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When the Giant meets the Ant
An Asymmetric Approach for Collaborative and Concurrent Object Manipulation in a Multi-Scale Environment

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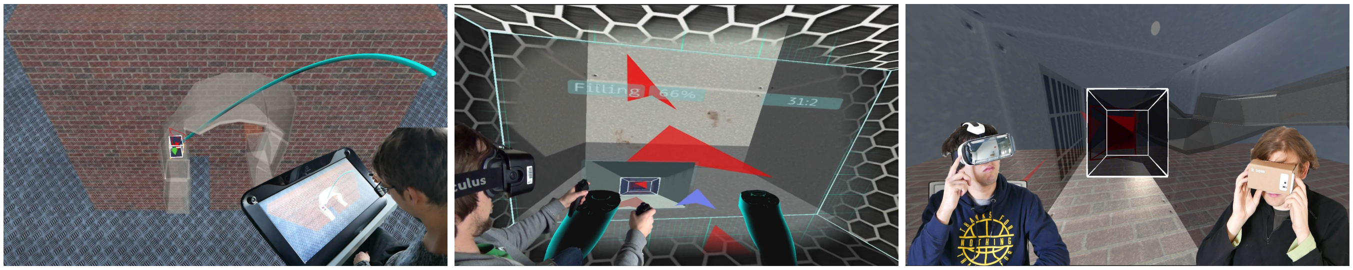
(a) (b) (c)

Figure 1: Collaborative manipulation of a virtual object (here, a cube) based on an asymmetric setting between two users who can be helped by two additional users. (a) The first participant has a global view of the scene and moves the object with a 3D bent ray. (b) The second user is placed inside the object and precisely rotates and scales it. (c) Two additional roles can be added. The first one helps to scale the object using a third person view of it. The other one is a spectator who switches between the other participants' viewpoints and helps them with oral communication.

ABSTRACT

In this paper, we propose an innovative approach that enables two or more users to manipulate an object collaboratively. Our goal is to benefits from the wide variety of todays VR devices. Therefore, our solution is based on an asymmetric collaboration pattern at different scales in which users benefit from suited points of views and interaction techniques according to their device setups. Indeed, each user application is adapted thanks to plasticity mechanisms. Our system provides an efficient way to co-manipulate an object within irregular and narrow courses, taking advantages of asymmetric roles in synchronous collaboration. Moreover, its aims to provide a way to maximize the filling of the courses while the object moves on its path.

Keywords: Collaborative 3D Interactions ; Shared Virtual Environments

Index Terms: H.5.3 [Information interfaces and presentation (e.g HCI)]: Group and Organization Interfaces—Computer supported cooperative work (CSCW); I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques

1 INTRODUCTION

In this paper, we propose a set of metaphors that enables several users to collaborate in a shared multi-scale Virtual Environment (VE) [7, 12] in order to achieve collaborative manipulation tasks in Virtual Reality (VR). Such tasks could consist in overcoming different obstacles by moving, rotating and scaling an object collaboratively. This kind of collaborative manipulation can be used to simulate industrial tasks such as in an automotive factory where cumbersome objects must be carried by several collaborators [1]. To do so, we propose an asymmetric collaboration between two or more users with different devices (cf. Fig. 1). These users are embedded in a co-located multi-scale VE thanks to a model inspired from the Immersive Interactive Virtual Cabin (IIVC) generic model [5].

This work is motivated by the current state of the VR market. All devices used are or will be soon on the consumer market: a zSpace, an Oculus Rift with a Razer Hydra, a Gear VR and a Google Cardboard. Indeed, today there is growing number of available VR visualization and interaction devices. Each setup does not offer the same interaction capabilities. That is why our approach benefits from this diversity by proposing a set of interaction techniques adapted to different device setups in order to perform a collaborative manipulation task. These techniques are automatically associated to the suited users with plasticity mechanisms. Plasticity is defined as the capacity of an interactive system to withstand variations of both the system physical characteristics and the environment while preserving its usability [18]. Here, we demonstrate an example of plasticity for device and collaboration adaptations thanks to the models presented by Lacoche et al. [8].

As proposed by Pihno et al. [13], our approach splits the Degrees

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of Freedom (DoFs) of the manipulated object between collaborators in order to maximize the system efficiency: the *Giant* (with a global viewpoint) controls the object's translation, while the *Ant* (inside the object) sets its scale and rotation. In our shared multi-scale VE, this approach allows the *Giant* to quickly move the object, while the *Ant* performs better accurate transformations and has a suited viewpoint to maximize the courses filling. The object's rotation can also be shared between the two main users using a particular fusing scheme inspired from the asymmetric integration by Ruddle et al. [16]. In this case, we use a non-linear merging factor for the *Giant*'s action according to its ray bending. Last, the third helping user (with the 3^{rd} person viewpoint of the object) can also set the scale of the manipulated object by asymmetrically integrating its action with the *Ant*'s one. All metaphors for controlling these DoFs are designed to have an easy and quick learning curve for the end user.

In order to demonstrate the interest and the efficiency of our solution, we have proposed to test it in the context of the IEEE 3DUI contest 2016. The goal of this contest was to move a cube collaboratively through different labyrinths, while maximizing the courses filling of the object. Most examples given in this paper are based on the manipulation tasks required by this contest.

This paper is structured as follows: first, an overview of this work is presented in Section 2. Second, we present collaborators' roles of our proposal in Section 3, then we detail interaction techniques in Section 4. Section 5 describes our implementation and Section 6 discusses informal feedbacks of test users. Last, we conclude and present perspectives of this work in Section 7.

2 OVERVIEW

In this work, referring to the classification by Margery et al. [11], we focus on cooperation at level 3. We want that the different users can change the same object transformation at the same time. This kind of synchronous collaborative object manipulation in CVE can be divided in two families: symmetrical and asymmetrical approaches. In the first symmetrical approach, collaborators benefit from equivalent viewpoints and interaction capabilities. This collaboration can be homogeneous based on 3D ray [14] or 3D pointer (i.e virtual hands metaphor) [4, 1], or heterogeneous, for instance mixing a 3D ray for a user, and a 3D pointer for another one [13]. On the contrary, in asymmetrical approaches, the users collaborate in a multi-scale CVE, i.e they have different viewpoints, thus their interaction techniques must be adapted to their different capabilities [3, 5]

Both families can be implemented in two different ways: split of DoFs (level 3.1) or concurrent modification involving a merge policy (level 3.2). In our work, we use both conditions in order to maximize the efficiency of the whole proposed approach. Basically, the object manipulation uses a split of DoFs policy between the *Giant* and the *Ant*. However, in some conditions, the *Giant* can take the lead on the *Ant* rotation capability in order to help him. This is done by merging both inputs with a custom policy giving a bigger influence to the *Giant* action. Then, if a third user joins the CVE, the scale of the object is controlled using a cooperative interaction with the *Ant* at level 3.2. We did not find any related work that uses this kind of adaptable approach. Moreover, our proposal involves a kind of hybrid manipulation/navigation technique for the *Ant*. Indeed, the *Ant* is placed inside the manipulated object, moved by the *Giant*. This feature involves the *Ant*'s navigation in the CVE, controlled by the *Giant*. However, the *Ant* does not control the manipulated object location, thus, the approach does not require any navigation technique even if the Ant may feel as in a car or a spaceship. This hybrid approach is also an innovative way to apprehend co-manipulation using an asymmetrical approach to improve the efficiency of this difficult task.

3 ASYMMETRIC COLLABORATIVE SCENARIO

We propose an asymmetric collaboration where each user benefits from interaction capabilities adapted to his interaction devices in order to move, rotate and scale a virtual object. It is based on two main roles, a *Giant* with a global view of the shared environment, and an *Ant* inside the manipulated object. Two other roles are also possible for assisting the two main users.

3.1 Global View: the *Giant*

The first user is interacting on a zSpace[1] as shown in Figure 1a. It is composed of a 3D stereoscopic display with head tracking and of a 3D tracked stylus for interacting. The zSpace screen is used to create a window to the VE. Therefore, this user has a global view of the scene and can roughly manipulate the object in order to move it really fast in easy passages. This user can translate the object and also shares with the *Ant* the possibility to rotate it.

3.2 Micro View: the *Ant*

The second user visualizes the scene with a Head-Mounted Display (HMD), here an Oculus Rift[2] as shown in Figure 1b. He is interacting with a Razer Hydra[3] composed of two 3D tracked controllers. We exploit the immersion feeling given by the HMD to place this user inside the manipulated object. This position enables him to manipulate the object with a fine accuracy. His role is essential to overcome difficult passages and maximize the courses filling by the object. He can scale the object and shares the possibility to rotate it with the *Giant*. His scale in the scene also offers him direct interaction possibilities such as pushing buttons to trigger different actions.

3.3 Third Helping User

As shown in Figure 1c, the third user is interacting with a GearVR[4], an HMD with a 2D trackpad. His role is optional. This user has a third person view of the manipulated object. His role is to help the *Ant* to scale it with slide gestures on the GearVR trackpad. Therefore, the scaling capability is shared by these two users.

3.4 Spectators

The last role is a spectator. It is available on multiple devices. In our scenario, he uses a Google Cardboard[5] as shown in Figure 1c. Multiple spectators can be included in the shared VE. These users can switch between the other participants' viewpoints. Here, it is done by pulling the Cardboard trigger. They can help the other participants by giving oral instructions.

4 INTERACTION TECHNIQUES

The collaborators benefit from complementary interaction techniques to perform collaborative manipulations task that need translating, rotating, and scaling. An example of task is given in Figures 1a, 1b and 1c. This task is one of the tasks required by the IEEE 3DUI contest 2016. The goal is to pass a cube through a labyrinth while maximizing the courses filling of the object. First, we present the Giant's interation technique based on a bentray in Subsection 4.1. Then, we describe the Ant's interaction technique in Subsection 4.2, and the handling of optional concurrent manipulation (for the object rotation and scale) in Subsection 4.3.

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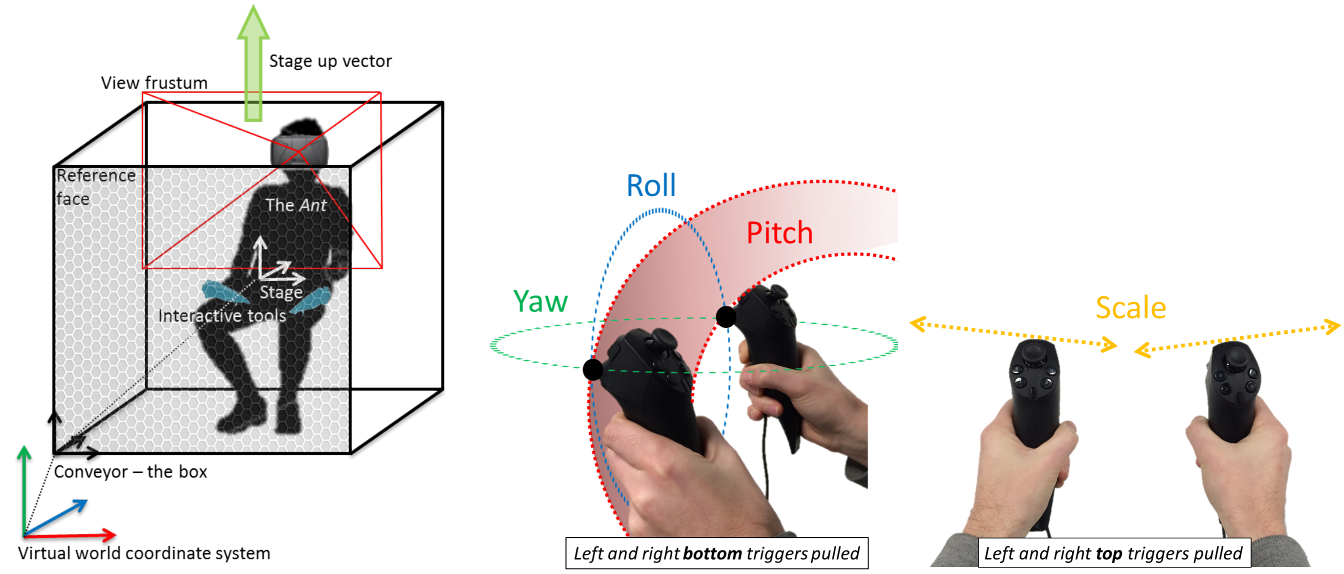
[1] `http://zspace.com/`

[2] `https://www.oculus.com/en-us/`

[3] `http://www.razerzone.com/fr-fr/gaming-controllers/razer-hydra-portal-2-bundle`

[4] `http://www.samsung.com/fr/galaxynote4/gear-vr/`

[5] `https://www.google.com/get/cardboard/`



(a) (b) (c)

Figure 2: (a) The *Ant*'s IIVC instantiation. The front textured face of the object (here, a box) is the current stage front face that is used as reference for object manipulation performed by the *Ant*. The stage coordinate system is always centered in the object. (b) and (c) The two metaphors used by the *Ant* to rotate and scale the manipulated object.

4.1 Global Manipulation

The user on the zSpace (*Giant*) can translate the object (actually the *Ant*'s conveyor in the IIVC model) with a bent ray inspired from the interaction technique proposed by Riege et al. [15]. The ray is controlled in position and rotation by the tracked stylus. One button is used for object grabbing, and the other buttons are used to switch between four point of views: front, left, back and right. The ray is bent during the object translation in order to respect three constraints:

- First, the manipulated object is attached to the ray extremity with a spring joint, as proposed by Fröhlich et al. [6]. The physical collider of the object avoids it to pass through other objects. The ray is bent accordingly.
- Second, we manually limit the ray extremity speed when an object is grabbed. The goal is to not disturb the distant user inside the manipulated object and reduce his cybersickness.
- Third, a last constraint is optional. We added an active help for the translation. It is a *magnetic path* that represents the perfect path to follow. The manipulated object is also connected to the closest point on this path with a spring joint.

To make the others understand the *Giant*'s actions, his head, stylus and 3D ray are rendered in the shared environment as shown on the top Figure 5a.

4.2 Inside Object Manipulation

The *Ant* is placed inside the manipulated object. He can scale and rotate it with the two Razer Hydra controllers thanks to bimanual metaphors inspired from the work of Cutler et al. [2]. These manipulations are performed with a fix reference: the object front face. This reference face can be changed. Figure 2a illustrates our instantiation of the IIVC model for the Ant, and especially explains the meaning of the reference face in the user stage according to the manipulated object. We propose a symmetric technique between both hands to switch the current stage front face based on joysticks. Up, bottom, right and left joystick triggers are used to apply a 90° rotation to the stage. An asymmetric aspect is introduced in order to turn around the normal current front face. For this purpose, we use the joystick button capability, to choose if we turn in the clockwise or the counter-clockwise direction, according to the hand used.

Manipulations of the conveyor are physically constrained, thus, the manipulated object can not pass through an obstacle. As shown in Figure 2b, the rotation is made with a modified version of the grab-and-twirl metaphor. Compared to the classical version, the pitch rotation is performed with a metaphor close to a plane yoke by orienting the two controllers to the top or to the bottom. The scale of the object is controlled with a grab-and-scale metaphor by bringing closer or further the two Razer Hydra controllers while pushing two corresponding buttons (cf. Fig.2c). According to the selected mode, the object scale can be defined as uniform, based on the distance between the two controllers, or non-uniform by projecting the distances on the x,y and z axis of the *Ant*'s stage.

Two visual feedbacks are rendered to make the *Ant* understand the distance between the manipulated object and possible obstacles. First, we render particles at the collision points. Second, a virtual grid visible in blue at bottom in Figure 1b, parallel to the user current front face, is displayed outside of the object. In addition to these feedbacks, we compute a filling ratio that is displayed in the integrated Graphical User Interface (GUI). It allows the *Ant* to be aware of the courses filling by the manipulated object, and to maximize it by using this quantitative ratio as well as the 3D visual feedbacks.

In some particular situations, local interactors can be integrated at scale one in the VE. For instance, in the example given in Figure 5b, buttons are available in the scene for triggering different actions such as opening doors. These buttons are too smalls for the *Giant*. Therefore, as the two Razer Hydra controllers are rendered into the VE, the *Ant* can use them to interact with these local interactors. Here, by touching one button with one of the controller, the *Ant* can trigger the corresponding action.

To guide the *Ant* when he is placed in a closed environment such as the provided labyrinth, different spatial cues can help him. They are shown in Figure 1b. First, a World-In-Miniature [17] shows a third person view that focuses on the manipulated object. Second,

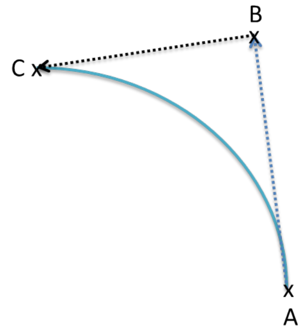


Figure 3: Scheme of the technique used to apply rotation to the object using the *Giant*'s bentray. A and B are respectively the beginning and the end of the straight, not rendered, ray. C is the end of the rendered bentray. Axis of rotation is computed as the cross product between $\overrightarrow{AB}$ and $\overrightarrow{BC}$.

an arrow simulates a compass to show him the direction to follow. Third, in the labyrinth, the path to follow is also indicated with arrow signs.

As shown in Figure 1b, a progressive transparency effect is applied to the manipulated object from the screen extremities to the screen center. This technique is adapted from the proposal described in [9]. Here, it is used as an anti-cybersickness filter that aims to make the peripheral view of the user consistent with his head movement. Therefore, the user's peripheral view is less disturbed by translations performed by the *Giant*. Some preliminary evaluations of this effect have been performed in another context and have shown good results.

For awareness issues, the viewpoint of the *Ant* is shown to the other users by displaying his frustum and stage up vector.

4.3 Concurrent Manipulation

As optional collaboration possibilities, we provide concurrent manipulation capabilities for the rotation and the scale of the object.

4.3.1 Rotation

We propose an optional rotation control scheme based on the concurrent action of the *Giant* and the *Ant*. In some particularly difficult circumstances, for instance if the *Ant* is completely lost and does not achieve to find the correct way to orient the object, the *Giant* can help him to rotate the object by acting on the *Ant*'s conveyor orientation. For this purpose, the Giant can use his bentray-based interaction technique as explained in scheme Fig.3. The interaction starts when the bending of the ray is up to a specific threshold, i.e when $\overrightarrow{BC}$ length is up to 2.0m in our implementation. Then, the manipulated object rotation is controlled based on velocity according to the $\overrightarrow{BC}$ length, as follow:

```
Each frame
if $\overrightarrow{BC}$.length > threshold then
    angle = $((\overrightarrow{BC}.length - threshold) * velocity * deltaTime)^2$
    object.rotateAround($\overrightarrow{AB} \times \overrightarrow{BC}$, angle)
end if
```

It results in a concurrent manipulation with the rotation capability of the *Ant* that is performed by integrating both actions with a growing *Giant*'s factor according to its ray bending.

4.3.2 Scale

The scale control is shared between the *Ant* and the user of the GearVR. To solve this concurrency, we add the factors that the two users want to apply to the scale. Thus, the fuse of the concurrent scale control is not based on an average method, but on a relative setting that allows synchronous manipulation without conflict. It means that each frame, each user asks to the scale manager component to increase or decrease the object scale by a vector. Then, this manager adds all the requests and sets the object scale accordingly if possible (i.e taking care of environmental physical constraints).

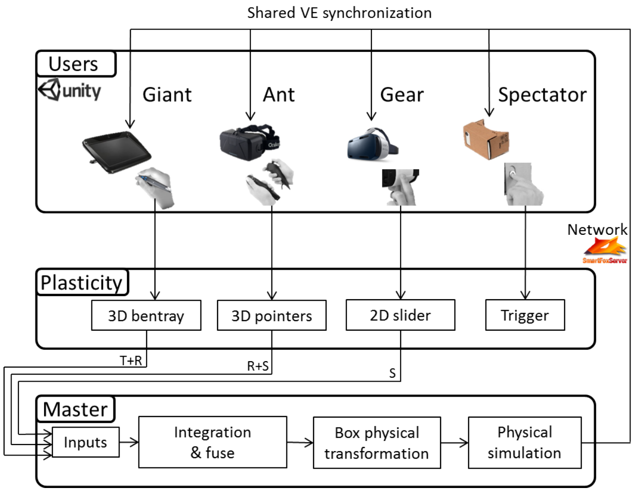


Figure 4: The global architecture of our implementation. T,R and S respectively refer to translation, rotation and scale.

5 IMPLEMENTATION

Regarding the implementation of the prototype, Figure 4 illustrates the architecture of the application. A software overlay of SmartFox Server[6] is used to manage collaboration. It ensures the synchronization of the shared VE between the different users as well as a consistent physical simulation. For rendering, scripting and managing the scene we use the Unity3D game engine[7]. The interaction part is independent from the devices and from the game engine used. Indeed, it is developed with an implementation of the plasticity models presented by Lacoche et al. [8]. With this solution, each user automatically benefits from the adapted interaction techniques according to his available devices. These plasticity mechanisms also give us the possibility to easily exchange the current devices used. For instance, we could use an HTC Vive[8] instead of the combination Oculus Rift / Razer Hydra for the *Ant* or any desktop environment instead of the Google Cardboard for the spectator.

6 PRELIMINARY TESTS

We did not perform any formal evaluation. However, we tested our approach with different users and scenarios. These first test users have experience with VR applications and 3D interactions. Regarding the commands of the *Ant*, we first tried the classical version of the grab-and-twirl metaphor in order to modify the manipulated object rotation. The different users did not feel comfortable with this interaction and they seemed to perform better with our interaction technique that reminds a plane yoke. Indeed, as the user is placed inside the object, controlling it as the user would control a vehicle seemed more natural. To continue, the different visual feedbacks for the *Ant* for making him understand his spatial relationship with the environment were added after multiple tests. Indeed, as the user did not known well the different labyrinths, they seemed to bo relatively lost after multiple movements. For the *God*, we have compared the bent ray with a classical straight one without any speed limitation. This approach was really easy to understand for the *God* but it was really disturbing for the *Ant* to move as fast. Moreover, when the *Ant* was translated too fast, he did not have the time to anticipate the next obstacles and adapt his rotation.

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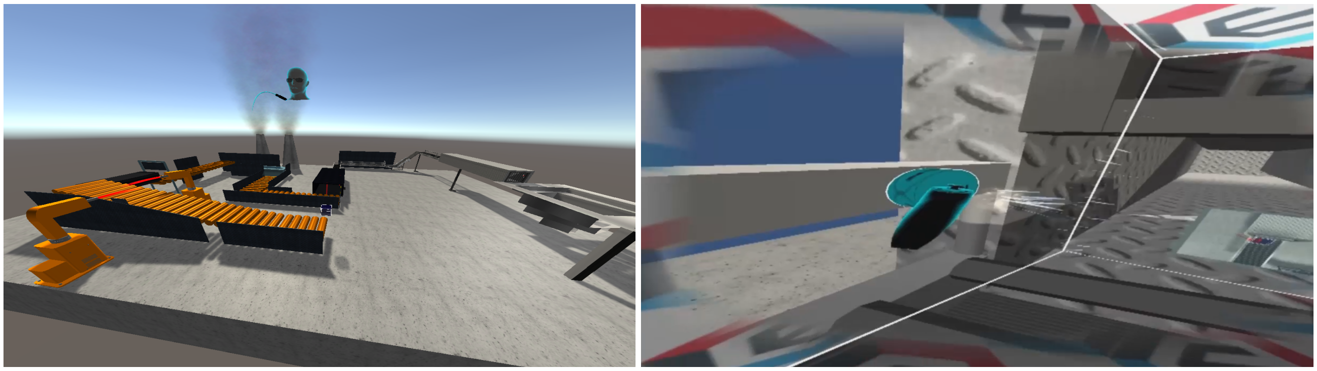
[6] `http://www.smartfoxserver.com/`
[7] `https://unity3d.com/`
[8] `https://www.htcvive.com/us/`



(a) (b)

Figure 5: The virtual factory scene that provides scale-one interactions. Buttons are present in the scene to trigger different actions such as opening doors or painting the object. Triggering these actions is needed to fulfill the task. Therefore, as shown on (b), the *Ant* has direct manipulation capabilities, he can push a button by colliding it with one of his controllers.

7 CONCLUSION & PERSPECTIVES

In this paper, we proposed an asymmetric approach for co-manipulation in shared multi-scale environment. It is based on the collaboration between a *Giant* with a global view of the scene and an *Ant* immersed inside the manipulated object. Additional users can also be included to help the two main users in their task completion. Moreover, our approach benefits from a plasticity mechanisms that handle the automatic adaptation of the interaction technique according to the device used by the different users with heterogeneous setups.

This work has been proposed to complete the different tasks required by the IEEE 3DUI contest 2016. An illustrative video has also been published with the short descriptive paper [10].

Preliminary users tests show a good efficiency of the different interactions techniques. A formal evaluation should be done in order to confirm the performances of the approach. First, it would be interesting to compare our proposal with a solution from the state-of the art where the collaboration is symmetrical, i.e with equivalent roles and viewpoints. Second, our solution includes an oral communication between the different participants. It would be interesting to evaluate the set of interaction techniques without this oral communication. As a result, we could include other awareness mechanisms in order to improve the collaboration when the participants can not talk with each other.

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