Immersive Data-Driven Storytelling Design Space

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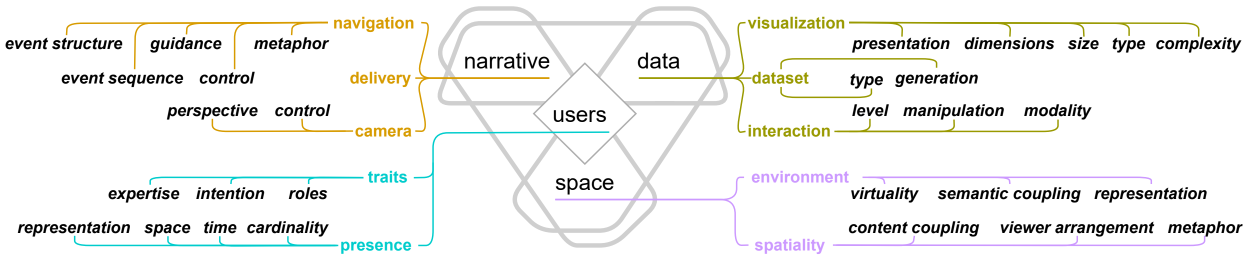

Fig. 1: Overview of our design space of *Immersive Data-Driven Storytelling*, grouped by four major design aspects.

1 Introduction

In this document[1], we describe our design space for immersive data-driven storytelling. First, we describe the four general design aspects that constitute this emerging notion, followed by a detailed description of each design dimension. Next to the name of each dimension, we use a combination of the following icons to indicate how the dimension was created:

- The dimension was directly informed by the scoping review results. In the description of each dimension, whenever we reference a paper from the final corpus of the scoping review, we use an icon next to the citation (e.g., [26]).
- The dimension was influenced by the journalism or games parts of our scoping review. We also reference this material with specific icons for journalistic material [ ] and games [ ].
- The dimension was influenced by our previous experience, e.g., on immersive analytics. Every unhighlighted reference in the dimension descriptions is part of this bundle. When possible, we transfer existing categorizations to the values of our dimensions (e.g., Segel and Heer's article on Narrative Visualization [51] influenced several dimensions).

2 Design Space Overview

Our design space consists of four major aspects: *Narrative*, *Data*, *Users*, and *Space*. The order in which these categories are discussed does not reflect their importance, as all play an equally vital role in crafting immersive data-driven stories. **Narrative** refers to the components specific to the narration and/or story design and delivery (see Section 3). **Data** contains the dimensions related to generation, visualization, and interaction with the data (see Section 4). **Users** refers to the human aspects, both in terms of user traits and the general features related to the users (see Section 5). Lastly, **Space** is concerned with the environment and spatiality aspects that come into play for immersive data stories (see Section 6).

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[1]This Design Space is supplementary material for the full paper available at https://doi.org/10.1109/TVCG.2025.3531138

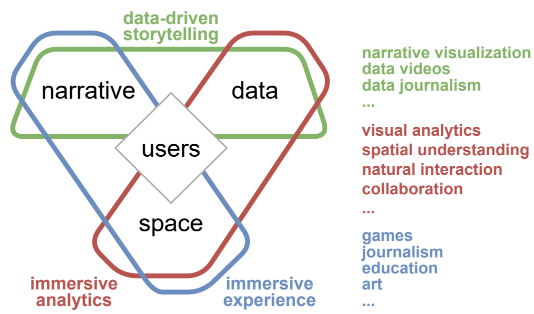

Fig. 2: The four major design aspects related to immersive data-driven storytelling: *Narrative*, *Data*, *Space*, and *Users* (at the center to signify their importance). The colored outlines indicate the related research areas that altogether influence the design of such experiences. Namely, *Data-Driven Storytelling* [51], *Immersive Analytics* [49] and *Immersive Experiences* (in particular, journalism and games). The keywords to the right of the diagram represent related notions to each field.

Figure 2 illustrates the way that these categories interact with each other. These categories are not orthogonal (i.e., well-designed immersive data stories will tightly integrate aspects of these categories, blurring the distinction between them). However, using this lens to analyze these experiences reveals the more mature areas that are involved. For instance, considering only the *data* and *space*, we are technically speaking of Immersive Analytics as it is concentrated on methodically examining the advantages and difficulties of employing immersive environments for data analysis.

As is the case with most design spaces, our proposed dimensions are not meant to be exhaustive nor self-contained since their interplay is what enables rich, engaging experiences. Therefore, we focus on aspects that altogether contribute to the overarching goal of immersive data-driven storytelling, highlighting open areas of research and largely unexplored design possibilities. The entire design space, including possible values for each dimension, can be found in the Appendix of this document.

3 Narrative

This design aspect encompasses the storytelling of the experience, such as the plot structure of the story, the agency that the user has over the resolution of the events and progression of the story, the medium used to deliver the narrative, and aspects of cinematography. An overview of the dimensions within this category can be seen in Figure 3.

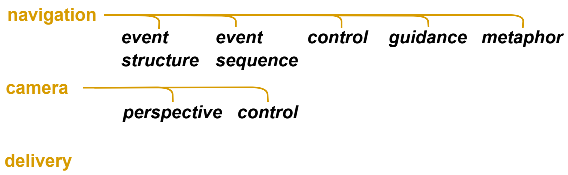

Fig. 3: Summary of the dimensions of the design aspect *Narrative*.

3.1 Navigation – Event Structure

We refer to the concept of an **event graph**, where nodes indicate views or narrative events and edges indicate the progression of the story to different events. Such structures are typically used to understand the structure of narratives and storyboarding (e.g., [15, 39]). We observed **linear** data stories (e.g., [9], [Hanami at home] but also **drill-down** structures (e.g., [Rocket science made easy] and **free-form graphs** (e.g., [24], [The World in 2070]. Additionally, the survey by Marques et al. on AR journalism [37] discusses simultaneous (parallel) linear structures and combinations of free-form graphs with other structures.

3.2 Navigation – Event Sequence

This dimension refers to whether the user can experience variance in the order of events due to their interactions [37]. It can be seen as the audience's traversal of the event graph from (a) beginning to (an) ending. Our defined values are **fixed** – there is no variance (typical of linear structures e.g., [1]), **interactive** – the variance depends on user decisions, e.g., [11], and we also propose to consider **random**, where there is variance in the sequence of events regardless of the user's decisions (e.g., stochastic events).

3.3 Navigation – Control

This dimension refers to the way that users can interact with and influence the story's progression. From least to most control, one could conceive data stories where the user has **no control** at all. Then, in **slide-shows**, the user can only trigger *next, previous,* or *jump* to a specific event (e.g., Microsoft PowerPoint, Google Slides). In **video-players**, the user can play, pause, rewind, skip forward or use some sort of progression bar to jump to a specific point in time (e.g., YouTube, Netflix). With **interactive media**, we refer to controls that require the user to (1) make a decision or (2) perform an action to progress the story. These controls are quite diverse, from a list of choices (e.g., traditional visual novels [8]) to performing an action or moving somewhere (typical of video games by, e.g., [Telltale], [Quantic Dream]). Lastly, **diegetic controls** refer to the transformation of abstract user interface components as part of the environment and thus perceivable by the characters of a story. In the video game industry, this well-received practice is notorious for increasing the engagement and immersion of the players [21, 50] as witnessed by games such as [I Expect You To Die], [Resident Evil 7], and [Half-Life: Alyx]. In AR/VR, this aspect of design becomes particularly relevant to multi-user systems, where the physical representations visible by more than one user are diegetic by definition.

3.4 Navigation – Guidance

This dimension refers to the presence or usage of specific components to guide the user's attention or actions, either towards regions of interest or towards interacting with objects to trigger story progression. Starting from the values by Segel and Heer [51], we found the following guidance techniques: **cues** [4], **highlighting** [1], and **transitions** (e.g., as camera movements [60]). Additionally, we found explicit mention of **presenter gestures** [17] as a means to trigger events in presentations and simultaneously draw the audience's attention. Lastly, we propose **character companions** (e.g., [Falcon Age], **landmarks**, and **traces** as alternatives to guide users, all of which are commonplace in video-games [5, 36].

3.5 Navigation – Metaphor

This describes the overall experience used to deliver the story. **Free-movement** refers to scenarios where the user makes use of natural movement (e.g., walking) or shortcuts (e.g., teleportation), and is not fixed to a specific path, i.e., the user can freely explore the narrative. **Vehicle** simply refers to being moved automatically through the narrative path as a passenger (or operator) of a device. For instance, an elevator that moves the user through several floors (e.g., [18]), or a roller-coaster (e.g., [9]), would fall under the vehicle metaphor. Lastly, we add **dynamic world**, considering the possibility to change the world around the user instead of moving the user through events.

3.6 Camera – Perspective

This refers to the position of the camera with respect to the user (or the main entity controlled by the user). Immersive technologies and single-user data-driven stories typically use **1st person** cameras (i.e., looking through one's own eyes or embodying an entity in first person). The concept of **3rd person** camera transferred from 3D video games to VR games, referring to cameras "over the shoulder" of the controlled entity. 1st and 3rd person perspectives have also been discussed in VR as a spectrum instead of fixed values by Hoppe et al. [20]. Moreover, **2nd person** views entail controlling an entity while the camera is on an entity that the user does not control. An example of this can be seen in a chase sequence in [Driver: San Francisco], where the player controls a fugitive vehicle but can only see from the perspective of a pursuing police car. In AR/VR, 2nd person perspectives can be realized by swapping the displayed content on two HMDs, which has been done recently for training simulations for medical education [33]. Lastly, it is possible to envision multiple (or multi-faceted) perspectives converging into a single perspective (i.e., "collective perspectives", also discussed as the 4th person perspective).

3.7 Camera – Control

This category refers to the degrees of control and interaction possibilities that the user has over the camera as an entity. **Free-roam** means the camera can be controlled freely and positioned anywhere. This is possible by default when using HMDs since the camera can be moved freely through physical movement. In gaming communities, free-roam also refers to fully free camera movement (i.e., "god views"). This could be emulated, e.g., in VR, by allowing the user to move the world freely around them. Considering cinematography (discussed for 3D data videos [60]), other values can be derived by, e.g., limiting the degrees of freedom of the camera or using automatic transitions [1, 9, 28]. We refer to these examples as cameras with a **fixed** property (*position, target, path, view*, etc.). For example, fixed *position* means that only the direction that the camera points to can be controlled.

3.8 Delivery

This dimension refers to the medium (or mixture thereof) used to deliver the narrative. The values of this dimension are **text** (e.g., [34, 57]), **audio** (e.g., [28, 65]), **images/glyphs** (e.g., [11, 59]), and **video/animation** (e.g., [1, 60, 62]). In (non-immersive) narrative visualization for journalism [51], the most typical values are text and audio. For text, the story is delivered using short text fields (labels, captions, headlines, annotations) or long descriptions (articles, introductions, summaries). For audio, the story is narrated through a presenter's voice or recorded speech. These trends continue in the results of our scoping review, as audio and text remain the most used and in similar ways as described.

4 Data

This design aspect encompasses the data *source*, *visualization*, and *interaction* possibilities. It is worth noting that these dimensions can be very tightly connected with the Narrative. For example, progressing the story by interacting with visualization is a means to tie together data interactivity and navigation (see Section 3: Navigation – Control and Camera – Control). These dimensions are strongly informed by the

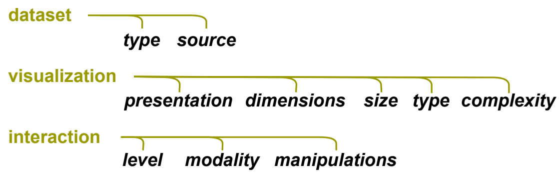

Fig. 4: Summary of the dimensions of the design aspect *Data*.

survey on immersive analytics by Saffo et al. [49]. The overview of the dimensions considered in this major category can be seen in Figure 4.

4.1 Dataset – Type

Based on the dataset types proposed by Munzner et al. [42], this dimension distinguishes **tabular** [25, 66], **networks** [11, 14], **spatial**, **volumetric** [1, 34], and **fields** as possible dataset types. We found that abstract data types are more common in data-driven stories, and we speculate that this is because the stories themselves can be used to facilitate the understanding of abstract data.

4.2 Dataset – Source

Adapted from the categories discussed in the literature about immersive analytics systems [38, 49], this dimension refers to the way that the source data is obtained by the immersive data story. The values for this dimension are **static, dynamic**, and **interactive**. Static refers to data from an immutable source. All systems from the scoping review support this type of source. Dynamic refers to data that is live-streamed [13, 54] into the data model of the system. Lastly, interactive refers to cases where the user influences the source of the data. For example, imagine a museum that shows the paths taken by previous visitors. Regardless of whether this information is live-streamed or stored for later display, it is affected by user interactions.

4.3 Visualization – Presentation

This dimension refers to the data representation on a spectrum from completely **abstract** (e.g., scatterplots, bar charts, node-link diagrams [4, 11, 14]) to completely realistic, **natural** representations (e.g., inherently 3D data such as volumetric datasets [1, 34], and *"augmented"* abstract data [29]). With respect to this dimension, the broad question of *"How much reality is necessary?"* was proposed by Isenberg et al. [23], considering that realism enhances the feeling of immersion [52].

4.4 Visualization – Dimensions

This category refers to the dimensionality of the data representation, not to be confused with the data dimensionality. Despite the intrinsic 3D nature of immersive environments, the usage of **2D** visualizations (e.g., bar charts, scatterplots, line charts on a 2D plane) remains popular among the results of the scoping review [4, 17, 26, 45]. However, **3D** visualizations translate naturally to immersive environments, for both abstract and inherently 3D data [1, 34, 60], as also witnessed in various immersive analytics tools [38, 49].

4.5 Visualization – Size

This dimension refers to the relative size of the visualizations concerning the average user, as described by Saffo et al. [49]. The values of this dimension are **small, medium**, and **large**, referring respectively to handheld, human-sized or much larger than a human. Immersive environments lend themselves well to large visualizations due to the potentially *"unlimited display space"*, especially in VR settings. Data visceralization [29] also employs large representations to effectively communicate scales to the user without specific value marks.

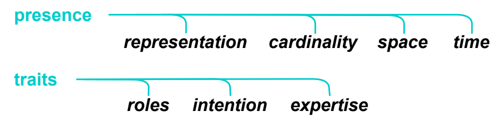

Fig. 5: Summary of the dimensions of the design aspect *Users*.

4.6 Visualization – Complexity

Based on the categorization used by Bowman et al. [6], this dimension differentiates between **low**, **medium**, and **high** complexity of the visualizations. Low complexity refers to the encoding or display of single values (bars, lines). Medium refers to using multiple visual variables (e.g., position, size, color) and ludophasmas (i.e., ghost-like guides). Lastly, high complexity refers to visualizations of structures like trees and graphs, as well as further visualization techniques that require significant visualization literacy to parse.

4.7 Visualization – Type

This refers to visualization technique(s) that are employed, e.g., **barcharts** [60], **node-link-diagrams** [14], **maps** [11], **linecharts** [9], and **volumes** [34]. After charting these values, we did not find a strong reason for using specific visualization types in the collected systems, but simpler visualizations are generally preferred.

4.8 Interaction – Level

Adapted from the categories by Segel and Heer [51], this dimension refers to the amount of interaction possibilities available to the user with respect to the visualizations. It is a spectrum from **no/limited interactivity** to **full interactivity**. The former refers to anything from static representations to minimal interaction (e.g., geometric zoom and pan [60]), while the latter refers to intricate interaction possibilities, which are comparable to dedicated immersive analytics systems [1, 11].

4.9 Interaction – Modality

Immersive systems support a variety of interaction modalities. With this dimension, we consider modalities discussed by Lee et al. [30]: **gaze, voice, touch**, and **tangible** (using, e.g., everyday objects). We include mid-air interactions under the **gestures** category, explicitly mentioned by Hall et al. [17] in their augmented chironomia system. Furthermore, we propose the values for **proxemics** and **body gestures** [27], as well as **generic input devices** like gamepads and VR controllers, which are used by most VR games.

4.10 Interaction – Manipulations

Originally based on the well-known interactions by Yi et al. [61] and referred to as manipulations by Saffo et al. [49], this dimension considers values **select, abstract/elaborate, connect, explore, filter, encode**, and **reconfigure**. These values are further informed by related work about data journalism [51, 63], where **inspection** (similar to select + elaborate) and **navigation** (similar to connect) are considered separately. However, we did not find a large focus on interaction in the results of the scoping review, coinciding with the findings of Marques et al. [37]. This dimension is closely related to topics discussed in the Narrative design aspect.

5 Users

This design aspects refers to the (human) users involved in the immersive storytelling. We use the word actors interchangeably to refer to the users, and we make a distinction between (1) presenter(s) and (2) audience member(s). Presenters include the author(s) of the story, the persona(s) that deliver narration directly or characters that play roles within the story. The audience refers to the users to whom the story is delivered. They may also play a role in the story if the story is interactive. Figure 5 illustrates the overview of the dimensions considered in this category.

5.1 Presence – Representation

This dimension refers to the way that the actors are portrayed and thus perceived by other actors. We determined three values for this dimension: **real-life**, **avatar**, and **non-visual**. Real-life is typical in AR settings where the users can be seen among the overlaid content. However, especially in VR settings, avatars of varying complexity are used to illustrate where the users are and what they are doing. The realism of avatars influences how the story is perceived [2, 43]. For instance, a serious setting would be dissonant if comical representations are used for the avatars. Lastly, non-visual representations such as disembodied voices are also commonplace in storytelling settings (e.g., omniscient narrators and audio guides [28]) and may be used to avoid occluding story or data elements when multiple audience members experience the story simultaneously.

5.2 Presence – Cardinality

This dimension counts the amount of presenters and audience members involved in the story. We consider the story author as the presenter if the story is told only through the environment (i.e., no presenter). Thus, we use presenter-audience cardinalities from **1-1** to **n-m**. Naturally, designing for and involving larger and broader audiences (e.g., immersive theaters [32]) are challenges associated with this dimension.

5.3 Presence – Space

This dimension refers to the physical or remote presence of the actors with respect to the others. **Co-located** means the actors are in the same physical space (e.g., an in-situ presentation [26]). **Co-presence** means that the actors have at least a virtual representation within the same physical space, even if they are physically in a remote location (e.g., [17]). **Distributed** means that the actors are in different physical and virtual locations simultaneously. Combining these values leads to "mixed presence" settings, which brings further technological and design-related challenges [22]. Furthermore, for both co-located and co-presence, one could detail the spatial arrangement of the users based on He et al. [19]: *face-to-face* (e.g., presentations or classrooms), *side-by-side*, or *concentric* (e.g., presenter surrounded by audiences).

5.4 Presence – Time

Closely related to the Space dimension, this dimension refers to whether the actors must be present **synchronously** (e.g., live presentations) or **asynchronously** (e.g., pre-recorded content). Most of the consulted papers involve asynchronous systems, where the content has been established and can thus be consumed by users (e.g., [1, 11, 28]). However, systems such as the Augmented Chironomia tool [17] and HoloStation [26] support live presentations.

5.5 Traits – Roles

This dimension refers to the characterization and involvement of the users in the storytelling process. It is subdivided into presenters and audiences. Presenters may not take part in the story, thus being **author only**, or they may play the role of a **character** within the story (e.g., narrator, guide, companion). The audience, on the other hand, can have an active, **participatory** role in the story, a passive **consumer** role, or they may be **bystanders**, uninvolved with the story but still present in the surroundings (e.g., in [14, 66]). While active and passive roles can be orchestrated and present a clear opportunity for specific design choices, the visual presence of bystanders can also have a non-trivial effect on the experience (e.g., occlusion, distraction, guidance). This presents an opportunity to explore design choices that accommodate such roles.

5.6 Traits – Author intention

Based on the discourse classification by Steen [53] and the identified purposes in storytelling by Ojo et al. [44], with this dimension, we refer to the intentions to **inform**, **persuade**, and **entertain**. The typical intention of data-driven stories is to inform since the data usage can increase readers' receptiveness and trust [46]. However, the scoping review also pointed us to Bastiras et al. work on using narrative visualizations in virtual reality to convince users about a theory [4] (i.e., to persuade).

Naturally, journalism exemplifies the usage of storytelling to inform and raise awareness. For example, the project [Sinking in Drought VR] makes use of simple data visualizations in AR to raise awareness of the effects of droughts and the amount of water needed to prepare food.

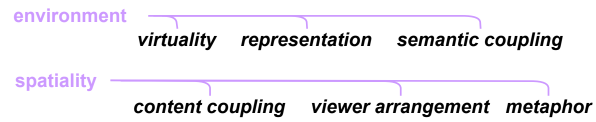

Fig. 6: Summary of the dimensions of the design aspect *Space*.

5.7 Traits – Audience expertise

This dimension addresses the literacy of users concerning visualization [7], technology [41], and even general storytelling tropes and structures. While the influence of the target audience expertise in each of these categories can influence the design of immersive data stories, we bundle them together for our categorization as a spectrum from **low** to **high** expertise, and once again encourage future research to investigate various levels of expertise.

6 Space

With this category, we discuss two major aspects regarding the general context of immersive data-driven storytelling: *Environment* and *Spatiality*. The overview of the dimensions that are considered in this category can be seen in Figure 6.

6.1 Environment – Virtuality

Inspired by the Reality-Virtuality Continuum by Milgram et al. [40], this dimension characterizes the amount of virtual elements in the environment. The values we characterize are **Virtual Reality** (VR), **Mixed Reality** (referring to AR or MR), and **Real World** (no virtual elements in the environment). Lee et al. describe examples of systems throughout this spectrum, from physical artifacts to HMDs [31].

6.2 Environment – Representation

This dimension defines the visual appearance of the storytelling environment. Bastiras et al. deliberately designed their environment to be unobtrusive during their study on narrative visualizations in virtual reality [4]. Their solution uses an **abstract** representation of a void surrounding the main scene. It follows from their reasoning, that a **realistic** representation of the environment can have an effect beyond distraction, in particular, if it is connected to the content of the data story directly (e.g., [29, 64]). We also consider the overall atmosphere chosen to deliver a data-driven story by distinguishing **neutral** (e.g., [4]) and **emotion triggering** surroundings (e.g., [3]).

6.3 Environment – Semantic Coupling

Closely related to the arguments described for Representation, we specify the connection between (1) the state or (2) elements of the environment representation and the story progression or data objects [16]. Clear examples of the influence of such semantic connections are highlighted in Assor et al. in their AR eco-feedback system for waste management [3], where garbage bags are placed in a typical dormitory room to communicate the unsustainability of such a hypothetical situation. We refer to this type of content coupling as **story-coupled**. The concept of semantic coupling can be extended further to, subtly or explicitly, illustrate properties of the data used for the story as well (**data-coupled**). Lastly, a deliberate choice may also be made to keep the environment completely **decoupled** of both story and data, as presented earlier on the work by Bastiras et al. [4] and several of the 3D data videos discussed by Yang et al. [60]. A strong example of both semantic and story coupling is the game Oblivion [25], where the shape of the island is in itself a visualization encoding climate data from the island Tuvalu.

6.4 Spatiality – Content Coupling

This category characterizes the spatial relation between other dimensions (data, narrative, and environment). To facilitate the discourse, we use two terms: **content**, which we use interchangeably to refer to *data* and *story*, and **context**, which we use to refer to either *data, story* or *environment*. Segel and Heer [51] describe the position of narration delivery and explanations with respect to the visualization through a category named *messaging* that includes, e.g., annotations, captions, and summaries. The data visualizations and accompanying narrative delivery are often placed *side-by-side*, and updated correspondingly according to the narrative navigation control (e.g., scrolling). This notion can be transferred to immersive environments, inspired by previous research on text placement in VR [47, 48]. **Embedded** relationships between visualizations and surroundings are discussed e.g., in PEARL [35], where the amount of time users spend in space while moving is shown on the ground. Likewise, an example of **situated** is shown by Tatzgern et al. [55] by placing linked information labels next to the bookshelf in the library. From our scoping review, an example of both embedding and situated coupling between data visualizations and (virtual) surroundings can be seen in HydrogenAR [58]. This system creates a fully virtual representation of a vehicle display and overlays data visualizations to educate about the fueling properties of said vehicle in the form of a tutorial. Naturally, the content and context may be **decoupled**, e.g., when the data visualizations are floating arbitrarily. Within these content/context arrangements, it is also possible to distinguish layouts (grids, stacks, linear, etc.).

6.5 Spatiality – Viewer Arrangement

Compared to traditional desktops, one of the essential advantages of immersive technology is the spatiality for presenting abundance of content at once, without the limitation of physical display areas. With this dimension, we employ the concepts of **exocentric** and **egocentric** arrangements [10, 56]. The former refers to situations where the user is outside of the content, whereas the latter refers to users placed within the content. From the scoping review, HydrogenAR [58] and Holostation [26] illustrate the consideration put into the arrangement of content with respect to both presenters (egocentric) and audience (exocentric).

6.6 Spatiality – Metaphor

The last dimension of our design space is an all-encompassing metaphor that describes the overall arrangement of every component of the immersive data-driven story experience. Once more, these categories are not exhaustive, but represent the predominant situations encountered in the papers of the scoping review alongside some general ideas of how such experiences may be shaped. The values we determined are thus: **keynote presentation** [26], **face-to-face demonstration** [17], **museum/gallery/zoo** [66], and **open-space/world** [25, 29, 64]. Of course, this is not a comprehensive list, and the number of useful structuring spatial metaphors is far higher (see [12] for an initial overview). Open spaces are also well-suited for AR and immersive projections, e.g., on buildings.

7 Image Credits

The icons , , are from the LaTeXpackage "fontawesome5", SIL OFL 1.1.

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A Appendix

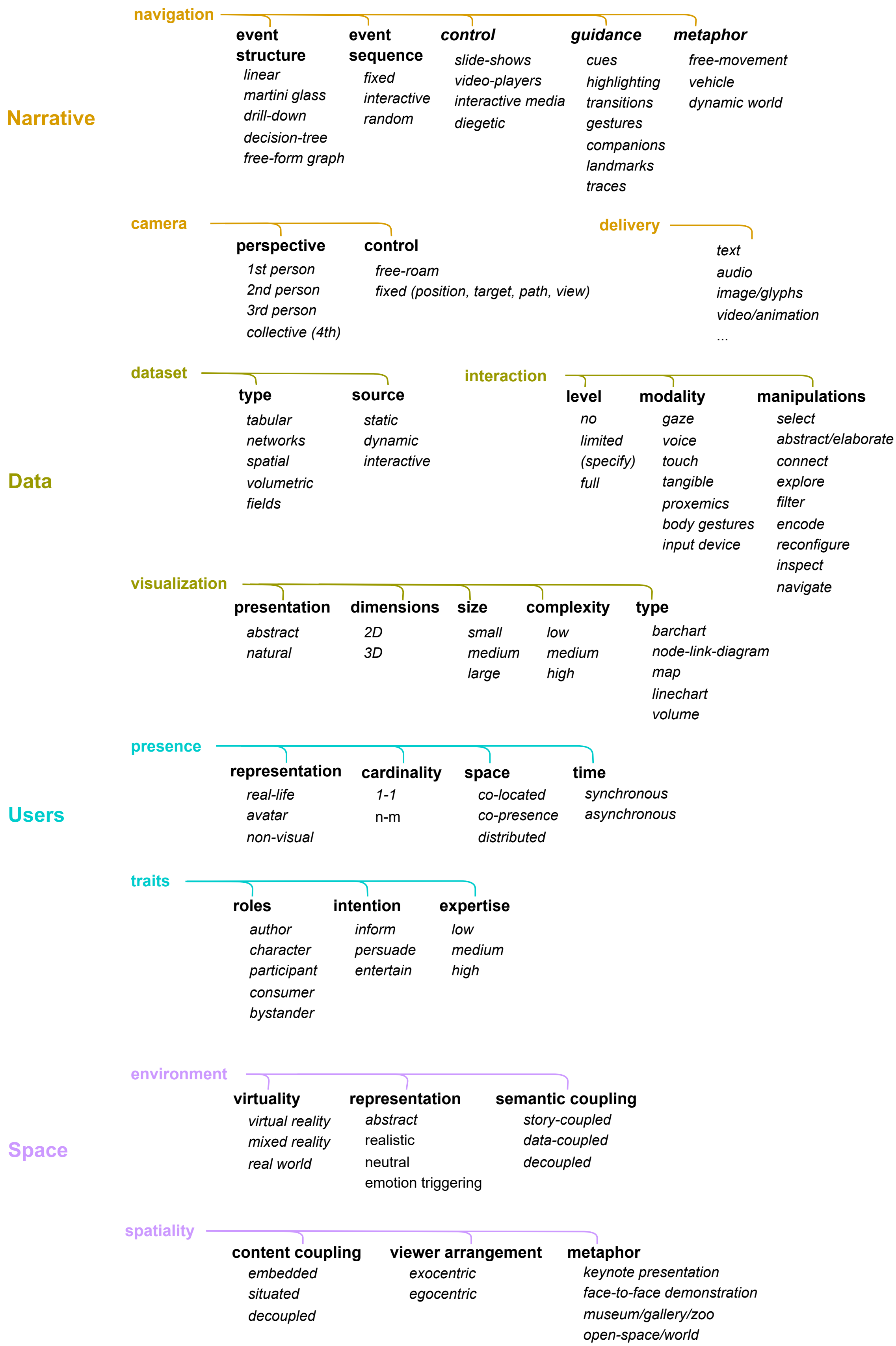

Fig. 7: Our design space for immersive data-driven storytelling including values for each dimension.