A note on process ontology for agents

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ABSTRACT

This paper suggests that agents should be seen as processes (occurrents) rather than objects (continuants), and attempts to analyse the consequences of this view. Aspects of process ontology are presented and claims are made that process ontology facilitates understanding agents. The focus is on *communication* rather than *contents* (ontologies), but the former requires the latter.

Keywords

process ontology, communication, agents as processes

1. INTRODUCTION

This paper suggests that agents should be seen as processes (occurrents) rather than objects (continuants), and attempts to analyse the consequences of this view. In particular, basic aspects of process ontology are presented and claims are made that process ontology facilitates understanding agents' properties, attitudes, identity and performatives.

The intention is to focus on those ontological aspects of agency related closer to *communication* (KQML performatives, FIPA communicative actions) than to *content languages* (KIF, FIPA SL). It is the former that differentiates between *agents* and *databases* (even if *temporal knowledge bases*). The latter connects to the problem of describing the structure of the world, i.e., the problem of building (top-level or domain) *ontologies*, with *taxonomies* and *mereotopologies* on its theoretical side,[1] and DL (description logics), OIL, DAML+OIL,[2] KIF and Ontolingua[3] on its implementation side. Both kinds of those ontological aspects of agency are important, but although one can build ontologies without being concerned with agents, there can be no successfully communicating agents without proper content languages and ontologies. Therefore, when exploring the ontological aspects of *communicating* agents (rather than of databases, or information sources/systems), one nevertheless needs to account for those parts of agents that are just databases. Those "just databases" need to be seen however as *temporal* (valid & transaction time; revision & update) *intentional knowledge bases* (beliefs, intentions, goals). Although *process ontology* seems appropriate for describing the whole, dynamic, causally evolving universe (including agents), only a few initial steps are sketched in this short paper how agent-specific ontological problems could be tackled. Further work should lead to a better understanding of agents (as temporal knowledge bases) and their communication—this should in turn facilitate building ontologies (including taxonomies) of agents, seen both as knowledge bases (temporal, and therefore *processes*) and as *communicating* processes (that have capabilities and offer services).

2. PROCESS ONTOLOGY

Process philosophy[4] emphasises *becoming*, rather than *being*. A thorough exposition of process philosophy can be found in [1], while [11] elaborates on process-based metaphysics. In process ontology *objects* are understood as *occurrents*, rather than *continuants*. A process-oriented approach seems appropriate not only for, say, production processes and weather, but for space-time and motion [9], and arbitrary objects as well. A thorough discussion on process philosophy is presented in [8], where processes are employed to account for a causally evolving universe, and its fragments. The information contained in Definition 1 and Theorem 1 below is extracted from [8].

Definition 1.
Let Π be a set, elements of Π are called *processes*. Let $\in$ and $\equiv$ be *primitive* binary relations on Π, with $\in$ denoting process *composition* and $\equiv$ denoting process *identity*. A binary relation $\leq$ on Π, called *fragmentation*, is defined in terms of $\in$. The following is a list of axioms and definitions; variables range over Π.

1. $\forall_{x,y}[x \equiv y \Leftrightarrow \forall_z[z \in x \Leftrightarrow z \in y]]$
2. $x \leq y$ *iff* $\forall_z[z \in x \Rightarrow z \in y]$
3. $\exists_x \forall_y [y \leq x]$
4. $x \equiv \top$ *iff* $\forall_y[y \leq x]$
5. $\forall_{x,y}\exists_z[x \leq z \wedge y \leq z \wedge \forall_u[(x \leq u \wedge y \leq u) \Rightarrow z \leq u]]$
6. $z \equiv x + y$ *iff* $x \leq z \wedge y \leq z \wedge \forall_u[(x \leq u \wedge y \leq u) \Rightarrow z \leq u]$
7. $\forall_{x,y}\exists_z\exists!_w[z \leq x \wedge z \leq y \wedge \forall_u[(u \leq x \wedge u \leq y) \Rightarrow u \leq z] \wedge x \equiv w + z \wedge \forall_u[(u \leq w \wedge u \leq z) \Rightarrow \forall_v[v \equiv u + v]]]$

[1] http://www.ladseb.pd.cnr.it/infor/ontology/
[2] http://www.daml.org/
[3] http://www-ksl.stanford.edu/knowledge-sharing/
[4] http://www.mailbase.ac.uk/lists/process-philosophy/

8. $z \equiv x \cdot y$ *iff* $z \leq x \wedge z \leq y \wedge \forall_u[(u \leq x \wedge u \leq y) \Rightarrow u \leq z]$
9. $z \equiv x - y$ *iff* $x \equiv z + (x \cdot y) \wedge \forall_u[(u \leq z \wedge u \leq (x \cdot y)) \Rightarrow \forall_v[v \equiv u + v]]$
10. $y \equiv x'$ *iff* $y \equiv \top - x$
11. $y \equiv \bot$ *iff* $x \equiv \top'$
12. $atomic(x)$ *iff* $x \not\equiv \bot \wedge \forall_y[y \leq x \Rightarrow y \equiv x \vee y \equiv \bot]$
13. $\forall_{x,y}[x \in y \Leftrightarrow atomic(x) \wedge x \leq y]$
14. $time\colon \Pi \longrightarrow \Pi$
15. $\forall_{x,y}[y \in time(x) \Leftrightarrow (atomic(y) \wedge \exists_u[u \in x \wedge time(u) \equiv time(y)])]$
16. $temporal(x)$ *iff* $time(x) \equiv x$
17. $moment(x)$ *iff* $\exists_u[u \in x \wedge time(u) \equiv x]$
18. $x \mathrel{\epsilon} y$ *iff* $moment(x) \wedge temporal(y) \wedge x \leq y$
19. $x \preceq y$ *iff* $temporal(x) \wedge temporal(y) \wedge \forall_t[temporal(t) \Rightarrow (t \mathrel{\epsilon} x \Rightarrow t \mathrel{\epsilon} y)]$

(1) is an *extensionality axiom*; (2) is a definition of *fragmentation*; (3) is a *universe axiom*; (4) defines a *universe process* $\top$; (5) is a *fusion axiom*; (6) defines a *fusion operator* $+$; (7) is a *fission axiom*; (8) defines an *inner fission operator* $\cdot$; (9) defines an *outer fission operator* $-$; (10) defines a *complement process*; (11) defines a *complement of the universe process*, denoted $\bot$, called *nothing*; (12) defines *atomic processes*; (13) is a *foundation axiom*; (14) introduces a unary function symbol *time*; (15) is a *temporal axiom*; (16) defines *temporal processes* as fixed-points of the *time* function; (17) defines atomic temporal processes called *moments*; (18) defines *temporal composition*, denoted ϵ, a temporal counterpart of the process composition $\in$; (19) defines *temporal fragmentation*, denoted $\preceq$, a temporal counterpart of the process fragmentation $\leq$;

THEOREM 1.
$(\Pi, +, \cdot, ', \bot, \top)$ *is a Boolean algebra.*
Let $\Gamma = \{x \mid \text{temporal}(x)\}$ *be a set of temporal processes.*
$(\Gamma, +, ')$ *is a subalgebra of* $(\Pi, +, \cdot, ', \bot, \top)$.

Process fragmentation (2) and *temporal fragmentation* (19) provide a starting point towards understanding the dynamic, causally evolving universe in terms of *processes* (fragments of the universe). Regarding the concept of time, the position can be summarised by saying that *time* is a *process* (temporal entities such as moments and intervals are processes); one could also decide for a certain *time structure* (e.g., linear discrete unbounded time), but this is omitted here.

There certainly is a conceptual difficulty with perceiving the universe in terms of *processes* rather than *objects*, as what we see are objects (temporal parts of processes); thinking about processes is thinking about movies, rather than single pictures. Fragments of the universe can be seen as bricks in a wall [8] being built by attaching a vertical column of bricks to the right side of what has already been built—with bricks being processes, and the whole columns being *times* or *time processes*. This might be seen as a radical approach, and needs to be explored, verified and understood before successfully applied. Although conceptually unconventional, the process-based approach gets rid of various problems, e.g., the *ship of Theseus puzzle*. This connects to the problem of *identity* and *change* (how can an object change, and still be the same?) and we are certainly interested in agents' identity and change.

Important aspects of process-based representations discussed in [8] are those of *causal influence* and *repeated patterns of influence*. As said in [8] on page 168, "the world is governed, moment to moment, by the causal influences present within it. [. . .] Some of these influences adhere to patterns that repeat, and that our ability to negotiate the dynamic world rests with our attention to these repeating patterns of influence. The permanence that we seek amid the change is to be found in the *patterns of influence* that arise as causal influence spreads throughout a collection of processes."

3. AGENTS AND COMMUNICATION LANGUAGES

There is no consensus yet on what *agents* are [12], but it is commonly accepted that *communication* is a vital aspect of *agency*—indeed, in [5] it is said that an *agent* is a system that can exchange knowledge using an *Agent Communication Language (ACL)*. Even if this definition is rejected, there are many characteristics of agents that can be extracted form ACLs, and therefore it is appropriate to consider existing ACLs to see how they contribute to the concept of *agent*.

Let consider the following issues.

- Weak and strong notions of agency.
- Attitudes.
- Identity, sub-agency and change.
- Performatives.

The question is whether these issues are affected by understanding agents as processes—claims are made that they are.

In [12] a *weak notion of agency* requires agents to have the properties of *autonomy*, *social ability*, *reactivity* and *pro-activeness*.

Claim 1 Process-centred view facilitates understanding such properties of agents as *autonomy*, *social ability*, *reactivity* and *pro-activeness*.

Clearly, *autonomy*, *social ability*, *reactivity* and *pro-activeness* all have a temporal character, and therefore one should see an agent as a process (with its temporal parts, the agent *now*, and at *the previous moment*), rather than as an object that changes while maintaining its identity.[5] Then *au-*

[5]It should also be noted that *individuating* software agents can be harder than individuating physical objects.

tonomy, *social ability*, and such are properties of *processes* (rather than their temporal parts).

A *strong notion of agency* also discussed in [12] requires agents to have *attitudes* such as *beliefs*, *intentions* and *goals*. Attitudes are partitioned into *information attitudes* (e.g. beliefs) and *pro-attitudes* (e.g. goals, commitments, intentions). It is also claimed that agents must have at least one kind of information attitudes and at least one kind of pro-attitudes.

Claim 2 Understanding agents as processes is appropriate for understanding agents' *attitudes* such as *beliefs* and *goals*.

Beliefs and *goals* (or sets of such) can be seen as temporal, intentional knowledge bases—these are *processes*, not *static objects*.

One of the advantages of the process-centred view (objects as *occurrents*), over the object-centred view (objects as *continuants*) is that the former avoids the *identity and change problem* (in the object-centred view an object x can change to an object y, yet preserving its identity).

Claim 3 Processes are not affected by the *identity and change problem*.

Two processes are identical, if they have the same *fragments*. An agent after a change is not identical to ... its (proper) temporal fragment (cf. *ship of Theseus*; *liar paradox*).

Performatives are *speech acts* that "succeeds by virtue of being said." Performatives are used in KQML [4, 6], but it is argued by Cohen [2] that some of *KQML performatives* are not *speech act performatives*—this situation is acknowledged in [7] but "accepted for historical reasons." Discussions on performatives can be found in [2, 3, 12], and on the FIPA site.[6] In [12] speech acts are categorised as (in most cases) either *representatives* (such as *informing*) or *directives* (such as *requesting*); these speech acts give rise to—on the side of agent architectures and ACLs—performatives (such as INFORM or REQUEST). Performatives (FIPA's *communicative acts*) can be "made" to be uttered by an agent as a result of the agent having certain attitudes, for instance, a goal (or intention) of asking Sally if it rains can result in a communicative act of an appropriate request (directed to Sally)—beliefs and goals associate with INFORMS and REQUESTS, respectively. In FIPA ACL communicative acts (actions) involve also *rational effects (RE)* and *feasibility preconditions (FP)*—these can be seen as linking goals with actions, their preconditions and effects, and plans.

Claim 4 Processes facilitate understanding performatives and preconditions and effects of actions.

Preconditions and effects (postconditions) of actions should probably be seen as *repeating patterns*, mentioned at the end of Section 2. This connects to several issues, such as *revising* (the past), *updating* (the present), *predicting* (the future), and *causally influencing* the evolving universe.

[6] http://www.fipa.org/

4. CONCLUSION

The account offered is very preliminary, but it seems promising. Current work within our KR research group[7] at DSTO,[8] Australia, focuses on revising the process ontology of [8], and incorporating *space* [10] into the Boolean algebra of *processes* and *time*. Issues of concern include ontologies, space, time, logistics, planning, attitudes, situation awareness, and agents (ATTITUDE agent platform, and interaction between agents, virtual humans and humans).

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