Context-Based 3D Grids for Augmented Reality User Interfaces

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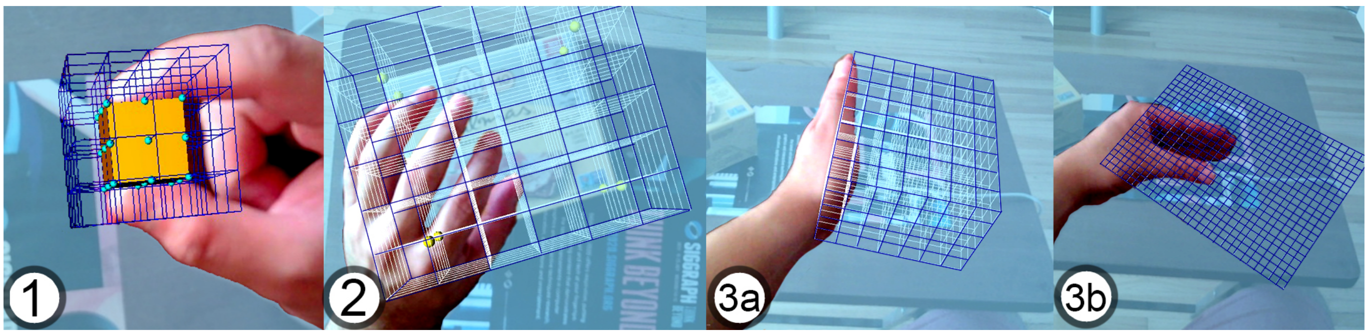

Figure 1. 1) When the user selects an object, object-bound grids are generated based on the object's scale, shape and orientation. 2) Users can use their non-dominant hand to invoke a 3D grid on top of an object in the scene. 3) Users can also add precision (a) and context (b) grids to the scene using natural hand gestures with their non-dominant hand.

ABSTRACT
Accurate 3D registration of real and virtual objects is a crucial step in AR, especially when manipulating those objects in space. Previous work simplifies mid-air 3D manipulations by removing one or more degrees of freedom by constraining motion using automatic algorithms. However, when designing objects, limiting the user's actions can affect their creativity. To solve this problem, we present a new system called *Context-based 3D Grids* that allows users to do precise mid-air 3D manipulations without constraining their actions. Our system creates 3D grids for each object in the scene that change depending on the object pose. Users can display additional reference frames inside the virtual environment using natural hand gestures that are commonly used when designing an object. Our goal is to help users visualize more clearly the spatial relation and the differences in pose and size of the objects.

Author Keywords
Augmented Reality; 3D User Interfaces; Design; Spatial Cognition; Gestures

CCS Concepts
•Human-centered computing → Mixed / augmented reality; Gestural input;

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INTRODUCTION
Augmented reality (AR) user interfaces help people design new objects by adding virtual content to the real-world [9, 21, 18]. This allows users to work directly in a 3D environment while taking advantage of the visual and haptic feedback provided by the real-world. These characteristics can simplify the process of object creation [23, 12]. However, besides the physical act of making the object, designing an object also depends on 3D visualization and the perception of 3D space, as users need to imagine how the object will look like while creating it. When thinking spatially, users face challenges. For example, although 3D registration has greatly improved in the last decade, there is room for improvement in the actual display technology [14], which presently renders the estimation of object size [8] and orientation [7] difficult. These challenges put a high cognitive load on the user's spatial skills, which can affect the performance of low spatial-ability users [2, 16].

To address these issues, we adapted Baudish's adaptive 3D grid [3] to AR in a new system called *Context-based 3D Grids* (Figure 1) that augments the real world with virtual content designed to extend a real-object shape to mid-air by providing different reference frames. Our system surrounds each object in the scene with a virtual 3D grid that helps users visualize the transformations operated while manipulating the object. Users also use natural hand gestures to display additional reference grids inside the virtual environment to help their spatial thinking. Finally, our system does not constrain the user's actions as it only provides visual feedback.

Use of Hand Gestures During the Design Process
Designers perform exploratory gestures as an aid to their spatial thinking when sketching or sculpting an object [6] to

describe spatial conditions [6] and to visualize the change of an object [25]. For example, Chandrasegaran et al. [5] did a systematic analysis of peoples' actions while designing an object and found that designers use their hands to point and to describe geometry and motions. Despite the importance of using hand gestures to describe spatial relations and other object conditions, previous AR user interfaces use other taxonomies of gestures to interact with the system [17, 19]. In opposition to these user interfaces, *Context-based 3D Grids* uses natural gestures to display reference frames inside the VE, which makes the interaction intuitive and fast.

AR Reference Frames For Object Design

AR user interfaces use different techniques to help users do precise 3D manipulations. For example, by making the virtual content interact with the objects in the real world [15, 4, 20], or by displaying visual templates on real-world objects [9, 26]. Finally, other systems superimpose 2D grids to the real-world [11, 23]. However, some of these systems need to know the user's goal and do not extend to mid-air. More importantly, they only provide one type of reference frame, which does not encompass all possible scenarios [24]. To solve these problems, *Context-based 3D Grids* display different types of reference frames inside the VE that are not task-dependent. These reference frames make comparing the pose of different objects easier.

CONTEXT-BASED 3D GRIDS

We aimed to help users focus on designing an object by removing the conscious engagement generated through constant interaction with the user interface, e.g. clicking on buttons or changing the mode [22]. Our goal is to avoid breaking the design flow, thus interfering with the creative process by making the interaction intuitive [13]. At the same time, we aimed to improve the users' spatial perception and visualization by highlighting the differences in scale and orientation between objects [8, 7]. Our work extends previous work on 3D reference frames like The Cage [3] and Smart3DGuides [1].

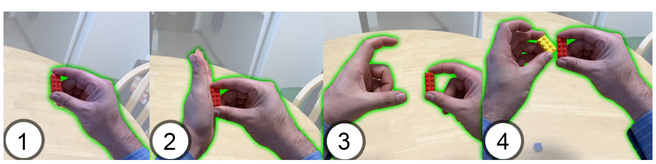


Figure 2. Natural hand gestures used in *Context-based 3D Grids*. 1) Grab an object, 2) Use non-dominant hand as reference plane, 3) Use non-dominant hand as scale reference, and 4) Compare two objects.

User interactions

We designed the gestures to invoke the reference frames using the spatial gestures identified by Chandrasegaran et al. [5] as a base. Then, we ran a pilot study where an expert designer modelled ten different 3D shapes using clay to verify that our gestures are used when designing 3D objects. The four selected gestures are shown in Figure 2. Users utilize both hands to interact with the system similar to Hayatpur et al.'s work [10]. The dominant hand moves the main object, and the non-dominant hand selects the reference frame to display.

Reference Frames

Context-Based 3D Grids can display four reference frames. The first one is an **object-bound reference frame** that works as a visual widget to see the object's local pose, and provides a local visual frame to help users do precise manipulations. This reference frame surrounds each virtual and real object in the scene with a virtual 3D grid extends the object reference frame to mid-air, rendering the object pose more clear to the user. The other three reference frames are **hand-based reference frame** and change depending on the user's current hand gesture. These reference frames help users compare the selected object pose with that of other objects and with the user's hand. Figure 3 describes all reference frames in detail.

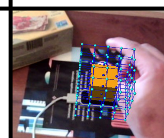
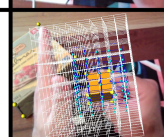
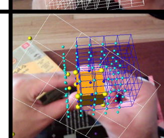
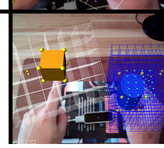
		Gestures	Reference Frames
Object-bound grid		Dominant Hand: Select Object Non-dominant Hand: Nothing	Object-fixed: Appears around selected object Hand-based: Nothing
Precision grid		Dominant Hand: Manipulate Object Non-dominant Hand: Straight near object	Object-fixed: Object current transformation Hand-based - Precision grid: It is an extension of object-fixed grid. The non-dominant hand also works as a plane to control the action.
Context grid		Dominant Hand: Manipulate Object Non-dominant Hand: Curved in C shape	Object-fixed: Object current transformation Hand-based - Context grid: It extends the hand orientation The cell size is based on the distance between the user's fingers.
3D grid		Dominant Hand: Manipulate Object Non-dominant Hand: Touch another object	Object-fixed: Object current transformation Hand-based - Context grid: Object current transformation.

Figure 3. The four reference frames. A) Object-bound Grid, B) Precision Grid, C) 3D Grid, and D) Context Grid

Implementation

We implemented *Context-Based 3D Grids* using C# in Unity (version 2019). For the AR module, we used Vuforia (version 9.2) and an AVerMedia web-camera (1080/30fps). For gesture recognition, we used a Leap Motion. The main limitation of the current prototype is the incorrect occlusions and inexact hand tracking caused by the hardware used. We expect this problem to disappear once we upgrade the web-camera to a Hololens.

CONCLUSION

We propose *Context-Based 3D Grids*, an AR system that helps users with their spatial visualization when designing a 3D object by displaying four different reference frames. These reference frames may help users do precise 3D manipulations in mid-air without constraining their actions or affecting the design process. Users interact with our system using natural hand gestures that make the interaction seamless and intuitive. Our informal exploration seem to validate our hypothesis. In the future, we will perform a formal user study, as well as implement *Context-Based 3D Grids* inside an AR modelling system for the HoloLens.

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