SlideSpace: Heuristic Design of a Hybrid Presentation Medium

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The Slide and Canvas metaphors are two ways of helping people create visual aids for oral presentations. Although such physical metaphors help both authors and audiences make sense of material, they also constrain authoring in ways that can negatively impact presentation delivery. In this article, we derive heuristics for the design of presentation media that are independent of any underlying physical metaphors. We use these heuristics to craft a new kind of presentation medium called SlideSpace—one that combines hierarchical outlines, content collections, and design rules to automate the real-time, outline-driven synthesis of hybrid Slide-Canvas visuals. Through a qualitative study of SlideSpace use, we validate our heuristics and demonstrate that such a hybrid presentation medium can combine the advantages of existing systems while mitigating their drawbacks. Overall, we show how a heuristic design approach helped us challenge entrenched physical metaphors to create a fundamentally digital presentation medium with the potential to transform the activities of authoring, delivering, and viewing presentations.

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1. INTRODUCTION

Since the release of PowerPoint in 1987, the dominant paradigm for the authoring and delivery of digital presentations has been based on the Slide metaphor, in which discrete display areas have fixed size, content, and order [Farkas 2009]. However, since the development of zoomable user interfaces for presentations [Good and Bederson 2002], a competing Canvas metaphor has emerged in which a single display area is navigated through continuous, nonlinear transformations of a dynamic viewport.

While these concrete metaphors help to address specific problems in content creation and visual communication, each metaphor creates challenges of its own [Good and

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Bederson 2002; Lichtschlag et al. 2009, 2012]. In this article, we explore opportunities to design a hybrid presentation medium that combines the benefits of different metaphors while mitigating the drawbacks of conventional authoring approaches.

Our literature analysis highlighted six key tradeoffs relating to the authoring, delivery and implementation of Slide versus Canvas presentations:

(T1) *Content problems*. Slides encourage excess cutting of content to fit; a canvas allows arrangements of content to grow unrestrained in two-dimensional space.

(T2) *Logical problems*. Slides break logical hierarchy when bullets are promoted to titles; a canvas breaks logical flow when the viewing path and layout differ.

(T3) *Contrast problems*. Slide titles in the same style mask variations in hierarchical level; the scale of canvas text can be misinterpreted as reflecting a hierarchy.

(T4) *Context problems*. Context is lost for backup slides moved to the end of the deck; canvas context can intrude on viewing frames and transition paths.

(T5) *Structural problems*. Nonlinear structure (e.g., a tree or network) is lost when serialized to slides; canvas structure becomes difficult to change over time.

(T6) *Navigation problems*. Slide navigation leads to incidental slide skipping; canvas navigation leads to incidental animation of all viewport contents.

Many of these problems arise because the same metaphors that facilitate viewer understanding also constrain presentation authoring. One broad solution is to separate the authoring medium from the delivery medium [Beamer 2003; Edge et al. 2013; Impress.js 2011; Slidy 2005; Zongker and Salesin 2003]. While this has the potential for powerful automation and greater visual consistency, it comes with a reduction in visual feedback and user control. The demands of writing markup, scripts, or code also create a steep learning curve and a barrier to mainstream acceptance. A key requirement for the design of an accessible presentation medium is, therefore, to deliver the benefits of automation without sacrificing learnability, feedback, and control.

We begin with a critical examination of existing presentation systems, concepts, and recommendations, culminating in six heuristics for the analysis and design of presentation systems (a conceptual contribution). We then use these heuristics to motivate the design of a hybrid presentation medium, SlideSpace (a system contribution). Finally, we describe a qualitative study of SlideSpace use in which we validate our heuristics, elicit feedback on the features they inspired, and elucidate tradeoffs with respect to existing metaphors and practices (an empirical contribution).

From these contributions, we conclude that hybrid presentation media have the potential to support new kinds of presentation authoring, and that SlideSpace is a promising first attempt at such a hybrid design. While the generality and expressiveness of conventional Slide and Canvas presentation systems means that they will always support the widest possible range of compositions and purposes, we are strongly encouraged by the ability of SlideSpace (and the implied possibility of other hybrid presentation media) to satisfy presentation authoring needs across a range of common and critical activities. Furthermore, since SlideSpace implements heuristics that target the clarity of visually supported communication, the resulting presentations have the potential to be "more audience oriented" (to quote a study participant) in ways that are of reciprocal benefit to the presenter. At the highest level, this work is thus an examination of how hybrid presentation media can help presentation authors to connect more effectively with presentation audiences, by transforming not only the visuals of the presentation, but its delivery by the presenter.

2. CONSIDERATIONS FOR PRESENTATION DESIGN

To derive appropriate heuristics for the analysis and design of presentation systems, we needed to understand the authoring concerns faced by presenters. We also wanted to

understand and potentially reuse the design concepts that existing digital presentation systems have used to address such concerns.

Since digital presentation systems are grounded in physical metaphors, we first review three key metaphors found in presentation systems: the Slide metaphor, the Canvas metaphor, and the Stage metaphor. Each of these metaphors embodies a different solution to the problem of communicating a logical hierarchy of talking points using a temporal sequence of visual representations.

It not always easy to differentiate between effects arising as a consequence of a metaphor in general versus its specific, concrete implementations. As described in the following sections, real presentation systems often extend their primary metaphors with features that make up for deficiencies of those metaphors. When we analyze the physical metaphors underlying presentation systems, therefore, our reference is the ways in which those metaphors have historically been realized in existing presentation systems, not the full space of design possibilities for extending such metaphors.

2.1. Physical Metaphors for Presentation Design

2.1.1. Slide Metaphor. The metaphor of projection slides has been examined by Farkas [2009] using the concept of mediation effects—characteristic ways in which a technology influences communication [Kaptelinin and Nardi 2006]. Negative mediation effects arising from particular features do not mean that those features are inherently bad— just that the effects need to be managed for effective communication. For example, a positive mediation effect is the ability to reuse content because of the modular nature of slides. However, the same similarity that makes slides modular and reusable also causes problems, especially if the default slide templates of a title, one or two levels of bullet points, and an optional graphic are used. This is due to three effects:

(S1) *Content cutting*. Authors may eliminate material to fit the available space, reducing clarity and completeness (e.g., by aiming for 3–4 bullet points per idea).

(S2) *Overflow distortion*. Authors may promote bullet points to slide titles, violating the logical hierarchy of ideas (e.g., by aiming for 3–4 bullet points per slide).

(S3) *Title flattening*. Authors may style all slide titles in the same way, masking variations in hierarchical level (e.g., by aiming for total consistency across slides).

All three effects can be addressed by workarounds [Farkas 2009]. First, manually reducing object sizes and spacing can reduce content cutting. Second, allowing bullet points to flow across slides with sequential titles (e.g., Title–1, Title–2) can reduce both content cutting and overflow distortion. Third, title flattening can be reduced by giving previews, reviews, or overviews of talk structure. Attributes such as font face and color can also be varied to signal the hierarchy of slide titles. These design concepts attempt to help viewers reconstruct hierarchies of talking points that have been flattened into a linear sequence of visuals. However, these workarounds may also have their own negative effects, in that they can reduce both *visual consistency* and *visual closure* (i.e., partially filled slides can appear unfinished or incomplete as a result).

Additional authoring concerns arise from the linearity of slide sequences. Lichtschlag et al. [2009] call this "time dominance." We translate their arguments into mediation effects at the whole-talk level, mirroring those of Farkas [2009]:

(S4) *Context cutting*. Backup slides at the end of the deck lose their context unless manually connected by hyperlinks (and authors need to know how to do this).

(S5) *Structural distortion*. Nonlinear structure (e.g., a tree or network) is lost unless reconstructed in overview slides (and authors need to anticipate the value of this).

(S6) *Navigation flattening*. Revisiting content requires slide skipping unless it is manually duplicated and maintained (and authors need to remember to do this).

Together, these effects motivate the need for authoring approaches that are not constrained by the similarity or linearity of slides.

2.1.2. Canvas Metaphor. Benefits of the Canvas metaphor have been explored by Lichtschlag et al. [2009, 2012], whose design concepts can be expressed in terms of how they avoid Slide mediation effects. First, changes in viewport size during authoring and delivery avoid content cutting and context cutting, respectively, since it can always be expanded on demand. Second, smoothly connecting one viewport (and associated visual elements) with the next allows continuous content to be shown without overflow distortion, as well as building up to the big picture without structural distortion. Third, the scalable canvas allows logical talk structure to be mapped directly onto a corresponding spatial structure, with dynamic detail-context transitions overcoming the effects of title flattening and navigation flattening.

However, just as the inherent similarity of slides can cause problems, so too can the inherent flexibility of canvas viewports. Our analysis identified three parallel effects:

(C1) *Content dumping*. A canvas encourages arrangements of content to grow freely without any spatial constraints (e.g., from an absence of filtering during layout);

(C2) *Path distortion*. A canvas breaks logical flow when the viewing path does not follow the spatial layout of content (e.g., from an absence of sequencing during layout).

(C3) *Title scaling*. The scale of canvas text can be incorrectly interpreted as reflecting its hierarchical level (e.g., from an absence of prioritization during layout).

Similarly, the inherent spatiality of canvas layouts causes problems related to those arising from the linearity of slides:

(C4) *Context intrusion*. Canvas context can intrude on viewing frames and transition paths in unanticipated ways (so authors need to remember to check for this).

(C5) *Structural ossification*. Canvas layout becomes harder to change over time as more parts are manually arranged in space (so authors need to resist giving in to this).

(C6) *Navigation animation*. Canvas navigation leads to visual movement of content in the path of the viewport (so authors need to consider the visual effect of their path).

A problem common to both the Slide and Canvas metaphors is that static content can reveal information prematurely. For Slide presentations, the consequences are limited to the audience reading ahead to the end of the slide [Abela 2008; Duarte 2008]. For Canvas presentations, the workaround of "hiding" content by making it very small or placing it very far away is exacerbated by navigation animation, resulting in dramatic camera movements that can cause disorientation and even motion sickness.

2.1.3. Stage Metaphor. The distinguishing feature of the Stage Metaphor is independently animated content. Like actors on a stage, visual elements enter and exit the screen, with meaningful interaction in between [Duarte 2008]. The progressive revealing of elements that is possible with the Stage metaphor [Abela 2008; Duarte 2008; Farkas 2009; Lichtschlag et al. 2009] can create visual transformations that are gentler and more incremental than whole-viewport slide cuts and canvas pans/zooms.

Two recommendations for creating animated presentations [Zongker and Salesin 2003] are to manage complexity through overlays and to do only one thing at a time. The drawbacks are also twofold: the effects of time dominance [Lichtschlag et al. 2009] from independently timed actions are more pronounced than Slide presentations, while gratuitous animation creates even more distracting motion than Canvas viewports.

It is important to note that the Stage metaphor is realized through animation features within all mainstream presentation systems as an extension of their primary Slide or Canvas metaphors. In our analysis, we therefore focus on the relative advantages and disadvantages of the more foundational Slide and Canvas metaphors.

2.2. General Recommendations for Presentation Design

Inspiration for heuristics can also come from how visuals will be perceived and understood. Principles of multimedia learning [Mayer 2009], derived over decades of research in educational psychology, can also be applied to presentation media:

(M1) *Multimedia Principle*. Use words and pictures together.
(M2) *Coherence principle*. Omit extraneous words and pictures.
(M3) *Redundancy principle*. Omit text intended to be spoken.
(M4) *Spatial contiguity principle*. Present related text and pictures nearby in space.
(M5) *Temporal contiguity principle*. Present related words and pictures simultaneously.
(M6) *Segmenting principle*. Divide material into a sequence of meaningful segments.
(M7) *Signaling principle*. Add cues that highlight the organization of key material.

These principles have been used to argue against the topic-subtopic structure seen in most slides [Garner et al. 2009]. The proposed alternative is the assertion-evidence structure of a succinct sentence headline stating the main assertion of the slide, supported by visual evidence that explains and elaborates upon the assertion.

For guidance on how to organize content onscreen, we can follow the "big four" principles of visual design: contrast, repetition, alignment, and proximity [Reynolds 2012]. The encompassing theory of *processing fluency* proposes that these principles affect the perceptual ease with which visual material can be processed, which in turn affects the viewer's evaluation (e.g., to agree or not) [Reber et al. 2004]. Negative viewer responses to visual disorder on slides (e.g., clutter, inconsistency, and misalignment) have been argued to result from reduced processing fluency [Abela 2008].

The effectiveness of presentations is also mediated by the tools used. In our previous work, we concluded a qualitative study of presentation practices by proposing four principles for presentation system design [Edge et al. 2013]:

(P1) *planning with points* encourages clear, purposeful text and logical structure;
(P2) *styling as a service* increases the exploratory design and consistency of visuals;
(P3) *linking between scenes* improves the verbal and visual connections between visuals;
(P4) *expanding on demand* supports content elaboration and skipping during delivery.

These principles are based on the premise that presentations can be conceived as a hierarchy of talking points to be communicated. Explicitly thinking in terms of such hierarchies is recommended in the literature as a way to prioritize and layer communication, as well as establishing a clear narrative structure. For example, the Beyond Bullet Points template is based on a three-act structure, with the second act presenting three key points, each supported by three explanations, each supported by three details. According to the book Beyond Bullet Points [Atkinson 2011]:

> You absolutely need an idea hierarchy to help you decide which of your slides are more important than others... A hierarchy breaks up a complex body of information into smaller pieces that are easier for working memory to handle and then prioritizes those pieces and places them in a particular sequence... A hierarchy is the natural way people routinely go through a reasoning process.

Thinking about how content can form a meaningful hierarchy is even more important when the presentation metaphor encourages the author to think about low-level

connections between content elements, but not the overall story. This is especially true for the Slide metaphor, which encourages the author to build slides in a flat, linear sequence. Even if the resulting slide connections make sense to the author, they may not be comprehensible to an audience during delivery. For this reason, almost all contemporary presentation experts recommend explicit hierarchical structuring of presentation content (e.g., Abela [2008], Atkinson [2001], Duarte [2010], and Reynolds [2012]).

Note that a hierarchical outline does not mean that the resulting presentation must be experienced by the audience as the traversal of a hierarchy. Conventional slide presentations already embody three distinct levels of detail: the talk title, the slide titles, and the slide bullets (which may themselves be nested). The hierarchical level of a slide element can usually be inferred from its size, position, and layout with respect to other slide elements; for example, a talk title is usually a large text box in the center of the first slide with a unique layout, while slide titles and bullet points usually occupy the top and bottom parts of a repeated slide layout. If distinctive section slides are added, this inserts an additional level of hierarchy between talk and slide titles.

Similarly, a hierarchical outline does not require that the underlying content forms a natural hierarchy. Even if the core content is a sequence of images, these would benefit from an introduction and conclusion in ways that introduce a degree of hierarchy. Conversely, if the content naturally forms some other form of nonlinear structure like a cycle or network, it remains the responsibility of the author to determine how to create a meaningful path through the material. Once such a path is determined, the addition of narrative organization again brings us back to a hierarchical structure. We, therefore, take the consideration of hierarchical structure as a fundamental part of preparing to deliver any form of presentation.

2.3. Digital Systems for Presentation Design

The first version of PowerPoint [Wikipedia 1987] was designed for printing overhead transparencies, and thus, contained no animations or transition effects. It established the Slide metaphor and remains the archetypical example of "slideware."

The contrasting Canvas metaphor has evolved across several systems. The Counter-Point system [Good and Bederson 2002] was the first to arrange completed slides on a canvas. A unique feature of this system was the use of layout rules to map a user-specified hierarchy of slides onto the canvas (e.g., arrange children of a slide in a circle around it). The pptPlex system [pptPlex 2011] also mapped slides onto a canvas, but in a restrictive grid layout. The Fly system [Lichtschlag et al. 2009] built on earlier work by foregoing slides altogether and supporting the atomic layout of content items. It also adopted a constraint of two zoom levels (topic and detail) to avoid the sense of disorientation that can arise from deep zoom. Finally, Prezi [2009] has subsequently popularized canvas presentations as a mainstream alternative to slides.

Both PowerPoint and Prezi extend their primary metaphors with the Stage as a secondary metaphor for content animation. An example system using the Stage as its primary metaphor is [PowToon 2012], which supports direct manipulation of object timelines for animated presentations embodying the visual aesthetic of cartoons.

2.3.1. Authoring beyond Physical Metaphors. A common approach to overcoming the constraint of linear slide sequences is nonlinear navigation. For example, the Customizable Presentations system allows authors to create a network of slide paths that can be dynamically navigated during delivery [Moscovich et al. 2003]. NextSlidePlease [Spicer et al. 2012] builds on this concept, automatically selecting the path that promises timely talk completion. Finally, Palette [Nelson et al. 1999] uses actual physical slides as random-access proxies to their digital counterparts. A second kind of extension is

to offer design automation. For example, the [PowerPoint Labs 2013] add-in can apply Stage effects (e.g., adding a rolling emphasis) to selected shapes on PowerPoint slides. This reduces the number of repetitive actions required to achieve a particular effect. Full separation between presentation structure and visuals takes design automation even further. For example, Beamer [2003] and Slidy [2005] support slide creation from markup in LaTeX and HTML, respectively; Impress.js [Impress.js 2011] supports canvas creation using HTML and CSS markup; and Slithy [Zongker and Salesin 2003] supports Stage and Canvas programming in Python. Such systems have the benefits of focusing attention on logical structure rather than visual style, using style rules to ensure visual consistency.

2.3.2. Presentation Activities beyond Authoring. In our present work, we focus on the activity of presentation authoring. However, the broader activities of presenting extend far beyond the creation of visuals. In our prior work, we have developed TurningPoint [Pschetz et al. 2014] for the initial brainstorming of content and mapping it to narrative structures in advance of slide generation; SidePoint [Liu et al. 2013] for the suggestion of related facts, descriptions, and images based on slide text; PitchPerfect [Trinh et al. 2014] for the rehearsal of slides annotated with notes for each visual element, planned speaking paths, and time targets; TalkZones [Saket et al. 2014] for the section-based setting of time targets to be visualized and followed during delivery; v4v [Dontcheva et al. 2005] for providing audience members with a personally controllable view of the presentation visuals; DemoWiz [Chi et al. 2014] for reperforming software demonstrations in live presentations; and a system for assisting authors with the management of multiple slide decks [Drucker et al. 2006]. Although these systems target slide presentations, they could all be adapted to support alternative presentation media and metaphors. We have also developed three systems that employ design automation in the creation of slides. The first, HyperSlides [Edge et al. 2013], supports the generation of hyperlinked slides from hierarchical text specifications. The second two systems— StyleSnap and FlashFormat [Edge et al. 2015]—support mixed-initiative approaches to slide editing that maintains visual consistency while creating and modifying the slides of a deck. Our present work takes this notion of design automation even further, exploring what forms presentation authoring and delivery could take if they were not constrained by existing physical metaphors. We hope that such automation can not only encourage greater design exploration on the path towards more consistent and comprehensible presentation designs, but free up time that can be dedicated to these other, often neglected activities of presenting.

3. HEURISTIC DESIGN OF THE SLIDESPACE SYSTEM

We wanted to explore the potential for a new approach to presentation authoring—one that combines the advantages of existing approaches while mitigating their drawbacks. We envisioned that any approach that achieves this objective is more likely a hybrid of existing, successful approaches than a new, unproven physical metaphor with its own set of tradeoffs.

Our initial step was to distill the collective considerations of the previous section into heuristics for the analysis and design of presentation systems. The results are summarized in Table I. We first used affinity diagramming to cluster concerns based on their associated authoring activities (e.g., style theming). For each of the six activities that resulted, we attempted to craft a heuristic that could be used to "question" the support provided by a given system design. These heuristics are potentially useful for evaluating any kind of presentation system, independently of its underlying metaphor, because the authoring activities are expressed in generic terms.

Table I. Six Heuristics for the Analysis and Design of Presentations Applied to Three Presentation Metaphors

Heuristics for Presentation Tool Design		Analysis of Physical Metaphors in Presentation Design		
Heuristic [H1-H6]	Related Concerns	Slide Metaphor	Canvas Metaphor	Stage Metaphor
Substantiating [H1] *Can talking points be illustrated with flexible quantities of media?*	*multimedia, coherence and spatial contiguity principles* *content cutting and dumping* *context cutting*	Slides can encourage too many text points with insufficient illustration of each	Canvas viewports can scale to illustrate any number of items, at a loss of visual detail	Stage animations can reuse screen space to illustrate points progressively
Segmenting [H2] *Can points be organized in a logical structure that is easy to modify?*	*segmenting principle* *planning with points* *overflow and path distortion*	Slide and bullet lists are easy to modify in isolation but not as a combined structure	Canvas layouts can reveal structure, but layouts are difficult to modify systematically	Stage animations have timings that are hard to visualize and modify
Signaling [H3] *Can presentation context be visualized in between content visuals?*	*signaling principle* *linking across scenes* *structural distortion* *navigation animation*	Slide insertion and content duplication are needed to create context-giving visuals	Canvas zoom out can reveal local context and global structure, at a loss of visual detail	Stage viewports are fixed so context-giving visuals must be built up manually
Spatial Theming [H4] *Can layout modifications be applied to visuals of the same type?*	*processing fluency* *visual consistency* *visual closure* *styling as a service* *context intrusion*	Slide templates can maintain spatial consistency, but direct edits override them	Canvas templates can provide starting layouts but need manual edits to extend and modify	Stage persistence keeps objects in place but screen layouts continually update
Style Theming [H5] *Can style modifications be applied to content of the same type?*	*structural ossification* *title flattening and scaling*	Slide templates can maintain style consistency, but direct edits override them	Canvas style rules can maintain style consistency, but direct edits override them	Stage style rules can maintain style consistency, but direct edits override them
Synchronizing [H6] *Can the current focus be clarified by hiding and highlighting content?*	*temporal contiguity & redundancy principles* *expanding on demand* *navigation flattening*	Slide duplication and systematic editing are needed to create a rolling visual focus	Canvas zoom in can add focus, but creates low visual context and excess viewport motion	Stage animations create implicit focus on the most recent visual transformation

We further clustered activities into three high-level qualities that can act as goals for presentation authors. Each of these translates directly into audience benefits:

(B1) *Logical coherence*. *Substantiating* each talking point with supporting media and *segmenting* talking points into a coherent structure supports logical processing.

(B2) *Visual consistency*. *Spatial theming* of elements into consistent layouts and *style theming* of elements to have consistent appearances supports visual processing.

(B3) *Oral coordination*. *Signaling* structure through overviews, previews, and reviews and *synchronizing* visuals with speech supports aural processing.

These goals are common to many kinds of presentation in education, academia, and business, and most appropriate for communication of complex or conceptual subjects that benefit from a clear visual structure. They are not in themselves sufficient to guarantee a good audience reception; for example, the presentation might exhibit all of these qualities yet fail to connect with the audience, perhaps because the author's chosen message, illustration, explanation, narrative structure, spoken delivery, demonstration, or pacing is inappropriate. Our prior work (discussed in the previous section) has tackled each of these potential problems in detail. In addition to not being sufficient conditions for presentation success, neither are these qualities necessary. Particular presentation contexts might benefit from reduced levels of each quality; for example, presentations intended to entertain might benefit from lower logical
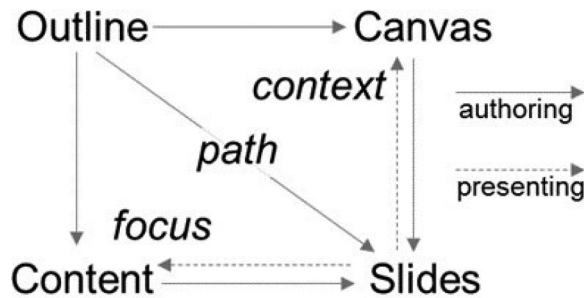
Fig. 1. SlideSpace presentations are built on a hierarchical outline of text points. These text points are spatially mapped onto a canvas that provides a master layout for slides. Each text point is illustrated by one or more slides that visually combine canvas text and a supporting content item (text, image, or video). A systematic traversal of the hierarchical outline of text points determines the slide path. Slides are styled to highlight the current focus and can be zoomed out to the canvas to give context during delivery.

coherence, presentations intended to exhibit (e.g., art or design work) might naturally have lower visual consistency, while presentations intended to inspire might benefit from lower oral coordination through more ambient, evocative backdrop images. Nevertheless, for presentations intended to inform, instruct, or persuade, these three qualities are of fundamental importance for authors and audiences alike.

We now walk through the design of our SlideSpace system, the high-level design of which is shown in Figure 1. We implemented the system as a Web application in HTML5, CSS, and javascript, using the AngularJS library for the UI and the D^3 library [Bostock et al. 2011] for rendering the slides and canvas.

3.1. Segmenting with an Outline-Driven Path

SlideSpace supports segmenting of the presentation into logical parts using a hierarchical outline of text points. Unlike prior systems that use a text outline [Beamer 2003; Edge et al. 2013], SlideSpace provides a visual outline editor that represents each point to be presented as a text block. This editor supports addition of text points at different levels as well as restructuring of blocks using drag handles. SlideSpace limits the outline to three levels to prevent disorientation from excessive nesting [Atkinson 2011]. The outline editor remains visible throughout the authoring process and drives the subsequent activities of designing the presentation canvas (Figure 2, top) and collecting supporting content (Figure 2, middle). It also provides an implicit path through the hierarchy of points, generating slides in depth-first order (Figure 2, bottom).

Although SlideSpace supports the hierarchical organization of text points, it does not require it—a linear sequence of top-level text points can be used to mirror the flat structure of a section-free Slide deck if desired. If the appropriate sequence or hierarchy of text points is unclear at the outset of the presentation authoring process, users are similarly free to create a flat, unordered list that can later be reorganized and structured as desired.

In terms of design concepts, the logical outline of text points separates the structure from the content, allowing each outline point to be an assertion and each content item to be evidence following the assertion-evidence structure. The hierarchical structure also creates a multiple path network enabling dynamic traversal during delivery. In terms of authoring concerns, this design adopts the planning-with-points strategy such that the final presentation follows the segmenting principle of dividing multimedia content into a sequence of meaningful units. Authoring in an outline without slide boundaries also reduces content cutting and overflow distortion, while the automatic extraction of the viewing path removes the potential for path distortion.
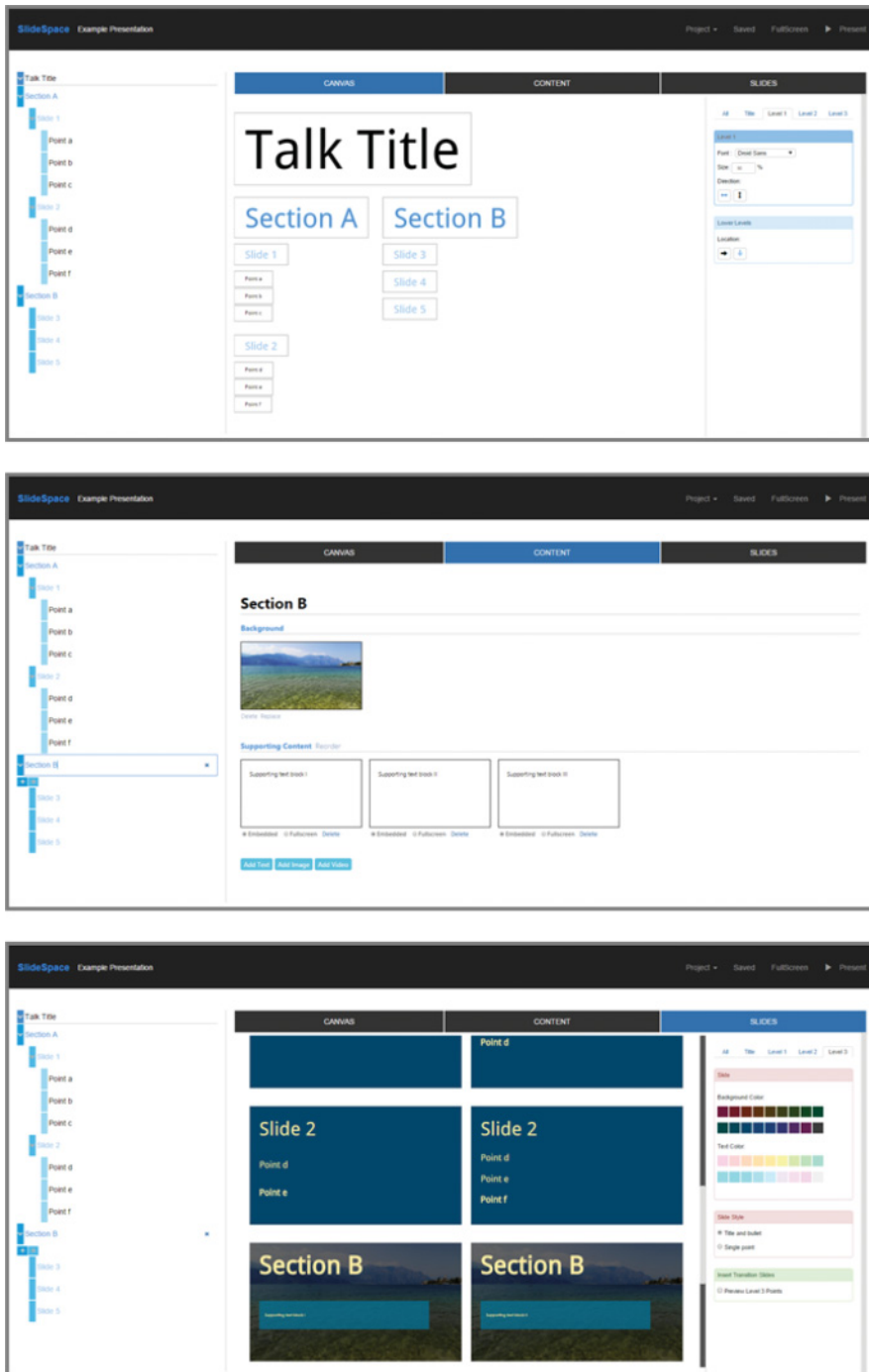
Fig. 2. SlideSpace UI: (top) canvas view with outline editor on left, canvas layout in center reflecting the outline structure, and canvas layout options on the right; (middle) content view with outline editor on the left and content associated with selected outline point to the right; (bottom) slides view with outline editor on the left, slides in the center combining canvas layout and content, and slide styling options on the right.

3.2. Spatial Theming with an Outline-Mapped Canvas

SlideSpace supports spatial theming through the novel use of a canvas that provides both a "master" layout for slides and a meaningful basis for animated transitions between text points. As the author adds, edits, and removes text points from the outline, the Canvas tab maps the hierarchy into a spatial layout (Figure 2, top). This layout is constructed automatically and in real-time based on layout rules that can be set for the whole canvas or independently by outline level. These rules specify the flow direction of text points (horizontal or vertical), the location of text points at lower levels (right or down), and the font face and size of text at that level (percentage of title font size). The layout algorithm automatically calculates appropriate alignment and spacing of text blocks, as well as the line wrapping strategy that will result in a visually balanced slide with clear information hierarchy. For example, canvas layouts created from different rules are shown in Figure 3.

In terms of design concepts, this approach uses layout rules to ensure consistency of the canvas layout, which is a direct mapping of the hierarchical talk outline. In terms of authoring concerns, this design adopts styling as a service to prevent structural ossification and unintentional changes to the visual hierarchy of titles, while ensuring visual consistency in the alignment, repetition, and proximity of elements.

3.3. Substantiating with Outline-Linked Content

SlideSpace supports substantiating of each outline point with a collection of related content items (text, images, or videos) whose purpose is to illustrate and explain that point (Figure 2, middle). The author interacts with such collections by clicking the "Content" tab. Each item can be set to appear in a content box embedded in the slide or expanded to fill the screen. An image or video can also be set as the background of associated slides, which then add a semitransparent contrast layer of appropriate lightness (black or white) to maintain text legibility (Figure 2, bottom and Figure 4).

In terms of design concepts, these outline-linked content collections act as evidence in the assertion-evidence structure and help authors manage complexity through overlays of content that do not persist on the canvas. Like consecutive slides with repeated titles (e.g., Title-1, Title-2), these transient content boxes reuse slide space to build understanding of a text point over multiple slides. In terms of authoring concerns, this design follows the multimedia, coherence and spatial continuity principles by placing only the related words and pictures of the focus text point together in a dedicated view. It also reduces content cutting while authoring (the temptation to stop considering additional content, e.g., because the slide is full) since content collections are not built in the constrained spaces of slides, as well as reducing the negative effects of content dumping (the temptation to continue adding content, e.g., because the canvas in unbounded) since additional content does not affect slide layouts.

3.4. Style Theming with Canvas-Composed Slides

Each SlideSpace slide is an illustration of a single outline point composed from its text on the canvas, optional canvas text from related points (i.e., its parent and peers in the outline), and an optional item from its content collection (Figure 2, bottom). SlideSpace supports style theming through rules that style all slides of text points at the selected level in the same way. Combined with the slide layout inherited from the canvas, such style theming ensures slides at each level have a consistent visual appearance.

3.4.1. Slide Contents. To differentiate slides representing text points at different levels in the outline hierarchy (e.g., a section slide versus a detail slide), the author can customize the contents of slides at each level. The author does this in the Slides tab by specifying which additional canvas text to include. The two options currently supported

Fig. 3.   Different canvas layouts generated from the same outline, based on variations in the relative locations and flow directions of text points at each of the three levels.

are single-point style for maximum focus and title-and-bullet style (showing the parent and preceding peers of the current text point) for meaningful context (Figure 4). This allows the detail level of slides to be adjusted quickly and systematically, e.g., to create strong visual contrasts between slide types or to make the detail level appropriate to the presentation display size (e.g., mobile phone vs. large projection screen). Automatic viewport resizing wraps the viewport around the specified canvas text before fine-tuning the slide layout to ensure there is sufficient space for any embedded content and sufficient variation in font size to communicate visual hierarchy. Other canvas text in hidden to prevent it from intruding on the view. Such independent animation of visual elements is an application of the Stage metaphor.

3.4.2. Slide Layout. The layout engine scales and translates text from its canvas positions to make space for an embedded content box and fill the available slide space in a visually balanced way, promoting a high degree of visual closure (and by extension, a polished appearance). Slides at the same level all share the same layout, differing only in the text used and the number of text points shown, as a way of increasing the potential for audience understanding through high processing fluency. When slides are set to include the peers of the focus point, the default behavior is to progressively reveal those peers over several slides. When they are set to flow vertically (the equivalent of bullet lists), the text boxes of the focus point and its preceding peers are centered in the available vertical space, adjacent to the content box. Before a new text point is added, existing points shift upwards to make space while retaining a balanced layout. Horizontal text points are added in their final position to maintain an aligned left margin. These progressive, animated "builds" are characteristic of the Stage metaphor.

3.4.3. Slide Styling. Another way to differentiate slide types, even if they share the same layout, is through styling rules that vary font face, font color, and background color by level. For example, weighting text based on hierarchy helps avoid the issue of title flattening. SlideSpace also always adds a bold emphasis to the text of the focus point to differentiate it from other, context-giving text points (Figure 4). Color and contrast schemes can be systematically manipulated in the Slides tab in ways that leverage the outline hierarchy and promote good contrast among visual elements and their backgrounds. The HCL color space of D^3 is used to create color palettes from which all combinations of foreground and background colors have the same perceptual contrast and can thus be freely interchanged. The primary control is a slider that simultaneously updates the text and background lightness of all slides in a way that maintains good contrast, inverting the lighter/darker relationship when passing midway. For slides with an image background, a black or white contrast layer is added automatically. The transparency of this layer can be adjusted in the Slides tab, as well as through hotkeys during the presentation (for calibration on the projection screen).

3.5. Signaling with Canvas-Context Transitions

SlideSpace supports signaling of upcoming and already-presented talk structure. Any such transitions automatically animate invariant content using motion tweening and fade other content in or out as required. This results in fluid viewport navigation that exhibits independent element animation in the style of the Stage metaphor.

SlideSpace supports both planned and spontaneous signaling. Planned signaling options are available in the Slides tab and insert slides into the default depth-first outline transversal. These slides reveal the context of the current text point on the canvas in two distinct ways. The first option is to "Preview" text points at level x, which inserts slides showing the canvas text of all level x peers of the same level x–1 parent following the introduction of that parent (Figure 4, top right). Once a point is
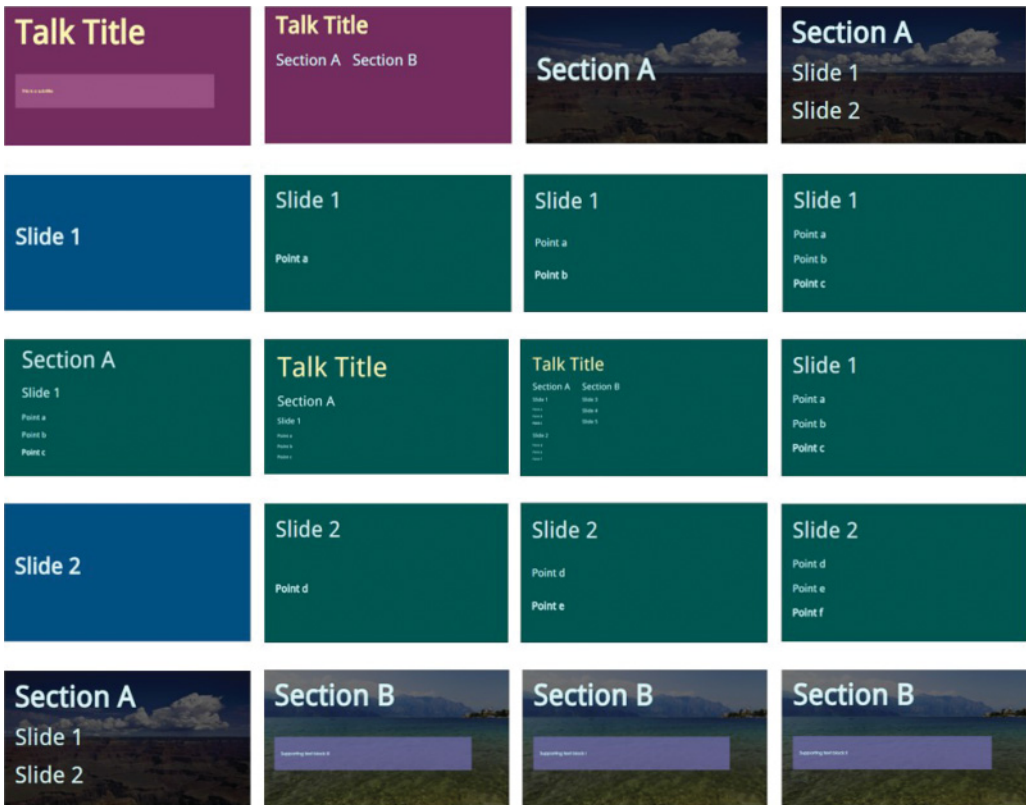
Fig. 4. SlideSpace slides. First row: talk title with text content; inserted preview of level 1 sections; first level 1 section in single-point style with background image; preview of level 2 "slides". Second and fourth rows: a level 2 "slide" in single-point style followed by progressive revealing of level 3 "points" in title and bullet style. Third row: navigating upward from "Point c" during delivery before returning to the focus point. Fifth row: inserted review of all level 2 "slides" belonging to the level 1 point "Section A" followed by three embedded text content items for the level 1 point "Section B." Slide colors reflect the level of the focus point.

previewed, its text remains visible on the canvas and subsequent slides, providing both presenter and audience with a visual roadmap of the points to come.

A second planned signaling option is to "Review" at level x, which inserts slides showing the canvas text of all level x peers of the same level $x-1$ parent following the presentation of those level x peers and their children (Figure 4, bottom left). This allows the overall sequence of level x peer points to be viewed and summarized in the context of their level $x-1$ parent before making a major transition to the next peer of the level $x-1$ parent, providing both visual and verbal continuity across different levels of the outline hierarchy. The effects of the preview and review options are symmetric and complementary, and anticipated to be of particular benefit when the presenter wants to reinforce the audience's memory and understanding of the overall talk structure.

The third and spontaneous way to use signaling is by performing an ad-hoc transition from a slide to its surrounding canvas during presentation delivery using a hotkey. Since all canvas text is hyperlinked to the introductory slide of the corresponding point, spontaneous transitions to canvas overviews can be used to navigate the presentation in a nonlinear fashion. This functionality allows the presenter to expand talking points on demand in a way that overcomes the problem of navigation flattening, and supports

nonlinear delivery of fundamentally nonlinear content for which the hierarchy is simply an aid to navigation.

In terms of authoring concerns, this design follows the signaling principle by highlighting the organization of material at the opportune moment of linking across scenes. Such repeated restructuring of the serialized material through navigation animation also limits the effects of structural distortion, helping viewers build and reinforce a mental model of the overall talk structure.

3.6. Synchronizing with Slide-Focus Transitions

SlideSpace supports synchronizing of visuals and speech during delivery through in-presentation controls that leverage the underlying outline hierarchy. The slides on the prepared path of the presentation can be navigated by pressing the *Right* and *Left* keys to move forwards and backwards, respectively. Pressing the *Up* key on a slide transitions to the canvas, expanding the viewport to include an additional level of talk structure while maintaining the focus on the current text point (Figure 4, third row). Pressing the *O* key (*O* for "overview") zooms all the way out to the overview of content presented so far. Pressing the *Up* key when the overview is already visible provides the additional visual context of all canvas text points, even those not yet presented. The same effect can be achieved immediately by pressing the *A* key (*A* for "all"). Clicking on any text in any canvas view navigates directly to the first slide associated with that text point, supporting nonlinear navigation. Pressing the *Down* key when viewing the canvas removes higher levels of talk structure down to the slide level. SlideSpace could also be extended to support structured navigation using gestures.

The automatic bolding of the focus point creates a rolling emphasis as the presenter moves through the presentation. To create conventional PowerPoint-like slides without bullet animation, the author can set slides at level *x* to be previewed and shown in title-and-bullet style. Since previewed bullets remain visible, the result is a series of slides with identical titles and all bullets, with the current bullet highlighted in bold type.

Overall, all animated transitions to preview, review, or introduce content follow the principle of only doing one thing at a time, providing a visual cue for the presenter to verbally link text points in ways that reinforce the narrative structure. In terms of authoring concerns, this design follows the redundancy and temporal contiguity principles by allowing concise text points to accompany related media on screen, while also providing clear cues for the speaker to elaborate on the current point or transition.

3.7. Summary of SlideSpace Design Contributions

SlideSpace is a hybrid of existing metaphors and interaction paradigms. Nevertheless, each aspect of the SlideSpace design embodies a novel concept for presentation design:

(D1) *Outline-linked content*. An outline of text points linked to content collections.
(D2) *Outline-mapped canvas*. A "master" canvas layout generated from an outline.
(D3) *Canvas-composed slides*. Slides synthesized from canvas text and content.
(D4) *Outline-driven path*. A slide sequence derived by traversing a talk outline.
(D5) *Canvas-context transitions*. Advance insertion of context-giving transitions.
(D6) *Slide-focus transitions*. Real-time control over focus-shifting transitions.

4. SLIDESPACE STUDY

We wanted to investigate how people use SlideSpace to create presentations, and how its emergent interaction qualities lead to advantages or disadvantages with respect to conventional presentation software. At a higher level, we wanted to understand the extent to which SlideSpace embodied the heuristics that motivated its design features, and the resulting implications for the future design of hybrid presentation media.

We did not have the goal of experimentally comparing SlideSpace use to that of common commercial presentation systems such as PowerPoint or Prezi, because (a) as a research prototype, SlideSpace lacks many of the features of such systems; (b) we wanted feedback from skilled presenters, who would have well-established practices and preferences regarding the use of such systems; and (c) we did not design SlideSpace to be better than these existing systems, just different in ways that may confer advantages for certain users and use contexts. Overall, we had four questions:

(Q1) *How do presenters use and respond to the hybrid medium of SlideSpace?*
(Q2) *When would SlideSpace be an appropriate presentation system and for whom?*
(Q3) *To what extent does SlideSpace embody our design heuristics in useful ways?*
(Q4) *How could future forms of hybrid presentation media improve upon SlideSpace?*

We chose to address these questions through a qualitative and seminaturalistic study design, in which skilled presenters used SlideSpace to create a presentation from prepared materials (an essay accompanied by a collection of images). This approach gave all participants a consistent starting point and allowed us to analyze the range of different approaches participants took to create a SlideSpace presentation from that point onwards. It also removed the distraction of searching for appropriate materials. In all other ways, it mirrored the task of creating an oral presentation from a written document created by a third party, as is common practice in business settings (e.g., the delegation of slide creation to a design vendor) as well as academia (e.g., presenting a paper to be discussed in a reading group). We do not have reason to believe that the mechanics of SlideSpace use would be substantially different if the user was also the originator of the written material to be presented, or if the material was held in mind rather than externalized in writing, although this is a limitation of our study design.

4.1. Participants

We recruited eight participants (four females, ages 23–50) through the email mailing lists of our institution, a local university, and a local Toastmasters group. Participant backgrounds spanned the areas of design, science, technology, teaching, marketing, and management. Two were Ph.D. students and six were senior professionals with the occupations of university professor, communications director, relations director, project manager, editor, and startup founder. All were highly experienced users of slide-based presentation software (Microsoft PowerPoint and Apple Keynote). All were also familiar with canvas presentations, with four being experienced in use of canvas presentation software (Prezi). No participants had previous exposure to SlideSpace. Participants freely volunteered their time and received a token gift for participation.

4.2. Procedure

We conducted one study session per participant, each lasting approximately two hours and spanning a preparatory phase, task phase, and discussion phase. The preparatory phase consisted of three parts and lasted approximately 20 minutes. First, we gathered information about the participant's background and presentation experience. Second, we gave the participant a live presentation of SlideSpace, using SlideSpace, for them to grasp the fundamental authoring approach as well as the nature of the audience experience. Third, we led the participant through the concrete use of SlideSpace features as they followed on their own machine.

We then moved on to the core task of the study: to create and deliver a presentation using SlideSpace. All participants used the same source material relevant to the local context: smoking bans in Beijing, China. This material consisted of an "Economist" essay [The Economist 2015] and some stock images relevant to the reading. Participants were encouraged to think aloud throughout the process, which we observed in

addition to using screen capture, audio recording, and automated logging of participant actions with the interface. We manually tracked which features the participant had used, and in the second half of the allocated authoring time, we encouraged the participant to experiment with any unused features. Participants were otherwise free to use SlideSpace however they pleased. The core task finished with the participant presenting their SlideSpace talk to the study conductor.

The final phase of the user study was a semistructured interview probing various aspects of the SlideSpace user experience and reflections on how it compared with their prior use of existing presentation software. We did not explicitly define or inquire about individual heuristics, since they represent relatively abstract concerns best understood through participants' rich description of concrete experiences. Instead, we used these heuristics as predefined categories for the coding of study transcripts, which we created from recordings of both the think aloud task protocol and post-task interviews.

4.3. Results and Discussion

We begin our analysis of results with a summary of high-level findings F1–F4, corresponding to the four questions Q1–Q4. Together, these findings suggest considerable potential for hybrid, heuristic-based presentation media like SlideSpace:

(F1) *How do presenters use and respond to the hybrid medium of SlideSpace?* Presenters use the hybrid medium of SlideSpace in a variety of ways, moving between views embodying different authoring media and output metaphors in ways that reflect personal preferences and strategies for presentation creation. SlideSpace encourages logical, big-picture, audience-centered authoring of presentations that clearly communicate both content and structure.

(F2) *When would SlideSpace be an appropriate presentation system and for whom?* SlideSpace is an appropriate presentation system for a wide range of presenter skill levels, talk lengths, and presentation stakes, most suitable for formal presentations in business-like contexts and situations in which authors are willing to trade freedom of artistic control for flexibility of consistent control.

(F3) *To what extent does SlideSpace embody our design heuristics in useful ways?* SlideSpace strongly embodies the six design heuristics developed through our analysis of prior presentation systems, concepts, and recommendations. Each of these heuristics has a clear, positive effect on the authoring experience, but any instantiation of these abstract heuristics in concrete designs will create new mediation effects whose impact and mutual influence should be considered.

(F4) *How could future forms of hybrid presentation media improve upon SlideSpace?* Future forms of hybrid presentation media could improve upon SlideSpace by relaxing its strict constraints on the consistency of visual output, supporting new forms of collaborative editing and theme sharing, and allowing for lightweight touch interaction and remixing of content across multiple presentations.

We now organize our discussion of results according to the questions Q1–Q4.

(Q1) How do presenters use and respond to the hybrid medium of SlideSpace?

Editing Behavior. Figure 5 illustrates the total time spent in each of the editing views (Canvas, Content, and Slide) for the eight participants (the Outline is common to all views). The average allocation of time was similar across the three views (mean 17 minutes for Canvas, 15 minutes for Content, and 13.5 minutes for Slides), although the fact that each of the three views attracted the most editing time for at least one participant points to a range of editing strategies. The Canvas view accumulated the most time for five of the eight participants and the most time on average across
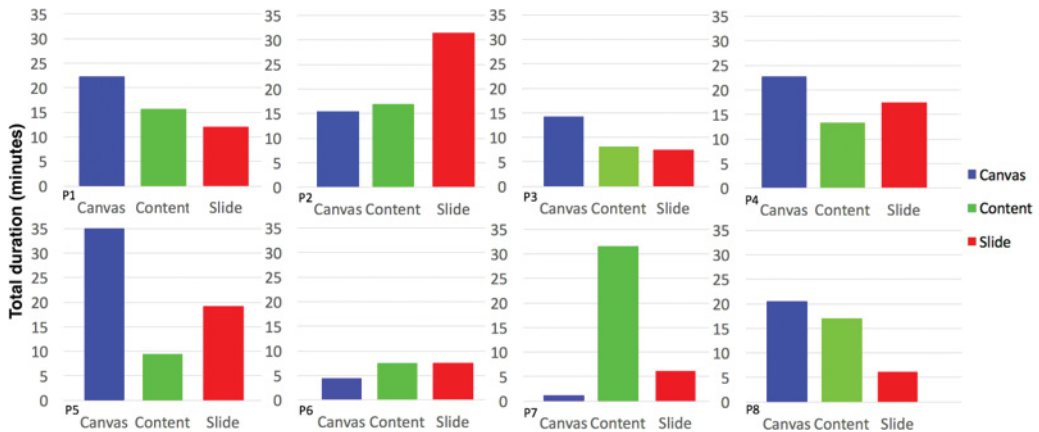
Fig. 5.   Aggregate time spent in each editing view (Canvas, Content, and Slide) for each of the eight partici-pants P1–P8. Each of the three views attracted the most editing time for at least one participant.

participants, although it was also the first listed and default view on the tabbed SlideSpace interface.

Figure 6 further shows how editing on the three views unfolded over time. This visualization reveals even greater variation in participants' editing strategies, ranging from a highly linear progression (from Canvas, to Content, to Slides) across a small number of view transitions (P3), to highly iterative and nonlinear editing (P5).

Figure 7 characterizes the resulting SlideSpace presentations in terms of the distri-bution of outline text points and supporting content items across the three levels. Only two participants (P5 and P8) built a conventional hierarchy with greater numbers of outline text points at deeper levels, and each of the three levels had the most text points for at least one participant. Outline text points typically exceeded supporting content items overall, but at least one participant had content items exceeding the number of text points at each of the three levels. Total outline text points ranged 12–19, and content items 6–14.

Although SlideSpace imposes structure on presentation authoring both in terms of the process (the three editing views) and the product (conforming to a hierarchical outline), we were encouraged by the diverse ways in which participants appropriated and worked within this structure according to their editing preferences. The separation of editing concerns could even make it easier to form and enact such preferences.

Authoring Approach. In addition to observed patterns of editing behavior, we were interested in how participants viewed the hybrid medium of SlideSpace and its blending of three editing views (and the underlying metaphors of Slide and Canvas). In terms of authoring approach, the general consensus from participants was that SlideSpace is much more structured than existing systems. However, in many cases, the Outline-driven approach positively reflected and supported established practices:

I already have an outline in my mind, so the outline stuff is pretty easy for me [P1].

I just use pen and paper to do the outline and then start on the PowerPoint. So as I said this [SlideSpace] is a very natural way to build it [P2].

[SlideSpace] helps me to think about, from a high level perspective, the overall planning of the outline of the entire presentation, instead of focusing on one slide at a time. In some ways, it is similar to what I've developed as a habit. . . And now this new tool is latching on to this mental model and this experience. I found this to be useful [P3].
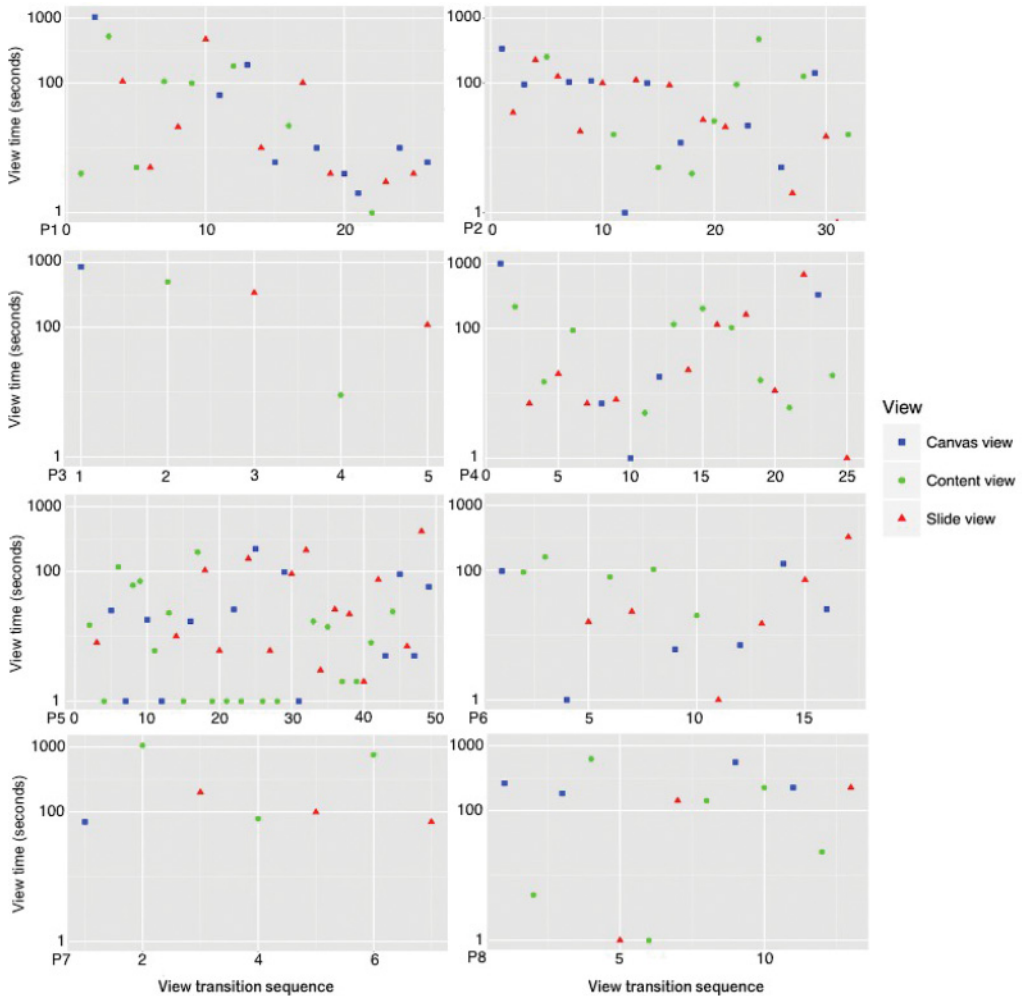
Fig. 6. Transitions between editing views over time for each of the eight participants P1–P8. Editing patterns varied from a highly linear progression from Canvas to Content to Slides, to highly iterative and nonlinear.

Participants also recognized the structured output as being of benefit to the audience, without deviating too far from the norms of Slide presentations:

> When I am presenting though, I think it is similar to PowerPoint [P1].

> If I use PowerPoint myself, I may create something very similar to this... this more structured kind of presentation will definitely help the audience [P2].

> I generally sense that the end result of what I just did is more audience oriented [P3].

> It's neat, it's like Prezi but slides. So a bit more familiar to an audience member probably than a Prezi... and more focused on the points [P6].

The primary visual difference between SlideSpace presentations and Slide presentations is Canvas animations that exploit and reinforce the outline structure. This Canvas-like quality was well received as an aid to guiding audience focus:
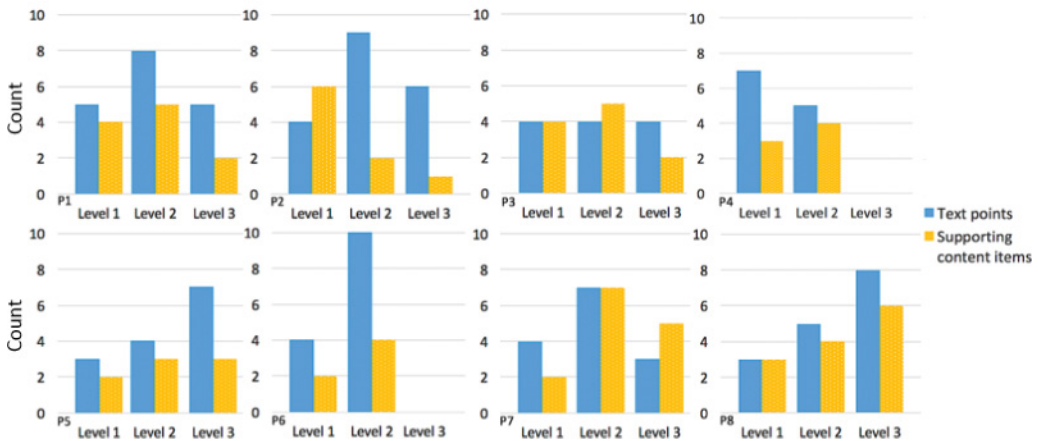
Fig. 7. Hierarchical distribution of outline text points and supporting content items for participants P1–P8. Each of the three levels had the most text points for at least one participant. Outline text points typically exceeded supporting content items overall, but at least one participant had content items exceeding the number of text points at each of the three levels. Total outline text points ranged 12–19, content items 6–14.

> I think it is good that the second and the third level animation is not as dramatic as the first level... But for level one it is fine to have more dramatic animations... it is refreshing for everyone, it shows everyone 'ok this is a new start' [P4].

> One of the real strengths is that it pulls in animation for you well. So if you want animation, it tries to say 'here are good principles of animation'... The transitions for showing where things came from, that's really useful... that overview can be powerful as well in certain types of meetings where we are going to be doing a lot of diving in and coming back out and we really want to be able to see how everything fits together [P7].

Participants also valued the presence of a Canvas during authoring, as well as the separation of editing into three distinct views and the resulting ease and speed of making large-scale structural and stylistic changes:

> It is very convenient and easier than PowerPoint because it gives me the whole picture. When I'm in the process of editing, this is very, very helpful [P1].

> It was like one thing at a time, less overwhelming to make a presentation... It was also more fun to make, just to keep the big picture layout right there [P6].

> It is quite helpful in terms of helping me think of the structure, the content flow, and then go back to different parts and fill in specific content. Then whenever I want to look at the big picture again, it is very easy for me to go back and revise, what is right and what is wrong. So I think the three perspectives are very helpful for me [P4].

For one participant, however, using the Canvas view to plan a presentation was *"too detached, too different"* [P3] from how they normally think about slides. For another, the animations during delivery could sometimes *"lose the sense of the canvas as a whole"* [P6] compared with Prezi, on account of content appearing, moving, and disappearing in the animation of slide builds and slide transitions. These comments reflect the tradeoffs inherent in creating a hybrid presentation medium that attempts to appropriate existing metaphors in new ways—the result is unlikely to satisfy the needs of all users in all situations. To gain a better understanding of which user groups and use contexts might particularly benefit from a hybrid presentation medium like SlideSpace, we now turn to study findings pertaining to our second question.

(Q2) When would SlideSpace be an appropriate presentation system and for whom?

Participants offered a wide range of situations in which SlideSpace would be an appropriate choice of presentation system.

Experience Level: Novice versus Expert. In terms of the presenter's experience level, participants gave reasons why SlideSpace could support both novices and experts:

> For less experienced PowerPoint users, it helps to prevent from mistakes like using the wrong fonts and using different fonts on all the slides. That ugly stuff... For more experienced presenters, they would know that structure and consistency are very important. More professional presenters would find it very useful [P2].

Talk Length: Short versus Long. Reasons were also offered for how SlideSpace could support both short and long talks, as well as both casual and keynote-level talks requiring different degrees of preparation. Participants also described how PowerPoint is sufficient for shorter talks and necessary for more customized ones, and might be preferred in such situations:

> I would use it for short-ish presentations so that the big picture outline wouldn't be too long or complicated... But if I was just doing a 10-minute presentation, it seems like it would give me most of what I needed in PowerPoint [P6].

> If a meeting is going to last 2–3 hours, [with SlideSpace] it is easier to just press to go up to the overview and then we know where we are so let's go back to continue [P5].

> If I want to create a quick talk, I will definitely use SlideSpace, it's really useful, it's fast. But if I really want to tailor a big presentation then I would still use PowerPoint because it is more powerful. It gives you more tricks you can play [P2].

> [SlideSpace] is a different mindset for presentations. I think the strong points for SlideSpace compared to PowerPoint is that it would be more easy and more powerful to create a keynote type presentation, something that you could go on stage and present to a large number of people... Compared to PowerPoint, where more power users need to do nitty gritty stuff and copy and paste numbers, technical data, and tables [P3].

Presentation Context and Style. A general consensus across participants was that SlideSpace was most suitable for formal presentations in business-like contexts and situations where users are willing to trade freedom of artistic control for flexibility of consistent control:

> It would be very useful for business managers, more useful than for teachers. Because teachers love to have a lot of freedom [P1].

> I think engineers would prefer to be more hands on and deep and more massaging things. But I think managers like me, from time to time, can see SlideSpace as a better tool than PowerPoint... [SlideSpace] would appeal most to a business type user audience... A perfect audience for this would be sales and HR [P3].

> Most of the time we want to keep the design consistent so it is very formal, it looks very business-like. I think it is easier this way [with SlideSpace]. But sometimes, you want to make it up in an artistic way, like some special design or special effect. People may want to use different styles in different slides, but this is better for business [P4].

Compared with PowerPoint and Prezi, participants expressed preferences for using SlideSpace for presentations whose content could be expressed as a linear sequence of conventional Slide layouts, but where the automatic generation of Slide layouts and Canvas transitions would improve the experiences of both authors and audiences:

I feel like Prezi seems most appropriate for less conventional presentations. Or ones where you have a lot more images, or where you have the ability to be abstract with it. You don't have to go in a linear direction necessarily. I feel like PowerPoint is good for introducing a product, if there is a specific order that things need to go in, or presenting results where you are just going through it one thing at a time. And I feel like SlideSpace is also really nice for linearly going through points. But it gives it a little bit more, it seems a little bit more fun that PowerPoint. You get that kind of canvas feel, but you still have slides. It is less abstract than Prezi but adds a little bit of that to it [P6].

I think something like PowerPoint or Keynote is the Swiss army knife, you want to make a presentation and you want a lot of control over how you want that presentation to run. And it's going to take you more time to put stuff together if you want specific layouts and animations. Prezi I think is if you want a spatial layout where you are zooming in and out like a map of the world or where you just really want to differentiate yourself from other presentations. I would see something like the SlideSpace program being more useful for 'I want the thing to look good and reasonable, and I want to leverage going up and down these hierarchy levels, but I don't want to have to think about how that happens. I just want some other designer who has built a good template for me to have done the work or the layout, good drawing of attention to things so that I can just populate my outline and they will take care of the delivery' [P7].

(Q3) To what extent does SlideSpace embody our design heuristics in useful ways?

Participant reflections on the capabilities and use of SlideSpace provided evidence both that SlideSpace embodied the design heuristics we had intended, and that each of these heuristics makes a valuable contribution to the presentation authoring experience.

Segmenting. Can points be organized in a logical structure easy to create and modify?

Segmenting in SlideSpace is mostly supported through the Outline hierarchy and its Canvas visualization. Participants noted how this encourages logical, top-down, big-picture thinking from the start, in positive contrast to the habit of committing ideas to slides without first having an idea of the overall structure:

I have a tool [SlideSpace] that will let me organize my thoughts... Without this, I think in a linear way. Now I think in a more logical way [P1].

I think this feels better. If I use Keynote or PowerPoint, usually I just focus on the details of each point in turn. But with this one [SlideSpace], I create all of the levels first and then I go back to enrich [them] [P5].

It was good. It forced me to think at the highest level how I'm organizing it, which was tricky, but I think it was good to have that big picture [P6].

It gives a hierarchical structure to the whole presentation and that structure comes at a very early stage of this presentation... It is a very bad habit of PowerPoint users that they start to write the first slides before knowing what the structure of the whole presentation is. So I think that is a very strong point for SlideSpace. That is, you must create the structure of the story before you go into detail of the slides [P2].

Participants also described how the hierarchical Outline of text points and the associated Content collections were both easy to modify, and the Canvas view of the Outline helps to highlight gaps and imbalances that can then be addressed:

I like these easy and simple levels, I can change it immediately... I think it is more efficient than PowerPoint because I do not have to worry about the levels. In PowerPoint I keep on changing that [P1].

It reminded me, 'Oh I need to work on this part because it is blank' [pointed to a level 2 point that lacked level 3 points initially but was subsequently developed further] [P1].

I like the Content concept. It provides a common place for adding all of these materials into one place so I can arrange and modify it [P3].

Segmenting in SlideSpace was limited to three levels of Outline hierarchy and a final level of Content for each outline text point. There was a general agreement that this degree and type of organization (i.e., a four-level hierarchy) is sufficient for many presentation needs. However, one participant expressed reservations about the rigidity of the Outline (only four levels) and the limited options for Content visualization (only one Content item per Slide):

> It felt a little constraining that I had to do everything on the four levels... If I want a presentation that feels more like a narrative or a story, this isn't set up for that, although I suppose I could do everything at the same level. But the story I want, I want things more organized around the rising and falling of action, the boundaries of episodes as they come and focusing on those. And so it is not as good for those kind of things. Or things where I want high variability in the amount of content on slides [P7].

In other words, SlideSpace does not implement the heuristic of segmenting in a neutral way—it introduces mediation effects just like the Slide and Canvas metaphors. In principle, a story is amenable to segmenting because of its linear structure and hierarchical division into acts and scenes. However, the way in which SlideSpace implemented segmenting in practice—calling Outline elements "points," requiring they be named for presentation to the audience, arranged on a Canvas that encourages visual balance, and traversed in a sequence of Slides that can only show a single Content item at a time—discourages use of SlideSpace (in its current form) for scenarios it could and should support. Extending the current system to use the language of storytelling, to separate organizational hierarchy from visual hierarchy, and to support richer content layouts, could all help to refine the mediation effects of SlideSpace to support a wider range of presentation genres.

Substantiating. Can text points be illustrated with flexible quantities of media?

Substantiating in SlideSpace is supported through the Content view, which allows each Outline point to be illustrated with a background image and a linear collection of text, image, or video media items (one slide is created to show each item in turn). Participants appreciated the way in which Slides were generated and styled automatically from Content collections, because it allowed them to focus on substance rather than appearance, and avoided premature decisions about where to add content:

> I enjoy the function of creating content, especially when you insert pictures into your slides. You don't have to worry about where to align them. It is also cool to have a picture as the background. [SlideSpace] helps you shade it, so you don't have to worry about that. Of course, I could do it with PowerPoint, but SlideSpace is a lot easier [P2].

> You can totally imagine someone starting to work on their slides, producing one slide at a time, or just dumping some content first and then later on trying to figure out where it fits on a slide and where the slide fits in the order of the slides... SlideSpace could be helpful for the right material to be presented if it is hierarchical in nature [P8].

Participants described Content as both the core of the authoring process and the "meat" of the final presentation, supported by the predictable generation of Slides:

> I know what I am going to put [in the Content view] and I know what part it would appear [in the Slide view]. I think this is really the essence of what makes this strong I do not have to try [the Slide view] until I've finished everything. I think I used Content a lot more. Because Canvas is already here, I don't worry about that [P1].

> Canvas is more like the bones, Content is like the meat, and Slides you see the real thing, so I think that is quite natural [P2]

However, while the separation of Content and Slides has benefits, there will always be users and use cases for which the direct manipulation of visuals is more important than maintaining explicit connections between points and their supporting media:

> To be honest, I still prefer to add the text here [in Slide view]. It's what I am used to doing. I hope that I could click here and then add something [P5].

Mediation effects also come into play here. SlideSpace is capable of supporting arbitrary images as content, and these images could in principle be as expressive as any static Slide, but the current prototype does not support within-tool creation of such layouts. The incorporation of such a feature is quite possible, however, and if implemented in the context of the point Outline, could also help to maintain implicit associations between points and content in ways that are resilient to restructuring.

Spatial Theming. Can layout modifications be applied to visuals of the same type?

Spatial Theming in SlideSpace is supported by layout rules that specify the level-by-level arrangement of Outline points on the presentation Canvas, and an inheritance convention whereby Slides inherit their layout from the resulting Canvas. Participants remarked how this approach ensured visual consistency and avoided the need to "worry" about committing to layouts that are costly to create and maintain:

> [SlideSpace] enforces, consistency of the whole deck. Again, that is also a problem with some people using PowerPoint. They create every slide in a different way, so it looks really awkward. SlideSpace helps you to make and keep the consistency [P2].

> I don't need to worry about where to put things. It is already all centered, etc. [P1].

One of the advantages of generating consistent layouts from a known structure is that they provide a foundation for transition animations that are similarly consistent (e.g., moving from a level 1 point to a level 2 point will look the same in all instances):

> The benefit of something like SlideSpace is I could set it across the entire system, every transition from a level 2 to a level 3 is going to look like this, where I can't do that in Keynote, I have to do that every single time for all of the transitions [P7].

The combination of the small text boxes in the Outline editor, the juxtaposition of point text in the Canvas view, and the limited Content options also creates a mediation effects encouraging short text points that add to the spatial consistency of Slides:

> [SlideSpace] forces me to not crowd my slides. There are only two things you can do: you can have a background, and you can have another thing... I think it can be easy to put too much text on slides and I think I probably do that sometimes, but then try not to. [SlideSpace] encourages you to not put too much text because it is just little boxes [in the Outline editor]. It reminds you that that is how your presentation should be [P6].

However, sometimes layout customization is desirable, either by modifying the existing layouts by level or overriding layouts on individual Slides:

> I'd want a little bit more control, like the layout. I like that it's going to handle the transitions between the level 1 and level 2 slides, great. My thought would be, given that these are the components that are going to be on the slide, can I move those things around a little bit to say, this is how I want things to look on this type of slide? [P7].

It would be possible to extend SlideSpace to support direct manipulation of both Canvas and Slides layouts, using ad-hoc motion tweening to animate between Slides and Canvas. However, the tradeoff would be the additional complexity of creating, managing, and reverting customized layouts (like in the PowerPoint Slide Master).

Style Theming. Can style modifications be applied to content of the same type?

Style Theming in SlideSpace is supported through font setting on the Canvas and color setting in the Slide view. Both options can be applied to all text points within a level or to the points of all levels. Participants appreciated the resulting ease of control as well as consistency, which was thought to be of benefit to the audience:

> The whole design makes presentations more comprehensible to the audience... consistency really helps the audience because the whole thing is tailored equally, the size of the words and color are consistent. And that is very, very difficult for new presenters using PowerPoint... the color and the font looks better than PowerPoint [P2].

> [Style rules] is what is missing in the current PowerPoint. I have to change every slide, like using the brush [Format Painter], which is the easier way, but this one, is just one click and everything is fixed. I like this very much, it is super practical [P4].

> You can change the font for everything and change the font for level 2 only, that was nice because I find myself copy and pasting that kind of stuff a lot in PowerPoint [P6].

While level-by-level style rules enable flexible exploration of design options with guaranteed consistency, sometimes there is need for more fine-grained customization. There is a tradeoff between the freedom to explore a constrained space of consistent designs versus the freedom to create a customized design without constraints:

> I do want to use SlideSpace if it can have more options or more freedom to edit. For now, the choices are very limited. I may not want to change everything. I may just want to change a few slides... [SlideSpace] solves the problem of one scenario but there are all these scenarios. Maybe you can have an option to change all of them, together, or just once... Because I am so used to choices, I expect that there are special scenarios, special requirements, there is a tradeoff [P4].

> If you really wanted to go into more detail, then there is a flexibility issue. It only lets you adjust the color or the lighting of the picture of the whole deck, but it really depends on the individual pictures how much lighting you want to put in. It's a tradeoff [P2].

Such customized fine-grained controls would be even simpler to incorporate into SlideSpace than the corresponding feature for Spatial Theming. However, the result would be a necessary increase in the complexity of the interface and mental model of interface use. Given the feedback from study participants, however, this cost is likely to be outweighed by the benefits of addressing a wider range of real-world scenarios.

Signaling. Can presentation context be visualized in between content visuals?

Signaling in SlideSpace is supported through the insertion of planned preview and review Slides during authoring and spontaneous transitions to various levels of Canvas overview during delivery. Participants commented how such features both encourage and remind users to follow the audience-centered practice of sharing the talk structure, and not relying on the audience to reconstruct it for themselves:

> It is a kind of reminder for people to review. For beginner learners. For me, I would never forget a summary, or like the general introduction [P1].

> For level 1 it is what I do normally, it is the most important. Summarizing to a table of contents like slide, it is very helpful [P3].

> As experienced a presenter as I am, I have an outline, but when I create the PowerPoint, the PowerPoint is still piece by piece. I see seldom people really do this [review]. So I think this is cool. This is really good. It reminds me that I should do something like this in my PowerPoint. Instead in my mind it is structured, but in PowerPoint you cannot really see the structure there. It is like writing an article. You have your own structure but [readers] don't see the outline unless you put one there [P2].

The automation of preview and review Slide insertion in SlideSpace was also felt to significantly reduce the burden of otherwise manually constructing such Slides and maintaining them across future modifications to presentation wording and structure:

> Compared to PowerPoint it cuts down the space of things that I need to work on or create because there is the fixed structure. So in the right circumstance where the presentation has this hierarchical nature it can help because it reduces your workload. I do not need to organize my slides by adding those review and preview slides to make it hierarchical. Because in PowerPoint you have to do that. I do that all the time [P8].

The ability to switch to different levels of Canvas overview at any point, all the way up to a full overview of all points presented so far or all points including those yet to come, was especially welcomed by participants who would often use such a feature:

> I would definitely use it every 10 minutes to remind the audience where we are. When I use Keynote, I create a slide like this myself [P5].

> I love how you can highlight one and then go back to this [overview]. With PowerPoint you need a slide for this. [Overview] is very lively, and very helpful [P1].

> [Overview] is helpful in showing the big picture when there is too much information and I'm going to switch to a completely different context and I need you to come back up with me. Then we will move to the next thing and we will zoom back in [P8].

> I would use it to help the audience better understand where we are and also give them the overview and also what they can expect in the later part of the talk. So, to keep the audience with me, with my speed and also my flow... If I want to jump to a certain slide, I can just review the whole structure and click anywhere, this is useful for me [P4].

Participants also cautioned against excessive use of Canvas transitions, however. Once participant also noted that such transitions don't just create a visually structured presentation, they require a structured verbal delivery with planned comments to make on these transitions (otherwise the resulting Slides may seem superfluous):

> If I add transition slides to each level, it might be too much, too many details [P4].

> I would maybe want to start out with it or end with [overview]. Or zoom out after every section to what we've seen so far [P6].

> It not only assumes that I have a very structured visual presentation, but also a very structured story behind it, which is not always the case. So by being so structured visually, it requires that I am more structured in how I am delivering the audio [P7].

This latter comment points to a mediation effect arising from the ease of inserting planned Canvas transitions. This effect may be of great assistance in contexts where the connections between points need to be made explicit, but a distraction otherwise.

Synchronizing. Can the current focus be clarified by hiding and highlighting content?

Synchronizing in SlideSpace is supported by the automatic addition of bold emphasis to the text of the point currently in focus, the default hiding of points to come (such points can optionally be revealed through the use of previews), and the ability to show a point as a "single point" rather than in conventional "title and bullets" style. Participants noted how the automatic focus highlighting saves effort, mirrors their existing practices, and helps the audience to follow the focus of the presentation:

> Usually I do a little bit of animation to enlarge a bullet point to highlight [it] [P8].

> I like the flow transitions, how it transforms from level 1 to level 2 to level 3... If you want to simulate something like this with PowerPoint we have to put quite a lot of effort in. I usually try to have something

polished like this, with transitions animated with stepwise bolding. All has to be done manually but here it is already taken care of [P3].

The ability to switch between single-point Slides and title and bullet Slides was also appreciated, especially for the ability of single-point slides to create a dramatic focus:

I find [single point] helpful, it looks very professional. After a short outline, I would prefer one sentence on the slide, because people might be tired of the whole thing. And it gets the focus, I like this change. It makes people feel like you have a new idea [P1].

I feel like this is kind of nice where I have the preview slide and then just the single point because it's like 'I already showed you these are subsections of the whole thing, so I don't need to keep that header here, now we are in this section' [P6].

Sometimes you don't want to put too much content on the slide, sometimes you just want to show an impressive picture just with one most important text point [P4].

However, the ability of text bolding to draw the audience's focus to the first visible bullet in title and bullet layouts was partially compromised by the relatively larger title text competing for the viewer's attention:

There is only one thing being bolded, but there is another thing twice the size up at the top so it's not like the bolded little puny thing is going to draw all of my attention [P7].

Future extensions of SlideSpace could consider additional strategies for drawing focus to particular points, for example, by exploring the use of color adjustments (e.g., hue, saturation, or brightness), font adjustments (e.g., font face, size, style, or kerning), and other forms of decorative emphasis (e.g., a focus box or icon).

(Q4) How could future forms of hybrid presentation media improve upon SlideSpace?

As already touched upon in the discussion of heuristics, SlideSpace or similar hybrid presentation media would benefit from more fine-grained control over the final output:

SlideSpace would be a better tool if we can do deep manipulation of the Slides [P3]

It should give the user more flexibility. When the user finishes slide generation, if the user wants to fix some of the slides, then she or he should be able to do that [P2].

The current SlideSpace prototype also has several implicit mappings to learn regarding assembly of the final output. Clearer feedback along with the ability to select a Slide and see which points and options created it would improve this process:

The slide layout that shows me the transition is useful. It is almost like a live slideshow. But I'm not too familiar with the ordering yet [P3].

[In Canvas view] I would prefer a little bit more than just boxes of text just stacked on each other. For example, maybe an indicator of beginning and end of a slide [P3].

In my mind, I don't have an automatic mapping from this canvas to the slides. But it makes sense once I see them. Sometimes I get mixed up, 'wait what did I just add', so if the transition slides could be marked as transition slides, that might be helpful [P6].

This slide layout makes me feel tired. Because when I look at the slide I then have to go to find the level [in Outline]. If I have more slides this would be a lot of work [P5].

Additional low-level feature requests included the ability to import the Outline from a text file [P1], the ability to associate points with notes in the Content view [P6], the ability to build custom animations [P3], the ability to add Slide numbers [P1], the ability to build the Outline directly on the Canvas [P2], the ability to present from a selected Slide [P7], the ability to export to the PowerPoint PPTX format [P2], the explicit

marking of Outline levels [P5], the suggestion of harmonious hue combinations [P1], and the inclusion of a color dropper [P4]. All of these features could be supported in the evolution of SlideSpace from a research prototype to a final product.

Further participant comments suggest new directions and greater potential for hybrid presentation media in general. The segmenting of content in an Outline hierarchy and the separation of editing concerns into different views both provide a foundation for natural divisions of labor in collaborative editing scenarios [P3]. The packaging of Outline templates and Canvas and Slide rule options into higher-level themes could open up new possibilities for sharing and experimenting with alternative designs [P2], reducing the need for option setting even further in ways that would be particularly amenable to touch interaction on mobile devices [P2]. Finally, the creation of a higher-level content repository could allow for greater reuse of content across presentations through the use of drag and drop [P3].

4.4. Limitations

Our study findings are based on the use experiences of eight skilled presenters from a range of professional backgrounds, constructing a single presentation from third-party materials and presenting to a single audience member in an artificial presentation context. As a result, findings may differ from potential studies of SlideSpace use by novice presenters, use by presenters from nonprofessional backgrounds, use to build multiple presentations over time, use to build presentations from first-party materials, or use to present to large audiences in real talk contexts. Investigating the extent to which SlideSpace use experiences vary in these situations remains future work.

5. CONCLUSION

This article has presented a systematic deconstruction and restructuring of presentation authoring, based on an extensive analysis of the literature on presentation systems, concepts, and recommendations. This process was mediated by the derivation of six heuristics for the analysis and design of presentation systems, and their application in the design of a new, hybrid presentation medium—SlideSpace. Our SlideSpace system aims to combine the best qualities of the two dominant metaphors used in existing presentation systems—the Slide metaphor and the Canvas metaphor. SlideSpace supports structured synthesis of canvas-based slides from hierarchical outlines, content collections, and design rules. Through a qualitative study of SlideSpace use, we validated our heuristics and showed that a hybrid presentation medium is capable of combining the advantages of existing systems and metaphors while mitigating their drawbacks. Compared against mainstream presentation systems, the current SlideSpace prototype represents a tradeoff between the freedom to explore a constrained space of consistent designs (with SlideSpace) versus the freedom to create a customized design without constraints. Future forms of hybrid presentation media have the potential to resolve this tradeoff, however, by exploring new mechanisms for supporting more refined visual customization of structured content. Overall, our heuristic design approach helped us challenge entrenched physical metaphors to create a fundamentally digital medium with the potential to transform the activities of authoring, delivering, and viewing presentations.

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