Does *Form* follow *Function*? Modeling the Dynamics of Design Exploration in Web Design with a GAM

Keywords: exploration; visual versus functional search; design evolution; computer graphics

Introduction and Theory: Design is an iterative and multi-phased search process, in which designers iterate their designs, guided by the goal to develop novel solutions that users want and value (Brunswicker & Prietula, 2023; Doll, Simon, & Daw, 2012). In this study, we focus on the design of web applications, design artifacts whose form and functionality become easily accessible to the users via the internet. Design theory suggests this search takes place across two design spaces constituting a design: A visual one that constitutes its form and its visual appearance, and a functional one, that constitutes the design's functionality (Hay et al., 2017; Simon & Newell, 1971). During the search process, designers move back and forth between both spaces to explore new forms and as well as functionality: They innovate their designs so that it appeals to the user while also ensuring that it offers the functionality they want. Since exploration takes effort and is a risky endeavor, designers face a challenge in how much and when they should explore a new form or functionality rather than exploiting and incrementally changing them. Literature grounded in theories of search and exploration versus exploitation would suggest that exploration typically happens early followed by phases of exploitation to refine a design (Billinger, Stieglitz, & Schumacher, 2014). Following this logic, one could hypothesize that exploration happens early in both search across form and functionality. Design theory, on the other hand, suggests that designers should shift attention from first exploring the design's functionality, followed by an exploration of its form, colloquially often expressed as "form follows function" (Sutcliffe, 2002). To resolve this theoretical hick-up, the research question that remains to be answered is: *When and how much do designers explore the form and the functionality of their designs as they evolve their design?* To answer this question we engage in an exploratory computational study that is based on a conceptual model of design evolution, represented as a co-evolving search process across two co-dependent search spaces, a visual and a functional one. We use methods of computer graphics and also specify a generalized additive model (GAM) (Wood, 2017), a statistical model well suited to study the complex relationship between interdependent co-variates (in our case the stage of exploration across the functional space, and the stage of exploration in the visual space). GAM allows us to model patterns without imposing strong assumptions on the nature of the patterns (Barton, Farewell, & Hallett, 2020).

Data and Methods: Our empirical study is focused on mash-ups, interactive forms of web applications that contain maps and charts. They create value for the users because they offer functionalities that allow users to examine complex data in a visual way (see Figure 1). We design an experiment with a 5-phased design process, in which designers had to design novel mash-ups that are useful for the end-user. The participants consist of senior software engineering students that were also trained in web design. 108 carefully sampled participants of the same skill level produced 540 apps. For each of the submissions we extracted the images as well as the source code of the mash-ups. We measure *exploration* (or *distance of search*) at the individual level based on the similarity of two consecutive design versions and create two distinct measures of visual and functional exploration. For *functional exploration* we extract the source-code functions of two consecutive submissions and calculate the Jaccard Similarity of the functions created by each individual at each subsequent phase (e.g. from 1 to 2,

and 2 to 3). For the distance of search in visual form, we measure the image similarities of the web application (figure 1) between two consecutive submissions using the SSIM (Wang, Bovik, Sheikh, & Simoncelli, 2004) algorithm that uses pixel-level data to extract changes in the visual structure of overall webpage. We also measure the distance of search across within visual subspaces of the overall visual space by also focusing on the change in similarity of two subcomponents, namely (1) charts and (2) maps. We extracted these visual subcomponents drawing upon methods from computer vision. All our measures of distance of search are on a scale from 0 to 1. To examine the dynamics of search we use a GAM (Wood, 2017), in which we add two co-variates measured at four stages of exploration (from phase 1 to 2 and so on) across the functional and the visual space. Our dependent variable is the distance of search (exploration). Since our dependent variable has a scale from 0 to 1, we adopt the beta family of GAM and specify the GAM formula that fits different smooths for the different categorical variables (a factor smooth interactions). We also include a varying intercept in the model.

```
gam(dist_search ~ s(stage, k = 4, fx = TRUE, by = type) + type,
data = df, family = betar(link="logit"), method = "REML")
```

Key Findings and Contributions: Figure 2 illustrates our empirical findings and depicts the mutual search pattern of an individual across the visual (left) as well as function search space (right). The results clearly suggest that the patterns of search across the visual and functional space are distinct. First, we observe that the distance of search is much higher in the functional space, compared to the visual space. Second, we also observe that the temporal pattern is distinct. While exploration in the visual space happens early, exploration in the functional space takes place at a later stage. Our GAM supports these findings (see figure 2, table removed due to length restrictions). The deviance is 38.2%. The stage of search is significant at $p < .0001$ for the model comparing the overall visual search space and the functional search space. This suggests that the effect of the stage is distinct for the visual versus the functional stage. Further, our model has an effective degree of freedom (edf) of larger than 2, which indicates a non-linear relationship between the stage of search and the degree of exploration (Zuur, Ieno, Walker, Saveliev, & Smith, 2009). When focusing on the visual space only to compare the search across the subcomponents as well as the search across the overall space (see figure 3), we also find that the dynamics of search also vary across the overall layout, the maps, and the charts (The independent variables are significant at $p < .0001$).

Our findings make at least *three contributions*: First, we contribute to the discourse on the temporality and dynamics of the distance of search by considering two co-dependent search spaces each constitute by different choice variables(Billinger et al., 2014). We find a significant difference in the temporality of the distance of search within the two co-dependent design spaces. Exploration across the visual search space evolves in distinct patterns compared to exploration across the functional search space. Second, we find that in the visual space, exploration happens early, while in the functional space, exploration takes place later. This suggests that exploration may indeed take place in later stages. Further, it also shows the design of web applications search follows the notion of "function follows form", rather than "form follows function". Finally, we find that within visual search, exploration is primarly driven by the visual structure of one sub-component rather than the overall general visual structure. With that, we also offer new insights to theories of design evolution. Finally, our study makes a novel contribution by using computational methods from computer vision and computer science to study social processes of exploration and exploitation. We consider the use of a GAM model as a significant contribution to the community of computational social scientists.

References and Figures: *References & tables upon request; figures on next page.*

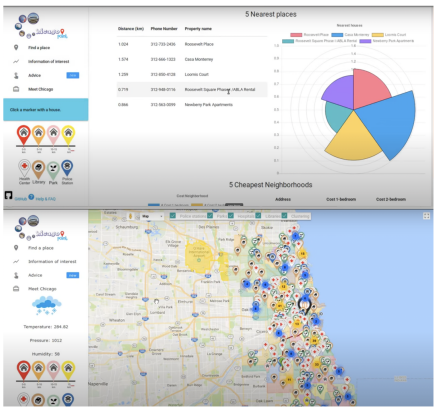

Figure 1: Sample of a Complete Web Application (with maps and charts)

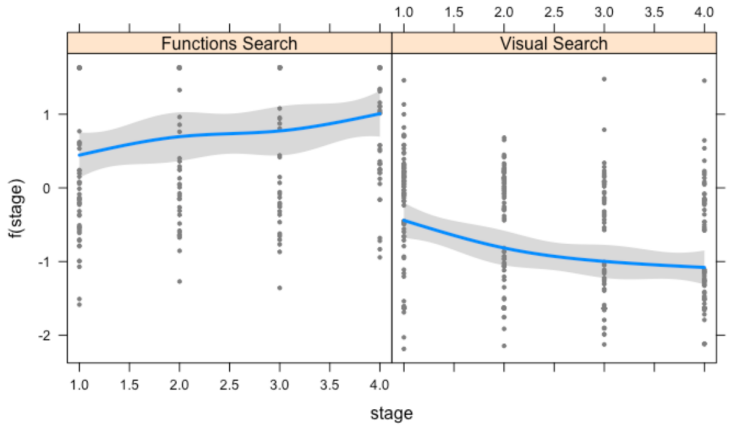

Figure 2: Comparison of Distance of Search across Visual (right: based on the changes to visual structure of the overall mash-up layout) and Functional Space (left: based on changes to all functions of the mash-up; x-axis is stage (represents phase transition), y-axis displays mean, confidence interval, and overall distribution.

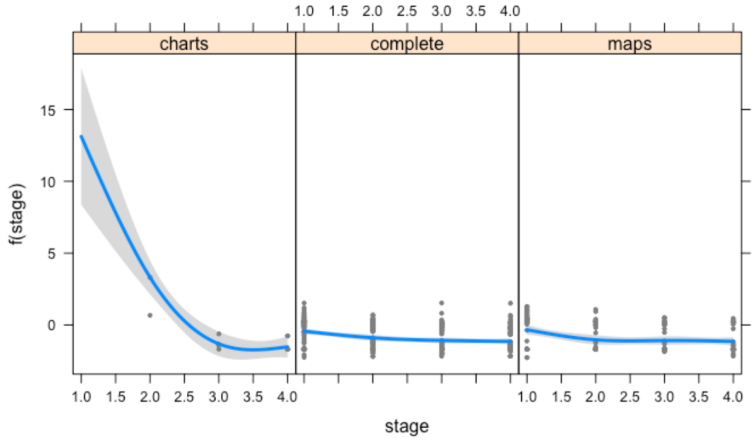

Figure 3: Comparison of Search Across Overall Visual Structure (Layout) and Subcomponents (Maps and Charts); x-axis is stage (represents phase transition), y-axis displays mean, confidence interval, and overall distribution.