An Ontology for Designing a Collaborative Platform Involving a Multi-touch and Multi-user Interactive Table

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Abstract: We have developed a platform running on a large multi-touch and multi-users table. Its intended application domain is the collaborative preliminary design phase of engineering projects. We also developed an ontology describing the virtual objects of the platform and the projects on which users collaborate. In this paper we first present the originality of this ontology. It extends the DOLCE-CORE ontology in order to model the true nature of the virtual objects that the users can manipulate on the device and the users' actions. We then present the different roles played by the ontology in the development of the platform. It serves as a reference of the semantics for the designers of the collaborative platform and as a model of the environment including table, participants, projects, etc. This model is mainly used by the intelligent agents of a multi-agent system whose objective is to support the participants during a working session around the table.

1 INTRODUCTION

Collocated collaborative work environments have become an increasingly popular field of research. Their application is often focused on performing collaborative and conceptual design work, such as brainstorming or project planning. The first goal of such systems is to provide a method for saving the content of collaborative work and distributing the data throughout the team. A secondary goal is to engender communication and collaboration amongst the team. The devices for capturing input data from the teams are the same ones which inhibit the productivity of group for socio-technological reason. For example, several meeting systems have been proposed to facilitate brainstorming which places its users at different desktop workstations with users focusing primarily on their screen. These systems diminish group awareness and collaboration because the attention is distributed throughout the system. Creativity and productivity are negatively impacted (Hilliges et al., 2007).

In response to the limitations introduced by the traditional hardware repurposed for collocated groupware, researchers are capitalizing upon the increased availability of vertical and horizontal interactive surfaces to fashion interactive whiteboards and tabletops capable of supporting a social framework more advantageous for group collaboration (Geyer et al., 2011). The TATIN-PIC project at the University of Technology of Compiègne continues with this approach in order to build a collaborative multi-display working environment for design and engineering teams. The hardware is composed of a large

Figure 1: Devices.

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multi-user multi-touch table, a large vertical whiteboard, individual graphics tablets and interactive vocal devices. The middleware is a multi-agent system which provides ample extensibility and stability to programmers when building applications for this interactive environment. This multi-agent architecture allows for easy integration of voice-controlled personal assistant agents which can perform tasks for the users around the interactive tabletop. Integrating these personal assistant agents, is a matter of designing a protocol for communication with these agents with the middleware.

To help designing the TATIN-PIC platform (Jones et al., 2011; Moulin et al., 2011), we defined an ontology hereafter referred as OntoTATIN-PIC. It is primarily aimed at helping the design team composed of multidisciplinary researchers. It is provided as a means to reduce the conceptual complexity of the TATIN-PIC project. Indeed, one must account both for the design projects done collaboratively by the design team, and for the platform itself. Concepts related to the project include project phases, individual and collective actions, designed artefact, used resources, or team members' roles. Concepts related to the platform include all newly created objects, and all actions allowed by the system. A second objective of OntoTATIN-PIC is to provide software agents with the conceptual resources allowing them to build a model of the on-going projects, which increases their supporting capacities.

Because the ontology spreads across a vast domain, we propose to build it using a multi-level and multi-component approach. Thus, OntoTATIN-PIC is structured inline with the well known DOLCE-CORE ontology in its more recent version (Borgo and Masolo, 2009; Masolo, 2010), adding modules to describe sub-domains like *actions* or *documents*. To let OntoTATIN-PIC answer the requirements, two versions of it have been designed using the OntoSpec method (Kassel, 2005): (i) an informal specification using the formalism of the OntoSpec method, used as a semantic reference for the project team; and (ii) an implementation using the MOSS formalism (MOSS, 2000), used by the software agents of the platform.

The purpose of this paper is to present and discuss the content of the ontology and its purposes. Section 2 summarizes the ontological framework; Section 3 describes some resources used for defining OntoTATIN-PIC, focusing on virtual objects appearing on the graphics surface and on the actions needed to manipulate them; Section 4 presents how the ontology is exploited; the conclusion presents ongoing work meant to complement the ontology and improve supporting features.

2 ONTOLOGICAL FRAMEWORK

We selected DOLCE-CORE (Borgo and Masolo, 2009; Masolo, 2010), to structure OntoTATIN-PIC. This section summarizes the structuring principles of DOLCE-CORE and presents two extensions required to define OntoTATIN-PIC: (i) an extension to the domain of actions; and (ii) an extension to the domain of entities bearing information.

2.1 Main Categories

DOLCE-CORE distinguishes four main categories of concrete entities having spatio-temporal extensions (Fig. 2).

Objects and Events are distinguished according to the way they are located in space and time: Objects, in particular physical objects like a person or a smartphone, are *mainly* linked to space, whilst Events are *mainly* linked to time. Objects obtain a temporal position through Events to which they participate. In particular Objects participate in their life, an Event with a temporal extension. Conversely, Events obtain a spatial location through Objects that generate them, e.g. the physical space your body occupies corresponds to the spatial extension of your reading of this article.

Qualities are dimensions or aspects according to which agents perceive, classify and compare Objects and Events. Individual Objects and Events possess their own individual Qualities. Such individual Qualities represent dimensions shared by classes of entities. One should note (Fig. 2) that Object Qualities are distinct from Event Qualities: physical Objects have a mass, have a shape, a texture, etc., whilst Events have a duration, may be fast or slow, may overlap in time or on the contrary happen before or after other Events.

Finally, Individual Qualities have a temporary location in a space specific to their Quality kind (e.g. "being a 2 meter length", "being a 36 second duration").

Entities that we have just mentioned are linked together through relationships. We mention here two main relationships: Objects (resp. Events) have for parts (hasForPart) other Objects (resp. Events); Objects temporarily participate in (participatesIn) Events.

Let us mention an important difference (in particular for OntoTATIN-PIC) among Objects. DOLCE makes the distinction between Physical Objects having a physical reality and Non-physical Objects having a cognitive or social reality (Masolo et al., 2004). Non-physical Objects exist because agents design them and communicate on them. Among Non-physical Objects, Mental Objects depend on an agent,

e.g. a mnemo-technical process belonging to a person, whilst Social Objects depend on several agents, e.g. a commercial company, rules of a game. Non-physical Objects do have a spatial position, but only indirectly, contrary to that of Physical Objects. As we will see in Section 2.3, such a distinction is crucial to account for the nature of objects being handled on the tabletop. But in the mean time we extend DOLCE-CORE with a set of minimal concepts to be able to conceptualize *actions*.

2.2 Actions

A central concept is that of Action. Following traditional approaches from the philosophy of action (Searle, 1983) we define an Action as an intentional process controlled by an entity capable of intentions (i.e. processes referring to the world in which the action happens). Such Actions (Fig. 2) contrast with Happenings that have no intentional cause. In the philosophy of action, one usually distinguishes several categories of intentions, which leads to distinguish several categories of actions according to the nature of the control(Pacherie, 2008). One can thus distinguish premeditated actions (initiated and controlled by a prior intention), from automatic or routine actions (controlled by an intention-in-action). Such a dimension corresponds to the first axis we select to classify Actions, distinguishing between Deliberate Actions and Non-deliberate Actions. We use a second semantic axis, corresponding to the individual or collective nature of the agent doing the Action. Thus, we distinguish between Individual Actions and Collective Actions, the latter having a collective agent, meaning a set of agents having emerging properties like that of being capable of action (Lawson, 2012). Within the TATIN-PIC project, a design team is a Collective undertaking a design project that is an example of Collective Action.

Specific relationships allow to describe Actions. In particular, an Action can be performed by the fact of carrying another Action (isGeneratedBy)[1]; Moreover, to reflect the different ways in which entities participate in Actions (e.g. an entity plays the role of agent, another the role of instrument), we introduce as many relations (called in the literature "casual relations" or "thematic roles") specializing the relationship of participation (participatesIn) between Objects and Events: hasForAgent, hasForInstrument, hasForResult.

[1]This generation can be causal in nature (e.g. I turn on a lamp by pressing on the switch) or based on a social convention (e.g. I indicate that I turn right by the fact to lift my right arm).

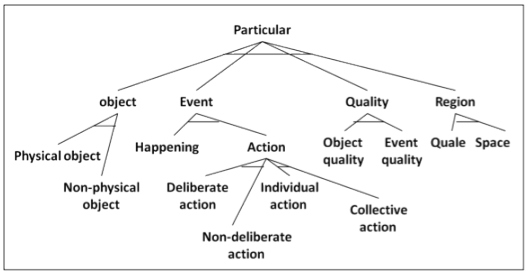

Figure 2: Main generic categories of entities. A vertical link indicates subsumption; an horizontal link indicates incompatible subsumed children.

2.3 Entities Bearing Information

A final extension we introduced concerns the conceptualization of textual or graphical inscriptions that bear some meaning for agents. Such inscriptions are related to the objects being handled on the multi-touch table, e.g. a drawing representing a Post-it note, a graphical representation of a project step. To define OntoTATIN-PIC we reuse the I&DA ontological module (Fortier and Kassel, 2004) that contains a set of generic concepts concerning semiotics. Here, we informally summarize the main concepts of I&DA (Fig. 3).

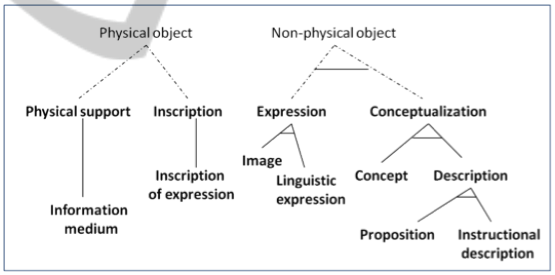

Figure 3: Main concepts of I&DA.

A Conceptualization is a conceptual content. I&DA distinguishes between two categories of Conceptualizations, namely Concepts and Descriptions. A Description loosely speaking, uses Concepts to relate to (refersTo) objects of the world. Among Descriptions, we distinguish between Propositions, corresponding to factual descriptions to which we can assign a truth value, and Instructional Descriptions, corresponding to imperative descriptions like "do this, then do that."

An Expression is an expression which represents the code of a Conceptualization in a communication language, like the linguistic expression "The room temperature is high" expressing a Proposition. The coding language may be text, graphics, or gestures. It can be low-level not understandable by a human, but rather interpretable by a machine.

An Inscription is the material embodiment, by means of stuff, of the shape of an entity. Creating an Inscription can be done from an entity directly, like a trace of steps or fingerprints, or indirectly by embodying an Expression referring to an entity, like a printed image or text, or a Braille cell.

A Physical support is a physical object supporting Inscriptions, that are temporarily stable in time. Some Physical Supports play incidentally this role, like a table being tagged, some dust in which something is written. Other Physical Supports, known as Information Media, are intentionally built to fill this support function and are thus technical artefacts, like a piece of paper, a board, a memory space inside a computer.

3 OntoTATIN-PIC

Building OntoTATIN-PIC consisted first in defining the various phases of the design process, namely, Brainstorming, Causal Analysis or Functional Analysis. In order to describe them semantically, we first examined the various objects that were generated and handled on the platform. The section focuses on the definition and characterization of the different objects, especially in the combination table/interactive board, and on the possible actions on such objects.

3.1 Manipulated Entities

TATIN-PIC device, composed of several media of type Information Medium (an interactive tabletop and an interactive board display which are coupled with tablets and smartphones), allows participants to manipulate, through tactile interaction and / or voice, light projections and act on entities that these lights represent. Each participant thus has a tactile menu and a tactile keyboard. Post-its notes are created and grouped. Several diagrams can be constructed and arranged.

Light projections are Inscriptions, in the sense of I&DA, more precisely Inscriptions of expression: they materialize Expressions. From the point of view of actions that the participants can complete, two main categories of Inscriptions are to be distinguished: first, Inscriptions that pictorially represent physical objects (e.g. a Post-it note) and permit on these Inscriptions actions similar to those carried out on the physical objects; secondly, Inscriptions representing non physical objects such as texts, groups of Post-its notes, tasks, risks, etc. In this section, we present these two categories of Inscriptions.

3.1.1 Virtual Objects

Among all inscriptions we identified in OntoTATIN-PIC, we defined the concept of Virtual Object (Fig. 4). This Inscription can on one hand represent a physical object of the real world as a Picture (an Expression), and on the other hand accept actions that can be done on such an object. Take an apple for example. Its projection onto the TATIN-PIC table is the image of an apple (thus an expression). If it is possible to act on this inscription, like peeling the apple or slicing the apple, as could be done on the real object, then that inscription becomes a ”Virtual Apple” instance of the category Virtual Object as we have defined it.

On the TATIN-PIC table a first inscription having this feature is the touch keyboard given to each participant. It is a faithful representation of a standard keyboard with all the keys and is immediately received as such by the participants. By using it, one can do the same actions as with a real keyboard: type a letter, erase text, validate commands, etc. We therefore introduce the Keyboard Picture expression to represent the picture of a keyboard, and the Virtual Keyboard expression of the Virtual Object category.

Another Virtual Object that we have characterized is the virtual Post-it note. Indeed, Post-it notes are an essential part of brainstorming phases. Participants use a large number or such notes to represent their ideas, to organize them, progressively grouping them before switching to other design phases. Post-it notes on the TATIN-PIC tabletop appear as yellow rectangles, like with standard paper Post-it notes, and offer some of their options (only those that are relevant to the application - for example it is not possible to tear a virtual Post-it note on TATIN-PIC) permitting a trivial and similar usage. Each participant can thus create a new Post-it note, write down a text, move the note, or else discard it. Thus, as for the virtual keyboard, we distinguish the expression representing a Post-it note picture (Post-it Picture) from the inscription of the expression on the tabletop that can be handled by a participant, i.e. the Virtual Post-it.

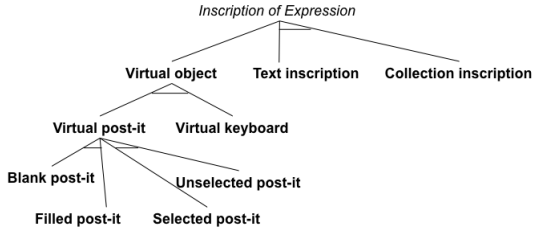

Figure 4: Virtual objects and inscriptions.

We refine OntoTATIN-PIC, distinguishing several types of Virtual Post-it. Thus, Blank Post-it represents

an empty virtual Post-it note, i.e. a Post-it note bearing no text. A Filled Post-it identifies a virtual Post-it note with a text. A Filled Post-it is an inscription that has for part (hasForPart) another inscription that is textual (Text inscription). This distinction allows us to differentiate between the action of creating a Post-it note (leading to a Blank Post-it), from that of filling a Post-it note, transforming a Blank Post-it into a Filled Post-it.

Likewise, in order to perform some actions, a participant must first identify a Post-it note on the tabletop, by selecting it, for example to discard it. This led us to introduce the notion of Selected Post-it that is a Virtual Post-it with the state "selected". In this case, the color of the Post-it note on the table is modified (the image changes). Conversely, an Unselected Post-it represents any Virtual Post-it that is not selected.

As we mentioned previously, participants gather Post-it notes together, making groups. These groups are an opportunity to discuss in the next section, inscriptions of non physical objects called collections.

3.1.2 Collections

To conceptually represent the notion of group we called upon the concept of Collection presented in section 2. A Collection is a non physical object. Participants do not manage a collection on the table but its representation taking the shape of an image on the tabletop. Thus, OntoTATIN-PIC, following the I&AD principles, distinguishes the image of the collection - an Expression called Collection Picture - a graphical representation of a Collection, from the lighted inscription of that Expression, as projected onto the tabletop and called Collection Inscription. A Collection Inscription has for part (hasForPart) other inscriptions: Virtual post-it or Collection Inscription. Two types of expressions represent different "views" of the same collection: Expanded Collection Picture is an image which allows viewing the entire content of a collection, meaning all its elements and links. Contracted Collection Picture is a compact view of that collection that does not show its internal structure but allows applying some actions to it.

As a non-physical object, a Collection exists only when it is discussed. In other words, a collection of Post-it notes (or of other collections) exists only when the participants' brainstorming evoke and recognize its existence. It could be the case without the Collection being represented (by a Collection Inscription). In this regard removing from the table a collection inscription does not necessarily lead to the removal of the collection (as a non physical object) that it refers to. Finally, any action on an inscription, has no de-facto effect on the collection itself. These aspects will be developed in section 3.2 about possible actions on collections. The next section concludes our presentation of objects evoking the contributions of the triptych Inscription-Expression-referenced entity in the project.

3.1.3 About Triptych Inscription-Expression-Referenced Entity

As we have seen previously, OntoTATIN-PIC is based on a triptych Inscription Expression and referenced entity. This ontological framework can account for different situations:

- A same Inscription materializes different Expressions. This case occurs when, for example, a virtual Post-it note color changes, which is equivalent to materialize a different picture. This case corresponds to a change of state of the Virtual post-it, which retains its identity. A similar case arises if participants have the possibility to customize the appearance of the keyboard (Keyboard picture change).
- A same entity is duplicated on one (or more) Information medium. This case occurs, for example, when a Virtual post-it or a Collection is copied to another Information medium. Duplication is to create a new Inscription with the same properties, except the location. Subsequently, the conceptualization can accompany different strategies: should the changes on an Inscription (e.g. change of the referenced entity, modifying only the Expression) be reflected on to the Inscription of origin or not?
- A same couple (Inscription, Expression) changes its referent. This case occurs, for example, when a Virtual post-it comes to represent a task, a risk in the project, or any other entity. This is a convenience that designers of the platform use, for example, to represent a chronogram. Conceptually, this change is reflected in the reference link (relationship RefersTo).
- A same entity is visualized using various Pictures. This is particularly the case of a Collection assuming an extended view (revealing images of its elements) and a contracted view (corresponding to the only presentation of its label).

To maintain such a model and act selectively on its different components, e.g. to change the visual representation of a Collection without changing its content, participants can perform various actions. In the next section, we present the conceptualization of these actions.

3.2 Actions

Following the modeling of actions that we introduced in Section 2, collective actions must be distinguished from individual actions. Collective actions essentially correspond to the different phases of the preliminary design process, performed in a collaborative manner. We focus here on the individual actions carried out by the participants on the objects described in the previous section and place emphasis on two aspects of our modeling of actions: i) precision in the identification of the objects on which actions bear and ii) usage of different conceptual relationships to finely describe actions.

On the first point, it should be noted that actions can bear both on Inscriptions (e.g., Moving a post-it, Moving a collection), Expressions (e.g., Ro-sizing a post-it, Expanding a collection) or other non-physical objects (e.g., Adding a member to a collection). Thus, for example, when a Collection is concerned, three types of action are distinguished: those on the Collection itself (aiming at changing its elements), those dealing with its graphical representation (an extended view integrating the presentation of its elements and a contracted view are available) and those bearing on its materialization on the table (the inscription can be changed of place). Of course, actions on objects have repercussions on other objects. For example, the addition of a Collection creates de facto a new Inscription. These effects must be described because they participate in the semantics of the actions.

Concerning the second point, namely the level of detail of the modeling of actions, we illustrate it on the identified actions involving Virtual post-its (see Figure 5).

Each class of actions is firstly described by means of casual relationships. Thus, Selecting a post-it is an action that: hasForAgent a Participant; hasForData an Unselected virtual post-it and hasForResult a Selected virtual post-it (which is actually the same instance of Virtual post-it, whose background color has been altered as a side effect of the action, in the sense that this is not an outcome intentionally targeted by the agent). The instrument used to perform the action may also be specified. Thus, Creating a filled post-it by voice is a kind of action performed by means of an earphone in which the participant gives the corresponding order.

In addition, several relationships between actions are exploited:

- The relationship of specialization. For example, Filling a post-it is a special case (specialization) of Editing a post-it: its data is a Blank post-it, which is filled with an editor. By contrast, Modifying a post-it amounts to modifying the contents of a Filled post-it.
- The relation of composition. For example, Creating a filled post-it is composed of two actions in sequence: Creating a blank post-it and Filling a post-it.
- The relationship isGeneratedBy. It allows to express that an action is consequence of another (in particular that gestures or speech acts generate previously described actions). Thus, Adding a member to a collection is a kind of action which isGeneratedBy an action of the type Bringing together two inscriptions. Indeed, in order to add an item to a Collection, one has to bring together on the table the item and the Inscription of the Collection.

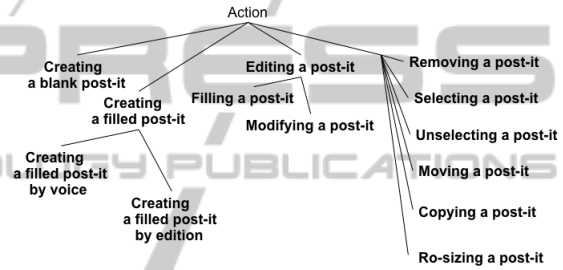

Figure 5: Individual actions concerning the manipulation of Virtual post-it in the project TATIN-PIC.

Up to now, OntoTATIN-PIC does not contain the description of the gestures of the participants. For example, Moving a post-it is performed by a gesture of the hand which consists in pointing the finger towards the Virtual post-it and moving it to its final position. In the future, we plan to complete OntoTATIN-PIC with a conceptualization of these gestures in order to be more accurate and complete in our reference semantics.

4 ROLE OF OntoTATIN-PIC

We present in this section the different roles played by OntoTATIN-PIC.

4.1 Reference Semantics

The first role of OntoTATIN-PIC was to serve as a common representation of the project for all members of the team. The act of collaboratively building an ontology of the project gave the team the opportunity to identify and define critical aspects of the system that would have otherwise been left implicit and ambiguous (e.g. the notions of project, phase and session).

This act of building a common vocabulary is especially important for multi-disciplinary teams.

The ontology of possible user actions in the TATIN-PIC system was also helpful to the designers of the user interface of the system. Explicitly specifying the requirements and outcomes of each action allows the designers to perform a cognitive walkthrough of the entire system. For example, when a user copies a Post-it note from one surface to another, user interface designers much explicitly examine the outcomes of such an action to decide whether future modifications of this Post-it note should be propagated throughout the system and also appear in its copies. For another example, when an inscription of a collection of Post-its notes is delete, the user interface designers must determine what happens to the collection, i.e. whether it is recorded somewhere as an undoable action or if it simply ceases to exist. Such questions often provoke helpful discussions on user experience and intention.

4.2 Semantics fo Human-Machine Dialog

In the TATIN-PIC system, users wear headsets and can trigger specific actions through vocal commands given to virtual personal assistants who can understand natural language. These virtual personal assistants are coded in OMAS (Barthès, 2011). In this environment, each assistant can have its own ontology for a semantic representation of the tasks and domain in which it is operating. Such local ontologies are derived from the general ontology of the TATIN-PIC project and is implemented using a representation language called MOSS.

MOSS is a complex frame-based representation language, allowing us to describe concepts, individuals, properties, classless objects, default values, virtual concepts or properties. MOSS is centered on the concept of property and adopts a descriptive (typicality) rather than prescriptive approach, meaning that defaults are privileged. MOSS has a query mechanism, allows multilinguism, and has other features detailed in its documentation (MOSS, 2000). Reasoning is done via the query system. An example of implementation can be found in (Bettahar et al., 2009).

When a participant uses vocal commands, those are analyzed with respect to the content of the ontology and the description of the tasks to achieve, themselves described by concepts of the ontology. When a task is selected, a dialog allows adding the necessary information to perform the task, or if the task is dangerous (e.g. deleting a collection) to ask for a confirmation before the action is completed.

4.3 Semantics for Exchanges among Agents

OntoTATIN-PIC also helps defining the protocol by which the different software components of the platform exchange information. Though the details of the software architecture are outside the scope of this article, the components of this system (i.e. interactive tabletop, whiteboard, headset) each have numerous software processes responsible for sending and receiving information when a user performs an action. The TATIN-PIC system is composed of two multi-agent platforms having different agent communication languages (ACL). Transfer agents (gateways) restructure the messages from and to the other platform. The exchange format follows the JSON grammar and syntax and use performatives derived from FIPA, e.g. inform, request, answer, cancel, or failure. The message content is also a JSON object, the properties of which correspond to concepts of the OntoTATIN-PIC ontology and are parameters of the action to perform by the agent receiving the message. The following message is a request for creating a collection of Post-it notes.

```
{"action" : "create",
  "args" :
    {"category" :
            "collection",
            "content" : "Structure",
            "ref" : ["p3-2-1", "p3-2-2"]}}
```

Here, parameters depend on the nature of the action requested. The content argument is the text to be inserted in the Collection label and the ref argument is the Post-it note list to be added to the collection created.

5 CONCLUSIONS

In this paper we have presented the OntoTATIN-PIC ontology used as a resource for the design of a collaborative platform involving a multi-touch and multimodal interactive work environment. This ontology plays a fundamental role as a reference semantics for the project team itself, but also for the human machine dialog and the exchanges between middleware agents of the platform.

OntoTATIN-PIC proposes a conceptualization of collective and individual actions achieved by the participants during collaborative activities and a conceptualization of objects created or produced during these activities and objects that the platform allows users to manipulate.

OntoTATIN-PIC is an extension of the founding DOLCE-CORE ontology. This approach gives to the necessary rigor for defining the true nature of the different objects involved in actions. In particular, we distinguish the actions having effects only on inscriptions and the actions which can also have effects on the expressions of these inscriptions or on the entities they reference.

Today we have an informal specification of our ontology in the language of the OntoSpec methodology and a partial implementation in the MOSS language. Two research opportunities emerge: on a conceptual level, it seems interesting to identify between DOLCE and the applicative concepts of OntoTATIN-PIC, an intermediate (and reusable) layer corresponding to an ontology of virtual reality; on an operational level, the issue of creating a detailed model of performed actions (by populating the identified classes with instances) is raised: it would help provide software agents with a better understanding of the work done.

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