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Introduction to Intelligent Agents and Multiagent Systems

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Topics

- (First) Definition
  - Agent
  - Multiagent System
- Example
- Key Problems

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Agents: A First Definition

- An agent is a computer system that is capable of performing independent (autonomous) action on behalf of its users or owners
  - An agent figures out what needs to be done to satisfy its users' goals, rather than constantly being told

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Multiagent Systems: A First Definition

- A multiagent system is one that consists of a number of agents, which interact with one another
- Agent act on behalf of their users
  - Users have different goals and motivations
- For successful interaction, agents need to
  - coordinate,
  - negotiate, and
  - cooperate with each other

Examples

- Space probe
  - Ground crew required to track progress
  - Decide how to deal with exceptions
    - Expensive; often not practical
- Internet agents
  - Search query for travel
    - Assembling information given requirement, e.g., flight, hotel, and transport
  - Intelligent alarm agent
    - Calendar, public transport or ride share availability
- Intelligent ringer agent
- Self driving cars

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Key Design Problems

- Agent design
  - How do we build agents that are capable of performing independent, autonomous actions in order to successfully bring out goals of their users?
- Society design
  - How do we build agents that are capable of interacting (cooperating, coordinating, negotiating) with other agents in order to successfully bring about goals of their users, particularly when the other agents cannot be assumed to share the same goals?
- *Micro* and *macro* perspectives

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Sample Questions

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Example Questions

- Agents are autonomous. True or false? [1 mark]
- What are micro and macro perspectives in multiagent systems [2 marks]

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Intelligent Agents

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Topics

- Agent and Environment
- Properties of Intelligent Agents
  - Reactivity
  - Proactivity
  - Social ability

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Revisiting: What is an Agent?

- Important point: An agent is *autonomous*
  - capable of deciding for itself and performing independent actions
- Definition
  - An agent is a computer system capable of performing autonomous action in some environment, in order to achieve delegated goals

Sense – Decide – Act Loop

- We think of agents as situated in an environment
  - Engage in a close-coupled loop
  - Continually interact with the environment

- sense – decide – act – sense – decide …

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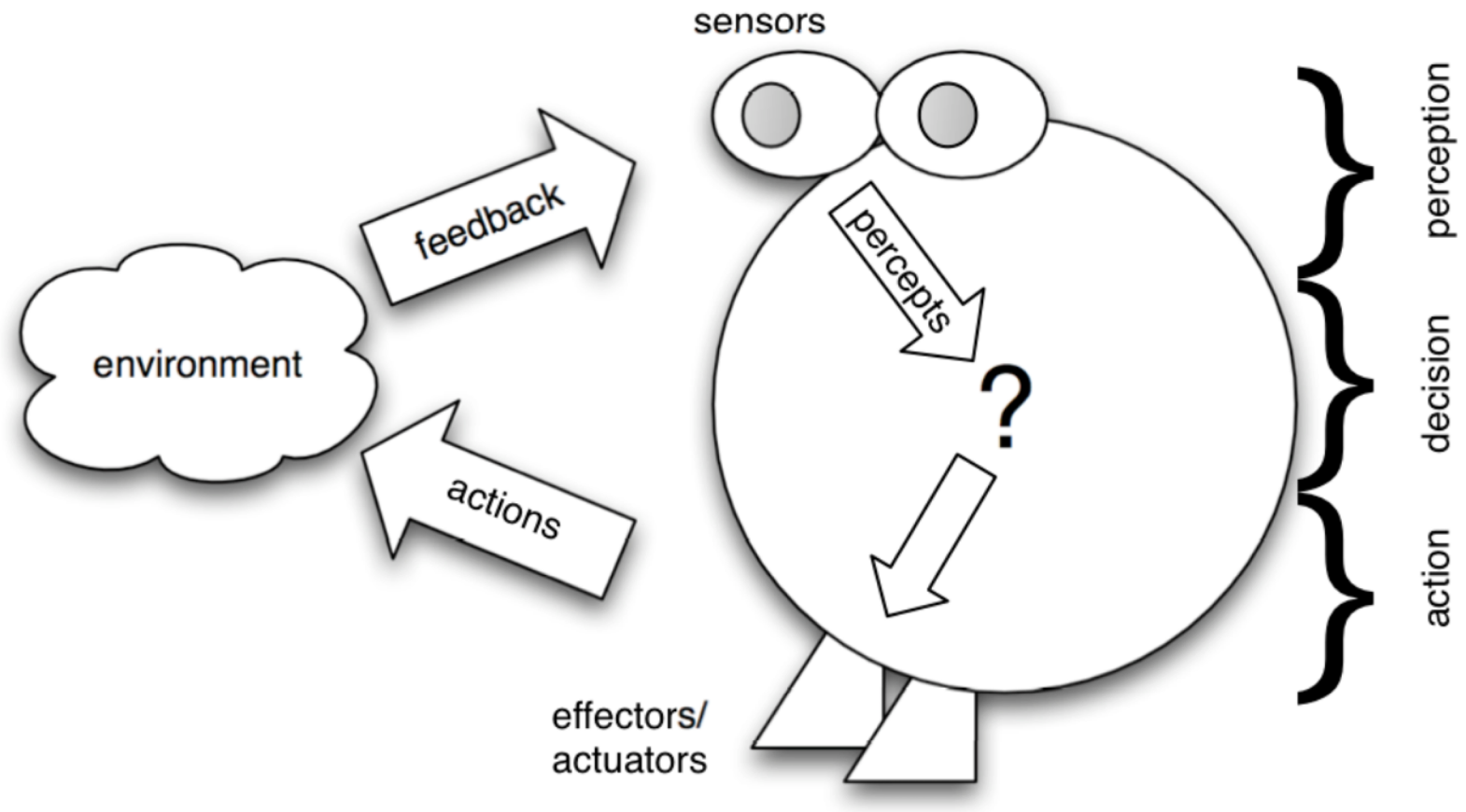
Agent and Environment



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Simple (Not Interesting) Agents

- Thermostat
  - delegated goal is to maintain room temperature
  - actions are to switch heating ON and OFF
- Unix biff program
  - delegated goal is to monitor for incoming email and flag it
  - actions are GUI actions

These examples satisfy the definition of an agent, but the decision making they are involved in is trivial

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Properties of Intelligent Agents

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Intelligent Agents

- Intelligent agents exhibit three types of behaviours
  - Reactive
  - Proactive
  - Social

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Reactivity

- Ideal scenario: environment is fixed
  - A program can just execute blindly
- Reality
  - Environment is dynamic
- A reactive system is one that maintains an ongoing interaction with its environment and responds to changes that occur in the environment
  - Response needs to be in-time for it to be useful

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Reactivity Example

Reactivity: Stimulus follows a response

- Smart Home
  - Turn on the yard lights when motion is detected
    - Racoon
  - Turn on the bedroom lights when someone enters
    - Pet moving around at night
- Thermostat

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Proactivity

- Reacting to environment is easy
  - Stimulus -> Response lookup table
  - Not the most effective behaviour
- Proactivity is about exhibiting a goal directed behaviour
  - Systematically working to achieve goal
  - Anticipate and take initiative

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Social Ability

- Real world is a multiagent environment
  - We cannot go around attempting to achieve goals without taking others in the account
- Social ability in agents is the ability to interact with other agents (and humans) via a communication language
  - Coordinate
  - Negotiate
  - Cooperate

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Sample Questions

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Example Questions

- Is a simple thermostat worthy of being called as an agent? Why? [1 marks]
- Describe the sense-decide-act loop? [2 marks]
- What is a reactive agent? [1 mark]
- Social ability in an intelligent agent is the ability to interact with other agents. List and explain the key aspects of social interactions. [3 marks]
- An agent is defined using the properties it exhibits. List and describe the three properties you associate with an intelligent agent. [5 marks]

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Social Ability

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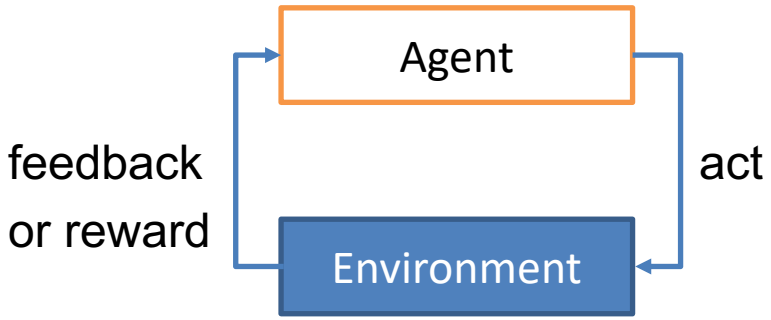
Single Agent: Sense – Decide – Act Loop



https://gym.openai.com/envs/CartPole-v1/

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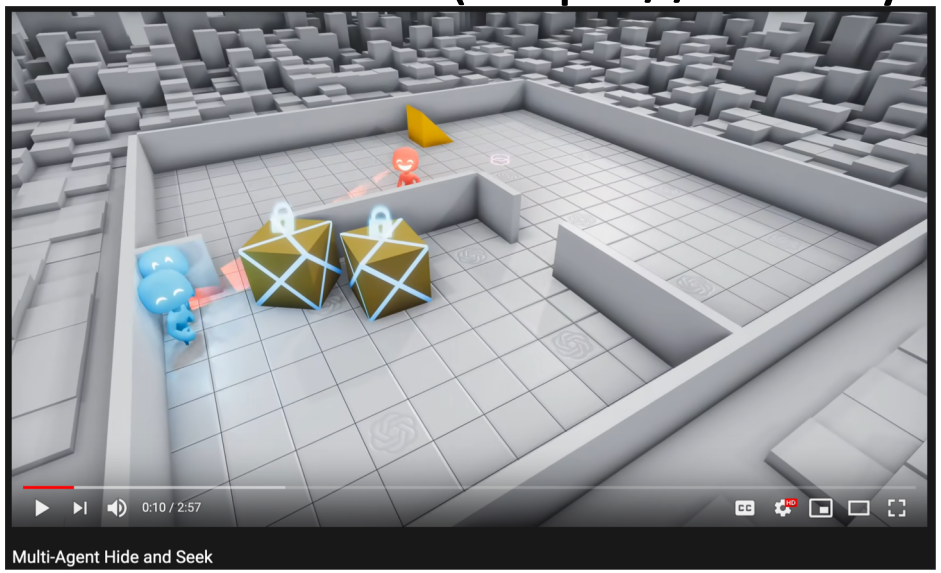
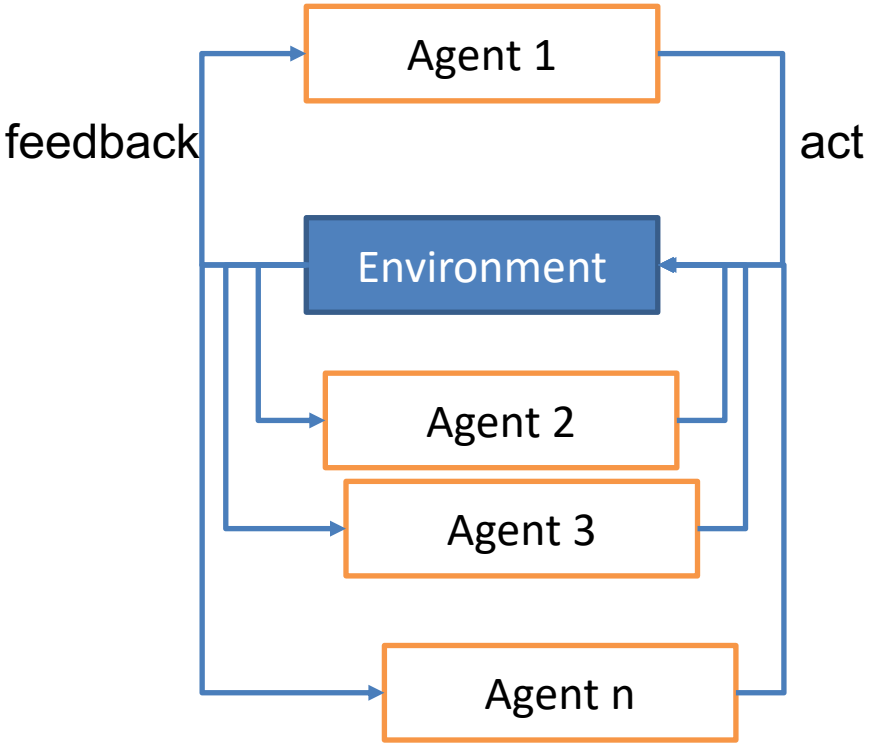
- Pause this video here and watch the Open AI Hide and Seek video (https://www.youtube.com/watch?v=kopoLzvh5jY)



- Think of how Sense-Decide-Act loop for multiple agents would look like?

Multiagent: Sense – Decide – Act Loop?



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Social Ability: Cooperation

- Cooperation is working together as a team to achieve a shared goal
- Often prompted either by the fact that no one agent can achieve the goal alone, or that cooperation will obtain a better result (e.g., get result faster)
- *Treasure hunt*
  - Cooperate and explore different areas

Social Ability: Coordination

- Coordination is managing the interdependencies between activities
- For example, if there is a non-sharable resource that you want to use and I want to use, then we need to coordinate
- *Car pooling*
  - Coordinate timing

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Social Ability: Negotiation

- Negotiation is the ability to reach agreements on matters of common interest
- Typically involves offer and counter-offer, with compromises made by participants
- *Buy-sell on Marketplace*
  - *Negotiate price*
- *One shared TV; different preferences*
  - You watch today, I watch tomorrow

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Properties of Environment

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Accessible (vs Inaccessible)

- Accessible
  - Agent has or can obtain complete, accurate, and up-to-date information about the state of the environment
  - A more accessible the environment, simpler to build agents to act in that environment
- Inaccessible
  - Internet
  - Physical world

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Deterministic (vs Non-Deterministic)

- Deterministic
  - Environment in which each action has a single guaranteed effect
  - No uncertainty about the resulting state
- Physical world is non-deterministic

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Episodic (vs Non-Episodic)

- Episodic
  - Performance of an agent is dependent on number of discrete episodes
  - No link between the performance of an agent in different scenarios

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Static (vs Dynamic)

- Static
  - Environment can be assumed to remain unchanged except by the performance of actions by the agent
  - Predictable
- Dynamic
  - Other processes or agents also operate in the environment
- Physical world is dynamic

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Example Questions

- Physical world is an example of deterministic environment. True or false? [1 mark]
- Describe any three properties of environment in which agents operate. Give one example for each. [3 marks]

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Social Norms

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Topics

- Norm Representation
- Norm Types and Lifecycle

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Introduction

- Norms characterize the interactions between agents
  - Inform agents about reasonable actions
- Directed from a subject to an object
- Constructed as a conditional relationship involving an antecedent and a consequent

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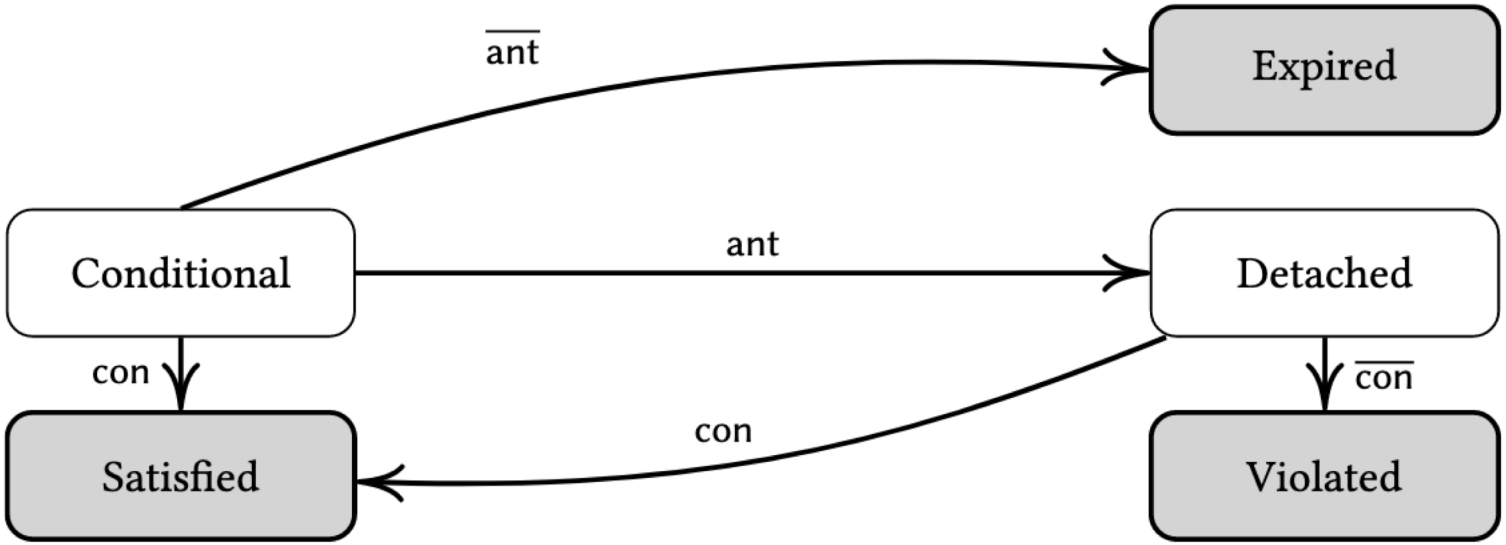
Norm Representation

- Norm is a tuple n(sbj, obj, ant, con)
  - n is the type
    - Commitment c, Prohibition p, Authorization a
  - sbj is the subject (or the debtor)
  - obj is the object (or the creditor)
  - ant is the antecedent
  - con is the consequent

Commitment

c(physician, hospital, emergency, operate)
A physician is practically committed to the hospital to operating upon patients in an emergency

- White rectangles represent non-terminal states
- Shaded rectangles represent terminal states



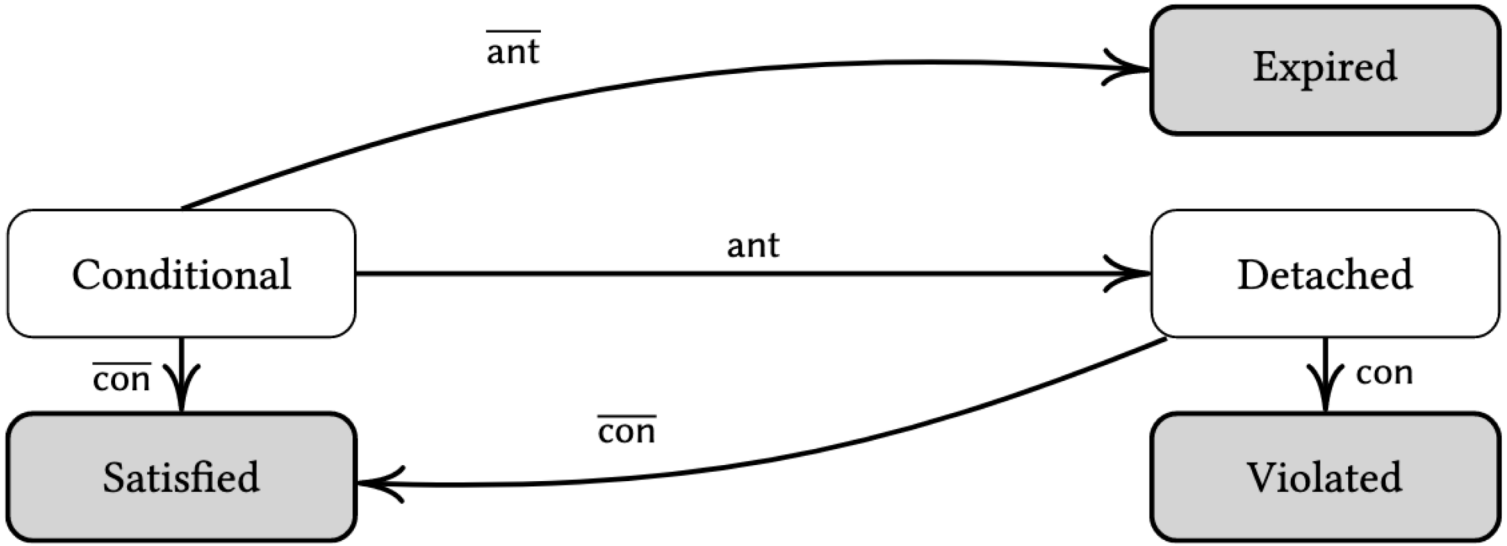
- Accountable party is the subject of the norm

In the example commitment, if the physician fails to operate upon patients, the commitment is violated

Prohibition

p(physician, hospital, true, share_PHI_thirdparty)

Physician is prohibited by the hospital from disclosing a patient's PHI to others (share_PHI_thirdparty)

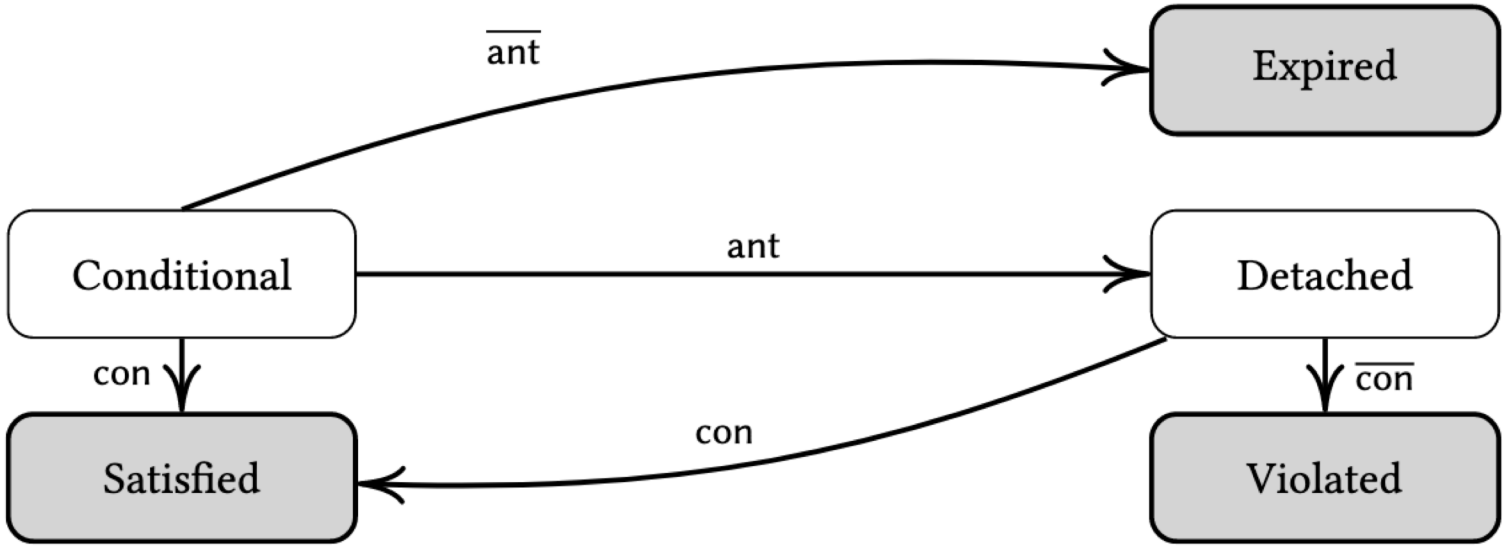


- Accountable party is the subject of the norm

The prohibition in the example is unconditional because its antecedent is true. If the patient's PHI is disclosed, the prohibition is violated

Authorization

a(physician, hospital, consent, EHR ∨ operate)
Physician is authorized to access EHR as well as operate upon a patient when the patient's consent is obtained



- Accountable party is the object of the norm

If the physician cannot access the patient's EHR or operate upon the patient when the authorization is detached, then the authorization is violated

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Example Questions

- Norms are directed from an object to a subject. True or False? [1 mark]
- Antecedent of a commitment norm could be True. True or False? [1 mark]
- In authorization, subject of the norm is the accountable party. True or False? [1 mark]

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Agent Communication

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Topics

- Foundations
- Traditional Approaches
  - Software Engineering
  - Artificial Intelligence
- Commitment-Based Approaches

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Foundations

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Speech Acts by Philosopher John Austin

- Also known as communicative act theory
- Communication is form of an action

- Judge declaring a couple married
  - Not merely reporting a fact
  - Brings a fact into existence
- “Marry me” “I do”

Speech Acts (2)

- Phrased in declarative form
  - Performative verbs

- “I declare this couple man and wife”
- “I request that you to marry me” and “I promise that I will marry you”

Speech Acts (3)

- Informative – “Shipment will arrive on Wednesday”
  - “I inform you that the shipment will arrive on Wednesday”
- Directive – “Send me the goods”
  - “I demand that you send me the goods”
- Commissive – “I will pay you £5”
  - “I promise that I will pay you £5”

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Agent Communication Primitives

- Small number of message types as primitives
- Reasonable but not adequate
  - Multiagent systems have several applications
  - Meanings we need for each are distinct
  - Official meaning may not be sufficient
  - Hardcoding may result in tight coupling

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Traditional Software Engineering Approaches

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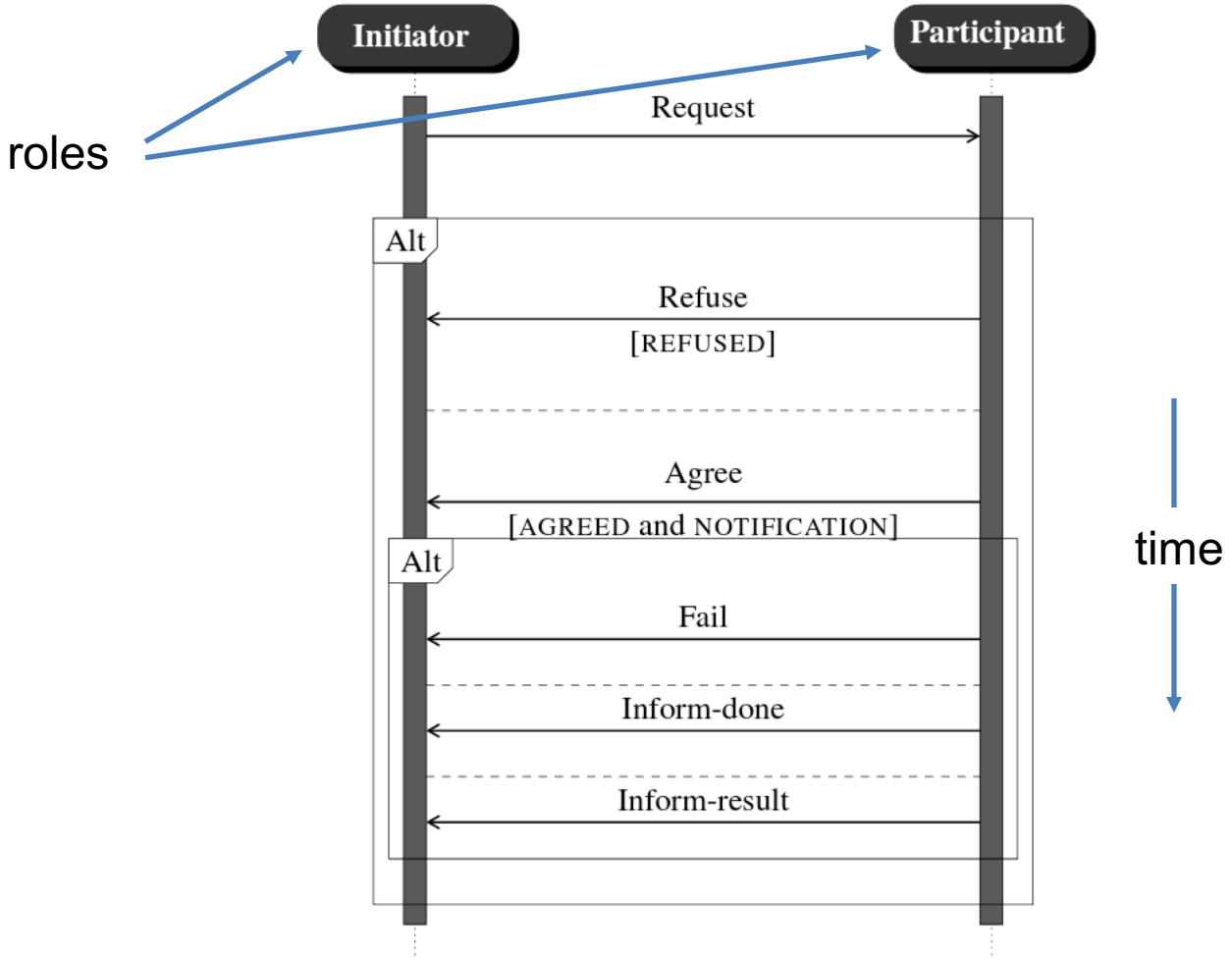
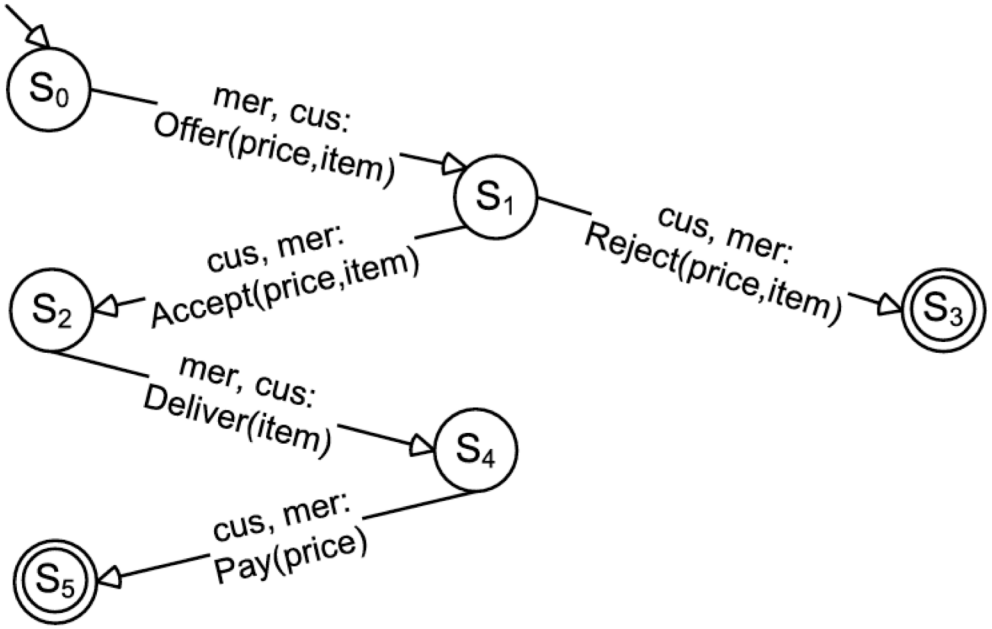
Sequence Diagrams

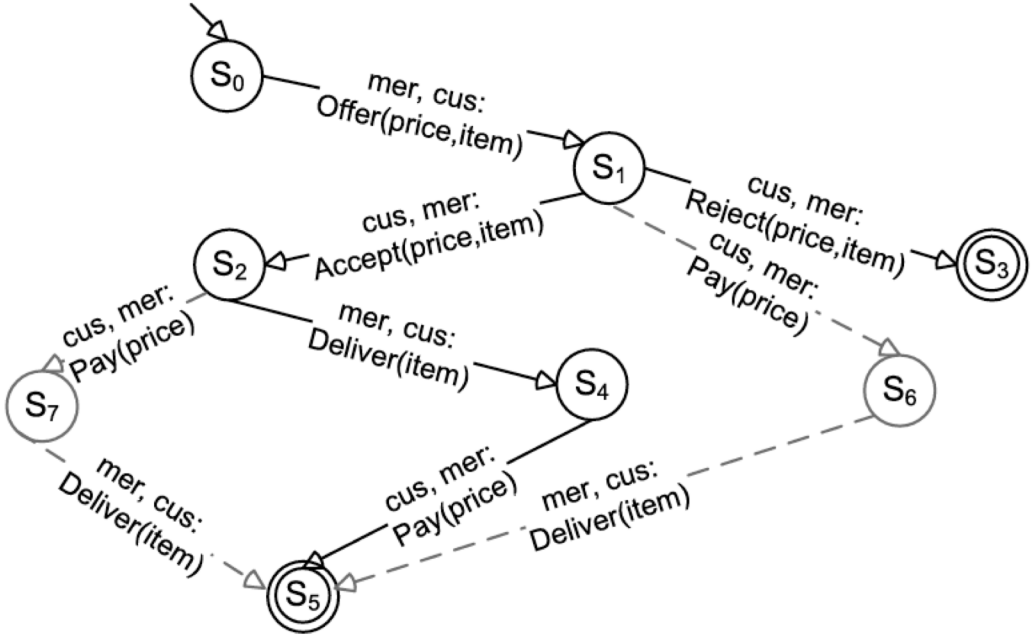


State Transition Diagrams

- Protocol as a state machine



- Alternative



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Evaluation w.r.t MAS

- Low level abstractions
  - Difficult to design and maintain
- Little flexibility at runtime
- Easy compliance checking but at the cost of flexibility

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Artificial Intelligence Approaches

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AI Approaches

- Knowledge Query and Manipulation Language (KQML)
  - Created by DARPA
  - Agents maintain a knowledge base in terms of belief assertions
  - Assumption: Agents are cooperative and designed by the same designer
- FIPA Agent Communication Language (ACL)
  - Specify a definitive syntax for interoperability
  - Specified the semantics of primitives

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Evaluation w.r.t MAS

- High level of abstraction
- Curtailed flexibility
- Verifying agent compliance is impossible

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Commitments-Based Approaches

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Commitment

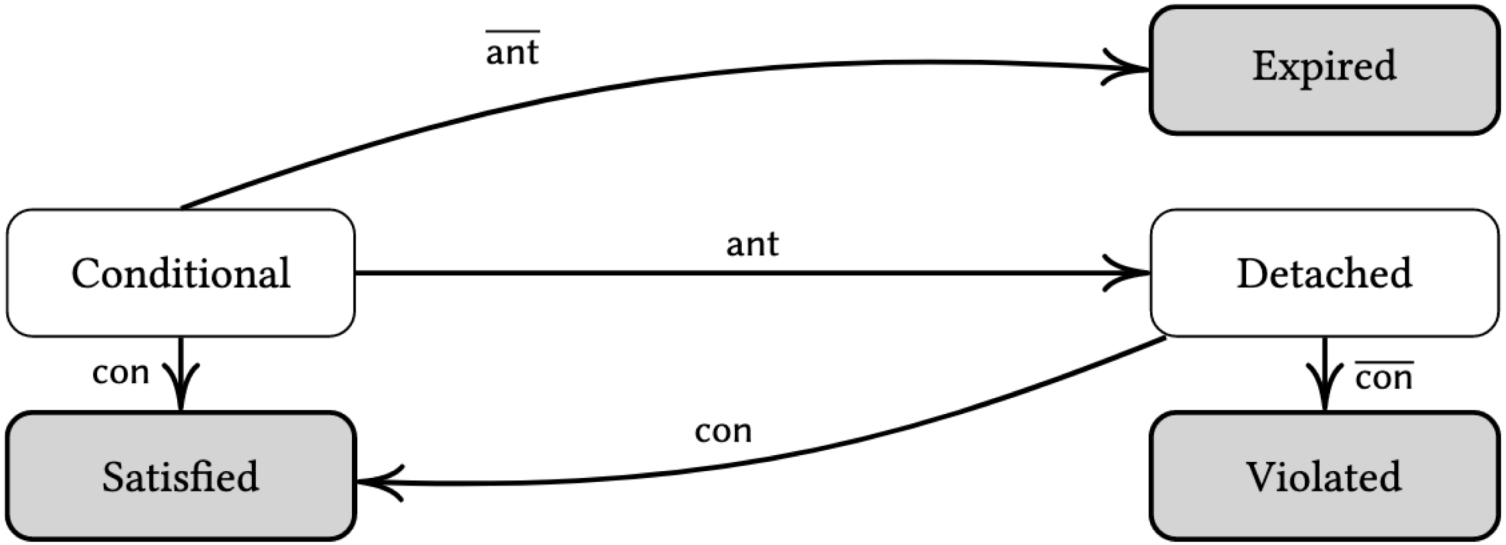
C(debtor, creditor, antecedent, consequent)

- debtor and creditor are agents
- antecedent and consequent are propositions

- C(x, y, r, u)
  - x is committed to y
  - if r holds, then x will bring about u

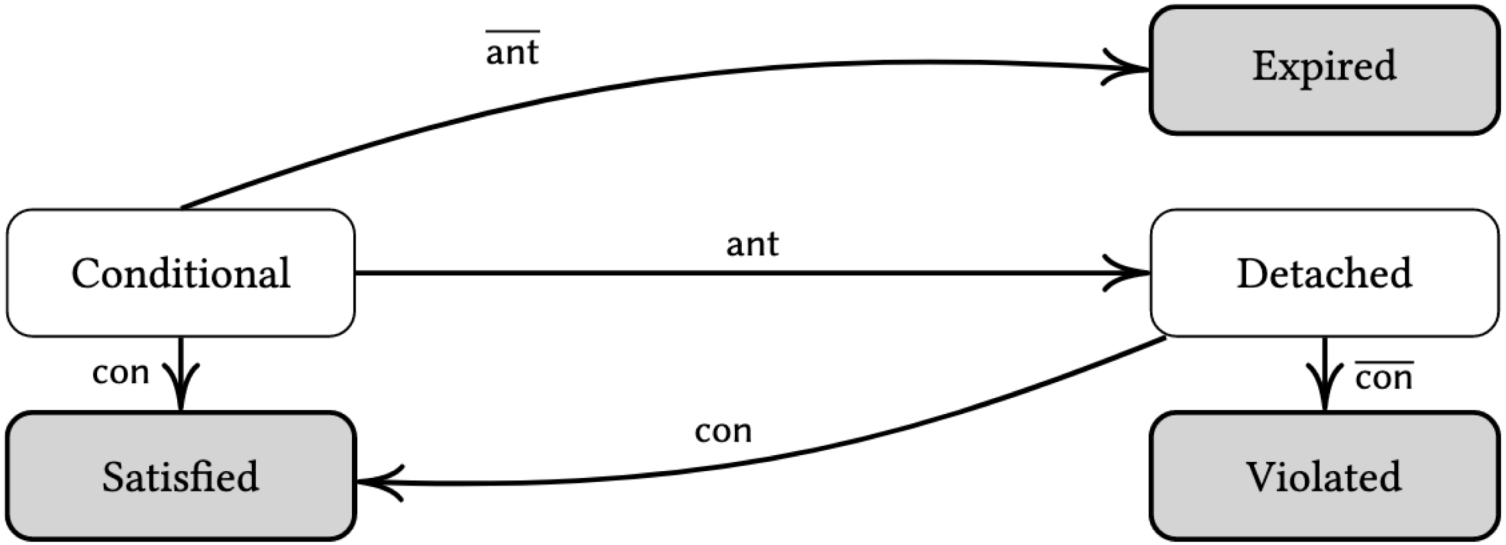
Commitment Life Cycle

- C(BookCo, Alice, £25, AIBook)



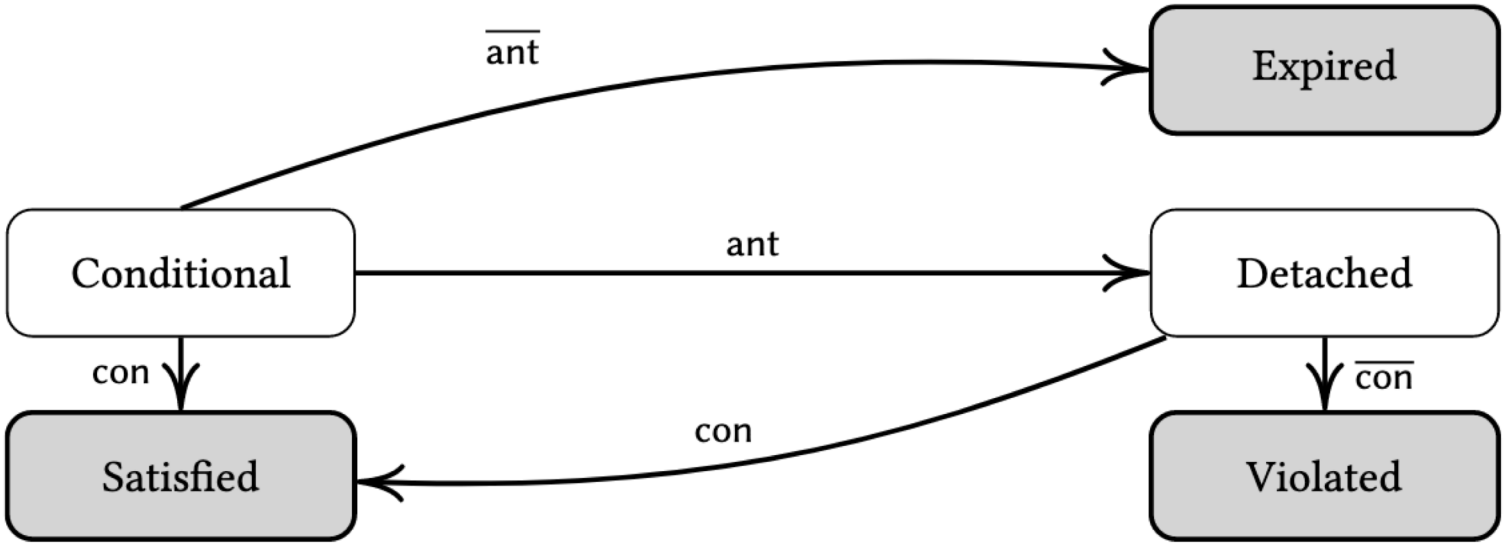
Detach Commitment

$C(BookCo,\ Alice,\ £25,\ AIBook) \wedge £25 \Rightarrow C(BookCo,\ Alice,\ \top,\ AIBook)$



Satisfy (or Discharge) Commitment

$$AIBook \Rightarrow \neg C(BookCo,\ Alice,\ \top,\ AIBook) \wedge \neg C(BookCo,\ Alice,\ £25,\ AIBook)$$

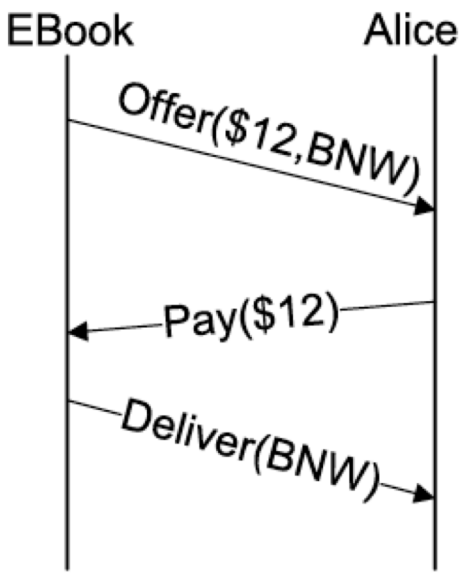


Commitment Operations

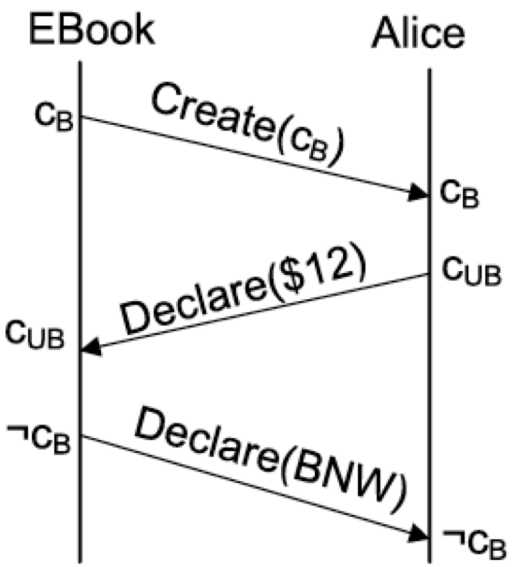
- CREATE(x, y, r, u)
  - performed by x; causes C(x, y, r, u) to hold
- CANCEL(x, y, r, u)
  - performed by x; causes C (x, y, r, u) to not hold
- RELEASE(x, y, r, u)
  - performed by y; causes C (x, y, r, u) to not hold
- DELEGATE(x, y, z, r, u)
  - performed by x; causes C (z, y, r, u) to hold
- ASSIGN(x, y, z, r, u)
  - performed by y; causes C (x, z, r, u) to hold
- DECLARE(x, y, r)
  - performed by x to inform y that the r holds

Commitment Protocol

- *Offer(mer, cus, price, item)*
  - *CREATE(mer, cus, price, item)*
- *Accept(cus, mer, price, item)*
  - *CREATE(cus, mer, item, price)*
- *Reject(cus, mer, price, item)*
  - *RELEASE(mer, cus, price, item)*
- *Deliver(mer, cus, item)*
  - *DECLARE(mer, cus, item)*
- *Pay(cus, mer, price)*
  - *DECLARE(cus, mer, price)*



Messaging



Meaning

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Additional Reading

- Singh, Munindar P. "An ontology for commitments in multiagent systems." *Artificial intelligence and law* 7, no. 1 (1999): 97-113.

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Example Questions

- How will the directive “ship me the goods” be treated in communicative acts? [1 mark]
- A protocol for payment through a third party could naturally be specified using the delegate of a commitment to pay. State whether true or false. [1 mark]
- Question of a type – given event traces, indicate whether a commitment is satisfied, violated, or continues to hold [5 marks]

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