Logics of Context for Multi-Agent Systems

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C&O @ ECAI’08, July 2008
Introduction
Propositions need contexts

problem of generality of propositions [McCarthy]:
propositions never absolutely true: always in context

- “Rio is in Greece”
  - true in the context of Greece / in the context of ECAI’08 / in the context of A.’s beliefs / . . .
  - false in ‘non-greek’ contexts / in the context of Lula’s beliefs / . . .

- indexicality: “the bridge is on the right” [Kaplan]

- $\exists$ function $ctxts(.)$ s.th. $ctxts(\varphi) =$ set of contexts associated to $\varphi$
Contexts are useful

**principle of locality of computation [Giunchiglia]:**

\[ \Delta \models \varphi \iff \Delta_\varphi \models \varphi \]

- \( \Delta_\varphi = \text{part of } \Delta \text{ relevant for } \varphi \)
  
  \[ = \{ \psi \in \Delta : \text{ctxts}(\psi) \cap \text{ctxts}(\varphi) \neq \emptyset \} \]

- benefits:
  - local, efficient computation
  - paradigm for distributed systems & multi-agent systems (MAS)
    - P2P inference systems [Chatalic, Goasdoué, Rousset et col.]
What is a context?

- in general: no commonly accepted definition
- in multi-agent systems: truth relative to the context of an agent
  - context = state of an agent
- logical form: "RioGreece is true in context i"
- ∃ several converging logics . . .
Existing logics of context

- different notations:
  - “ist(\(i, \varphi\))” Propositional Logics of Context (PLC)
    [McCarthy 93, McCarthy, Buvac et col.]
  - “\(i:\varphi\)” Multi-Context Systems (MCS)
    [Giunchiglia & Serafini 94, Giunchiglia, Serafini et col.]
  - “\(\Box i\varphi\)” modal logics, in particular for knowledge and belief
    [Hintikka 62]

- similar logics:
  - PLC can be embedded into MCS [Bouquet & Serafini 01]
  - MCS can be embedded into modal logic [Massacci 96]
  - differ in complexity [Massacci 96, Roelofsen & Serafini 06]
    - satisfiability problem is in NP for context logic
    - satisfiability problem is PSPACE complete for most modal logics
Overview of talk

take serious the ‘truth in context’ paradigm, in MAS framework

- analysis of acceptance in context
  - acceptance \( \neq \) belief
  - logic of acceptance in context
  - towards a basic ontology of institutions and interaction

- ‘contexts viewed from inside’
  - internal perspective \( \neq \) external perspective
  - logic of internal perspective

- contexts and modularity
Acceptance in context
Belief vs. acceptance

context = an agent’s *acceptance state*

- usually in MAS:
  context = an agent’s belief state [Giunchiglia & Serafini 96]

- acceptance ≠ belief:
  - belief = attitude constitutively aimed at the *truth* of a proposition
  - acceptance = output of a “decision to treat \( \varphi \) as true in one’s utterance and action” [Hakli 06]
Belief vs. acceptance (ctd.)

<table>
<thead>
<tr>
<th>belief</th>
<th>acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>not subject to will</td>
<td>voluntary</td>
</tr>
<tr>
<td>aims at truth</td>
<td>aims at utility</td>
</tr>
<tr>
<td>shaped by evidence</td>
<td>need not be shaped by evidence</td>
</tr>
<tr>
<td>has degrees</td>
<td>is binary</td>
</tr>
<tr>
<td>context-independent</td>
<td>context-dependent</td>
</tr>
</tbody>
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[Engel 99, Meijers 99, 02, 03, Hakli 06, Gaudou et al. 08]
What is a context of acceptance?

1. As an Airbus executive, N.F. accepts (for political reasons) that the A380 series will be delivered on time (and acts in consequence).
   - As a stock-owner, N.F. accepts (for prudential reasons) that A380 will not be ready on time (and acts in consequence).
   - Privately, N.F. doesn’t know.

2. In the context of the court, the lawyer accepts the innocence of his client.
   - Privately he believes the contrary.

3. Andreas qua European does not accept that Dollar is the official means of exchange.

⇒ social contexts
Social contexts are institutional contexts

social context = institutional context

- institution = rule-governed social practice [Tuomela]
- informal institutions = institutions in a large sense
  - examples: language [Wittgenstein, Searle], games [Wittgenstein], customs [von Wright], group of friends, autonomous MAS, . . .
  - spontaneous norm-change
    - agents able to create and manage institutions by themselves
- formal institutions = legal institutions [Sartor & Rotolo]
  - examples: Airbus Industries, trial, ECCAI, Monsanto, . . .
  - legislators establish and change norms
Acceptance in context: logical form

from now on:

MAS context  =  ⟨agent, social context⟩

- logical form of propositions in context:
  
  $i : x : \varphi$

  “while identifying himself with institution $x$, $i$ accepts that $\varphi$”

- for example:
  
  $\begin{align*}
  &\text{NF: Airbus: A380Ready} \\
  &\text{NF: StockMarket: ¬A380Ready} \\
  &\text{NF: EU: EuroMeansOfExchange} \\
  &\text{¬(NF: priv}_{\text{NF}}\text{: A380Ready)} \land \text{¬(NF: priv}_{\text{NF}}\text{: ¬A380Ready)}
  \end{align*}$
Acceptance and identification with an institution allows to characterize identification with an institution:

- \( i \rangle x \triangleq \perp = \text{“}i \text{ does not identify himself with} \ x\text{“} \)
- \( \neg (i \rangle x \triangleq \perp) = \text{“}i \text{ identifies himself with} \ x\text{“} \)

For example:

- \( \neg NF \rangle Airbus \triangleq \perp \)
- \( \neg NF \rangle StockMarket \triangleq \perp \)
- \( NF \rangle Boeing \triangleq \perp \)
- \( NF \rangle ECCAI \triangleq \perp \)
Belief as acceptance in private context

**Hypothesis:** for every agent $i$, $\exists$ institution $priv_i$
  - ‘$i$’s private institution’
  - acceptance in private context = individual belief
    - $\text{Believes}_i \varphi \overset{\text{def}}{=} i : priv_i : \varphi$

**Properties:**
  - $i$ always identifies himself with his private context $priv_i$:
    - $\models \neg i : priv_i : \bot$
  - mental states are inaccessible to others [Singh, Colombetti]:
    - $\models j : priv_i : \bot$ if $i \neq j$
“The members of the ruling party of Ruritania accept (as such) that the capitalist countries will perish soon.”

\[ \text{PartyMembers} : \text{Ruritania} : \text{CapitalistsPerish} \]

“Individually, none of them really believes so.”

\[ \bigwedge_{i \in \text{PartyMembers}} \neg (i : \text{priv}_i : \text{CapitalistsPerish}) \]

- illustrates that acceptance is independent from belief
- in particular, group acceptance does not imply individual belief:
  \[ (C : x : \varphi) \land \neg (i : \text{priv}_i : \varphi) \] consistent
Group acceptance and identification with a group

particular case: (informal) institution = set of agents

- \( \neg (C : D : \bot) \) = “group C identifies itself with D”
- \( \neg (C : C : \bot) \) = “group C is a constituted group”
- \( \neg (C : C : \bot) \land (C : C : \varphi) \) = “group C believes \( \varphi \)”
  - \( \text{Believes}_i \varphi = i : \text{priv}_i ; \varphi = i : \{i\} : \varphi \)
- a group can only identify with a supergroup:
  - \( C : D : \bot \) if \( C \not\subseteq D \)

[Gilbert 89]
Language: formal definition

- **basic sets:**
  - $Atms = \text{proposition symbols}$
  - $Agts = \text{agent symbols}$
  - $Insts = \text{institution symbols}$

- **BNF:**
  \[
  \varphi ::= p \mid \neg \varphi \mid \varphi \land \varphi \mid C : x : \varphi
  \]
  where $p \in Atms$, $C \subseteq Agts$, and $x \in Insts$

- **allows for nested acceptance operators:**
  - $C : x : (\bigwedge_{i \in C} i : x : \varphi)$
Semantics

- model: $M = \langle W, R, V \rangle$, where
  - $W$ nonempty set (possible worlds)
  - $R : (2^{Agts} \times \text{Insts}) \to 2^{W \times W}$ (accessibility relation)
  - $V : \text{Atms} \to 2^{W}$ (valuation)

- constraints on $R$:
  - if $v \in R_{C,x}(u)$ then $R_{C \cup C',x}(v) = R_{C \cup C',x}(u)$ (introspection)
  - if $R_{C \cup C',x}(u) \neq \emptyset$ then $R_{C,x}(u) \neq \emptyset$ (monotony)
  - if $R_{C \cup C',x}(u) \neq \emptyset$ then $R_{C,x}(u) \subseteq R_{C \cup C',x}(u)$ (inclusion)
  - if $v \in R_{C,x}(u)$ then $\exists \ i \in C$ such that $v \in R_{i,x}(v)$ (unanimity)

- truth conditions:
  - $M, w \models C : x : \text{RioGreece}$ iff $\forall w' \in R_{C,x}(w)$, $M, w \models \text{RioGreece}$

- satisfiability, validity, logical consequence: defined as usual
inference rules and axioms of modal logic K

supplementary axioms:

- $(C \cup C': x: \varphi) \rightarrow C: x: (C \cup C': x: \varphi)$  
  (pos. introspection)

- $\neg(C \cup C': x: \varphi) \rightarrow C: x: \neg(C \cup C': x: \varphi)$  
  (neg. introspection)

- $(C: x: \bot) \rightarrow (C \cup C': x: \bot)$  
  (monotony)

- $(\neg(C \cup C': x: \bot) \land (C \cup C': x: \varphi)) \rightarrow C: x: \varphi$  
  (inclusion)

- (but not $C \cup C': x: \varphi \rightarrow C: x: \varphi$!)

- $C: x: ((\bigwedge_{i \in C} i: x: \varphi) \rightarrow \varphi)$  
  (unanimity)

consistency, theoremhood, deduction: defined as usual

complete & decidable [Lorini et al., in progress]
Group acceptance and common belief

- Group acceptance implies individual acceptance:
  \[(C:x:\varphi) \land \neg(C:x:\bot) \rightarrow \bigwedge_{i \in C}(i:x:\varphi)\]

- A group member cannot be wrong about a group acceptance:
  \[(i:x:(C:x:\varphi)) \rightarrow (C:x:\varphi)\]
  ★ due to public nature of acceptance

- \((\text{Believes}_i \text{CommonBelief}_C \varphi) \nrightarrow \text{CommonBelief}_C \varphi\)
Grounding institutions on acceptance
Institutions require acceptance

[Hart 92, Conte et al. 98, Conte & Dignum 01, Boella & van der Torre 07]

The existence of a norm in an institution depends on the recognition and acceptance of the norm by the members of the institution.

- ‘acceptance *qua* member of an institution’:
  - $C : x : \varphi \land \neg C : x : \bot$

- institutional fact
  - $x : \varphi$ def $\bigwedge_{C \subseteq \text{Agts}} (C : x : \varphi)$
  - fact holding in context of an institution [Searle 69, Jones & Sergot 96]
  - fact that is accepted by all members of the institution
Institutional facts

“within institutional context \( x \), it is the case that \( \varphi \)”: 

\[
  x: \varphi \overset{\text{def}}{=} \bigwedge_{C \subseteq \text{Agts}} (C:x:\varphi)
\]

- \( EU: \text{EuroMeansOfExchange} \)

“\( \varphi \) is universally accepted as true”: 

\[
  \forall: \varphi \overset{\text{def}}{=} \bigwedge_{x \in \text{Insts}} x: \varphi
\]

- \( EU: \text{EuroMeansOfExchange} \land \neg(\forall: \text{EuroMeansOfExchange}) \)
Institutions have rules

[Tuomela]:

institution = rule-governed social practice

- rules = constitutive rules + regulative rules
- constitutive rules:
  - “nodding counts as agreeing”;
  - “In the USA, a green piece of paper with a certain shape, color, signature, etc., counts as a 1-Dollar-bill” [Searle 69]
- regulative rules:
  - “it is obligatory . . .”,
  - “it is forbidden . . .”,
  - “it is permitted . . .”
Defining constitutive rules

\[ \phi \xrightarrow{x} \psi \overset{\text{def}}{=} x : (\phi \rightarrow \psi) \land \neg \forall : (\phi \rightarrow \psi) \]

- “\(\phi\) counts as \(\psi\) in institutional context \(x\)”
- negative condition \(\neg \forall : (\phi \rightarrow \psi)\) avoids validity of \(\phi \xrightarrow{x} \top\)
- example: \textit{nodding} \(\xrightarrow{x}\) \textit{yes}, where \(x\) = ‘western Europe gestural language’
  - \(x : (\textit{nodding} \rightarrow \textit{yes})\)
  - \(\neg \forall : (\textit{nodding} \rightarrow \textit{yes})\)
    - because \(\neg y : (\textit{nodding} \rightarrow \textit{yes})\) for \(y\) = ‘Bulgarian gestural language’
- grounded on collective acceptance [Gaudou et al., AAMAS’08]
Defining regulative rules

- violation atom $\text{Viol}$: true in violation states [Anderson; Meyer]
- $\text{Oblig}_x \varphi = \neg \varphi \triangleright \text{Viol}$
  - “$\varphi$ is obligatory within institutional context $x$”
  - $\text{Oblig}_{\text{UK}}(\text{driveCar} \neg \text{driveRight}) = \text{normative fact in the UK}$
- $\text{Perm}_x \varphi = \neg \text{Oblig}_x \neg \varphi$
  - “$\varphi$ is permitted within institutional context $x$”
Institutions and acceptance: summary

- notion of collective acceptance explains how formal institutions can be created from informal institutions
  - primitive concepts: group acceptance + violation constant
  - from collective acceptance to individual acceptance: inclusion axiom
  - from individual acceptance to collective acceptance: unanimity axiom
    - other principles possible (majority; legislators)
- towards a formal ontology of institutions and organizations
- missing:
  - powers and delegation
  - communication
    - acceptance applies here, too...
Mentalistic vs. social semantics for speech acts

Problem [Singh, Colombetti]:

postconditions of \( \text{info}_{i,j} \text{RioGreece} \) in terms of beliefs?

- \( \text{Believes}_j \text{RioGreece} \)?
  - \( j \) might doubt \( i \)’s competence
- \( \text{Believes}_j \text{Believes}_i \text{RioGreece} \)?
  - \( j \) might doubt \( i \)’s sincerity
- \( \text{Believes}_j \text{Believes}_i \text{Believes}_j \text{RioGreece} \)?
  - …
- \( \text{Believes}_i \text{Believes}_j \text{Believes}_i \text{RioGreece} \)?
  - …
- …
Social approaches to ACL semantics

- problem: $j$ cannot access $i$’s mental state, and vice versa
  - mentalistic approaches agent communication languages are doomed to fail [Singh, Colombetti]

- idea: replace private belief by (public) commitment
  - postcondition of $\text{info}_{i,j} \text{RioGreece} = i$ committed towards $j$ that $\text{RioGreece}$ is true
  - commitments must be consistent: ‘stick to what you said’ (even if it’s a lie)
    - $i$ should not perform $\text{info}_{i,j} \neg \text{RioGreece}$ any more

- can be captured in the logic of group acceptance
  - commitment = public acceptance
  - $\text{Hearers}: x: (\text{Speaker}: x: \varphi)$
    - $x = \text{context of conversation}$
Commitment and acceptance

- FIPA-ACL speech acts [Gaudou et al. ECAI’06]
  - info\(_{i,j}\varphi\)
  - queryYN\(_{i,j}\varphi\)

- Walton & Krabbe’s dialogue games [Gaudou et al. ENTCS 07]
  - strong commitment \(SC(i, j, x, \varphi) = \{i, j\} : x : (\{i\} : x : \varphi)\)
  - weak commitment \(WC(i, j, x, \varphi) = \{i, j\} : x : \neg(\{i\} : x : \neg\varphi)\)
  - pre- and postconditions of PPD\(_0\) speech acts
‘Contexts from inside’: the logic
External vs. internal perspective

- MCS, PLC, epistemic logic: external perspective
- epistemic model: $M = \langle W, R, V \rangle$, where
  - $W$ nonempty set (possible worlds)
  - $R : Agts \rightarrow 2^{W \times W}$ (accessibility relation)
  - $V : Atms \rightarrow 2^W$ (valuation)
- conditions on every $R_i$:
  - serial, transitive, Euclidian (belief)
  - reflexive, transitive, Euclidian (knowledge)
- language: $\varphi ::= p \mid \neg \varphi \mid \varphi \land \varphi \mid \text{Believes}_i \varphi$
- formulas are evaluated in pointed models $\langle M, w \rangle$:
  - $M, w \models \text{RioGreece}$ iff $w \in V(\text{RioGreece})$
  - $M, w \models \text{Believes}_i \text{RioGreece}$ iff $\forall w' \in R_i(w), M, w' \models \text{RioGreece}$
pointed model $\langle M, w \rangle =$ point of view of the modeler
  
  - only one actual (‘real’) world $w$
  - either $M, w \models Rio\text{Greece}$ or $M, w \models \neg Rio\text{Greece}$
    
    ★ does not allow for the modeler’s ignorance
    ★ external modeler has perfect knowledge
  
  - mismatch: cf. set of possible worlds $R_i(w)$ for each agent $i$

limited applicability [Aucher 08]
  
  - modelling MAS ‘as a whole’: OK
  - modelling & implementing individual agents: ??
  - multi-agent belief revision: ??

wanted:
  
  - $\varphi =$ “modelling agent believes that $\varphi$”
  - logic of modelling agent $i$ ($\models^i$)
  - we expect: $\models^i \varphi \leftrightarrow \text{Believes}_i \varphi$
Internal perspective

semantics:

- same epistemic models: \( M = \langle W, R, V \rangle \)
- same truth conditions: . . .
- validity, logical consequence: formulas are evaluated in multipointed \( i \)-models \( \langle M, W_a \rangle \), where
  - \( W_a \subseteq W \) set of actual worlds (modelling agent \( i \)'s uncertainty)
  - for every \( w_a \in W_a \), \( W_a = R_i(w_a) \)
- logical consequence
  - \( \varphi \models^i \psi \) iff for all multipointed \( i \)-models \( \langle M, W_a \rangle \):
    - if \( M, w \models \varphi \) for all \( w_a \in W_a \), then \( M, w \models \psi \) for all \( w_a \in W_a \)
properties:

- \( \models^i \varphi \iff \models^{ext} \text{Believes}_i \varphi \)
- \( \models^i p \leftrightarrow \text{Believes}_i p \)
- invalid:
  - \( \not \models^i p \rightarrow \text{Believes}_j p, \text{for } j \neq i \)
  - \( \not \models^i \text{Believes}_j p \rightarrow p, \text{for } j \neq i \)
  - \( p \not \models^i \text{Believes}_j p \text{ for } j \neq i \)
  
axiomatization [Aucher 08]

- \( \vdash^i \text{Believes}_i \varphi \rightarrow \varphi \)
- if \( \vdash^{ext} \varphi \) then \( \vdash^i \varphi \)
- if \( \vdash^i \varphi \) and \( \vdash^i \varphi \rightarrow \psi \) then \( \vdash^i \psi \)

added value: straightforward extension of AGM belief revision to MAS [Aucher 08]

- view multipointed model as set of multiagent possible worlds
Contexts and modularity
From contexts to modularity

- principle of locality: instead of $\Delta \models \varphi$, compute $\Delta\varphi \models \varphi$
- how can one avoid recomputing a new $\Delta\varphi$ for every $\varphi$?
- preprocess $\Delta$:
  - replace $\Delta$ by a set $\{\Delta_1, \ldots, \Delta_n\}$ such that
    \[ \models \Delta \iff (\Delta_1 \land \ldots \land \Delta_n) \]
  - define selection function $\mu : \langle \Delta, \varphi \rangle \mapsto \{\Delta_1, \ldots, \Delta_n\}$
    such that $\mu(\Delta, \varphi) = \Delta\varphi$
- benefits:
  - conceptually clearer
  - $\{\Delta_1, \ldots, \Delta_n\}$ easier to maintain than monolithic $\Delta$
    - revision, update, merging, . . .
  - cf. software engineering: ‘high cohesion’ & ‘low coupling’
Modularizing by vocabulary splitting

- natural construction: build $\mu(\Delta, \varphi)$ from $\mu^0(\Delta, \text{voc}(\varphi))$

$$
\mu(\Delta, \varphi) \overset{\text{def}}{=} \bigcup_{a \in \text{voc}(\varphi)} \mu^0(\Delta, a)
$$

- find finest splitting of $\text{voc}(\Delta) \overset{\text{def}}{=} \text{finest partition } \{A_1, \ldots, A_n\} \text{ of } \text{voc}(\Delta) \text{ such that } \exists \Delta_1, \ldots, \Delta_n \text{ with:}

  1. $\models \Delta \iff (\Delta_1 \land \ldots \land \Delta_n)$
  2. $\text{voc}(\Delta_i) \subseteq A_i$
  3. for all $\psi$ such that $\text{voc}(\psi) \subseteq A_i$: $\Delta \models \varphi$ iff $\Delta_i \models \varphi$
finest splitting is unique [Parikh 99]
▶ two possible splittings of $p \land (q \lor r)$: $\{\{p, q, r\}\}$ and $\{\{p\}, \{q, r\}\}$
▶ finest: $\{\{p\}, \{q, r\}\}$

normal form for $\Delta$

in propositional logic: can be found by computing prime implicates [Bienvenu et al. 08]

used in relevance-based revision [Parikh 99, Kourousias & Makinson 07, Bienvenu et al. 08]
case of pre-existent modules:

- just check whether $\Delta \cup \Delta'$ is a conservative extension of $\Delta$:
  
  $\Delta \cup \Delta' \models \phi$ iff $\Delta \models \phi$, for all $\phi$ s.th. $\text{voc}(\phi) \subseteq \text{voc}(\Delta)$

[Lutz, Walther & Wolter 07, ..., Herzig & Varzinczak 07]
Conclusion
acceptance in context is a useful concept
  ▶ explains constitutive and regulative rules in institutions
  ▶ provides a commitment-based semantics for agent communication languages
  ▶ cheap alternative to common belief (no induction axiom)

the ‘real’ logic of agents in context should be an internal logic

t.b.d.:
  ▶ investigate properties of acceptance logic
    ★ complexity (conjecture: PSPACE)
    ★ clarify relation with common belief
  ▶ internalize the logic of acceptance
Papers

- logic of group acceptance and group belief
  - [Gaudou, Herzig & Longin ENTCS 06; Gaudou, Herzig & Longin KR 06; Gaudou, Herzig, Longin & Nickles ECAI 06; Gaudou, Longin & Lorini AAMAS 08; Lorini & Longin KR 08; Gaudou, Phd 08]

- logic of internal perspective on belief
  - [Aucher, Phd 08]

- modularity
  - [Herzig & Varzinczak, AiML 06; Herzig & Varzinczak, IJCAI 07; Herzig & Varzinczak, JELIA 07; Varzinczak, Phd 07; Bienvenu, Herzig & Qi, ECAI 08]