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Bringing Interactivity into Spatial Content Layout Optimisation

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Automatic layout optimisation allows users to arrange augmented reality content in the real-world environment reducing the need for tedious manual interactions. This optimisation is often based on modelling the intended content placement as constraints, defined as cost functions. Applying cost minimisation algorithms is expected to lead to the desired placement, but, in practice, there are situations where the models fail to satisfy what the user needs. Thus, the capability to control the optimisation results and parameters is crucial. In this position paper, we report on our work on user-defined spatial content optimisation and anticipate the upcoming challenges and opportunities.

CCS Concepts: • **Human-centered computing** → **Interactive systems and tools**.

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1 INTRODUCTION

With the recent increase in AR/VR technology development (environment tracking, quality of display, and gesture recognition), consuming pervasive content anywhere and anytime has become possible. Recent research has demonstrated that displaying virtual 2D or 3D data around the user and within the real world provides increased spatial understanding thanks to depth cues, decreases the information clutter thanks to the increased display size, and supports more natural interaction techniques such as gestural input [15] and body-based navigation [5]. However, the bottleneck to fully exploit such potential lies in the user interface limitations. In particular, manually arranging this content in the surrounding real world is a very complex and tedious task, yet critical for efficient access to the data [10].

Previous works have tried to overcome this issue by automatically optimizing the content placement in AR environments, removing the need for any user input. The optimization can be based on different constraints such as semantic association [3], user perspective [7], the geometry of the environment [6] or content persistence over time [8]. However, these approaches lack any form of user control over the resulting placement optimization, even though adding interaction into optimization systems has been shown to be beneficial and appreciated by users in other contexts [9]. There is a need for intermediate approaches in augmented reality to combine user input and automatic layout adaptation.

In this position paper, we report on our recent work[12] exploring the concept of user-driven constraints to control layouts using the optimisation-based approach in augmented reality. Based on our research experience, we then discuss the challenges and opportunities of considering this "human-in-the-loop" layout optimisation. This position paper aims to provide our initial guidelines to help researchers and practitioners address the research agenda on understanding and adapting user interfaces using an optimisation-based approach.

2 USER-DRIVEN OPTIMISATION IN AR

This section briefly presents our recent work on user-driven constraints for layout optimisation in Augmented Reality [12]. Our approach lets users define and set up their own constraints directly within the real-world environment. It's driven by using a set of design objectives based on recommendations from previous works:

- Human in the loop: the driving motivation for our approach is to allow users to refine the virtual content optimization and go beyond the "black box" approach that does not support user interaction. The user can bring new knowledge into the placement approach (e.g. based on personal preferences or unforeseen situations). This could lead to increased user trust and confidence in the system[9].
- Holistic design: our goal is to unify the interaction experience by considering all the interactions of the system and the constraints at once [16]. This leads to more fluid interactions [4] and minimizes the presence of delimiter gestures between the different interactive commands.
- Natural hand gestures: our goal is to adopt a device-less approach based on hand gestures, which are common in immersive AR systems. Hand gestures are highly intuitive and can favour gesture discoverability and memorization [19].
- Direct manipulation: our approach requires delimiting spatial surfaces or edges in 3D. It should thus support direct manipulation, which has been shown to allow the performance of complex motions in AR, such as in the context of authoring animations [1].
- Minimize dependency on GUIs: As a result of previous objectives, our design should avoid the use of traditional GUIs, which tend to break the interaction flow and have been shown to perform worse than gestures to active commands in augmented reality [14].

We created a design space for user-driven interaction and explored input gestures that can be employed to define the user-driven constraints of our design space through a user elicitation study. Using the results of this study, we proposed a holistic system design and implementation demonstrating our user-driven constraints, which we evaluated in a summative user study where participants had to create several constraints at the same time to arrange a set of virtual contents.

2.1 Design space

Our design space considers three dimensions: the user-driven constraints, the regions of interest, and the constraint parameters. We defined eight different user-driven constraints: *Attractive Edge*, *Repulsive Edge*, *Containment*, *In-view*, *Preference*, *User Perspective*, and *Semantics*. We then described the effect of optimization for each constraint (see Figure 1).

We considered four significant regions of interest where the constraints apply: a point, a 1D line, a 2D surface or a 3D volume. Each of these regions represents common parts of the spatial environment to which the virtual content may

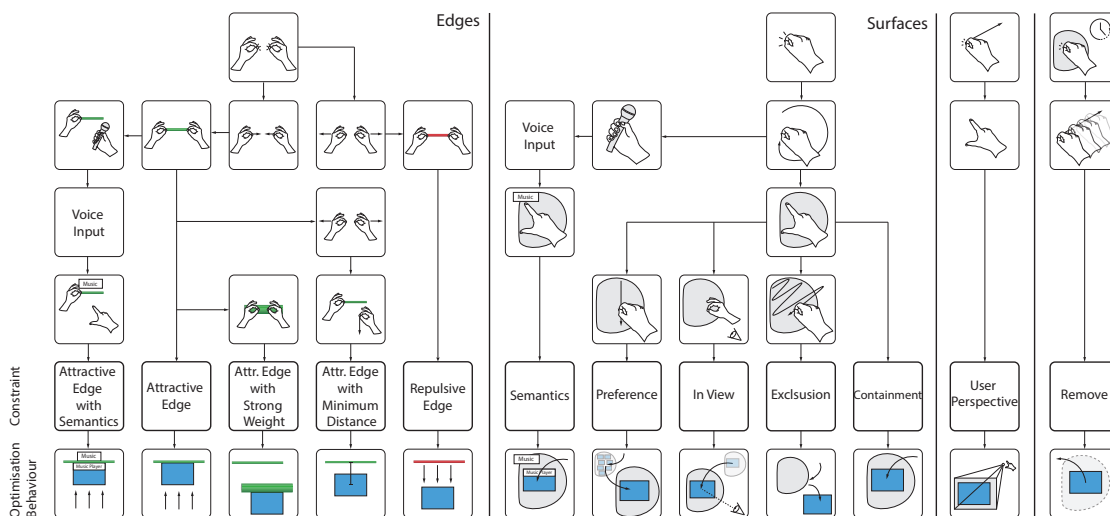
105 be associated: a position in mid-air (point), the edge along a piece of furniture (1D Line), the surface of a wall or table
 106 (2D surface), or a 3D area around a physical object (3D volume).

107 Some of the constraints depend on particular parameters. For instance, the edge constraint can be parameterized by
 108 defining a positive or negative weight to increase the attraction or repulsion of its spring. The edge constraint can also
 109 include a minimum distance parameter, which defines the minimum distance from the edge at which content may be
 110 placed, leaving a buffer region in between.
 111
 112

113 2.2 Gesture collection and implementation

114
 115 After creating the design space, we conducted an elicitation study to explore the design space of the gestures that
 116 could be used to define our user-driven constraints and inform our following system development. We wanted to move
 117 away from the inherited UI interfaces that populate current augmented reality platforms that rely on 'legacy' GUI
 118 components. The components such as contextual menus and UI widgets break the interaction flow and distract the
 119 user's attention from the surrounding world.
 120

121 Instead, our goal was to explore the use of spatial gestures to define user-driven constraints. We asked participants to
 122 create signs for the eight constraints of our design space: attractive and repulsive edge, containment, exclusion, in-view,
 123 preference, user perspective and semantics.
 124
 125



145 Fig. 1. Complete diagram describing the final set of gestures of our system. All gestures begin from one of the four states shown at
 146 the top, each following a unique path to the constraints at the bottom.
 147
 148

149 We implemented the set of gestures resulting from our elicitation study (Fig. 1) and their underlying optimization for
 150 user-driven constraints using MRTK for HoloLens 2 and Unity. To follow our design objectives, we proposed a uniform
 151 set of gestures limiting the need for delimiters and favouring interaction fluidity. We implemented the gestures with
 152 the MRTK core services input system, to detect hands and get data from pointers. Once the scanned environment mesh
 153 is registered by the MRTK spatial awareness system, we use the integrated raycast pointer to perform the interaction.
 154 For example, a surface container is created by pinching and dragging the raycast pointer on the environment mesh.
 155
 156

The attractive or repulsive edges are created by pinching with two hands and moving inwards or outwards, respectively. Once the region is created, we optimize our virtual content placement using the MRTK SolverHandler. To attach the virtual content to a given region, we adapted the MRTK solver SurfaceMagnetism to our needs. Since we wanted to specify the region where to attach our virtual objects, we added weights to each type of region and changed them dynamically depending on the type of constraint applied to the region. The system then searches for the highest region weight and uses it to attach virtual objects.

To optimize the virtual content position for an attractive edge, we first created an edge object and attached virtual content to it. To apply proper orientation of the virtual content, we used Unity Physics Engine to create a hinge connecting the content to the edge. Once this was done, we applied and tweaked the MRTK Follow Solver to the edge. To implement the behaviour of the repulsive edge, we also used the MRTK Follow Solver and the Minimum Distance parameter as repulsion distance. We apply repulsion only in a direction parallel to the edge forward vector.

When combining different constraints, we had to address the question of how to associate the virtual content already present in the environment with each constraint. We adopted a distance-based approach, where each constraint (except semantics) has an area of effect defined by a distance threshold. The semantic regions attract virtual content wherever it is located. The other virtual objects within this threshold are affected by constrained optimization. This provides the user with the flexibility of associating virtual content to a given constraint by simply approaching the window to the constraint surface/edge, or redirecting content between constraints if desired.

Each constraint, either surface or edge, has a limited capacity: a small containment area (i.e. smaller than a widget) can contain only one single widget, and the widget spans out of the area. Other widgets that overpass the capacity of the containment area are not optimized (i.e. do not move from their location). If the user defines a preference surface, those widgets that cannot fit move to the preference surface.

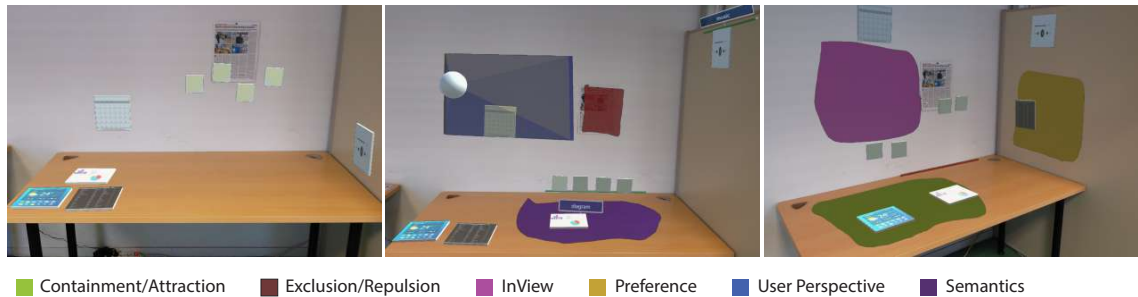


Fig. 2. Our user study started with the virtual content manually distributed in the space during the warm-up activity (left). Then users had to arrange the content in two steps, either using a manual approach or with our user-drive constraints. With our approach, the first step (centre) involved Exclusion, Attractive Edge, Semantic Edge, Semantic Surface and User Perspective constraints; the second step (right) involved Repulsive edge, Preference, Containment and In-View constraints.

2.3 Summative study

After the prototype implementation, we conducted a summative study to validate the use of our gestures for creating a user-driven layout optimization (see Figure 2). Our user-driven approach was preferred to a manual arrangement and required a lower workload on the temporal and physical demands. Besides, this study allowed us to test the use of several constraints at the same time. These were promising results, even though they were collected on a controlled use

209 case with a limited number of virtual content. We also gathered valuable feedback that will allow us to improve the
210 system in the future, particularly towards providing users with even more control over the system.
211

212 **3 CHALLENGES AND OPPORTUNITIES OF OPTIMIZATION-BASED APPROACHES IN AR** 213

214 Our research reveals new challenges and opportunities of introducing user interaction into optimization-based ap-
215 proaches for spatial UI arrangement in Augmented Reality, which can inspire HCI researchers interested in computational
216 approaches.
217

218 **3.1 Tradeoff between gesture vocabulary and constraint parameters** 219

220 In our previous work, we created a design space along three dimensions: user-driven constraints, regions of interest and
221 constraint parameters. We only explored a part of our design space through a gesture elicitation study. According to the
222 results of this study, participants tried to reduce the complexity of interaction by using simple gestures, often derived
223 from or combined with other gestures. Moreover, they wanted the interaction to be consistent for creating regions
224 and constraints. However, exploring the design space in depth and introducing more gestures to cover all constraint
225 possibilities (combinations of regions and constraint parameters) will lead to more complex interactions. Therefore,
226 there is a need to explore the tradeoff between the complexity of the gesture set, and the level of control of constraints
227 parameters.
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231 **3.2 Balance between hard and soft constraints** 232

233 In our system, we implemented only hard constraints and adopted a distance-based approach. Only virtual objects
234 within the distance threshold are affected by constrained optimization. However, we did not investigate the combination
235 of multiple constraints with a soft constraint approach, e.g. when the solver does not lead to an optimal solution, but to
236 a compromise between multiple constraints [13]. An unanswered research question is what the user expectations of
237 such optimization are and how to allow users to change from hard constraints to soft ones if needed.
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241 **3.3 Switching between optimisation modes** 242

243 There are two possible options to optimize the content layout: iterative or sequential. The iterative approach separates
244 the constraints creation from the content layout optimization, whereas the sequential does both at the same time. In
245 our system, we adopt the second approach, i.e. the surrounding content position is dynamically optimized as the user
246 creates the constraints. However, it may be interesting to explore an iterative approach, which would allow the user to
247 clearly distinguish the environment setup phase from the phase of interaction with the content. This iterative approach
248 would need to address the challenge of how to let participants know where the content would be placed after creating
249 several constraints.
250
251

252 **3.4 Understanding constraints** 253

254 In our system, we colour-coded the constrained regions to provide real-time feedback during constraint creation.
255 However, such coloured regions might be disturbing when performing real tasks. As a future improvement of our
256 system, we could reduce the brightness or opacity of regions when they are not in use. On the contrary, when a user
257 wishes to interact with the region, the system may highlight or outline such regions and give more details about them
258 (capacity, minimum distance). Moreover, users might want to see the relations between constraints. The challenge is
259
260

261 how to provide users with the appropriate visualization of the constraint parameters, such as the weights, without
262 visually overloading the user's environment.
263

264 3.5 Future needs for robust and flexible layout optimization. 265

266 Our current system implementation aims to demonstrate the general approach of user-defined constraints from the
267 perspective of gestural interaction. To this end, we used a built-in solver, the MRTK Solver. This solver has some
268 limitations, though, mainly when dealing with inconsistencies across various constraints, e.g. when a specific content
269 can be attached to two surfaces, which can provoke unwanted jittering of the content. Adopting a distance-based
270 approach, where the constraints only have a limited area of influence, reduces this problem to very particular cases.
271

272 Given the complexity and level of details of real-world geometry, developing a more robust optimization system
273 will probably require to use of an external solver, such as the one developed by Mellado et al. [11], which has already
274 been successfully used for optimizing the placement of 2D widgets on projected interfaces [13]. Future works need to
275 address the non-trivial challenge of extending this 2D optimization to 3D or predicting the impact on user performance
276 [2]. With this future implementation would come the question of the system ceiling, i.e. how many virtual widgets and
277 constraints can be effectively used, both from a user and a systems perspective.
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285

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