Exploring Novel Interactions for Intelligent Sketching Interfaces: Towards a Computational Model of Sketching for Graphical User Interface Design

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Abstract

Sketching interfaces are widely used by designers to create visual prototypes. However, they are limited by the interaction techniques and the workflows that designers employ. Usually, a designer has to rely on a stylus or a mouse to manually create paper-like sketches throughout the process. Yet, novel interactive hardware (e.g., virtual reality, voice user interfaces, and shape-changing tangibles) has become widely available in recent years, and many novel computational methods have been proposed. I believe the intersection between sketching interfaces, advanced hardware, and computational methods is worth exploring. The aim of my research is to progress towards more natural and intelligent sketching interfaces. In order to achieve this goal, a deeper understanding of the process of sketching for graphical user interface design will be required. My research plan is, therefore, twofold: (1) re-define the design space for sketching in graphical user interface design with regard to their input and output modalities and underlying computational models and (2) introduce novel interactions to intelligent sketching interfaces to provoke new insights into the core characteristics of sketching. I anticipate that my research can act as a starting point for future systems and workflows of graphical user interface design that deeply integrate computational methods.

Introduction

Intelligent sketching interfaces are sketch-based design tools that incorporate computational methods to support the creation of technical and artistic drawings facilitating the design process. They draw on research of creativity support tools [1], sketch-based systems [2], intelligent user interfaces [3] and co-creative systems [4]. Sketching interfaces trace back to the very beginnings of the human-computer interaction discipline (e.g., Sketchpad in 1963 [5] or GRAIL in 1969 [6]). Recent advances in computational methods (e.g., in interactive optimization [7] and co-creation with artificial agents [4]) and interactive hardware (e.g., virtual reality, haptics) have, however, started to transform how and when designers employ sketching in the design process.

So far, the progress of these two fields have largely remained separate. Many sketching systems incorporating computational design and co-creative features

retain the conventional mouse-and-keyboard or stylus-based interaction techniques. Most of the sketching systems built upon novel interactive hardware, similarly, focus on translating traditional sketching workflows to these new interactive paradigms. My research aims to bridge this gap by exploring the intersection of novel interaction techniques *and* computational methods to progress towards more natural and intelligent sketching interfaces.

This research faces one key theoretical challenge that needs to be addressed in the work: There is no comprehensive model of sketching in user interface design that co-creative or intelligent sketching interfaces can be built upon. While early models of the *role* of sketching in the design process do exist (e.g., in exploration [8]) and even extend to novel interaction techniques (e.g., VR [9]), the process of ideation and exploration through visual and spatial communication is poorly understood with most key contributions dating back one or even two decades (e.g., [10], [11]). To effectively address the technical challenge of translating the advances in sketch recognition, sketch generation, interactive optimization and user adaptation into usable and useful systems utilizing novel interaction techniques, this theoretical challenge needs to be addressed as well. As Johnson and colleagues put it in their seminal review on computational support in sketching interfaces: "We must understand the purpose and practice of sketching as it is done *without* computation if we hope to effectively support it *with* computation" [2, pp. 7–8].

My project therefore contributes towards a computational model of sketching in graphical user interface design by creating intelligent sketching interfaces that make use of novel interactive hardware and computational methods to advance our understanding of how and why designers use sketching in their workflows. At the same time, the proposed systems explore new avenues for research into supporting those processes. By exposing designers to novel sketching interfaces, my research provokes new interactions and sheds light on so-far poorly understood aspects of sketching.

To achieve this goal, I propose three studies each representing one example publication to become part of my dissertation. Each of the proposed research projects addresses on of the three open questions in intelligent sketching interfaces that I consider to be most pressing to address the challenges described above. The first represents an update of the most comprehensive overview over computational support in sketching interfaces that—while still being cited regularly—is naturally lacking considerable advances since its publication thirteen years ago. This study answers the question: What is the status quo of intelligent sketching interfaces and which computational models are they built upon? It relates to work in the Ubiquitous Computing and Interaction group by Ken Pfeuffer on computational modeling in interaction (e.g., [12]) and on sketching interfaces (e.g., [13]).

The second study takes advantage of a novel interaction technique (i.e., pen-interaction) and collaboration mode (i.e., a shared digital canvas) in the field of co-creative sketching systems to explore the role of artificial assistance in co-creative graphical user interface design. It answers the question: Which collaboration modes can intelligent sketching interfaces leverage for co-creative graphical user interface design? It relates to work by Ken Pfeuffer on sketching with stylus-input (e.g., [13], [14]) and by Clemens Klokmose on combinatorial

optimization for graphical user interface design (e.g., [15]).

The third study utilizes a novel interaction technique for sketching interfaces (i.e. speech and gaze input) to acquire additional contextual information about a designer's sketches. This information is, in turn, used to create a mixed-initiative interaction enhancing designers' productivity. It builds upon work by Chandrasegaran and colleagues suggesting that so-called "non-sketching actions" like complementary verbalization carry useful additional information that current sketching interfaces do not sufficiently take advantage of [16]. Speech and gaze input is used to inform an artificial assistant about the characteristics of the sketch to be created. On the basis of this information, the likely next steps in the sketching process are predicted and, given sufficient confidence, suggested to the designer. This study answers the question: How can non-sketching actions be utilized by intelligent sketching interfaces? It relates to work by Ken Pfeuffer and Hans Gellersen on gaze and pen input (e.g., [17], [18]) and on computational modeling by Ken Pfeuffer (e.g., [12]) and João Evangelista Belo (e.g., [19]).

Together, these three studies form a strong starting point for the investigation of novel interaction techniques for computational support in sketching interfaces and thereby represent a meaningful step towards a deeper understanding of sketching in graphical user interface design as well as more natural and powerful sketching interfaces. The key contributions of the proposed projects are:

- An updated comprehensive review of intelligent sketching interfaces.
- Novel intelligent sketching systems utilizing state-of-the-art computational methods and interaction techniques.
- Computational models of common sketching activities in graphical user interface design.

Method

The three studies proposed below take different methodological approaches to answer their respective research questions. In this way, they are designed to not only address a relevant research gap but also to highlight the variety of approaches that the research area of intelligent sketching interfaces allows. While my primary approach is research through design [20]—creating usable and useful artifacts for designers while contributing to the knowledge base surrounding sketching in graphical user interface design—, alternative approaches like behavioral studies utilizing controlled laboratory experiments could similarly be used to contribute towards a computational model of sketching. I argue for artifact-driven research as it can more readily transfer into practice [20] and therefore contribute to improved support for designers. Additionally adopting a model-driven approach to interaction design, my research methodology allows for effective and transparent scrutiny. The specific methods employed by the three proposed studies are described in further detail below.

Example Study 1: Intelligent Sketching Interfaces: A Review

As of 2022, the most comprehensive and regularly cited overview of intelligent sketching interfaces, their input and output modalities, and computational approaches was published thirteen years ago [2]. While it still offers valuable in-

sights into the history of intelligent sketching interfaces, it naturally fails to take recent developments into account. As a result, common interaction techniques in sketching interfaces (e.g., pen input) and relevant computational methods (e.g., interactive optimization) are not sufficiently portrayed. To give researchers in the field as well as myself a starting point to efficiently identify related works, an update of Johnson and colleagues' review is required. Taking this opportunity to revisit the works in that review as well as to supplement it with more recent findings additionally allows us to take a new perspective—that of underlying computational models—on the history of intelligent sketching interfaces. Such a new study could, therefore, establish a more holistic account of computational support in sketching interfaces overall.

A review covering such a large amount of work naturally faces considerable theoretical and technical challenges. Over the years, several disciplines (e.g., HCI, AI, computer graphics, software engineering, cognitive science) have contributed relevant knowledge regarding the design of intelligent sketching interfaces. Bringing these contributions together and setting an appropriate scope for their review requires careful definition of an intelligent sketching interface. As far as I am aware, no such definition exists in the literature. Creating a suitable definition is therefore a necessary sub-goal and relevant contribution of the updated review as well. The key contributions of this study are:

- An updated overview of computational support in sketching interfaces.
- A comprehensive definition of intelligent sketching interfaces.
- A novel overview of the computational models underlying intelligent sketching interfaces in literature.

Example Study 2: Pen and Pencil: Co-Creative Sketching of Graphical User Interfaces on a Shared Digital Canvas

Recently, sketching systems have been proposed that utilize novel computational methods to support the design of graphical user interfaces. Todi and colleagues, for example, use model-based optimization to aid designers in finding appropriate layouts for their graphical user interface sketches [7]. Similarly, Dayama and colleagues use a mixed integer linear programming approach to support designers in creating grid-based layouts for wireframes [21]. Taking a wider perspective on sketch-based design support, co-creative systems have been devised that utilize sketch generation to assist designers in their ideation and exploration activities. Karimi and colleagues, for example, use a deep learning-based model to generate tentative drawings that act as inspiration for designers solving specific sketching tasks [4].

Many of these systems aim to support exploration and evaluation of design alternatives by creating digital assistants that co-create sketches together with the designer. Within the user interface, these digital assistants often occupy a fixed area on screen, either in form of a separate canvas (e.g., [4]) or suggestion area (e.g., [7], [21]). Users can interact with the assistant either via mouse-and-keyboard (e.g., [21], [22]) or via touch input (e.g., [7]). As a result, these systems only capture one out of many interaction modes of collaborative drawing [24], namely communication using separate canvases. By taking inspiration from co-creative drawing systems (e.g., [25]), a new intelligent sketching system

is devised that utilizes a shared digital canvas and pen input to investigate collaborative sketching of graphical user interfaces between a human and artificial agent. The general workflow of this system is described below:

Initially, the system presents users with an empty digital canvas to draw on using a provided stylus. The output of this stylus, the 'pen', is styled to resemble black ink. As a user draws on the canvas, she explores different designs and revisits and refines what she has already created. Eventually, the designer will come to a stop where she is thinking about possible solutions to a specific interaction problem or about new design directions to explore. This is when lines styled like thin gray pencil drawings start to appear and either 'fill in' the existing sketches (local optimization) or create separate, alternative sketches next to the existing ones (global optimization). This second kind of drawings—the 'pencil' sketches—are the result of a sketch generation model whose output is animated and styled to suggest drawings by a polite assistant offering new ideas to the primary designer. Trained on a dataset of graphical user interface elements and screens (e.g., [26], [27]) and driven by a model-based optimizer (e.g., [7]), this generative model provides underlays acting as starting points for further exploration or refinement. In order to respect designers' need for control in co-creative systems [22], however, these drawings receive less visual importance through decreased weight (i.e., thinner lines and lighter color) and by slowly disappearing over time (i.e., animating opacity) to be replaced by alternative drawings. Users can further erase any drawings by the assistive system additionally supporting perceived control. The result is a mixed-initiative co-creative sketching system for graphical user interface design that can be used to evaluate a novel collaboration mode for human and artificial designers. This evaluation is conducted with designers regarding their perceived control during the design process and satisfaction with the result. The key contributions of this study are:

- A novel design tool utilizing state-of-the-art sketch generation models and pen-based mixed-initiative interaction.
- Design principles for shared canvas-based co-creative systems.
- Evaluation of an optimizer-driven co-creative sketching system.

Example Study 3: Using Speech and Gaze to Inform Co-Creative Sketching of Graphical User Interfaces

Historically, intelligent sketching systems have mostly relied on a paper-and-pen metaphor for their graphical user interfaces. In these interfaces, users can draw on a canvas—the 'paper'—using predefined shapes or using gestures with a mouse or pen [16]. Recently, however, multimodal interaction and alternative interaction techniques have gained some traction in the field of intelligent design support tools. Todi and colleagues, for example, studied natural language interaction for their graphical user interface retrieval system supporting ideation and development [28]. Similarly, Huang and colleagues use natural language input for their co-creative sketching system Scones where users direct an artificial sketching agent through text commands [29]. Turning towards gaze as an input modality, Çığ and Sezgin utilize eye gaze movement to predict and adapt a pen-based sketching interface by switching interactions modes (e.g., from drawing to dragging) based on sensor fusion [30]. What these examples have in common is

that they consider "non-sketching actions" [16] as part of the sketching activity and as part of natural communication in early-stage design [31].

Building on these previous works, this study presents a novel intelligent sketching interface that utilizes speech, gaze and pen input to inform a predictive sketch generation model. Given sufficient probability, it offers suggestions or completions for graphical user interface designs. While datasets for sketches of user interface elements (e.g., [32]) and layouts (e.g., [27]) already exists, this study contributes a novel dataset of gaze, speech and pen input collected from participants directed to draw common user interface elements. In this way, the study acts both as a replication and complement of [32]. This dataset is used to train the predictive model underlying the proposed sketching interface. The usefulness of such a multimodal intelligent sketching interface is evaluated in a qualitative study with designers. The key contributions of this study are:

- Design principles for the design of multimodal intelligent sketching interfaces.
- Replication of a recent study contributing a valuable dataset for co-creative sketching systems.
- A novel dataset of speech, gaze and pen input collected from participants drawing common user interface elements.

Conclusion

By exploring novel interaction techniques for intelligent sketching interfaces, this project contributes towards a computational model of sketching in graphical user interface design and thereby opens up new avenues for effective computational support of the design process. It supports both the understanding and dissemination of computational design and its grander vision of reliably achieving desirable interactions. I anticipate that my research can act as a starting point for future systems and workflows of graphical user interface design that deeply integrate computational methods and progress towards more natural and intelligent sketching interfaces.

References

[1] B. Shneiderman, "Creativity support tools: accelerating discovery and innovation," *Commun. ACM*, vol. 50, no. 12, pp. 20–32, Dec. 2007.

[2] G. Johnson, M. D. Gross, J. Hong, and E. Yi-Luen Do, "Computational Support for Sketching in Design: A Review," *FNT in Human–Computer Interaction*, vol. 2, no. 1, pp. 1–93, 2009.

[3] S. T. Völkel, C. Schneegass, M. Eiband, and D. Buschek, "What is 'intelligent' in intelligent user interfaces?: a meta-analysis of 25 years of IUI," in *Proceedings of the 25th International Conference on Intelligent User Interfaces*, Cagliari Italy, 2020, pp. 477–487.

[4] P. Karimi, J. Rezwana, S. Siddiqui, M. L. Maher, and N. Dehbozorgi, "Creative sketching partner: an analysis of human-AI co-creativity," in *Proceedings of the 25th International Conference on Intelligent User Interfaces*, New York, NY, USA, 2020, pp. 221–230.

[5] I. E. Sutherland, "Sketchpad: A man-machine graphical communication system," Massachusetts Institute of Technology, 1963.

[6] T. O. Ellis, J. F. Heafner, and W. L. Sibley, "The Grail Project: An Experiment in Man-Machine Communications," RAND Corporation, RM-5999-ARPA, Sep. 1969.

[7] K. Todi, D. Weir, and A. Oulasvirta, "Sketchplore: Sketch and Explore with a Layout Optimiser," in *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, New York, NY, USA, 2016, pp. 543–555.

[8] Y. T. Shih, W. D. Sher, and M. Taylor, "Using suitable design media appropriately: Understanding how designers interact with sketching and CAD modelling in design processes," *Design Studies*, vol. 53, pp. 47–77, Nov. 2017.

[9] E. K. Yang and J. H. Lee, "Cognitive impact of virtual reality sketching on designers' concept generation," *Digital Creativity*, vol. 31, no. 2, pp. 82–97, Apr. 2020.

[10] K. D. Forbus, R. W. Ferguson, and J. M. Usher, "Towards a computational model of sketching," in *Proceedings of the 6th international conference on Intelligent user interfaces*, New York, NY, USA, 2001, pp. 77–83.

[11] K. Forbus, J. Usher, A. Lovett, K. Lockwood, and J. Wetzel, "CogSketch: Sketch Understanding for Cognitive Science Research and for Education," *Topics in Cognitive Science*, vol. 3, no. 4, pp. 648–666, 2011.

[12] A. Yuan, K. Pfeuffer, and Y. Li, "Human Performance Modeling with Deep Learning," in *Artificial Intelligence for Human Computer Interaction: A Modern Approach*, Y. Li and O. Hilliges, Eds. Cham: Springer International Publishing, 2021, pp. 3–31.

[13] K. Pfeuffer, A. Dinc, J. Obernolte, R. Rivu, Y. Abdrabou, F. Shelter, Y. Abdelrahman, and F. Alt, "Bi-3D: Bi-Manual Pen-and-Touch Interaction for 3D Manipulation on Tablets," in *The 34th Annual ACM Symposium on User Interface Software and Technology*, New York, NY, USA: Association for Computing Machinery, 2021, pp. 149–161.

[14] K. Pfeuffer, K. Hinckley, M. Pahud, and B. Buxton, "Thumb + Pen Interaction on Tablets," in *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, New York, NY, USA, 2017, pp. 3254–3266.

[15] S. Park, C. Gebhardt, R. Rädle, A. M. Feit, H. Vrzakova, N. R. Dayama, H.-S. Yeo, C. N. Klokmose, A. Quigley, A. Oulasvirta, and O. Hilliges, "AdaM: Adapting Multi-User Interfaces for Collaborative Environments in Real-Time," in *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, New York, NY, USA: Association for Computing Machinery, 2018, pp. 1–14.

[16] S. Chandrasegaran, D. Ramanujan, and N. Elmqvist, "How Do Sketching and Non-Sketching Actions Convey Design Intent?" in *Proceedings of the 2018 Designing Interactive Systems Conference*, New York, NY, USA, 2018, pp. 373–385.

[17] K. Pfeuffer, J. Alexander, M. K. Chong, Y. Zhang, and H. Gellersen, "Gaze-Shifting: Direct-Indirect Input with Pen and Touch Modulated by Gaze," in *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*, New York, NY, USA, 2015, pp. 373–383.

[18] K. Pfeuffer, J. Alexander, and H. Gellersen, "Partially-indirect Bimanual Input with Gaze, Pen, and Touch for Pan, Zoom, and Ink Interaction," in *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, New York, NY, USA, 2016, pp. 2845–2856.

[19] J. M. Evangelista Belo, A. M. Feit, T. Feuchtner, and K. Grønbæk, "XR-gonomics: Facilitating the Creation of Ergonomic 3D Interfaces," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, New York, NY, USA: Association for Computing Machinery, 2021, pp. 1–11.

[20] J. Zimmerman, J. Forlizzi, and S. Evenson, "Research through design as a method for interaction design research in HCI," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, New York, NY, USA, 2007, pp. 493–502.

[21] N. R. Dayama, K. Todi, T. Saarelainen, and A. Oulasvirta, "GRIDS: Interactive Layout Design with Integer Programming," in *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, New York, NY, USA: Association for Computing Machinery, 2020, pp. 1–13.

[22] P. O'Donovan, A. Agarwala, and A. Hertzmann, "DesignScape: Design with Interactive Layout Suggestions," in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, New York, NY, USA, 2015, pp. 1221–1224.

[23] J. Journeaux and H. Gørrill, *Collective and Collaborative Drawing in Contemporary Practice: Drawing Conversations.* Cambridge Scholars Publishing, 2018.

[24] C. Jansen and E. Sklar, "Exploring Co-creative Drawing Workflows," *Frontiers in Robotics and AI*, vol. 8, 2021.

[25] N. Davis, C.-P. Hsiao, K. Y. Singh, and B. Magerko, "Co-Creative Drawing Agent with Object Recognition," *Proceedings of the AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment*, vol. 12, no. 1, pp. 9–15, 2016.

[26] V. P. Sermuga Pandian, S. Suleri, and Prof. Dr. M. Jarke, "UISketch: A Large-Scale Dataset of UI Element Sketches," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, New York, NY, USA, 2021, pp. 1–14.

[27] V. P. Sermuga Pandian, S. Suleri, and M. Jarke, "SynZ: Enhanced Synthetic Dataset for Training UI Element Detectors," in *26th International Conference on Intelligent User Interfaces - Companion*, New York, NY, USA, 2021, pp. 67–69.

[28] K. Todi, L. A. Leiva, D. Buschek, P. Tian, and A. Oulasvirta, "Conversations with GUIs," in *Designing Interactive Systems Conference 2021*, New York, NY, USA: Association for Computing Machinery, 2021, pp. 1447–1457.

[29] F. Huang, E. Schoop, D. Ha, and J. Canny, "Scones: towards conversational authoring of sketches," in *Proceedings of the 25th International Conference on Intelligent User Interfaces*, New York, NY, USA, 2020, pp. 313–323.

[30] Ç. Çığ and T. M. Sezgin, "Gaze-based prediction of pen-based virtual interaction tasks," *International Journal of Human-Computer Studies*, vol. 73, pp. 91–106, Jan. 2015.

[31] A. Adler and R. Davis, "Speech and sketching for multimodal design," in *ACM SIGGRAPH 2007 courses*, New York, NY, USA, 2007, pp. 14–es.

[32] V. P. Sermuga Pandian, S. Suleri, and Prof. Dr. M. Jarke, "UISketch: A Large-Scale Dataset of UI Element Sketches," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, New York, NY, USA: Association for Computing Machinery, 2021, pp. 1–14.