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Channels for Agent Communication

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- 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:

$\langle i, \text{inform}(j, \phi) \rangle$

[**FP**] $B_i\phi \wedge \neg B_i(B_j\phi \vee B_j\neg\phi)$

[**RE**] $B_j\phi$

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. “ $\text{inform}(i, j, \phi) \rightarrow \mathcal{O}_i(\text{defend}(i, j, \phi))$ ”
- ▶ Constitutive rules
 - **Establish** *new* social realities
 - Often classificatory in nature:
“ $\text{assert}(i, j, \phi) \rightarrow \text{inform}(i, j, \phi)$ ”

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”

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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

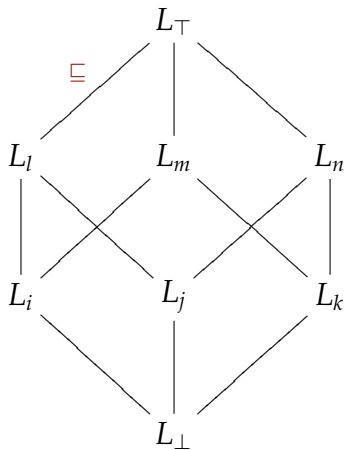
Properties

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 $N_1 \supseteq N_2$
- ▶ $\langle \text{CXT}(\mathcal{C}), \sqsubseteq \rangle$ forms a complete **lattice** of local logics, with meet and join operations

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

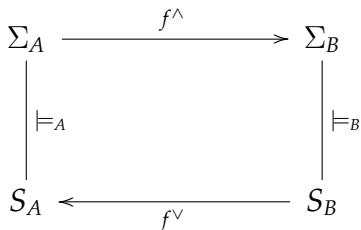
$$b. L_1 \sqcup L_2 =_{\text{def}} \langle \mathcal{C}, \text{Reg}(\vdash_1 \cup \vdash_2), N_1 \cap N_2 \rangle$$

Local Logics on \mathcal{C} $\langle \text{CXT}(\mathcal{C}), \sqsubseteq \rangle$ 

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:

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

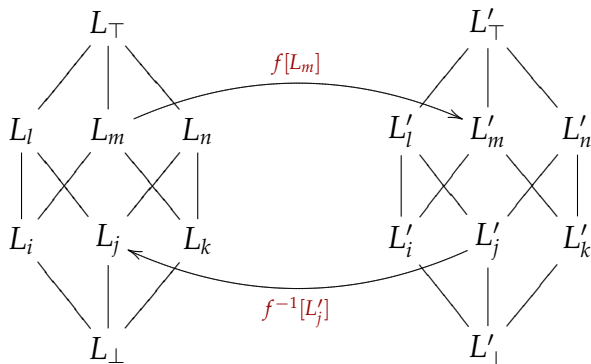


Moving Logics over Infomorphisms

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

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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 $\mathcal{C}_P = \langle S_P, \Sigma_P, \models_P \rangle$ 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 $\{\text{raiseHand}(x), \text{scratchHead}(y), \dots\}$
- ▶ For $s \in S_P, \sigma \in \Sigma_P, s \models \sigma$ when σ is true in s
- ▶ E.g. $s \models_P \text{scratchHead}(x) \vee \neg \text{scratchHead}(x)$

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 $\{\text{makeBid}(x), \text{purchase}(x,y), \dots\}$
- ▶ e.g. $s \models_S \text{makeBid}(x) \wedge \text{purchase}(x,y)$
- ▶ $\text{CXT}(\mathcal{C}_S)$ is the realm of **normative rules**

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

Formalizing Institutions

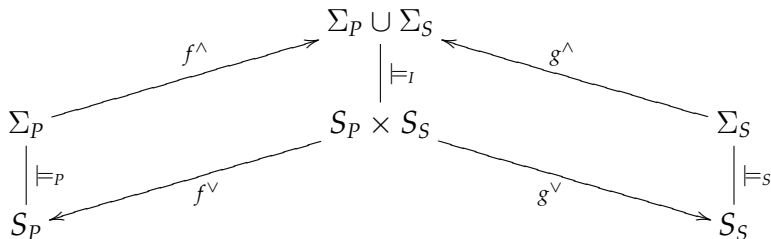
A channel classification \mathcal{C}_I connecting \mathcal{C}_P and \mathcal{C}_S

- ▶ **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 $\langle s_0, s_1 \rangle \in S_I$:

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

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

... 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:

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

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

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

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

$$(A \Rightarrow_c B) \wedge (A \equiv A') \vdash A' \Rightarrow_c B \quad / \quad (A \Rightarrow_c B) \wedge (B \equiv B') \vdash A \Rightarrow_c B'$$

- ▶ 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

$$A \Rightarrow_c B \wedge A \supset A' \not\vdash A' \Rightarrow_c B \quad / \quad A \Rightarrow_c B \wedge B \supset B' \not\vdash A \Rightarrow_c B'$$

- ▶ Left strengthening and right weakening

$$A \Rightarrow_c B \not\vdash (A \wedge A') \Rightarrow_c (B \vee B')$$

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



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