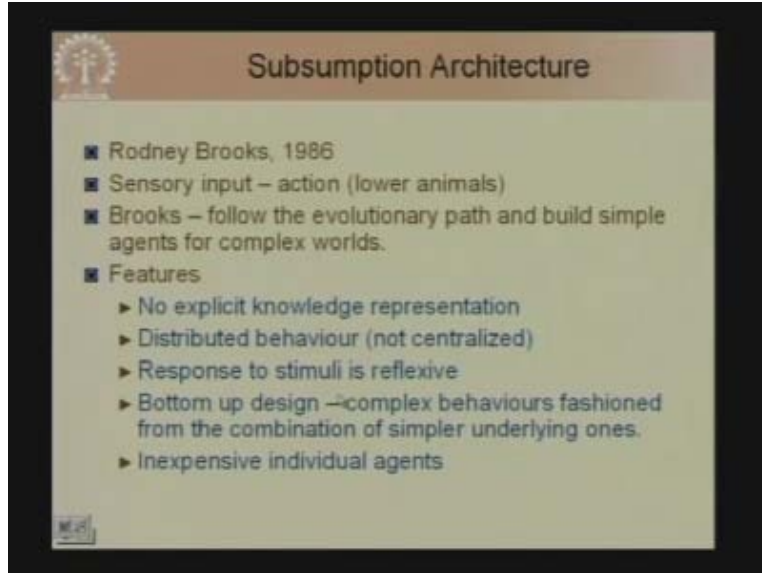
can also be implemented by neural networks or one can implement the mapping by algorithm. So, this mapping can be implemented in a rule based manner using a neural network or using some algorithms.

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So such agents where the action depends only on the percepts and there is no deliberation involved are called reactive agents. The term reactive agent means those agents whose information come from sensors and they can take actions through their actuators or effectors. And we can additionally assume that the actions change the current state of the world and the agent can only take some action without any deliberation. Such agents are also called stimulus response agents. They have no notion of history but all their history is encoded in the current state as the sensors see it right now.

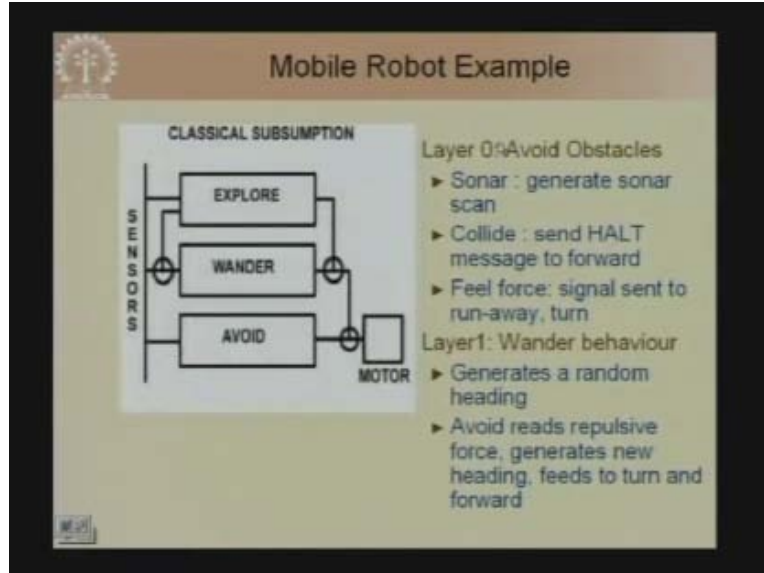
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Now let us talk about professor Rodney Brooks of MIT and the **subsumption** architecture he proposed based on stimulus response agents. In 1986 professor Rodney Brooks gave this notion of the subsumption architecture. His argument was that lower animals behave in a largely reactive manner. They have a very little sense of deliberation. Therefore, most of their actions are reactive actions. And his argument was that in the time scale of evolution reactive behavior came much earlier than deliberative behavior. And he has been able to show that a number of such components having simple reactive behavior can achieve a surprising degree of intelligence.

Thus, Brook's idea has been to follow the evolutionary path how life has evolved and build simple agents for complex worlds. It is a combination of simple agents working well in the complex world. The features of the subsumption architecture are that there is no explicit knowledge representation. Behavior is not centrally controlled but behavior is distributed among different components. The response to stimulus is reflexive and more importantly the design is bottom up. The complex behaviors are fashioned from the combinations of simple behaviors. Simple behaviors are put together to achieve complex behaviors. And each individual agent is simple and inexpensive. Therefore the subsumption architecture is basically a layered architecture.

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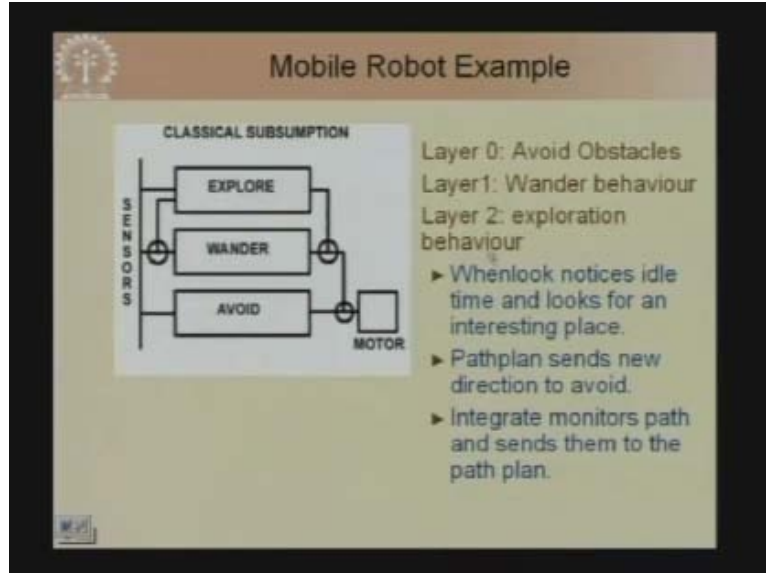


According to professor Brooks the time scale for evolution has been 5bn years. It has take 5bn years to evolve from single cells since cells evolved to the present day. The first humans appeared two and a half million years ago only whereas the first cells appeared 5bn years ago and symbols did not appear until only 5000 years ago. Therefore his proposition is that we should look at simpler behavior as the first step towards building intelligent agents.

Hence, in subsumption architecture there are different layers of behavior and higher layers override lower layers and each activity in each layer consists of a simple finite step machine. Now, this is an example of a simple architecture proposed by Rodney Brooks. In this system there are several layers. This is a very simple robot. In the layer zero there is the avoid obstacles layer. In this layer there are several sensory organs. The sonar component generates sonar scan, the collide component sends halt message to forward and the feel force component is the signal sent to runaway or turn around. So layer zero of the agent is to avoid obstacles. This is the first layer of the agent which enables the agent to navigate in an environment without colliding with other agents. So it is a very simple behavior of a navigating robot without using a lot of deliberation.

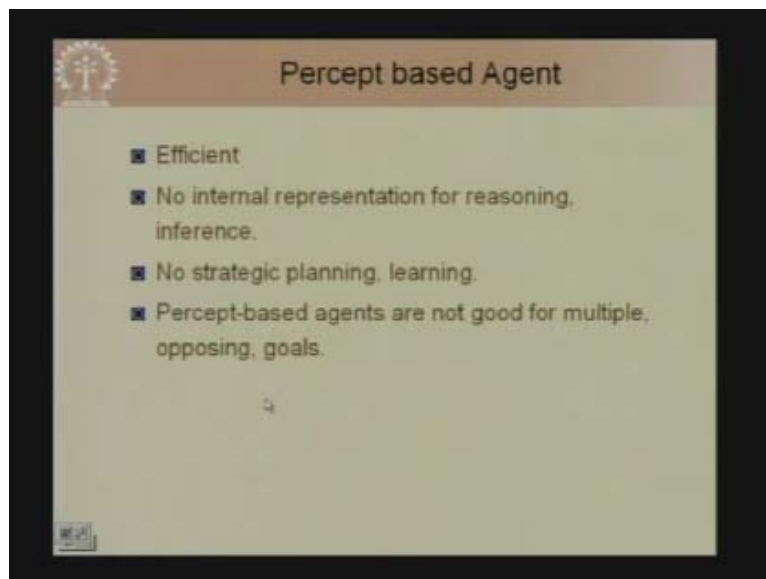
In the second layer, layer 1 there is the wander behavior. This wander behavior generates a random heading. It allows the robot to occasionally wander. So in the wander layer there are two components. One generates a random heading and secondly the avoid component reads repulsive force and generates new heading and feeds that to turn and to forward.

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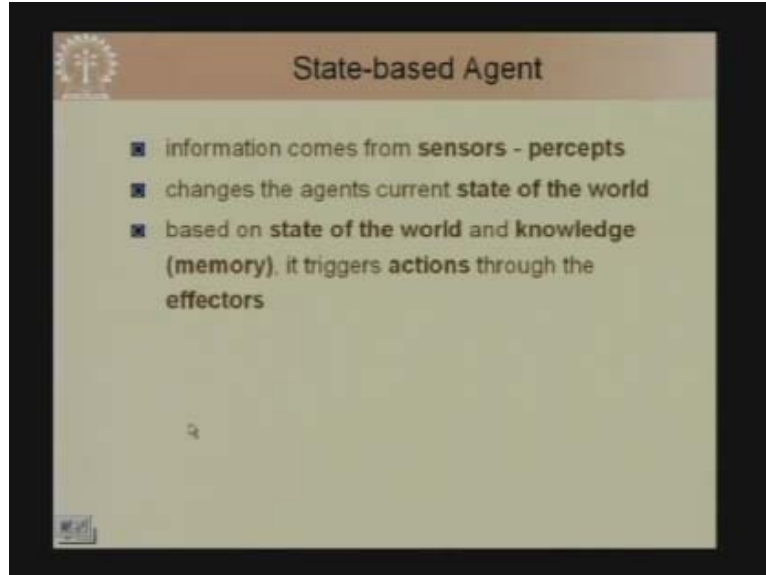
Layer 2 that is the third layer has the exploration behavior. So this has several components. The **whenlook** component notices whenever there is idle time it looks for an interesting place. The path plan component sends new direction to avoid. The integrate component monitors path and sends them to the path plan.

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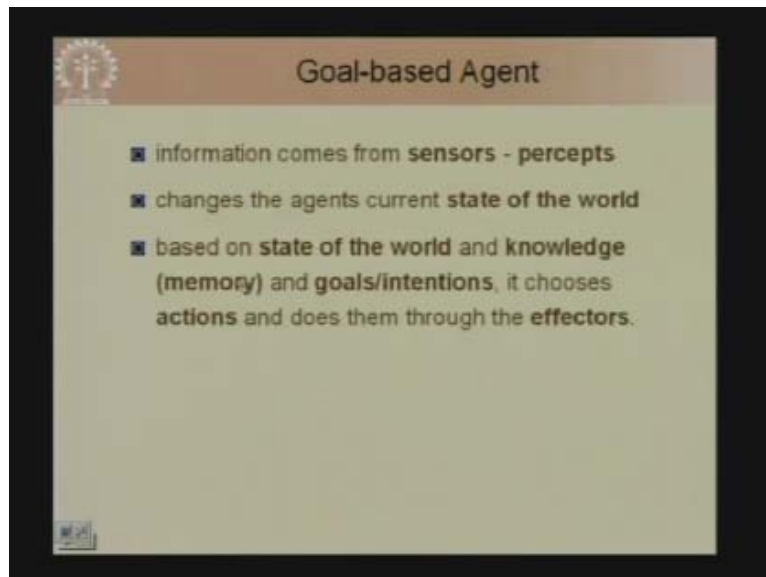
So as we have seen this percept based agents are efficient because they do not require internal representation for reasoning or inference. However, there is no strategic planning or learning and they are not good for multiple opposing goals.

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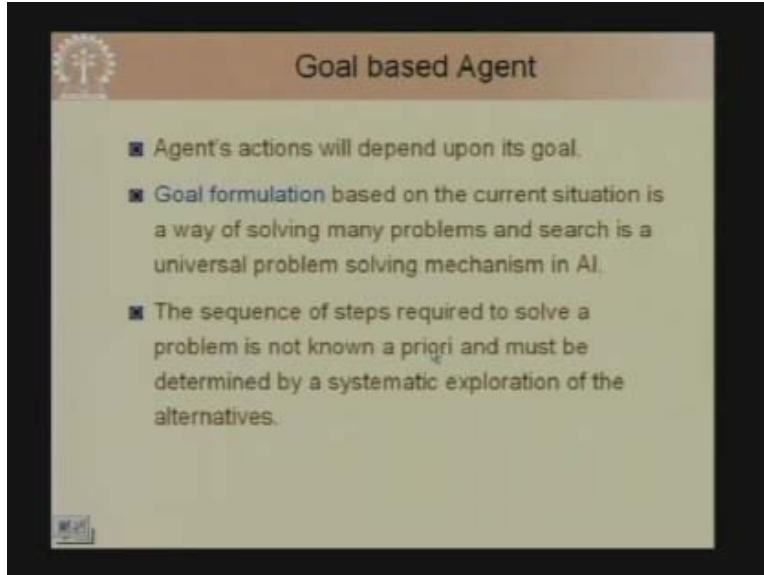
In the second type of agent the more knowledge rich agents we come to state based agents. In state based agents information comes from sensors and it changes internally the agent's current view of the world based on the state of the world and the knowledge the agent has. It triggers action through the effectors. And in order to do this the agent does some deliberation.

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So based on the state of the world and knowledge the agent chooses the action and carries out the action through the effectors.

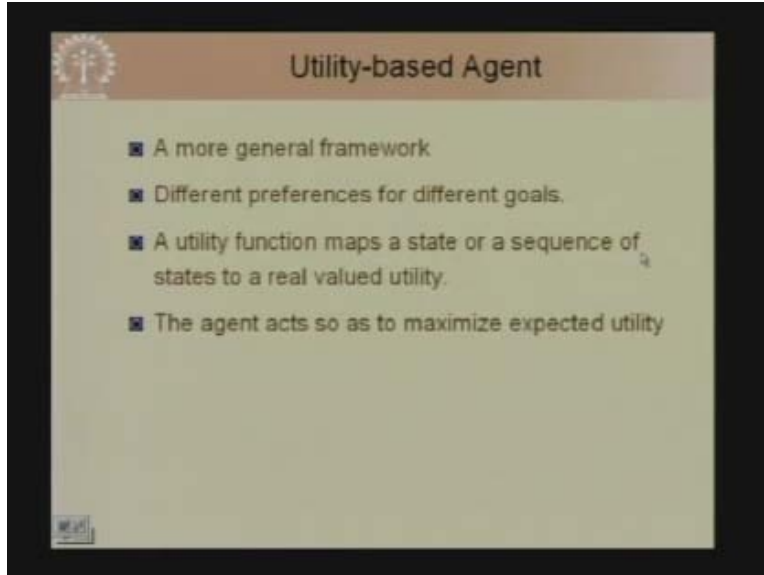
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Now, in goal based agent the agent's action depends upon its goals and goal formulation is based on the current situation. Therefore, based on the goal that the agent has to achieve and the current state of the agent as it perceives the agent goes through some deliberations to decide what the next action should be.

We will look at search and planning. These are the two fields of AI in which we will look at different ways of deciding what action to take in order to achieve the agent's goals. Hence, in goal based agents the sequence of steps required to solve a problem is not known a priori. They are not available in a table and they must be determined by a systematic exploration of the alternative actions by deliberations.

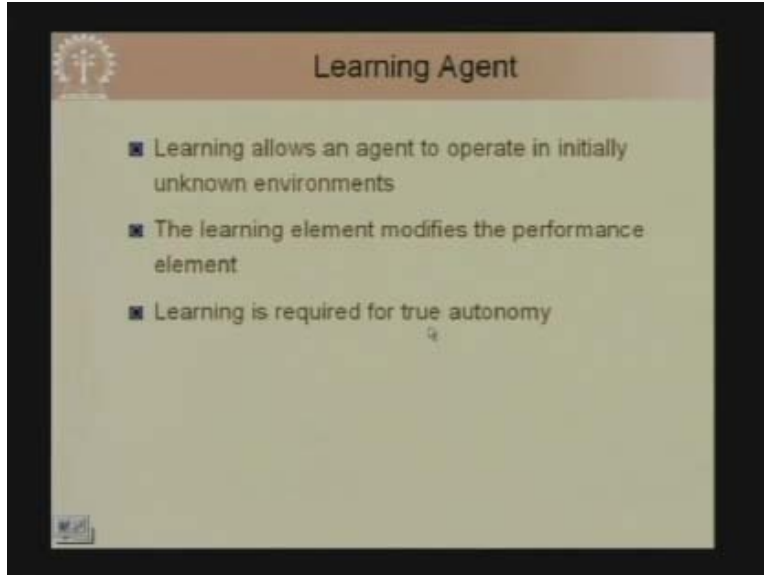
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Thirdly, we have utility based agents. Utility based agents are akin to goal based agent but they are a more general frame work. If an agent has several goals and it can achieve only some of them these goals may have preferences associated with them as to which goals are more preferable. In this case we can talk about utility based agents where we have different preferences for different goals.

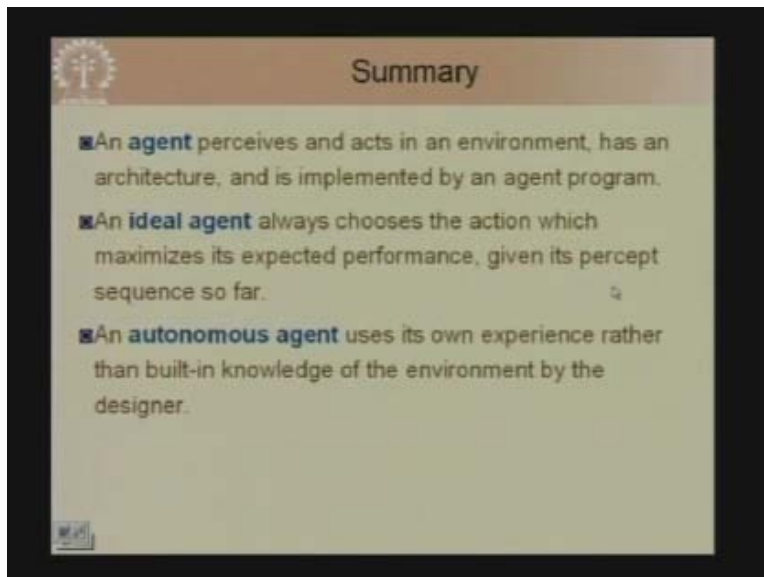
A utility function is a very general function that maps a state or a sequence of states to a real valued utility. So a state is mapped to a utility value and we can say that the goal of the agent is to maximize its utility or the goal of the agent is to maximize its expected utility. When we look at the **decision** theory we can consider agents which are based on utility. And finally and very importantly we have learning agents.

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We have said that learning is an extremely important component of autonomy. An autonomous agent should have some learning built into it. Learning allows an agent to operate in unknown environments. And the learning element modifies the performance element and learning is required for true autonomy. We will take up learning later in this course when we look at several types of learning that can be carried on by the agents.

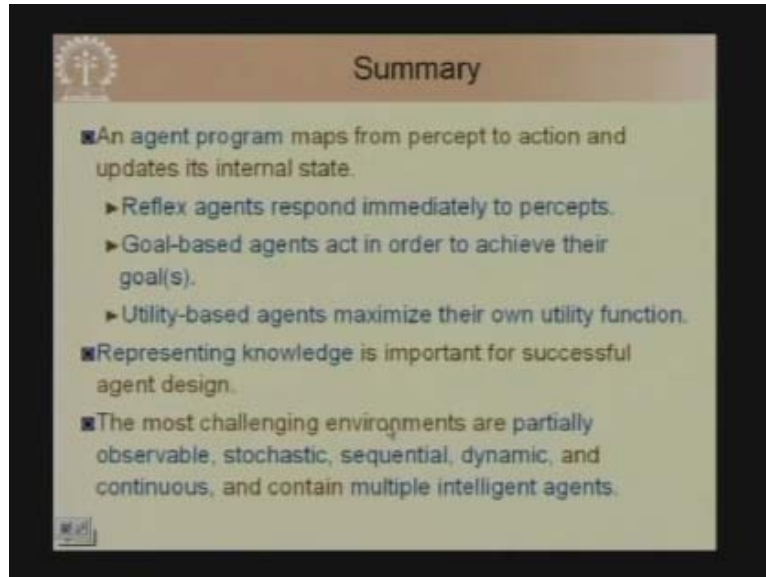
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In summary of today's lecture an agent perceives and acts in an environment, it has an architecture and an agent is implemented by an agent program. An ideal agent chooses

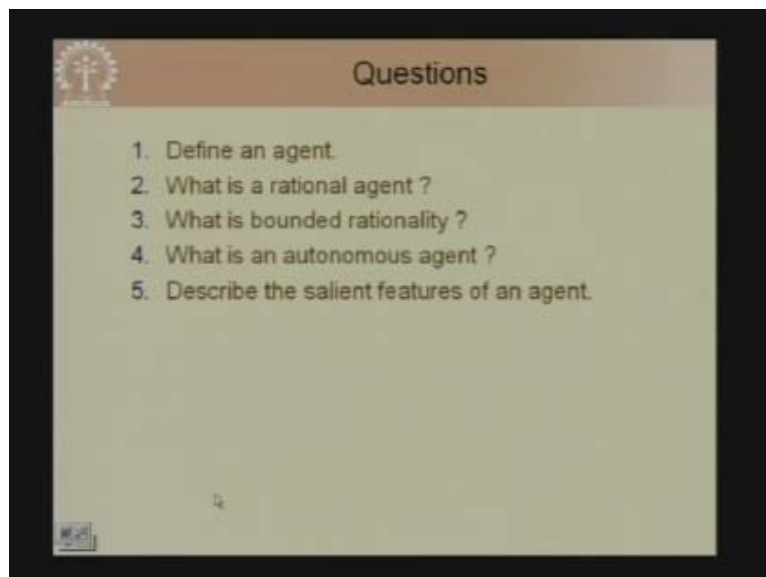
the action which maximizes its expected performance. An autonomous agent uses its own experience rather than built-in knowledge of the environment by the designer.

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An agent program maps from percept to action and updates its internal state. Reflex agents respond immediately to percepts. Goal based agents act in order to achieve their goals. Utility based agents maximize their own utility function. And then in order to have goal based agents the agent must represent its knowledge, must represent its history, must have some background knowledge etc. So, representing knowledge is important for successful agent design.

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Now we will come to a set of questions based on today's lecture.

Question 1: Define an agent.

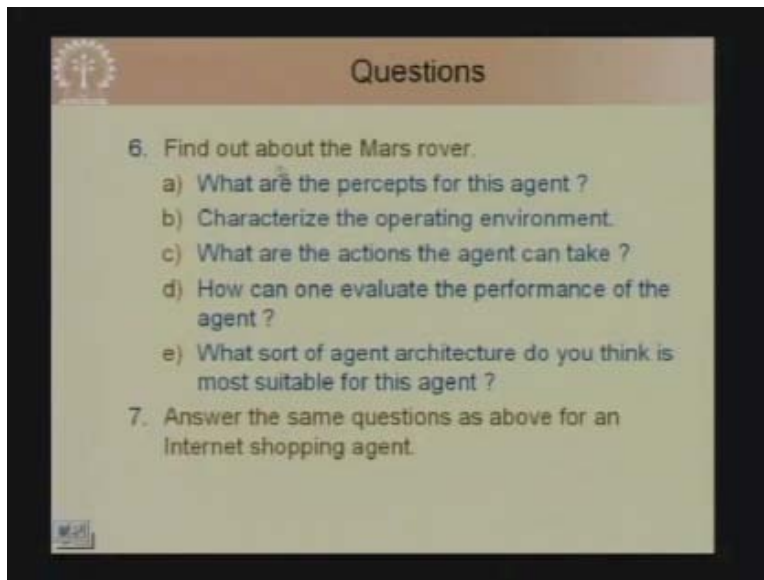
Question 2: What is a rational agent?

Question 3: What is bounded rationality?

Question 4: What is an autonomous agent?

Question 5: Describe the salient features of an agent.

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Question 6: Find out about the mars rover.

What are the percepts for this agent?

Characterize the operating environment for this agent.

What are the actions that this agent can take?

How can one evaluate the performance of this agent?

What sort of agent architecture do you think is most suitable for this agent?

Question 7: Answer the same questions above for an internet shopping agent.