Creating and Analyzing Stereoscopic 3D Graphical User Interfaces in Digital Games

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ABSTRACT

Creating graphical user interfaces (GUI) for stereoscopic 3D (S3D) games is a difficult choice between visual comfort and effect. We present a S3D Game GUI Design Space and a list of S3D-specific attributes that emphasizes integrating visually comfortable interfaces into the game world, story and S3D view. To showcase our approach, we created two GUI concepts and evaluated them with 32 users. Our results show quality improvements for a combination of bottom position and visual attachment for a menu. In a referencing interface, placing the reference near to the target depth significantly improved perceived quality, game integration, and increased presence. These results confirm the need to create S3D GUIs with perceptual constraints in mind, demonstrating the potential to extend the user experience. Additionally, our design space offers a formal and flexible way to create new effects in S3D GUIs.

Author Keywords

Stereoscopic 3D; game; graphical user interface; design space; depth; user experience; presence; visual 3D quality.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous. H.5.2 User Interfaces (D.2.2, H.1.2, I.3.6)

INTRODUCTION

Many of today's digital games can be played with S3D vision. However, only a few games are explicitly designed with stereoscopic vision in mind, offering the same content with added perceived depth. Thus, common GUI patterns like a global menu bar or labels referencing specific 3D objects somehow appear on top of deep spatial impressions of the game world. The added depth suddenly changes how we perceive these GUIs. For example, they might suddenly appear too distant from an underlying object. Given the expected growth of S3D content in the coming years due to next generation video game consoles and the arrival of autostereoscopic displays, we lack a formal approach of creating interesting and comfortable GUIs in these games.

Figure 1: S3D image pair of our evaluation game prop. (use parallel free view for S3D impression)

The aim of this paper is to support creating new and comfortable game GUIs (e.g., menus and icons) in S3D games. We first analyze benefits, challenges and perceptual requirements of S3D GUIs. This analysis led to our proposal of a S3D Game GUI Design Space and specific S3D interface patterns that relate to spatial and diegetic integration of game UI elements in stereo games. We subsequently showcase using the design space to develop two S3D game GUI concepts. A user study explores their impact on user experience within the context of several metrics including perceived 3D image and game GUI quality, game integration, presence, and simulator sickness. The final section discusses transfer of this impact back into the design space and its applicability in S3D GUI creation.

RELATED WORK

Benefits of Stereoscopic 3D

Playing S3D games is often preferred over non-stereoscopic versions [22]. S3D provides additional information about spatial location, size, shape, or orientation of 3D objects [7]. In medical telepathology settings, S3D offers superior image quality with regard to resolution, color and surface structures [8]. Performance in visual information processing can be increased up to ten times [27]. An actual performance benefit in video games was not found in general, only in isolated 3D manipulation tasks [13]. Virtual scenes [11], video clips [9] and games [22] experienced in S3D induce an increased perceived presence and immersion [18]. Images appear more natural in S3D [18] and gamers tend to interact more directly with them [22]. An S3D scene draws more attention towards details requiring more time to explore it [10].

Challenges and Disadvantages of S3D

S3D benefits can only be expected if the stereoscopic vision is not accompanied by distortions (e.g., contradicting depth cues, ghosting/cross-talk, exaggerated disparity) [29].

Another important issue is the accommodation convergence conflict: the accommodation is fixed to the distance of the screen plane while the convergence varies with the fixated parallax; the two cues are separated, causing an unnatural viewing experience. To solve this issue, the parallax should remain within a so-called comfortable viewing range (CVR) [24]. Bad S3D can cause a negative experience due to visual discomfort [15] associated with symptoms of visual fatigue (e.g., eye strain, headache) [6]. Even watching high quality S3D can induce simulator sickness [19].

Existing Findings concerning S3D Game Interfaces

Based on psychophysiological findings, previous work proposes recommendations for GUI design: A head-up-display (HUD) should be positioned at screen depth or close-by, using depth and transparency. Some elements can be raised slightly to add visual interest [21]. A previous analysis of game GUIs for designing visual elements in 3DTV recommends reducing the amount of graphical information by showing explicit information, (e.g., current round in a racing game), only when the value is updated [23]. The authors further recommend to integrate information implicitly into the scene (e.g., by showing ammunition on the weapon model as in Dead Space), also noted by Mahoney et al. [16]. Referencing objects (e.g., the cross-hair) should be positioned in depth; a laser pointer helps to travel between foreground depths of the weapon to the target object in distant depths [23] as people perform better with a spatial pointing tool than just with a cursor; as viewing the tool helps to assess spatial configuration [25]. It is further proposed to position elements in depth near to the referenced object without being occluded by closer objects, as achieved in Portal 2 [23]. Aside from these findings, we found no formal user evaluation that supports these effects. Given the complex perceptual requirements, a concise design framework could support designers creating and experimenting with game GUI elements in S3D.

APPROACHING S3D GAME INTERFACE CREATION

We start our approach towards developing such a design framework by looking at game GUIs with the special characteristics of S3D vision in mind. The goal is to provide a comprehensive tool that helps designing GUI elements in S3D games, considering their functional purpose, and possible parameters specific to S3D games. A game interface enables the player to communicate with the game and to exchange information in bi-directional ways [20]. Providing feedback and control are the two main goals. We focus on the specialties of graphical S3D feedback. Visual feedback communicates current status of the game (e.g., health, score) or describes concepts within the game [1].

Integration into Story and the Game World

We also take secondary goals into account, namely immersion and atmosphere, which can be combined as presence describing the experience of the game as one's own experience [28]. Hence, the fictional level of the game and the impact of the GUI on the immersive experience is a first main concern towards creating S3D game GUIs.

The other central aspect of stereoscopy is of course the added sense for space and depth. As described, depth positioning implicates a comprehensive set of opportunities and challenges, weighing effect against visual comfort. We thus consider the optimal spatial integration of visual UI elements as our second goal.

In many games, the GUI is designed as an abstract layer, partly occluding the game scene with text or icons, sometimes even parts of the screen are reserved for menus. These elements are clearly separated from the game content itself. By shifting those elements in depth into the game world, to reduce the range of parallaxes in favor of visual comfort, the GUI elements may become part of the game world itself, possibly interfering with the immersion or even appearing to be part of the fictional experience. So how can we arrange GUI elements in 3D space and what does this mean for the fictional level of the game?

In their analysis of visual UI elements in S3D games as an inspiration for 3DTV content, Schild and Masuch group elements into explicit, implicit, and referencing information visualization in games [23]. Explicit elements are common GUI elements giving information on an abstract layer aside. Implicit elements are elements containing functional information through their design within the game world (e.g., the weapon model shows the currently selected weapon). Being part of the game world, these implicit items should be spatially integrated. Referencing elements are part of the HUD but reference objects inside the world.

This categorization describes a gradient between spatial and fictional integration. We further explore this topic using the concept of diegesis. In video games, diegesis comprises the narrative game world, its characters, objects and actions [5] which can be called intra-diegetic. Status icons or menu bars are not part of the game world itself, a game character does not know about them. Those items are extra-diegetic. Considering the spatial position in S3D games, it would be intuitive to position extra-diegetic items on the screen layer, on top of the deeper game world. However, they can still be positioned in the same depths of the game world as well. Also intra-diegetic items can reflect narrative content on an abstract but diegetic meta-level which could not be visualized as an explicit object inside the game world (e.g., making the border of the screen flash bloody red when the main character is hit in a first person shooter). A suitable design space that reflect both the diegetic and the spatial characteristic was proposed by Fagerholt and Lorentzon [4].

Fixing Interfaces to the World and the View

One additional design aspect in S3D games is how interface elements are displayed in the view and how this changes when the view changes within the world. Kim et al. analyzed 3D menus in a head-mounted display. They divided menus into three configurations: world fixed, object-fixed, and view-fixed menus [12]. This concept helps us to identify upcoming challenges and possible solutions.

A view-fixed GUI element stays at a fixed position and orientation within the view of the player (e.g., a head-up display). It may visually interfere with the game world. This could be solved by using a shine-through effect. The parallax can be adjusted to show the world securely behind the screen layer, positioning all view-fixed GUI elements at screen depth. Still, visual design and alignment of the GUI on screen may have a unique impact on usability in S3D. A *world-fixed* menu has a static world position (e.g., the player has to walk to a certain position within the virtual world to control the menu). An object-fixed menu would move with its referenced world object. We combine world-fixed and object-fixed elements into a single world-fixed category with specific issues: How is a reference between a world-fixed GUI and an object visualized (e.g., a spatial line may help changing between depth planes)? Where around the object should the GUI be positioned, what happens if the element is occluded?

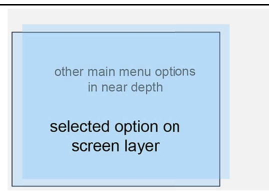
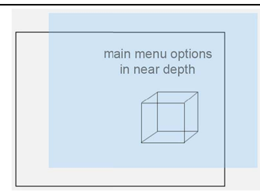
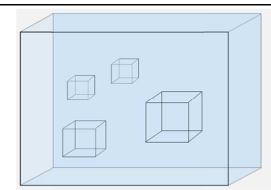
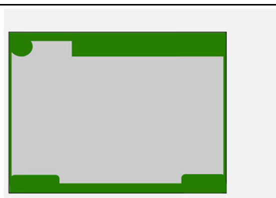
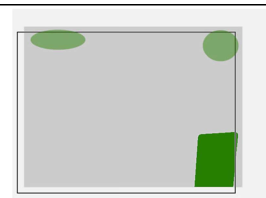
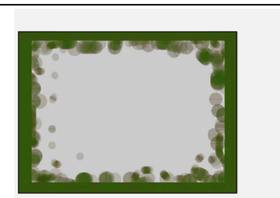
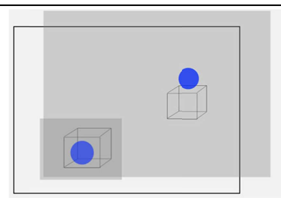
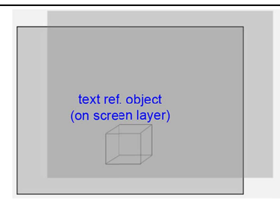
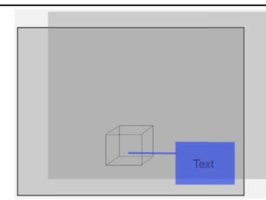
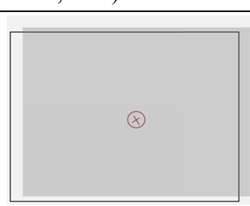
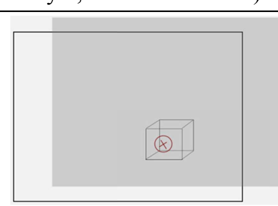
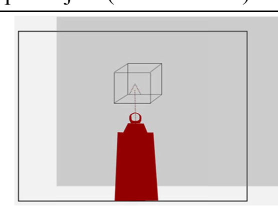
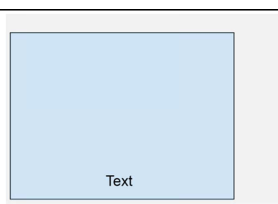
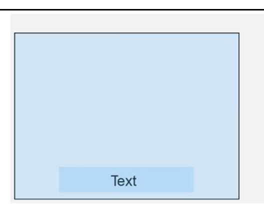
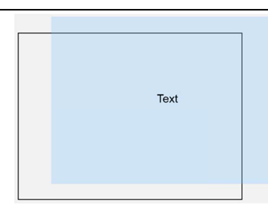
Shell-Interface (SI) Describes the start and configuration of the game, e.g., main menu, settings, save and load, often separated from the game on an extra screen.	 **SI1**: selected/deselected options on different layers (Just Cause 2)	 **SI2**: distribute different options on different layers (Blur)	 **SI3**: menu as scattered 3D objects in 3D space (Metro 2033)
Global Control Interface (GCI) Can provide global status information (e.g., inventory, next task, current position on a map, health status) and menu functionality (e.g., select army, mode switches).	 **GCI1**: opaque elements at screen depth, fixed to the screen border (Civilization 5)	 **GCI2**: transparent or diegetic 3D objects at near depth (mobile phone in GTA4)	 **GCI3**: semi-transparent meta-diegetic effects in periphery of view (Far Cry 2)
Referencing Interface (RI) Augments the world with additional explicit information on specific world objects shown through text or an icon.	 **RI1**: icon or text in front of object or above an object at object depth (Portal 2, Blur).	 **RI2**: icon or text at screen layer referencing an object in depth (Far Cry 2, Fifa Soccer 2011)	 **RI3**: text at screen layer connected with a line to the 2D positon of depth object (Batman: AA.)
Cross-hair Interface (CI) Describes direction of shooting, is a direct spatial reference of the foreground weapon (fixed to the view) towards the target object (fixed to the game world).	 **CI1**: cross-hair is semi-transparent at close depth (Avatar)	 **CI2**: cross-hair has dynamic depth positon, limited by the target object (Crysis 2, Just Cause 2)	 **CI3**: diagetic weapon model at screen depth simulated gun sight (Far Cry 2)
Text Interface (TI) Textual elements provide dialogues, in-game status information, e.g., current speed, or player instructions.	 **TI1**: Text on screen layer	 **TI2**: Text on semi-transparent object at screen layer (Portal 2)	 **TI3**: 2D/3D Text at close depth (Blur)

Table 1. Overview of game UI classifications and possible S3D versions.

A Design Space for Stereoscopic 3D Game GUIs

Based on the previous assumptions, we propose to combine the two models: we exchange the yes/no decision on world-integration [4] with a classification of view-fixed vs. world-fixed elements, similar to Kim et al. [12]. This enforces the focus onto the view which is a key aspect in S3D vision.

Some interface items might even contain properties of both view and world (e.g., position next to a world object but orientation with the view). The same might be true for the intra-/extra-diegetic classification, when game characters directly address the player (e.g., asking to press a certain button during a tutorial). This concept is known as "Breaking the fourth wall", used in more than 200 games[1]. We hence choose seamless dimensions instead of a sharp classification.

The proposed space is a two-fold S3D game GUI design grid covering the categories view-fixed and world-fixed on the horizontal axis and extra-diegetic vs. intra-diegetic on the vertical axis (see Figure 2). The grid helps to decide the spatial and fictional integration of GUI elements, giving each element a 2D position in the grid. This step supports designing a UI element either in resemblance with, or in contrast to the diegetic and spatial design of the game.

Classification of Game Interfaces

As a next step, we describe five typical design patterns commonly used in visual game interfaces: shell interfaces, global control interfaces, referencing interfaces, cross-hair interfaces, and text interfaces. According to what we found in playing existing S3D games, adding depth in S3D vision to these patterns occurs in various ways. Table 1 describes and visualizes exemplary variations for each category

Design Properties of Stereoscopic 3D Game Interfaces

Based on the analysis of related work and many existing games, we extracted a list of properties which might help in crafting UI elements particularly in S3D games. This list is by no means complete as creativity should always try to extend its boundaries. It provides a selected set of design decisions weighing S3D effect against comfort with a certain impact on the spatial and diegetic experience.

Peripheral position: Centered elements are often expected to relate to the world (PeP1). Most elements in the periphery are extra-diegetic control or status displays (e.g., a score value) (PeP2). Diegetic graphical elements in the periphery of the view can implicitly inform about the game status (e.g., blood splatters at low player health) (PeP3).

Vertical position: Elements in the foreground or fixed in the view should be positioned at the bottom (VPo1). Elements in the background/world are expected in an upper part of the view (VPo2). The more diegetic, the more physically correct (in terms of the game physics) it must behave.

[1] http://www.giantbomb.com/breaking-the-fourth-wall/92-138/

Spatial design: World-fixed/diegetic objects should contain the spatial property and thus scale of parallaxes of the scene (SpD2). Extra-diegetic/view-fixed objects should still be embodied (not flat) but at other spatial scales (SpD1).

Depth motion: Dynamic depth motion creates a space around objects which might better fit into the world (DMo2) than being fixed to the view. Here, static design may be better (DMo1).

Attachment: Floating GUIs appear especially abstract and unnatural in stereo. This can be avoided by attaching elements to a surface or to the screen frame which fits view-fixed objects (PhA1). Objects in the world should be physically attached to (PhA2).

Amount of parallax: Objects on the screen layer provide best readability which fits abstract non-diegetic information (AoP1). Spatially positioned near to the screen border, they can be related to the view. A fair amount of parallaxes better references the world (AoP2). Extreme parallaxes cause discomfort and may break diegesis (AoP3).

Sign of parallax: Pop-out effects have to occur without edge violation which at best fits to static view objects. Only few world-objects can use this effect (SoP1). The deeper behind the screen layer an object is, the more it seems belonging to the world (SoP2).

Blur: Abstract, non-diegetic objects should provide visual clarity (Blu1). Blur has a natural quality, which fits better to diegetic GUI objects in the world (Blu2).

Opacity: Occlusion occurs both in the view and in the world. Semi-transparency or a shine-through effect can be used to keep a GUI in the view (Opa1). Interpenetration decreases the diegetic character of an element and seems unnatural. Occlusion feels natural in the world (Opa2).

Reference: Object-specific references often refer to both the view and the world (Ref1), especially the extra-diegetic ones. Highlights marking selections of world objects should be well integrated into the world (Ref2). Global references, describing a game status should only be in the world, when they are diegetic (Ref3), or else fixed with the view (Ref4).

Grouping: As with depth-motion, view-fixed objects should be grouped per depth layer, to avoid creating new spaces which interfere with the world-space (Gro1). Scattering is more natural, fitting to world-fixed elements (Gro2).

Fitting S3D Properties and Interfaces to the Design Space

In Figure 2a, we inserted the aforementioned attributes into our design space, as to how we expect their impact on diegetic/spatial interaction. Likewise, we put all the GUI variants from Table 1 into the same space in Figure 2b. By comparing the two figures, we can easily consider nearby or distant attributes and reflect on creating alternative versions and their effects on user experience. We evaluate this approach in the next section.

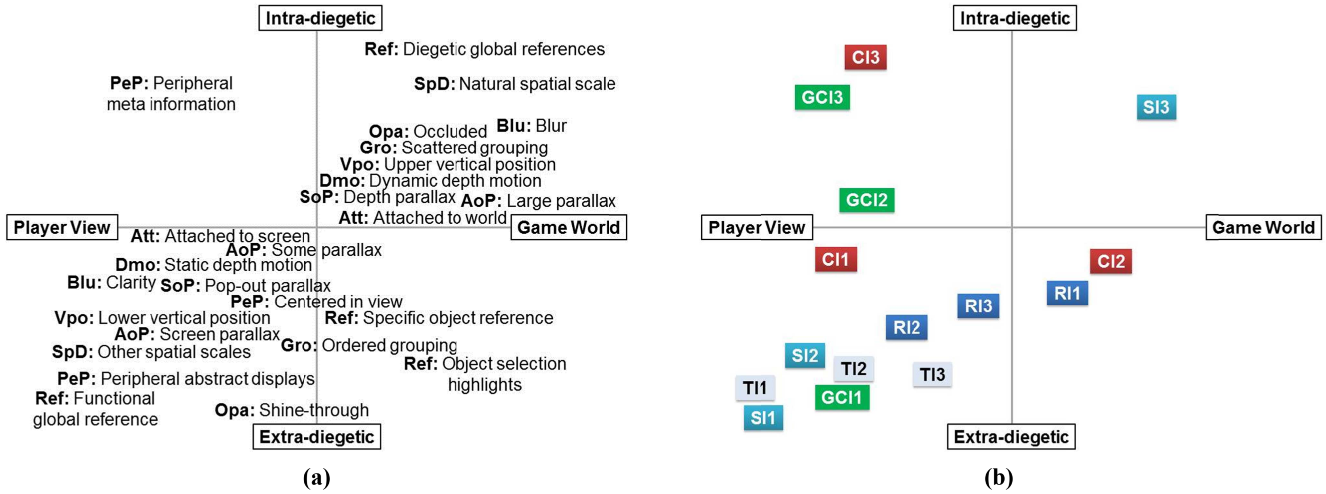


Figure 2. The S3D design grid with (a) various characteristics of the aforementioned S3D design attributes; (b) the same grid showing the aforementioned game GUI classifications. By looking up the 2D position for a certain GUI, important S3D-related design decisions can be extracted.

S3D GUI DESIGN CASE STUDY

The main purpose of our study is to evaluate perceived quality and spatial/diegetic integration of variants created using our S3D GUI design space. There are two general approaches. First, we can check nearby properties, and evaluate their impact on the perceived quality. Is it really important to address these properties as recommended based on psychophysiological findings? A second option is to try shifting an interface towards a different experience. We can address multiple characteristics of a design attribute and evaluate varying versions of our interface. In our case, we will try to increase the perceived spatial integration into the game world. We hypothesize that:

1. Integrating S3D design attributes in the design of game interfaces increases the perceived S3D quality.
2. Varying game interfaces according to S3D specific characteristics affects the perceived spatial experience.

We tasked 32 participants in a simulated gaming situation to rate short S3D video sequences showing different variants of two GUIs in a fictional S3D game scenario.

Method

Prototype Game Setting

To provide a both immersive and controllable game setting, our game prototype consists of a diegetic introduction and video mock-ups: To let users experience a natural game-like situation, we provided the users with a document featuring an introduction to the game situation, an overview map and icon descriptions, along with a background story that puts the test cases into diegetic context:

Short version: *"Yesterday, inspector B. Nocular reached Paris after a long and stressful journey. For a long time he had tried to disclose the secret of the inventor of stereoscopic 3D. One hint has reached him, where a French optician had built the first stereoscopic apparatus in 1850. This information led Mr. Nocular on a sticky afternoon to the old attic of 21 Rue de l'Odéon. The roof is crowded with old furniture, rummages and a lot of boxes. The inspector brought a tool box with useful equipment with one to collect new information about the stereoscope."*

We evaluated visual effects using video mock-ups of the game scene. Non-interactive videos have been successfully used to evaluate interactive interfaces for more than twenty years. They "produce extremely quickly multiple videos which have only one variable changing from the base-line"[2]. As Buxton notes, a video can provide "a real sense of experiencing what this would be like" [3].

The game scene was implemented using Autodesk 3ds Max based on a free 3D model. The model was selected for a balanced arrangement between foreground and background as well as for a depth budget of 10 m at maximum with scattered objects in many depth layers. The avatar (Mr. Nocular) moves in first person view along a predefined animation path through the attic. The parallaxes of the model range from 0 mm to 29 mm (positive). To watch the scene in comfortable S3D, two cameras separated by 63 mm (average inter-ocular distance), were integrated with the additional script "StereoCam Modifier" [17]. Each scene was rendered into a S3D video showing 1680x1050 pixels at 30 fps with a length of 10 seconds. The videos were displayed on a 22" LCD screen at 120 Hz natively running the video resolution in the Stereoscopic Player (3dtv.at) using Nvidia 3D Vision driver and shutter glasses.

Test Cases

Of this scene, we selected two sets which each focus on different design attributes and GUI category: (1) the vertical position and attachment characteristic of a global control interface and (2) the choice of depth layer for a referencing icon interface.

(a) GCI	Attached (At)		Floating (Fl)	
Top (To)	**ToAt**		**ToFl**	
Bottom (Bo)	**BoAt**		**BoFl**	

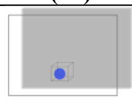
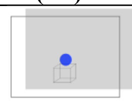
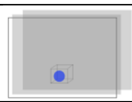
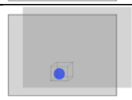
(b) RI	In front (Fr)		Above (Ab)	
Distant depth (Dd)	**DdFr**		**DdAb**	
Near depth (Nd)	**NdFr**		-	
Screen depth (Sd)	**SdFr**		-	

Table 2: Variants (a) of the global control interface (GCI) test case and (b) of the referencing interfaces (RI) test case.

The first set of test cases integrates a status bar as a *global control interface* (containing, a score value, a toolkit and a map) as used in many games (GCI1 in our classification). Regarding our design grid, related attributes include choosing a *lower vertical position*, *screen parallax*, using *other spatial scales*, and *attaching objects to the edge* to avoid floating in stereo. We address the impact on user experience by varying two of these attributes: vertical position and attachment characteristic. Does being used to seeing nearer objects in the lower field of view actually have an influence? Do floating objects really cause issues in S3D? For the two variables we created four different test variants (see Table 2a).

The second set of test cases examines *referencing interfaces* which provide abstract information in reference to a part of the game world (cf. RI1). In monoscopic viewing, showing an icon in front of an object is a clear reference indicator. In S3D the chosen depth layer might influence the perceived reference. The four variants of the referencing interface show an icon indicating a point of interest for a certain object using a similar 2D position. Looking up RI1 in our design grid, we find it next to the specific object reference and near to *some parallax*. *Large parallax* and *screen parallax* are further apart, ranging more towards the view or the world. Respectively we vary the depth position of the icon from screen level, between object and screen, and near to the object at a distant layer. We test the latter variant in two sub-variants: above or directly in front of the reference object (see Table 2b). The icon consists of a blue world-fixed spatial model with the same spatial scale as the scene. It has a black exclamation mark texture and is displayed in relation to a chest in the background of the scene or alternatively in the left corner above a cradle at a similar depth layer (eight variants at four different depth positions).

a) 3D Image Quality		**b) GUI Quality**	
ImQ	Image Quality	PiD	Position in Depth
Sha	Sharpness	VPo	Vertical Position
Nat	Naturalness	Des	Design
ViC	Viewing Comfort	ExC	Expressive Clarity
DeE	Depth Experience	Rea	Readability
c) Game Integration		**d) Simulator Sickness SSQ**	
SpI	Spatial Integration	Nau	Nausea
GwI	Game-world Integr.	Ocu	Oculomotor
StI	Story Integration	Diso	Disorientation
Int	Potent. Interactivity	Tot	Total SSQ
e) Spatial Presence Questionnaire MEC-SPQ			
AA	Attention Allocation		
SSM	Spatial Simulation Model		
SP:SL	Spatial Presence: Spatial Location		
SP:PA	Spatial Presence: Possible Actions		
HCI	Higher Cognitive Involvement		
SoD	Suspension of Disbelief		

Table 3: The set of metrics used in our study with acronyms.

Participants

The sample comprised 32 participants (16 female), mostly students of our university (n=30). The age varied between 20 and 34 years, with a median of 24 years. The participants were offered free fruits, candy and beverages during the test sessions. They received "study points" they need to earn in their courses. The evaluation was approved by our ethics board. All participants were informed about the aim and procedure of the study and had to sign an agreement including a list of possibly occurring symptoms. All participants successfully passed a prior S3D vision test. Over 80% of the sample reported prior experience with S3D cinema movies, 40.6% of the participants about 4-9 times and another 21.9% of the sample more than 10 times. Previous experience for 1-3 times with S3D-TV is reported by about 32% and with S3D games by about 25% of the sample group. General game experience was reported by 28 subjects (87%) with an average game time per week of 1-5 hours (n=16) up to more than 30 hours (n=1).

Metrics

Our set of metrics consists of a combination of adapted image quality metrics and standardized questionnaires (see Table 3). Our *3D Image Quality* metric includes five dimensions (see Table 3a), based on an extended 2D image quality metric (ITU-R Rec. BT. 500) (cf. Lambooij et al. [14]). The analysis of the quality of the game GUI (*GUI-Quality*) was also divided into five dimensions (see Table 3b). All these factors were rated on a continuous scale ranging from "bad" to "excellent". Additionally, the perceived *Game Integration* of the game GUIs was measured with four more items (see Table 3c). Possible dizziness or other subjective disorders were measured using the *Simulator Sickness* Questionnaire (SSQ) [26], (see

(a) GCI[1]		**BoAt>ToAt**	**BoAt>BoFl**	**BoAt>ToFl**	**ToAt>Bofl**	**ToAt>ToFl**	**BoFl>ToFl**	**ANOVA**
GUI-Quality (cf. Table 3b)	VPo	$p<.01$, $d=1.36$		$p<.01$, $d=1.62$	$p<.01$, $d=1.28$		$p<.01$, $d=.1.55$	$F(2.163, 67.062)=30.658$, $p<.01$*
	PiD			$p<.05$, $d=.71$				$F(3, 93)=5.101$, $p<.01$
	Des			$p<.05$, $d=.61$				$F(2.338, 72.483)=4.061$, $p<.05$*
	Rea			$p<.05$, $d=.68$		$p<.05$, $d=.56$		$F(3, 93)=5.360$, $p<.01$
(b) RI[2]		**DdAb>DdFr**	**DdAb>NdFr**	**DdAb>SdFr**	**DdFr>NdFr**	**DdFr>SdFr**	**NdFr>SdFr**	**ANOVA**
3D-Quality (cf. Table 3a)	ImQ			$p<.05$, $d=.46$				$F(1.531, 47.450)=5.202$, $p<.05$*
	Sha					$p<.05$, $d=.58$		$F(1.906, 59.099)=4.951$, $p<.05$*
	Nat		$p<.05$, $d=.76$	$p<.01$, $d=.95$		$p<.05$, $d=.64$		$F(2.491, 77.219)=7.781$, $p<.01$*
	ViC		$p<.01$, $d=.63$	$p<.01$, $d=1.15$		$p<.01$, $d=.88$	$p<.05$, $d=.59$	$F(2.325, 72.076)=16.351$, $p<.01$*
	DeE			$p<.01$, $d=1.03$	$p<.05$, $d=.75$	$p<.01$, $d=1.04$		$F(2.239, 69.413)=11.825$, $p<.01$*
GUI-Quality (cf. Table 3b)	VPo	$p<.05$, $d=.87$	$p<.01$, $d=.86$	$p<.01$, $d=1.21$				$F(2.515, 77.969)=8.734$, $p<.01$*
	PiD		$p<.01$, $d=1.68$	$p<.01$, $d=2.71$	$p<.01$, $d=1.16$	$p<.01$, $d=2.09$	$p<.01$, $d=.72$	$F(3, 93)=49.855$, $p<.01$
	Des		$p<.05$, $d=.6$	$p<.01$, $d=.86$				$F(3, 93)=6.059$, $p<.01$
	ExC		$p<.01$, $d=.93$	$p<.01$, $d=1.11$		$p<.01$, $d=.5$		$F(2.37, 73.455)=10.261$, $p<.01$*
	Rea							$F(2.110, 65.423)=4.535$, $p<.05$*
Game Integration (cf. Table 3c)	Spl		$p<.01$, $d=.93$	$p<.01$, $d=1.6$		$p<.01$, $d=1.04$	$p<.01$, $d=.64$	$F(1.984, 61.504)=15.148$, $p<.01$*
	Gwl		$p<.05$, $d=.6$	$p<.01$, $d=1.08$		$p<.01$, $d=.8$	$p<.05$, $d=.51$	$F(3, 93)=12,237$, $p<.01$
	Stl		$p<.01$, $d=.7$	$p<.01$, $d=.973$	$p<.01$, $d=.54$	$p<.01$, $d=.82$		$F(2.369, 73.449)=15.424$, $p<.01$*
	Int				$p<.05$, $d=.74$	$p<.01$, $d=1.17$		$F(2.098, 65.027)=8.509$, $p<.01$*
MEC-SPQ (cf. Table 3e)	SP:SL			$p<.01$, $d=.8$		$p<.05$, $d=.77$		$F(2.330, 72.230)=14.022$, $p<.01$*
	SP:PA			$p<.01$, $d=1.1$		$p<.01$, $d=.99$		$F(2.013, 62.413)=8.576$, $p<.01$*
	HCI					$p<.05$, $d=.66$		$F(2.140, 66.352)=3,07$, $p=.05$*
	SoD			$p<.05$, $d=.46$		$p<.01$, $d=.5$		$F(3, 93)=3.681$, $p<.05$

[1]cf. Table 2a, [2]cf. Table 2b, * Significance using „Greenhouse-Geisser"-correction; d = Cohen's d effect size..

Table 4. Pairwise comparisons of significant differences (a) for the Global Control Interface and (b) the Referencing Interface

Table 3d).It contains three dimensions, measured through 16 items on a 4-level Likert scale (ranging from "no symptoms" to "severe symptoms"). The three dimensions are combined in a Total SSQ metric. *Spatial Presence* was measured by the short version of the MEC Spatial Presence Questionnaire (MEC-SPQ) [28]. It includes six dimensions (see Table 3e), each assessed using four items.

Procedure

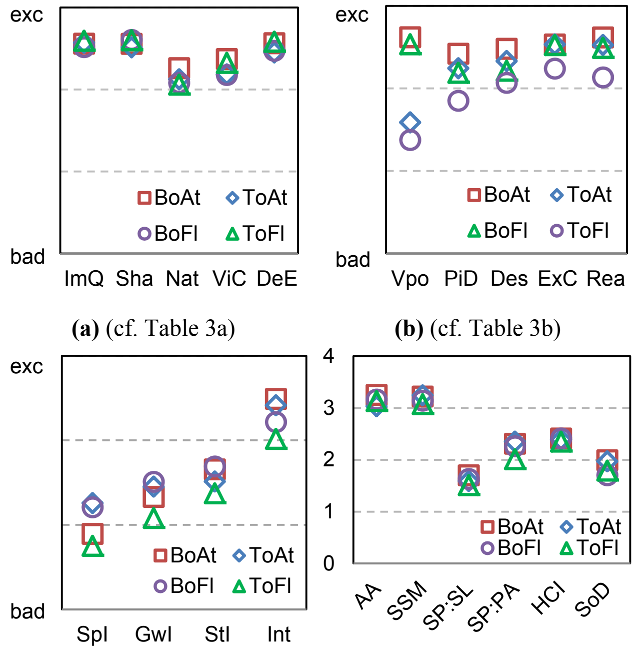
The study was conducted in a testing lab on campus. Test material, metrics, hardware, lighting conditions and viewing distance remained identical. Two computers were used to display test videos and questionnaires separately. The participants could switch computers by turning their chair. We collected demographic and SSQ pre-condition data and started with an entry video of the attic scene (30 seconds long, repeated for 2-3 times). After the introduction the investigator took a back seat without watching the displays. Each participant then viewed 8 test sequences, four sequences with the GCI and four sequences with the RI in one of both variants (reference to chest or cradle) in randomized order. Each video sequence included three repetitions (10 seconds each), separated by a black image (3 seconds). After each sequence, the screen remained black and the questionnaire (S3D quality metrics and MEC-SPQ) was presented at the other computer. The participants could then start the next sequence. The post-SSQ was measured to detect physiological discomfort. Finally the investigator thanked for the participation and handed the gratification. A whole session took about 80 minutes per participant.

Results

The results are analyzed using repeated-measures analysis of variance (ANOVA) with Bonferroni post-hoc-correction for pair-wise analysis. In case of a positive Mauchly-Test the Greenhouse-Geisser correction is used. For the sake of clarity, we divide the rating/likert scales into three equal parts, calling mean values "low/negative" (0 to 30 for the rating; 0 to 1.33 for likert), "average/medium" (30.1-60; 1,34-2.66), or "high/positive" (60.1-90; 2.67 to 3).

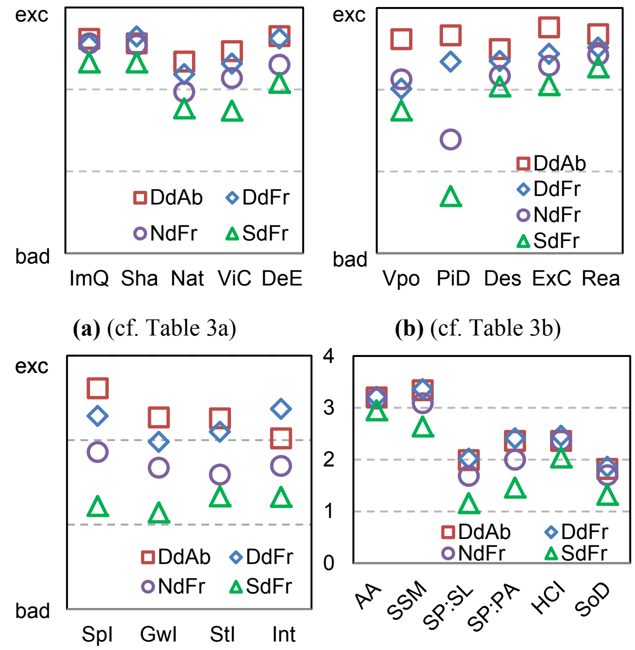
Global Control Interface (GCI)

The *3D Image Quality* analysis of the GCI shows no significant differences between the mean values of the four variants for all five metrics. They all range positively. The game *GUI-Quality* was judged more differently. Most dimensions are positive except for average means in both top position menu configurations (ToFl, ToAt) in Vertical Position and for ToFl in Position in Depth. Bottom placement and attachment (BoAt) always gains the highest mean score, while ToFl shows always the lowest mean. These differences are significant in VPo, PiD, Design, and Readability. The largest effect is in VPo: For both settings of attachment, the bottom vertical position is significantly preferred (BoAt>ToAt; BoFl>ToFl). The attached versions gain higher means across all items than the according floating versions with identical vertical positions, but none



(a) (cf. Table 3a) **(b)** (cf. Table 3b) **(c)** (cf. Table 3c) **(d)** (cf. Table 3e)

Figure 3. GCI results in (a) 3D Image Quality, (b) GUI Quality, (c) Game Integration and (d) Presence.



(a) (cf. Table 3a) **(b)** (cf. Table 3b) **(c)** (cf. Table 3c) **(d)** (cf. Table 3e)

Figure 4. RI results in (a) 3D Image Quality, (b) GUI Quality, (c) Game Integration and (d) Presence.

of these differences are significant except one: Rea is significantly yet slightly higher for ToAt than for ToFl.

The results for the *Game Integration* items resulted in low to average means for Spatial Integration, average values for Game-world and Story Integration. All mean values for potential Interactivity are positive. The ANOVA shows a significant impact of the design variants in Spl and Int, but we found no pairwise significant effects. *Presence* results generally show high means for AA, SSM, average means for SPPA and HCI, and low means for SPSL and SoD. We found no significant impact on presence by the different variants, except for a trend in SPPA (BoAt > ToFl).

Referencing Interface (RI)

In contrast to the GCI, the analysis of the *3D Image Quality* of the RI shows interesting effects for the variants. Positioning the icon at screen depth (SdFr) constantly provides the lowest mean values across all dimensions. The highest mean scores are delivered by the icon position directly above the related object at distant depth (DdAb), except for Sharpness with a preference for the presentation in front of the object at distant depth (DdFr). Generally, all means are positive except for a rather average Nat at SdFr and NdFr and average ViC at SdFr. The pairwise comparison shows significant differences between one or both distant depth conditions (DdAb, DdFr) and SdFr (sometimes even with NrFr), indicating improvements for all *3D Image Quality* metrics at the more distant depth.

As to the *GUI-Quality*, DdAb again scored the highest means and SdFr the lowest across all items. All other values are positive except the following: SdFr is rated especially low in Position in Depth and average in Vertical Position, NdFr gets an average mean rating in PiD. Both Distant depth conditions (DdAb, DdFr) are rated significantly more positively for PiD than the other two depth conditions (NdFr, SdFr) and even the NdFr is rated better than SdFr. Means of DdAb are significantly higher than all other conditions in VPo, even than DdFr, and higher than SdFr and NdFr in Design and Expressive Clarity.

Likewise for the *Game Integration* ratings, DdAb scores the highest means for DdAb in all dimensions, except for DdFr is highest in Interactivity. SdFr always receives the lowest means. DdAb and DdFr are rated positively across all dimensions, except DdFr is average in Game-world Integration. All integration means for SdFr and NdFr are average. This difference is reflected significantly in the post-test: Both Dd conditions significantly outperform SdFr and partly NdFr in Spatial Integration, Story Integration, and GwI. Even NdFr is significantly rated higher than SdFr in SpI and GwI. DdFr is rated significantly more potentially interactive than SdFr and NdFr.

In contrast to the GCI, the RI variants influence the perceived *Spatial Presence*: We found highest mean values for DdFr and lowest for SdFr, but little absolute difference between DdFr, DdAb and NdFr. In general, we found high means for AA, mostly high SSM (except SdFr), and average means in SP:PA, SP:SL, HCI and SoD, except for SdFr, which received low means in SPSL and SoD. These differences were significant between the Distant depth conditions and SdFr in SP:SL, SP:PA, and SoD. For HCI we only found a significant effect with DdFr to SdFr. AA and SSM show no significant differences.

SSQ and other findings

Regarding *Simulator Sickness*, we found higher post-values in Ocu, Diso, Total, but not in Nau. However, based on a Wilcoxon-signed-rank test, none of these differences were significant. Looking at the genders separately, we found both strong and significant effects only with females in Diso (Z=1.981, p<.05), Ocu (t_{15}=-2.328, p<.05) and Total SSQ (t_{15}=-2.229, p<.05). As to the different versions of the RI videos, four referencing a chest and four referencing a cradle, we found no significant differences in any metrics.

DISCUSSION

Our study revealed interesting impact from varying visual effects on user experience using the test cases.

Global Control Interface

With the view-fixed status bar at the bottom or the top, either attached to the edge using a semi-transparent bar, or floating freely, we found a significant impact of the vertical position as a design aspect in S3D GUIs, directly affecting how the quality of the GUI is judged. The other dimensions are only influenced by vertical position in combination with the semi-transparent background versus the floating version. No significant decrease was found by just putting a menu to the top position with an unchanged attachment condition. All mean values for attached variants are higher than their floating counterparts, but not significantly, except for one: Visual attachment improved readability over Floating only in the top position conditions. Therefore both vertical position and visual attachment may significantly influence perceived quality of a foreground GUI object, but at best in a certain combination of the two. In our case, designing a menu bar at the bottom with a semi-transparent background to provide attachment to the screen was clearly preferred over floating objects at a top position.

Referencing Interface

The analysis of the RI with the spatial icon, positioned in depth to relate to a world object, brought more comprehensive results. Overall, the distant depth conditions clearly outperform the screen depth conditions across all tests. Choosing a depth plane next to the world object significantly improved *3D Image Quality* including Visual Comfort and Naturalness, and *GUI-Quality*, with preferred Vertical and Depth position, and gains in perceived Design, and Expressive Clarity. The Distant depth position also increased how integrated the GUI feels with the game space and the story, helping to perceive it more as part of the game world. Our participants noted a higher potential of Interactivity. These effects are further constituted in higher presence results in Self Location and Possible Actions.

Besides the problematic Screen depth, placing the icon at Near depth brought some improvement but was still outperformed by Distant depth condition in many tests and felt less natural. Within the two Distant depth conditions, the Above condition scored higher mean scores, except for presence. Of these differences, only Vertical Position in the *GUI-Quality* test was significant, though.

Based on these results, moving a referencing interface into the depth of the target object and placing it slightly above is highly recommended. It can improve visual and interactive quality and adds to the spatial and diegetic integration into the game world. However, such a design can cause occlusion problems, when the icon is referencing an occluded object. In our case, the cradle and so the icon were partially occluded during the video by foreground balks. This had no effect our results. It would be interesting to examine perceived quality and game world integration when showing the icon shining through occluding balks.

Reflections on the S3D Game GUI Design Space

We created our test cases using the proposed design grid which lets designers put GUI attributes in relation to the view or game space and to the game story or an abstract layer. Both our test cases report an impact on quality by different characteristics of S3D-relevant attributes (e.g., Vertical Position, visual attachment, or Position in Depth). This confirms our first hypothesis. Only for the second test scenario, we found an impact on *Game Integration*. As a result, the different Distant depth-variants would be positioned more to the upper right on the grid in comparison to RI1, describing the added spatial and diegetic integration. This repositioning also fits to the direction of the near and distant parallax attributes. This result not only confirms our second hypothesis but shows that we can vary the design towards more distant S3D attributes, increasing the experience of world integration and presence, one of the few known improvements in S3D games. Likewise, in case of the first test case, we chose to vary attributes quite near to the GUI pattern within the design space—and found no impact on world integration.

CONCLUSIONS

We have proposed a S3D Game GUI Design Space that emphasizes the spatial and diegetic integration of GUI elements within the game world. We used the design space to create a global control interface, a menu, with varying vertical position and visual attachment, and a referencing icon interface exploring the choice of depth layer.

As posed in our hypotheses, the created variants affected UX differently: We found strong quality improvements for a combined use of bottom position and visual attachment for the foreground menu. In a referencing interface, putting the reference near to the depth of the object significantly improved perceived quality, spatial and diegetic integration, and increased presence. The impact on spatial and diegetic integration can even be mapped back into the design space.

This shows how visual S3D interface design and perceptual constraints can influence user experience. It further demonstrates applicability of the S3D Game GUI Design Space. As a first formal yet flexible creation tool, it is intended to support others in creating novel S3D Game GUI designs and evaluations with their games and genres. Such future creations and analyses will eventually lead to even more generally valid findings for designing S3D GUIs.

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