Oujda
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MAS Course 03

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CONTENTS

DECIDE

DECIDE Project (& SDU) [Hallenborg 08]

DECIDE: Applying Multi-Agent Design and Decision Logic to a Baggage Handling System

VOWELS approach

- A as different kinds of local decision makers
- E as the airport itself, including the structures
- I following the FIPA standards
- functional O as imposed by the E of the airport

Main interests

- Decentralized control towards more flexibility
- Cognitive interactions towards negotiation

K. Hallenborg & Y. Demazeau, "DECIDE: Applying multi-agent design and decision logic to a baggage handling system", Int. Workshop on Engineering Environment-Mediated Multi-Agent Systems, EEMMAS'07, LNCS 5049, pp. 148-165, Dresden, 2008.

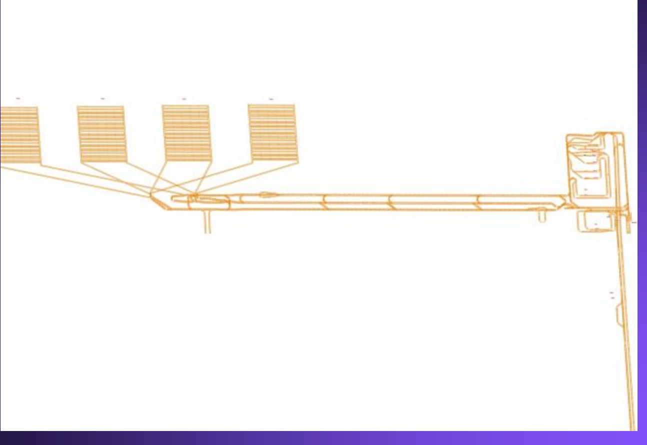
Changi Airport : Baggage handling

Task of the system
- … to transfer transit baggage to correct destination (gate)

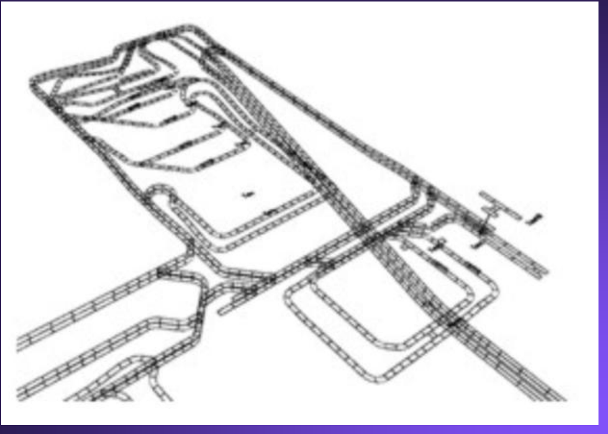
Systems consist of
- Input facilities (Toploaders)
- Conveyors, totes or Destination Coded Vehicles (DCVs)
- Dischargers
- Elastic Block Storage (EBS)

Situation
- Many unknown factors
  - Baggage not sorted at first
  - Destination first known at scan
- Changes in flight schedule data
- Capacity of handling systems are limited

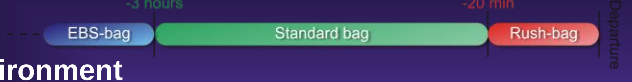
Changi Airport : T3



Changi Airport : Input Area



Changi Airport : Specifications



Environment

- Area: 2.5 x 1.2 km
- Elastic Block Storage (EBS) for 3000 totes
- > 5000 elements (2-7 m/s)

Agents

- 14 Toploaders (7 in T3)
- Diverters and Mergers
- 37 Dischargers (19 racetracks)
- 500-800 totes in peak time

Performance

- 11 mn max from T1 to T3, 9-10 mn max within T3

DECIDE : Traditional vs. MAS control

Traditional approach: “Static shortest path”

- The “statically” shortest routes between all toploaders and dischargers are calculated and stored in the system
- Only changed in case of failure and line breakdowns
- An inducted tote gets a route number, and the PLCs known how to forward it at diverters based on that route id
- Case-based fine-tuning, management to avoid dead-lock

DECIDE : Traditional vs. MAS control

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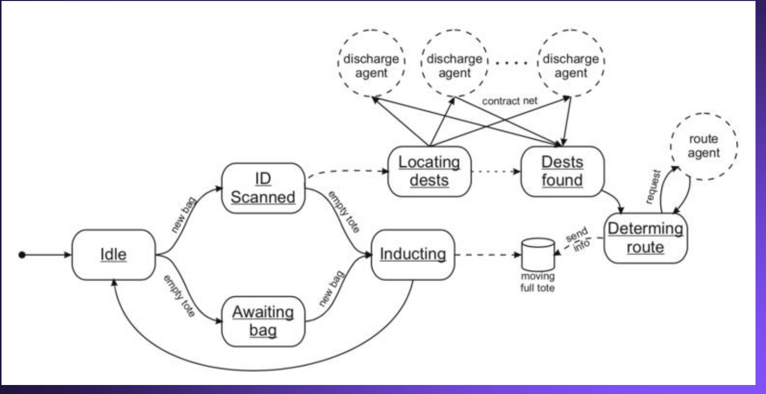
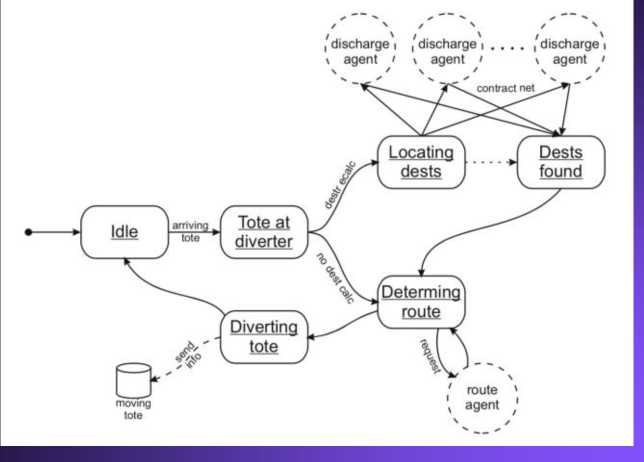
MAS approach : “Routing on the way” – no booking

- Direct only to next node in the graph of the system
- Constantly update the “dynamic route lengths”
- (Local) observations impact the decision among alternatives
  - Queues, number in lines, delay, urgency, etc.
- Exchanged among agents using standardized messages

DECIDE : State graph of toploaders



DECIDE : State graph of diverters



GAME THEORETIC INTERACTION

Game Theoretic Interaction [Zermelo 13]

Agents are assumed to be high-level decision makers confronted with a static interaction

- the interaction is modeled
- utilities are assigned to potential outcomes
- an analysis is made of one's opponent
- an action is selected.

The object here is to define rationality axioms that constrain the agents' behavior in interesting ways

Iterated Case Analysis

		K	
		c	d
J	a	3 3	4 2
	b	1 1	2 4

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But reasoning about K's choosing d, J will choose b

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K

J		c	d
	a	3 3	5 2
	b	2 5	1 1

Less stable situation.
How does the rational agent solve the following interaction ?
(Game of Chicken)

Iterated Case Analysis

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More complex situations

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How about this basic interaction ?
(Battle of the Sexes)

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How about this basic interaction ?
(Battle of the Sexes)

(Prisoner's Dilemma)
In a case like this, binding deals can help to provide solutions

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- communication and deal-making
- probabilistic assumptions regarding payoffs
- special assumptions regarding one's opponent
- conjunctive offers

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COGNITIVE AGENTS

Classes of Cognitive Agents [Erceau 91]

processes, actors

communication primitives

Classes of Cognitive Agents

communicating modules

communication protocols

processes, actors

communication primitives

Classes of Cognitive Agents

cooperative agents	mutual representations, task allocation,
communicating modules	communication protocols
processes, actors	communication primitives

Classes of Cognitive Agents

intentional agents	intentions, engagements, partial plans
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Classes of Cognitive Agents

negociating agents	negotiated conflict resolution
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Classes of Cognitive Agents

organized agents	multiple perspectives social laws, rules
negociating agents	negotiated conflict resolution
intentional agents	intentions, engagements, partial plans
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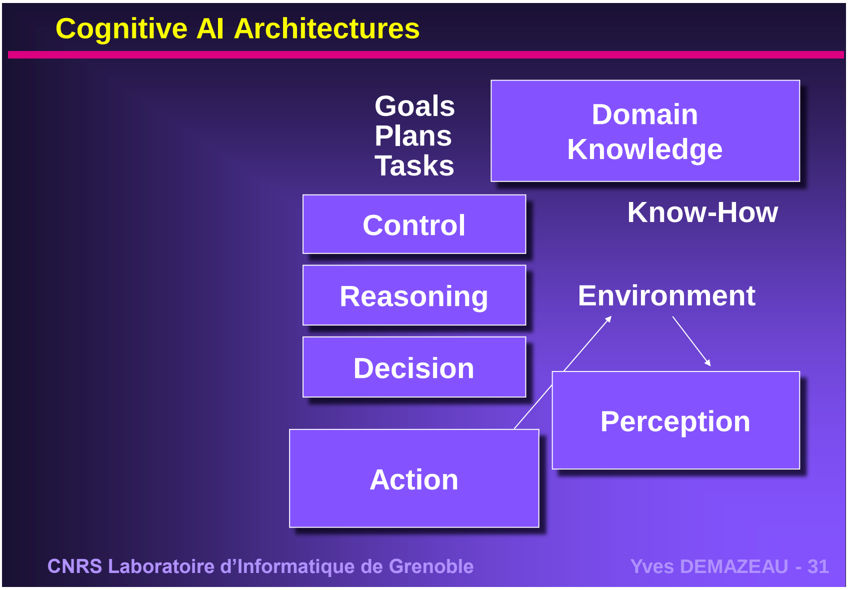
Cognitive AI Architectures
Goals
Plans
Tasks
Domain Knowledge
Control
Know-How
Reasoning
Environment
Decision
Perception
Action
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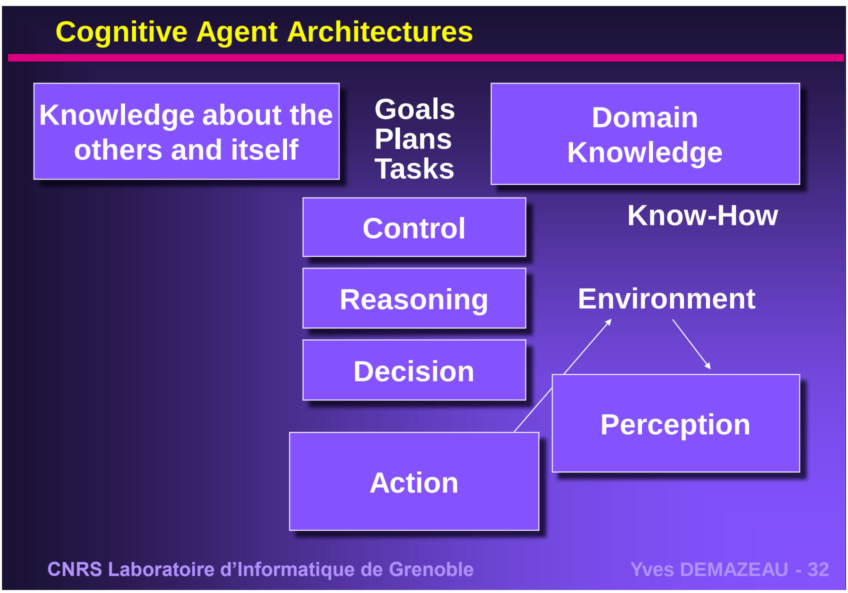
Cognitive Agent Architectures
Knowledge about the others and itself
Goals
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Cognitive Agent Architectures

Mutual Representations

dynamic societies
---> mutual representations of agents

- **who knows what :** the information available
- **who knows how to do what :** the competences
- **who performs what :** the tasks being performed
- **who intends what :** the intentions, the goals
- **who is committed in what :** the commitments

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how to represent this knowledge ?
how to update this knowledge ?

BDI Agent Architectures [Bratman 79]

The behavior is driven by mental attitudes such as intentions, beliefs, goals, fears, etc.

The three main mental attitudes are beliefs, desires (goals), and intentions :

Intentions are persistent goals imposing an agent to act. Persistent goals are goals that are dropped only if they have already been achieved or if they are believed to be not reachable.

Beliefs, Desires, and Intentions have lead to the major cognitive agent class of architectures : the BDI architectures

Intentionality at the agent level

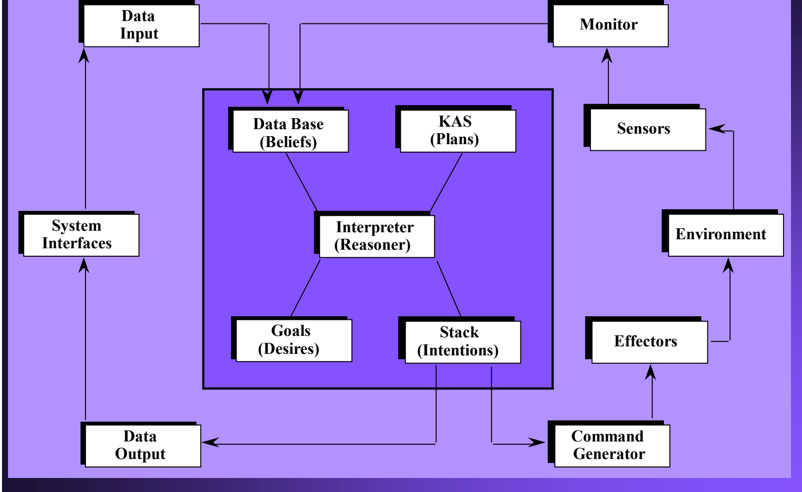
Distinction between

- intending an action
- intending to perform an action in some future (intention defined as a persistent goal to perform in the future)

To intend to perform an action assumes that

- X believes that A is possible
- X does not believe that he will not perform A (he is committing itself to perform A)
- X believes that, if some conditions are fulfilled, it will perform A
- X does not try to fully realize the consequences of A

(BDI) Agent Architecture [Georgeff 85]



The Inadequacy of Standard Logics

The need to have theories telling about what an agent believes in

There is an impossibility to use a standard classical logics (monotonic, universal, atemporal)

- from
  - V.Hugo=Writer(NotreDame)
  - Believe(Jean,Writer(NotreDame) = Writer(Misérables))
- you deduce
  - Believe(Jean, V.Hugo=Writer(Misérables))

There is a need to develop and use other logics

Logics of Knowledge and Beliefs

Logical theories about beliefs based on modal logic

Knowledge and Beliefs

- K(A, father (John, Peter))
- B(A, father (John, Peter))

Semantics of these logics is generally based on Possible World semantics

Possible World Logics

- B(X,f) is true if and only if f is true in every world reachable by the agent X
- Implies omniscience

Sentential Logics

- B(X,f) is true if and only if f is true for the theory associated to the agent X
- Lack of semantical referential

A standard modal logic for beliefs

Distribution axiom

Bel(a, (p ⇒ q)) ⇒ Bel(a, p ⇒ Bel(a,q)) (K)
Bel(a, p) ∧ Bel(a, (p ⇒ q)) ⇒ Bel(a, q))

Non contradictory principle

Bel(a,p) ⇒ ¬Bel(a, ¬p) (D)

Positive and negative introspection

Bel(a,p) ⇒ Bel(a,Bel(a, p)) (4)
¬Bel(a,p) ⇒ Bel(a,¬Bel(a, p)) (5)

Formalizing goals and intentions

Formal theories of intentions do exist, they usually associate the intentional states of the agents to their actions and consequences

Ex: Cohen et Levesque:

- Agent a has p as a persistent goal if it has the goal that p be true later, if it believes that p is not true now, and if it will drop the goal that p will be true later as soon as either it believes that p is true or that it will always be false.
- Goal-p(a,p) = Goal(a,Later(p)) ∧ Bel(a, ¬p) ∧ ((Bel(a,p) ∨ Bel(a,Always(¬p)) -> ¬Goal(a,Later(p)))

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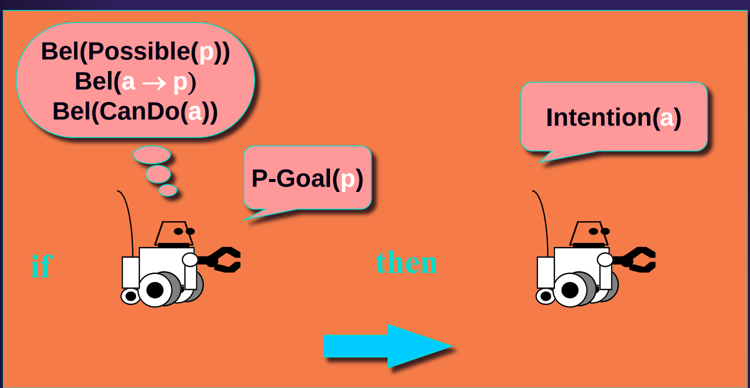
- $\text{Goal-p}(a,p) = \text{Goal}(a,\text{Later}(p)) \wedge \text{Bel}(a, \neg p) \wedge ((\text{Bel}(a,p) \vee \text{Bel}(a,\text{Always}(\neg p)) \rightarrow \neg\text{Goal}(a,\text{Later}(p)))$

Some problems

- what happens if the action is performed by another agent?
- what happens when an agent has several intentions ?
- when does an agent resign with some intention ?
- ...

General intention based behavior [Ferber 95]



Architectures based on cognitive agents

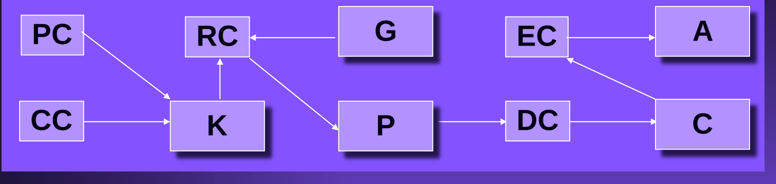
Small systems based on implementation of theories

- Agent-0 (Y. Shoham 90)
- COHIA (Demazeau 90)
- Placa (M. Thomas 93)
- Concurrent MetaM (M. Fisher & M. Wooldridge)
- ...

More elaborate systems:

- Mages (T. Bouron & J. Ferber 91)
- Grate (N. Jennings 93) and Archon (90)
- ASIC (O. Boissier 93)
- Interrap (J. Müller 95)
- ...

KP Agent Architecture [Demazeau 90]



INPUT : perception stimuli

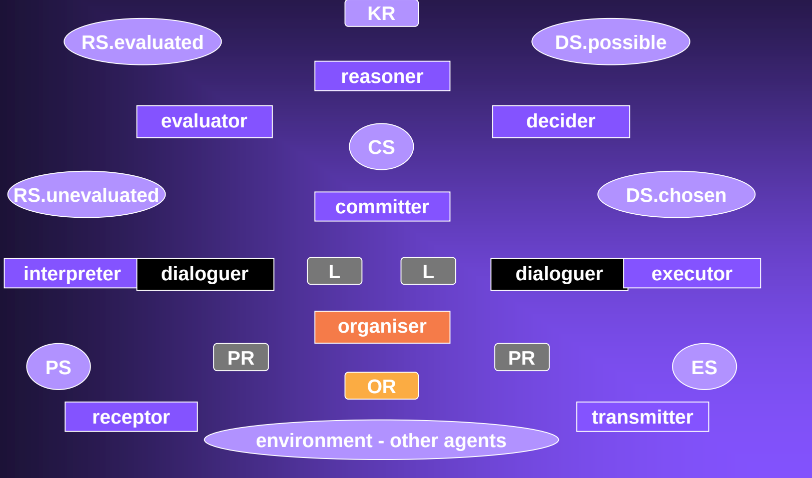
- PC perception capabilities (1st hand)
- CC communication capabilities (2nd hand)
- K knowledge G goals
- RC reasoning capabilities P possible plans
- DC decision capabilities C choices
- EC execution capabilities A actions

OUTPUT : action on agents or environment

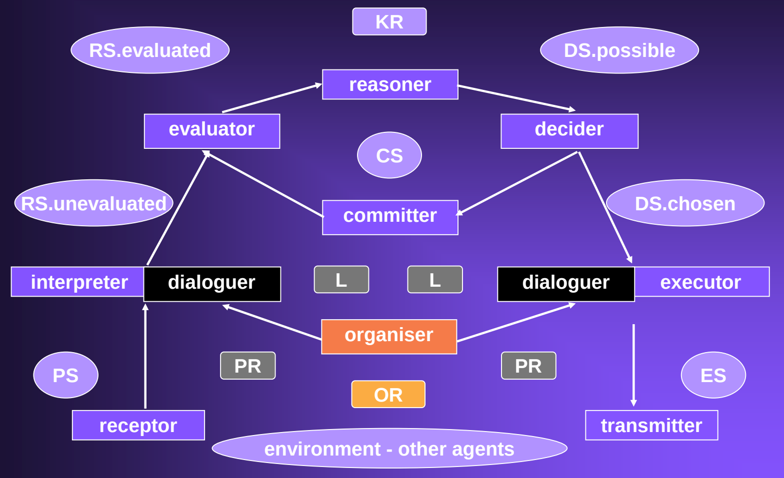
ASIC [Boissier 93]

O. Boissier & Y. Demazeau, “ASIC: An Architecture for Social and Individual Control and its Application to Computer Vision”, 6th Eur. Workshop on Modelling Autonomous Agents in a Multi-Agent World, MAAMAW'94, pp. 135-149, Odense, 1994.

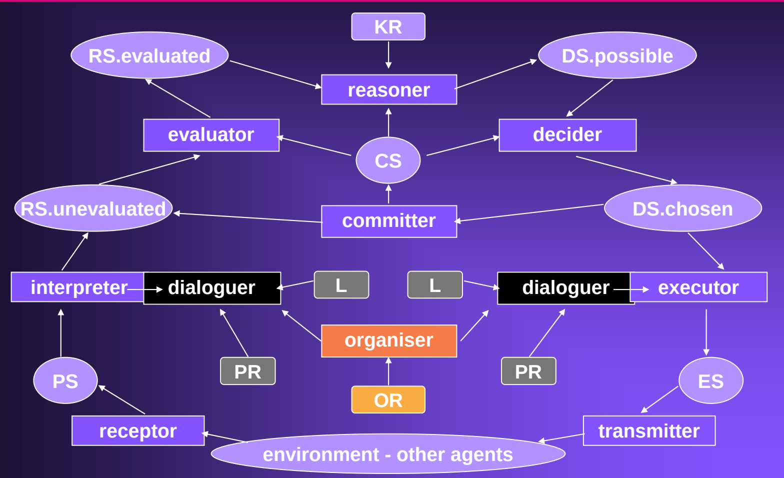
ASIC : Knowledge and Processes



ASIC : Control Flow

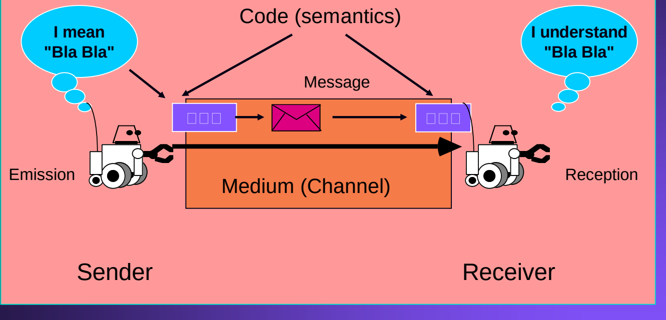


ASIC : Data Flow



SPEECH ACTS

Classical model of communication



Sender / Receiver relationship

Point to point
- (M1) A : B, Hello *A knows its receiver*

Broadcast
- (M2) A : All, Hello *A does not know its receiver*
- (M2') A : {x | dist(A,X) < d}, Hello

Broadcast communications can be reduced to point to point communications using a "broker" as an intermediate agent

- (M3) A : {x | P(x)}, M *A does not know its receiver but an intermediate agent*
- (M3') A : C, broadcast M
- (M3'') for all x that C knows C : x, M

Message meaning

Fixed signification
=> intentional communications
Semantics of the communication is shared by the sender and the receiver
- Supposes a language of communication common to all
- Problems of standards definition

The sender intends the meaning of the message

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Meaning depends on the receiver
=> incident communications
The receiver gives a meaning to the communication
There is no "intentional" meaning of the sender
Communications are "signals"

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Classification along mode / transmission / coding

	Types of communications	Communication mode	Transmission	Coding and interpretation
Cognitive	Message passing communications	point to point and broadcast (using a broker)	direct	Intentional
	Messenger communications	point to point and broadcast (using a broker)	by messenger	Intentional (but depends on the messenger)
Reactive	Stimuli/signals	broadcast	propagation in the environment	Incident

Rationale of Communication

Main theoretical support : Speech Acts Theory (Austin, Searle) where communications are regular actions

Agents communicate using Interaction Languages possibly associated with Interaction Protocols used to control the flow and sequencing of communication

Interaction protocols are modelled by Automata or Petri nets

Well-known Interaction Languages include KQML (without protocols, developed by the Knowledge Sharing Effort) and ACL (with protocols, developed by the Foundation for Intelligent Physical Agents)

Speech Acts [Austin 62]

Concept developed initially in the context of the philosophy of language (Austin, Searle, Vanderveken, ..)

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Communicating is acting

- Sentences are not only true of false, they perform speech actions
- Communications are viewed as a regular actions which have to be generated and processed like every other kind of action

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Communication is pragmatic

- It usually explains what is performed, not to what it refers (more direct communication rather than indirect one);
- Requesting to do something is a way to achieve some goal

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Speech Acts

Categorizing communication types : e.g. inform, ask ask-to-do, ask-for-info, request, answer, propose, warn, promise ...

Decompose a sentence F(P) into its performative F and its content P

- Ask(the light is on) *is the light on?*
- Inform(the light is on) *the light is on!*
- Request(the light is on) *switch on the light, please*

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Speech Acts

Austin A speech act contains 3 acts:

- **Locutionary Act :** uttering of words and sentences with meaning
- **Illocutionary Act :** type of action, *intent* of the utterance
- **Perlocutionary Act :** expected *(desired) result* of the utterance

Searle Classification of illocutionary acts into assertives, directives, commissives, declaratives, and expressives

Brennenstuhl Grouping into models, ordering of the categories according to their temporal relationship and degree of strength, appropriate frameworks to structure dialogue protocols

Speech Acts : Classes [Searle 69]

Assertive : gives an information about the world by asserting something

Directive : gives directives for the interlocutor

Promissive : engages the locutor to accomplish certain acts in the future

Declarative : accomplish an act with the very pronouncement of the statement

Expressive : gives the interlocutor indications about the mental state of the locutor

Speech Acts : Semantics [Cohen 79]

A communication, using speech act theory can be specified in terms of the mental states of both the sender and the receiver

There are necessary and sufficient conditions for performing speech acts

Request(s, r, p) = *def*

Pre: $Goal(s,\phi) \wedge Bel(s, [p \rightarrow \phi \wedge \neg CanDo(s,p) \wedge Helpful(r,s) \wedge CanDo(r,p)])$

Post: $Bel(s, Intend(r,p))$

Where p→f means: if p happen then f will be true

KQML [Finin 92]

One of the most important implementation of speech acts:

- Describe a set of performative like Request, Achieve, Deny, Ask-all, Subscribe, evaluate, delete, ...

Has been implemented as a set of communication primitives:

- Java agents

KQML : Basics

Produced by ARPA- KSE (Knowledge Sharing Effort).

- Based on Speech Act theory where a message is a performative indicating what the receiver is expected to do with the message
- Offers a variety of message types, represented as performatives, that express an attitude regarding the content of the exchange.
- Message content: KIF formalism (Knowledge Inter-exchange Format)
- Provides a message format and message handling protocol supporting run-time knowledge sharing and interaction among agents.
- LISP, 41 performatives, 1st order predicate logic
- Informal semantics, no protocols, no commitment performatives

KQML : Syntax

The syntax of KQML message is based on a balanced parenthesis list

- the initial element of the list is the performative ; the remaining elements are the performative's arguments as keyword / value pairs

(ask-one : receiver *weather-station*
: sender *forecaster*
: content *rain(today, X)*
: language *prolog*
: reply-with *day10*)

KQML : Examples of performative

ask-one S wants one of R's instantiations of the *:content* that is true of R

ask-all S wants all of R's instantiations of *:content* that are true of R

stream-all multiple-response version of ask-all

tell the sentence is in S's Virtual Knowledge Base

achieve S wants R to do make something true of its physical environment

broker-one S wants R to find one response to a performative

KQML [Finin 92]

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Semantics drawbacks

- Mixture of performative of different categories: lack of structure such as ISO standards for communications.
- Some performative are lacking (e.g. there are no promissive)
- Full of incoherencies (cannot be used as such)
- Weak semantics (work on this subject follows the work of Cohen & Levesque)

KQML : Criticisms [Cohen 95]

Cohen and Levesque: 3 general difficulties with KQML specification

- Ambiguity and vagueness the meaning of the reserved or standard performatives is rather unclear
- Misidentified performatives it is an error to include acts such as ACHIEVE, BROKER, STREAM-ALL as performatives because an agent cannot execute another agent's actions or satisfy another agent's goals, merely by saying so (i.e., sending a message) . In fact, the relevant performative should be a directive act (e.g., a request).
- Missing performatives missing entirely the commissives, which commit an agent to a course of action. The prototypical example of a commissive is promising; other examples include accepting a proposal, agreeing to perform a requested action, etc.

KQML : Improvement [Labrou 97]

- A semantic description that associates states of the agent with the use of the language's primitives (performatives).
- The semantic approach uses expressions, that suggest the minimum set of pre- and post- conditions that govern the use of a performative, along with conditions that suggest the final state for the successful performative.
- Example : tell(A,B,X)
  1. A states to B that A believes the content to be true.
  2. BEL(A,X)
  3. Pre(A): BEL(A,X) KNOW(A,WANT(B,KNOW(B,S)))
     Pre(B): INT(B,KNOW(B,S)), S being any of BEL(B,X), or (BEL(B,X)).
  4. Post(A): KNOW(A,KNOW(B,BEL(A,X)))
     Post(B): KNOW(B,BEL(A,X))
  5. Completion: KNOW(B,BEL(A,X))
  6. The completion condition holds, unless a *sorry* or *error*

CONVERSATIONS

From Speech Acts to Agents Conversations

Communications are not performed as a set of isolated messages

From a cognitive science point of view, the utterance is carrying a potential of several meanings, and the final meaning is co-constructed in the course of a conversation (dialogism)

From a computer science point of view, communications are structured into conversations, i.e. stylized sequences of messages (protocols)

Speech act theory is still not capable to address this conversational issue

DIALOGISM [Bakhtin 29]

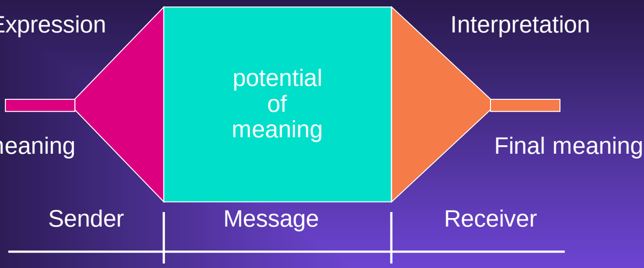
The meaning of an utterance is co-constructed in the course of the dialogue

An utterance does not carry one meaning but a potential set of different meanings, including the intended meaning of the sender

The receiver interprets the utterance it gets into a meaning that may be different from the one expected by the sender, and reacts accordingly

The receiver's reaction may be different from the one expected by the sender which then adapts its behavior for further exchange

DIALOGISM Potential of meaning



The three meanings

- the one the sender wants to give to its message
- the one the receiver interprets from the message
- the onethe sender thinks the receiver has interpreted

are checked during the conversation to maintain mutual understanding in spite of possible shifts

DIALOGISM Example of possible misunderstanding

Do you have a phone ?
M1=Ask phone number

Yes, my phone number is…
M1=M2=Ask phone number

Yes, I already have one.
M2= Trying to sell a phone (M1)

Yes, it is there.
M2=Ask where the phone is (M1)

Mutual understanding

Render the
Misunderstanding explicit
Re-expression of M1

Accept M3
Abandon M1

Interaction Protocols [Demazeau 94]

A framework to define and structure

- with which and why, when, what and how communicate
- what the sender should expect after sending a message, and how to react to a message

A common frame of reference for the agents

- the rules that must be followed in order to interact
- general rules that determine how agents should behave in various situation

Interaction Protocols

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Representation as transition networks

- defining the set of possible transitions which link a set of states that the agents may alternately occupy according to the effective exchanged interaction acts
- a transition may constraint the filling of some fields in the interaction act.
- it also may be labelled by a condition that an agent has to satisfy before using the transition.

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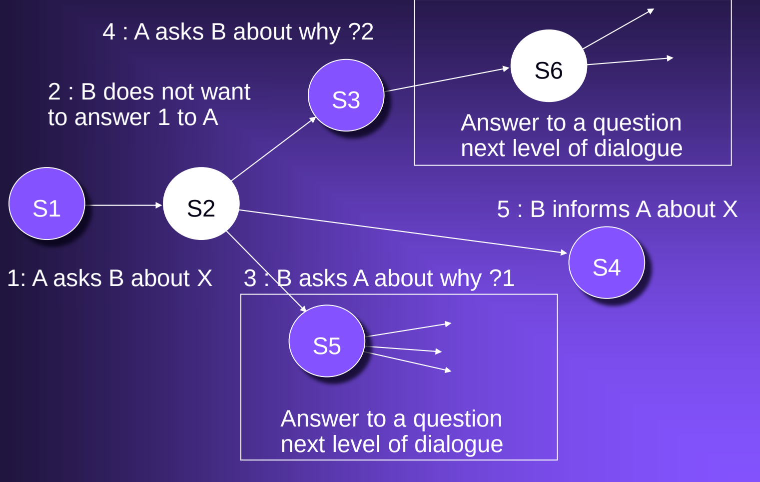
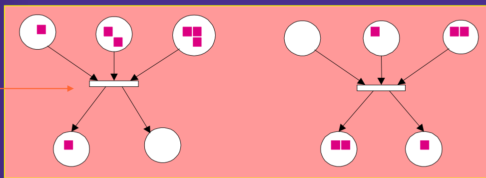
Interaction Protocols : a typical Request protocol



Petri Nets [Petri 62]

Petri nets have been created to express concurrent processes as a generalization of automata. They are made of places, transitions and tokens (marks), with accompanying rules of transition firing

transition
can be fired



Very well adapted to describe protocols

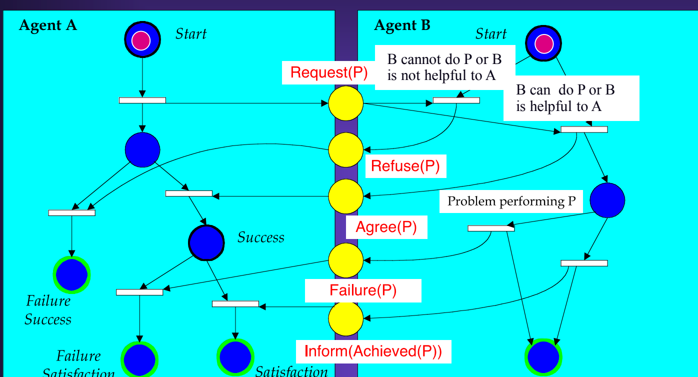
- Already used broadly to describe network protocols

A wide range of Petri net models

- Basic, Colored, Time, etc...

Request Protocol as Petri Nets

Example: requesting to do something



Request Protocol as Petri Nets

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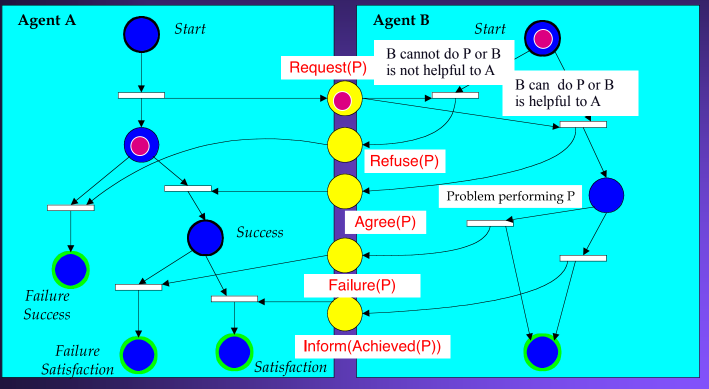

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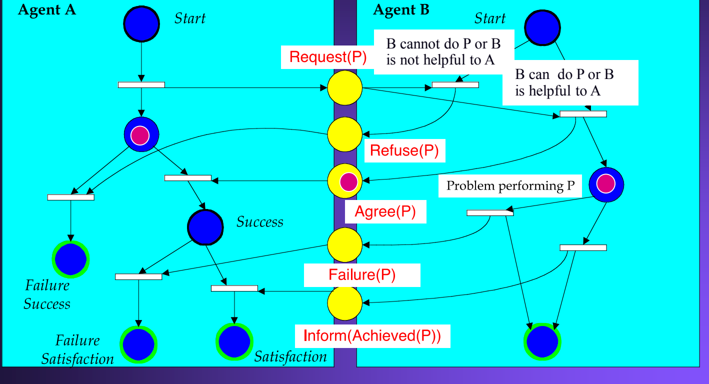

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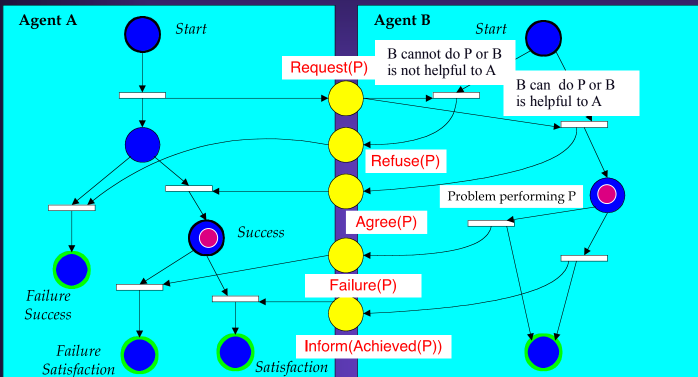

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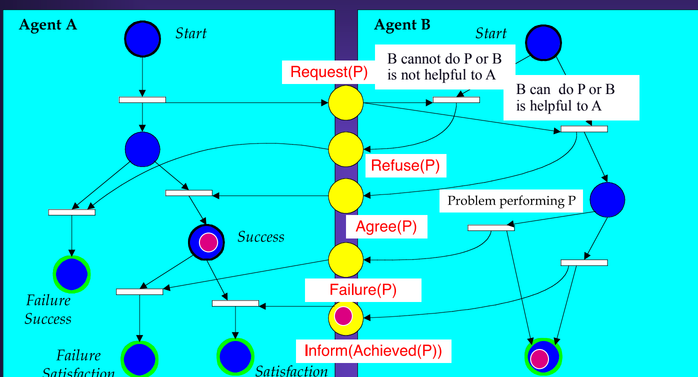

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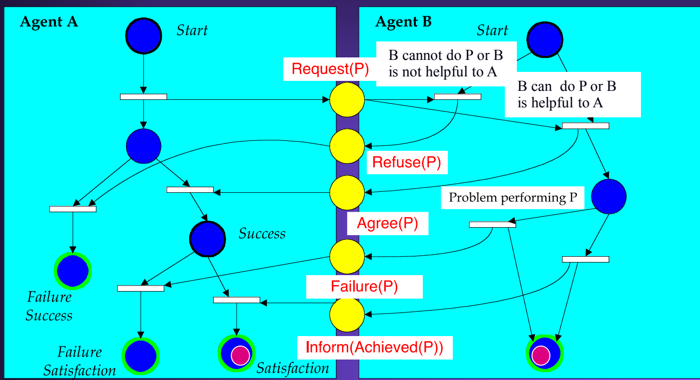
Example: requesting to do something



IL (Interaction Language) [Demazeau 95]

< IL message > ::=

< communication message >
- translates the message from a pure distributed systems point of view

< multi-agent message >
- referring the multi-agent domain knowledge

< application message >
- e.g. application language for computer vision

The IL message is physically supported by the communication message

The IL message is ontologically supported by the application message

IL : Communication Message

The Communication physically supports the IL

< communication> ::=

< from >
- referring the sender

< to >
- referring the receiver (agent entity or broadcast)

< id >
- identity of the message

< via >
- channel (direct message passing, BB, HBWC)

< mode >
- mode (synchronous, asynchronous)

IL : Multi-Agent Message

The Multi-Agent message determines the intention of the sender and its expected results in addition to a interaction protocol for reference

< multi-agent message > ::=

< type >
- either : present, request, answer, or inform

< strength >
- prioritizing the message from sender's point of view

< nature >
- reflecting the expected control layer of the receiver

<protocol>

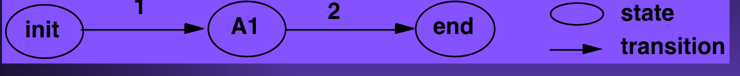
<position>

IL : Illocutionary Strength [D'Inverno 90]

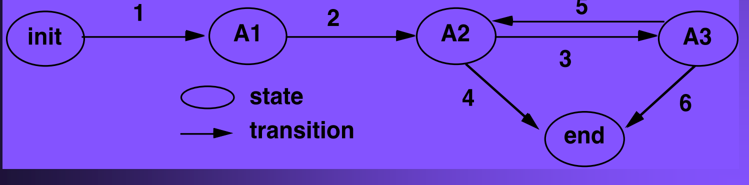
1. Action requesting
2. Information seeking
3. Information probing
4. Information checking
5. Instructing
6. Informing
7. Understanding event
8. Warning
9. Advising
10. Persuading
11. Promising
12. Bargaining
13. Impressing
14. Intimidating
15. Threatening
16. Commanding
17. Encouraging
18. Expressing
19. Offending
20. Misleading
21. Amusing

IL : "Request" Protocol [Boissier 93]

The "Simplest Request-Answer" Protocol



The "Request until Satisfaction" Protocol



IL : "Introduction" Protocol [Demazeau 92]

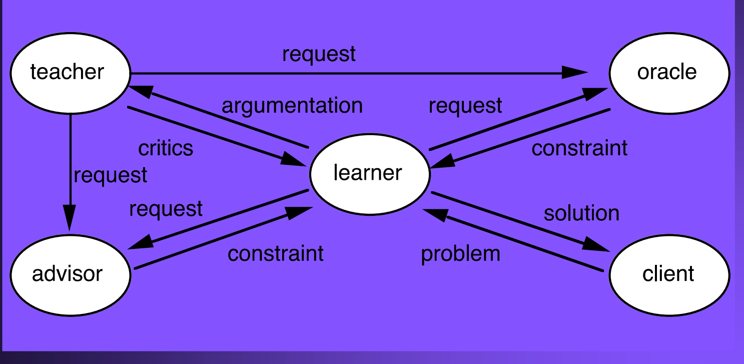
Acquiring new - and refining current - knowledge between agents when introducing a new one, assuming a description at several levels of detail (RO,BA,DE,US,EX)

1. broadcasting { (ROi , { BAij } j) i}
2. refining according to agents mutual interests
- same RO and same BA -> **duplication**
- (detection of redundancy)
- same RO and different BA -> **competition**
- (towards negotiation, subcontracting)
- different RO and same BA -> **incoherence**
- (detection of inconsistencies, towards learning)
- different RO and different BA -> **information**

3. uses four dedicated interaction protocols

IL : MOSCA Learning Protocol [Quinqueton 95]

An interaction protocol that recursively implements the learning mechanism of an agent



Interaction Protocols Formalisation [Koning 98]

J.-L. Koning, G. François & Y. Demazeau "Formalization and Pre-Validation for Interaction Protocols in Multi-Agent Systems", 13th European Conference on AI, ECAI'98, Wiley, pp. 298-302, Brighton, August 1998.

ACL [FIPA 96]

Foundation for Intelligent Physical Agents

- International (but very European)

ACL : Agent Communication Language

- A communication language based on speech acts similar to KQML, but with a clear semantics based also on modal logic
- It adopts the notion of interaction protocols
- In the process of standardization

KQML+ [Moulin 97]

A language to enable novice users to interact with artificial agents, a compromise between KQML, IL, ACL, and dialogism

Rationalization of the performatives
- every primitive performative and its associated semantics

Taking into account social conventions
- to express the non-literality of human utterances

Taking into account human dialogism
- by enabling positioning and expectations

Taking into account the social power
- from ordering to politeness

TALISMAN

TALISMAN (academic project) [Stefanini 95]

Traitement Automatique des Langues par un Système Multi-Agents Crisstal (F), LIFIA-CNRS (F)

Multi-level morpho-syntactic analysis of the written French minimizing ambiguities by interactions

Approach

- simplified Demazeau's COHIA agent model
- agents : preprocessing, morphological analysis, syntactical analysis, segmentation into propositions, transformations, ellipses, coordination, negations
- Sian's interaction protocols to initialize, to regulate communication exchanges, to realize agent control
- full implementation on Bim/Prolog - Sun WS

M.-H. Stéfanini & Y. Demazeau, "TALISMAN: a multi-agent system for Natural Language Processing", in 12th Brazilian Symposium on AI, SBIA'95, pp. 310-320, Campinas, 1995.

TALISMAN : Agents

Restriction of multiple solutions (usage of local grammars, interaction between levels)

- ---> cooperation between modules

Language variations, complex linguistic phenomena :

- ---> evolutionary system : modification of strategy

Introduction of new modules :

MORPH : morphology	TRANSF : transformation
PRET : preprocessing	COORD : coordination
SEGM : segmentation	ELLIP : ellipsis
SYNT : syntax	NEGA : negation
STAT : statistics	+ interaction protocols

TALISMAN : SYNT(AX) Agent

its knowledge
verbs dictionaries, locals grammars
indicators of lexical structure, indicators of grammatical structure, prepositions introducing adverbial sentences

its abilities
detection of adverbial, prediction based on governed verbs ...

its reasoning capabilities
linguistics heuristic for conflict resolution

its goal
to find syntax structure(s)

TALISMAN : Dynamics

Interactions are based on both safe (not ambiguous) information (e.g. syntactical structures, morphological categories, ...) and uncertain information or linguistics heuristics

When new knowledge is validated by an agent, it modifies its local memory and restart its resolution process.

The agent may also update the interpretation of the sentence that is accessible to every component of the system

The system stops on its own when there is no further updating to be done on the interpretation

TALISMAN : Interaction Protocols

<MORPH> <SYNT>
<MODIFY | CONFIRM>
<ambiguous form>

<MORPH> <SYNT>
<PROPOSE | CONFIRM>
<structure ISG>

<TRANSF> <SYNT>
<MODIFY | CONFIRM>
<QTO sentence>

COMPLEMENTARY REFERENCES

Complementary references

The most elaborated development of KQML

K. Bouzouba, B. Moulin, “KQML+: An extension of KQML in order to Deal with Implicit Information and Social Relationship”, 11th Florida AI Research Symposium Conference, pp. 289-293, 1998.

A foundational paper about beliefs, desires, and intentions

P. Cohen & H. Levesque, “Intention is choice with commitment”, Artificial Intelligence, 42, 213-26, 1990.

An early paper dealing with norms, to constrain agents

F. Dignum, “Autonomous agents with norms, Artificial Intelligence and Law”, Vol. 7, Issue 1, pp. 69-79, 1999.

One of the early language to program BDI agents

A. Rao, “AgentSpeak(L): BDI Agents Speak Out in a Logical Computable Language”, 7th Eur. W. on Modelling Autonomous Agents in a Multi-Agent World, MAAMAW’96, pp. 42-55, Eindhoven, 1996.