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# Data Driven Design Framework for Adaptive Mixed Reality User Interfaces for Road Cycling and Beyond

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## Abstract

Road cycling presents a more challenging use case for Mixed Reality interface design. Smart glasses can facilitate decision making by placing information in context, yet prototyping in-situ is challenging. While low-fidelity studies offer observational insights, positional guidelines for interface design are sorely needed. Building on previous high-fidelity analysis, this paper presents an extension – a data driven design framework consisting of a methodology and browser-based supportive tooling. It enables designers to prototype user interfaces for cycling and other dynamic environments, based on data from prior user sessions. Adhering to values of Optimisation, Steerability, Legibility, and Continuity, it is a marked improvement in translating insights into practical designs. The designer is supported in optimising and customising the positioning of an MR user interface, with interface elements transparently and continuously negotiating visual real-estate during prototyping. The designer arrives at actionable interface layouts for evaluation without compromising safety.

## CCS Concepts

• Human-centred computing – Visualisation – Visualization design and evaluation methods; • Human-centred computing – Visualisation – Visualization techniques; • Human-centred computing – Visualisation – Visualization systems and tools;

## Keywords

mixed reality, methodology, visualisation, user interface, cycling, prototyping, tooling, design

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## 1 Introduction

Road bicycle racing is as much a cognitive challenge as a physical one. Athletes balance endurance and strategy in dynamic environmental and race conditions. Timely delivery of context-relevant information can provide a competitive edge. This is typically delivered via handle-bar mounted displays or ear-pieces, each posing ergonomic challenges in use, that presents an opportunity and a challenging use case for introducing Mixed Reality. Smart glasses can facilitate decision making by delivering context-relevant information in the field of view. An effective implementation needs to avoid occluding hazards, and causing cognitive overall or attentional tunnelling. The visual field real estate needs to be balanced between the value of the information at a given location and the subsequent cost to the situational awareness. To this end, Adaptive User Interfaces can dynamically adapt the interface to fit changing situational demands. The question of how to implement such a solution safely remains an open one. Design guidelines are missing and sorely needed. Involving the end-users early in the design process is required to identify user preferences and fulfil their needs adequately [1]. However, conducting usability research, prototyping, as well as testing in the field can be unsafe and impractical, requiring proxies [2]. Low-fidelity studies in prototyping Mixed and Virtual-Reality (MR, VR) user interfaces [3–6] are used to elicit user needs and to collect insights on preferences. However most deliver largely qualitative insights, and lack quantitative positional interface guidelines.

The work presented in this paper builds on the methodology of discovery and collection of user preferences for road cycling that has been conducted in a previous lab-based user study [7], in which low-fidelity data collection was combined with systematic high-fidelity analysis. Therein, in individual generative sessions with participants, two distinct scenarios were considered – uphill and downhill. Following an iterative design process [8], participants expressed their varied preferences for placement of virtual objects using a semi-cylindrical 3D canvas, with annotated acetate cut-outs (akin to [9]) against a static backdrop. Aggregated findings were presented in equirectangular visual-field heatmaps for relevant metrics (e.g., speed), showing where given information was favoured to be positioned. Context was shown to impact the placement of objects (e.g., gradient information found more frequently in layouts for riding uphill, or speed indicator sitting closer to the horizon when riding downhill). Heatmaps were used to translate the fuzzy observational data into the positioning of objects in a suitable and balanced layout for use in practice. Two constraints were apparent: there is finite visual field real estate, and while heatmaps often overlapped, only a single virtual object can occupy a certain area at any one time.



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The challenge was that the interaction between the designer and the data was not sufficiently supported. Designer’s task of positioning information in the visual field required combining the insights from multiple heatmaps into a single optimised MR user interface (UI) design. This paper presents a data-driven design framework for which values of Optimisation, Steerability, Legibility, and Continuity are core. The design framework is composed of a novel methodology and browser-based supportive tooling, that extends the previous high-fidelity design process described above.

The proposed methodology provides a designer the ability to steer the prototyping of user interfaces for cycling, based on observational data from prior user sessions – with the benefit of this design framework in retaining fine control and customisation. To this end, the associated tooling, the Configurator, offers accessible optimisation and assembly, with a rich visualisation of interface mock-ups. It is a marked improvement in translating previously collected positional data into actionable design specifications. The tooling communicates the UI objects’ continuous negotiations for space, visualising reasons for their placement in the visual field.

The resultant product of the design process is an optimised user interface layout for MR for road cyclists. Mixed Reality usability researchers and user interface designers alike, stand to benefit from this work, as it contributes to bridging the gap in design guidelines in a challenging application, as is road cycling. While it remains the primary use case, the design framework is generalisable to any domain involving MR in a dynamic environment or context dependent informational needs.

## 2 Background and Related Work

Understanding how to design interactive technologies is one of the grand challenges of the Sports HCI field [10]. Designing MR solutions for such contexts poses challenges of value in performance benefit, usability, prototyping, and safety. To this end, road cycling performance is explored in 2.1, and studies related to MR in cycling are found in 2.2. Prototyping is addressed in 2.3, and adaptive interfaces are reflected on in 2.4. The knowledge gap addressed by this paper is summarised in 2.5.

### 2.1 Performance and Data in Road Cycling

Road cycling racing, the focus of our work, is a sport of brain and brawn, suited for an HCI intervention. It is as much about stamina, i.e. keep on pushing despite pain fatigue, as knowing when to push harder or slower in a suitable gear [11]. Making decisions concerning either, has been shown to benefit from just-in-time information [12, 13], enhancing awareness of road conditions [14], or physiological state (e.g., heartrate [15]). Studies in professional cycling have modelled physiological demand [16, 17], and explored delivery of pacing strategies using adaptive feedback [18, 19]. Recent changes to regulations concerning race-day communication [20] have led to a greater role for onboard devices.

### 2.2 MR Interfaces for Cycling and other Dynamic and Safety-Critical Sports Contexts

When using an MR device, see-through display solutions in particular, the user is shown a virtual layer projected over their real-world

view, that may supplement, obscure, or even occlude critical real-world cues. Conversely, the virtual layer may be used to make an object that is obscured physically [21] visible or to warn of an impending hazard [22], underscoring the importance of context-specific, adaptive interfaces. While potentially beneficial [18, 23], this may also be dangerous when applied in a dynamic environment, such as an outdoor road environment. Studies in related domains reveal that placement must consider task demands and circumstances, e.g., to avoid attentional tunnelling [24]. Effective and safe adoption of MR requires careful domain-specific guidelines for positioning information.

### 2.3 Methodology for Prototyping of MR and VR User Interfaces

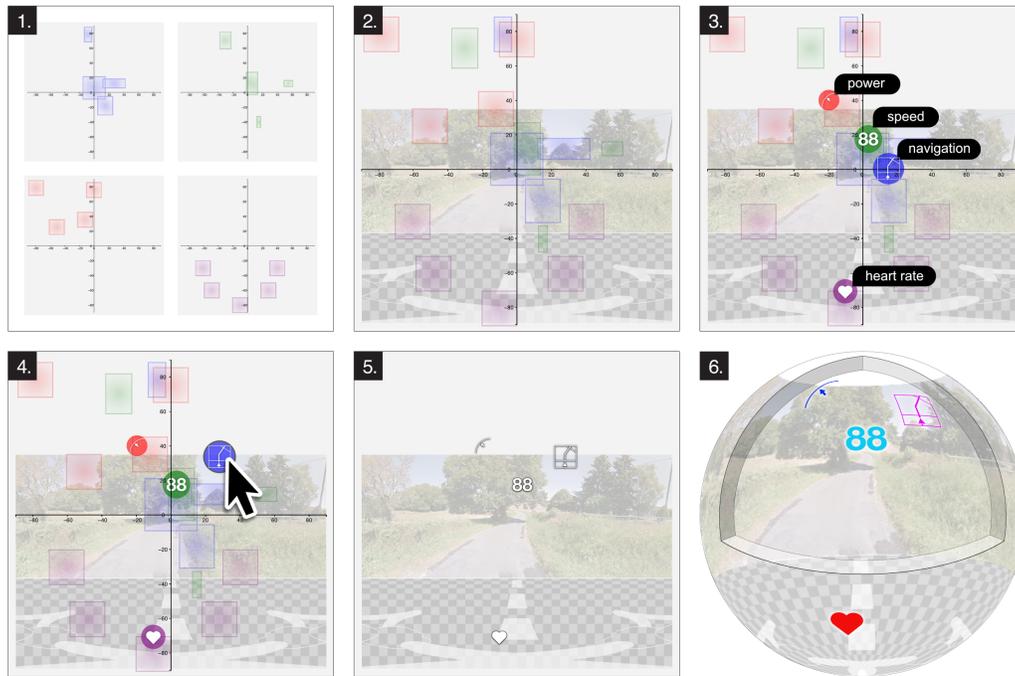
Low and medium fidelity prototyping approaches [3–6] have shown the importance and value of early stage prototyping of MR and VR user interfaces. These methods make it possible to elicit preferences without the cost and complexity of full development and deployment. Our earlier study [7] applied a similar low-fidelity approach, specific to road cycling, but combined it with a novel high-fidelity systematic approach, delivering metric- and context-specific visualisations of information positioning, based on aggregated insights. It offered design guidelines in a form of heatmaps and mock-ups. The approach towards an optimised user interface layout was twofold: frequency data determined apportioned ordered lists, that were used for placing an object in the visual field based on its respective heatmap. The order mattered, as the layout was built incrementally, with each additional object securing its position in the shared layout canvas on a first come basis. However, as the heatmaps were opaque and overlapping, the methodology left the final assembly of an optimised mock-up a manual task. This, while potentially useful (e.g., varying equipment and cycling styles), rendered the accessibility of the final design guidelines lacking, open to bias and influence of the interface designer.

### 2.4 Adaptive User Interfaces

Adaptive User Interfaces (AUIs), if applied appropriately [25–27], provide a promising approach to continuously tailor on-screen information depending on ‘user status, system task and current situation’ [28]. An application of MR in this context further mandates such an AUI [29] that, in addition, manages the amount of information presented to a cyclist to prevent cognitive overload [30] or attention tunnelling [22, 31]. Visual overlays in sports (and the wider mobility context) must respect both user preferences and critical constraints in a continuously changing environment [32]. To this end, there is a definite need to know what information road cyclists require in different context, how they want it presented, and what kind of presentation they consider safe and convenient.

### 2.5 Knowledge Gap

This study embraces the challenge of adaptive interface design in the context of road cycling, where context-specific MR design guidelines are sorely needed. Data-driven design research requires a systematic and transparent approach to data processing and analysis. However, to be accessible, tooling is needed to turn insights into guidelines, by continuously facilitating optimisation in a manner



**Figure 1: – Conceptual design – 1. A selection of heatmaps of observations from a previous study [7] are gathered; 2. Previously, the designer would manually assemble a layout; 3. Designer is now assisted with optimising a layout; 4. Designer adjusts the layout; 5. Designer changes the view to evaluate; 6. Designer exports and evaluates the UI in higher fidelity VR or in-situ MR**

which is transparent, legible, and allowing a degree of influence in the hands of the designer. By introducing a design framework that furthers the field with a systematic high-fidelity data-driven design methodology and tooling, this work bridges the gap between the more accessible low-fidelity MR usability research, and high-fidelity demands of MR interface design practice.

### 3 Conceptual Design

This chapter establishes the concept behind the design framework, whereas the details of the implementation are discussed in the next section. A prospective user of the Configurator is a designer of a user interface for MR glasses for use in motion (here: road cycling) by the end-user (road cyclist). In that capacity, the designer could benefit from an appropriate initial design that optimally attributes visual field in exchange for valuable information, based on known user needs and preferences. Oftentimes, it is then the designer’s prerogative to choose whether to rely on user insights (user-centred design) or the designer’s intuition, or a mix thereof.

In a previous lab-based study [7], participants were asked to express their needs for information for road bicycle racing, as well as their preferences for presenting and positioning this information. The observed insights for placement of objects (henceforth: observations, Figure 1 top-left) in the visual field were aggregated and presented as heatmaps, one for each of many investigated categories (e.g., type: speed, when going downhill). However, the subsequent method of combining the individual heatmaps into a singular design proved to laborious and non-transparent.

The Configurator solution proposed in this paper is designed to improve the previous method [7], taking heed of four design values: Optimisation, Steerability, Legibility, and Continuity. The Configurator systematically finds an optimised layout, by negotiating occupation of finite space based on past observation data (Figure 1, top-right). It allows the designer to steer the design as assembled, by affording in-context intervention of both the order of spawning, and fine-tuning of positioning (Figure 1, bottom-left). The output should be legible and representative (Figure 1, bottom-right), with clear communication of reasons for the proposed positioning of the objects (e.g., visualising the forces at play). Lastly, the Configurator continuously and smoothly responds to changes in the layout and new input criteria.

The Configurator consists of two parts (Figure 2), presented simultaneously, within a single tooling – the Smart Canvas (with force-based positioning), and the Designer User Interface which the designer uses to interact with the generated result of an optimisation. The changes applied by the designer are interpreted directly and presented back in real time. The output of the Configurator are user interface layouts for MR glasses. Details of the implementation are discussed in the next section.

### 4 Interaction and System Design

This section details how the designer interacts with the Configurator tooling (screenshot in Figure 3) and sheds light on some of the technical detail. During iterative switching between design

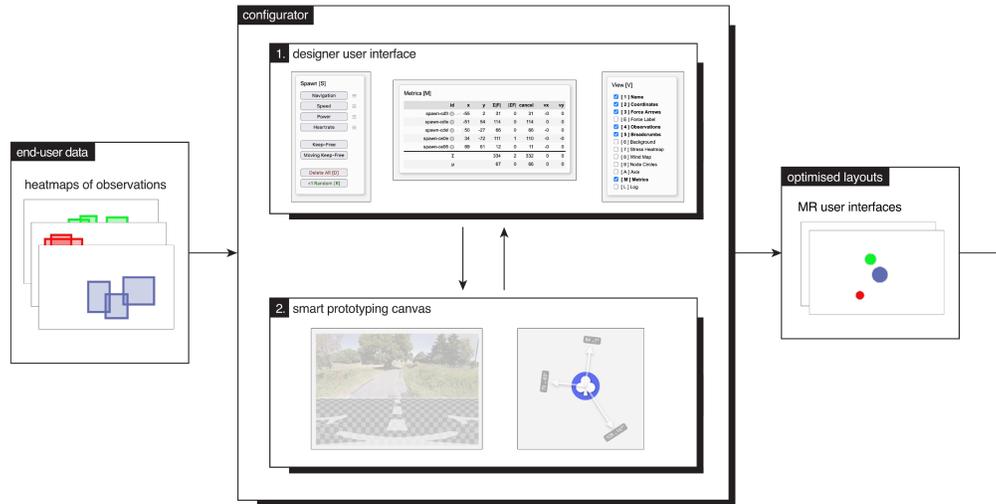


Figure 2: – Conceptual design of the Configurator tooling

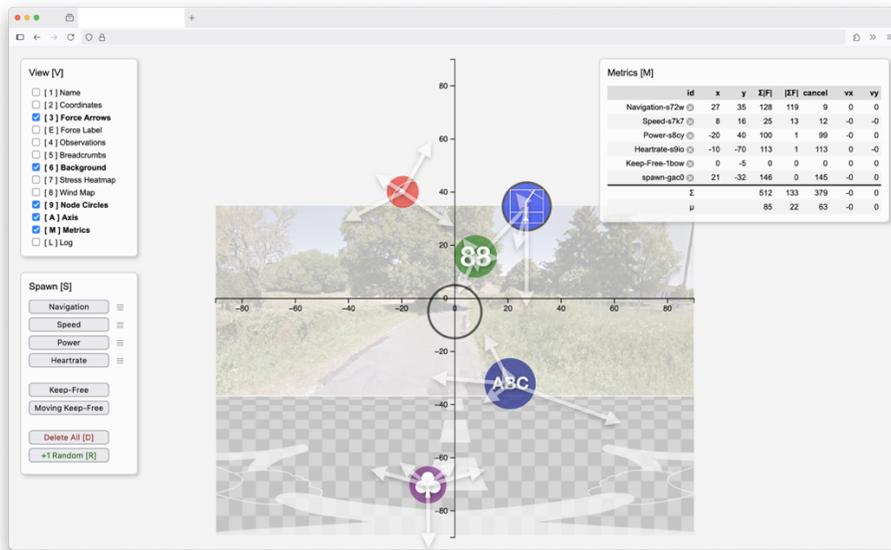


Figure 3: – Composite screenshot of a designer using the Configurator tooling, with arrows showing the forces acting on six nodes

and evaluation, the designer is continuously assisted in their design process. The designer interacts with the tooling through the Designer’s User Interface with the optimised outcome presented back within the Smart Prototyping Canvas. Figure 4 presents an example multi-step workflow, starting with a blank slate, utilising data from a previous user study [7], and finishing by exporting a finished layout.

The designer’s capabilities are detailed in the following sections, following the flow of the design process above. Section 4.1 describes the spawning capability. Section 4.2 details the determination of positions of UI objects (nodes). The evaluation process is summarised

in 4.3. The flow diagram in Figure 5 outlines the methodology in finer detail: inputs, outputs, and key functionalities of the system. Section 4.4 documents further detail concerning the development and where to find the current live, functional, interactive implementation of the Configurator tooling, to explore the interaction capabilities firsthand.

### 4.1 Spawning a node

Adding a node to the Smart Canvas is referred to as spawning. Presented in the Smart Canvas, a single node (user interface object)

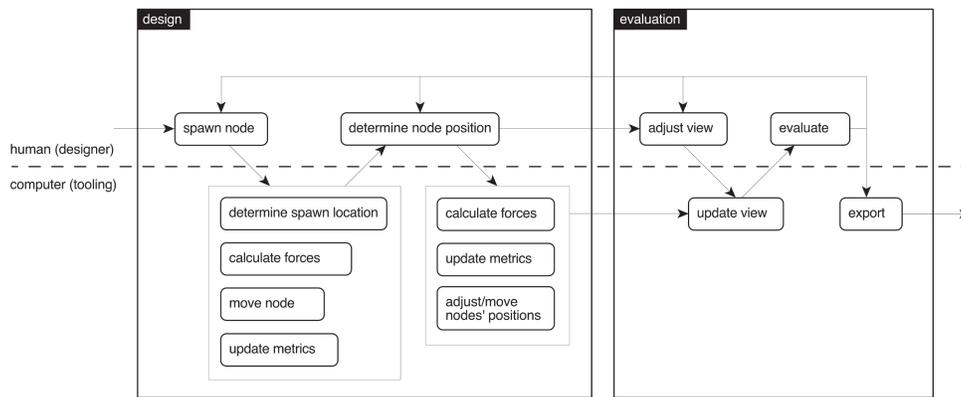


Figure 4: – Example of the design process with the use of the design framework

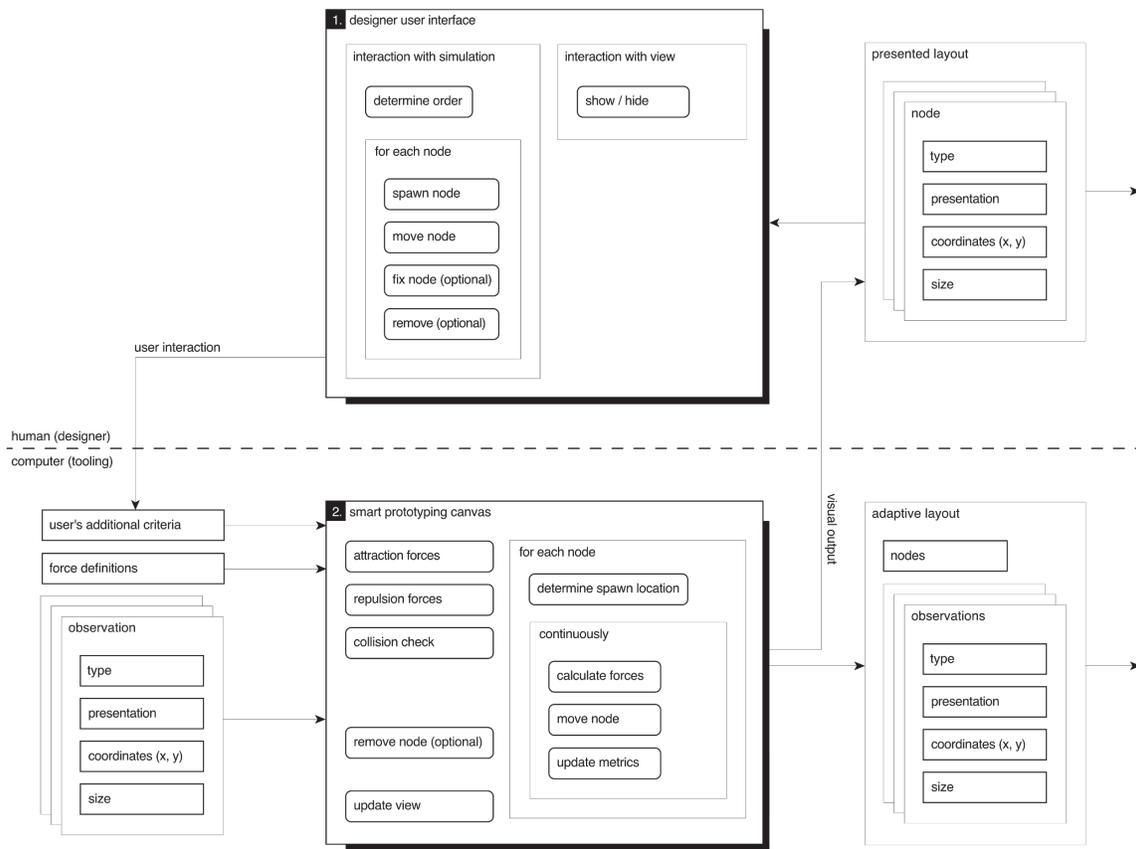
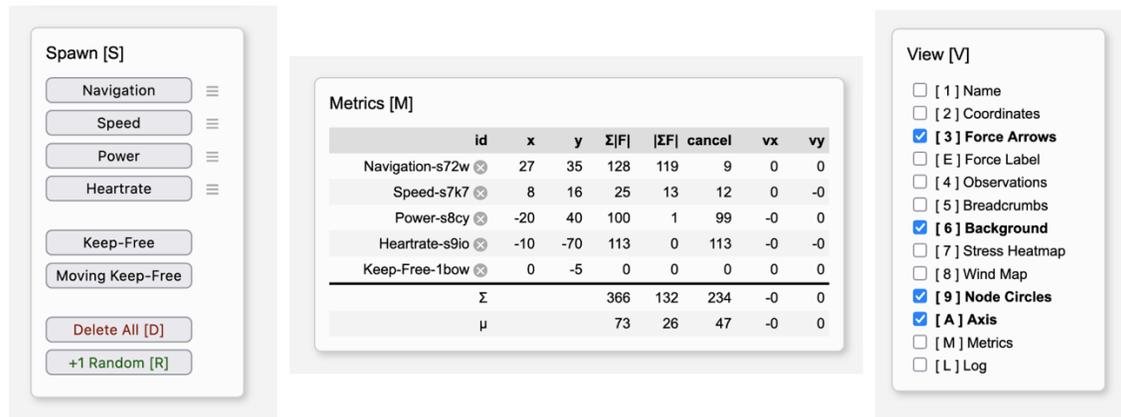


Figure 5: – Flow diagram of the methodology depicting interaction during use of the Configurator, with inputs left and output right

is represented by a circle (see Figure 3) with an enclosed icon of the prospective carrier of information e.g., a number in a green circle, a map in blue or a symbol in purple. It is an element of the prospective MR end-user user interface, intended to fulfil a specific role of delivering information in a user-specified way. The

Configurator in its current state of development is used by the designer for inclusion and positioning of such nodes.

As part of the Designer’s User Interface, within the Spawn Panel, (Figures 3 and 6, left) the designer is presented with a list of buttons (subdivided into three sections). Using a button, the designer can



**Figure 6:** – Spawn Panel (left) with three groups of buttons for adding and removing various nodes from the on-screen simulation; Metrics Panel (middle) displaying various metrics of the nodes present in the Smart Canvas; View Panel (right) with checkboxes for controlling the view of the simulation

spawn a node (e.g., a navigation node), having it take place in the Smart Canvas as determined by observational data from a previous user study (current data is stubbed). The order of the buttons is based on apportioned lists resultant from frequency data from a prior series of low-fidelity, exploratory end-user sessions. The designer can engage the buttons in or out of sequence or may elect to rearrange their order by dragging and dropping the buttons. Below, the designer can spawn two special case Keep-Free nodes: static, and moving. These nodes set themselves apart by having a translucent appearance (thus no colour) and no icon (Figure 3, node near the origin). Their function is to occupy space in the Smart Canvas without occupying the visual field, thus ‘keeping free’ the view of the real world. The static Keep-Free node can be moved by the designer to ensure a given area of the visual field is kept free of nodes, with other nodes colliding against it. The Moving Keep-Free node acts similarly but moves along a hardcoded path (here: from the horizon downward). The designer can thus preview a behaviour of a proposed Adaptive User Interface functionality, where the smart glasses adjust the layout dynamically in-situ after having detected e.g., a pothole, a crossing animal, or a cycling fan with a cardboard sign obstructing the road.

The last section features two additional buttons. Herein, the designer can clear the Smart Canvas by removing all nodes altogether, or spawn a randomly generated node. For accessibility, said buttons are assigned keyboard shortcuts (see Appendix A).

## 4.2 Determine position of a node

As the designer fills the Smart Canvas with more nodes, the tooling adjusts their positions accordingly (based on specific heatmaps of observations). As the nodes are continuously searching for an optimal positioning the designer can track the outcome in the continuously updated preview. The designer can directly interact with nodes in the Smart Canvas by moving and fixing. Using drag and drop the designer can reposition a node. Upon release the node is again subject to built-in force-driven mechanics. The designer can also fix a node by double clicking, securing its location within

the Smart Canvas, making it resistant to the built-in mechanics. Double clicking again releases the fixed state and position. Visually, a fixed node is discerned by an added thick black outline (provided the appropriate ‘node circles’ layer is not hidden from view).

## 4.3 Adjust view and Evaluate

Throughout the design process the designer is presented with a continuously optimised layout. Using the View Panel (Figure 3 left, Figure 6 right) the designer can modify the view of the Smart Canvas to match the design phase and the level of detail required – from understanding individual node’s positioning, through its negotiations for space with other nodes (Figures 7 and 8), to previewing a finished user interface layout without the underlying data (Figure 1).

The View Panel contains an annotated list of checkboxes used by the designer to manipulate the visibility of various objects in the Smart Canvas. The background layer helps visually translate otherwise abstract coordinates into representative locations (e.g., asphalt, curb, road furniture) as found in these locations in the use context. Conversely, hiding the background makes reading the labels on the arrows easier. The Breadcrumbs visualise the sources of attractive forces a node experiences from its corresponding observations, while Force Arrows show the effective strength of said forces. Force Labels further quantify the strength through numerical labels. In the Metrics Panel (Figure 3 right, Figure 6 middle) the designer can inspect numerical data for each of the nodes present in the Smart Canvas. Furthermore, the designer may remove individual nodes entirely. Columns with data are shown for the  $x$ - and  $y$ -coordinates, the stress (sum of the absolute forces), the cancellation force (absolute sum of forces), and the velocities in each axis. In the bottom rows the designer can see the sums- as well as the averages of the appropriate columns.

## 4.4 Implementation

During design use, the Smart Canvas (see Table A1) consists of nodes that are subject to forces, that in turn help determine their

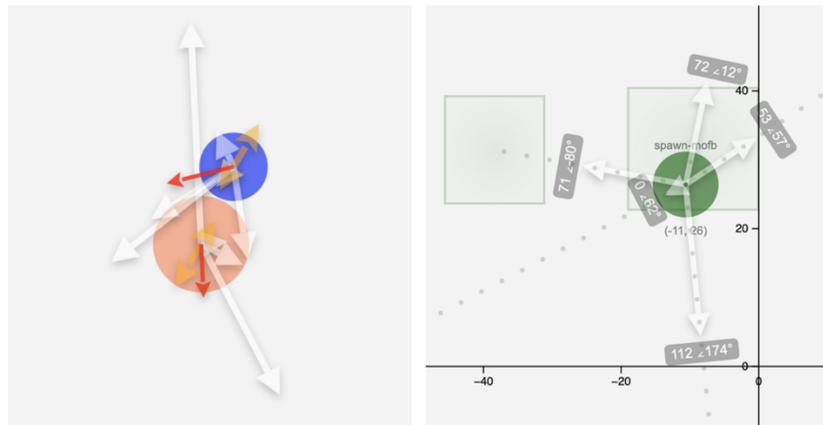


Figure 7: – Two nodes colliding and negotiating space (left) with coloured arrows showing the forces currently acting on each node; node seeking force equilibrium as subject to attractive forces from its related observations (shown as rectangles) (right)

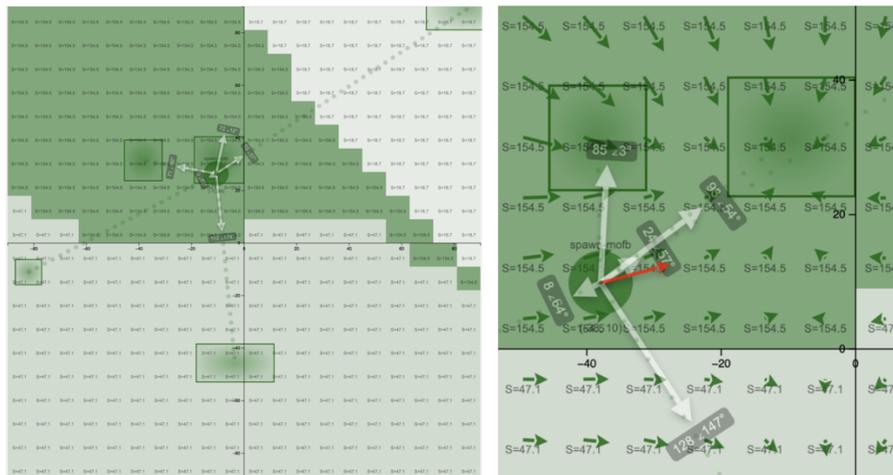


Figure 8: – Example of a smart spawning process, with a visible Stress Heatmap (left, also right) and Wind-Map (right)

optimal position. Nodes fight and negotiate for space, with the details of the force-based mechanics described in Appendix B. The aggregated insights from our previous study [7] (in a form of metric-specific heatmaps) serve as input for the forces, defining their magnitude and origin, e.g., pulling heart rate towards the most observed preferred position near the handlebar.

A node is therefore subject to multiple attractive forces (visualised as arrows in the canvas, Figure 8), one from each observation (idem rectangles) included in each respective heatmap. A node will thus seek a place of force equilibrium where it is in an optimal position, pulled equally in all directions.

The Smart Canvas includes a Smart Spawning Algorithm which optimises the process of spawning a node. Although the locations of a given node’s past observations are known, the forces they exert may result in multiple places in the canvas where a force equilibrium can be found. Which equilibrium place the node settles on is therefore dependent on the place from where it started its

search, and the forces it subsequently experienced on its way there. Spawning that same node at different locations will effectively result in it settling in different local optima that might not be the global optimum. To this end, the designer is relieved off the task of optimising the spawning process (for detail, see Appendix C), while also enriching evaluation by affording transparency of the optimisation process (Figure 8, Stress Heatmap, Wind-Map).

The design framework is under active development. The Configurator tooling is web-browser-based, with a working ‘production’ version available for testing and preview at [33, 34]. For further detail, see Appendix D.

## 5 Discussion and Future Work

The data-driven design framework introduced in this paper integrates and expands our previous structured methodology [7] with dedicated tooling. It assists the designer by making observational data from a previous user study more widely available (in a web

browser), and makes UI positional insights concerning a 3D display device accessible on more common 2D devices. The tooling lowers the barrier of entry (technology, knowledge, access) and offers a wider audience the capability to step into the role of an MR designer. Empowering more end-users (road cycling athletes) to take part early in the design process through such a proxy is of importance, especially if in-situ prototyping and evaluation are challenging, impractical, or unsafe (e.g., designing while cycling downhill).

Using the presented tooling, the designer can effectively create optimised layouts of user interface objects, based on empirical end-user preference data, and their additional supplementary criteria. The optimisation addresses both initial spawning and subsequent negotiations for visual field space. The designer is presented continuous visual feedback on the state of the simulation and the forces at play. Lastly, the designer retains control and steers both the view and the optimised layout itself, offering the functionality of both an analysis tool and a design and evaluation tool (subject to future study).

As part of the design methodology, the presented interaction between the designer and the tooling can be seen as collaborative. From the perspective of ‘the Configurator as a fellow designer’, both parties have the ability to move nodes within the canvas and affect the final design outcome. Whereas from the view of ‘Configurator as a medium’, it fosters the voices of past (human) fellow designers who have contributed to the dataset.

In its current iteration, the designer interacts with stubbed data in a format matched to data collected from our previous user-study [7]. While developed as a design and data processing tool, the Configurator can act as a data collection tool to boot. In the proposed methodology, a designer starts from initial end-user needs and preferences, creates an initial layout that can then be customised to better satisfy their needs and preferences (inclusion, positioning, priority). The data from these design sessions represents user needs and preferences much the same as the source data, which can then be included in the dataset, informing subsequent prototyping sessions. Collecting data while using and basing on previously collected data should be done with care, to avoid a recursive feedback loop. A possible approach would be to only store new observational data when a designer themselves makes a deliberate customisation (by fixing a node) of a herein proposed layout, and to exclude the ‘floating’ nodes positioned purely by the force-driven equilibrium mechanics built into the Smart Canvas.

The Configurator is in active development. A planned functionality in the release schedule is a mobile-phone-based Virtual-Reality (VR) preview of the proposed MR user interface. With this capability designers can better evaluate their design for 3D display devices despite the layouts having been designed in the 2D Smart Canvas ‘proxy’ environment. As proposed by [7], employing a moving background would further raise the fidelity of the experience, allowing designers to evaluate the Adaptive User Interface functionality in a controlled environment.

The order of buttons in the list of hardcoded nodes is defined by frequency from our previous user study [7]. The presented methodology does allow for a designer to determine their own priority list and spawn nodes in a chosen order. However, the spawning order does not impact the ‘seniority’ of nodes as they negotiate for space with one another. An implementation of this functionality in the

Configurator could further make nodes spawned earlier be more resistant to positional change, making earlier interface decisions hold more weight.

The observation data used as input in the Configurator only includes positive observations, and no negative ones. Participants of our previous lab-based study [7] were asked what information they wished for and where it should be positioned, but not areas that they would expressly avoid. This avoidance was deduced, and not explicitly expressed. The force-based mechanics, as developed in the Configurator, do allow for negative forces had such data been available, and would represent an interesting avenue of future study. Alternatively, in using the Configurator as a data collection tool as alluded above, the data of current designers’ positions of Keep-Free nodes can be seen as equivalent to negative observations as part of a ‘universal negative heatmap’.

Current, when a designer fixes a node, said node is fixed in an absolute way – rendering it persistently positioned, and resistant to all forces. An alternate implementation of ‘fixing’ could instead have a node replace its previously associated heatmap observations (and their forces) with a single observation in a desired position (as a sole force of attraction). This would enable a fixed node to have a single preferred position (as intended), but still allowing node’s minor movement due to other forces like collisions (with other nodes). In so doing, fixed nodes would also accommodate for (dynamic) Keep-Free nodes.

Lastly, the Configurator in its current implementation considers nodes to be circles with an enclosed icon (e.g., a number or a symbol). Future research and development will explore whether rectangular nodes are a better option.

## 6 Conclusion

The data-driven design framework presented in this paper combines a methodology with supportive software tooling. The novelty of the proposed design framework lies in enhancing designer’s ability to generate optimised user interface layouts, while satisfying the criteria of Optimisation, Steerability, Legibility, and Continuity in Adaptive User Interface Design. It further raises the fidelity of the previous high-fidelity approach [7] for processing observational data on end-user preferences for MR user interface design. In so doing, it contributes to pushing the boundary of mixing the benefits of low-fidelity data capture with high-fidelity processing. The feasibility of the developed Configurator application has been demonstrated. Offered in a browser, it makes the gathered data more accessible and portable for future designers of MR user interfaces for road cycling and beyond. Planned implementation of a VR preview can be used to test the in-situ Adaptive User Interface functionality.

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## A – Composition of the Configurator

## B – Force-Based Mechanics

The Smart Canvas integrates multiple forces based on a set of pre-defined and hardcoded rules. It positions nodes dynamically and continuously. As shown in Figure 7, arrows indicate the magnitude and direction of each of the forces acting on the two nodes, while nodes negotiate space between each other. The white arrow represents attractive forces from observations, orange arrows illustrate collision forces while the red arrow depicts the effective net force, and therefore the motion the node will undergo in the subsequent moment (single simulation frame, or 'tick'). Added repulsive forces ensure a strict lack of overlaps between nodes. The per-node attractive forces are stronger based on proximity and fade out smoothly with distance. The forces exerted by observations (rectangles) are proportional to their size. Mimicking physical objects, the implemented integration attributes velocities to the nodes, that slowly decays with time.

**Table 1: – Ordered layer list of the composition of the Configurator tooling**

Layer (descending)	Function	User Interaction (keyboard shortcut)	Fixed to
View-panel	Checkboxes for changing the view	Toggle view of other layers with mouse or keyboard shortcuts (V)	Browser canvas
Spawn-panel	List of buttons for spawning prepared sets of nodes, deleting all nodes, spawning a random node	Click buttons, reorder buttons by drag and drop (S)	Browser canvas
Metrics-panel	Live metrics for each node, total, and average per node	(M)	Browser canvas
Log-container	For troubleshooting	(L)	Browser canvas
Axis	Reference of coordinates	(A)	SVG canvas
Nodes	Container of all nodes		SVG canvas
Node (for each)	A placeholder for a prospective carrier of information in an MR user interface	Move by drag and drop; Double click to Fix the node; Hover to show objects in other layers	Floating, subject to simulation forces
Icon	Visual reference of information’s presentation (e.g. number, graph, symbol)		Node’s centre
Circle	Visual reference of space occupied by node	(9)	Node’s centre
Name Label	Display node ID name	(1)	Node’s centre
Coordinates	Display current coordinates in a custom coordinate system	(2)	Node’s centre
Force arrows	Visual representation of forces acting on node	(3), (E)	Node’s centre
Breadcrumbs	Visual references (lines) to each corresponding observation	(5)	Centres of node and corresponding observation
Wind Maps			
Node (for each)	Visual of relative force and direction of forces experienced by node at given location	(8)	SVG canvas
Stress Heatmaps			
Node (for each)	Visual of stress force experienced by node 80 ticks after release at given location	(7)	SVG canvas
Observations			
Node (for each)	Locations and sizes of observations from past experiments	(4)	SVG canvas
Environment background	Example reference of real-world view	(6)	SVG canvas
Grey backdrop	Backdrop		SVG canvas

## C – Smart Spawning Algorithm

With each spawning action, the Smart Canvas runs a mini simulation, sampling a grid of 20x20 spawn locations (Figure 8), to determine and store two measures: (1) The immediate net force experienced upon release (henceforth: Wind), and (2) The strength of the Stress (sum of all absolute forces;  $\sum|F_i|$ ) a node would experience after being given time to settle (80 simulation ticks). The values of the immediate net force are visualised as a Wind-Map (Figure 8, right), with arrows showing visually the relative strength and direction. The values of the eventual stress for each candidate spawn position are stored and visualised as a Stress Heatmap (Figure 8, left). Following sampling all spawn positions, the function chooses the position with the highest stress. Upon each spawning, with the intent of communicating the choice for a spawn location, the latest Stress Heatmap and Wind-Map are left visible (while previous heatmaps are hidden). Hovering the mouse over a given node

makes the given node’s Stress Heatmap and Wind-map temporarily visible anew.

## D – Technical Implementation Details

The proposed Configurator is a browser-based interactive tooling, written in JavaScript (disclosure: ChatGPT was used to assist development), atop the D3 [35] visualisation framework (version 7.9.0).

The designer relies on the 2D area of the browser’s window, to represent the 3D space of the visual field (Figure 3). To this end, the canvas area is an equirectangular projection of the semi-spherical area, ranging from  $-90$  to  $+90$  both horizontally and vertically, where the  $(0,0)$  coordinate represents a gaze straight ahead at the horizon. The area is centred in the browser window. The Smart Canvas scales proportionately to fill the browser window and accommodates the browser’s variable aspect ratio by dynamically extending beyond the minimum axis bounds ( $-90$  to  $90$ ). The axis

and background layers are overlaid atop for visual reference of the context and of the coordinate space.

The tooling relies on the 'd3-force' module, which "implements a velocity Verlet numerical integrator [36] for simulating physical forces on particles". In the context of this solution, a node (UI element) is subject to attractive (observed placement locations) and repulsive forces (collisions with other nodes), moving through the canvas seeking a force equilibrium. The simulation is computed on the frontend and is drawn live in an SVG object embedded within the webpage. No information is sent to the server, and no frontend

caching or saving is implemented. The solution is interactive, affording the designer the ability to interact via mouse and keyboard, to control the canvas as well as the view thereof. By adjusting the view, the tooling switches easily between prototyping and evaluation. At the time of writing, the pre-programmed observation data is stubbed but follows the format of our previous study [7]. The structure of the Configurator, including definitions and descriptions of its Designer User Interface elements (e.g. Stress Heatmap) can be found in Appendix A. The background image used was exported from Google Maps Street View, matching the location used as context background during the previous study.