CmpE 593
Multiagent Systems

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Agent Communication

Based largely on
Service-Oriented Computing: Semantics, Processes, Agents
– Munindar P. Singh and Michael N. Huhns, Wiley, 2004

Interaction and Communication

- Interactions occur when agents exist and act in close proximity:
  - resource contention, e.g., bumping into each other
- Communications are the interactions that preserve autonomy of all participants
- Communications can be realized in several ways, e.g.,
  - through shared memory (if agents are collaborative)
  - because of shared conventions
  - by messaging passing

Rationalistic Tradition

- Orientation
  - Describe the situation in terms of objects and their properties
  - Derive rules that apply to situations
  - Apply the rule to the current situation
- Literal meaning (not context-dependent)
- Hard to use in many settings
  - Example of water in the fridge (Winograd and Flores)
  - “John has never failed a student in Linguistics 265” (Winograd and Flores)

Speech Act Theory

- Speech act theory, developed for natural language, views communication as action
- It considers three aspects of a message:
  - Locution, or how it is phrased, e.g., "It is hot here" or "Turn on the air conditioner"
  - Illocution, or how it is meant by the sender or understood by the receiver, e.g., a request to turn on the air conditioner or an assertion about the temperature
  - Perlocution, or how it influences the recipient, e.g., turns on the air conditioner, opens the window, ignores the speaker

Illocution is the core aspect

Speech Act Theory (1)

- Assertives: Describe the state of the world
- Directives: Attempt (in varying degrees) to make the other person do something
- Commissives: Commit the speaker (in varying degrees) to a course of actions
- Expressives: Express a psychological state (e.g., apologies).

Speech Act Theory (2)

- Declaratives: Make the content of the act match reality
- Permissives: Allow an action to be taken
- Prohibitives: Ban an action to be taken

Examples?

Speech Act Theory Applied

- Classifications of illocutions motivate message types, but are typically designed for natural language
  - rely on NL syntax,
- Most research in speech act theory is about determining the agents' beliefs and intentions, e.g., how locutions map to illocutions
- For agents,
  - determining the message type is trivial, because it is explicitly encoded
  - determining the agents' beliefs and intentions is impossible, because the internal details of the agents are not known

Syntax, Semantics, Pragmatics

For message passing

- *Syntax*: requires a common language to represent information and queries, or languages that are intertranslatable
- *Semantics*: requires a structured vocabulary and a shared framework of knowledge (a shared ontology)
- *Pragmatics*:
  - knowing whom to communicate with and how to find them
  - knowing how to initiate and maintain an exchange
  - knowing the effect of the communication on the recipient

ACL Semantics

What is the semantics of queries, requests, promises?

- *Mentalist*: each agent has a knowledge base that its messages refer to. An agent promises something if it intended to make that promise
- *Public*: semantics depends on laws, protocols, and observable behavior

Evaluation: For open systems, public semantics is appropriate, because a semantics without compliance doesn't make sense

Informing

How can one agent tell another agent something?

- Send the information in a message (message passing)
- Write the information in a location where the other agent is likely to look (shared memory)
- Show or demonstrate to the other agent (teaching)
- Insert or program the information directly into the other agent (master --> slave; controller --> controllee; "brain surgery")

Querying

How can one agent get information from another agent?

- Ask the other agent a question (message passing)
- Read a location where the other agent is likely to write something (shared memory)
- Observe the other agent (learning)
- Access the information directly from the other agent ("brain surgery")

A Classification of Message Types

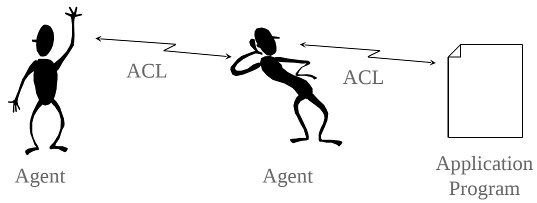
- Structure-based (syntactic)
  - distinguish messages based on grammatical forms in natural language
- Meaning-based (semantic)
  - distinguish messages based on a notion of intrinsic meaning

    prohibitive is different from *directive*, despite syntactic similarity
- Use-based (pragmatic)
  - distinguish messages based on their roles in specific classes of protocols

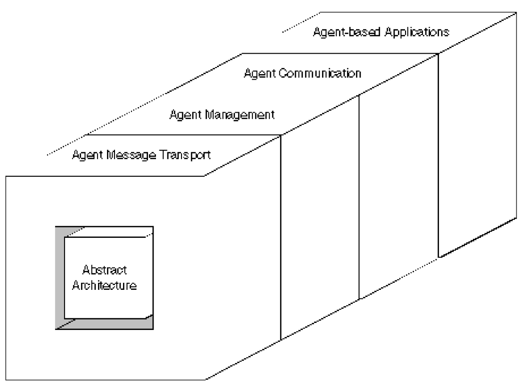
    assertion is different from *acknowledgment*

Agent Communication Languages (ACL)

- KQML: Knowledge Query and Manipulation Language
- FIPA ACL

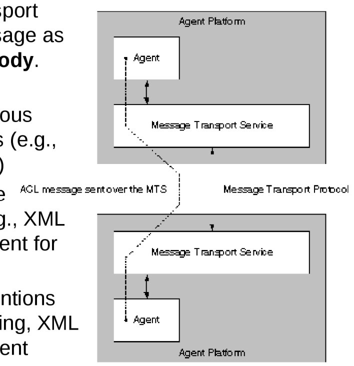


Structure of Specifications

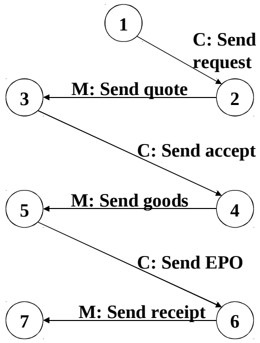


Agent Message Transport

- Agent Message Transport (AMT) defines a message as an **envelope** plus a **body**. Together they handle
  - Guidelines for various transport protocols (e.g., IIOP, HTTP, WAP)
  - Message envelope representation (e.g., XML for HTTP, bit-efficient for WAP).
  - FIPA ACL represention (e.g., string encoding, XML encoding, bit-efficient encoding).



FSM Representation of NetBill Protocol



- The merchant may start the protocol by sending a quote.
- The customer may send an accept prior to offer.
- The merchant may send the goods prior to accept.

These variations are not allowed in the FSM representation.

Commitment Protocols

- Protocols enable open systems to be constructed
- Interaction protocols expressed in terms of
  - Participants' commitments
  - Actions for performing operations on commitments (to create and manipulate them)
  - Constraints on the above, e.g., captured in temporal logic
- Examples: escrow, payment, RosettaNet (107 request-response PIPs)

Commitments

- A commitment is an obligation from one party to another to bring about a condition.
- A unilateral commitment
  - ***C(x, y, p)***: *x* commits to *y* to bring about *p.*
  - C(merchant, customer, receipt)
- A conditional commitment
  - ***CC(x, y, p, q)*** is a conditional commitment: *x* commits to *y* to bring about *q* if *p* is brought out first*.*
  - CC(merchant, customer, pay, receipt)

Commitment Operations

1. Create(e, x, c) : Establishes the commitment *c*.

(I will pay 5YTL to Ali)

2. Discharge(e, x, c) : Resolves the commitment *c*.

(I paid 5YTL to Ali)

3. Cancel(e, x, c) : Cancels the commitment *c*.

(I cancel my commitment to pay 5YTL to Ali)

4. Release(e, x, c) : Releases the debtor from the commitment *c*.

5. Assign(e, y, z, c) : Assigns a new creditor, *z*, to an existing commitment *c*.

6. Delegate(e, x, z, c) : Delegates a new debtor, *z*, to an existing commitment *c*.

Commitment Manipulations

[redacted]

Reasoning Rules

1. ***C(x,y,p)*** **ceases to exist when the proposition *p* becomes true.**

2. ***CC(x,y,p,q) ceases to exist when the proposition p becomes true, but C(x,y,q) is created.***

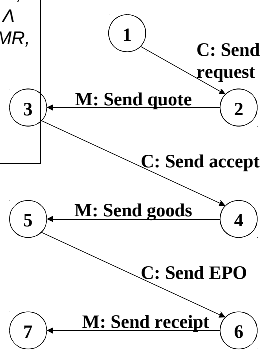
- CC(merchant, customer, paid, receipt)
- Customer makes “paid” true
- C(merchant, customer, receipt)

Definitions for Message Content

promiseGoods(i, m): *CC(MR, CT, accept(i, m), goods(i)) Λ promiseReceipt(i, m)*: *CC(MR, CT, pay(m), receipt(i))*

promiseReceipt(i, m): *CC(MR, CT, pay(m), receipt(i))*

receipt(i): the merchant has delivered the receipt.



request(i): the customer has requested a quote.

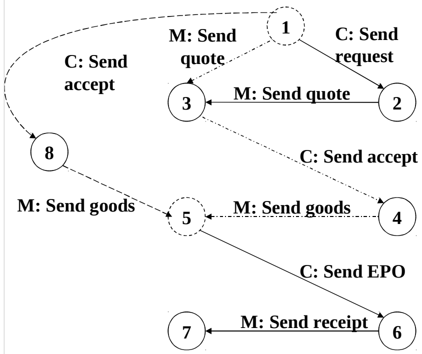
accept(i, m): *CC(CT, MR, goods(i), pay(m))*

pay(m): the customer has paid the agreed amount.

Commitment Protocol

- *A protocol specification*
  - contains a set of *actions* and the commitments and propositions they initiate.
  - does not specify any final states.
  - does not explicitly state the transitions; transitions follow from operations and reasoning rules on commitments.
- *A protocol run*
  - specifies the paths between states
  - lists which actions happen and their ordering
  - is complete if all unilateral commitments are resolved at the end.

Sample Protocol Runs



R = [[happens (sendquote (software,H816,51), t191), happens(sendaccept (software,H816,51),t190), happens(sendgoods (software,H601,51),t189)], [before(t191,t), before(t191,t189), before(t191,t190), before(t190,t), before(t190,t189), before(t189,t)]];

R = [[happens (sendaccept (software,H601,51),t193), happens(sendgoods (software,H601,51),t192)], [before(t193,t), before(t193,t192, before(t192,t)]] ;

Compliance with Protocols

In an open environment, agents are contributed by different vendors and serve different interests

- How can an application check if the agents *comply* with specified protocols?
  - Coordination aspects: traditional techniques
  - Commitment aspects: representations of the agents' commitments in temporal logic
- Commitment protocols are specified in terms of
  - Main roles and sphere of commitment
  - Roles essential for coordination
  - Domain-specific propositions and actions

Verifying Compliance

- Specification
  - models based on *potential causality*
  - commitments based on branching-time TL
- Run-time Verification
  - respects design autonomy
  - uses TL model-checking
  - local verification based on observed messages

Run-Time Compliance Checking

- An agent can keep track of
  - its pending commitments
  - commitments made by others that are not satisfied
- It uses this local model to see if a commitment has been violated
- An agent who benefits from a commitment can always determine if it was violated

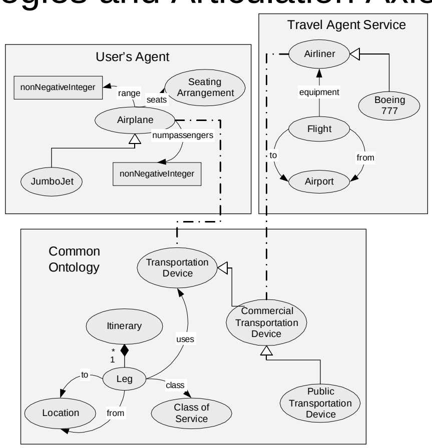
Ontology

- A specification of a conceptualization or a set of knowledge terms for a particular domain, including
  - The vocabulary
  - The semantic interconnections
  - Some simple rules of inference and logic
- Some representation languages for ontologies:
  - Unified Modeling Language (UML)
  - Resource Description Framework Language Schema (RDFS)
  - Web Ontology Language (OWL)
- Some ontology editors: Protégé, Webonto, OilEd

Common Ontologies

- A shared representation is essential to successful communication and coordination
  - For humans: physical, biological, and social world
  - For computational agents: common ontology (terms used in communication)
- Representative efforts are
  - Cyc (and Opencyc)
  - WordNet (Princeton)
  - Several *upper-level* ontologies

Ontologies and Articulation Axioms



Knowledge Representation

- Interoperability levels
  - Syntactic: parse
  - Semantic: understand
- Expressive power
- Procedural versus declarative
  - Declarative pros: enables standardization, optimization, improved productivity
  - Declarative cons: nontrivial to achieve and causes short-term loss of performance
  - Trade-offs shifted by Web to favor declarative modeling

Relations

- Hierarchies in knowledge representation
  - Inheritance (isA) relation
  - Part-whole (isPartOf) relation
- Binary relation R between S and T relates zero or more members in S to zero or more members in T
- Partial order between objects
  - Antisymmetry: [redacted]
  - Transitivity: [redacted]

Hierarchies

- Partially-ordered binary relations
- Taxonomy:
  - *isA* relation denotes subclasses
  - Ex: A human is a mammal
  - Antisymmetric and transitive
- Meronomy:
  - *isPartOf* relation denotes one object is a part of another object
  - Ex: A wheel is part of a car
  - Asymmetric and irreflexive

Modeling

- A universe of discourse (set of entities)
- Concepts that identify the entities
- Relationships among entities
  - Cardinality Constraints
  - Temporal Constraints
  - Rule Constraints
- Functions that map entities to other entities

Exercise: Which Conceptualization Has More Expressive Power?

- awg22SolidBlueWire(ID5)
- blueWire(ID5, AWG22, Solid)
- solidWire(ID5, AWG22, Blue)
- wire(ID5, AWG22, Solid, Blue)
- wire(ID5)^size(ID5, AWG22)^type(ID5, solid)^color(ID5, Blue)

Conceptualization

- Guidelines
  - Concepts must have instances
  - Inference of properties based on membership
  - Nonredundancy: Subconcepts must have one different property
- Modularity
  - Don’t rewrite predicates when adding properties
  - Ex: wire(ID5, AWG22, Solid, Blue)
- Extensibility
  - Model values as objects
  - Ex: permanent (Blue) ^color(ID5, Blue)