Understanding Visual, Integrated, and Flexible Workspace for Comprehensive Literature Reviews with SketchingRelatedWork

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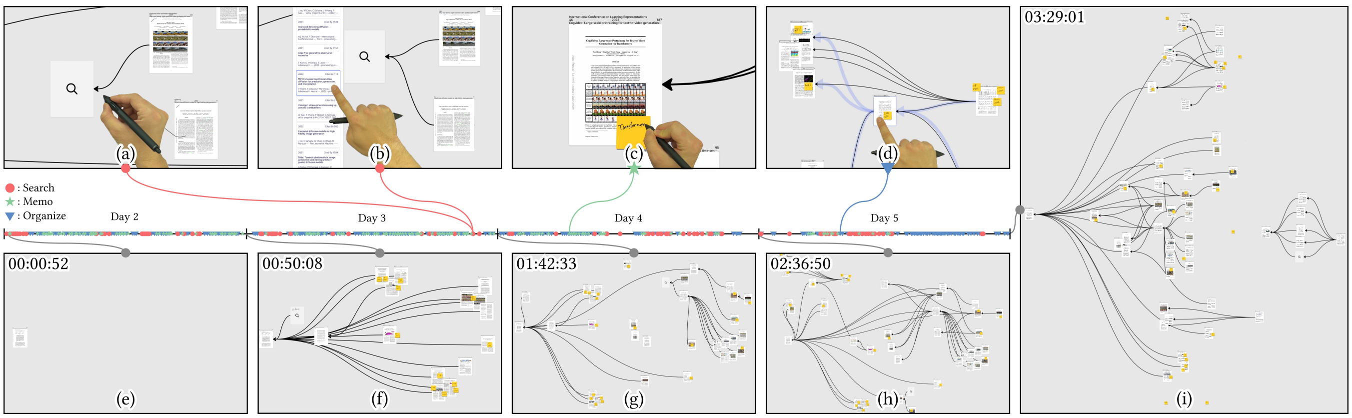

Figure 1: A graduate student specializing in computer vision (P2) conducted a literature review on a topic of interest using the *SketchingRelatedWork* system. He (a) sketched citation relationships and (b) found papers by using them as search conditions, (c) took memos on thumbnails of the collected papers, and (d) curated citation relationships between the collected papers. (e-h) Over four days, spending about one hour each day, he gradually expanded his node-link diagram to include 51 papers, 59 citation relationships, and 29 sticky notes and (i) completed a representation of the research landscape.

ABSTRACT

Writing an academic paper requires significant time and effort to find, read, and organize many related papers, which are complex knowledge tasks. We present a novel interactive system that allows users to perform these tasks quickly and easily on the 2D canvas with pen and multitouch inputs, turning users' sketches and handwriting into node-link diagrams of papers and citations that users can iteratively expand in situ toward constructing a coherent narrative when writing Related Work sections. Through a pilot study involving researchers experienced in publishing academic papers, we show that our system can serve as a visual, integrated, and flexible workspace for conducting comprehensive literature reviews.

CCS CONCEPTS

• **Human-centered computing → Interaction techniques**.

KEYWORDS

Related work, inking, node-link diagram

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1 INTRODUCTION

Researchers write Related Work sections to explain that their papers are based on an existing body of knowledge, but differ from it, and also contribute to it. To do so, they investigate hundreds of papers over several weeks or months, cite dozens of related papers, and describe their relationships in writing.

A common method of investigating related papers is to find a seed paper that is considered highly relevant and then conduct an exhaustive survey of the papers cited by the seed paper and those citing it [5, 6]. By doing so, researchers can collect a comprehensive list of old and new papers on the topic.

However, each paper usually cites dozens of others. Also, hundreds of others may cite it. Therefore, as the above process is repeated, the number of papers to collect can increase exponentially. At this point, it is easy for researchers to feel anxious about possibly skipping important papers, overwhelmed by the growing pile of

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papers to read and analyze, and frustrated by the lack of a visual representation to help them see the big picture.

We thus present a novel interactive system that allows researchers to find and organize many papers quickly and easily with pen and multitouch inputs. It enables users to find papers by simply sketching their citation relationships with other papers on the 2D canvas as boxes, arrows, and handwriting and, from this process, construct a node-link diagram that can help users take advantage of their spatial memory (Figure 1).

2 RELATED WORK

In writing Related Work sections, researchers find, read, extract information from, record, and review existing papers [25]. In doing so, they often use commercial tools that help them efficiently manage a large number of papers in a list [7, 24]. However, understanding complex citation relationships between papers from such a list can be difficult [18].

Node-link diagrams can visualize citation relationships of many papers [5, 6, 8, 14, 16, 22, 26, 28, 30, 32, 34]. In a node-link diagram, nodes can be placed anywhere on a 2D canvas, and links can express any relationship between nodes. In our system, users can take advantage of this flexibility.

People are known to better remember an item's location when they put it in a place that they choose [29, 35]. Therefore, our system, similar to what Chau et al. [5] proposed, lets users manually arrange papers and connect them on the 2D canvas to construct a node-link diagram. This contrasts previous works that automatically arrange nodes without user intervention [6, 8, 14, 16, 26, 28, 30, 32, 34].

Moreover, what appears in the printed form of the paper, such as the title, text, images, and overall layout, can help people decide what to read [23]. Therefore, our system, similar to what Matejka et al. [23] proposed, represents nodes as thumbnails of paper pages, offering a quick visual overview that can aid in faster decision-making. This contrasts previous works [5, 6, 8, 14, 16, 22, 26, 28, 30, 32, 34] that represent nodes as abstract symbols and labels.

Xia et al. [36] proposed a system in which users sketch their thoughts with a pen first, and turn them into smart objects later. Subramonyam et al. [33] proposed a system in which users highlight parts of text first, and turn them into a node-link diagram later. Similarly, in our system, users sketch papers and citation relationships with a pen, and the system retrieves actual data, so users can construct a node-link diagram from the natural journaling process.

Node-link diagrams can also be used to express search conditions: Users can assign keywords to nodes and links to specify node and link types [12, 27], and define relationships between known and unknown entities [12, 20]. Based on these works, our system allows users to create a node-link diagram that includes not only known nodes and links derived from user sketches [33, 36] but also unknown nodes, from which users can issue graph-based queries and find new information.

Finally, Ma et al. [21] proposed a set of sketch-based interaction techniques to find and organize academic papers into a node-link diagram. In this study, we propose a complete system that builds on these techniques in which users can also read the collected papers and organize them in bulk. In addition, we conduct a pilot study in which we validate the usefulness and effectiveness of the system in facilitating actual literature reviews in real-world scenarios involving researchers across different majors.

3 SYSTEM

The design goal of this system is to help researchers quickly and easily find and organize relationships within the existing body of knowledge when writing Related Work sections. When users sketch papers and relationships between papers on the 2D canvas, the system helps users complete the sketches as a node-link diagram comprising actual papers and citations (Figure 2).

In this system, a node-link diagram serves three roles. First, it helps users find new related papers in situ using parts of the diagram as a graph of search conditions (Figure 3). Second, it helps users create a unique layout of papers visualized as thumbnails of the paper pages (Figure 4a) and memos visualized as sticky notes (Figure 4b), taking advantage of their spatial memory. Third, it helps users curate only those citations important for constructing a coherent narrative (Figure 4c-e).

4 IMPLEMENTATION

We implemented our system as a tablet application for pen and multitouch inputs using Unity. We utilized Selvy Pen SDK [2] to recognize users' handwriting and Serp API [31] and SemanticScholar API [17] to retrieve papers' metadata, which contained URLs to the PDF files of the papers.

5 PILOT STUDY

We conducted a pilot study with experienced researchers from different majors to test the usefulness and effectiveness of our system. Over a total of six days, they used the system for conducting literature reviews, and participated in pre- and post-interviews, in which they compared using our system with their usual workflows.

Participant. We recruited four graduate students with different majors (two males and two females, ages 26-29) in electrical engineering (P1), mechanical engineering (P2), biological sciences (P3), and chemical and biomolecular engineering (P4). All participants had experience writing and publishing academic papers. On average, they have each published 3.5 papers as first authors or co-authors.

Procedure. On the first day, we visited their respective workplaces and interviewed them about their usual workflows in conducting literature reviews. Also, we taught them how to use our system using an instruction sheet, and provided sufficient opportunities to practice until they became familiar with it.

From the second day to the fifth day, we visited their respective workplaces and asked them to conduct a literature review on a topic of interest using our system while we observed them work. After each session with us, which lasted for about an hour, they were asked to study the collected papers for a deeper understanding in their personal time.

On the sixth day, we asked the participants to complete a 5-point Likert scale survey based on the NASA TLX [13] and a 5-point Likert scale survey on their preferences for each system feature. Afterward, we debriefed them by showing their usage logs and node-link diagrams by date (Figure 1) and interviewed them about the pros and cons of our system relative to their usual workflows.

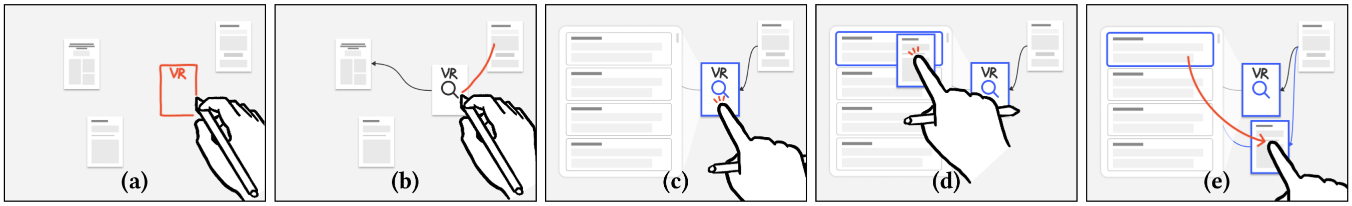

Figure 2: Users can sketch papers on the 2D canvas by (a) drawing boxes, writing keywords, and (b) drawing citation relationships. Then, (c-d) the keywords and citation relationships recognized in the sketch are used as search conditions to find papers in an external database [9]. (e) Users can collect papers at locations they wish to place. The citation links to and from the collected papers are automatically generated.

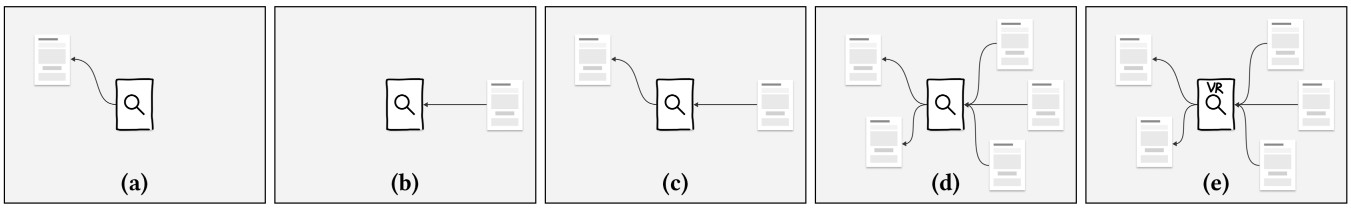

Figure 3: By drawing various node-link diagrams, users can query (a) all papers citing one paper, (b) all papers cited by one paper, (c) all papers citing one paper and cited by another paper, (d) all papers citing multiple papers and cited by other multiple papers, and (e) all papers containing specific words, citing multiple papers, and cited by other multiple papers.

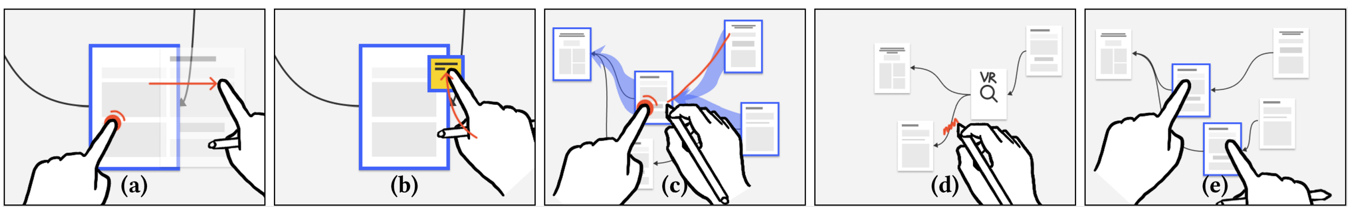

Figure 4: Users can (a) navigate pages of papers by long-pressing a collected paper with one finger and dragging it with another finger, (b) create sticky notes by sketching small squares and attach them to papers by dragging them with one finger, (c) view all citation relationships of a collected paper to all the others by long-pressing it with one finger when curating specific relationships, (d) erase unnecessary information by scribbling over entities, and (e) make multiple selections of papers by long-pressing a paper with one finger and tapping other papers with another finger.

Measurement. We recorded the total usage time of our system, the total number of papers, links, and sticky notes by time, the total invocation counts and elapsed times of all the system's functions, and the video capture of the screen.

6 RESULT

We report the results of the pre-interviews, the program usage logs, the survey responses, and the post-interviews.

6.1 Pre-Interview

According to the participants, they begin literature reviews by exploring recent papers on publication websites such as arXiv [3], bioRxiv [4], Nature [19], and Science [1] or conducting keyword searches in databases like Google Scholar [9]. They prioritize papers based on title, venue, publication year, citation count, abstract, figures, and introduction. Additionally, they explore other papers cited by the papers or more recent papers that cite the papers.

As the number of papers grows, participants employ tools like Mendeley [24], Notion [15], Google Sheets [10], and Google Slides [11] to group related papers for facilitating quick information retrieval. They store related papers in the same folder in Mendeley [24], and summarize the papers, make notes, and scrap notable figures in separate Notion [15] documents (P1, P2). They also record metadata and assign custom keywords on each paper in Google Sheets [10] and revisit specific papers by filtering by those keywords (P3). Finally, they utilize Google Slides [11] to consolidate notes and notable figures from multiple papers into units of narrative (P4).

6.2 Usage log

We collected 14 hours and 16 minutes of usage logs from the four participants, who created 162 paper nodes, 148 citation links, and 107 sticky notes using our system in total. Each participant used the system for 3 hours and 34 minutes, and created 40.5 paper nodes, 37.0 citation links, and 26.8 sticky notes on average (Table 1).

Notably, some participants primarily collected papers through graph-based queries, resulting in a relatively higher number of automatically generated citation links (P1, P2, P3) (Figure 2e). Others

Table 1: System usage log by participant.

	Time	*Paper nodes*			*Citation links*				*Sticky notes*	*Query*				*Viewing all citations*
		Total	*Added*	*Deleted*	*Total*	*Generated*	*Added*	*Deleted*		*Total*	*Keyword*	*Graph*	*Both*	
P1	03:43:10	38	63	25	39	58	15	34	37	89	16	60	13	22
P2	03:29:01	51	85	34	59	92	4	37	29	113	17	54	42	3
P3	03:28:52	30	65	25	25	41	3	19	12	112	22	48	42	40
P4	03:35:39	33	38	5	25	4	26	5	29	92	56	20	16	69
Avg.	03:34:10	40.5	62.7	22.3	37	48.7	12.0	23.7	26.7	101.5	27.7	45.5	28.3	33.5

primarily collected papers through keyword-based queries, resulting in a relatively higher number of manually added citation links (P4).

6.3 Survey

In the NASA TLX-based 5-point Likert scale survey on the subject demands experienced during the tasks (Figure 5), our system received average scores below neutral (lower is better) on all questions, while the usual workflow received average scores equal to or above neutral on Q1, Q5, and Q6.

However, at the time of writing this late-breaking work, there were no statistically significant differences between the scores of our system and the usual workflow due to the small sample size, which we expect to increase in future work.

In the 5-point Likert scale survey on the preference for each system feature (Figure 6), all features (Q1-27, 4.4) received average scores equal to or above neutral (higher is better). Specifically, scores for sketching papers and relationships (Q1-14, 4.3), collecting papers (Q15-18, 4.4), navigating and manipulating (Q19-24, 4.5), and making sticky notes (Q25-27, 4.6) were all above neutral. In addition, all survey responses on the usability and usefulness of the system were above neutral (Q28-33, 4.5).

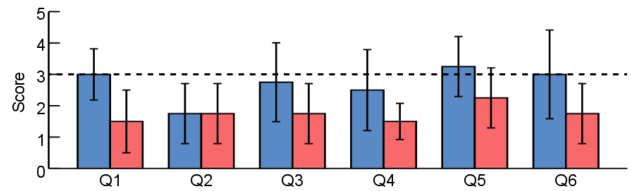

Figure 5: 5-point Likert scale scores on subjective demands (Q1: mental, Q2: physical, Q3: temporal, Q4: performance, Q5: effort, and Q6: frustration). Dashed line: neutral (lower is better), blue: usual workflows, red: ours, error bar: ±2 SE.

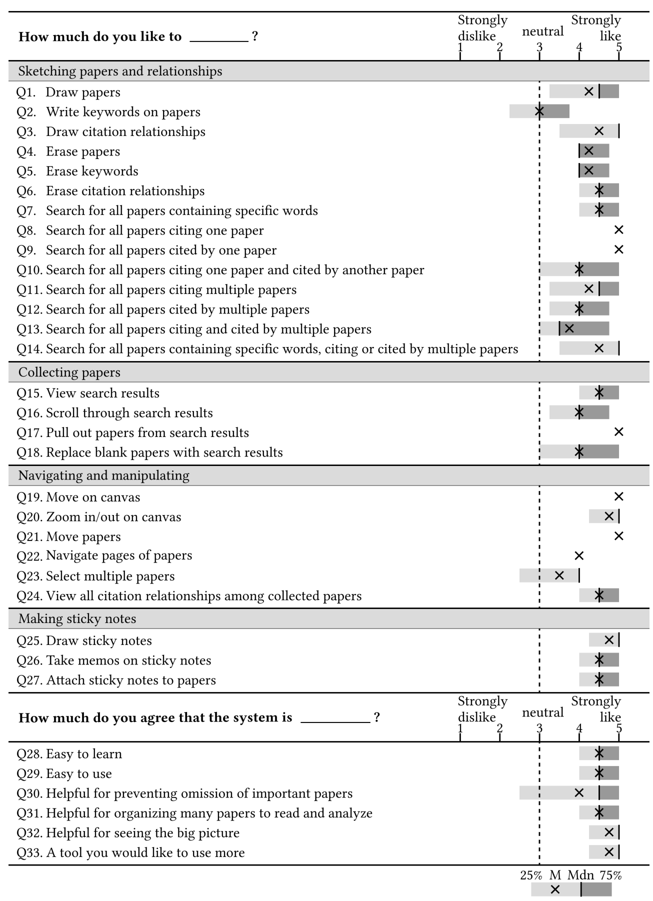

Figure 6: 5-point Likert scale scores on preferences for all features of our system. Dashed line: neutral (higher is better).

6.4 Post-Interview

We organized the responses from the post-interviews.

6.4.1 By finding and organizing papers on the 2D canvas, participants could classify papers upon collection, navigate through collections of papers, and multitask among papers.

• **Classify papers upon collection.** Participants could place papers on the 2D canvas during the collection process, to group the papers with similar topics (P1) (Figure 7a), distinguish unread papers from read ones (P2), and arrange papers in their desired reading order (P1, P2, P4).

• **Navigate through collections of papers.** In contrast to finding a paper in the hierarchical file explorer by remembering the filename of a paper and the subfolder it belongs to, as if "digging for something buried in the sand (P3)", participants could view the entire collection of papers at once (P1) and find papers by their position, as if "reading a map (P3)".

• **Multitask among papers.** Participants could track which papers were read and to what extent by looking at the thumbnails of the papers spread across the 2D canvas (P4). Using this feature, they could browse multiple papers simultaneously (P1, P3), in contrast to completely reading one paper before moving on to another.

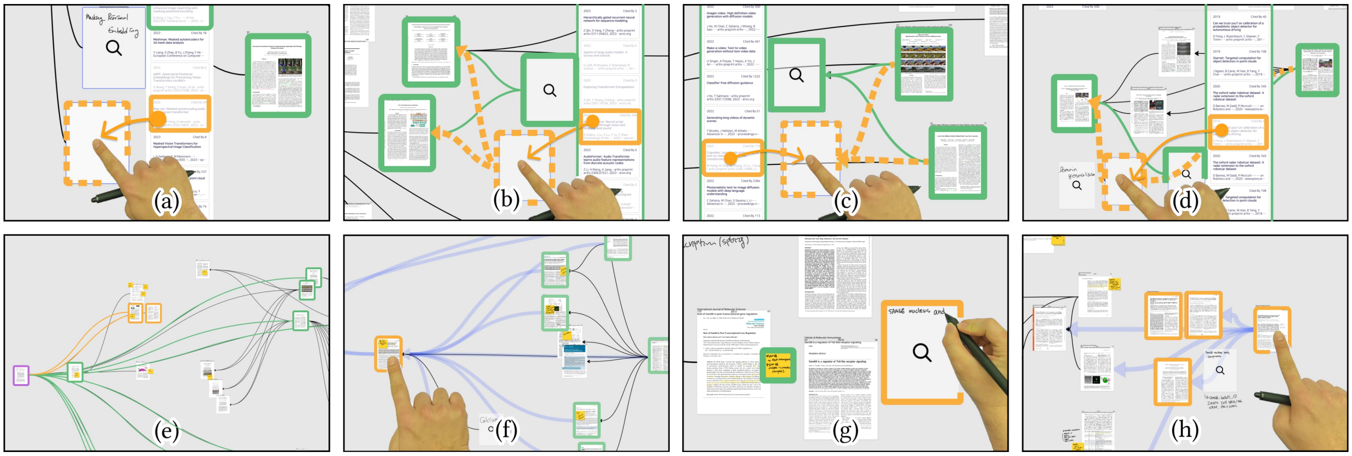

Figure 7: Reproducted snapshots of participants using our system for comprehensive literature reviews. (a) P1, specializing in audio and speech processing, collected vision-related papers (green) on the right side and language-related papers (orange) on the left side of the search panel. (b) P1 collected a cross-pollinating paper (orange) by searching for papers citing a speech deep learning paper and a vision deep learning paper (green). (c) P2, specializing in computer vision, collected an important paper (orange) by searching for papers cited by two video-generating AI papers (green). (d) P2 collected a similar paper (orange) by searching for papers cited by a survey paper on 3D point network and also citing a paper on 3D point dataset which he also used in his own research (green). (e) P2 noticed that among the papers citing a generative AI paper (purple), he had not investigated the LiDAR papers (orange) as thoroughly as others (green) and decided to further investigate this domain. (f) P3, specializing in optogenetics, newly learned about calcium ion reactions in cancer cells from a paper (orange) and viewed citation relationships to see if previously collected papers (green) referred to these reactions. (g) P4, specializing in RNA engineering, noted keywords (green) about Alzheimer's-induced protein while reading a paper and searched for papers (orange) using those keywords. (h) P4 collected four papers (orange) from the search results and viewed citation relationships among them to determine which was the most similar to her own research and therefore should be read first.

6.4.2 By specifying search conditions through a graph, participants could find important, similar, and cross-pollinating papers.

• **Find important papers.** Participants could find important papers by searching for papers cited by multiple papers on a shared topic, despite not knowing any specific seed papers (P1) or exact keywords (P2) to guide their search (Figure 7c).

• **Find similar papers.** Participants could find papers with a similar approach to their own research by searching for papers citing specific papers that were highly relevant to theirs (P1, P2) (Figure 7d).

• **Find cross-pollinating papers.** Participants could find cross-pollinating papers by searching for papers citing papers from distant fields, and try different combinations to make new discoveries (P1) (Figure 7b).

6.4.3 By making and attaching sticky notes, participants could annotate knowledge and thoughts.

• **Annotate knowledge and thoughts.** Participants could annotate keywords (P1, P2, P3, P4), summaries (P3, P4), reading progress (P3), importance (P2, P3), and research ideas (P4) (Figure 7g) on sticky notes and attach them to thumbnails of paper pages. By doing so, they could build a layer of knowledge and thoughts on top of the node-link diagram (P2, P4).

6.4.4 By viewing citation relationships among collected papers, participants could understand research topology, discover overlooked relationships, and fill the literature review gap.

• **Understand research topology.** By examining how the papers cited each other and which papers were most cited, participants could grasp the overall dynamics among the papers (P3, P4), which was particularly valuable in deciding what to read first when they were unfamiliar with the field (P4) (Figure 7h).

• **Discover overlooked relationships.** By occasionally checking all citation relationships among all collected papers, participants could discover unexpected citations between collected papers (P2, P3) (Figure 7f), letting them revisit those papers in a new light or organize the papers in a new way.

• **Fill the literature review gap.** By looking at how dense or sparse particular sectors of their node-link diagrams were with the collected paper nodes and citation links, participants could identify potential gaps in their literature reviews and plan their subsequent investigations accordingly (P2, P3) (Figure 7e).

7 DISCUSSION

Based on our study results, we discuss how our system can assist in conducting comprehensive literature reviews.

• **A visual workspace reduces the mental load.** When organizing papers in a list, individual relationships between them and the overall context are not immediately apparent, making it difficult for researchers to navigate and synthesize complex knowledge. In contrast, a visual workspace, featuring node-link diagrams with thumbnails of paper pages, citation arrows, and sticky notes, enables researchers to more intuitively understand the research landscape and more easily revisit thoughts arising during the literature review.

• **An integrated workspace inspires follow-up searches.** In the usual workflow involving different programs for different tasks, frequent switching between programs can cause distractions, making it easy for researchers to lose track of the context and ideas that emerge during literature reviews. In contrast, an integrated workspace, equipped with graph-based queries that seamlessly connect the tasks of finding and organizing papers, enables researchers to more effectively utilize what they have investigated and thought so far when finding new papers.

• **A flexible workspace enhances organizational strategies.** When storing paper files in a hierarchy of subfolders, the process of glancing at all stored papers and systematically evaluating their relevance can be cumbersome, making it challenging for researchers to review and revise their organizational strategies. In contrast, a flexible workspace, supporting the direct arrangement of papers on the 2D canvas and the tracking of all citation relationships among them, enables researchers to iteratively organize and progressively refine their research landscape as their understanding of the research field deepens during literature reviews.

8 CONCLUSION & FUTURE WORK

In this study, we present a sketch-based interactive system for inking a node-link diagram of research papers. In the system, users can search for papers through in situ graph queries, alleviating the anxiety of finding papers; utilize the infinite 2D canvas as a workspace for browsing and note-taking, alleviating feelings of being overwhelmed by reading papers; and progressively refine their knowledge graph of related work, alleviating the frustration of organizing papers.

We conducted a pilot study involving four experienced researchers from different majors who used our system for comprehensive literature reviews for over 14 hours and created 162 paper nodes, 148 citation links, and 107 sticky notes. The study demonstrated that the system, offering a visual, integrated, and flexible workspace, can reduce the mental load, inspire follow-up searches, and enhance organizational strategies.

In future work, we plan to quantitatively assess the task performances of the component interactions and qualitatively evaluate the usability of our system through formal user studies.

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