Trust and Consequences: A Visual Perspective

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Abstract. User interface (UI) composition and information presentation can impact human trust behavior. Trust is a complex concept studied by disciplines like psychology, sociology, economics, and computer science. Definitions of trust vary depending on the context, but are typically based on the core concept of "reliance on another person or entity". Trust is a critical concept since the presence or absence of the right level of trust can affect user behavior, and ultimately, the overall system performance. In this paper, we look across four studies to explore the relationship between UI elements and human trust behavior. Results indicate that UI composition and information presentation can impact human trust behavior. While further research is required to corroborate and generalize these results, we hope that this paper will provide a reference point for future studies by identifying UI elements that are likely to influence human trust.

Keywords: Trust, cooperation, user interface, visualization, design, typology, model.

1 Introduction

The user interface (UI) is a key component of any system that involves user interaction – including desktop and mobile applications, Web, social media tools, Virtual Reality interfaces, and robot control systems. The UI can be defined as the space where humans interact with other entities, such as machines. What is included in a UI (composition) and how it is displayed (information presentation) can impact performance, workload, situation awareness (SA), and usability. As a consequence, UI composition and information presentation may influence human perceptions and behavior, including trust. Trust is important in many contexts, including commercial transactions, military command and control, social media, and teleoperation. This paper reviews four studies that examine the relationship between UI components and trust – spanning different UI designs as well as different trust contexts.

First, we define trust and identify factors that affect trust. Next, we review the four studies individually, focusing on what each of the studies reveal about the relationship between UI design and trust. Finally, we integrate the results, discussing overall conclusions, open questions, and further avenues of investigation.

2 Background

Trust is a complex concept studied by diverse disciplines such as sociology [1], psychology [2], economics [3], and computer science [4]. While definitions of trust have varied across contexts, researchers attempting to reconcile these literatures have proposed a general definition of trust as "a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions and behaviors of another [5]." As trust dictates how people interact with others, including other people or machines, trust can drive user behaviors and, ultimately, overall system performance. Indeed, research has shown trust to be important in improving performance ([6], [1]), aligning motivations [7], improving cooperation [8], and improving knowledge transfer [9].

2.1 Types of Trust and Affecting Factors

McKnight and Chervany [10] identify three major components in their typology of trust. *Dispositional trust* represents personal traits that promote trusting behavior. *Institutional trust* represents expectations regarding the current situation. *Interpersonal trust* represents beliefs about the trustworthiness of others. Some researchers use the terms interpersonal and institutional trust to distinguish between trust in people and organizations. In this paper, institutional trust refers only to the situation.

This McKnight model is complemented by computer science research, which finds that experience can shape trust [11], as in Figure 1. Through repeated interactions, feedback changes a person's general willingness to trust (dispositional), understanding of the environment (institutional), and belief in the reputation of others (interpersonal). *Experience* is relevant in social media, where iterative effects of incoming information affect trust behavior of the user, such as the TasteWeights we will examine in this paper. In economic and psychology research, experience has been shown to directly affect dispositional and interpersonal trust [28].

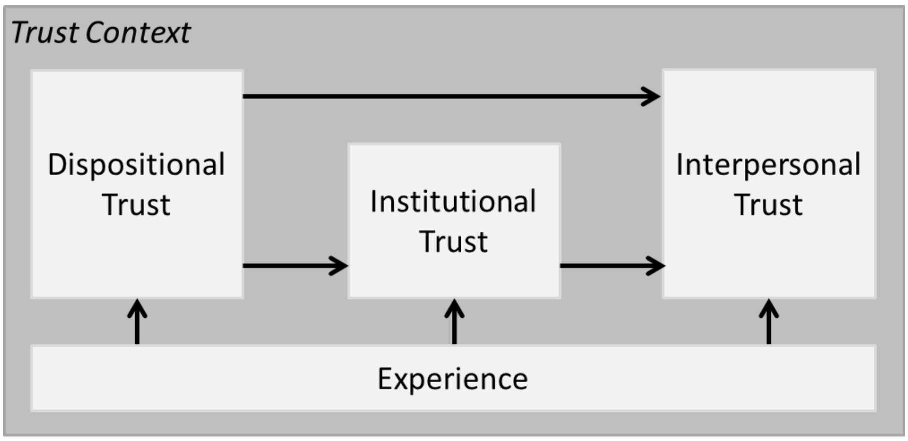

Fig. 1. This model, adapted from McKnight and Chervany [10], shows how experience affects dispositional, institutional, and interpersonal trust components.

Hancock et al. [12] proposed a similar model of trust, in the context of human-robot interactions. They identify three major categories: *human-related factors* (e.g., abilities and characteristics such as propensity to trust), *robot-related factors* (e.g., performance- and attribute-based), and *the environment* (e.g., task characteristics). Note that categories of human-related factors, robot-related factors, and the environment overlap significantly in their scope with dispositional, interpersonal, and institutional trust components of the McKnight model, respectively. Most of the robot-related factors (e.g., dependability, reliability, level of automation, and performance) are largely applicable to interactions with other systems or agents beyond human-robot interaction. Some of the key factors influencing trust in technology have been summarized as involving system reliability, validity, and understandability [13].

Understanding how the trust environment works (i.e., institutional trust or environment-related factors) can have an important effect on what trust-related behaviors are actually realized. Martin et al. [14] studied how different levels of information regarding the presence and performance of other "participants" influenced behavior in the repeated Prisoner's Dilemma – a game from economics in which both players are independently better off defecting, but are jointly better off cooperating. In this case, cooperation increased as participants better understood how their actions influenced the other's performance. Computational models that elaborated on the dynamics of the emergence of cooperation over time, suggest that the increased level of cooperation with more information is associated with an increased level of trust. Trust emerges as a gradual reduction of "surprising" actions occurring between the pairs with repeated interactions, where expected actions are increasingly in agreement with actual actions taken by an opponent over time.

The UI is positioned between users and a broader system that may include other human (or non-human) actors. As the UI can influence the user's understanding of the environment either directly (e.g., information-provision, transparency) as well as through reducing demands on human cognition (e.g., reducing operator workload), UIs are likely to have an important influence on trust-related behaviors.

3 UI and Trust

The relationship between UI and human trust behavior has been studied in e-commerce and Web page design. There are UI principles and guidelines for promoting trust in users (e.g. [15]), and empirical studies of aspects of UI design, showing that page layout, navigation, style, graphics, and content elements can have significant effects on the perceived trustworthiness of e-commerce sites [16]. A strong relationship between UI quality and user reported trust can be observed in Web retailer page designs [17]. In addition, the user's trust increases with perceived system usability [18].

Still, empirical studies on the impact of specific aspects of UI on trust are limited. In this paper, we explore the relationship between UI elements and human trust behavior by looking at commonalities and patterns across four past studies we conducted in this domain. The types of trust studied include *interpersonal trust* (e.g., trusting a team member to convey accurate information, trust in information sources, and trusting an agent to behave in a certain way) and *institutional trust* (e.g., aspects of UI and source reliability). Two of these studies are in the context of an abstract game, the iterated Diner's Dilemma (DD) ([22], [24]). The High Value Target (HVT) study explores trust within the context of a command and control (C2) scenario. The last study, TasteWeights (TW), is on user behavior when using a recommender system, focusing on "inspectability" and "control" aspects [19]–[21].

3.1 First Diner's Dilemma Study (DD1)

The goal of this experiment was to study how UI and the behavior of others influenced situation awareness, cooperation, and self-reported trust in the Diner's Dilemma (DD) [22]. The scenario involves three individuals who agree to split the bill evenly before going out to dinner. At dinner, each individual chooses to order either the expensive, higher-quality dish (lobster), or the inexpensive lower-quality dish (hot dog). Each diner's goal was to maximize his or her 'Dining Points.' Dining Points were calculated based on the quality of the diner's own meal divided by the diner's share of the bill.

The experiment involved one human participant playing repeatedly against the same two computer-based co-diners for 50 rounds. There were six co-diner strategies divided into "cooperation encouraging" and "cooperation discouraging" categories based on how the computer-based opponents played. Twenty-four undergraduates at the University of California volunteered for the study. Participant ages ranged from 18 to 25, and 63% were female.

UI Elements. Three different UIs were used in this study, identified as UI Levels 1 through 3 (). Each UI level added new UI elements.

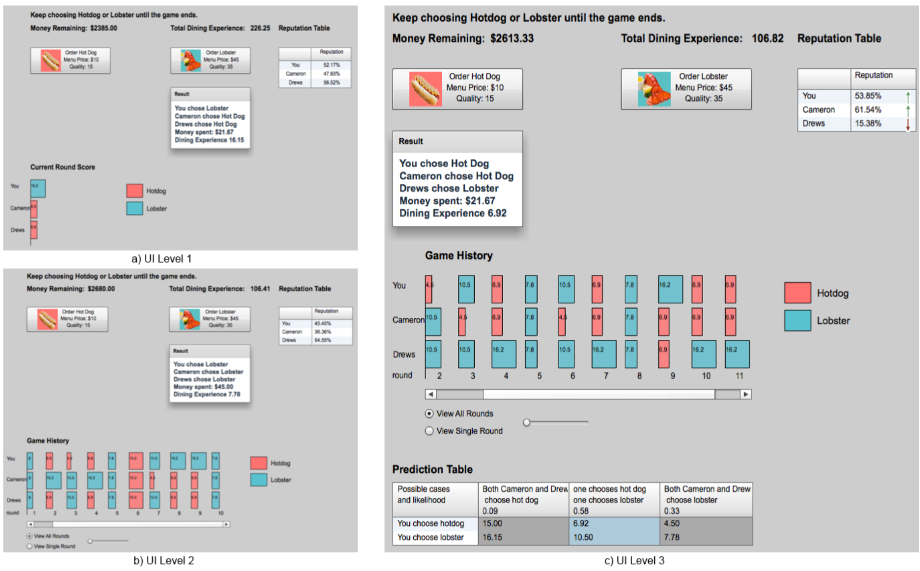

Fig. 2. The first Diner's Dilemma study with three UI levels.

UI Level 1. This UI included a display to indicate the user's remaining money and total dining experience points gained, which was updated after each decision. Additionally, a panel labeled "Current Round Score" presented the user's and co-diners' decisions and scores from the previous round, presented as a bar that was color-coded to distinguish between menu items. Additionally, a panel labeled "Reputation Table" displayed the percentages of times the participant and co-diners decided to cooperate (i.e., chose hot dog).

UI Level 2. For this visualization, the "Current Round Score" was augmented with "Game History" that provided a segmented bar display that illustrated all past decisions of each player and the scores of those decisions. Information on past rounds were intended to help the user understand the impact of their decisions and to investigate trends in their co-diners' decisions.

UI Level 3. Here, a "Prediction Table" presented the expected probability of one, both, or neither of the co-diners to cooperate, assuming that their decisions to cooperate were independent. The table also includes the possible scores the participant would receive if they chose to cooperate or not, given each of those scenarios.

Results. An analysis of variance (ANOVA) revealed a significant effect of UI Level on cooperation, $F(2,105) = 5.45$, $p = 0.012$. A post-hoc Tukey-Kramer test found higher cooperation in UI Level 1 compared to UI Level 2, $p = 0.025$, and to UI Level 3, $p = 0.042$; but no significant differences between UI Levels 2 and 3. Overall, the simpler UI appeared to improve cooperation, and by implication, trust.

3.2 **Second Diner's Dilemma Study (DD2)**

The second study was designed as a follow up to the previous Diner's Dilemma study (DD1) [22]. Similar to DD1, the goal was to study how UI and the behavior of others affected SA, trust, and performance; however, the UI elements were updated as described below. In addition, objective SA was measured using the Situation Awareness Global Assessment Technique. Participants were matched with simulated co-diners, as before, which played one of five strategies. Ninety-five participants were recruited from Amazon Mechanical Turk. Participant ages ranged from 19 to 60, and 39% were female.

UI Elements. Three different UIs were used in this study, identified as UI Levels 1 through 3. Similar to the previous study, each UI level built on the previous level by adding new UI elements (
Fig. **3**).

UI Level 1. This UI level shows the user their current dining points, the food quality and cost of each menu item, the current round, and the results from the previous round in terms of dining points. Only the most current and recent game states are presented. The difference between DD1 [22] and this study is that this omits the reputation display along with general graphical and visual changes.

UI Level 2. This UI level includes all UI features from Level 1 UI, and adds a 'History' panel to provide historical game information to the participant. The difference between DD1 [22] and this study is that this omits the score display feature.

UI Level 3. This UI level adds a "Long Term" panel to help estimate the user's longer-term dining score under cooperation or defection scenarios. This is an interactive panel where the participant can enter his or her assumptions about opponent behavior and calculate the expected dining points. Compared to the previous study, this panel is interactive and emphasizes long-term outcomes.

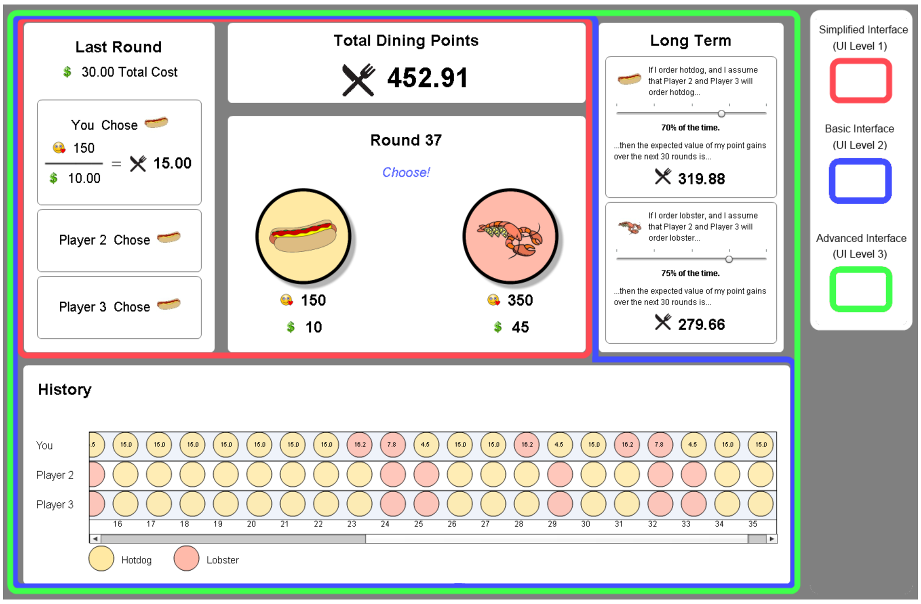

Fig. 3. The second Diner's Dilemma study with three UI levels.

Results. A two-factor ANOVA on cooperation showed a significant main effect for the co-diner strategy, $F(4,80) = 4.87$, $p = 0.001$, a marginal effect of UI Level, $F(2, 80) = 2.56$, $p = 0.084$, and no interaction. Post-hoc Tukey HSD tests indicated significantly higher cooperation for UI Level 2 compared to UI Level 3. Overall, UI Levels 1 and 2 appeared to improve cooperation, and by implication, trust.

3.3 High-value Target Study (HVT)

This study was designed to explore issues of trust in a human partner as well as trust in information sources in a simulated command and control (C2) task. Participants completed the task in pairs, and their goal was to find and capture a series of high value targets (HVTs) on a grid-based map as quickly as possible. Within each pair, one participant was assigned the role of the Intelligence (Intel) Officer, and the other was assigned the role of the Operations (OPS) Officer. The Intel player's responsibility was to process incoming messages that provided information about the possible location of HVTs. These messages came from two different sources, Source A and Source B. In each round of game play, one of these sources was randomly assigned to be 90% accurate, while the other was 10% accurate. The OPS player's responsibility was to assign 4 platoons under his/her command to various locations on the grid map in order to capture HVTs.

UI Elements. There were two manipulations in this study. The first was whether the information available to each player was shared or limited. In the Limited condition, players only had access to the information pertinent to their own role (e.g. only the Intel player could see the incoming messages from Source A and Source B). In the Shared condition, players were able to view the same information. Our interest was in determining if having access to all information, including the information the other player was using, was helpful or detrimental to performance, trust, and SA.

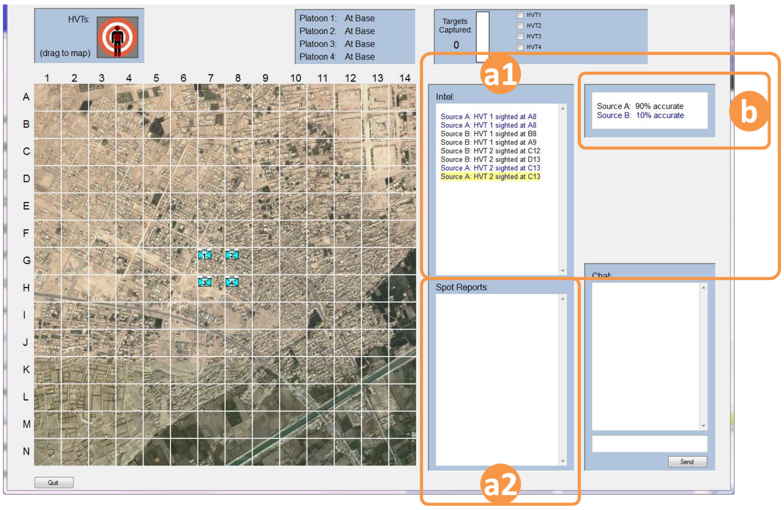

Fig. 4. The HVT study with varying UIs. The first manipulation is whether (1) a1 and a2 are shown to both players, or (2) a1 is shown to Intel and a2 is shown to OPS only. The second manipulation is whether (1) b is hidden, (2) b is visible presenting congruent information, or (3) b is visible presenting incongruent information.

The second manipulation was what information was provided on each round to the participants about the reliability of each of the two sources. There were three conditions: None, Congruent, and Incongruent. In the None condition, no information was provided. In the other two conditions, an additional UI element was visible that displayed information about the accuracy of each source. In the Congruent condition, the information displayed matched the actual accuracies of the two sources. In the Incongruent condition, the opposite information was displayed (**Error! Reference source not found.**; so, for example, if Source B was assigned to be the 90% accurate Source in a given round, the displayed information would label Source A as 90% accurate and Source B as 10% accurate in the Incongruent condition).

Results. Results indicated that self-reported trust in one's partner was lower in the Shared condition than in the Limited condition ($F(1,54) = 6.40$, $p = 0.014$). There was a marginal effect upon self-reported trust in one's partner, with lower levels of trust in the Incongruent condition (F(2,108) = 2.49, p = 0.088). Supporting this finding, target capture times were slower in the Incongruent condition than in either the None or the Congruent conditions (F(2,52) = 7.96, p = 0.001). Participants only rated the two sources as much more similar in their reliability in the None condition than in the Congruent and Incongruent conditions (F(2,78) = 20.50, p<0.0001).

3.4 TasteWeights Study (TW)

It is important to consider how the UI impacts trust at the system [25] or institutional [10] levels. To exemplify this, we now describe the TasteWeights visual recommender system [20] and an associated user study [19] that was designed to explore the roles played by interface on the development of trust and general acceptance of the system's recommendations. In particular, the study focused on the UI properties of "inspectability" and "control".

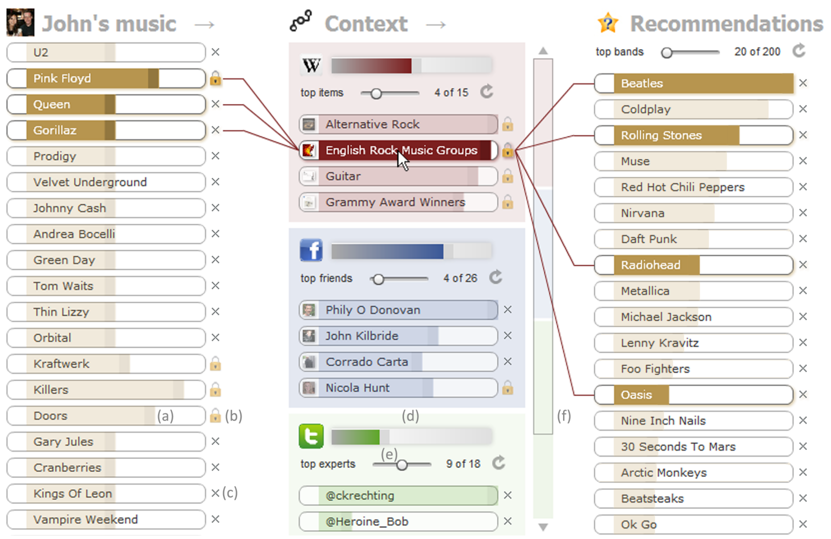

Fig. 5. The TasteWeights visual recommender system showing musical artist recommendations for one user based on a preference profile. Profile items are shown on the left column and recommendations are shown on the right, generated by recommendation sources in the center.

TasteWeights is a visual representation of a collaborative filtering recommendation algorithm [26] that leverages multiple sources to generate recommendations for one target user. The system builds on previous research on interactive UIs for recommender systems [27][21]. Fig. 5 shows the three-column interface with the user profile on the leftmost column, recommendation sources in the center and a list of recommendations (output) on the right. Bostandjiev et al. [20] explain how the ranked lists of social, semantic and expert nodes in the center column and ranked, filtered and combined to produce the personalized recommendation list on the right. The column views and associated interactions support both inspection (leading to explanation), and control of the algorithm. A study n = 297 was performed to evaluate the effect of inspection and control on the overall user trust in the system's recommendations, as determined by various satisfaction and perception metrics. Details of the study are reported by Knijnenburg et al. in [19].

UI Elements. Participants were assigned one of two inspection conditions: right column only (the typical "list view" as a benchmark), or the full provenance graph shown above. Participants were allowed to manipulate weights on nodes through the horizontal sliders (Fig. 5). Three control conditions were tested: item-level, neighbor-level, and full control. Subjective experiences were assessed through pre and post questionnaires. Recommendation accuracy was evaluated by gathering post-hoc item ratings from participants.

Results. Knijnenburg et al. [19] discusses structural equation model of the key results from this study. To summarize with respect to UI influence on system level trust: the UI provides an explanation of what the algorithm is doing to produce recommendations. The authors call this feature "inspectability". In turn, the explanation generates a level of understanding that enables an end user to control the system via interactions with the UI. In particular, manipulations on profile items or connected neighbor weightings vs. the benchmark no-control condition impacted understanding of the system and algorithm, which in turn increased perceived satisfaction with and control over the output. This had a strong positive effect on perceived quality of the system's recommendations and overall satisfaction (seen as a proxy for trust) in the system. This relation was impacted by domain expertise and trust propensity.

4 Conclusion

In this section we investigate how the four studies fit into a trust classification and where there may be gaps that future studies can fill. We also look at summary results across these studies for commonalities and differences.

These four studies focus on different aspects of the model in Fig. 1. Table 1 organizes these studies by types of trust investigated. In this paper, *institutional trust* refers to the user's expectations regarding the situation, encompassing the UI that mediates trust formation by affecting the user's interaction with the situation. *Dispositional trust* is expected to have an effect on all types of trust, as shown in Fig. 1. In future efforts, analyzing dispositional trust as a covariant might allow us to observe stronger effects in studies like DD1, DD2, and HVT. Table 2 summarizes UI elements presented across these studies and their effect on the user from a trust perspective. The generalizability of the results presented in this table is limited for multiple reasons. First, the four studies are not directly comparable, since their context and experimental setups are different. While DD1 and DD2 are very similar studies, HVT and TW are very different. Second, it is difficult to isolate the effect of a UI element without the context that surrounds it. Third, there may be unidentified factors that cause the observed behavior other than the UI. Nevertheless, we hope this table will provide a starting point for researchers who study the relationship between UI and trust, and help focus efforts on UI elements that might impact human trust behavior.

Table 1. Trust components explored through experimental design.

Study		Interpersonal	Institutional Trust
Diner's Dilemma	DD1	Co-diners (computer strategies)	- Current and previous scores - Score histories with opponent score - Prediction panel (short-term focus)
	DD2	Co-diners (computer strategies)	- Current and previous scores - Score histories without opponent score - Long-term panel (long-term focus)
High-value Targets	HVT	Human operator (partner)	- Shared/limited information
		Information sources	- Reliability of sources
TasteWeights	TW	Recommendation system	- Provenance graph - Control over UI (weights)

Table 2. This table summarizes the observed effect of UI elements from a trust perspective. Legend: "⇧"=increase; "⇩"=decrease; "--" no change in trust.

Study	UI Element	Impact on Trust	Trust Measurement
DD1	#1. Score histories with opponent score	⇩ (co-diners)	*User's cooperation proportion / rate was used as a proxy to trust*
DD1	#2. Prediction panel (short-term)	-- (co-diners)	
DD2	#3. Score histories without opponent score	⇧ (co-diners)	
DD2	#4. Long Term panel (interactive & long-term focused)	⇩ (co-diners)	
HVT	#5. All information presented to all users (Shared)	⇩ (partner)	*Self-reported trust in one's partner and subjective ratings of information source reliability (used as a proxy to trusting sources)*
HVT	#6. Only user-pertinent information presented (Limited)	⇧ (partner)	
HVT	#7. Incongruent information	⇩ (partner) ⇩ or ⇧ (info sources)	
HVT	#8. Congruent information	⇩ or ⇧ (info sources)	
TW	#10. Increased control over UI (item/neighbor vs. no control over weights)	⇧ (system)	*Overall satisfaction and perceived recommendation quality as a proxy to trust*

An interesting finding is the effect of presenting historical transaction information (i.e., game history in the context of DD1&2) to the user (#1 and #3 in Table 2). In DD1, interpersonal trust decreased with the inclusion of this visualization, whereas in DD2 trust actually increased. The two visualizations were not identical and DD1 included co-diner scores while DD2 did not. Taken at face value, these results suggest that at least under certain scenarios seeing the opponent's historical scores may reduce cooperation, hence trust in one's opponent. A follow-up study with a larger sample size is necessary to verify these results. This has implications for systems where both collaborative and competitive behaviors are possible.

Another interesting finding is the effect of the projection panel (#2 and #4 in Table 2) added to help support higher levels of user SA. The two versions of this panel used in DD1 and DD2 did not provide the intended effect. Instead, it either had no effect or reduced trust. These results highlight the challenges involved in providing higher levels of SA support. For example, #2 was intended to be a prediction panel to provide projection SA support, but it focused on one (the next) round only, without factoring in long-term consequences of not cooperating. On the other hand, while #4 attempted to emphasize long-term consequences of user's actions, the added UI complexity or information might have made it hard to learn and use. This is consistent with #5 that sometimes more information can have a detrimental effect.

In the HVT study, presentation of incongruent information (#7; mismatch between the actual and advertised quality of information streaming from sources) has the expected effect of affecting trust in information sources. However, this has a spillover effect of reducing trust in partner, even though ideally one would expect participants to make accurate trust attributions. This has implications for UI tool and visualization design to help users develop better trust attributions. For #7 and #8, the direction of change in trust was not recorded, though one might suspect trust in information sources was reduced in #7 and increased in #8 given the nature of the UI change.

5 Discussion and Future Work

This paper reviews four studies and organizes their results in a trust framework. There are many challenges associated with running studies that explore trust. Differentiating between different types of trust can be difficult because of overlap in definitions.

Future studies should make an attempt to isolate and analyze the effects of individual UI elements on trust. This will help design and build UIs that produce the right level of trust. Also, there are many aspects of trust. A systematic approach to methodically study all aspects of trust will help paint a more complete picture of our understanding of human trust behavior.

Some of these goals may be as elusive as trust itself. There are many definitions and classifications of trust. Different domains look at it from different perspectives. Still, there are commonalities. Regardless of the domain, we hope that this paper will guide future research in terms of where to focus efforts and what UI elements may result in trust behavior changes.

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