Consensus Building in Collaborative Sequencing with Visual Awareness

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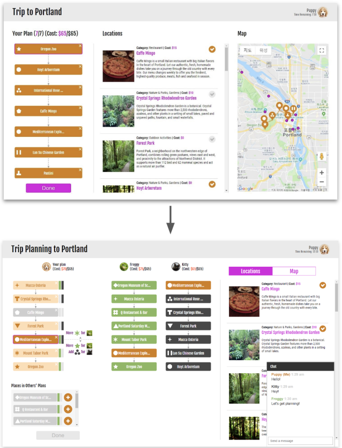

Figure 1: Users first utilize the individual screen (top) to independently construct their preferred sequence, and then the collaborative screen (bottom) through which they reach a consensus with their group.

Author Keywords

Consensus; Visual awareness; Group work; Decision-making

CCS Concepts

•**Human-centered computing** → **User interface design; Collaborative content creation;** *Information visualization;*

Abstract

Collaborative Sequencing (CoSeq) is the process by which a group selects and arranges a set of items into a particular order. CoSeq is ubiquitous, occurring across diverse situations like trip planning or course scheduling. Although indicating preferences, communicating, and consensus building in CoSeq can be overwhelming for groups, little research has aimed at effectively supporting this process. To understand the design space of CoSeq, we ran a formative study to observe how participants utilize visualizations to strategically reduce their cognitive burden. We derived a novel design to enable sequence comparison using visualizations and evaluated its effect through a study. We found that attitudinal measures for the efficiency and effectiveness of the consensus building process were significantly improved with our design.

Introduction

Collaborative Sequencing (CoSeq) is a type of group decision-making task where a group must decide on a sequence. It is a commonly occurring task across casual and formal domains, like travel itinerary planning [18] and curriculum planning [25]. In several CoSeq scenarios, members of a group are collectively responsible for and affected by the resulting outcome—e.g. a group of tourists deciding on an itinerary and following it during their travel. In these situations, it is desirable to build consensus regarding the se-

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quence among the group members [6] so that the entire group feels greater satisfaction towards the process [12] and the outcome [23].

Consensus building can be challenging in CoSeq due to the distinct qualities of this type of task. For the group to properly assess their agreement with a sequence, they need to evaluate and discuss each decision involved in creating the sequence—specifically, which items to include and the particular order between them. Additionally, to adequately evaluate each of these decisions, members must have a comprehensive understanding of possible alternatives and implications of adding or deleting these alternatives.

Several systems have been previously designed to tackle the challenge of assessing multiple decisions and their respective alternatives in sequencing tasks. Among these, recommender systems that leverage large-scale data [7, 8, 15, 21, 24, 18, 9] and crowdsourcing systems that harness human computation [26, 20] have been common approaches to provide users with item selection and ordering recommendations. While these systems were able to support users' sequencing processes, they only address the sequencing tasks of individuals. Thus, they are unable to support the expression of opinions by members in a group and the identification of conflicts within these opinions. These processes are fundamental to consensus building.

However, for all members of a group to express their opinions and for others to be aware of these opinions, a significant amount of time and effort is necessary [6]. Due to this challenge, several tools have been designed to facilitate this process and, in turn, support consensus building [1, 19, 27, 14, 13]. Although these systems were effective at increasing awareness of others' opinions and facilitating the identification of conflicts, all of them were designed to support tasks that have a single final decision. For example, Hong et al. [14] allowed groups to collaborate in the process of filtering through location candidates to facilitate the selection of one location for an event, and ConsensUs [16] visualized conflicts in opinion to support the process of selecting one candidate to admit to an engineering school. In these systems, the user manually specifies their preferences across various criteria. Due to multiple decisions involved in collaboratively constructing a sequence, applying this approach would result in iteratively specifying and comparing preferences for each decision independently. This is unsuitable because of excessive time and effort.

An additional challenge of consensus building in CoSeq is the detrimental influence that early knowledge of members' preferences can have on other members' preferences and the final outcome. As such, previous work has shown that it is preferable for members to initially form their preferences and opinions independently [17, 22]. However, this requires additional effort from group members prior to the consensus building process to independently identify and document their preferences prior to fuller collaboration and then socialize these preferences optimally.

To address these three challenges—developing preferences independently, facilitating the awareness of preferences socially, and enabling conflict identification in a multiple decision-making scenario like CoSeq—we propose a process based on the model introduced by Briggs et al. [5]. Our process involves three stages. First, each group member individually constructs their preferred sequence. This allows members to independently explore alternatives and form their preferences. Second, the group compares the individually constructed sequences to identify similarities and differences. By comparing their sequences, members gain awareness of other members' preferences with respect to their own, and can identify conflicts by focusing on the

List of nodes and edges	Lists all nodes and edges included in any of the sequences, with the group awareness visualization by Hong et al. [14].
Merged graph	Visualizes the sequences into one merged graph, based on the technique by Andrews et al. [3].
Adjacency matrix	Adjacency matrices have been demonstrated to be effective for the comparison of graphs [2]. Sequences are a subset of graphs.
Visualized edit distance	Visualizes the minimum number of modifications needed to change a sequence into another through the edit distance, a common method used to compare graphs [10] and trees [4].

Table 1: The visualization wireframes were designed by applying previous work to support sequence comparison.

Figure 2: In the sequence space, each location added is represented in the sequence space by a rectangle with the location's name (center) and a unique icon (left) to facilitate its recognition. Arrows between nodes show the ordering of them in the sequence and this ordering can be altered by drag-and-drop.

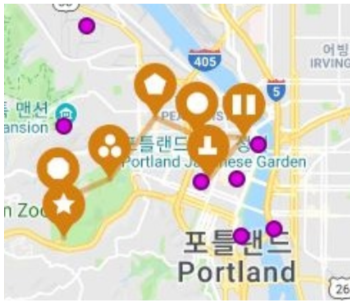


Figure 3: In the map, the user can see locations added to the sequence, represented as markers with the location's unique icon, and lines connecting the markers of locations that are adjacent to each other in the sequence.

sequence differences. Third, the group then iteratively resolves the identified conflicts through discussion to reach consensus on a final sequence.

To better understand how this process performs in real life, we conducted a formative study that identified three primary user needs when comparing sequences in a group travel planning task. Based on these needs, we designed a research prototype, TWINE, which provides visual support to satisfy these needs, and allows users to compare sequences and reach a consensus (see Fig. 1). Through a within-subjects controlled user study of 45 participants, we evaluated the effect of this visual support in the consensus building process of groups. We found evidence that this visual support can increase the efficiency and effectiveness of the process.

In short, the primary contribution of this work is to identify three design goals for a novel research prototype for CoSeq tasks through a literature survey and a formative study, and to evaluate its effects on the consensus building process in a group itinerary planning task.

Formative Study

Allowing members of a group to individually construct their desired sequence allows them to establish their preferences. Then, an effective design for the visual comparison of multiple sequences should facilitate the identification of similar or conflicting opinions within the group and support the consensus building process. However, designing such a visualization is challenging due to the difficulty in comparing three or more sequences, in contrast to the comparison of only two [11]. To understand the effective design for the comparison of multiple sequences, we conducted a formative study. In the study, four participants were presented with wireframes of four different visualizations (see Table 1). These participants were undergraduate/graduate students with previous experiences in group travel planning. They were each tasked to compare the itineraries constructed previously by three fictitious travellers using any of the four wireframes and construct a sequence that would lead to the greatest total satisfaction from these three travellers. Using a think-aloud protocol, participants were encouraged to verbalize their thoughts and reasoning throughout the task. Through open coding, three high-level design goals were derived from the study. Below, "nodes" refer to locations included in an itinerary and "edges" refer to locations adjacent to another in the itinerary.

G1: Provide an overview of similarities and a detailed view of differences. All four participants followed a process in which they first identified all nodes and edges that were shared by two or more itineraries. For this purpose, they utilized the adjacency matrix and the list of nodes and edges which provided overviews of similarities. After identifying similarities, they relied on more detailed views, like the visualized edit distance, to identify conflicts within these similarities (e.g. a node included in all the sequences but with different connected edges in each).

G2: Support the comparison of the ordering of nodes by both their edges and their relative positions in the sequences. With respect to ordering, participants utilized both the adjacency matrix and the list of nodes and edges to compare the sequences with respects to edges. Additionally, several participants utilized the visualized edit distance to compare the relative positions of nodes. By looking at the visualization of node move operations, participants recognized whether a specific node was more common at the beginning, middle, or end of the three given sequences.

G3: Support interactions for the resolution of conflicts during the identification of conflicts. When identifying

Category: Restaurant | Cost: $15
Caffe Mingo
Caffe Mingo is a small Italian restaurant with big Italian flavors in the heart of Portland. Let our authentic, fresh, homemade dishes take you on a journey through the old country with every bite.

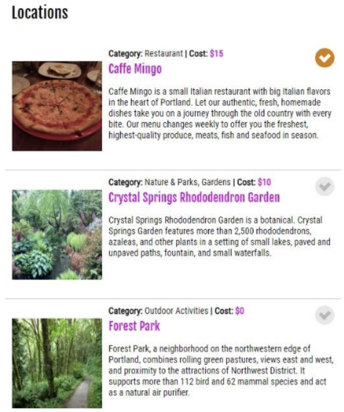
Category: Nature & Parks, Gardens | Cost: $10
Crystal Springs Rhododendron Garden
Crystal Springs Rhododendron Garden is a botanical. Crystal Springs Garden features more than 2,500 rhododendrons, azaleas, and other plants in a setting of small lakes.

Puppy (Me) 1:29 am
Hello!

Kitty 1:29 am
Hey!

Froggy 1:30 am
Let's get planning!

Figure 4: In the collaborative screen, the user can see their group members' sequences, with the nodes encoded in the unique color assigned to each member; compare sequences with the visual sequence comparison; and discuss with their group through the simple chat interface.



Category: Restaurant | Cost: $15
Caffe Mingo
Caffe Mingo is a small Italian restaurant with big Italian flavors in the heart of Portland. Let our authentic, fresh, homemade dishes take you on a journey through the old country with every bite. Our menu changes weekly to offer you the freshest, highest-quality produce, meats, fish and seafood in season.

Category: Nature & Parks, Gardens | Cost: $10
Crystal Springs Rhododendron Garden
Crystal Springs Rhododendron Garden is a botanical. Crystal Springs Garden features more than 2,500 rhododendrons, azaleas, and other plants in a setting of small lakes, paved and unpaved paths, fountain, and small waterfalls.

Category: Outdoor Activities | Cost: $0
Forest Park
Forest Park, a neighborhood on the northwestern edge of Portland, combines rolling green pastures, views east and west, and proximity to the attractions of Northwest District. It supports more than 112 bird and 62 mammal species and act as a natural air purifier.

Figure 5: The user can see information of each available location on the list, add a location to their sequence by clicking on a location entry, and remove them from their sequence by clicking on the entry again.

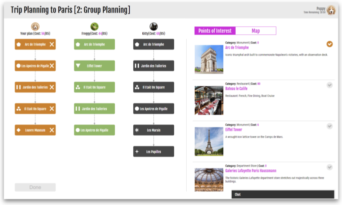


Figure 6: Collaborative screen of the baseline version of our prototype which only juxtaposes the group members' sequences, without providing the visual sequence comparison.

conflicts, participants expressed a need to understand how the conflicts could be resolved. Specifically, they wanted to explore the effects certain modifications to a sequence would have to the congruity between that sequence and the others. However, none of the four visualizations effectively afforded for this type of exploration.

To summarize, while existing visualizations like adjacency matrix and edit distances could be useful for comparison, visualizing effects of potential modifications to resolve conflicts was harder to perform using existing work.

TWINE: A Prototype Implementation

To afford these three goals together, we created TWINE, a Web-based CoSeq prototype designed for travel itinerary planning. TWINE embeds the proposed process of individual to collaborative sequencing. Additionally, it provides a visual sequence comparison technique, designed with the design goals derived from our formative study, to support the identification of similarities and conflicts in opinion during the collaborative phase. The system consists of an individual screen and a collaborative screen.

Individual Screen

In this screen (shown at the top of Fig. 1), the user constructs their preferred sequence or travel itinerary. The individual screen includes three components: a list of locations, a sequence space, and a map. The user can browse through the available locations in the list (see Fig. 5) and add them to their sequence. Added locations are shown in the sequence space (see Fig. 2) and the map (see Fig. 3). Once satisfied with their sequence, the user can proceed by submitting their sequence.

Study Setup
Task. First, individually construct their preferred sequence. Then, compare sequences in their group and discuss to reach a consensus.
Conditions. Groups performed the task twice with different conditions; the order was counterbalanced. (a) Control condition: a baseline version of our prototype (see Fig. 6). (b) TWINE condition: a version with the visual sequence comparison.
Dataset. For fair comparison, two US cities, similar in terms of area and population, were chosen: Portland & Denver. For each, a dataset of 20 locations was prepared. All participants reported to have never visited or lived in either city.
Participants. 15 groups of 3 friends from a local university were recruited using online forums (age M=22.0, SD=1.81, 37 males and 8 females) and were compensated $20.00 for a 90-minute dispersed synchronous task.

Table 2: Details on study setup.

Collaborative Screen

After all members have submitted their sequences, the group proceeds to the collaborative screen (shown in Fig. 4). In this screen, the user can see their members' sequences and modify their own sequence. Modifications are displayed in real-time to their group members. The group reaches a consensus once all of the members' sequences have been modified to be the same. To facilitate comparison of the sequences, our visual sequence comparison technique is embedded to the sequence space in this screen.

Visual Sequence Comparison

Our visual sequence comparison interface consists of three main components: visual awareness of shared nodes, ordering details on hover, and list of missing nodes.

Visual Awareness of Shared Nodes: The user is provided with visual awareness on which of their group members also selected a node that is included in the user's sequence (G1). Other group members are represented as a stub to the right of each node, encoded in the respective member's assigned color if that member also included that node in their sequence (Fig. 4(a)). Otherwise, the stub is colored gray. If a node was selected only by the user, the node is colored gray to emphasize a significant difference (G1).

Ordering Details on Hover: By hovering on a node in their sequence, the user can evaluate similarities and differences for a node's relative position and edges. For relative position, hovering on a node highlights that node in the other members' sequences (Fig. 4(b-1)). This shows if a node is positioned closer to the start, middle, or end of a members' sequence (G2). For edges, hovering on a node displays to its right, information (Fig. 4(b-2)) about which member has different adjacent nodes and what those nodes are (G1, G2). It also informs the user of which actions should be taken to match other members' edges (G3).

List of Missing Nodes: The list of missing nodes displays nodes selected by other members but not by the user (Fig. 4(c)). The list of missing nodes also supports visual awareness of shared nodes using colored stubs belonging to other members (G1). The user can easily include any of these nodes in their own sequence by clicking the plus button next to each of these nodes (G3).

Evaluation

To evaluate the effects of TWINE, we conducted a within-subjects study. For details on the study conditions and participants, see Table 2. Through a survey and a NASA-TLX questionnaire, we investigated the effect with respect to two metrics: efficiency (time and effort needed to reach a consensus), and effectiveness (satisfaction towards the process and outcome). Overall, most participants expressed a preference for the TWINE condition (see Fig. 7) and our findings indicate that this was due to the effect of the visual support on the efficiency and effectiveness.

With regards to efficiency, our study results showed evidence that visual support may decrease the amount of effort needed for consensus building (see "Perceived Efficiency" and "Aggregated NASA-TLX" in Fig. 8). Our survey responses indicate that this higher efficiency was due to the visual support facilitating the identification of sequence similarities and differences, which participants interpreted as similarities and differences in opinion.

For example, G7P2 responded that agreement in opinions could quickly be identified: *"It was easy to see, at a glance, all the locations that I shared with my group and this helped*

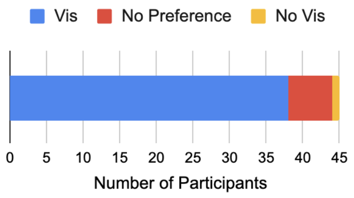


Figure 7: 38 participants stated that they preferred the TWINE condition, 6 had no preference, and 1 preferred the Control condition.

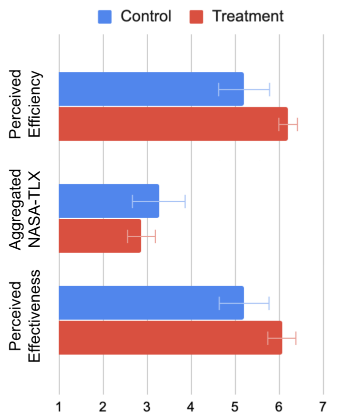


Figure 8: Wilcoxon signed-rank tests of the survey responses showed that, in the TWINE condition, participants' perceived efficiency was significantly higher ($z=28.0$, $p<.000$) and cognitive workload, calculated through NASA-TLX, was significantly lower ($z=327$, $p<.05$). Perceived effectiveness ($z=20.0$, $p<.000$) was also significantly higher in the TWINE condition.

me save time in finding agreements in opinion." Additionally, G8P2 mentioned that the color encoding of nodes led them to change their opinions: *"The locations that only I selected were colored grey. This helped me to quickly reduce my differences in opinion."* By highlighting major points of agreement and disagreement, the visual support allowed group members to focus on the main conflicts hindering consensus and to easily understand how to adjust their opinions to resolve these.

Additionally, our results suggest that visualizing significant agreements or disagreements can also increase the satisfaction towards the process and outcome (see "Perceived Effectiveness" in Fig. 8). This can be attributed to the visual support's influence on the structure of the groups' discussions, which was noted by many participants.

Most participants described a similar discussion structure in which they first decided to fix the nodes shared by all the members and then discussed including the remaining nodes: *"We tried to include all the locations that all our members selected. Then, we discussed to decide on whether to include those locations that were only selected by one or two members. (G10P3)"* By fixing nodes shared by all, groups could ensure equal base satisfaction towards the final outcome. Discussing all nodes selected by at least one member allowed each member to express all of their opinions with respect to selecting a new node. Granting opportunities for the expression of opinions or concerns is essential for effective consensus [6]. Therefore, the discussion structure encouraged by the visual support could have resulted in a more satisfactory process and outcome.

Conclusion

Our study allowed us to gain evidence on the benefit of the visual sequence comparison on the consensus building process in a CoSeq task. By facilitating sequence comparison, the visual support allowed groups to reduce their perceived efforts by focusing on the conflicts in opinion that were mainly impeding consensus. Additionally, it encouraged a discussion structure, which was perceived to be effective, through which the level of satisfaction shared by group members could be maximized.

We acknowledge a couple of limitations to our work. To control for group dynamics, we conducted our study with groups of three friends. However, the consensus building process depends significantly on the type of the group (e.g. strangers, co-workers, or family members) and its size. Additionally, as our study was designed as a controlled lab experiment to control for understanding the effects of visual support, it may not replicate real world situations (e.g. asynchronous and remote settings). Lastly, as our study focused on travel planning, these findings may not be generalizable to all types of CoSeq tasks.

In this work, based on previous literature and a formative study, we show that user goals including visual sequence comparison and conflict identification for a CoSeq task of travel planning can not be met with existing visualizations, and a novel design that provides such support can lead to gains in perceived effectiveness and efficiency. With the findings from this study and consequent future studies, a more comprehensive understanding of the design space for CoSeq can be developed.

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