Social Performance Measurement for Multiagent Systems

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Motivation

- Multiagent systems (MAS) find their way to industrial and commercial applications
- Measuring their performance becomes increasingly important
- Agent-oriented Software Engineering (AOSE) provides no methods yet
- Motivation for *social performance measurement*:
  - challenge: complexity (decentralisation, emergence, micro-macro)
  - opportunity: exploiting high-level communication between agents
- This talk: first steps and initial results

Overview

Introduction

Introduction

Software Engineering is (among other things) concerned with meeting product requirements, such as

- availability,
- modifiability,
- security,
- usability,
- ...

In *Performance Engineering*, ideally,

- *external attributes* should be derived from
- *internal attributes*

Introduction (II)

In MAS particularly challenging due to

- encapsulation of functionality at agent-level,
- adaptive agents in dynamic environments,
- complex interactions between computational sub-processes,
- emergent (unforeseen) macro-level phenomena,
- potential ignorance of agents' internal functionalities.

➡ lack of work on performance measurement

Introduction (III)

Observation:
MAS exhibit certain properties that are actually *advantageous* in the development of measures of internal attributes.

1. They are (usually) based on deliberative, knowledge-based (i.e. symbolically operating) agents.
2. Agents in MAS (usually) communicate in high-level languages such as KQML or FIPA-ACL.

Principles of Social Performance Measurement

Social Performance Measurement (I)

Idea of social performance measurement: To exploit

(a) the existing *layer of ongoing, symbolic communication* in the system which

(b) captures the *interactions* between agents

(c) and which is *comprehensible* for humans.

Goals:

- develop simple, easily measurable measures based solely on internal communication data ($\Rightarrow$ social)
- map these to external attributes

Social Performance Measurement (II)

Assumptions:

- MAS exhibit *social properties* that come about from communication processes
- use *communication data* as data material for performance measurement

Communication can be

1. a (textual) message passed between two or more agents or
2. some (physical) action that an agent performs publicly.

Social Performance Measurement (III)

Advantages:

1. By measuring communication we abstract from non-communicative properties of the system ➡ immense reduction of global system complexity
2. We can exploit knowledge-level representations between knowledge-based agents
3. We are able to measure performance in *open systems* (where internal agent data cannot be accessed)

Prerequisite for defining measures: definition of an underlying MAS model.

A Generic MAS Model

A Generic MAS Model

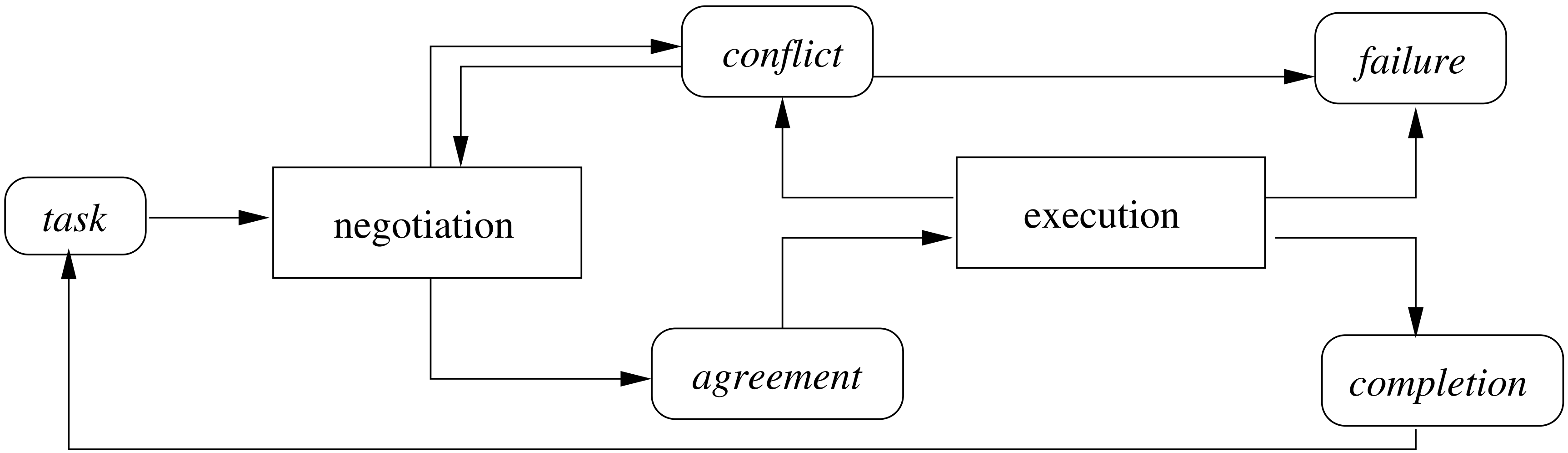
- MAS consists of a set of agents $\mathcal{A} = \{a, b, c, \dots\}$ capable of communicating in a high-level ACL (here: FIPA-ACL)
- Semantics of the ACL are common knowledge and obeyed (benevolence is *not* implied by this)
- MAS has to perform tasks from $\mathcal{T}$ that enter the system at arbitrary points in time
- A real-valued measure

$$d : \mathcal{T} \to \mathbf{R}$$

for the difficulty of the tasks is available

A Generic MAS Model

Top-level processing cycle:



Communication (I)

Subset of FIPA-ACL messages of the form

$$\texttt{performative}(\texttt{sender}, \texttt{receiver}, \texttt{content})$$

where

$$\begin{array}{llll} \texttt{performative} \in & \{\texttt{inform}, & \texttt{inform\_done}, & \texttt{inform\_re} \\ & \texttt{agree}, & \texttt{accept\_proposal}, & \texttt{request}, \\ & \texttt{cfp}, & \texttt{reject\_proposal}, & \texttt{propose}, \\ & \texttt{failure}, & \texttt{not\_understood}, & \texttt{refuse}\} \end{array}$$

We measure all quantities wrt *total number of messages* $TNOM = |M|$ where the set of all messages is

$$M = \{m_1, m_2, \ldots m_n\}$$

Communication (II)

Further definitions:
Partitioning messages according to tasks in

$$M_T = \{m_{T_1}, \ldots m_{T_{n_i}}\}$$

where $T \in \mathcal{T}_{curr}$ (set of processed tasks=$\mathcal{T}_{curr} \subseteq \mathcal{T}$) such that

$$M = \biguplus_{T \in \mathcal{T}_{curr}} M_T.$$

Partition tasks into "successfully completed" and "failed" tasks:

$$\mathcal{T}_{curr} = \mathcal{T}_{succ} \uplus \mathcal{T}_{failed}$$

Defining Social Performance Measures

Basic Performance Measures (I)

Very simple: counting messages and message types

1. *MPTD=messages per task and difficulty*:

$$MPTD = \sum_{T \in \mathcal{T}_{curr}} \frac{M_T}{d(T)}$$

2. *fail-fast* version ($0 \leq \alpha \ll \beta \leq 1$):

$$ff\_MPTD = \alpha \cdot \sum_{T \in \mathcal{T}_{succ}} \frac{M_T}{d(T)} + \beta \cdot \sum_{T \in \mathcal{T}_{failed}} \frac{M_T}{d(T)}$$

Basic Performance Measures (II)

Less trivial: we can define *types* of performatives. Assume partition

- $\mathit{Type1} = \{\texttt{request}\}$,
- $\mathit{Type2} = \{\texttt{inform}, \texttt{inform\_done}, \texttt{inform\_ref}\}$
- $\mathit{Type3} = \{\texttt{cfp}, \texttt{propose}\}$
- $\mathit{Type4} = \{\texttt{reject\_proposal}, \texttt{refuse}\}$
- $\mathit{Type5} = \{\texttt{accept\_proposal}, \texttt{agree}\}$
- $\mathit{Type6} = \{\texttt{not\_understood}, \texttt{failure}\}$

➡ We can count occurences of these types

Basic Performance Measures (III)

We obtain as further measure the *mean message type usage* $MMTU$:

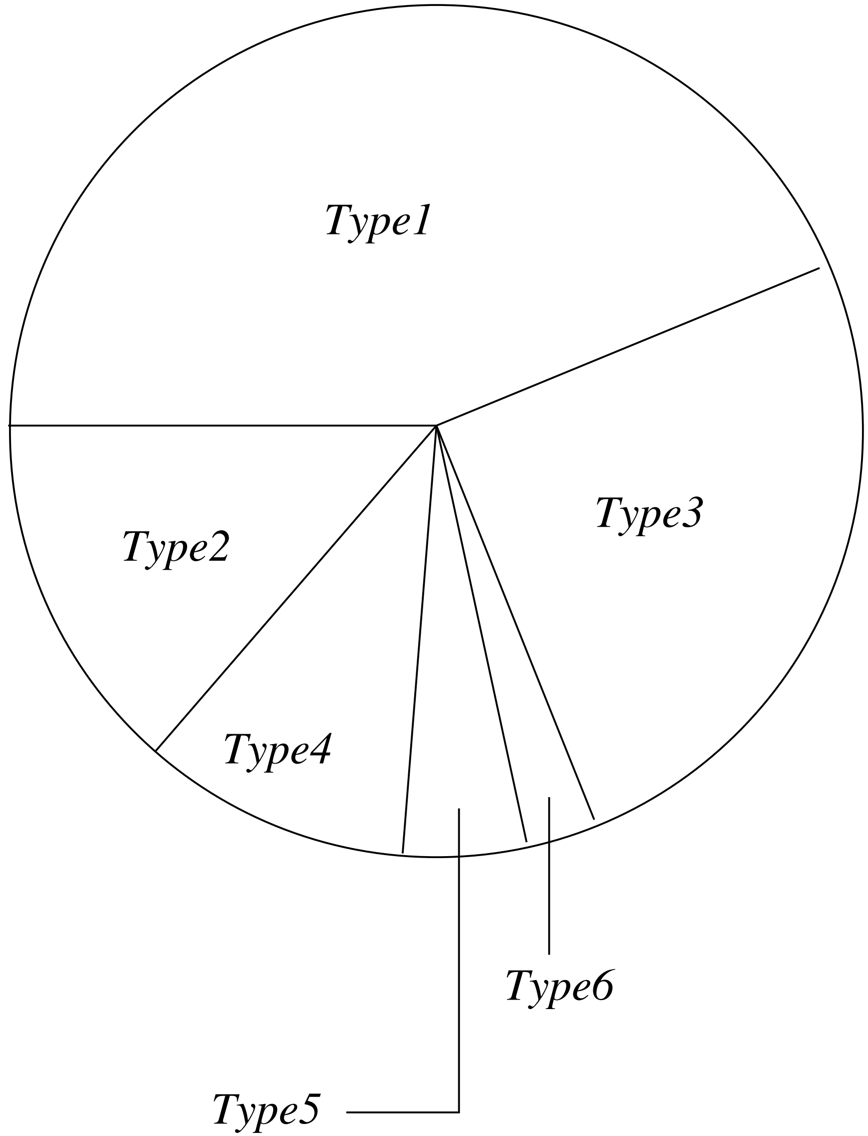
$$MMTU(x) = \frac{1}{|\mathcal{T}_{curr}|} \sum_{T \in \mathcal{T}_{curr}} \frac{|\{m \in M_i | type(m) = x\}|}{|M_T|}$$

for $x \in \{\mathit{Type1}, \ldots, \mathit{Type6}\}$ Trivially $MMTU$ subsumes *mean performative usage*.

Visualisation: *message type partition chart*

Basic Performance Measures (IV)

Example:



Basic Performance Measures (IV)

$MMTU$ can be refined through parametrisation, e.g.

$$MMTU(x, d_1, d_2) = \frac{1}{|\mathcal{T}_{curr}[d_1 : d_2]|} \sum_{T \in \mathcal{T}_{curr}[d_1:d_2]} \frac{|\{m \in M_i | type(m) = x\}|}{|M_T|}$$

where

$$\mathcal{T}_{curr}[d_1 : d_2] = \{T \in \mathcal{T}_{curr} | d_1 \leq d(T) \leq d_2\}$$

Alternatives to difficulty: subsets of agents/agent types, spatial network regions, etc.

Complex Message Patterns (I)

- Simple measures don't allow for *syntactic analysis* of communication

➡ We introduce *message patterns* to abstract from message sequences

- Use variables $A, B, C \ldots$ for messages or message fields (participant, content) and $\star$ as a wildcard symbol
- *Examples:*
  $p = [\texttt{accept}(A, B, \texttt{do}(A, X)), *, \texttt{do}(A, X)]$
  $q = [\texttt{accept}(A, B, \texttt{do}(A, X)), (\neg\texttt{do}(A, X))^n]$
- Define $matches(m, p)$ as a boolean function that matches message sequence m against pattern p

Complex Message Patterns (II)

Pattern-based measures:

- Average length of p:

$$mean\_length(p) = \frac{1}{|\mathcal{T}_{curr}|} \sum_{matches(m,p) \wedge m \in M} length$$

- Task-relative version:

$$mean\_length(p) = \frac{1}{|\mathcal{T}_{curr}|} \sum_{matches(m,p) \wedge m \in M} \frac{length}{|M_{\mathcal{T}}}$$

- Frequency of occurence:

$$frequency(p) = \frac{|\{m \in M | matches(m,p)\}|}{|M|}$$

Complex Message Patterns (III)

Examples:

Let

$$p_a = \bigcap_{Q\in\mathcal{A}}[\texttt{propose}(P,Q,X),*,\texttt{accept}(Q,P,X)],$$
$$p_c = \bigcup_{Q\in\mathcal{A}}[\texttt{propose}(P,Q,X),*,\texttt{reject\_proposal}(Q,P,X))]$$

Then *mean time to agreement* ($MTTA$) and *mean time to conflict* ($MTTC$) can be defined as

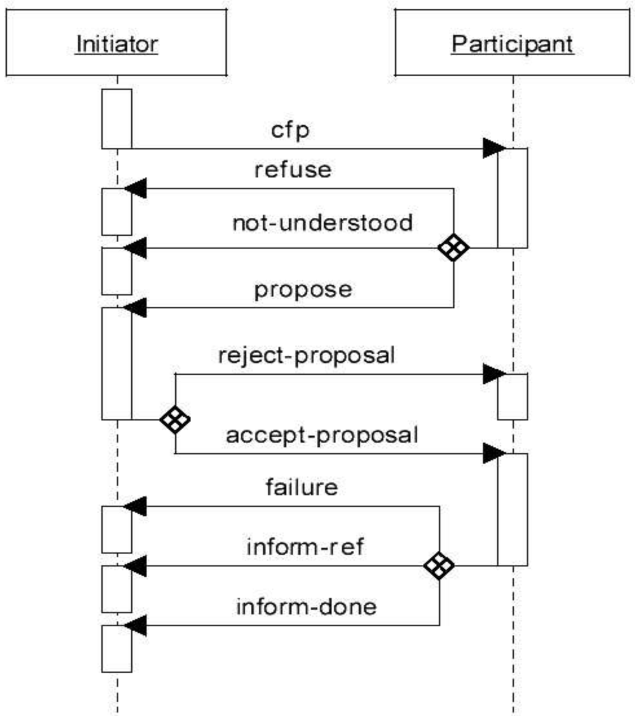
$$MTTA = mean\_length(p_a),$$
$$MTTC = mean\_length(p_c)$$

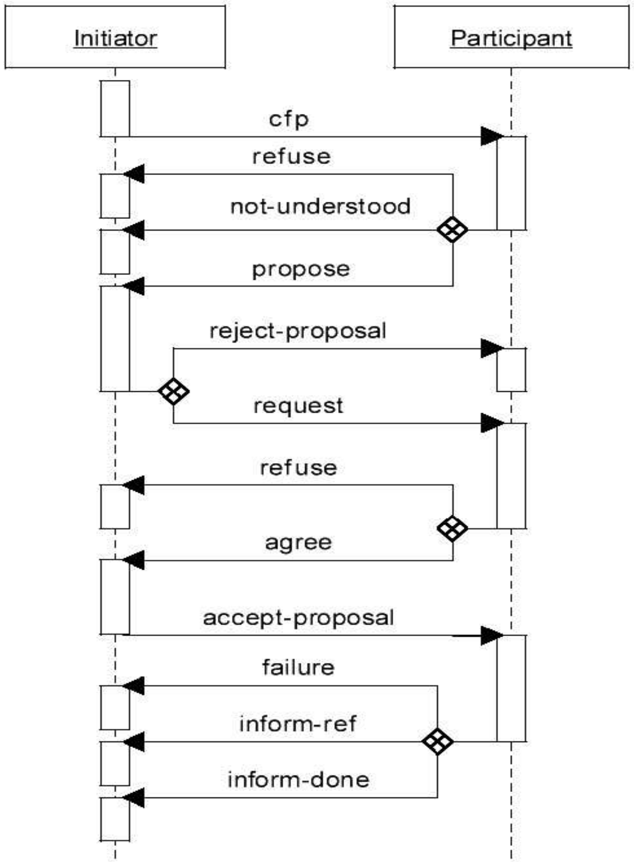
➡ Usefulness of measure definitions in applications depends on *interaction protocols*

Example

Example (I)

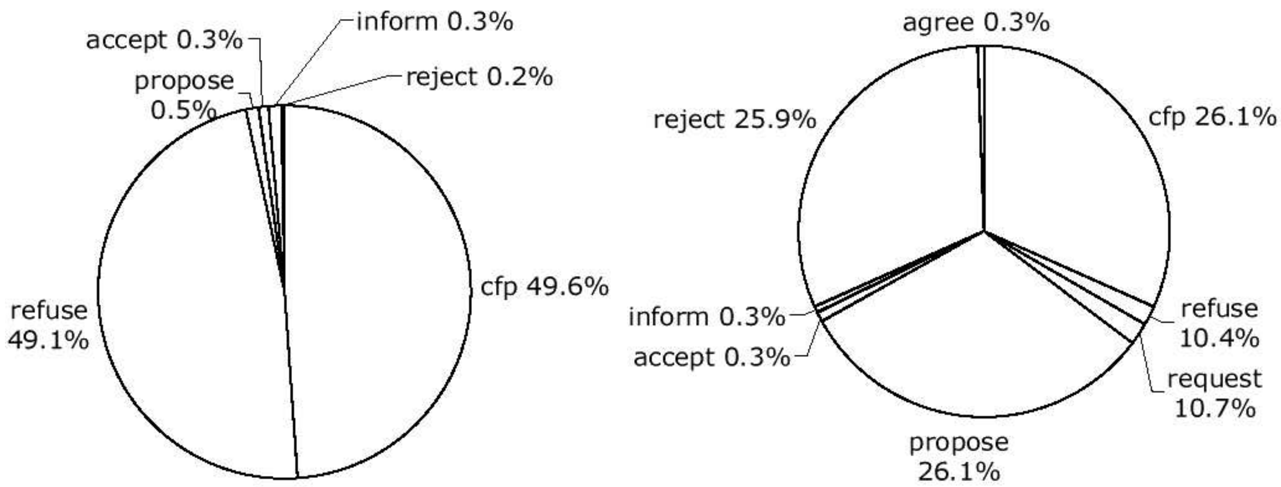
Comparison of the Contract-Net Protocol with the Contract-Net-With-Confirmation Protocol:





Example (II)

- Problem: find internal attribute that best predicts *assigned tasks ratio* (ATR) where ATR(CNP)=0.65 and ATR(CNCP)=1.0
- Evaluation of $TNOM$ (20130/30768 resp.) offers no explanation
- Neither does evaluation of $MMTU$:



Example (III)

- Therefore, we measure the frequency of "rejected unconditional proposals"

  $p = [\texttt{propose}(A, B, X, \{\}), *, \texttt{reject\_proposal}(B, A, X$

- Result: $\mathit{frequency}(p, \mathrm{CNP}) = 0.35$, $\mathit{frequency}(p, \mathrm{CNCP}) = 0.0$

➡ Superiority of CNCP is due to avoidance of "hasty allocations"

➡ Complex measure explained what simple measures couldn't explain

Conclusions & Outlook

Summary

- We suggested *social performance measures* for MAS based on measuring communication processes
- Claimed that these aid complexity reduction while correctly predicting *external* from *internal attributes*
- Main feature: abstraction from intra-agent reasoning processes and physical execution
- Exploiting knowledge-level representations intelligent agents use
- Defined concrete measures, illustrated usefulness with examples

Outlook (I)

- Development and critical evaluation of further generic measures (in particular, standardised patterns)
- Further refinement of measures (advanced statistical methods)
- Definition of qualitative *semantic measures*:
  - classification into processing phases
  - analysing social relationships
  - logical properties - view communication as
    - distributed search
    - constraint satisfaction processes
    - distributed theorem proving

Outlook (II)

- Investigation of relationship external $\leftrightarrow$ internal attributes
- Explore combination of social-level and cognitive-level measurements
- Explore more complex social phenomena (group formation, socialisation, power, authority, etc.)
- Develop tools for automatic measurement of complex MAS

Thank you for your attention!