Flexible Communication Based on FIPA-ACL

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Introduction

- Agents: Entities which act upon the environment they inhabit.
- Attitudes like belief, goal and intention are used to model agents.
- Specific programming languages have been defined which implement these attitudes as explicit data structures.

Motivations

- Multi-agent systems are potential candidates to be used in crucial systems like electronic commerce, industrial process control, and information retrieval
- Agents use a common language to communicate (ACL). Example: FIPA-ACL
- When an agent sends a message: Preconditions, Effects on local information
- In the receiver side: Update local information upon receiving a message
- Previous work: The language ECCS: $\mathbf{Static}$ nature of preconditions and effects
- We change the semantics to be $\mathbf{Dynamic}$: A programmer will define a set of communicative actions *performatives*

Introduction: Overview of the Work

- Information Store (IS) to represent beliefs($\mathbf{B}$), Goals($\mathbf{G}$) and intentions($\mathbf{I}$).
- Agent programming language (ECCS), focussing on communication and concurrency.
- Syntax of ECCS
- Semantics of information store
- Conclusion

Multi-Modal Logic $PrBG_n$

- $Ag = \{1, \ldots, n\}$ a set of agents.
- $\mathcal{P} = \{p, q, r, ...\}$ a set of atomic predicates; $\mathbf{true}$ and $\mathbf{false}$ are constants.
- Multi-modal Logic $PrBG_n$:
  - any element of $\mathcal{P}$ is in WFF_{PrBG};
  - $\mathbf{true}$ and $\mathbf{false}$ are in WFF_{PrBG};
  - if F and H are in WFF_{PrBG} then so are

    $\neg F \quad , F \vee H \quad , F \wedge H \quad , B_i F \quad , G_i F$ where $i \in Ag$.
- B_i satisfies axioms $\mathbf{K}$, $\mathbf{D}$, $\mathbf{4}$, $\mathbf{5}$ and G_i satsifies axioms $\mathbf{K}$, $\mathbf{D}$

Modal Logic of knowledge, Belief,...

- Axioms $\mathbf{K}$, $\mathbf{D}$, $\mathbf{4}$, and $\mathbf{5}$:
  - $\mathbf{K}$: $\vdash B(\phi \Rightarrow \psi) \Rightarrow (B\phi \Rightarrow B\psi)$
  - $\mathbf{D}$: $\vdash B\phi \Rightarrow \neg B \neg \phi$
  - $\mathbf{4}$: $\vdash B\phi \Rightarrow BB\phi$
  - $\mathbf{5}$: $\vdash \neg B\phi \Rightarrow B \neg B_i \phi$
- Semantics of $PrBG_n$ formulas are defined in terms of Kripke structure $M = (S, L, B_1, \ldots, B_n, G_1, \ldots, G_n)$
- Accessibility relation of $\mathbf{B}$ operator is *serial*, *transitive* and *Euclidean*. ($\mathbf{G}$ is Serial)
  - $Euclidean$: if $(s, s') \in B$ and $(s, s'') \in B$ then $(s', s'') \in B$.
  - $serial$: For any $s \in S$ there is a $s' \in S$ s.t. $(s, s') \in B$.

Belief and Goal bases

- We assume each agent (say i) has a finite $\mathbf{belief}$ $\mathbf{base}$ and a finite $\mathbf{goal\ base}$, denoted Ψ_{B_i} and Ψ_{G_i} respectively, and defined as:

$$\Psi_{B_i} \subseteq \{\omega \mid \text{where } \omega \text{ is a closed } PrBG_n \text{ formula}\}$$

$$\Psi_{G_i} \subseteq \{\omega \mid \text{where } \omega \text{ is a closed } PrBG_n \text{ formula}\}$$

- We assume the set of beliefs and the set of goals are consistent, i.e., $\Psi_{B_i} \not\models \mathbf{false}$, $\Psi_{G_i} \not\models \mathbf{false}$.
- The satisfaction relation between pairs of form $\langle \Psi_i, \phi \rangle$ where $\Psi_i = (\Psi_{B_i}, \Psi_{G_i})$ and $\phi \in PrBG_n$, is defined as:
  - $\Psi_i \models B_i\phi$ iff $\Psi_{B_i} \models \phi$
  - $\Psi_i \models G_i\phi$ iff $\exists \omega \in \Psi_{G_i},\ \omega \models \phi$
  - $\Psi_i \models I_i\phi$ iff $\Psi_i \models G_i\phi$ and $\Psi_i \not\models B_i\phi$.

Syntax of ECCS

syntax

- Syntax:

$$\pi ::= \ 0 \mid \bar{c}(m).\pi \mid c(m).\pi \mid update(O_i\omega).\pi \mid perform(b(\vec{t})).\pi$$
$$\mid query(\omega).\pi \mid observe(l).\pi \mid \pi_1 + \pi_2 \mid A(\vec{t}).\pi$$

- $b(\vec{t})$ is a basic action defined as: $\langle\ b(\vec{x}) : \phi(\vec{x}), \psi(\vec{x})\ \rangle$
- $A(\vec{t})$ is a procedure call defined as: $A(\vec{x}) =_{def} \pi(\vec{x})$
- M_i = $\langle$ *i*, $\Psi^0_{B_i}$, $\Psi^0_{G_i}$, *Bacts, Ch, LB,* Π, *P_acts* $\rangle$
- A multi-agent system:
  $M = \ M_1 \mid M_2 | \ldots |M_n$
  where $M_i(i \in Ag)$ are agents

Agent Communication Language FIPA

- FIPA: 4 primitive performatives, 16 composite performatives.
- Example:
primitives: inform, request
composite: propose, query
- Syntax of performatives: $\langle i, j, perf(\alpha) \rangle$.
- Semantics of performatives: FP and RE.
- Example: $\langle i, j, inform(p) \rangle$,

$$FP = B_i p \wedge \neg B_i Bif_j \; p \wedge \neg B_i Uif_j \; p,$$

$$RE = B_j p$$

Example

- A robot agent i which is able to move blocks from a position to another position.

  Ψ_{B_i} =$\{$`over(a,b), over(b,v), table(v), table(w)`$\}$

- The basic action *move(x,p1,p2)* moves the block x on the object $p1$ onto the object $p2$.

  `move(x,p1,p2):`
  `pre =` B_i`over(x,p1)` $\wedge$ $\neg B_i$`over(y,x),`
  `post =` B_i`over(x,p2)`

- The agent i has the goal G_i *empty(v)*; Thus it might move all the blocks from the table `v` onto the table `w`.

Example continued ...

- We define a label Mv to move all the blocks from a position to another position.

  Mv(x,p,t')=
  query($B_i$over(z,x)). Mv(z,x,t'). move(x,p,t') +
  query($\neg B_i$over(z,x). move(x,p,t')

- The main program to make the table t empty might be defined as follows:

  Π = query(G_i empty(t)).
  {query($B_i$over(x,t) $\wedge$ $B_i$table(t')). Mv(x,t,t').Π} +
  {query($\neg B_i$ over(x,t)). update(B_i empty(t)) }

Semantics of ECCS

Semantics

- The configuration of an agent i is a tuple $\langle \Pi_i, \Psi_i, \theta_i, did(i,a) \rangle$.
- The semantics of basic action is:

$$\frac{\Psi_i \models pre(b(\vec{t}\theta_i/\vec{x}))\ ,\ \Psi_i' = revise(\Psi_i, post(b(\vec{t}\theta_i/\vec{x})))}{\langle perform(b(\vec{t})).\Pi_i, \Psi_i, \theta_i, - \rangle \rightarrow \\ \langle \Pi_i, \Psi_i', \theta_i, did(i, perform(b(\vec{t}\theta_i))) \rangle}$$

Semantics of input/output

- To send a message, the sender must satisfy some preconditions. In addition there might be some revisions in the mental states of the agents involved in the communication.
- Definition of $perf_{out}$ and $perf_{in}$
  - $perf_{out}(r,\alpha) = \langle \omega(self, r, \alpha), \rho(self, r, \alpha) \rangle$
  - $perf_{in}(s,\ \alpha) = \langle -, \rho(self, s, \alpha) \rangle$
-

$$\rho ::= 0 \mid update(O_i \omega).\rho \mid perform(b(\vec{t})).\rho \mid query(\omega).\rho \mid$$
$$observe(p).\rho \mid \rho_1 + \rho_2$$

Semantics of input/output

Example: inform

$\mathbf{inform}_{out}$ ($\mathbf{r}$, α):

$$\begin{aligned}
\mathtt{pre} \;&= \; \mathtt{B_{self}}\alpha \wedge \neg \mathtt{B_{self}} \mathtt{B_r}\alpha \wedge \neg \mathtt{B_{self}} \mathtt{B_r} \neg\alpha \\
\mathtt{post} \;&= \; \mathtt{update(}\ \mathtt{B_{self}} \mathtt{B_r} \mathtt{B_{self}}\alpha\ ). \\
&\quad\; \mathtt{query(}\ \mathtt{B_{self}Trusts(r,self)}\ ). \\
&\quad\; \mathtt{update(}\ \mathtt{B_{self}} \mathtt{B_r}\alpha \wedge \sim \mathtt{G_{self}} \mathtt{B_r}\alpha\ )
\end{aligned}$$

$\mathbf{inform}_{in}$($\mathbf{s}$, α)

$$\begin{aligned}
\mathtt{post} = \; &\mathtt{update(}\ \mathtt{B_{self}} \mathtt{B_s}\alpha\ ). \\
&\mathtt{update(}\ \sim \mathtt{B_{self}} \mathtt{G_s} \mathtt{Done(a)}\ ). \\
&\mathtt{query(}\ \mathtt{Trustable(s)}\ ).\ \mathtt{update(}\ \mathtt{B_{self}}\alpha\ )
\end{aligned}$$

where $a \in \{\ \bar{c}_{s(self)}(\text{inform}(\alpha)),\ \bar{c}_{s(self)}(\text{inform\_if}(\alpha))\ \}$

Semantics of input/output

We define the $big\text{-}step$ transition relation $\Longrightarrow$ as:

$$\frac{}{\langle \rho.\Pi, \Psi, \theta, - \rangle \stackrel{\epsilon}{\Longrightarrow} \langle \rho.\Pi, \Psi, \theta, - \rangle}$$

$$\frac{\begin{array}{c}\langle \rho.\Pi, \Psi, \theta, - \rangle \stackrel{\tau}{\rightarrow} \langle \rho'.\Pi, \Psi', \theta', - \rangle \ , \\ \langle \rho'.\Pi, \Psi', \theta', - \rangle \stackrel{\epsilon}{\Longrightarrow} \langle \rho''.\Pi, \Psi'', \theta'', - \rangle\end{array}}{\langle \rho.\Pi, \Psi, \theta, - \rangle \stackrel{\epsilon}{\Longrightarrow} \langle \rho''.\Pi, \Psi'', \theta'', - \rangle}$$

Semantics of input/output

- Output: Assume ω=*pre(perf*$_{out}$*(j* θ_i, α θ_i*))*, and ρ= *post(perf*$_{out}$*(j* θ_i, α θ_i*))*.

$$\frac{\Psi_i \models \omega, \quad \langle \rho.\Pi_i, \Psi_i, \theta_i, - \rangle \; \overset{\epsilon}{\Rightarrow} \langle \Pi_i, \Psi_i', \theta_i', - \rangle}{\langle \bar{c}_{ij}(perf(\alpha)).\Pi_i, \Psi_i, \theta_i, - \rangle \; \rightarrow \langle \Pi_i, \Psi_i', \theta_i', did(i, \bar{c}_{ij}(perf(\alpha\theta_i))) \rangle}$$

Semantics of input/output

- Output: Assume ω=*pre(perf$_{out}$(j θ_i, α θ_i))*, and ρ= *post(perf$_{out}$(j θ_i, α θ_i))*.

$$\frac{\Psi_i \models \omega, \quad \langle \rho.\Pi_i, \Psi_i, \theta_i, - \rangle \stackrel{\epsilon}{\Rightarrow} \langle \Pi_i, \Psi'_i, \theta'_i, - \rangle}{\langle \bar{c}_{ij}(perf(\alpha)).\Pi_i, \Psi_i, \theta_i, - \rangle \; \rightarrow \langle \Pi_i, \Psi'_i, \theta'_i, did(i, \bar{c}_{ij}(perf(\alpha\theta_i))) \rangle}$$

- Input: Assume ρ=*post(perf$_{in}$(i θ_j,$\alpha\theta_j\eta$))*, and η is a valuation of the free variables of $\alpha\theta_j$.

$$\frac{\theta'_j = \theta_j\eta, \quad \langle \rho.\Pi_j, \Psi_j, \theta'_j, - \rangle \stackrel{\epsilon}{\Rightarrow} \langle \Pi_j, \Psi'_j, \theta''_j, - \rangle}{\langle c_{ij}(perf(\alpha)).\Pi_j, \Psi_j, \theta_j, - \rangle \; \rightarrow \langle \; \Pi_j, \Psi'_j, \theta''_j, did(j, c_{ij}(perf(\alpha\theta_j\eta))) \; \rangle}$$

Semantics of parallel composition

In the semantics of parallel composition there are two cases: An agent might do an internal action or two agents might communicate according to the following rule:

Let $\bar{c_{ij}}(perf(\alpha))$ be the message to be sent by i, and $c_{ij}(perf(\beta))$ be the message to be received by j. Assume there is a most general unifier η such that $\alpha\theta_i = \beta\theta_j\eta$.

$$\frac{\langle \Pi_i, \Psi_i, \theta_i, - \rangle \rightarrow \langle \Pi_i', \Psi_i', \theta_i', did(i, \bar{\gamma}) \rangle \quad , \ \langle \Pi_j, \Psi_j, \theta_j, - \rangle \rightarrow \langle \Pi_j', \Psi_j', \theta_j', did(j, \gamma) \rangle}{[...|\langle \Pi_i, \Psi_i, \theta_i, - \rangle|...|\langle \Pi_j, \Psi_j, \theta_j, - \rangle|...] \rightarrow}$$

$$[...|\langle \Pi_i', \Psi_i', \theta_i', did(i, \bar{\gamma}) \rangle|...|\langle \Pi_j', \Psi_j', \theta_j', did(j, \gamma) \rangle|...]$$

where $\bar{\gamma} = \bar{c}_{ij}(perf(\alpha\theta_i))$ and $\gamma = c_{ij}(perf(\beta\theta_j\eta))$.

Example

```
Global function Agt = {(j,a) --> true }
```

Agent i:

Initial_beliefs ={ `Bel i Trustable(j)` }

Initial_goals ={ `Goal i Do(<j,a>)` }

Comm_channels ={ `c=(i,j), d=(j,i)` }

Main program:

```
query(Goal i Do(<k,act>)).    /* act is bound to a, and k is bound to j */
(i,k)!(request(act)).         /* sending a message to k */
{ (k,i)(agree(act)) +         /* receiving a message from k */
  (k,i)(refuse(act))
}.
{ query(Bel i (Goal k (Do<k,act>))).
  { (k,i)(inform(Do(act))) +
    (k,i)(failure(act)) }
}
```

Example

Agent j:

Initial_beliefs ={`Bel j Trusts(i,j), pre(a)`} /*`pre(a)` are the preconditions of `a`*/

Initial_goals ={ }

Comm_channels ={ `c=(i,j), d=(j,i)` }

Main program:

```
(i,j)(request(act)).     /* act is bound to a */
{ query(Goal j Do(<j,act>)).
      (j,i)!(agree(act)).
      perform(act).
      { (j,i)!(inform(post(<j,act>)))   +  /* either inform or failure will run
        (j,i)!(failure(<j,act>)) }          according to their preconditions */
} +
{ query(not Goal j Do(<j,act>)).
   (j,i)!(refuse(<j,act>))
}
```

Model checking

- The logic CTL_{BG}:

$$\mu ::= true \mid done(< i, a >, \mu) \mid \phi \mid \neg\mu \mid \mu \wedge \mu \mid \mathbf{EX}\mu \mid \mathbf{EG}\mu \mid \mathbf{E}\mu\mathbf{U}\mu'$$

  where ϕ is a local formula about the mental state of agents.

- We simplify the Kripke structure to remove unnecessary states.
- Sincerity condition: $\mathbf{AG}$ *(* $\mathbf{EX}$ *done(*$\langle$ *i,perf(*α*)* $\rangle$*, true)* $\Rightarrow$ *FP(perf(*α*)))*
- Blind commitment: $\mathbf{AG}(I_i\phi \Rightarrow \mathbf{AF}B_i\phi)$
- Open minded commitment: $\mathbf{AG}(I_i\phi \Rightarrow \mathbf{AF}(B_i\phi \vee B_i\neg possible(\phi)))$

Examples

- Flexibility of defining various semantics for communicative acts
- New communicative acts can be defined with appropriate operational semantics
- An issue for future work is the implementation of the framework.