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A study of dynamic information display and decision-making in abstract trust games

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ABSTRACT

User interfaces that display dynamic information have the ability to influence decision makers in networked settings where many individuals collaborate. To understand how varying levels of information support affects behavior (cooperation vs. defection) in a social dilemma, a user interface (UI) was developed and an online experiment (N=901) was conducted based on the iterated Diner's Dilemma, a version of the n-player Prisoner's Dilemma.

There were 3 main findings: (1) as more UI support was given, participants became more likely to retaliate against defection than they were to initiate defection; (2) participant situation awareness (SA) increased as more UI support was given but decreased in the presence of forgiving co-actors; and (3) the need for UI support to make good decisions was diminished as co-actors became more likely to exploit. These results can inform the design of information support tools for collaborative settings.

1. Introduction

Today, many decisions are made online through user interfaces (UI) with multiple collaborators and complex information systems. In such settings, mutual cooperation is important for effective and efficient completion of work and analyses, however, self-interested actions frequently threaten to undermine cooperation (Robbins, 1995). When users make decisions through a UI, unique challenges and opportunities arise for the designers of those interfaces. For instance, showing the right information at the right time to a decision maker may improve the quality of decision making, but hiding information from a self-interested actor at a critical moment may improve cooperation, thus benefiting the group as a whole.

As the number of individual actors in collaborative settings increases, decision makers are more likely to become susceptible to information overload as they try to keep track of all relevant information. For instance, technology has complicated human organization (Edmunds and Morris, 2000), especially in business settings where flat hierarchies are becoming more common (Meyer, 1998). In such settings, the benefits of promising features to clients or independently committing to deadlines will accrue to the individual, but the cost of the work will be spread among teams. Social resentment may accrue towards individuals that take advantage of their teams repeatedly, which might negatively impact the performance of the organization. An individual might want to know about all of the impacts of their decisions but as organization size increases, the impacts become more complex. This organizational problem has many parallels in academic research settings where benefits primarily accrue to the first author, classroom settings where multiple students must contribute to a class project, or military settings where some individuals take on more risks than others. Past research (Gonzalez et al., 2015; Onal et al., 2014b; Teng et al., 2013) has indicated that exposing the right information to these decision makers can increase cooperation and overall outcomes. Still, characteristics such as altruism, trust propensity, and aggressiveness of the involved individuals can vary between situations, which could affect how information systems alter human decisions.

In this work, we use the Diner's Dilemma – a multiplayer generalization of the two player Iterated Prisoner's Dilemma (IPD) (Andreoni and Miller, 1993; Gneezy et al., 2004; Kreps et al., 1982; Liberman et al., 2004) – to study how human cooperative behavior is impacted not only

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by varying levels of information support, but also by the altruism and selfishness of co-actors. Past studies have often used economic game theory to study social dilemmas such as the one outlined above; moreover, the Diner's Dilemma shares the most similarities to the organizational problems being studied. Here, we will use term "diner" when referring to an individual decision maker and "co-diner" when referring to this player's co-actors. In the Diner's Dilemma, several diners eat out at a restaurant over an unspecified number of days with the agreement to split the bill equally each time. Each diner has the choice to order the inexpensive dish (cooperation) or the expensive dish (defection). Diners receive a better dining experience (here, quantified as *dining points*) when everyone chooses the inexpensive dish compared to when everyone chooses the expensive dish. The quality-cost ratio of the two items available in a valid Diner's Dilemma game must meet a few conditions. First, if the player were dining alone, ordering hotdog should maximize dining points. Second, players must earn more points when they are the sole defector than when all players cooperate. Finally, the player should earn more points when the player and the two co-diners all defect than when the player is the only one to cooperate. This "game payoff matrix" means that in one round of the game, individual diners are better off choosing the expensive dish regardless of what the others choose to do. However, over repeated rounds, a diner's choice can affect the trust of other co-diners and cooperation may (or may not) develop, which affects long term prosperity of the group.

This work studies the simplest version of the Diner's Dilemma – the three player's Diner's Dilemma – to study the relative magnitude of coactor behavior and UI design on a decision-maker. While the two-player IPD was also considered for study, its simplicity does not commensurately require the use of a UI, due to the player needing to keep track of only a single co-diner.

Two initial studies were conducted by the authors, study 1 (Teng et al., 2013) and study 2 (Onal et al., 2014b), which are described here. Both studies indicated that the amount of information available to an agent has an effect on their decision or next course of action by affecting trust and cooperation. Study 1 showed a positive correlation between trust and situation awareness, suggesting that UIs might be an effective way to encourage trust in social settings. Study 2 indicated that showing increased amounts of information through a UI about past, present, and future decisions made by co-diners in social settings tends to increase cooperation, which indicates increased trust (see Cox, 2004). These previous two studies are unable to answer questions about the relationship between the UI, the propensity of co-diners to exploit, individual user cooperation, situation awareness (SA), and the resulting performance of the individual user. This work seeks to shed light on those relationships through an increased variation of simulated co-diners. Here, we hypothesize that the UI may have a different effect on cooperation under certain co-diner exploitation rates. This leads to the following research questions:

1. To what extent can a UI improve SA? How are SA and cooperation related?
2. Can a UI be used to encourage or discourage human cooperative behavior?
3. Does the effect of a UI on human cooperative behavior change with the propensity of co-actors to exploit?
4. To what extent do co-actor behavior and UI support affect performance of the individual decision maker?

2. Background and related work

This section first presents a survey of work in user interfaces and cognitive psychology. Next, relevant work in trust games research is surveyed. Finally, two previous research studies conducted by the authors are presented in detail.

2.1. Human decision making, user interfaces, and situation awareness

UIs that assist in decision making are being used ubiquitously: assisting road navigation, recommending movies and music (Resnick and Varian, 1997), assisting in military operations (Chen and Barnes, 2012; Greenemeier, 2010), and as an aid in determining the geometric boundaries of biological structures that have been imaged (Wu et al., 1995). Decision support systems have been a topic of research for quite some time (Shortliffe et al., 1975). In decision making situations, human behavior is affected by what information is available. Dynamic information displays can assist humans by managing complexity and providing the right information at the right time (Horvitz and Barry, 1995). Unfortunately, there are finite limits on the human ability to incorporate large amounts of information (Fougnie and Marois, 2006), which means that any complex algorithm that filters down all available information must make a hard choice about which information to summarize and how. For instance, in networked business organizations, UIs might provide information to leaders about team morale, which can inform them about when teams can be pushed further in terms of productivity. Designing for effective delivery of personnel information to managers becomes a more challenging UI problem as the number of personnel grows.

It is possible that much of the information that is shown on a user's display (or console) is not internalized and not incorporated into the user's decision-making process. Therefore, an effective UI for information delivery must be one that produces a high level of situation awareness (SA) in the user. This means the UI must summarize the current state of the decision maker's environment and its history such that the operator is able to project into the future. SA is defined as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995). The three states of SA are detailed as follows:

- Level 1 SA (Perception) is simple awareness of multiple situation elements (objects, events, people, systems, environmental factors) and their present states (locations, conditions, modes, actions),
- Level 2 SA (Comprehension) is achieved by integrating Level 1 SA elements through time to understand their past states and how this will impact goals and objectives, and
- Level 3 SA (Projection) is achieved through integrating Levels 1 and 2 SA information and extrapolating this information to project future actions and states of the elements in the environment

Research from other domains (Ardichvili et al., 2003; Chen et al., 2014; Gevins et al., 1997) supports the idea that SA is a useful tool to model human decision-making in complex, dynamic environments. When designed properly, UIs have the potential to positively impact a user's SA (Endsley, 2016), which is one of the necessary requirements for good decision making. Thus we hypothesized that UI's potential to increase performance would be mediated by situation awareness, that is, a user performs better when SA is higher and UIs contribute to increased SA by providing the necessary information.

One of the ways that effective UI design boosts SA is by overcoming limitations in a user's attention and working memory (Endsley, 2003). Direct attention is not only required for perception and processing of cues but also for the later stages of decision making. People typically employ a process of rapid information sampling from several cues, following a pattern dictated by their long term memory which concerns the relative priorities of information, and is proportional to the frequency at which information changes. Since the supply of attention is limited, more attention to some elements may increase the SA on those elements, but may decrease SA on other elements when attention limits are reached.

The ability of a UI to improve SA is also limited by a user's ability to comprehend and rely on elements of information in the interface. Comprehension can be improved through static explanation (training) and dynamic explanation. Dynamic explanations are added to systems primarily to increase transparency of computational processes at the time of use, which has been shown to improve trust in systems and reduce user error (Knijnenburg et al., 2012). A goal of explanation features is to improve SA of system operations (Chen et al., 2014), which would allow a user to make better judgments about when to rely on UI information.

Gonzalez et al. (2015) and Martin et al. (2011) conducted experiments that demonstrate how information displays can affect decision-making in the IPD. A key finding of these works was that an increase in information in the user-interface led to an increase in cooperation behavior, joint-performance, and satisfaction. Pairs of participants in the experiment were given different levels of interdependence information (whether and how each participant's decision affected the other) across four different levels of information exposure. The increase in cooperation seen in these experiments might be explained by a participant's feeling of obligation to reciprocate when historical data was laid out before them via the UI, however, the study by Martin et al. (2011) suggests that individual characteristics strongly influence how participant's react to increased information. Unfortunately, these two works do not report on answers to questions about how the UI might affect SA under different levels of co-actor selfishness, which is the goal of this research.

2.2. Trust and the cooperation problem

In certain situations, cooperation can lead to better outcomes than when people act selfishly and independently (Weber and Murnighan, 2008). In economics, the Prisoner's Dilemma is an abstract game used to study cooperation. In the Prisoner's Dilemma, two players decide to take an action (cooperate or defect) without communication beforehand, where defection leads to a higher outcome for an individual regardless of the other players actions, but with mutual cooperation leading to a higher outcome than mutual defection. Multiplayer, iterated forms of this game (Diner's Dilemma or the Public Goods Game) are useful for studying dynamically changing situations, such as military arms races. The proportion of mutual cooperation in an iterated game of Prisoner's Dilemma can be considered a measure of trust between the two participants, as choosing to cooperate makes an individual vulnerable to the worst possible outcome.

The notion of trust has diverse meanings across a number of fields such as sociology, psychology, economics, and computer science (Onal et al., 2014a). Here, we take a general definition of trust to be a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions and behaviors of another (Rousseau et al., 1998). Trust dictates how people interact with each other, their tools, and their environment; thus "trustability" impacts the effectiveness of interactive interfaces. In this experiment, participants in the Diner's Dilemma game develop a trust-based relationship with the simulated co-diners and the information display that was provided. Moreover, the UI is positioned as a mediator of interpersonal trust by exposing and cataloging the actions of each individual in real-time, which has been shown to increase cooperation and interdependence. In the Diner's Dilemma, trust (or potentially, mistrust) develops as the co-diners develop the knowledge to predict each other's actions over time, which affects their future behavior.

Psychological motives to cooperate in the Prisoner's Dilemma can be complex. Early empirical evidence suggests that human behavior was not dictated only by selfish considerations but also by other regarding preferences (see for example, Dawes and Thaler, 1988; Rapoport and Chammah, 1965). Research models suggest a direct benefit from the well-being of others (often described as altruism, for example, Dawes, 1980), a preference for equality in outcomes (Fehr and Schmidt, 1999), and a preference for kind behaviors that allow the other player access to better outcomes (Rabin, 1993). In addition to the reputation benefits of cooperating in an iterated Prisoner's Dilemma, these models help to promote cooperation in the face of more selfish motives. The latter two preferences for equity and kindness also allow for mutual defection and call for it when/if the other players defect. If we translate these theories to our current design, all models call for cooperation with a baseline Tit-for-Tat (TFT) strategy, and there are at least two potential arguments for defection in TFT strategies with random defection. Moreover, evidence suggests that people are willing to pay a cost to retaliate to defection (Fehr and Gächter, 2002).

In spite of the findings of pro-social preferences, selfish motives continue to be observed in these experimental designs, though more weakly than would be predicted by traditional economic rationality. These motives do not seem to be inherent individual differences but could potentially be acquired. Findings indicate that those exposed to a traditional economic education are generally less inclined to cooperate in a public goods game than others (Frank et al., 1993). People will also often engage in selfish motives when they can get away with it. In experiments with the dictator game (Dana et al., 2006), people were willing to accept a smaller payout that could not be shared than to take a larger payout which could have been shared, i.e., people are willing to pay to be (secretly) selfish. As random forgiveness increases in the TFT strategies in our design, the consequences of being selfish are reduced.

In social dilemmas, participants are not always aware about how their actions influence other people and vice versa. This can quickly create a situation where less-than-optimal results are achieved for all participants, as higher levels of information about the game and the strategies taken by other players have been shown to greatly improve the outcome for all (Rapoport and Chammah, 1965). More recently, a study by Weber and Murnighan (2008) has shown that consistent contributors, actors that consistently contribute to the public good regardless of the actions that their co-actors take, can have a significant positive impact on the behavior of the group as a whole. Consistent contributors occurred naturally in four previously-collected datasets, and were shown to improve overall cooperation. These results suggest that awareness of interdependence encourages pro-social behavior and trust in these interactions.

In this work, we examine the boundaries where pro-social behavior breaks down and also the impact of consistent contributors with a varying level of UI support. Specifically, we want to understand if players, who might otherwise behave altruistically, would fail to cooperate if the information support available to them indicated it was not in their best interest. Conversely, we are also interested in understanding if aggressive or selfish players can be teased into cooperation when a UI indicates the benefits.

2.3. Previous studies

Two studies were previously conducted on the Diner's Dilemma by the authors to answer several basic questions relating to trust, situation awareness, and the UI.

Study 1: The first study we conducted (Teng et al., 2013) was, to our knowledge, the first work that examined the relationship between situation awareness and UIs for any version of the IPD. This work focused on the relationship between cooperative behavior and situation awareness in Diner's Dilemma, wherein a human played repeated rounds of the game with two computer co-diners. Based on SA theory and design principles, the authors developed three different UIs that were expected to represent the information needed to support a specific SA Level. Several Trust-related metrics were also assessed, including percentage of cooperation over time and subjective level of self-reported trust toward the co-diners. They found that participants in the most simple UI treatment cooperated more frequently when simulated co-diners encouraged cooperation, but participant defection increased when the UI displayed more information. It was also concluded that cooperation level is a good indicator of the trust that participants place in their co-diners.

Study 2: Study 2 (Onal et al., 2014b) honed in questions related to the effects of UI components on awareness and decision-making behavior. Study 2 built on study 1 by expanding the sample size, varying the co-diner strategies, and revamping all UI levels to induce the desired SA and using a Situation-Awareness Global Assessment Test (SAGAT) style

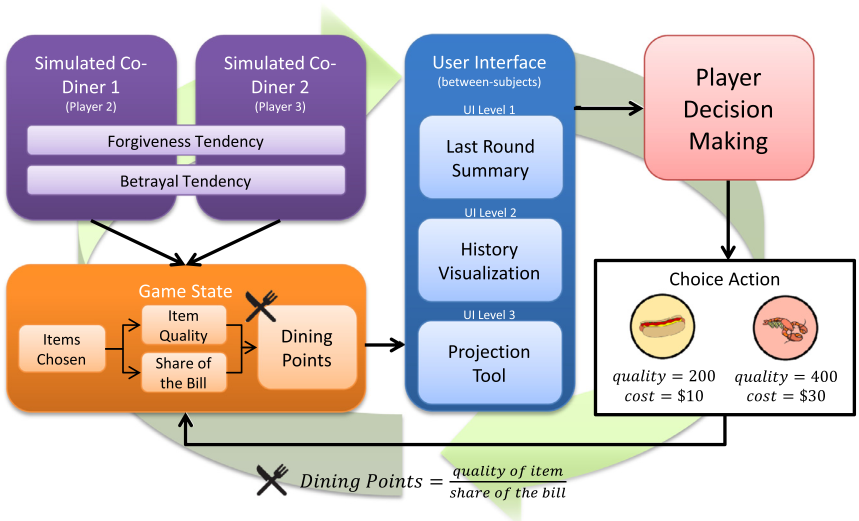

Fig. 1. Overview of the Diner's Dilemma game and experiment. Player participants interacted with a UI (Fig. 3) to play the Diner's Dilemma game. One of three different UIs and one of eleven different co-diner strategies were chosen randomly for each participant. Forgiveness and betrayal refer to the degree to which the co-diners would forgive defection and punish cooperation, respectively. Players tried to maximize their Dining Points, which are determined each round by the quality of the item selected divided by the player's share of the bill. The "History Panel" which showed a summary of past rounds or the "Projection Panel" were available depending on the treatment assigned.

questionnaire to assess participant understanding of the game and the interface. An online study of 95 users was conducted using Amazon's Mechanical Turk (AMT). Participants played repeated trials of the DD game, and answered evaluative questionnaires at multiple stages in the game. The experiment highlighted two key results: First, there is a strong correlation between SA and performance in the game, and second, UI composition and information presentation have an impact on human trust and cooperation behavior.

In summary, the Studies 1 and 2 found that UI increased performance, cooperation, and that situation awareness and dining points were highly correlated. Despite these findings, there were some limitations in the work. For example, the range of co-diner strategies were limited, the third UI level did not achieve the desired SA effect when compared with the second UI level, and the sample size was limited to fewer than 100 participants. The work presented here was designed in part to address these limitations.

3. Methodology

The goal of this experiment was to understand cooperative behavior under a variety of different information support and co-diner behavior conditions. This section discusses the detail of the experiment methodology.

3.1. Overview

In this experiment, participants interacted with a web-based implementation of the Diner's Dilemma game and were recruited online through AMT. An overview of the game flow is shown in Fig. 1. During the game, the user's goal was to maximize his or her "dining points," defined as the ratio of the food quality of the chosen meal divided by the diner's share of the bill. In each round, the participant must weigh the pros and cons of selecting either hotdog or lobster by assessing the cost/value trade-offs involved, the co-diner behavior, and the long-term gain of a chosen strategy. A complete list of game terms can be found at the bottom of Table 2.

The payoff matrix in Table 1 was used in the game and creates a valid dilemma for the player. The exact values (hotdog \$10 w/200 quality, lobster \$30 w/400 quality) were refined based on a pilot study, which examined how well the participants understood the mechanics of the game. Participants in the pilot reported that they were able to quickly divide these numbers in their head to see the trade-offs.

Table 1
Dining points gained based on the actions of co-diners. The cost of a hotdog is \$10 with a quality of 200, and the cost of a lobster is \$30 with a quality of 400. Dining points are calculated as quality divided by share of the bill.

Dining points gained for round outcomes.			
	Both cooperate	One cooperates	Neither cooperates
Player chooses hotdog	20.00	12.00	8.57
Player chooses lobster	24.00	17.14	13.33

The simulated co-diners played variants of Tit-for-Tat (TFT), a simple but effective strategy in which the co-diner makes the same choice that the participant did on the previous round. Co-diner strategies varied from pure TFT along two parameters: forgiveness and betrayal. The higher the forgiveness parameter, the more likely the simulated co-diner would respond to a lobster order with a hotdog order in the next round. The higher the betrayal parameter, the more likely the co-diner would respond to a hotdog order with a lobster order in the next round. Forgiveness was intended to simulate the potential altruistic nature of an individual and betrayal was intended to simulate selfishness or aggressiveness. To make the game more understandable for the human participant and to simplify result analysis, simulated co-diners reacted only to the human decision and not to each other.

The flow of the experiment, as the participant experienced it, is shown in Fig. 2. A pre-study and post-study collected demographic metrics, while two freeze pop-ups tested participant knowledge at unexpected times during the game. When beginning the game, participants completed a pre-study questionnaire that collected some basic demographic information and were required to answer three screening questions to test their attention. They were then directed to an interactive training session that explained the game rules in detail. Specifically, participants were trained in the use of each information element of the UI separately before the game was played (SA of UI components was measured at training time an reinforced). This was done to maximize the elimination of effects that are related to misunderstanding of the UI components. In this work, we also avoid "recommending" any choice for the participants by maximizing the transparency of the provided information. After the training, if the participants were ready to continue,

Table 2
Terms used in the study, including independent and dependent variables.

Term name	Type	Description
UI level	Independent var.	1, 2, or 3 selected randomly when the participant started the study. The Level 1 UI only provides the central panel and the 'Last Round' panel, Level 2 provides the Level 1 components plus the "History panel", and the Level 3 UI contains the Level 2 components plus the "Estimate my Score" panel. See Fig. 3 for a visual of each component.
Simulated co-diner strategy	Independent var.	A variant of Tit-for-Tat, with one noise parameter for the co-diner's reaction when the player cooperates, and one noise parameter for the reaction when the player defects.
Cooperation	Dependent var.	Proportion of rounds that participant chose Hotdog.
Performance	Dependent var.	To measure performance, closeness to optimal strategy was used, which is the difference between observed cooperation percentage and optimal cooperation percentage (dependent on simulated co-diner strategies).
SA	Dependent var.	Situation awareness: performance on the questionnaires given during the game that tests both game understanding, and the past/future state of the game. Two identical SAGAT tests were given – SAGAT 1 and SAGAT 2, at fixed times during the middle of the game (timing was not told to participants).
Trust propensity	Dependent var.	Participant response to the statement "I am a trusting person."
Altruism	Dependent var.	A measure of altruism, measured by participant response to a question in the pre-study similar to the dictator and investment/trust games.
Trust	Dependent var.	Participant reported trust on a Likert scale, the participant's response to the question "How much do you trust this pair of co-diners?"
Dining points	Game term	For each round, the ratio of item quality (either 200 for hotdog or 400 for lobster) to share of the bill.
Cooperation	Game term	In this version of Diner's Dilemma, the action of ordering hotdog.
Defection	Game term	In this version of Diner's Dilemma, the action of ordering lobster.
Reciprocation	Game term	A game situation: following a hotdog order with a hotdog order, or a lobster order with a lobster order. For example, the Tit-for-Tat strategy is to reciprocate 100% of the time.
Forgiveness	Game term	The tendency of a co-diner to choose not to reciprocate a lobster order, i.e., that co-diner "forgives" a lobster order by choosing hotdog in the next round instead.
Betrayal	Game term	The tendency of a co-diner to choose not to reciprocate a hotdog order, i.e., that co-diner "betrays" a hotdog order by choosing lobster in the next round instead.
Strategy regime	Game term	One of three one-dimensional regions (refer to Fig. 6) of co-diner behavior which define the dominant (best performance) strategy for that region: either "cooperation," (center) "exploitation," (left-side) or "avoidance" (right side). The points between each region, where it does not matter if the participant cooperates or defects, are termed the "pivot points."

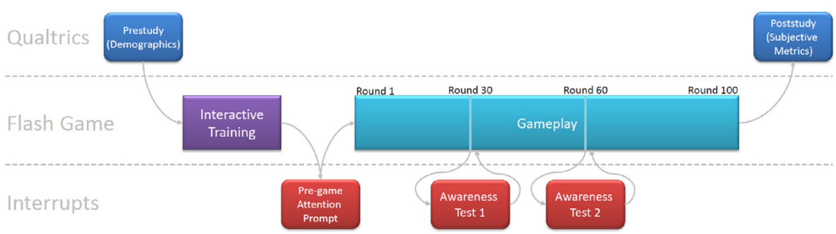

Fig. 2. A participant's experience through the experiment system.

participants played a 100-round game of Diner's Dilemma. Since participants were told they would be paid more for better scores but were not penalized during training, a prompt alerted them when the training ended and when they began to play for points. When all rounds were completed, the users were directed to a post-study questionnaire where they provided feedback on the game and the simulated co-diners.

3.2. Experiment setup

An 11×3 between-subjects method was used. Two simulated co-diners played Tit-for-Tat with eleven variations of forgiveness and betrayal parameters. Three different UIs were designed that exposed varying degrees and complexity of information.

An informal in-laboratory pilot study was conducted to ensure that the different interface components were providing adequate information to the participants. Pilot evaluation data consisted of free response feedback and informal interviews with the participants. The UIs and a training module were iteratively improved through pilot testing before experimentation (three alternative UIs, two of which are not described here) were considered for deployment in the experiment). The pilot revealed that the game was most easily explained to new players through the concept of direct reciprocity (this concept is explained fully in Nowak, 2006), which was then used to explain game rules to the participants in the online experiment.

3.3. Independent variables

The user interface used in the game is shown in Fig. 3. For the purpose of our study, we avoided showing the participant information that might be considered an expert opinion, potentially biasing them towards cooperation or defection, in line with literature on system transparency and explanatory interfaces (Cosley et al., 2003; Knijnenburg et al., 2012; Saner et al., 2009). Instead, participants were shown one of three configurations of the UI with varying amounts of information. The Level 1 UI only displays the bare minimum amount of information necessary for a participant to perceive the environment, although clever users would still be able to achieve SA Level 2 or 3 by paying close attention or taking extra time to perform an analysis. The Level 2 UI aids comprehension of co-diner behavior by displaying an enumerated game history that participants can examine to get a quick synopsis of co-diner behavior from the outset to the current round. Finally, the Level 3 UI included a tool that allows a participant to create "what-if" scenarios for the long term gains of their choices.

- Level 1 UI (no support, see green box of Fig. 3): all participants were shown, at a minimum, 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. This view explicitly reports on only the most current and recent game states, leading us to hypothesize that the participants would not be able to keep track of co-diner behavior as easily as subjects using the more advanced interfaces.

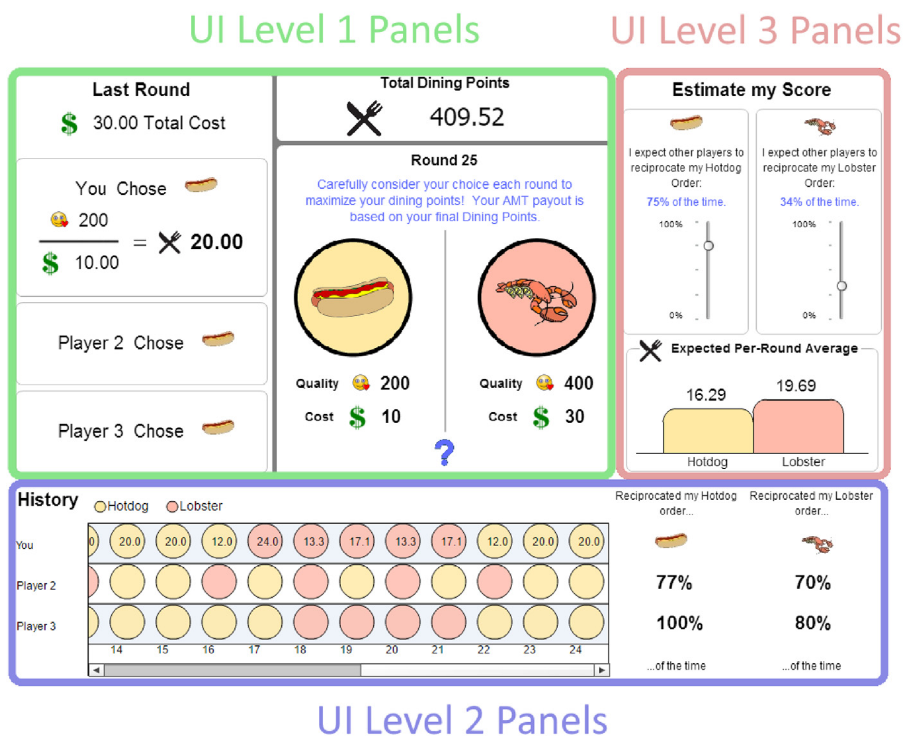

Fig. 3. The user interface for the Diner's Dilemma game. Participants either interacted with UI Levels 1, 2, or 3. Panels are indicated in green, blue, and red. Participants saw all panels below their level, for instance, participants in UI Level 2 saw the UI Level 1 and UI Level 2 Panels. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

- Level 2 UI (history, see blue box of Fig. 3): this UI level includes all UI features from Level 1 UI, and adds a "History" panel to provide historical game information to the participant. In our first experiment, Teng et al. (2013) presented both the participant and co-diner score in a game history panel. Their results showed a drop in participant cooperation when the history panel was presented. Based on their observation that presenting co-diner score can promote retaliatory behavior, we omit the score display feature from our UI design.
- Level 3 UI (history + projection, see red box of Fig. 3): this UI level includes all UI features from Levels 1 and 2 UIs, and adds a "Projection" panel to provide long-term projection information. In this panel, the participant can enter his or her assumptions about co-diner reciprocation behavior and calculate the expected dining points. The designers intended these assumptions to be drawn from the Level 2 UI, but other assumptions can be entered at any time to explore the payoff space. By default, nothing is selected, so as to avoid biasing the participant in either direction.

The eleven co-diner strategies inflicted upon participants were created by varying two parameters. The first parameter was the probability of co-diner "forgiveness," or the probability that the co-diner will cooperate (order hotdog) given that the player previously defected (ordered lobster). The second parameter was the probability of co-diner "betrayal," or the probability that the co-diner will defect given that the player previously cooperated. The extent of forgiveness or betrayal can be thought of in terms of distance from completely reciprocal (Tit-for-Tat) behavior. To examine and compare the independent effects of forgiveness and betrayal, we either varied forgiveness or betrayal (but not both) in each of our configurations. This design allowed us to isolate the effects of each parameter in our analysis. The eleven configurations and the number of participants who completed each condition are shown in Fig. 4.

Due to the payoff matrix (see Table 1), the choice of the eleven co-diner strategies creates three "regimes": one-dimensional regions where either an all-cooperate or an all-defect strategy dominates all others in terms of dining point payoff. The first regime is the "cooperation" regime: these are cases where the human player is best off (in terms of dining points) always cooperating. This occurs in the Tit-for-Tat co-diner strategy and close to it (low rates of either forgiveness or betrayal). The second regime is the "exploitation" regime: cases where the human player best off always defecting. This occurs with high co-diner forgiveness rates. The third regime is the "avoidance" regime: cases where the human player is again best off always defecting. This occurs with high co-diner betrayal rates. Two points do not fall into any regime, which are called the "pivot points," these points occur at the boundary between the three regimes, where cooperation being optimal switches to defection being optimal and vice versa. At these two points, there was no unique strategy that maximized dining points, since the expected performance average does not differ between hotdog and lobster.

3.4. Dependent variables

For each participant, detailed round data was taken, allowing each session to be reconstructed in its entirety. Our main research questions were related to decision making behavior, cooperation percentage, and score on the two SAGAT questionnaires. Dependent variables are listed in Table 2.

A prestudy and poststudy were given to participants before and after playing the game, respectively (refer to Fig. 2). Important to our analysis was the measurement of trust propensity (via participant response to the question "I am a trusting person") and altruism. Trust in co-diners was taken post-study with the question "How much do you trust this pair of co-diners?" Similar to the dictator game (Kahneman et al., 1986) and the trust/investment game (Berg et al., 1995), altruism was measured with the following scenario:

> *"You have $50. You can keep this money and do with it whatever you wish or you can send some or all of it to another person in another room (whom you will never see or meet). They are also given $50 and the same instructions. Any money sent will be tripled on the way to the other*

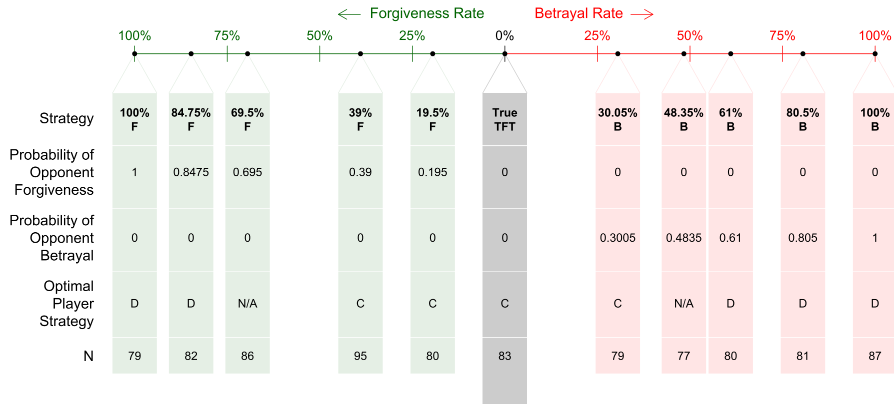

Fig. 4. Quantities of participants in each co-diner strategy condition. At 48.35% betrayal and 69.5% forgiveness, player choice does not matter statistically, as the expected dining points in each round is the same for the choice of hotdog or lobster.

person. Thus, if you send them $10, they will receive $30; if they send you $30, you will receive $90, and so on. You can send them any amount that you wish. You can send them nothing if you wish. This decision is completely up to you."

"How much of your $50 would you send?"

A key challenge in the experimental design was the measurement of SA. Although there are several approaches for the direct measurement of SA, the SAGAT is a widely tested and validated technique (Endsley, 1988) for objectively measuring SA across all of its elements (Levels 1–3) with numerous studies supporting its validity and reliability (Gugerty, 1997; Hogg et al., 1995). While SAGAT is noted to not cause any severe observer effects, SA-related questions must be adapted to each domain based on a decision-making requirements analysis. Thus, the SA benchmark was designed to measure the participant's knowledge of the decision-making rules that would maximize dining points in any hypothetical game of Diner's Dilemma. There were a total of 8 questions in each of two questionnaires (one after 50 rounds and after 90 rounds), all with multiple-choice answers (3 or 4 options). The questions were:

1. Up until this point, what proportion of the time did you order hotdog?
2. Up until this point, what proportion of the time did player 2 order hotdog?
3. Up until this point, what proportion of the time did player 3 order hotdog?
4. What situation produces the largest sum of dining points among the three diners?
5. What situation produces the smallest sum of dining points among the three diners?
6. If you order hotdog for the remainder of this game block, you expect, on average...
7. If you order lobster for the remainder of this game block, you expect, on average...
8. Which statement about the optimal game strategy is correct?

Measuring optimal decision-making from participant behavior record data posed a significant methodology challenge. First, points scored in the game cannot be used to compare performance between different co-diner strategy conditions. This is because co-diner strategy significantly limited the number of total points that could be gained even with perfect decision making from the player (the random nature of co-diner behavior can also cause some small variance in the number of points that can possibly be gained). Second, it is impossible to know for sure whether a participant is making optimal moves due to an understanding of the game or merely by coincidence – a potential confound. In theory, rational behavior from the player must involve some amount of exploration to "probe" what co-diners are likely to do in the case of each choice. Moreover, a rational actor may also question whether the co-diners behave consistently or are also changing their strategy as the game develops. Third, participants may exhibit behaviors for other reasons, such as ordering hotdog 100% or 0% of the time for altruistic or selfish reasons. One way around all of this might be to ask the participant why a move was made, for each move made in the 100-round game, however, this would be impractical due to requiring too much of the participant's time and issues with noisy responses.

In order to make the measurement of optimal decision-making feasible, we simply measured the distance from optimal strategy based on the strategy regime. This puts the performance as a decimal number between 0.0 (participant always choose the wrong item) and 1.0 (participant always choose the right item). Although theoretically this would confound a perfect performer (100% correct moves) with a satisficing player who did no exploration, none of our 901 participants player the entire game without ordering each item at least once. This method also has the nice property of ranking players based on how quickly they figure out co-diner behavior and take advantage of it. More complicated methods of measuring participant performance were considered, such as requiring a certain amount of exploration to get a perfect score, but any metric used in the AMT setting would have issues of confounding rational with random player behavior. The closeness metric is straightforward in comparison.

3.5. Participants

The Diner's Dilemma game was deployed on AMT and data was collected from 901 participants. Participant age ranged from 18 to 75 with an average of 32. 49% of participants were male while 51% were female. Only complete participant records were included in our analysis (35% of the participants dropped out and these records were discarded). The participant pool was limited to the US and participants were told that they would be paid $1.50 with an additional bonus of up to $1.50 based on their performance in the game.[1] AMT is a web service that provides attractive tools for researchers who require large participant pools and inexpensive overhead for their experiments. Numerous experiments have been conducted, notably Buhrmester et al. (2011), assessing the validity of using the service to collect research data, and these studies have generally found that the quality of data collected from AMT is comparable to (and perhaps even better than) what would be collected from supervised laboratory experiments (Hauser and Schwarz, 2015).

[1] For simplicity, all participants were paid $3.00 regardless of performance, however, the participants thought they would be paid more for better performance.

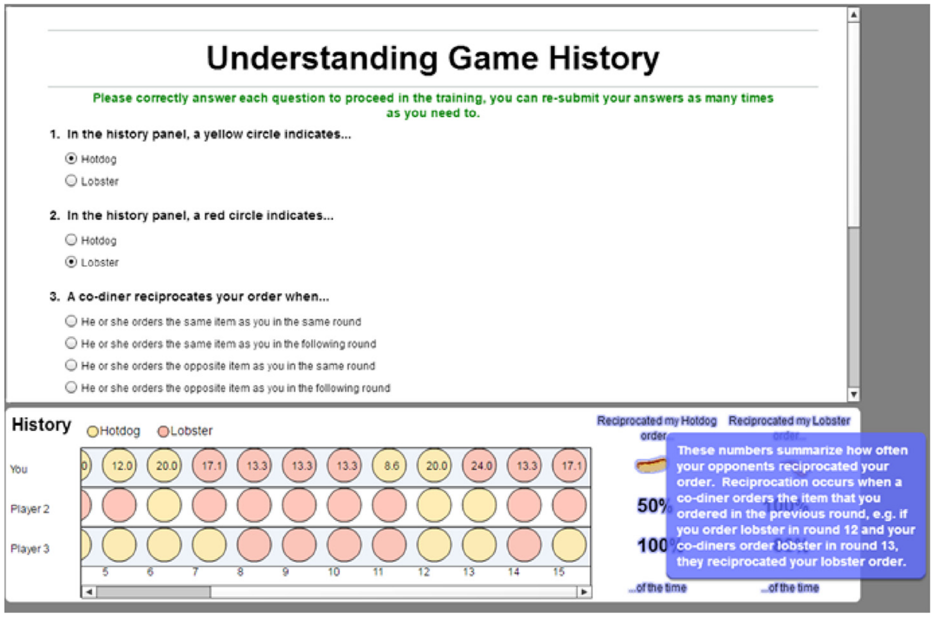

Fig. 5. During the training session, participants were could spend as much time as needed collecting information about the interface and playing an indefinite number of practice rounds. They were intermittently re-prompted to proceed to the next part of the study, which required the correct answer of multiple choice questions about game concepts and information in the interface. Use of UI Levels 2 and 3 required the understanding of the concept of reciprocity, which was tested. Participants in the pilot study had an easier time with this conceptualization than two other variants of the same information.

3.6. Training

An interactive training session was designed to insure that participants had a basic understanding of the game and the interface before they could proceed to the game trial. First, the following description of the game was given:

> *"In this game, you will be dining with two co-diners multiple times at the same restaurant. Every round, you must choose to order either Hotdog (cheap but low quality) or Lobster (expensive but high quality). You can assume that you have enough money to dine out each time (your cash will not run out), however, you still prefer to save money! You have agreed to split the bill every round regardless of what items are ordered, and your overall performance is measured in terms of dining points, which is the ratio of food quality to money spent. If everyone orders Hotdog, you can get 20 points per round, but if you order Lobster and both your co-diners order hotdog, you can get 24 points (but your co-diners will lose out)."*

Next, information about the interface was provided through tooltips and components of the game were iteratively added as the participant proceeded through the training (Fig. 5). Participants could play as many practice rounds as they wanted against two co-diners playing Tit-for-Tat with 10% noise (i.e. simulated co-diners deviated from Tit-for-Tat 10% of the time), but were eventually prompted to complete some SA questionnaires (up to 3, one for each UI level). The information required to answer each question was explicitly available at the time the questionnaire was presented, and participants were allowed to submit answers as many times as they needed to complete the questionnaire. At the end of the training session, participants were allowed to continue using the interface as long as they liked before advancing to the next portion of the study.

4. Results

We considered the effect of varying the UI level and co-diner strategy on the cooperation rate, participant performance in terms of the participant's closeness from the optimal strategy, situation awareness, and trust. An analysis of each relationship is given and then we construct a pathway model over all of our dependent variables to better understand how our measurements relate to each other.

4.1. Cooperation rate

Fig. 6 shows the average participant cooperation percentage for each co-diner strategy, grouped by UI level. Forgiveness and betrayal are separate variables, so this figure actually represents two separate graphs which have been joined at the middle. Cooperation remains fairly consistent on the left side of the pure tit-for-tat point up until the pivot point, where cooperation drops off sharply. Cooperation appears to drop more smoothly to the right of the pure tit-for-tat point. The effect of the UI is visibly greater in the cooperation and exploitation regime.

4.2. SA

Aggregate participant SA was seen to increase with each level of UI provided, a visual of which is shown in Fig. 7. A two-way mixed ANOVA showed a significant main effect of UI level upon SAGAT test scores ($F(2905) = 3.69, p = .03$), with scores improving with increasing UI level. There was also a main effect of SAGAT test time on score ($F(1905) = 11.91, p < .001$), with scores improving from the first to the second SAGAT questionnaire.

The SA questions and their mean correct responses are given in Table 3 (refer back to Section 3.3 for the specific questions). UI Level 2 caused about a 10% increase in the participant's ability to estimate how often they and player 2 cooperated, however, there was not much increase for the ability to estimate player3's cooperation rate. Furthermore, the increase was mitigated somewhat when the UI Level 3 components were added. UI Level 3, however, increased the participant's ability to answer all strategy questions, especially questions 5 and 8.

4.3. Performance

Fig. 8 shows how the UI level affected participant performance. Performance was calculated as the percent of time that the participant chose the option that led to the highest expected dining points. Pivot points are excluded as there neither selection was better than the other at that

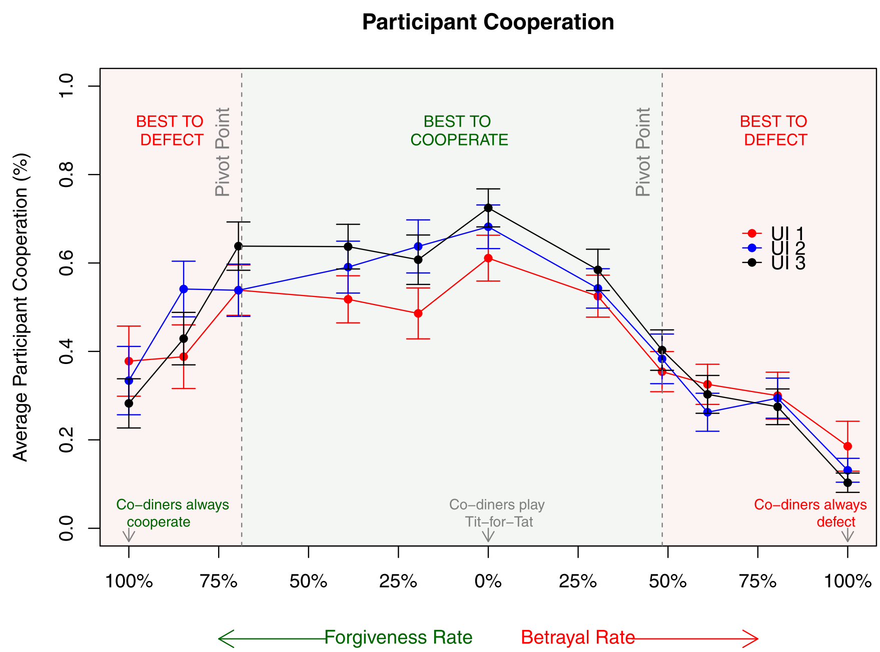

Fig. 6. The cooperation percentage for each co-diner strategy, grouped by UI level, error bars are 95% confidence interval. Forgiveness rate indicates the rate that simulated co-diners will respond to a lobster order with a hotdog order, and betrayal rate indicates the rate that simulated co-diners will respond to a hotdog order with a lobster order. Note the three regimes divided by the pivot points; in the far left and far right regions the optimal strategy would be to defect 100% of the time, and in the central region 100% cooperation would yield the best performance.

Table 3
The SA questionnaire that was used at two points during the game (1st and 2nd). Multiple choice answers were given to participants (not shown). Participants typically had trouble with questions 5 and 8. UI Level 3 caused the highest aggregate increase in SA. The eight questions used to assess SA are listed in Section 3.3.

Mean correct on Situation Awareness Global Assessment Test (SAGAT)								
Question #	*UI Level 1*		*UI Level 2*		*UI Level 3*		*All*	
	1st	*2nd*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*
1	0.47	0.50	0.52	0.57	0.52	0.54	0.50	0.54
2	0.48	0.52	0.53	0.57	0.51	0.55	0.51	0.55
3	0.49	0.52	0.50	0.58	0.48	0.58	0.49	0.56
4	0.42	0.42	0.54	0.48	0.58	0.55	0.51	0.48
5	0.38	0.37	0.35	0.35	0.38	0.38	0.37	0.37
6	0.49	0.50	0.57	0.62	0.61	0.63	0.56	0.58
7	0.46	0.47	0.53	0.52	0.53	0.54	0.51	0.51
8	0.35	0.34	0.32	0.35	0.40	0.41	0.35	0.37

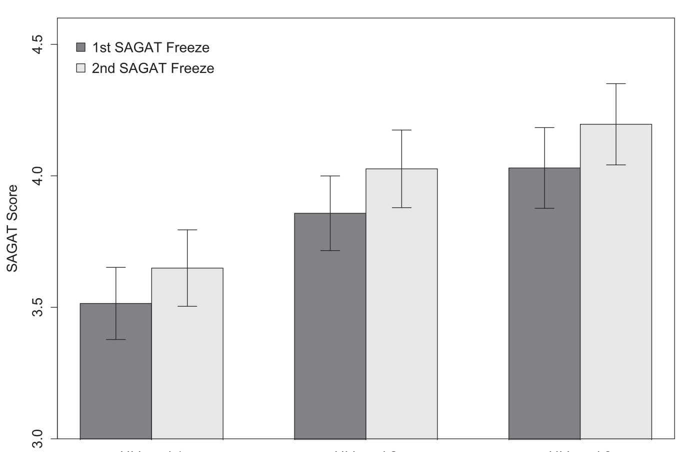

Fig. 7. Average scores for UI Level 1 were (3.5,3.65), UI Level 2: (3.86, 4.02), UI Level 3: (4.02, 4.19). Error bars are one standard error.

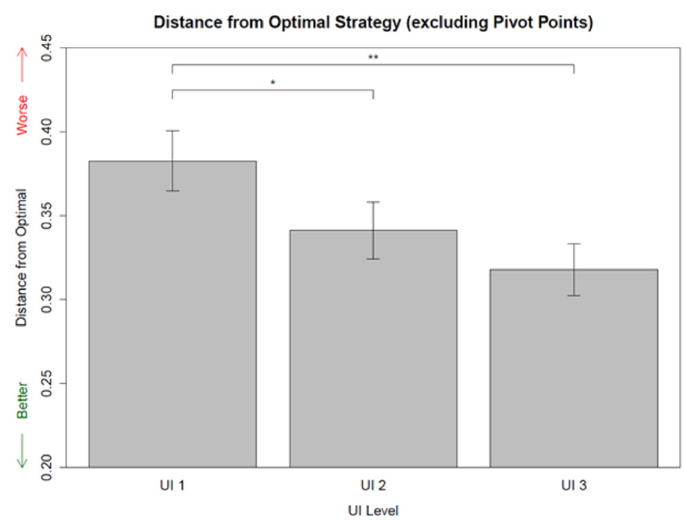

Fig. 8. Closeness to optimal strategy, error bars are 95% confidence interval. Participants were much more likely to make an optimal decision when using UI Level 3. Pivot points were excluded from this analysis, as player choice becomes arbitrary under those conditions. Significance levels: * = 0.05, ** = 0.005.

point. Fig. 9 plots observed participant behavior against the theoretical optimal strategy. Better performance tends to increase (indicating improved performance) with increasing UI level. An ordered logistic regression showed a significant linear improvement in performance with increasing UI level ($b = -0.03, t(743) = 2.47, p = .01$).

4.4. Trust in co-diners

Fig. 11 shows the mean trust in co-diners reported by users during the post-study, grouped by strategy. Fig. 10 shows the cooperation rate for comparison. These graphs are similar to Fig. 6, where forgiveness increases to the left of the center and betrayal increases to the right. These plots highlight two results. First, the tendency of participants to

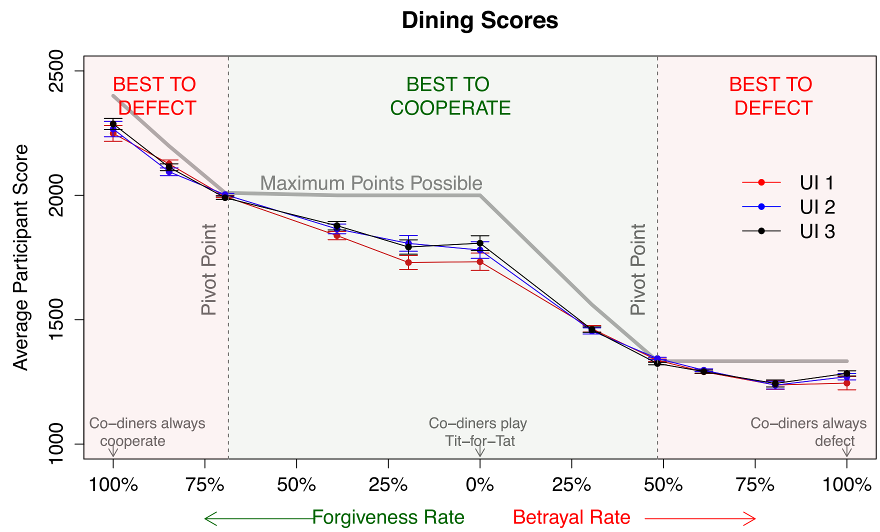

Fig. 9. Dining points earned relative to the maximum available. Data is grouped by UI level. Players actually perform worse compared to optimal in the central "cooperation" regime, which is indicated by a larger gap between the gray line and the observed red/blue/black lines. At the pivot point, player choice no longer matters so we see the theoretical and observed behavior converge. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

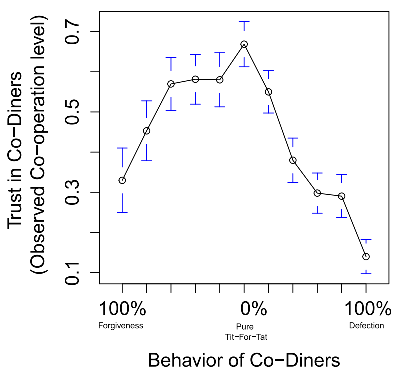

Fig. 10. Cooperation observed from participants.

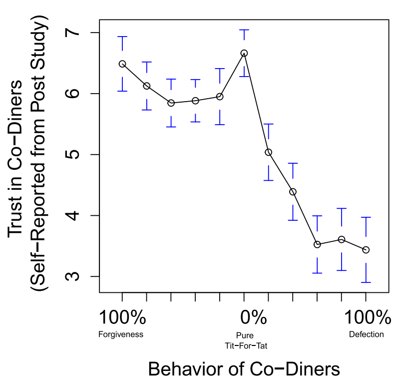

Fig. 11. Self-reported trust in co-diners.

respond to co-diner betrayal with betrayal was mirrored by reported trust in co-diners. Second, participants reported that they trusted forgiving co-diners even as they exploited them. Additionally, participants reported more trust in co-diners when they played pure tit-for-tat than when there was some degree of forgiveness.

4.5. Path analysis

The results of fitting the data to a path model (Ullman and Bentler, 2003) are shown in Table 4. This model was constructed by

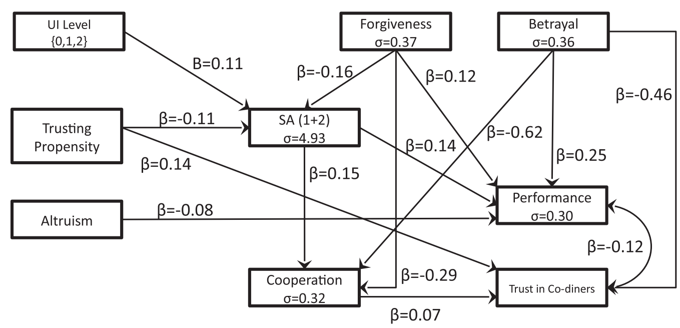

Fig. 12. A network visualization of the pathway model. Beta (or *B*-values, for UI) are shown on each edge. Standard deviations are shown on variables with real units. Beta values indicate the standard deviation change in the regressand with a unit change in the regressor. The *B*-value for UI indicates the standard deviation change in SA for each level of UI added. *p*-values and standard error values are shown in Table 4.

ordering all variables in the study into groups based on their causal relationships (e.g., observed participant cooperation cannot affect the UI treatment that was assigned) and then saturating all regressions with all available variables. This saturated model was then trimmed of insignificant effects to produce four candidate models. The model shown in Table 4 had the lowest Bayesian Information Criterion (BIC)/Akaike Information Criterion (AIC) score of all tested models. Fig. 12 shows a visualization (Schumacker and Lomax, 2004) of the model with regression coefficients (β) and covariance terms.

From Table 4, we can see that both co-diner forgiveness and betrayal parameters had an effect on the participant's cooperation. We can also see that participants were sensitive to the different co-diner strategies to different degrees. This decrease appears to be steeper with increased betrayal than it is with increased forgiveness, with the coefficient for the effect of betrayal ($\beta = -0.62$) being about twice as large as the coefficient for forgiveness ($\beta = -0.29$). This effect can also be visually observed in Fig. 9. Additionally, participants who performed well on the SAGAT questionnaires (SAGAT 1 score was typically within 95% of SAGAT 2 score, refer to Fig. 7) cooperated more ($\beta = 0.15$).

SA was taken as a linear sum of the scores on both SAGAT questionnaires. The total SA score was influenced by co-diner forgiveness ($\beta = -0.16$), UI level ($B = 0.11$), and trust propensity ($\beta = -0.11$). Note that UI level is unscaled and ordinal (0,1,2), so UI Level 2 had an effect size of 0.11 standard deviations and UI Level 3 had an effect size of

Table 4
A pathway model built on all study variables. Regressands (left-hand side variables) are shown in the left column, with all regression terms (right-hand-side variables, or regressors) shown in the second column. The regressand can be expressed as a linear sum of the regression terms multiplied by their coefficients, which are shown in the "Estimate" column. All variables except for UI were scaled, so estimates (the β term) are in units of standard deviation. Recall that "Performance" is measured as closeness to optimal rather than the raw dining score. Model fit: $N = 901$ with 22 free parameters = 41 participants per free parameter, $RMSEA = 0.039$ (CI: [0.021, 0.058]), $CFI = 0.974$, $TLI = 0.944$ over null baseline model. $\chi^2(12) = 28.592$.

Regressand	Regression (←) or covariance (↔) term	Estimate (β/B)	Std. error	p-value
Cooperation ($R^2 = 0.26$)	← Forgiveness	−0.29	0.037	0.0 (***)
	← Betrayal	−0.62	0.037	0.0 (***)
	← Situation awareness	0.15	0.029	0.0 (***)
Situation awareness ($R^2 = 0.05$)	← Forgiveness	−0.16	0.033	0.0 (***)
	← UI level	0.11	0.033	0.008 (**)
	← Trust propensity	−0.11	0.033	0.001 (**)
Trust ($R^2 = 0.26$)	← Betrayal	−0.46	0.032	0.0 (***)
	← Cooperation	0.07	0.031	0.025 (*)
	← Trust propensity	0.14	0.029	0.0 (***)
Performance ($R^2 = 0.07$)	← Forgiveness	0.12	0.041	0.005 (**)
	← Betrayal	0.25	0.041	0.0 (***)
	← Situation awareness	0.14	0.032	0.0 (***)
	← Altruism	−0.08	0.032	0.015 (*)
	↔ Trust (reported)	−0.12	0.028	0.0 (***)

0.22 standard deviations. Reported trust in co-diners (taken during the post-study) was profoundly impacted by the degree of betrayal the participants endured ($\beta = 0 - .46$). Participants that cooperated more also reported higher trust in co-diners ($\beta = 0.07$). Final performance, in terms of closeness to optimal strategy, was beneficially affected by forgiveness ($\beta = 0.12$) and betrayal ($\beta = 0.25$). Participants with higher SA performance also performed better ($\beta = 0.14$), but altruistic participants performed worse ($\beta = -0.08$). Reported trust and performance were negatively correlated ($\beta = -0.12$).

5. Discussion

This section answers the research questions outlined in the introduction and discusses the observed relationship between the UI, situation awareness, cooperation, and performance.

5.1. To what extent can a UI improve SA? how are SA and cooperation related in this setting?

Measuring SA allowed for the decoupling of UI design and dependent metrics of interest. In this research, we were interested in measuring cooperation or performance, but when SA is used to mediate UI and performance, model fit improves. This makes sense from a practical standpoint - if information is shown but is not paid attention to or internalized by users, the UI cannot have an effect on decision making. Effective UI support is the one that best focuses attention, which leads to increased SA and thus better decisions. A goal of UI design could be to increase SA for a given task and researchers could eschew approaches that treat the participant as a black box, which bypass SA measurements and only consider performance.

Increased UI support caused a significant increase in SA, but the low R^2 of participant SA in this study indicates the existence of latent variables, likely some of which are related to individual characteristics of the participant. This actually strengthens the case for using SA measurements for user interface research as it can capture many of these individual characteristics without the need for their inclusion as question items, which take up participant time.

According to our model (Table 4), forgiving strategies from co-diners caused lower SA in participants. In fact, the β value of forgiveness was higher than the B value of UI level. Forgiveness thus could have a maximum effect of reducing the SA of the participant by $1/0.37 * 0.16 = 0.43$ standard deviations (in the "always cooperate" condition). Also note that participants performed worse overall in terms of closeness to optimality in the "exploitation" regime. The observed lower SA could be due to less perceived need for strategizing in these conditions – participants did not lose out on many points in the exploitation regime whether they exploited or not. This fits with the idea that people react much less favorably when subjected to unfairness by other decision makers (Hibbing and Alford, 2004).

Additionally, participants with higher trust propensity displayed simultaneously higher trust in co-diners and lower situation awareness. However, trust propensity and observed cooperation related (negatively) only through a full mediation effect via SA, while observed cooperation and self-reported trust were only very weakly related (see Figs. 10 and 11). Instead, the model predicted that trust was largely determined by the level of betrayal. This leads us to the conclusion that trusting propensity may actually be a risk factor for co-actors in collaborative settings. Moreover, reported trust is not likely be a reliable predictor of cooperative behavior.

5.2. Can a UI be used to encourage or discourage human cooperative behavior?

In study 1 (Teng et al., 2013), the inclusion of more UI support did not necessarily increase cooperation and in some cases actually resulted in a decrease. This could be due to less effective UI support and information, but the relationship between SA and cooperation was not thoroughly explored. However, it was still identified that participant reported trust in co-diners and cooperation proportion were correlated, as was also the case in this experiment. For strategies in this previous experiment that discouraged cooperation, we saw that the UI encouraged cooperation even less than in the present results, most likely for the similar reason that the desire to punish bad behavior overcomes the influence of information from the UI, and possibly the desire for improved individual outcome.

In study 2, (Onal et al., 2014b) explored the relationship between situation awareness and cooperation rates. The Levels 2 and 3 UIs in that experiment, which differed slightly from the current UIs, had also increased performance and cooperation. We found that situation awareness and dining points were highly correlated. However, the range of co-diner strategies in Onal et al. (2014b) was limited, but cooperation behavior observed in the treatments with the more defection prone strategies opened the question of whether or not the UI could continue to maintain high SA (and therefore cooperation) even when co-diner betrayal increases.

The present study has again linked cooperation, SA, and UI for social dilemmas. However, as indicated by Fig. 6 the effect of the UI on cooperation was not equal for all ranges of co-actor behaviors.

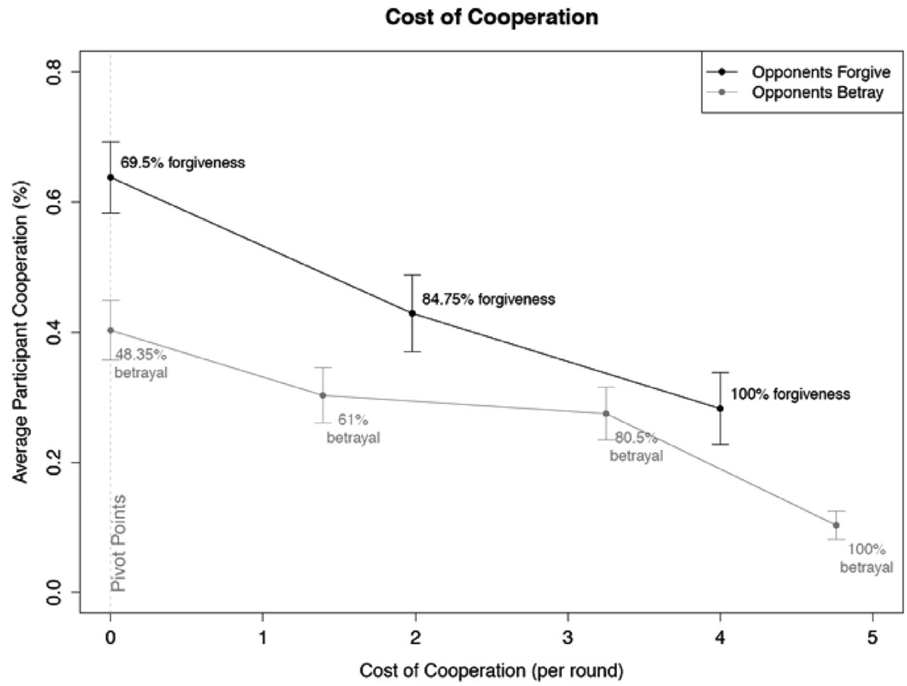

Fig. 13. Observed difference in cooperation between participants who dealt with forgiving or exploitative co-diners. Groups are broken down by co-diner strategy (as in Fig. 6), and the vertical axis represents observed cooperation percent for that group. The horizontal axis indicates the points lost when a participant cooperates 100% when the co-diner strategy is fixed, thus, the far left line indicates the pivot points, and the strategies between the pivot points in Fig. 6 are accordingly not plotted. The dark black line represents the far left side of Fig. 6, and the light grey line represents the far right side. The optimal strategy for all points graphed here should be to cooperate 0% of the time, but this was not observed.

5.3. Does the effect of a UI on human cooperative behavior change with the propensity of co-actors to exploit?

In general (across all co-diner strategies), more UI support predicted increased cooperation, but was fully mediated by SA. More SA also predicted more payoff-maximizing behavior, which is indicated by the observed increase in performance. However, Fig. 6 suggests that the effect of the UI was also dependent on co-diner strategy. In the "avoidance" regime (right side) participants using the Level 1 UI appear to cooperate relatively more than participants using the Level 2 or 3 UIs. This could be due to the fact that the History Panel made the patterns of co-diner defection much easier to see. Still, in the "cooperation" regime, the UI appears to have the highest impact on participant cooperation. To quantify the apparent interaction effects between UI and co-diner strategy, the following regression model was tested:

$$\begin{aligned} cooperation = {} & B_1 I_2 + B_2 I_3 + B_3\ exploitation + B_4\ avoidance \\ & + B_5 I_2 * \ exploitation + B_6 I_2 * \ avoidance \\ & + B_7 I_3 * \ exploitation + B_8 I_3 * \ avoidance \end{aligned} \tag{1}$$

where B indicates the regression coefficients (1–8) and I indicates the user interface (1–3).

This multivariable regression (adjusted $R^2 = 0.24$, $p < .001$) revealed how the effects of the UI change when co-diner behavior deviates from tit-for-tat and enters the exploitation/avoidance regime. First, the regression again confirms the overall cooperative effect of UI Levels 2 ($B_1 = 0.07, p = .05$) and 3 ($B_2 = 0.10, p < .01$) as well as the cooperation-reducing effects of the exploitation ($B_3 = -0.15, p = 0.048$) and avoidance ($B_4 = -0.27, p < .001$) regimes. However, in the "avoidance" regime, UI Level 2 ($B_6 = -0.12, p = .03$) and UI Level 3 ($B_8 = -0.14, p = .01$) have a slight, but significant, cooperation discouraging effect. Next, in the "exploitation" regime, the effect of UI Level 2 ($B_5 = -0.02, p = .81$) was non-significant, however, UI Level 3 ($B_7 = -0.13, p = .06$) had a marginal cooperation-reducing effect. This analysis suggests that different levels of UI support might be appropriate in different situations to maximize group benefit. For instance, when some co-actors behave in a way that is pathologically altruistic, showing less information about the benefits of exploiting these individuals (UI Level 3) may encourage long term group cooperation. However, more information could be shown when an individual decision maker is repeatedly taken advantage of by his or her co-actors. Similarly, as co-actor behavior approaches true tit-for-tat, information should be maximized to encourage cooperation. To examine this further, a follow-up study could be designed with multiple human co-diners where each participant is given a different interface based on their trusting propensity and altruism profile.

5.4. To what extent do co-actor behavior and UI support affect performance of the individual decision maker?

On average, higher SA resulted in increased performance for participants. Table 4 indicates that more UI support and less co-diner forgiveness means higher SA and thus higher performance. In some cases performance of the individual was increased at the expense of the performance of the group. Even participants with high SA were estimated to cooperate less when opponent forgiveness was high and to a greater extent for high betrayal conditions. This means that participants with low SA may have contributed more to the well being of the group, regardless of their actual intentions.

Our co-diner strategies were quite simple (drawn from an independent and identically distributed random variable), so participants in the game were not able to sway co-diners into cooperation by consistent contribution behavior. The UI was designed to increase the situation awareness and performance of the individual using it, without regard for the group's well-being. As noted in the previous section, participants using the Level 1 UI still attempted to punish forgiving co-diners, but to a marginally lesser extent than the participants in UI Level 3. If the performance of the entire group is of concern, it may be prudent to design a UI that attempts to maximize that objective, rather than the individual's performance.

The model described in Table 4 found that participants were far more likely to retaliate to defection than they were to exploit over-forgiving co-diners. Fig. 13 shows the observed difference in cooperation between participants in the far-left and far-right regions of Fig. 6. As you move from the left to the right, you can see how many points are lost by deviating from the optimal strategy under these conditions (100% betrayal). Initially, we hypothesized that participants in the far left and right regions would react to the co-diner strategies in the same way, that is, the lines for each region in Fig. 13 should be more or less the same. The observed behavior was much different: participants simply did not exploit the simulated co-diners as much as they could despite the obvious personal benefit, and participants in the high-betrayal conditions were far more likely to behave closer to the optimal strategy. Thus the difference that the UI made was greater when the potential for mutual cooperation was greater.

5.5. Limitations

The methodology in this study was focused on evaluating decision-making performance in response to increased information. However, many other factors can influence the behavior of a decision maker in similar settings, for instance: the emotions communicated by co-actors (Choi et al., 2015), empathy on the part of the participant (Parfit, 1981), reciprocal altruism (Boyd, 1988), and trust (Yamagishi et al., 2005). This study measured trusting propensity and altruistic tendency which has illuminated part of the relationship between these personal characteristics and SA/performance, notably, our statistical model (Table 4) found no relationship between altruism and SA but did find a relationship between trusting propensity and SA. Additional research would be needed to determine if the effects of the UI remain when emotive avatars were used (such as in Choi et al., 2015), or under other conditions.

Although our preliminary work (Teng et al., 2013) examined a number of noisy co-diner strategies, this study individually manipulated the betrayal and forgiveness of co-diners such that betrayal was always 100% when forgiveness was not, and vice-versa. This means that the study data cannot support hypotheses about the relationship between UI, SA, and performance when forgiveness and betrayal are simultaneously deviated from 100%. Still, the results of this study indicate that increased forgiveness leads to a marginal decrease in cooperation and increased betrayal leads to a significant decrease in cooperation. This data might be used to predict behavior at the untested co-diner strategy points, but follow-up research would be needed for verification.

6. Conclusion

We designed a decision support interface for the Diner's Dilemma and conducted an N=901 experiment to study human decision making with various levels of UI support. We found that: (1) participants were more likely to retaliate against defection than they were to initiate defection, especially when more UI support was given; (2) participant SA and cooperation increased as more UI support was given but decreased in the presence of more forgiveness from co-diners; and (3) the need for UI support to make good decisions was diminished as co-actor became more likely to exploit. This experiment supports the theory that the ability of a UI to improve individual decision making in collaborative settings is dependent on the selfishness or altruism of co-actors. Knowledge gained from this work can help user interface designers to encourage cooperative behavior in social settings or maximize the benefits to an individual decision maker.

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