Japan Advanced Institute of Science and Technology

Channels for Agent Communication

Stijn De Saeger
stijn@jaist.ac.jp

March 7, 2007

- Institutions for Agent Communication

- Formalizing Institutions
  Channel Theory
  Institutions in Channel Theory

Agent Communication Languages

- Multiagent systems as a "*technological extension of human society*" ([2])
- Many aspects of agent societies and interaction modeled after the "real" world
  - Epistemic logic, belief revision, ...
- Protocols (ACLs) for agent interaction
  - Theory of Speech acts (Austin, Searle)

ACLs and Speech Acts

ACL semantics usually defined in terms of agents' **mental attitudes** (beliefs, intentions,desires,. . .)

Example: FIPA definition of the *inform* speech act:

$$< i, \mathsf{inform}(j, \phi) >$$

$$[\mathbf{FP}] \quad B_i\phi \wedge \neg B_i(B_j\phi \vee B_j\neg\phi)$$

$$[\mathbf{RE}] \quad B_j\phi$$

Mentalistic Semantics of Speech Acts

Problems with this approach (Singh, Colombetti et al.)

- Long-standing problems with the formalization of intensional concepts like belief
- Tension between **public** nature of communication and **private** nature of agent beliefs
  - FP and RE should be *verifiable* and *transparent*
  - Belief updates do not capture the *social* updates triggered by speech acts
- Speech acts as moves in a **dialogue game**

Social Semantics for Speech Acts

But: social semantics for actions is substantially different!

- Requires *collective intensionality*

Given in terms of normative and constitutive rules

- Normative rules
  - **Regulate** *existing* forms of behaviour
  - E.g. "$\mathsf{inform}(i, j, \phi) \rightarrow \mathcal{O}_i(\mathsf{defend}(i, j, \phi))$"
- Constitutive rules
  - **Establish** *new* social realities
  - Often classificatory in nature:
    "$\mathsf{assert}(i, j, \phi) \rightarrow \mathsf{inform}(i, j, \phi)$"

Social Semantics for Speech Acts

Institutions

- *[…] "institutions" are systems of constitutive rules. Every institutional fact is underlain by a (system of) rule(s) of the form "X counts as Y in context C". (J. Searle, [3]:)*
- Constitutive rules as "count-as" conditionals:

$$X \Rightarrow_c Y$$

- Virtual institutions in normative MAS

Institutions

Logical Properties

Multiple levels of **context dependence** in a statement "$X \Rightarrow_c Y$"

- X stems from an ontology of so-called "brute facts"
- Y denotes some "social" aspect of reality
- C lives in the realm of "institutions"

- Institutions for Agent Communication

- Formalizing Institutions
  Channel Theory
  Institutions in Channel Theory

Preliminaries: Channel Theory

- *Qualitative* information theory
- Born out of situation semantics in 1990's
- *Information Flow: The Logic of Distributed Systems* (Barwise and Seligman, [1])

Classifications

A **classification** $\mathcal{C} = \langle S, \Sigma, \models \rangle$ consists of

- A non-empty set S of situations (events, actions,...)
- A non-empty set Σ of situation *types* (attributes, properties, ...),
- A classification relation $\models \subseteq S \times \Sigma$, such that $s \models \sigma$ when s is of type σ.

A classification $\mathcal{C}$ is **boolean** when Σ is closed under boolean connectives, and $\models$ is classical satisfaction inductively defined on the structure of formulae $\phi \in \Sigma$

Classifications Support Information

A **sequent** $\langle \Gamma, \Delta \rangle$ is a pair of sets $\Gamma, \Delta \subseteq \Sigma$

- $\Gamma \models_s \Delta$ iff, when $s \models \gamma$ for **all** $\gamma \in \Gamma$, then $s \models \delta$ for **some** $\delta \in \Delta$

- *Theorem*: For situations $S' \subseteq S$, the theory of S' given by $\{\langle \Gamma, \Delta \rangle \mid \Gamma \models_{S'} \Delta\}$ is **regular**, meaning it satisfies:

Identity:	$\sigma \models \sigma$	$(\sigma \in \Sigma)$
Weakening:	if $\Gamma \models \Delta$ then $\Gamma, \Gamma' \models \Delta, \Delta'$	$(\Gamma, \Gamma', \Delta, \Delta' \subseteq \Sigma)$
Global Cut:	if $\Gamma, \Sigma_0 \models \Delta, \Sigma_1$ for all partitions $\langle \Sigma_0, \Sigma_1 \rangle$ of Σ', then $\Gamma \models \Delta$	$(\Gamma, \Delta, \Sigma' \subseteq \Sigma)$

Information Contexts

A **local logic** L is a tuple $\langle \mathcal{C}, \vdash, N \rangle$ where

- $\mathcal{C}$ is a classification,
- $\vdash \subseteq \mathcal{P}ow(\Sigma_{\mathcal{C}}) \times \mathcal{P}ow(\Sigma_{\mathcal{C}})$ is a regular consequence relation on the types of $\mathcal{C}$, and
- $N \subseteq S$ are called "normal situations", i.e. situations the theory $\vdash$ is "about". Thus, $\Gamma \models_N \Delta$ when $\Gamma \vdash \Delta$

L is **sound** when $N = S_A$

L is (locally) **complete** iff $\Gamma \vdash \Delta$ whenever $\Gamma \models_N \Delta$ (*globally* when $N = S_A$)

Information Contexts

Properties

Given two contexts $L_1 = \langle \mathcal{C}, \vdash_1, N_1 \rangle$ and $L_2 = \langle \mathcal{C}, \vdash_2, N_2 \rangle$

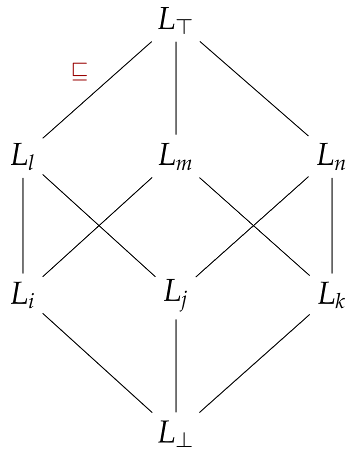
- $L_1 \sqsubseteq L_2$ iff $\vdash_1 \subseteq \vdash_2$ and $N_1 \supseteq N_2$
- $\langle \mathsf{CXT}(\mathcal{C}), \sqsubseteq \rangle$ forms a complete **lattice** of local logics, with meet and join operations

  a. $L_1 \sqcap L_2 =_{def} \langle \mathcal{C},\ Reg(\vdash_1 \cap \vdash_2),\ N_1 \cup N_2 \rangle$

  b. $L_1 \sqcup L_2 =_{def} \langle \mathcal{C},\ Reg(\vdash_1 \cup \vdash_2),\ N_1 \cap N_2 \rangle$

Local Logics on $\mathcal{C}$

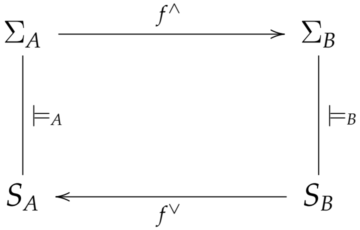
$\langle \mathsf{CXT}(\mathcal{C}), \sqsubseteq \rangle$



Information Flow between Classifications

Given classifications A and B, an **infomorphism** $f : A \rightleftarrows B$ from A to B is a pair of contravariant functions $\langle f^\wedge, f^\vee \rangle$ such that:

$$\forall s \in S_B,\ \sigma \in \Sigma_A : f^\vee(s) \models_A \sigma \text{ iff } s \models_B f^\wedge(\sigma)$$

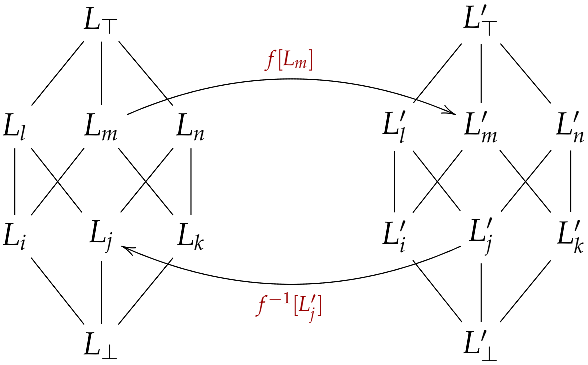


Moving Logics over Infomorphisms

Given an infomorphism $f : A \rightleftarrows B$, and local logics $L_A = \langle A, \vdash_A, N_A \rangle$ and $L_B = \langle B, \vdash_B, N_B \rangle$:

- $f[L_A] = \langle B, \vdash'_A, N'_A \rangle$, where
  - $a.\ \vdash'_A = \{\langle f^\wedge(\Gamma), f^\wedge(\Delta) \rangle \mid \Gamma \vdash_A \Delta\}$
  - $b.\ N'_A = \{s \in S_B \mid f^\vee(s) \in N_A\}$
- $f^{-1}[L_B] = \langle A, \vdash'_B, N'_B \rangle$, where
  - $a.\ \vdash'_B = \{\langle \Gamma, \Delta \rangle \mid f^\wedge(\Gamma) \vdash_B f^\wedge(\Delta)\}$
  - $b.\ N'_B = \{f^\vee(s) \in S_A \mid s \in N_B\}$

Moving Logics over Infomorphisms



Reasoning Across Contexts

$$\frac{\Gamma \vdash_A \Delta}{f^\wedge(\Gamma) \vdash_B f^\wedge(\Delta)}\ f\text{-Intro} \qquad \frac{f^\wedge(\Gamma) \vdash_B f^\wedge(\Delta)}{\Gamma \vdash_A \Delta}\ f\text{-Elim}$$

- f-**Intro**: reasoning **in** the direction of f
  - Sound
  - Complete when $f^\vee$ is surjective ($S_A = f^\vee(S_B)$)
- f-**Elim**: reasoning **against** the direction of f
  - Sound when $f^\vee$ is surjective
  - Complete

- Institutions for Agent Communication

- Formalizing Institutions
  Channel Theory
  Institutions in Channel Theory

First Approximation

A given event or situation *s* supports an institutional fact *Y* in a context *C* when:

i. *s* has a physical property *X*, such that

ii. *X* is a proxy for *Y* by virtue of some institution *I*, where

iii. "*X counts as Y in context C*" is a constitutive rule of *I*.

Example: Classifying "Physical" Reality

A boolean classification $\mathcal{C}_P = \left\langle S_p, \Sigma_P, \models_P \right\rangle$ of physical reality (i.e. *brute facts*), where

- S_P is a non-empty set of "real-world" situations
- Σ_P is (at least) a propositional language built from types $\{\mathsf{raiseHand(x)}, \mathsf{scratchHead(y)}, \ldots\}$
- For $s \in S_P$, $\sigma \in \Sigma_P$, $s \models \sigma$ when σ is true in s
- E.g. $s \models_P \mathsf{scratchHead(x)} \vee \neg\mathsf{scratchHead(x)}$

Classifying "Social" Reality

Another classification $\mathcal{C}_S = \langle S_S, \Sigma_S, \models_S \rangle$ modeling the *social* dimension, where

- S_S is a non-empty set of social situations
- Σ_S is a propositional (deontic?) language built from types $\{\text{makeBid(x)}, \text{purchase(x,y)}, \ldots\}$
- e.g. $s \models_S \text{makeBid(x)} \wedge \text{purchase(x,y)}$
- $\text{CXT}(\mathcal{C}_S)$ is the realm of **normative rules**

$$\text{makeBid(x,y)} \vdash_{AUC} \text{C}_\text{x}(\text{purchase(x,y)})$$

Formalizing Institutions

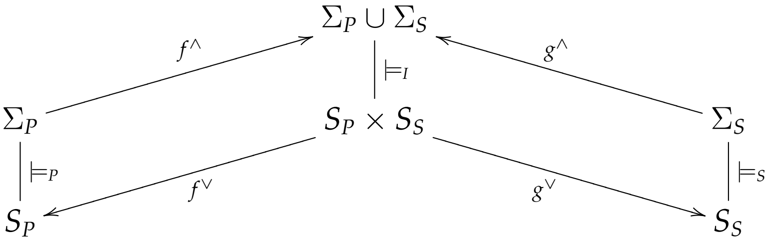
A channel classification $\mathcal{C}_I$ connecting $\mathcal{C}_P$ and $\mathcal{C}_S$

- **Institutions** as theories on $\mathcal{C}_I$ about how to align $\mathcal{C}_p$ and $\mathcal{C}_S$

Formalizing Institutions

A channel classification $\mathcal{C}_I$ connecting $\mathcal{C}_P$ and $\mathcal{C}_S$

- **Institutions** as theories on $\mathcal{C}_I$ about how to align $\mathcal{C}_p$ and $\mathcal{C}_S$



Alignment Semantics

$\mathcal{C}_I = \langle S_I, \Sigma_I, \models_I \rangle$ as the **sum classification** $\mathcal{C}_P + \mathcal{C}_S$

- A set of connection tokens $S_I = S_P \times S_S$
- Disjoint union $\Sigma_I = \Sigma_P \cup \Sigma_S$
- For $\langle s_0, s_1 \rangle \in S_I$:

  $\langle s_0, s_1 \rangle \models_I \sigma_P$ iff $s_0 \models_P \sigma$

  $\langle s_0, s_1 \rangle \models_I \sigma_S$ iff $s_1 \models_S \sigma$

…with straightforward infomorphisms f and g, e.g.

$$f^{\wedge}(\sigma) = \sigma_P$$
$$f^{\vee}(\langle s_0, s_1 \rangle) = s_0$$

Institutions as Local Logics on $\mathcal{C}_I$

Count-as conditionals defined in terms of constraints:

$$X \Rightarrow_C Y \quad \text{iff} \quad f^\wedge(X) \vdash_{L_C} g^\wedge(Y)$$

- raiseHand(x) $\Rightarrow_{Auc}$ makeBid(x) iff

$$f^\wedge(\text{raiseHand(x)}) \vdash_{L_{Auc}} g^\wedge(\text{makeBid(x)})$$

- raiseHand(x) $\Rightarrow_{Vot}$ vote(x) iff

$$f^\wedge(\text{raiseHand(x)}) \vdash_{L_{Vot}} g^\wedge(\text{vote(x)})$$

Logical Properties of the Count-as Relation

Generally accepted desirables:

- Left / right logical equivalence
  $(A \Rightarrow_c B) \wedge (A \equiv A') \vdash A' \Rightarrow_c B$ / $(A \Rightarrow_c B) \wedge (B \equiv B') \vdash A \Rightarrow_c B'$
- Left disjunction
  $(A \Rightarrow_c B) \wedge (A' \Rightarrow_c B) \vdash A \vee A' \Rightarrow_c B$
- Right conjunction
  $(A \Rightarrow_c B) \wedge (A \Rightarrow_c B') \vdash A \Rightarrow_c B \wedge B'$

Non-desirables:

- Left and right logical consequence
  $A \Rightarrow_c B \wedge A \supset A' \nvdash A' \Rightarrow_c B$ / $A \Rightarrow_c B \wedge B \supset B' \nvdash A \Rightarrow_c B'$
- Left strengthening and right weakening
  $A \Rightarrow_c B \nvdash (A \wedge A') \Rightarrow_c (B \vee B')$

Count-as Conditionals

Nonmonotonicity

Problems with Weakening

$$\text{raiseHand(x)} \Rightarrow_{Auc} \text{makeBid(x)}$$

$$\text{raiseHand(x)}, \text{scratchHead(x)} \not\Rightarrow_{Auc} \text{makeBid(x)}$$

Thank You

- J. Barwise and J. Seligman.
  Information Flow. The Logic of Distributed Systems.
  Cambridge Tracts in Theoretical Computer Science, Cambridge University Press, 1997.

- N. Fornara, F. Viganò, and M. Colombetti.
  Agent communication and institutional reality.
  In *International Workshop on Agent Communication AC2004*, pages 1–17, 2004.

- J. R. Searle.
  Speech Acts: An Essay in the Philosophy of Language.
  Cambridge University Press, Cambridge, 1969.