**Modified**

Now that we have already looked at the agent communication languages. The nesting for the agents to be able to interact and communicate effectively is to define a proper interaction protocol when they need to interact.

So as you can see, the agent communication language define the syntax and semantics of single utterances. But for the single utterances to go into a flow between agents and form a meaningful dialogue or conversation, then they most of the time need to follow some proper interaction protocol.

The interaction protocol specify the rules of interaction, these rules of the procedure for conversation, including the permissible agent roles involved in the interaction. So for instance, one agent may be asking for information, another agent will be responding by informing the first one of the relevant information and so on and so forth.

So not only there is the roles of the agents involved in the conversation, but also there is a sequence of message changes between the agent roles. So what message will be utter first to initiate the conversation and then to respond to that utterance, what is the appropriate message to send back and so on and so forth. And also there could be constraints on the content of the messages exchange between the agents as well.

Now, for the conversation to be meaningful, all participating agents must conform to the interaction protocol to enable the rational conversations. Some example of the interaction protocol that has been defined for multi agent systems, the most famous one probably the ContractNet protocol CNP. Now this protocol has been introduced for task allocation. So one agent having a task that it needs all the agent to help it achieve or accomplish. And so the agents having the task will send out a request for the other agents asking for the agents with the capability of performing the task to send back their proposal, also called the bid. And then the agent who has the staff will compare the bids and then choose the right agents to perform the task.

So this contract protocol comprise five stages the recognition stage, the announcement, the biding, the awarding and expediting stages. So to start with the recognition, an agent recognize it has a problem that it wants help because it involves a number of tasks it cannot solve by itself or it prefer not to solve by itself. Possibly because if it solve the task by itself and then it may not have the high quality solution or maybe because it will not be able to meet the deadline.

So the agents need help from all the agents and after recognizing that I had a problem, then the agents can proceed to the next stage. In this stage, the agent having the problem that requires some path to be accomplished. This agent will send out the announcements, could be by broadcasting to all the agents within the broadcasting range or it could send specific messages to specific agents who can see the announcement.

The specification must encode the specification of the announcement must encode the description of the task. Clearly, if you ask all the people to work on the task for you, you need to describe what the task is about and also specify any constraints, for instance, what the deadline is, what are the quality constraints that you expect that the other agents will meet for doing your task. And also possibly some other meta information. For instance, information about Bit for this task must be submitted by certain time.

So these meta informations are related to the interaction protocol. After all the agents receive the announcement from the agent who has the task, they will have to decide on whether they want to bid for the task. For instance, in this example you can see that A two decide that he does not want to bid for the task, while a three and a four decide that they will both bid for the task.

So related to the decision could be the agent capability of doing the task. So for instance, a 2 may decide that he doesn't have the ability to do it, or maybe because of the quality constraints, the deadline, and also maybe the price information, because in many cases when an agent puts out the task, they need to pay to the agents who perform the task. And so they also need to specify what is the price that they willing to pay, the maximum price that they're willing to pay.

So there are some other constraints such as whether an agents have the capability to deliver the task according to that quality constraints, according to the deadlines, according to the price information. If an agent choose to bid, then you submit a tender. So in this particular example you can see that both a three and a four submitted tender and after this, the task owner, the agent who initiated the request for bids, must decide who to award the contract to and the decision now is communicated to the winning agents.

In this example, the agent, the owner of the task agent A one, decide to award the task to a four and so communicated this decision to a four and also notify the losing agent as well. So that means that there are also a message from a one to a three, notify in a three that he has not been successful in getting the contract, so the successful contractor perform the task.

So in this case, a four needs to expedite the task and the process of performing the task may actually involve another round, some future rounds of subcontracting. So using conjunctive protocol, a four might actually send out announcements to ask for all the agents to work on some of the subtasks for him as well, or for him or her as well.

Ah. To design interaction protocols, there are two main approaches the top down approach. So interaction protocol specifications are already being predefined and publicly available. Examples, including some of the interaction protocol defined by FIFA, such as congenital protocol. Iterate congenital protocol.

Now, an agent designer can implement the agent to play the appropriate role in the interactions. So, because the interaction protocol already been defined and well known and publicly available. So when I design my agent, I will just implement my agent to take part in these protocols. And the benefit here is clearly that agent can engage in meaningful conversations by follow the predefined interaction protocol. Because this is a common protocol, everyone understand it, everyone follow it, and so the conversations will be well defined.

On the other hand, top down approach may not always be feasible. So if an agent join a society of agents, it may not know about any publicly available interaction protocols. So in such a case, when agents may just emerge into a society, then a bottom up approach may be needed. Here, the agent designers will make the agents that sufficiently aware of the meanings of different kind of messages and also have the capability.

So the agents that the designer design has the capability of understand the goals, the beliefs, and all the mental attitudes that the other agents possess. Then when the agents trying to solve its own problem, then it use a planning process in order to try to come up with the task. And among those tasks is identify some other agents that need to interact with.

And this process that an intelligent agents perform may actually cause some interaction protocol to arise. So I come into a society not knowing about what the interaction protocol they have there, but I might always try, I might start asking politely about some information. I might be asking very politely about whether they can help me with doing certain things. And so the audio agents, when they see that the way that I interact is not something that too unacceptable, so they see that my behavior is acceptable, then they may actually interact back to me with their own way of interaction.

And so the interaction protocol then emerged from this process of agents trying to explore different step of interactions. And then in the end, they emerge into a common protocol to allow the agents to communicate and interact with each other. And so the IPS will arise spontaneously from the interactions. Clearly, the second part of method, the bottom up interaction protocol definition is much harder to achieve and requires agents with intelligence and some smartness in their behavior.

So the easier one is clearly to follow some top down predefined interaction protocols. And FIFA already defined many interaction protocols that agent designer can use. So in this list, you can see a few examples of these FIFA interaction protocols. For instance, request interaction protocol, query interaction protocols, contract interaction protocol, and so on and so forth. So the full list can be found here.

Now, I will go through two of these interaction protocols defined by CPA to show you how agents can be designed to participate in these interaction protocols. The first one is CPA request protocol. This protocol is defined to allow one agent to request another agent to perform some action. So the requester is also called the Initiator will send a request message. So clearly here the performative is request and then the content of the message will be what the initiator want to request and the participant will receive this request.

The participant has two choice that it can take. So the first one is that it refused. This request could be because it's unable to perform that action or maybe because some reason. So the Initiator set a price. So after you finish my request and then you will receive this reward and then the participant think that the reward is too small and therefore refuse to fulfill the request. Or the other possible choice is that the participant actually agree. And so when it's agree and then it send back the message agree and notifications necessary.

So that means that I agree to do it. And not only that I will do it, but I also notify you of the outcome of my action as well. So because of that, the agents will start working on the task. So after they agree and then they're working on the task. And then after working on the task now, depending on the outcome now, if they fail to deliver it and then they send back the notification of failure, if they actually complete the task and then they inform the initiator that the task has been done or not. Inform the initiator of the results of working on the task and then this will be done by L agents. L equal to two in this example.

Another interaction protocol defined by FIFA is FIFA ContractNet interaction protocol. In this interaction protocol is based on the ContractNet protocol that I mentioned before. Here we have the task owner called the Initiator who will send out the call for proposal to end participants. Sending call for proposal to end participants, it could be procrastinating and then their end participant receive this coffee proposal.

Among the N participants who receive the coffee proposal, then N of them will get back before the deadline. And so among these N agents who get back to the Initiator, then I agents will refuse. So let's say that the Initiator broadcast and then there are 100 agents who receive this announcement and before the deadline, ten. So n equal to ten. So this is an example here, n equal to ten out of 100 agents, ten agents actually get back.

And then among these ten agents, there are seven agents who refuse. Could be because they don't have the ability, could be because they cannot really meet the deadline, could be because they cannot meet the quality constraints, and then there will be another three, because ten agent getting back and then seven refuse. Now, three agents, such a equal to three will propose saying that I can do it and this is my proposal.

So the proposal will say that I can do it at this level of quality and it will take me this much time and it will cost you this much money, for instance. So after receiving these proposals, then the initiator have to decide on which proposal that it will accept. And so let's say that it will accept two proposal and reject one proposal, so it reject one, so receive back three proposals, but then it will say that I need two agents to help me on this one, and so I reject one, and then I accept the proposal from two.

And so now the participants who receive the accept proposal will work on the task. And then after working on the task now, depending on the outcome now, if they fail to deliver it and then they send back the notification of failure, if they actually complete the task and then they inform the initiator that the task has been done or not. Inform the initiator of the results of working on the task and then this will be done by L agents. L equal to two in this example.

**Summarise**

The lecture emphasized the importance of interaction protocols in enabling effective communication among agents, building upon the foundation of agent communication languages. Interaction protocols govern the flow of communication and dictate the rules of engagement during dialogues or conversations. These protocols define the roles of agents, the sequence of message exchanges, and even constraints on message content.

Interaction protocols are pivotal for meaningful conversations, ensuring all participating agents adhere to established rules to facilitate rational discourse. An exemplary interaction protocol is the ContractNet protocol (CNP), specifically designed for task allocation. This protocol comprises several stages: recognition, announcement, bidding, awarding, and expediting. The task owner initiates the process by recognizing the need for assistance and broadcasting announcements to other agents. Participants then decide whether to bid, submitting tenders that encode their capabilities and constraints. The task owner awards contracts and communicates decisions to successful and unsuccessful bidders.

Two approaches to designing interaction protocols were discussed: the top-down approach and the bottom-up approach. The former employs predefined protocols, while the latter allows protocols to emerge through agent interactions. The lecture highlighted specific FIFA interaction protocols, such as the request protocol and the ContractNet protocol, showcasing how agents can be designed to participate effectively. The top-down approach offers a straightforward implementation, whereas the bottom-up approach requires agents with intelligence to adapt and evolve protocols over time.

***Important***

**THE INTERACTION PROTOCOL FOR MULTI-AGENT SYSTEMS**

The nesting for the agents to be able to interact and communicate effectively is to define a proper interaction protocol when they need to interact. For the conversation to be meaningful, all participating agents must conform to the interaction protocol to enable the rational conversations.

**CPA INTERACTION PROTOCOLS**

CPA request protocol is defined to allow one agent to request another agent to perform some action. There are a number of potential outcomes here. How agents can be designed to participate in these interaction protocols.

**FIFA INTERACTION PROTOCOL**

Another interaction protocol defined by FIFA is FIFA ContractNet interaction protocol. In this interaction protocol is based on the ContractNet protocol that I mentioned before. Among the N participants who receive the coffee proposal, then N of them will get back before the deadline. Seven agents will refuse.

**Original**

Now that we have already looked at the agent communication languages. The nesting for the agents to be able to interact and communicate effectively is to define a proper interaction protocol when they need to interact. So as you can see, the agent communication language define the syntax and semantics of single utterances. But for the single utterances to go into a flow between agents and form a meaningful dialogue or conversation, then they most of the time need to follow some proper interaction protocol. The interaction protocol specify the rules of interaction, these rules of the procedure for conversation, including the permissible agent roles involved in the interaction. So for instance, one agent may be asking for information, another agent will be responding by informing the first one of the relevant information and so on and so forth. So not only there is the roles of the agents involved in the conversation, but also there is a sequence of message changes between the agent roles. So what message will be utter first to initiate the conversation and then to respond to that utterance, what is the appropriate message to send back and so on and so forth. And also there could be constraints on the content of the messages exchange between the agents as well. Now, for the conversation to be meaningful, all participating agents must conform to the interaction protocol to enable the rational conversations. Some example of the interaction protocol that has been defined for multi agent systems, the most famous one probably the ContractNet protocol CNP. Now this protocol has been introduced for task allocation. So one agent having a task that it needs all the agent to help it achieve or accomplish. And so the agents having the task will send out a request for the other agents asking for the agents with the capability of performing the task to send back their proposal, also called the bid. And then the agent who has the staff will compare the bids and then choose the right agents to perform the task. So this contract protocol comprise five stages the recognition stage, the announcement, the biding, the awarding and expediting stages. So to start with the recognition, an agent recognize it has a problem that it wants help because it involves a number of tasks it cannot solve by itself or it prefer not to solve by itself. Possibly because if it solve the task by itself and then it may not have the high quality solution or maybe because it will not be able to meet the deadline. So the agents need help from all the agents and after recognizing that I had a problem, then the agents can proceed to the next stage. In this stage, the agent having the problem that requires some path to be accomplished. This agent will send out the announcements, could be by broadcasting to all the agents within the broadcasting range or it could send specific messages to specific agents who can see the announcement. The specification must encode the specification of the announcement must encode the description of the task. Clearly, if you ask all the people to work on the task for you, you need to describe what the task is about and also specify any constraints, for instance, what the deadline is, what are the quality constraints that you expect that the other agents will meet for doing your task. And also possibly some other meta information. For instance, information about Bit for this task must be submitted by certain time. So these meta informations are related to the interaction protocol. After all the agents receive the announcement from the agent who has the task, they will have to decide on whether they want to bid for the task. For instance, in this example you can see that A two decide that he does not want to bid for the task, while a three and a four decide that they will both bid for the task. So related to the decision could be the agent capability of doing the task. So for instance, a 2 may decide that he doesn't have the ability to do it, or maybe because of the quality constraints, the deadline, and also maybe the price information, because in many cases when an agent puts out the task, they need to pay to the agents who perform the task. And so they also need to specify what is the price that they willing to pay, the maximum price that they're willing to pay. So there are some other constraints such as whether an agents have the capability to deliver the task according to that quality constraints, according to the deadlines, according to the price information. If an agent choose to bid, then you submit a tender. So in this particular example you can see that both a three and a four submitted tender and after this, the task owner, the agent who initiated the request for bids, must decide who to award the contract to and the decision now is communicated to the winning agents. In this example, the agent, the owner of the task agent A one, decide to award the task to a four and so communicated this decision to a four and also notify the losing agent as well. So that means that there are also a message from a one to a three, notify in a three that he has not been successful in getting the contract, so the successful contractor perform the task. So in this case, a four needs to expedite the task and the process of performing the task may actually involve another round, some future rounds of subcontracting. So using conjunctive protocol, a four might actually send out announcements to ask for all the agents to work on some of the subtasks for him as well, or for him or her as well. Ah. To design interaction protocols, there are two main approaches the top down approach. So interaction protocol specifications are already being predefined and publicly available. Examples, including some of the interaction protocol defined by FIFA, such as congenital protocol. Iterate congenital protocol. Now, an agent designer can implement the agent to play the appropriate role in the interactions. So, because the interaction protocol already been defined and well known and publicly available. So when I design my agent, I will just implement my agent to take part in these protocols. And the benefit here is clearly that agent can engage in meaningful conversations by follow the predefined interaction protocol. Because this is a common protocol, everyone understand it, everyone follow it, and so the conversations will be well defined. On the other hand, top down approach may not always be feasible. So if an agent join a society of agents, it may not know about any publicly available interaction protocols. So in such a case, when agents may just emerge into a society, then a bottom up approach may be needed. Here, the agent designers will make the agents that sufficiently aware of the meanings of different kind of messages and also have the capability. So the agents that the designer design has the capability of understand the goals, the beliefs, and all the mental attitudes that the other agents possess. Then when the agents trying to solve its own problem, then it use a planning process in order to try to come up with the task. And among those tasks is identify some other agents that need to interact with. And this process that an intelligent agents perform may actually cause some interaction protocol to arise. So I come into a society not knowing about what the interaction protocol they have there, but I might always try, I might start asking politely about some information. I might be asking very politely about whether they can help me with doing certain things. And so the audio agents, when they see that the way that I interact is not something that too unacceptable, so they see that my behavior is acceptable, then they may actually interact back to me with their own way of interaction. And so the interaction protocol then emerged from this process of agents trying to explore different step of interactions. And then in the end, they emerge into a common protocol to allow the agents to communicate and interact with each other. And so the IPS will arise spontaneously from the interactions. Clearly, the second part of method, the bottom up interaction protocol definition is much harder to achieve and requires agents with intelligence and some smartness in their behavior. So the easier one is clearly to follow some top down predefined interaction protocols. And FIFA already defined many interaction protocols that agent designer can use. So in this list, you can see a few examples of these FIFA interaction protocols. For instance, request interaction protocol, query interaction protocols, contract interaction protocol, and so on and so forth. So the full list can be found here. Now, I will go through two of these interaction protocols defined by CPA to show you how agents can be designed to participate in these interaction protocols. The first one is CPA request protocol. This protocol is defined to allow one agent to request another agent to perform some action. So the requester is also called the Initiator will send a request message. So clearly here the performative is request and then the content of the message will be what the initiator want to request and the participant will receive this request. Now the participant has two choice that it can take. So the first one is that it refused. This request could be because it's unable to perform that action or maybe because some reason. So the Initiator set a price. So after you finish my request and then you will receive this reward and then the participant think that the reward is too small and therefore refuse to fulfill the request. Or the other possible choice is that the participant actually agree. And so when it's agree and then it send back the message agree and notifications necessary. So that means that I agree to do it. And not only that I will do it, but I also notify you of the outcome of my action as well. So because of that, the agents will start working on the task. So after they agree and then they're working on the task. And so after working on the task, now there are a number of potential outcome here. So after working on the task and then the agent failed to deliver it and so it sent back the notification that I actually fail to do the action that you asked me to do, or it could also complete it and then so it informed the Initiator that I complete the task and the task is now done. Or could be that not only that I complete the task but with certain kind of results and so inform and then also send back the results of doing the path. For instance, I work on building the device and then after building the device and now this is the cost that it took me to build a device. And so this kind of results may be part of the informed message that the participant send back to the Initiator. Another interaction protocol defined by FIFA is FIFA ContractNet interaction protocol. In this interaction protocol is based on the ContractNet protocol that I mentioned before. Here we have the task owner called the Initiator who will send out the call for proposal to end participants. So sending call for proposal to end participants, it could be procrastinating and then their end participant receive this coffee proposal. Among the N participants who receive the coffee proposal, then N of them will get back before the deadline. And so among these N agents who get back to the Initiator, then I agents will refuse. So let's say that the Initiator broadcast and then there are 100 agents who receive this announcement and before the deadline, ten. So n equal to ten. So this is an example here, n equal to ten out of 100 agents, ten agents actually get back. And then among these ten agents, there are seven agents who refuse. Could be because they don't have the ability, could be because they cannot really meet the deadline, could be because they cannot meet the quality constraints, and then there will be another three, because ten agent getting back and then seven refuse. Now, three agents, such a equal to three will propose saying that I can do it and this is my proposal. So the proposal will say that I can do it at this level of quality and it will take me this much time and it will cost you this much money, for instance. So after receiving these proposals, then the initiator have to decide on which proposal that it will accept. And so let's say that it will accept two proposal and reject one proposal, so it reject one, so receive back three proposals, but then it will say that I need two agents to help me on this one, and so I reject one, and then I accept the proposal from two. And so now the participants who receive the accept proposal will work on the task. And then after working on the task now, depending on the outcome now, if they fail to deliver it and then they send back the notification of failure, if they actually complete the task and then they inform the initiator that the task has been done or not. Inform the initiator of the results of working on the task and then this will be done by L agents. L equal to two in this example.