Collaborative Dynamic Queries: Supporting Distributed Small Group Decision-making

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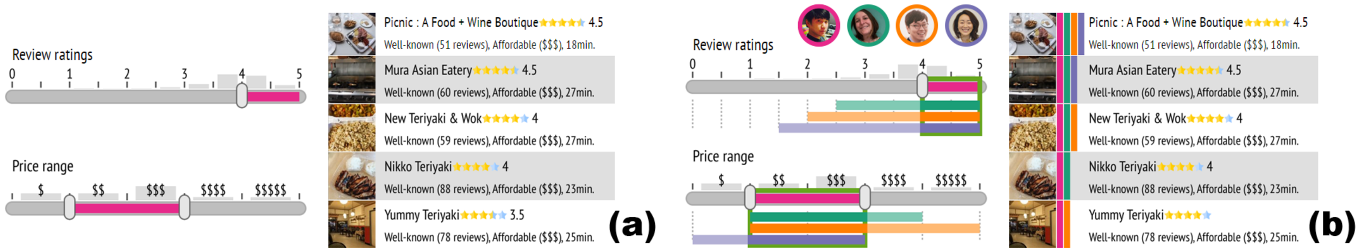

Figure 1. Two designs for group filter user interface (UI). For each UI design, the left side shows filter widgets and the right side shows a list of filtered candidates. The filter UI design (a) presents the baseline, whereas (b) presents *group awareness* which is comprised of information about filter ranges that group members indicated, and which members' ranges include which candidates.

ABSTRACT

Communication is critical in small group decision-making processes during which each member must be able to express preferences to reach consensus. Finding consensus can be difficult when each member in a group has a perspective that potentially conflicts with those of others. To support groups attempting to harmonize diverse preferences, we propose *Collaborative Dynamic Queries* (C-DQ), a UI component that enables a group to filter queries over decision criteria while being aware of others' preferences. To understand how C-DQ affects a group's behavior and perception in the decision-making process, we conducted 2 studies with groups who were prompted to make decisions together on mobile devices in a dispersed and synchronous situation. In Study 1, we found showing group preferences with C-DQ helped groups to communicate more efficiently and effectively. In Study 2, we found filtering candidates based on each member's own filter range further improved a groups' communication efficiency and effectiveness.

Author Keywords

Collaborative Dynamic Queries, Group awareness, Group filtering, Visualization, Consensus, Group decision-making

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H.5.3. [Information Interfaces and Presentation]: Group and Organization Interfaces

INTRODUCTION

People routinely find themselves in different types of small groups, such as family, friends, or co-workers, needing to make decisions together. In such situations, it is common for each member in the group to indicate their preferences over a set of decision criteria [4] so that everyone can find an agreeable candidate [9,14]. For example, a group of friends might seek a restaurant for a Friday night gathering while balancing individual preferences regarding the types of cuisine or the price range. A group of co-workers might seek to find a place for an offsite meeting while balancing their choice using competing criteria, such as available amenities.

Group members individually use online information seeking services such as Yelp, Amazon, or Airbnb to make decisions together. Despite the prevalence of collaborative decision-making, most of the services supporting such decisions are designed with a general, "de facto" assumption of an individual usage scenario [5,30]. For example, existing services present *dynamic queries* [2,18], which expose decision criteria to users and help them filter candidates along the criteria, supporting individual members as they iteratively search candidates and find different subsets of interest [34]. While knowing information about other members' preferences regarding the criteria would help each member to understand the rationale behind the choice of others and contribute to establishing consensus, current designs do not offer such information to groups. The lack of support for group usage contexts generally leads groups to put additional efforts into *grounding* (i.e., a group determining that they are communicating based on the same propositions, terms, and goals) [37] and thereby increases the *cost of integration* (i.e., a group synthesizing different preferences among members) [19]. Such efforts can make the decision-making process tedious and less satisfactory.

In this work, we propose *Collaborative Dynamic Queries* (C-DQ), which can be applied as a UI component in group decision-making support systems. We work from the position that C-DQ can act as a *moderator* and help groups efficiently build consensus and effectively make agreeable decisions. To make C-DQ function as a moderator, it is designed to present *group awareness*, which allows group members to be aware of other members' filter selection ranges and which decision candidates are within whose filter ranges. C-DQ also presets three modes of *group filtering*: *ego-centered filtering* – filtering candidates based on each member's own filter ranges; *group-inclusive filtering* – showing candidates that match at least one member's filter ranges; and *group-exclusive filtering* – selecting candidates that match within everyone's filter ranges. Fig. 1 shows how C-DQ can be applied in filter design for groups. Fig. 1(a) shows the filter design without group awareness. In contrast, Fig. 1(b) shows group members' filter ranges (at the left side of the UI), as well as which decision candidates are within whose filter ranges (at the right side of the UI). Fig. 1(b) applies ego-centered filtering.

To understand how group awareness and different filtering methods affect small groups' decision-making behavior and perception, we conducted two controlled studies with nine groups that each included four mutual friends. In terms of the use context that we aimed to cover in these studies, we focused on dispersed situations in which mobile devices are part of decision-making practices, as they commonly are in the real world today [5]. The results of Study 1 show that group awareness improves the efficiency and effectiveness of communication and simultaneously increases perceived satisfaction with decisions when compared to the baseline condition. Study 2 results indicate that ego-centered filtering allowed groups to communicate more efficiently and effectively than group-inclusive filtering.

This work offers the following contributions.

- Design of Collaborative Dynamic Queries (C-DQ) for supporting small group decision-making
- Findings indicating *how* C-DQ affects small groups' decision-making behavior and perception and *why*
- *MCSquared*, a JavaScript library that enables designers to customize the client side of C-DQ based on their design goals (available at http://mcsquared.systems)

RELATED WORK

Designing collaborative systems for a group is an active area of research in Human Computer Interaction (HCI), Information Visualization (InfoVis), Computer Supported Collaborative Wok (CSCW), and Information Retrieval (IR) [11] with a substantial body of existing literature but also many unexplored research spaces [23].

Supporting Group Tasks with Visualization

While there are a variety of collaborative systems designed for supporting different types of group tasks, researchers in HCI and InfoVis have paid much attention to designing systems for collaborative visual analytics where the goal is to help a group of professionals derive *insights* from analyzing a vast amount of information [19,36]. For example, Brennan et al. introduced a framework for distributed workers' analysis [7]. Heer and Agrawala derived seven guidelines for designing collaborative visual analytics systems [19]. Isenberg and Sheelagh's work [22] has led to multiple systems to support collaborative analysis of visualizations among small groups of experts. Casual scenarios (e.g., supporting non-professionals) explored in HCI and InfoVis are presented by Heer et al. with Sense.us [20] and by Viégas et al. with ManyEyes [38]. These systems expand collaborative analytics from small groups of specialists to larger and more casual userbases. These systems commonly focus on enabling groups of users to use visualizations to perform analytics and derive insights from data (e.g., identifying patterns or anomalies) [1]. However, comparatively less research focuses on supporting group-based *decisions* while leveraging human visual capabilities.

A different line of research focuses on understanding the effects of shared *group awareness* in collaborative systems. Supporting group awareness is considered useful when supporting group decision-making in real time, where information related to a decision is dynamically changing and frequent monitoring is required [10]. In HCI, Isenberg and Fisher propose visual cues for group awareness in document queries and searching activities [24]. In InfoVis, Hajizadeh et al. demonstrate the effects of awareness in tabular data [16], and Mahyar and Tory show the efficiency benefits of presenting awareness in linked common work (LCW) [29]. Results from these studies indicate that a group can benefit from sharing knowledge and understanding of activities that others are performing [19,24]. In certain instances, group awareness can also help avoid redundant work [16]. Evidence from these prior studies suggests that group awareness could improve group decision-making tasks by enabling the group members to share their intention in visual format and thereby reduce the *communication costs* required for establishing common ground.

Dynamic Queries & Collaborative Information Seeking

Dynamic Queries (DQ) allow users to indicate their preferences over multiple widgets relevant to search goals, updating results dynamically [2]. People use DQ to achieve complex compositions of filters which enable them iteratively to refine a subset of results of interest [8]. Such queries are usually used in faceted browsing and search systems to support a single user who is seeking to narrow large information spaces to smaller subsets by expressing complex sets of filters [18]. Yet, to the best of our knowledge, none of the previous work explores the collaborative aspect of DQ, nor their potential to support small group decision-making.

Perhaps the most relevant work in this space is scented widgets [39], which integrate visual cues with an interaction widget to materialize "information scent" [33]. An aspect of collaboration supported by scented widgets is social navigation. For example, widgets are augmented by a visual bar indicating how many other people selected a value or a range of values. However, understanding appropriate designs for applying such scents when supporting information exploration using group filters needs further investigation.

Meanwhile, other researchers in HCI and CSCW have focused on the design for supporting collaborative information searching. For instance, Jetter et al. proposed tabletop systems with tangible widgets to help groups of casual users find their travel destinations together [27]. Morris presented a system called SearchTogether to support collaborative web searching [31]. Bently proposed SearchMessenger to avoid frequent switching back and forth between multiple apps in collaborative information seeking [5]. This line of research indicates that collaborative searching and decision-making are increasingly prevalent, and further investigations are needed for supporting such emerging phenomenon [30].

DESIGN OF COLLABORATIVE DYNAMIC QUERIES

We explore the role of moderators and modes of group filtering methods in small group decision-making scenarios to identify the design dimensions of C-DQ. We then elaborate on how we realized the dimensions in our design.

Moderators in Small Group Decision-Making

Understanding methods for facilitating consensus in group decision-making is a core topic in communication, management science, and organizational research [12,14]. Deciding on a single option among many candidates that every member agrees is intrinsically challenging [6]. Part of the reason comes from the difficulty of supporting group awareness—a general understanding of (1) who in the group agrees or disagrees about which candidates (2) and each member's preferences [37], both of which are the basis for individual opinions regarding the candidates [25]. In addition, in many contexts, members may iteratively adjust their preferences until a decision has been finalized. In such instances, it is not a trivial matter for each member to track the dynamically changing preferences of others [6,14]. Because of such issues, researchers have explored agents called *moderators* [28,32] who play the following roles:

- **Role 1.** A moderator aggregates *preferences* over a set of decision criteria of a group and surfaces them to members.
- **Role 2.** A moderator provides information about the *candidates* that match with individual and group preferences, and helps a group to identify if there is a feasible candidate that could lead to a decision.
- **Role 3.** In case there is no agreement, a moderator facilitates group consensus by identifying the sources of disagreement and suggests *preferences to relax* so that agreement can be reached within a group.

While deploying a moderator may help a group reach a decision efficiently with improved group awareness, attempts to incorporate a moderator in a decision-making loop imply the use of a trained human agent [28] or an algorithm tailored to a specific domain [32] for supporting a group of professionals. To date, deploying a moderator in everyday group decision-making has not been practical [3]. For example, while everyday group decision-making occurs frequently with DQ in online systems, little effort has been made to improve a consensus-based, collaborative decision-making process with moderators in DQ.

We propose the model of C-DQ, which can act as a moderator in collaborative information-seeking scenarios for small group decision-making. DQ enables a single user to filter candidates based on a set of preferences over decision criteria. C-DQ extends DQ to usage in a collaborative decision-making context by presenting *group awareness*. Group awareness is supported by visualizing two types of *group preferences*. First, each member in a group indicates their own preferences over decision criteria via filtering widgets. Then a system visualizes the indicated preferences of a group to each member's client. We call such preferences *preferences-on-criteria*. Second, a system presents visual cues that show which candidates are within whose filter ranges. We call these visual cues *preferences-on-candidate*. We posit that supporting group awareness enables C-DQ to act as a moderator in the following manner:

- **Role 1.** C-DQ allows each member to aware other members' preferences over decision criteria without the need for explicit communication.
- **Role 2.** C-DQ provides awareness of candidates that match criteria of each member in a group, facilitating the identification of candidates that could lead to a decision.
- **Role 3.** When an agreeable candidate does not exist, C-DQ helps each group member to identify how relaxing specific preferences can lead to consensus.

Group Filtering in Small Group Decision-Making

Another crucial factor that could influence a small group's behavior in finding consensus is reflecting each member's different preferences-on-criteria when applying a filter. We expect that most users are familiar with DQs designed for individual usage contexts. Therefore, we anticipate the users would more familiar with *ego-centered filtering*, which filters candidates based on one's own filter ranges. When it comes to group decision-making contexts, however, this method would likely present a different set of candidates to different members. Presenting such *unsynchronized candidates* across group members may lead individuals to put additional effort into finding a candidate that another member is referring to and prevent effective communication among the group members.

Applying different group filtering methods would support synchronizing "current candidates on focus" among different members in a group. We decided to consider everyone's

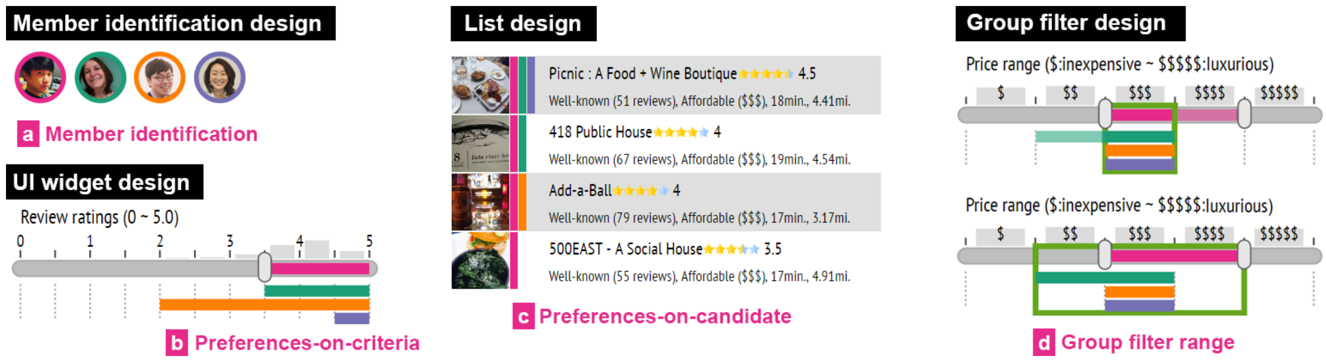

Figure 2. Design of C-DQ with five design considerations for mobile UI

preferences-on-criteria altogether when filtering the candidates, which would eventually present *synchronized candidates* across a group. This synchronization could be achieved by either selecting candidates that match (1) within everyone's preferences-on-criteria – which we call *group-exclusive filtering* or (2) at least one individual's preference-on-criteria – which we call *group-inclusive filtering*.

Design Considerations

Based on the two dimensions we identified, we present five *design considerations* that C-DQ may comply with. We constrained the target platform to mobile.

1. Visually distinguish each member in a group: Identification of each member is an important issue, as each member's preferences would highly be influenced by other members' depth of knowledge related to the decision, cultural and social background, power, and prior relationships [26]. In encoding identification information, we use color (e.g., using ColorBrewer [17]), along with an additional dimension if necessary (e.g., member's name and/or a profile image – see Fig. 2(a)). Color encoding can be useful in another sense: if necessary, member identity can be anonymized by assigning the same color to everyone.

2. Visually present members' preferences-on-criteria close to a widget: In designing C-DQ, we present group's preferences-on-criteria in close proximity to the DQ widget where each member would input one's own preferences (see Fig. 2(b)). We envision that such design could help each member to (1) easily relate one's own preference range with the rest of the group's preferences and (2) identify the range that has agreement or not. We expect such capability could help a group to relax the preferences they do not feel strongly about when consensus is not present. However, we note that visualizing individual preferences among group members as opposed to aggregated ones has obvious tradeoffs. The most problematic issue for the mobile scenarios we consider here is the display budget (screen space) it requires, even potentially hindering an overview of the DQ criteria. Nevertheless, as the focus of C-DQ is for *small* groups, we concluded the potential communication value of this design would outweigh the drawbacks, as clear identity presentation can help interpersonal assessment.

3. Present "information scent" to guide users to decision candidates: As DQ typically involves multiple criteria (with "and" Boolean operation among the criteria which is a widely adopted practice), we expect a user's indication of strict preferences on merely one criterion can result in no information being presented. In such instances, a user may be puzzled in terms of which widget to move and to where to move it. To avoid such situations, we present an additional "visual scent" [39] on each widget, which indicates the distribution of candidates for each criterion (See gray bars on the top of a slider in Fig. 2(c)). The experts expected that this additional information would inform each group member in terms of which criteria to relax to see more information.

4. Visually couple preferences-on-candidate with each of filtered item: We visually couple preferences-on-candidate with each filtered item presented on a screen. In visualizing preferences-on-candidate, we use the layout of a stacked horizontal bar chart, where each bar (which indicates preferences-on-candidate within a group of *the* item) includes one or multiple stubs that have the same width as the stubs. A stub appears when a member agrees with the item (color-coded with each member's color – See Fig. 2(d)). With this design, each member would be able to visually identify who would agree or disagree with the corresponding candidate, and visually compare candidates in terms of how many members would agree to each.

5. Visually distinguish the range indicated from a member and the range used for filtering candidates: The filter ranges that a system applies for filtering candidates in group-inclusive and group-exclusive filtering would likely be different from the ranges indicated by an individual user. The discrepancy between what a member *indicates* and what a system *shows* could confuse the member. To avoid such a situation, we visually distinguish the ranges selected by a member and the ranges used for applying filter. The design of widget UIs in Fig. 2(e) show how C-DQ visually distinguishes the range indicated by a user and the range used for filtering candidates. The bounding box that includes four bars presents the range used for filtering candidates. Note that the range set by a user is the same across the two UIs, yet the UI at the upside (group exclusive) only includes $$$, whereas the UI at the bottom (group inclusive) includes from $$ to $$$$.

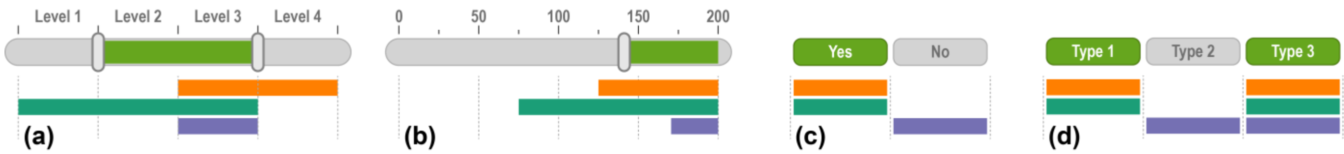

Figure 3. Four C-DQ types in MC2: (a) Ordinal C-DQ, (b) Quantitative C-DQ, (c) Boolean C-DQ, and (d) Nominal C-DQ

MCSQUARED

Based on the aforementioned five design considerations in the previous subsection, we present a JavaScript library, *MCSquared*. The library is built based on the following considerations: First, the library allows researchers and practitioners to flexibly customize the width and height of every graphical component presented on a screen so that the library can be applied in any type of device platform and screen resolution. Second, the library presents four types of C-DQ. Our list of C-DQ types was developed in consultation with [34]. Third, the library supports anonymizing member identities by removing the color encodings. The library is available at http://mcsquared.systems. The specific features of each C-DQ type are presented as follows:

1. Ordinal C-DQ: Ordinal C-DQ allows users to filter candidates based on *ordered* categories. (e.g., Yelp users filter out local businesses based on price range from "$" to "$$$$.") The design of ordinal C-DQ uses a slider with snapped handles. Depending on the nature of criterion, ordinal C-DQ presents one handle (for setting a minimum or a maximum range) or two handles (for setting both a minimum and a maximum ranges). Fig. 3(a) presents the design of ordinal C-DQ.

2. Quantitative C-DQ: A user filters candidates based on quantity with the quantitative C-DQ. For example, a user can filter out hiking trails based on a round trip distance. Like ordinal C-DQ, quantitative C-DQ can have one or two handles. In addition, different types of scale, such as linear, power, or logarithmic scale, can be applied in quantitative C-DQ. Fig. 3(b) presents the design of quantitative C-DQ.

3. Boolean C-DQ: Boolean DQ can be used for filtering candidates based on dichotomous options (i.e., yes or no). Fig. 3(c) presents the design of a potential Boolean C-DQ.

4. Nominal C-DQ: Nominal DQ is used for filtering candidates based on a categorical scale that has no order or quantity among them. (e.g., a user can select types of food such as French and/or Korean for filtering restaurants). A user can select none of, one of, or multiple of the options. Fig. 3(d) presents the design of a potential nominal C-DQ.

Mobile Web App

We implemented a mobile web app that a group of users can use to collaboratively find travel destinations with C-DQ. In developing the app, we incorporated five modules, which are widely used in supporting collaborative travel destination finding in online services used in the real world, and

Figure 4. Screenshots of a mobile web app built for collaborative place searching with C-DQ: (a) Two screens in the left show five modules included in the mobile web app (b) Three screens in the right present three conditions used in Study 1 and Study 2.

discussed in HCI and CSCW research (e.g., [13,30,5]). Fig. 4(a) shows the detail of the five modules in the web app. At the top side of the screen, the app presents a *list view* module (see List in Fig. 4(a)) and a *map view* module (see Map in Fig. 4(a)). A user can see more detail (including a high-resolution image, address, and one Yelp review) about each candidate by tapping an item in the list module, or a marker in the map module. Both modules present the same set of candidates in a different visual format and a user can toggle between a list or a map (see Toggle1 in Fig. 4(a)). At the bottom side of the screen, the app presents a *C-DQ* module (see C-DQ in Fig. 4 (a)), and a *chatting* module (see Chatting in Fig. 4(a)). Toggle2 in Fig. 4(a) allows users to access either C-DQ or the chatting module. Division of the screen into top and bottom allows users to modify filter settings on the bottom *while* seeing the refined candidates on the top at the same time, which is an important principle for supporting an iterative information seeking process [35]. Lastly, the app provides a *search* module (see Search in Fig. 4(a)), so that a user can directly query the detail of any destination without changing filter settings. This search module can be useful when one member mentions a specific place, but the rest cannot see the place in their list and map modules due to the different filter range settings.

The app can support collaborative place finding in different formats: (1) with or without presenting group awareness, and (2) with applying one of the three group filtering methods. Three conditions shown in Fig. 4(b) show some examples. C1 supports group destination finding tasks *without* group awareness, whereas C2 presents with group awareness. C2 filters candidates based on ego-centered filtering. However, C3 uses group-inclusive filtering. The three conditions were used in the two studies to understand the effects of group awareness (Study 1) and filtering methods in small group decision-making (Study 2).

STUDY 1: EFFECT OF GROUP AWARENESS

In Study 1, we aim to understand the effect of group awareness presented with C-DQ in small group decision-making. Specifically, (1) we investigate whether group awareness externalized in C-DQ could help members to be aware of the others' preferences with less communication effort and consequently lead a group to reach consensus more efficiently than without C-DQ. (2) Secondly, we examine whether group awareness in C-DQ could make communication more effective (meaning that group members felt the communication proceeded in a fairer fashion, and felt more comfortable, and more confident with the process as opposed to the process without C-DQ). Our hypotheses are as follows:

- **H1.** Presenting *group awareness* with C-DQ will reduce the amount of communication effort, indicating *efficient communication* in small group decision-making.
- **H2.** Presenting *group awareness* with C-DQ will lead to *effective communication* in small group decision-making.

Apparatus

To test these hypotheses, we conducted an experiment with a within-subject design by manipulating group awareness: without C-DQ (referred to as **C1** see C1 in Fig. 4(b)) and with C-DQ (referred to as **C2;** see C2 in Fig. 4(b)). For manipulating stimuli, C1 did *not* present preferences-on-criteria in a C-DQ module whereas C2 did. In addition, C1 did *not* present preferences-on-candidate in a list and a map module, while C2 did. To make a fair comparison between C1 and C2, we searched two restaurant types that each had similar numbers of places from 47.396°S, -122.440°E to 47.859°N, -122.075°W we can collect from Yelp 2.0 API. As a result, we prepared two datasets of French (408 places) and Japanese (399 places) restaurants. We set the bounding box based on where study participants were residing at the time of the study, as presenting restaurants that the participants can try increases ecological validity. Also, we chose five decision-criteria types for our C-DQ module that are widely used in travel decision-making [13,15,21]. Four of these criteria rely on quantitative scales: (1) average review ratings, (2) the number of user ratings contributed (as a measure of overall popularity), (3) travel time, and (4) distance to restaurants. One criterion is presented based on an ordinal scale: (5) price range.

Methods

To rigorously examine the impact of C-DQ, we controlled the possible confounding factors that may affect group decision-making processes including group dynamics and synchrony of the decision-making process. To control group dynamics, we recruited groups of four (controlling group size) participants who are mutual friends (controlling group history, hierarchy among the members) through mailing lists of one large university in the USA (controlling homogeneity within group members). Further, to measure how C-DQ affects group decision efficiency and/or effectiveness, we chose a synchronous and dispersed group decision-making setting for the study—all the group members were engaged in decision-making at the same time from remote locations using a mobile device. Through a screening survey, we recruited 5 groups of 4 friends (age M=22.4, SD=4.72, 8 males and 12 females). As for the size of the groups in the study, we consulted [30], which reports nearly 100% of survey participants responded they had experience in searching information with a group of 4 or fewer. The groups participated in Study 1 represented a range of their friendship periods from 6 months to 12 years (M=4.7 years, SD=2.82). Participants indicated that they felt close to their friends in the group (M=4.05 in 5-Likert scale), and all groups were naturally mixed-gender. More than a half of participants (n=13) reported that they use online systems such as Airbnb more than once a week.

Upon arrival at the lab, a group was told about the goals and overall process of the study. Then each group was asked to make decisions twice, once using an app without group awareness support (i.e., C1) and once using an app with group awareness support (i.e., C2). We assigned the two conditions in a counterbalanced order. Groups explored the Japanese restaurants in their first trial, then the French next. With this study design, we aimed to (1) remove the learning effect on data between the two trials and (2) decouple the datasets from two conditions (i.e., half of the groups use Japanese and another half use French in C1). For each trial, a group first familiarized themselves with the app of a given condition for 5 minutes. Then, each member was led to one of four separate rooms to simulate a dispersed group decision-making situation. They received an Apple iPhone7 that presented an app corresponding to a given condition. One member in each group was randomly assigned the role of the person who would finalize the decision based on the discussion among the four participants. Each group was guided to spend as much time as they wanted to make a well-informed decision, and when they reached a final decision, the designated individual was instructed to press a button in the app that signified the end of their decision-making process. Session completion time and chat logs were recorded. Upon completing *each* trial, group members answered a survey (in total, they answered the survey twice). After finishing the two trials, participants were paired for post-decision interviews. Each member in a pair had an equal opportunity to answer all the questions.

Measures

We used mixed-methods including quantitative (behavioral log, survey) and qualitative data (behavioral log: chat log, survey: open-ended questions, interviews).

Quantitative Data

Communication efficiency was defined as "how efficiently the application supports a group decision-making process." Communication efficiency was measured from both the behavioral log and the survey. From the behavioral log, efficiency was measured by (1) total time spent to reach a final decision as a group, and (2) the number of chat messages as a group. Perceived communication efficiency was also measured via survey by asking participants to indicate their level of agreement with 3 survey questions on a 7-point Likert scale, "This application helps us more easily/quickly/openly reach a decision as a group" (Cronbach α=.81). Communication effectiveness was defined as "how effectively the application supports a group decision-making process." As it is a construct based on subjective perception toward the group decision process rather than observable behaviors, we only measured it by survey questions asking the extent to which each participant agreed with 3 questions on a 7-point Likert scale, "This application helps us more fairly/confidently/comfortably reach a decision as a group" (Cronbach α=.83).

Qualitative Data

We collected qualitative data from three sources: the group chat logs, open-ended questions in the survey, and the closing interview. In the interview, participants were asked to recall their behaviors with C1and C2, and to explain why and how they used the application.

Results

Group Awareness in C-DQ and Communication Efficiency

To see whether C-DQ could make communication more efficient, we ran a linear regression analysis with the survey data by SPSS 19. In the model, we added a nested term (participants' ID within the group number) to control for the group and individual differences, and to clearly examine the effect of C-DQ. Although we had 20 participants in 5 groups in Study 1, one participant did not click the submit button after finishing a survey, and one group didn't press a button for confirming their decision. We excluded these records and conducted analyses with survey of 19 participants and a behavioral log of 4 groups. We found that the perceived communication efficiency was significantly higher in C2 (M=6.47, SD=.56) compared to C1 (M=4.94, SD=1.76 b= 1.333, $p<.000$). This result also holds in the analysis of the behavioral logs using the group as the unit of analysis. A paired t-test analysis indicates that the group decision was significantly faster in C2 (total time spent to reach a decision: M=637.75 sec, SD=86.07) compared to C1 (M=813 sec, SD=186.72, t=3.29, df=3, $p<.05$). People also exerted less effort in C2 (the number of chat lines per group: M=56, SD=12.99) than in C1 (M=88.50, SD=26.26, t=2.95, df=3) but the difference was not statistically significant (p=.06), partially due to the small sample size. We counted how many candidates a group discussed in each trial and found no significant differences between C1 (M=5, SD=1.63) and C2 (M=5, SD=2.19), which indicates that groups considered a similar number of candidates between the two conditions. These results indicate that presenting group awareness with C-DQ increases the efficiency of communication in small group decision-making (H1 supported).

We analyzed qualitative data to investigate the relationship between presented group awareness in C-DQ and communication efficiency. We found that group awareness in C-DQ made participants feel they were able to (1) understand each other's preferences easily, which was useful for establishing common ground within a group, and (2) lead a decision without too much of effort.

Many participants mentioned they liked the support for group awareness because it enabled them to quickly understand what others value. They found such capability was important for establishing common ground. For example, G4P4 noted that he did not need to spend too much time to learn and compare others' preference: *"I like how I can view other people's needs/requirements. Sometimes it is difficult to ask a group where they want to eat because hearing everyone's opinion is time consuming/not efficient. This app (C2) allows us to examine everyone's preference and compare pretty easily."* Participants mentioned that group awareness helped them to easily find what prevents a group from reaching agreement, and to mitigate their own preferences to align with others: *"I could easily look up a restaurant that someone mentioned by matching up with their preferences using the bars!"*

Participants explained that they actually did not feel like they need to chat for too long in C2. "*It (C2) cut down on the amount that we had to communicate. I could easily see what someone wants in terms of money, popularity, distance... we didn't have to talk as much, because you could just tell, which one was already the best match that fit was in all our ranges. (G4P4)"* We further analyzed the chat logs to understand which aspects contributed to the reduced number of lines of chatting in C2. We found all five groups in C1 attempted to establish common ground on the criteria range through chatting (e.g., "G1P2: *Lets fix the constraints, then we can decide among the options").* On the contrary, such a pattern did not appear in C2 chat logs. Participants in C2 tended to more directly start discussing candidates. In C2, decision criteria were mentioned only for discussing a specific candidate's quality rather than for establishing common ground on criteria.

Group Awareness in C-DQ & Communication Effectiveness

We built another linear regression model with a nested term (participants' ID within the group number) to examine the effect of C-DQ on perceived communication effectiveness while controlling for the group effect in the model. The result shows that group communication was more effective when using C2 ($M=6.49$, $SD=.72$) than using C1 ($M=5.15$, $SD=1.71$) with statistical significance ($b=1.526$, $p<.000$). Thus, group awareness when using C-DQ supported more effective group communication (H2 is supported).

In the qualitative analysis, we found many participants recalled that C-DQ with group awareness helped them to (1) achieve a fairer communication, (2) with the reduced ambiguity in communication, benefitting the group as a whole and each individual accordingly.

A majority of participants noted that they perceived their group decision was fairer to all the members in C2 than C1 in interviews. G2P3 explained how his group decision was "rational": *"It gives a more rational approach to the whole process, that [the participant's usual group decision making practice] is usually full of irrelevant yadda yadda. With this app, everything looks fair because we had everyone's opinion taken into account."* G3P2 noted his group decision-making was fairer because it did not single out anyone's preference: *"it was perfect because we could set our preferences based on what we wanted in our food price, popularity, and more. We didn't have to leave anyone behind because we knew exactly what everyone wanted, and we could come to a mutual decision together."* When a disagreement happened, they felt C2 helped the designated decision maker to make a better decision based on what would be more likely to satisfy a majority of the group members: *"One member in particular was trying to convince us for some other place towards the end. But our leader chose 2 popular restaurants and asked us to vote. Finally, we agreed. (G2P1)"*

Group awareness in C-DQ also helped participants understand clearly what others need, which made them feel more confident about the communication. They mentioned that the preferences-on-criteria presented in C2 was helpful for understanding each other with less ambiguity. G3P1 mentioned how arbitrary language could be: *"If I say, I don't want to go much farther, what do I really mean by not going far? Do I mean 20 miles, do I mean five miles? It really depends."* G1P3 said C2 helped her to know what her friend meant by 'expensive': *"In the first part (C1), someone said I don't want to go to an expensive place. We started to say what do you mean by that? $$? $$$? But in second part (C2) you actually can see what they do in ranges."*

STUDY 2: EFFECT OF GROUP FILTERING

In Study 2, we further explore the design space for C-DQ in terms of understanding how different filtering methods that present synchronized *or* unsynchronized candidates might engender different effects. We expect that ego-centered filtering is the approach most likely to be familiar to users, recognizing at the same time though that presenting unsynchronized candidates across members can negatively affect communication effectiveness. Meanwhile, in group-exclusive filtering, every member should agree to relax their preferences-on-criteria in a coordinated way to explore new candidates, which would impose too great of a constraint on group seeking to iteratively explore candidates. We see that such an approach may not be suitable for small group decision-making. Thus, we exclude this filtering method in Study 2. Instead, we used group-inclusive filtering to provide synchronized candidates to the group, anticipating that this approach could support comprehensive awareness in terms of who is interested in which candidates, thus making the communication more effective. However, presenting comprehensive candidates could also result in having too many candidates to consider in the single view, which would reduce communication efficiency. Based on these assumptions, we set our hypotheses as follows to understand how different filtering methods would affect group communication in small group decision-making:

- **H3.** Presenting *ego-centered filtering* will result in more efficient communication than applying *group-inclusive filtering* in a small group decision-making process.
- **H4.** Applying *group-inclusive filtering* will result in more effective communication than applying *ego-centered filtering* in a small group decision-making process.

Apparatus, Methods, and Measures

In Study 2, we applied the design of ego-centered filtering in the C-DQ module in one condition (referred to as **C2;** see C2 in Fig. 4(b)), and the design of group-inclusive filtering in another condition (referred to as **C3;** see C3 in Fig. 4(b)). The process, data source, and analysis methods for Study 2 were identical to those of Study 1. In terms of participants, we recruited groups of friends using the same method we used in Study 1. In total, there were 4 groups of 4 friends (age $M=22.25$, $SD=4.51$, 8 males, 8 females). They had a range of friendship periods from 6 months to 10 years ($M=4.4$ years, $SD=2.48$). They reported their friendship was generally "strong" (M=4 in 5-likert scale). The groups made decisions twice with C2 and C3 (under counter-balanced order). We collected data from three sources: behavioral log, surveys, and a closing interview.

Results

Group Filtering & Communication Efficiency

We hypothesized that C2 would show higher communication efficiency than C3, and thus ran all the analysis in the same way as we had in Study 1. A linear regression model with a nested term (participant ID within the group) shows that C2 (M=5.72, SD=1.5) has a significantly higher level of perceived efficiency compared to C3 (M=4.89, SD=1.5, b=.833, p<.000). Also, group decisions were significantly faster in C2 (total time spent to reach a decision: *M*=448 sec, SD=36.52) compared to C3 (M=798.75 sec, SD=74.87, t=-15.05, df=3, p<.001). People exerted less effort to make their decision in C2 (the number of chat messages per group: M=40, SD=13.34) than in C3 (the number of chat lines per group: M=59.75, SD=25.26); however, the difference was not statistically significant (t=-2.83, df=3, p=.06). These results show that group decision-making was more efficient in C2 than C3 (H3 supported).

In our qualitative analysis, we found participants felt C2 to be more efficient than C3 because the candidates that appeared in the list in C3 often overwhelmed the participants. For example, G8P3 mentioned *"There's just like a lot more options to go through for the second one (C3) … I don't think I was able to do through the whole list."* Another participant in the same group mentioned that his group had to spend more time on the possible options while narrowing down the candidates: *"it (C3) gave the whole range of the whole group. Because it was a bigger range, we had to narrow it down… so, I guess, that took more time. (G9P2)"* Conversely, participants noted that C2 was quicker and easier to use than C3 in general because they were asked to consider fewer candidates. G9P2 noted *"we were able to choose from that small list of what we wanted."*

Group Filtering & Communication Effectiveness

We initially expected that C3 would allow groups to more effectively communicate. However, a linear regression with a nested term (participant's ID in the group) shows that perceived communication effectiveness measured from the survey to be significantly higher in C2 (M=5.77, SD=1.24) than C3 (M=5.04, SD=1.57) (b=.729, p<.000), which means C2 is better than C3 to increase perceived effectiveness in the group communication (H4 not supported).

We conducted qualitative analysis with data from chat logs and interviews to understand why participants felt communication in C3 less effective. In the interviews, we did find many participants appreciated the capability of seeing the synchronized candidates across a group in C3. For example, G7P4 said, *"the app was supposed to be focused on coming to a consensus that we all agree on; the second app (C3) would definitely work better because we can see what everyone agrees on rather than just our own personal preference."* They said the synchronized candidates helped them to consider candidates from the perspective of a group as a whole. However, many participants felt the negative side of seeing synchronized candidates in C3. We found many participants were reluctant about candidly expressing their preferences and felt they had to conform to opinions of majority in C3. G7P1 said *"(In C3) there were three matches at the top and then from there I could see I wasn't in the same price point as them so that made me compromise with them…I saw that they were willing to pay more, I was willing to pay more as well."* G7P2 remarked, *"I could see not only what works for me, but what works for other people even though it doesn't work for me…I could just move my review rating down…"* Participants said they felt uncomfortable when they were able to see their "unique" preferences were obstructing a group from finding consensus in C3: *"it (C3) sees everyone's choices but if I can't see mine, then it's kinda hard to just transition to agree with the group… Cause when you look at the group, I felt isolated from the group choices cause I can't see my own choices in there (G9P1)."*

We found the pressure of having to follow the major opinions brewed perceptions of unfairness: *"In the first condition (C2), you just explore wherever you want, then try to just see if there's a fit into other people's opinion, which kind of makes you feel much more like, express yourself better? (G9P2)",* as well as privacy concerns: *"I felt like my privacy was intruded in on the second one (C3) … We could see who has the cheapest taste and I didn't like that. I will want to keep my preferences silent because we always have a big group [of friends] (G8P1)."* Pressure was evidently appeared in the chat logs as well. By analyzing the chat logs, we found that in C3, participants chatted to establish common ground, but their focus carried a different tone and different purpose than in the C2. In C3, participants exerted pressure on others to change their preferences so that the group could more rapidly reach consensus. This pattern was evident in such log comments as: "G6P2: *You don't fit us, G6P1…*G6P1: *I should fit now*."; "G7P1: *G7P4, change your review thing, make it bigger cus you ain't matching with us* … G7P3: *G7P1 isn't matching with anyone*"; "G9P1: *What happened to G9P4's price range?…A bit scary (that the range of G9P4 is $$$), I'd say $$…*G9P4: *Changed it*."

DISCUSSION

The results of Study 1 indicate the group awareness presented in a C-DQ module facilitates efficient group communication. Using C2 enabled the groups to make decisions significantly more quickly. In addition, perceived group communication efficiency in C2 was significantly higher than in C1. In our analysis of the chat logs, we found participants exerted more effort to establish common ground on the criteria in C1 (e.g., "G2_P3: *Let's keep popularity to 100 plus"*) compared to making a decision in C2. In contrast, groups in C2 did not need to exert such effort because they were able to *see* all the preferences-on-criteria. Meanwhile, perceived effectiveness in C2 was significantly higher than

C1, which aligns with the patterns we identified in the interview. Many participants felt that the decision-making was fairer and less ambiguous in C2 than C1. In general, participants felt more satisfied with the decisions they made in C2 than C1. A 7-point Likert scale at the end of the survey shows that participants felt more satisfied with their decisions in C2 (M=6.81, SD=.33) than C1 (M=6.36, SD=.87). (b=.451, $p<.05$)

The results of Study 2 show that C2 contributes to more efficient communication than C3. Participants in C2 made faster decisions, with fewer lines of chatting than those in C3. We assume these improvements were in part because C2 had fewer candidates presented at the top side of the web app than C3. Meanwhile, some participants in Study 1 noted potential difficulties they encountered while using ego-centered filtering. G3P2 described her experience when she could not follow up on what her group was talking about in reference to a specific restaurant — she could not see the restaurant just because her preference did not match with others, so the specific restaurant did not appear on her list. She recalled, *"it was very hard to reach a decision without seeing restaurants on others' ranges."* Such observations made us expect C3 would make communication more effective than C2. However, the results in Study 2 indicated otherwise. Patterns appearing in the chat log of C2 in Study 2 were similar to those in Study 1; that is, participants tended *not* to put additional effort into establishing common ground on the decision criteria. However, in C3, we saw evidence of participants working harder to establish common ground through chatting more, even though they were able to *see* the others' preferences-on-criteria. We assume this was because the perception of seeing *shared* candidates led members to feel more obligated to find consensus. Such a feeling of obligation might have led them to ask others to shift their preferences-on-criteria through chatting. The perceived group communication effectiveness in the survey shows that C2 was significantly higher than in C1.

Even though synchronized candidates in C3 did not result in the effects we expected, we found participants in Study 2 agreed that C3 was valuable. Some participants suggested ideas to avoid negative impact they felt in C3. For example, some suggested presenting a function that could remove identity information when necessary. Another idea was to give a group leeway to choose C2 or C3 depending on the stage of the decision-making process. For example, members could use C2 when they individually explore candidates then switch to C3 when a group has narrowed the potential candidates from which they will make their final decision.

Our initial inquiry started from whether externalized group awareness in C-DQ can compensate for possible ambiguity in textual communication and lead a small group to establish common ground with a reduced cost of integration. While conducting two studies, we witnessed participants' excitement over being able to make a group decision together in a superior way than their current practices would allow. We conducted a lab study to understand core effects of C-DQ. Even though we focused findings in a specific condition, we see there is potential that C-DQ can act as a generalizable UI solution in group information seeking and/or decision-making processes. More studies that cover different use contexts (e.g., professional usage, collaborative visual analytics), different device platforms (e.g., desktop), and a different scale of users (e.g., a bigger group or crowd) may open interesting future research opportunities.

LIMITATIONS AND FUTURE WORK

While we saw initial evidence that C-DQ has value in small group decision-making, we acknowledge limitations as follows. First, to remove confounding factors, we conducted studies with groups of friends. However, the process of group decision-making can deeply change depending on the nature of a group (e.g., a group with different ages, nationality, or cultural background, or a group type – e.g., friends, co-workers, or family). Second, we chose synchronous situations to conduct the lab studies and did not consider asynchronous situations. Third, we simulated dispersed situations in our study, but design considerations for face-to-face situations might differ. Fourth, we fixed the number of criteria to five to control the difficulty of a task between conditions, but the number of criteria can vary depending on the situation (e.g., considering more than ten criteria, or merely one), which could affect the effect of C-DQ. Fifth, while a lab study was appropriate for focused findings, we anticipate a deployment study would allow us to understand long-term impacts of C-DQ. Finally, we conducted the studies with only 9 groups of 36 participants. More participants may necessary for providing conclusive evidence of our findings.

CONCLUSION

We examined the role for C-DQ to function as a moderator in small group decision-making and found initial evidence that visually externalized group awareness can support a group in making an agreeable and satisfactory decision with reduced cost for communication. We also identified that the way in which the system handles each member's filter ranges may incur some different effects in different use context. We anticipate that our work sets up the possibility for a deeper understanding of different designs (e.g., group awareness visualization strategies that can consider better privacy, easier persuasion, or indicating different degree of importance each criterion) for C-DQ that may work in various situations (e.g., different use context, different platforms, different size of a group).

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