

December 6, 2017

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Socially-Aware Dialog System

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December 2017

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*Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosoph
In Language and Information Technologies*

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Keywords: Socially-Aware, multimodal machine learning, temporal sequence learning, cognitive architecture, neural dialog model, socio-psychology theoretical framework, rapport, conversational strategy, spoken dialog systems, discourse analysis, social reasoning, natural language generation

Abstract

Based on the literature from computational linguistics, people pursue multiple conversational goals in dialog, which include those that fulfill propositional functions, contributing informational content to the dialog; those that fulfill interactional functions, such as managing conversational turn-taking; and those that fulfill interpersonal functions, managing the relationship between the interlocutors. In the past two decades, the spoken dialog system community has made great advances on modeling the propositional, to a lesser extent, the interactional functions of human communication. For instance, Apple Siri, Microsoft Cortana, and Amazon Alexa have been released to assist human user to finish tasks in a more efficient way.

The interpersonal functions of conversation, whether these be trust, social bond, rapport, interpersonal closeness, or empathy, have been far from being addressed, however, in part because of: (1) a lack of models of interpersonal goals and strategies in human communication. (2) the open-ended nature of the resulting social dialog.

As dialog systems become more common and frequently used as interfaces to search and other computing tasks, propositional content and interactional content will not suffice. In this thesis, therefore, I address these challenges by proposing a socially-aware intelligent framework which exploit a path to systematically generate dialogs that fulfill interpersonal functions.

A socially-aware intelligent framework is able to explain how human in dyadic interactions build, maintain and tear down social bond through the use of specific conversational strategies that function to fulfill specific social goals, and that are instantiated in particular verbal and nonverbal behaviors. In order to operationalize this framework, we argue that four capabilities are need to achieve in a socially-aware intelligent system: (1) automatically recognize social conversational strategies used by human user (2) accurately estimate the dynamics of social bond through observing the dyadic interaction (3) reason appropriate conversational strategy for the system to use while taking into account both task goal and social goal (4) realize surface-level utterance that interleaves the task conversation and social chat.

Our socially-aware dialog system focuses on blended conversations that mix goal-oriented task with social chat. The social chat will "grease the wheel" in a conversation to improve the task performance. As a proof of concept, we have induced a modular-based socially-aware personal assistant for a conference.

Since neural dialog model has recently shown great promise in modeling open-domain conversation, we move advance to propose a conditional variational autoencoder based model that operationalize socially-aware framework for dialog generation. To validate the generalizability of our framework, we propose to implement a neural dialog model based socially-aware negotiation system and run a user study with it. We hope the results will show the system has capabilities of facilitating the negotiation process through building a social bond with human user along the way.

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Chapter 1

Introduction

For decades researchers in Artificial Intelligence have focused their attention on building autonomous systems that act like humans. Currently, three prevailing types of spoken dialog systems/bots are developed: One is task completion bot that helps user to book movie tickets, reserves seat of restaurants and etc. The second one is info bot which is designed for information access purpose through an interactive Q&A system over knowledge base. The last one is social chatbot that aims at engaging the users in open-domain dialog. We have made great strides in that area, but now it is time to re-examine the enterprise. Humans are not autonomous - why, therefore, are human-like machines? Instead, humans are deeply interdependent with other humans. This thesis proposal develops technologies needed to analyze intrinsically interdependent social phenomena such as rapport and how to use the results of those analyses to build a socially-aware dialog system that can in turn be interdependent with humans, in ways that improve both machine and human performance. In this era of fears that Artificial Intelligence will destroy humanity, a socially-aware dialog system that interacts with people in a whole new way, personalizing the interaction and improving task performance by relying on information about the relationship between the human user and system. Next-generation of dialog system will improve its collaboration skills with human users through shaping the socio-emotional bonds that form the fabric of society.

Our primary interest is interpersonal rapport since rapport has been identified as an important function of human interaction, but to our knowledge no model exists of building and maintaining rapport between humans and conversational agents over the course of a conversation that operates at the level of the dyad. **In this thesis work, we mainly focus on designing a socially-aware dialog system that builds interpersonal closeness (rapport) over the course of a conversation along with carrying the task through understanding human behaviors and generating appropriate response.** In chapter 2, we leverage existing literatures and a corpus of peer tutoring data to develop a computational model of rapport, which serves as the foundation of our socially-aware theoretical framework. To operationalize this framework, in chapter 3, we review the architecture of our modular-based socially-aware dialog system, which is a personal assistant that helps conference attendees to achieve their goals, including introducing them to other attendees and telling them about sessions that fit their interests. It is an overview of our proposed modules and demonstrates the effectiveness of rapport-building conversational strategies on improving task performance. Before describing our each individual developed module, in chapter 4.1, we conduct a follow-up experimental study of the proposed theoretical framework to quantitatively investigate the pattern of conversational strategy usage in human dialog as well as initially validate its effectiveness on both social(rapport) and task (learning). Towards this end, we examine similarity in use

and timing of the relationship oriented communicative strategies such as self-disclosure, reference to shared experience and praise, during a reciprocal peer tutoring interaction. Then, we move forward to introducing each of our designed modules for socially-aware dialog system. In terms of detection, in chapter 4.2, we dive into content level of the utterance and leverage quantitative method to automatically recognize different conversational strategies. Since our system has capabilities of automatically recognizing different conversational strategy, in chapter 4.3, we step towards data-driven discovery of the temporally co-occurring and contingent behavioral patterns that signal high and low interpersonal rapport. We validate the discovered behavioral patterns by predicting rapport against our ground truth (30 second thin slice rapport) via a forecasting model involving two-step fusion of learned temporal associated rules. In terms of reasoning, in chapter 5, our system first carries out the classic kind of AI task reasoning needed to determine how best to fulfill the users goals. Then it carries out a brand new kind of reasoning what we call social reasoning to determine how to carry out the conversation (including language and body language) with the user so as to best accomplish both the task (information-seeking, teaching, calendar management, etc.) and social goals (managing rapport, etc.).

In the end, we move from conventional modular-based system to end-to-end neural network based system. In chapter 6, we present a novel knowledge-guided conditional variational autoencoder model that is able to incorporate prior linguistic knowledge to guide the dialog generation process. Building upon this model, in chapter 7, we propose a reinforced knowledge-guided conditional variational autoencoder model to operationalize socially-aware framework and apply this neural dialog model in negotiation domain in which interpersonal dynamics has been proved to play a surprisingly significant role.

1.1 Thesis Statement

In this thesis work, we mainly focus on designing a socially-aware dialog system that builds interpersonal closeness (rapport) over the course of a conversation along with carrying the task through understanding human behaviors and generating appropriate response.

1.2 Thesis Contributions

- Computational model of rapport: The computational model is the first to explain how humans in dyadic interactions build, maintain, and destroy rapport through the use of specific conversational strategies that function to fulfill specific social goals, and that are instantiated in particular verbal and nonverbal behaviors (Zhao et al., 2014; Sinha et al., 2015).
- Techniques for automatic recognizing Conversational Strategy: We have implemented a conversational strategy classifier to automatically recognize the users conversational strategies particular ways of talking, that contribute to building, maintaining or sometimes destroying a budding relationship. These include self-disclosure (SD), elicit self-disclosure (QE), reference to shared experience (RSD), praise (PR), violation of social norms (VSN), and back-channel (BC). By including rich contextual features drawn from verbal, visual and vocal modalities of the speaker and interlocutor in the current and previous turns, we can successfully recognize these dialog phenomena with an accuracy of over 80% and with a kappa of over 60% (Zhao et al., 2016a,c).

- Techniques for automatic estimating rapport level: We use the framework of temporal association rule learning to perform a fine-grained investigation into how sequences of interlocutor behaviors signal high and low interpersonal rapport. The behaviors analyzed include visual behaviors such as eye gaze and smiles, and verbal conversational strategies, such as self-disclosure, shared experience, social norm violation, praise and back-channels. We developed a forecasting model involving two-step fusion of learned temporal associated rules. The estimation of rapport comprises two steps: in the first step, the intuition is to learn the weighted contribution (vote) of each temporal association rule in predicting the presence/absence of a certain rapport state (via seven random-forest classifiers); in the second step, the intuition is to learn the weight corresponding to each of the binary classifiers for the rapport states, in order to predict the absolute continuous value of rapport (via linear regression) model. Ground truth for the rapport state was obtained by having naive annotators rate the rapport between two interactants in the teen peer-tutoring corpus for every 30 second slice of an hour long interaction. Our framework performs significantly better than a baseline linear regression method that does not encode temporal information among behavioral features.
- Techniques for enabling a dialog system to plan conversational style and strategy towards achieving both social and task goal: We have designed a social reasoner that decides the appropriate conversational style and strategy with which the dialogue system describes the information the user desires so as to boost the strength of the relationship between the user and system (rapport). The social reasoner is implemented as a spreading activation model- a behavior network consisting of activation rules that govern which conversation strategy the system should adopt next. Our Social Reasoner is inspired both by analysis of empirical data of friends and stranger dyads engaged in a task, and by prior literature in fields as diverse as reasoning processes in cognitive and social psychology, decision-making, sociolinguistics and conversational analysis. Our experiments demonstrated that, when using the Social Reasoner in a Dialogue System, the rapport level between the user and system increases in more than 35% in comparison with those cases where no Social Reasoner is used(Oscar J. Romero, 2017).
- Techniques for operationalizing socially-aware framework in an end-to-end neural dialog model: We proposed a reinforced knowledge-guided conditional variational autoencoder model that will be able to generate dialogs with socially-aware intelligence.(Zhao et al., 2017)

Chapter 2

Theoretical Framework

2.1 Introduction

Human are deeply interdependent with each other in society. Modeling such social process between human and system is complicated. As the first step, we start to learn empirical findings of human-to-human interaction through reviewing previous socio-psychological literatures about intrinsically interdependent social phenomena, such as rapport, trust or interpersonal closeness. From there, we develop the first dyadic computational model of rapport that able to explain how humans in dyadic interactions build, maintain, and destroy rapport through the use of specific conversational strategies that function to fulfill specific social goals, and that are instantiated in particular verbal and nonverbal behaviors. This theoretical framework will serve as the guidelines for us to further design and implement our socially-aware dialog system.

Rapport, a feeling of connection and closeness with another, feels good, but it also has powerful effects on performance in variety of domains, including negotiation (Drolet and Morris, 2000), child care (Burns, 1984), counselling (Kang et al., 2012) and education (Bernieri and Rosenthal, 1991). As agents increasingly take cover tasks such as those described above, we maintain that it is important to evoke a feeling of rapport in people interacting with those agents so as to improve their task collaboration - and recognize rapport in people interacting with agents so as to know when the system has been successful, it turns out, however, that what constitutes rapport-evoking and rapport signaling behavior varies widely. While prior work [e.g. (Karacora et al., 2012)] has confirmed that some rapport-signaling behavior such as attentiveness is capable of enhancing task performance, there has existed no rigorous models of the mechanism underlying the relationship between social and cognitive functioning in tasks such as these (Kreijns et al., 2003), nor do there exist computational models of interpersonal closeness that can tell us how rapport signaling behavior should change over the course of a long-term collaboration between a human and an agent. One obstacle to models of this sort is the fact that, as (Bernieri and Gillis, 2001) has written, "rapport is a social construct that must be defined at the level of a dyad or larger group." Dyadic processes of this sort have traditionally posed challenges to modeling since, as (Bickmore et al., 2005) have described, a change in the state of one partner will produce a change in the state of one partner will produce a change in the state of the other. We believe that prior attempts have not sufficiently distinguished between the social functions that lead to rapport, the conversational and behavioral strategies that play a role in those social functions, and the observable phenomena that make up those strategies. Rapport is sometimes experienced on a first meeting but most often it must be built and maintained - or it will destroyed. Drawing these distinctions has also allowed

us to move toward an implementable computational architecture, described in the following subsection of this chapter, that takes into account both participants' cognition, intentions, actions and beliefs, and their interplay, within one person and across the dyad.

2.2 Related Work

A number of prior papers have addressed the issue of rapport, or related notions such as trust, friendship, and intimacy, between people and agents. An early paper (Cassell et al., 1999) used prior work in sociolinguistics and social psychology to develop a computational model of trust, and a computational architecture to establish trust between a person and virtual agent. The system, however, did no assessment of the user's level of trust, and only built trust through verbal behavior - primarily small talk. While successful in building trust - particularly with extroverts - a subsequent paper (Bickmore and Cassell, 2005) demonstrated the need for incorporating nonverbal behavior into the model. Since then, Bickmore and his colleagues have gone on to develop a model that describes strategies for an agent to build a relationship with a user over time.

Until recently, much like the early work described above, these systems have primarily engaged in a set of predetermined conversational strategies without associated updates in underlying goals or representations of the user or the user-system dyad (Vardoulakis et al., 2012). While not always successful at promoting rapport, these strategies have had positive effects on the non-dyadic construct of engagement (Bickmore et al., 2011). (Bickmore and Schulman, 2012) has relied on accommodation theory to design conversational strategies intended to generate discourse that matches a user's level of intimacy, and to increase intimacy. The prior goal was met but not the latter, perhaps because, as the authors themselves indicate, the model of intimacy was quite simplistic, without the kinds of goals, subgoals, and conversational strategies laid out here. On the other hand, accommodation theory provided a successful means for assessing the user's level of intimacy, which bears keeping in mind for future work. Following on from this work, (Sidner, 2012) developed a planning algorithm that keeps track of the intimacy level of the user, and produces session plans that target both relational and task goals. The activity planning approach seems promising, however the session plans appear to be made up of activities that are appropriate at a particular level of closeness rather than activities that have been shown specifically to *increase* closeness. Our approach, whereby conversational strategies target sub-goals that specifically manage rapport, might be more successful at moving the system and user further along on the relational continuum.

An alternative approach is represented by the work of Gratch and colleagues (Gratch et al., 2006; Huang et al., 2011), who target immediate rapport in the service of implementing a sensitive listener. In this work, the level of goals and conversational strategies are avoided, and instead the agent attempts to elicit the experience of rapport by working at the level of observable phenomena - coordinating its nonverbal behavior to the human user. Rather than treating rapport as a dyadic or interpersonal construct, they address it similarly to other display functions and perhaps not surprisingly, as with other engaging displays, they have found increased user engagement. Most recently they have extended this approach to the analysis of the nonverbal behaviors that accompany intimate self-disclosure (Kang et al., 2012). However, by not taking into account the relative roles of the two interlocutors, and the nature of their relationship, they have ignored the significant difference in conversational strategies between interlocutors with different levels of power in the relationship.

In contrast to the prior work described here, our work distinguishes between the dyad's goals (overarching goals such as "create rapport" or sub-goals such as "index commonality"), their conversational strategies (such as "violate sociocultural norms through rude talk" or "initiate self-disclosure") and the observable verbal and nonverbal phenomena that instantiate those phenomena (such as mutual eye gaze, embarrassed laughter, or insults). This tri-partite distinction allows us to generate the same behaviors (insults, for example) in different contexts (early or late in the relationship) to achieve different goals (destroy rapport or enhance it). The unit of analysis of the computational model we present is the dyad, with system state updates impacting the model of the user, and of the user's model of the system, and particular weight placed on intrinsically dyadic constructs such as reciprocity.

2.3 Social Science Literatures for Rapport Management

(Tickle-Degnen and Rosenthal, 1990)'s work on the changing nonverbal expression of rapport over the course of a relationship has had significant impact on the development of virtual agents. They provide an actionable starting point by outlining the experience of rapport as a dynamic structure of three interrelating behavioral components: positivity, mutual attentiveness and coordination. Behavioral positivity generates a feeling of friendliness between interactants; mutual attentiveness leads to an experience of connectedness; and behavioral coordination evokes a sense of "being in synch". The work posits that the relative weights of those components change over the course of a relationship; the importance of mutual attentiveness remains constant, while the importance of positivity decreases and that of coordination increases.

While (Tickle-Degnen and Rosenthal, 1990)'s work is predicated on a dual level of analysis - what they call "molecular" and "molar," researchers in virtual agents have relied more on the molecular level, meaning that they have translated (Tickle-Degnen and Rosenthal, 1990)'s components directly into observable behavioral expression or action. (Tickle-Degnen and Rosenthal, 1990), however, propose that it is the molar level that is more predictive - that is, that theory should attend to the conversational strategies and goals of communication that interactants use to be positive, be attentive and to coordinate. In fact, they suggest that "initial encounters are rigidly circumscribed by culturally acceptable and stereotypical behavior" while, after some time, "rather than following more culturally-defined communication conventions, they would develop their own conventions and show more diversity in the ways they communicate thoughts to one another." This aspect of their work has largely been ignored in subsequent computational approaches to rapport. In the development of agent models and an architecture to realize them, however, this leaves us less than well-informed about what the agents should do. How do we determine what is meant by "stereotypical behavior" or "more diversity in the ways they communicate"? How should we represent the goals of two interactants and conversational strategies to fulfill the goals? In the current work, then, we discuss a broad range of literature that allows us to understand the kinds of strategies that interactants use in rapport management, and the kinds of goals and functionality those interactants intend. As we do so, we pay particular attention to the dyadic nature of these constructs, and how they change over the course of a relationship. Our review focuses on 3 top-level goals that make up rapport - **face management**, **mutual attentiveness**, and **coordination** - and some of the subgoals that achieve those top-level goals - such as *becoming predictable*, *appreciating the other's true self*, and *enhancing the other's face*. We also describe many of the conver-

sational strategies that achieve those goals - initiating mutual self-disclosure, adhering to behavioral expectations or norms, and so forth.

(Spencer-Oatey, 2005) offers an alternative approach to (Tickle-Degnen and Rosenthal, 1990)'s to conceptualizing the strategies and behaviors that contribute to rapport, and we find it more complete and more convincing for our purposes. She points out that rapport management comprises the task of increasing rapport, but also maintaining, and destroying it. In her perspective, each of these tasks requires management of face which, in turn, relies on behavioral expectations, and interactional goals. Our data support the tremendous importance of face, as the teens alternately praise and insult one another, all the while hedging their own positive performance on the algebra task in order to highlight the performance of the other. The data also contain numerous examples of mutual attentiveness and coordination as putative input into rapport management, but we found it difficult to code positivity independently of its role in face. Our formulation below, therefore, posits a tripartite approach to rapport management, comprising mutual attentiveness, coordination, and face management.

Face management: (Brown and Levinson, 1978) define positive face as, roughly, a desire by each of us to be approved of. They posit that politeness functions to avoid challenging that desire, as well as to boost the other's sense of being approved, while *face-threatening acts* (FTA) challenge face. (Spencer-Oatey, 2008a), however, points out that this definition ignores the interpersonal nature of face, and she defines "identity face" as the desire to be recognized for one's positive social identity, as well as one's individual positive traits. In this context, FTAs can challenge one's sense of self or one's identity in the social world. On the flip-side, *face-boosting acts* can create increased self-esteem in the individual, and increased interpersonal cohesiveness - or rapport - in the dyad. Of course (Spencer-Oatey, 2005) points out that what constitutes politeness, other face-boosting acts, and FTAs, is not fixed, and is largely a subjective judgement about the social appropriateness of verbal and non-verbal behaviors. She attributes these judgments about social appropriateness to our "sociality rights and obligations" - how we feel entitled to be treated based on the behaviors we expect from others – which in turn derive from sociocultural norms, including the relative power and status of the two members of the dyad, and interactional principles. Fulfilling these rights and obligations induces a feeling of being approved and, in turn, increases rapport.

What, however, are these sociocultural norms and interactional principles? A key aspect of the theory laid out here is that *behavioral expectations* (the instantiation of "sociality rights and obligations") are allied with sociocultural norms early in a relationship, and become more interpersonally determined as the relationship proceeds. Thus, the stranger dyads in our data spend a fair amount of time agreeing with one another when they first meet, in ways that fit upper middle class politeness norms (when asked what he wants to be when he grows up, one teen responds "I kind of want to be a chef" to which the other politely responds "I'd think about that too"). Friends, on the other hand, are less likely to demonstrate polite responses (one teen asks the other "wait why do you have to keep your hat on" to which the other responds "it's [his neck] not supposed to be in the sun" and receives in reply "yeah it's really swollen and ugly"). In both cases while the behavioral expectations have changed (politeness has been replaced by teasing), the fact of meeting them continues to be rapport-increasing.

How does one learn enough about the other to adapt behavioral expectations? **Mutual attentiveness** is an important part of the answer, as (Tickle-Degnen and Rosenthal, 1990) have

described. Mutual attentiveness may be fulfilled by providing information about oneself through small talk (Cassell and Bickmore, 2003) and self-disclosure (Moon, 2000). Social penetration theory (Taylor and Altman, 1987) describes the ways in which, as a relationship deepens, the breadth and depth of the topics disclosed become wider and deeper, helping the interlocutor to gain common ground as a basis for an interpersonally-specific set of behavioral expectations. Self-disclosure, however, plays another role in rapport-building, as when successful it is reciprocal (Derlega et al., 1993) – self-disclosure in our data is most often met with reciprocal self-disclosure at a similar level of intimacy. This kind of mutual responsiveness signals receptivity and appreciation of another's self-disclosure (Derlega et al., 1993) and the very process enhances **coordination** among the participants (much as we argued is the case for small talk (Cassell and Bickmore, 2003)), likewise increasing a sense of rapport. The goal of coordination as a path to rapport is also met by verbal and nonverbal synchrony (Zanna, 1999), and this is common in our own data.

In addition, while self-disclosure is not always negative, it may be, and this is a way to challenge one's own face, and thereby boost the face of the other. For that reason it is common in rapport management. In our own data, for example, strangers quickly began to share superficial negative facts about themselves, such as their presumed poor performance on the algebra pre-test at the beginning of the session. When met with a self-disclosing utterance at the same level of intimacy and with the same negative valence ("oh my gosh I could not answer like half of those"), the interlocutors increased mutual gaze and smiling, and proceeded to more intimate topics, such as their poor performance at keeping their pets alive. In fact, (Bronstein et al., 2012) found that in a negotiation setting not reciprocating negative self-disclosure led to decreased feelings of rapport. (Treger et al., 2013) point out the role of humor in rapport; it is a particularly interesting rapport management strategy as it too follows behavior expectations, whereby generally-accepted humor is successful early in the relationship, and humor that violates sociocultural norms may be successful as a strategy to increase liking and rapport only later in the relationship. In our data from teenagers, this rule is only sometimes observed, and the effect of humor that violates behavior expectations is swift and negative.

Self-disclosure, then, serves multiple goals in rapport management. Yet another is to reveal aspects of one's "true self" as a way of indicating one's openness to being truly seen by the other, and hence one's availability for rapport. According to (Rogers, 1966), the "true-self" is composed of important aspects of one's identity that are not always validated in one's daily life. People are highly motivated to make these important aspects of identity a 'social reality' - to have these attributes acknowledged by others so that they become authentic features of their "self-concept" (Bargh et al., 2002). This explains *why* interlocutors engage in self-disclosure - perhaps even *why* rapport is sought in interactions with strangers.

Based on the literature surveyed above, it is clear that mutual attentiveness to, and learning about and adhering to, the behavioral expectations of one's interlocutor is helpful in building rapport. Initially, when interactants are strangers, without any knowledge of their interlocutor's behavioral expectations, they adhere to a socioculturally-ratified model (general expectations established as appropriate in their cultural and social milieu). This may include behaving politely and in accordance with their relative social roles. As the relationship proceeds, interlocutors increasingly rely on knowledge of one another's expectations, thereby adhering to a shared and increasingly interpersonally-specific set of sociality rights and obligations, where more general norms may be purposely violated in order to accommodate each other's behavioral expectations.

Why, however, might two interactants violate sociocultural norms when others around them are adhering to those norms? (Baumeister and Leary, 1995) suggests that people have an unconscious motivation to affiliate themselves to a group, which drives them to participate in social activities and search for long-term relationships. The fact of violating sociocultural norms may in fact reinforce the sense that the two belong in the same social group and this may enhance their unified self-image (Tajfel and Turner, 1979) through reinforcing the sense of in-group connectedness through a comparison with other individuals who don't know these specific rules of behavior. This is supported by our own findings on peer tutoring, whereby rudeness predicts learning gain (Ogan et al., 2012). We know that rapport between teacher and student increases learning. When tutor and tutee are strangers, their behavior complies with sociocultural norms. Impoliteness may reduce the learning gain in strangers by challenging rapport through violating those sociocultural behavioral expectations. When tutor and tutee are friends, however, they have knowledge of one another's behavioral expectations and are thus able to follow interpersonal norms and sacrifice sociocultural norms. Rudeness, may be a part of the interpersonal norms. It may also be a way to cement the sense that the two are part of a unified group, and different from those around them. The topics they are rude about may also serve to index commonalities between the two, as referring to shared experience also differentiates in-group from out-group individuals.

2.4 Study Context



Figure 2.1: Camera View 1 and Camera View 2

Reciprocal peer tutoring data was collected from 12 American English-speaking dyads (6 friends and 6 strangers; 6 boys and 6 girls), with a mean age of 13 years, who interacted for 5 hourly sessions over as many weeks (a total of 60 sessions, and 5400 minutes of data), tutoring one another in algebra (Yu et al., 2013). Each session began with a period of getting to know one another, after which the first tutoring period started, followed by another small social interlude, a second tutoring period with role reversal between the tutor and tutee, and then the final social time. The setting is shown in Figure 2.1 We chose peer tutoring as it is a domain in which rapport has been shown to have a positive effect on student learning see (Ogan et al., 2012).

Prior work demonstrates that peer tutoring is an effective paradigm that results in student learning (Sharpley et al., 1983), making this an effective context to study dyadic interaction with a concrete task outcome. Our student-student data, in addition, demonstrates that a tremendous amount of rapport-building takes place during the task of reciprocal tutoring (Sinha and Cassell, 2015b).

2.5 Theoretical Computational Model of Rapport Management

The literature review above, while not allowing each component sub-goal or strategy the space it deserves, provides a sense of the complexity, but also of the mundane nature of rapport management between people. We wish to be seen and known the way we truly are, and we want the way we are to be approved; we desire affiliation with a social group; we are more comfortable when the behavior of our interlocutors matches our expectations; we wish for the success of our interpersonal and our task goals. These common sense and everyday goals work together to lead us to desire rapport, and to build it, even with strangers, and to put effort into maintaining it with friends and acquaintances. In order to represent these goals and desires in a computational

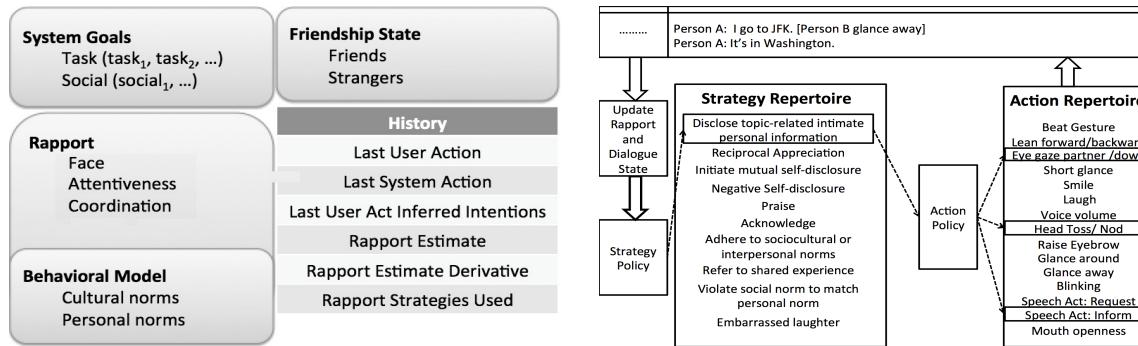


Figure 2.2: Dyadic state (left) and Strategy/Action repertoire (right)

model, we must take into account the fact that while rapport is dyadic, it nevertheless depends on the cognition, actions, beliefs and intentions of each interlocutor, and on the perception by each interlocutor of these aspects of the mind of the other interlocutor. In the computational model, therefore, we represent the state of each participant, and of that participant's perception of the state of the interlocutor, which enables us to reason about the cognition and rapport orientation (enhancement, maintenance, destruction) of the dyad, based on observable behaviors. More specifically, Figure 2.2(left) presents the *dyadic state*, which may be updated after each user's turn or incrementally. Figure 2.2(right) displays how a user and system state leads to a choice of *Strategy* and then of *Action* (although the latter is beyond the scope of the current chapter). Of course, in order to allow rapport state monitoring and management, we need to detect the goals and conversational strategies of the interlocutors on the basis of the behaviors we observe them engaging in, and we need to assess their contribution to each rapport orientation. Below, for rapport enhancement, maintenance and destruction we list, from the perspective of the agent trying to achieve those goals, the strategies and their contribution to the series of sub-goals and interrelating behavioral components of rapport we laid out above - face, mutual attentiveness, coordination. The conversational strategies enumerated here are no doubt not exhaustive. However they include all phenomena found in the literature that were also represented in our data.

In the **rapport-enhancement** orientation (Figure 2.3), people are assumed to begin at state T_1 (stranger) and to have a desire to build rapport with each other, for the reasons laid out above. If we regard rapport-enhancement as a shared task of the dyad, there are different paths to achieve it. In terms of face, people might establish the sub-goal of boosting the interlocutor's face in order to achieve the goal of increasing rapport. Some conversational strategies to accomplish

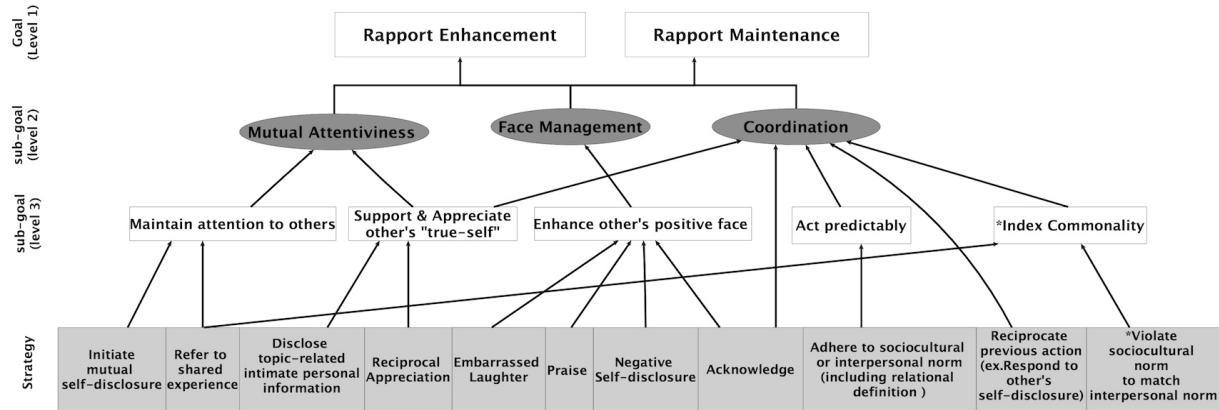


Figure 2.3: Social Functions and Conversational Strategies for Rapport Enhancement and Maintenance

this are to self-disclose negative information, to praise or acknowledge the other's social value, or embarrassed laughter. Social comparison theory (Festinger, 1954) describes how individuals are able to realize and claim more positive social value for themselves through comparison with the other's weaknesses. Our peer tutors illustrate this when they engage in embarrassed laughter around their weaknesses in algebra, giving an opportunity for their partner to feel more competent.

As described above, predictability is a core part of coordination. In order to achieve this sub-goal, interactants adhere to behavior expectations. At the initial state T_1 , the expectations are guided by sociocultural norms which include the obligation to engage in social validation of the interlocutor's self-disclosures, and to reciprocate with similarly intimate self-disclosure. This also functions to signal attentiveness to the interlocutor. In fact, initiating mutual self-disclosure is a compelling strategy for learning about an individual at the initial stage of the relationship as well as for signaling attentiveness. In our data we also observed that peers often demonstrate mutual attentiveness by referring to past shared experience. As well as increasing common ground, acknowledging and reciprocating reference to previous experience function to increase coordination.

In the **rapport-maintenance** orientation (Figure 2.3), people are assumed to begin at state T_2 (Acquaintance) and have a desire to maintain the current harmonious relationship. Those marked with (*) refer to rapport maintenance only. Typically, friends have some knowledge of each other's behavioral expectations and in order to maintain high rapport, dyads mark their affiliation with one another, and their shared membership in a social identity group. Indexing commonality strengthens connectedness between in-group members. Compared to stranger peers, friend peers refer to more intimate shared experiences. Moreover, contrary to the sociocultural norms that govern behavior during rapport enhancement, friends may violate sociocultural norms to match their interlocutor's behavioral expectations for example, through rudeness to one another or swearing, both of which were common among friends in our corpus.

In the two orientations just described, we presented strategies for building and maintaining rapport with our interlocutor. However, the **rapport-destruction** orientation is useful in the sense that detecting it will help us choose appropriate rapport "recovery" strategies. (Zhao et al., 2014) provides more details about rapport-destruction strategies.

2.6 Conclusion

Leveraging a broad base of existing literature and a corpus of data of friends and strangers engaging in peer tutoring, we have made steps towards a unified theoretical framework explaining the process of enhancing, maintaining and destroying rapport in human to human interaction. It should be noted that in this chapter we have traced the relationship between rapport management goals and sub-goals and their associated conversational strategies. We have occasionally described how a conversational strategy is instantiated by a set of observable verbal and nonverbal actions, which will provide quantitative analysis in the following chapters.

Chapter 3

Computational Architecture for Socially-Aware Framework

3.1 Introduction

In the previous chapter, we introduce our theoretical framework of rapport. Now, we induce a modular-based computational architecture to operationalize this framework, which will serve as a personal assistant in a conference and is functioned to facilitate rapport with human user along with carrying task of recommending session to attend and people to meet in a conference. The goal of the system is to leverage rapport to elicit personal information from the user that can be used to improve the helpfulness and personalization of system responses. We will review the function of each module in this architecture and the details of our developed modules will be discussed in the next following chapters.

3.2 Computational Architecture

Figure 3.1 shows the overview of the architecture. Our developed modules in this thesis are **Conversational Strategy Classifier**(Chapter 4.2),**Rapport Estimator**(Chapter 4.3) and **Social Reasoner**(Chapter5).We integrate them together with other common components of a dialog system such as ASR, NLU and TTS.

All modules of the system are built on top of the Virtual Human Toolkit (Hartholt et al., 2013).During the recognition and understanding procedures, Microsoft’s Cognitive Services API converts speech to text, which is then fed to Microsoft’s LUIS (Language Understanding Intelligent Service) to identify user intents. OpenSmile (Eyben et al., 2010) extracts acoustic features from the audio signal, including fundamental frequency (F0), loudness (SMA), jitter and shimmer, which then serve as input to the rapport estimator and the conversational strategy classifier modules.Conversational strategy classifier will automatically recognize particular styles and strategies of talking that contribute to building, maintaining or sometimes destroying a budding relationship. OpenFace (Baltrušaitis et al., 2016)) detects 3D facial landmarks, head pose, gaze and Action Units, and these also serve as input to the rapport estimator.Rapport estimator provides the score of current relational state between the user and system. In decision-make step,task

reasoner that focuses on obtaining information to fulfill the user's goals, and a social reasoner that chooses ways of talking that are intended to build rapport in the service of better achieving the user's goals. Finally, on the basis of the output of the dialog manager (which includes the current conversational phase, system intent, and desired conversational strategy) sentence and behavior plans are generated. The generated sentence plan is sent to BEAT, a non-verbal behavior generator (Cassell et al., 2004), which tailors a behavior plan (including relevant hand gestures, eye gaze, head nods, etc.) and outputs the plan as BML (Behavior Markup Language), which is a part of the Virtual Human Toolkit (Hartholt et al., 2013). This plan is then sent to SmartBody, which renders the required non-verbal behaviours.

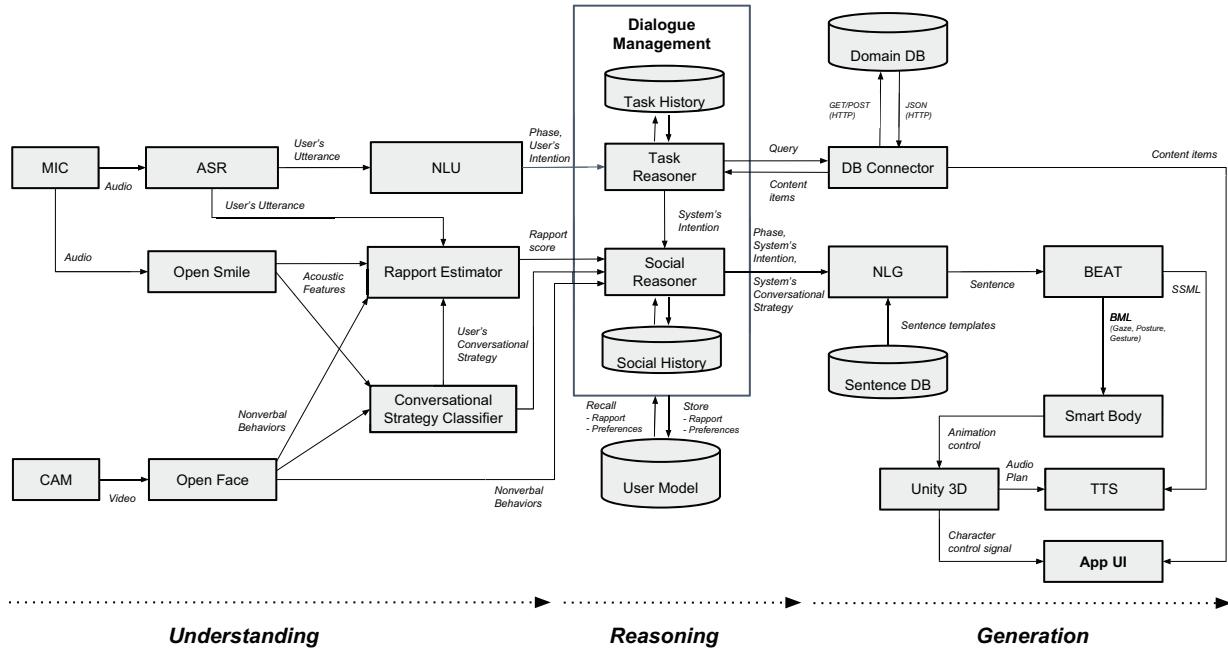


Figure 3.1: Computational Architecture of dyadic rapport

3.3 Dialog Examples

Our integrated system was demoed at the SIGDIAL conference. Sample dialogue in Appendix is extracted from an actual interaction with the system, annotated with the outputs of the different modules as the system works to meet social and task goals.

Chapter 4

Multimodal Behavior Understanding in the Social Context

4.1 Socio-Cognitive Effects of Conversational Strategy Congruence

4.1.1 Introduction

In chapter 2, we introduce our computational model of rapport. As conversational strategies contribute to building, maintaining (or, sometimes, destroying) a budding relationship, it is important to understand what conversational strategies people use, whether they use some more than others, and whether particular ones are more useful than others in particular learning or social contexts (perhaps some work better with boys than girls, or some with old friends rather than new, or some might work better in social situations while others in classroom work etc). In addition, it is important to understand the time-bound patterns of reciprocity, synchrony, or the lack thereof in the use of these conversational strategies to see if not just the type of strategy but also the mutuality of its use, and the dynamics of its use over time plays a role in the impact of its use.

Therefore, as a follow-up experimental study, we leverage structure from the patterns of conversational strategy usage (both cumulative and temporal) by students engaged in reciprocal peer tutoring, and examining their impact on learning and rapport. Specifically, we looked at the conversational strategies of self-disclosure, reference to shared experience and praise and operationalized two measures to quantify the similarity in their usage by two partners : a)first, absolute difference in the number of strategies used, b)second, a dynamic time warping based distance to capture alignment in the timings of strategy usage. Furthermore, since researchers have long posited that friends learn better together than do strangers, we investigated how friends and strangers differ in their conversational strategy exchange patterns. In addition, as prior work has found differences between boys and girls in the use of relationship-building talk, we looked at gender differences. Finally, we examined how interlocutors differ while working in task vs. social conversations, as well as in their interaction with each other over a period of weeks.

4.1.2 Related Work

The social exchange theory, which defines social behaviors as an exchange (Homans, 1958; Hill and Stull, 1982) motivates our analysis. During the development of relationships, social exchange is regulated by a series of obligations (Emerson, 1976) - how we feel entitled to respond based on the behaviors we expect from others (for e.g, desire to be approved of). Some prior work has proposed that reciprocity is a very important social norm in the early stages of a relationship (Altman, 1973). Conversational strategies can be perceived as social bids. The degree to which interlocutors are successful determines how these exchange patterns will vary over time. For instance, there is always risk and benefit involved during self-disclosures (Petronio, 2012). The costs of disclosing are increased vulnerability and less privacy. The benefits are increased trust, rapport and reciprocation, which could outweigh the costs (Ioinson and Paine, 2007). Therefore, we are interested in investigating how peer-directed social bids, facilitated by the conversational strategies of self-disclosure, reference to shared experience and praise, affect learning and rapport outcomes.

4.1.3 Experiment Setup

In this study, we conduct our experiment on CMU reciprocal peer tutoring dataset(Yu et al., 2013), which has been explained in chapter 2. Since our goal is to explore socio-cognitive effects of conversational strategies congruence, we introduce both learning outcome and rapport outcome in the following.

Learning Outcome

For every reciprocal peer tutoring session, the tutee was provided with a working sheet comprising of ≈ 10 questions on linear equations, which were to be solved and briefly explained step-by-step. In addition, the tutor was given a correctly solved version of the working sheet that he/she used to guide the tutee in the tutoring period.

To assess learning outcomes during and after the process of tutoring, we computed the following two measures reflecting problem correctness: a)**L1 attempted:** Total percentage of problems correctly solved by the tutee in each of the peer-tutoring sub-sessions in a session, out of total problems attempted in the working sheet. A question in the working sheet was marked as attempted, if at least one step was partially or fully solved, b)**L2 solved:** Total percentage of problems correctly solved by the tutee in each of the 2 peer-tutoring sub-sessions in a session, out of total problems present in the working sheet.

Rapport Outcome

After each session, both participants in the dyad completed 7 point likert scale (1 = Disagree Strongly; 7 = Agree Strongly) questionnaires, reflecting the dimensions of **Attentiveness** (3-item scale indexing interest, attention and respectfulness of the partner towards the speaker, Cronbach $\alpha = 0.42$), **Positivity** (2-item scale indexing friendliness and warmth towards the partner, $\alpha = 0.72$), **Coordination** (3-item scale indexing whether partners felt in sync, could say everything that they wanted to say and that the interaction was not frustrating, $\alpha = 0.64$), and **Long Term Rapport** (3-item scale indexing whether the partners felt that they knew each other, were more comfortable and had greater liking compared to the previous interaction session, $\alpha = 0.78$). In addition, the

questionnaire asked about **Self-efficacy** (7-item scale indexing whether the partners thought they were good tutors, learned a lot from tutoring and were concerned about tutoring quality, motivation and impact on the tutee, $\alpha = 0.5$).

In order to compute a dyadic measure from individual questionnaire ratings, we computed the following two measures: a)**R1 total**: Total score for each questionnaire dimension, calculated by addition of individual questionnaire scores, b)**R2 mean&sd**: Mean of the score for each questionnaire dimension for the dyad, subtracted by the standard deviation. Intuitively, this metric will be higher if average questionnaire scores are higher for the dyad, as well as individual variability from the mean is lower, and vice versa.

4.1.4 Methodology

Coding of Conversational Strategies

In order to construct a reliably annotated corpus, we employed 3-5 human annotators to code conversational strategies that prior work has shown to contribute to rapport. In this section, we explored conversational strategies of self-disclosure, reference to shared experience and praise. Annotators were provided with explicit definitions and examples to use in making their judgment(see Appendix). Inter-rater reliability of conversational strategy annotations, computed via Krippendorff's alpha was 0.753 for self-disclosure, 0.798 for reference to shared experience and 1.0 for praise. After achieving high enough inter-rater reliability, most of the sessions were coded by independently by the annotators. Below, we briefly describe the rationale behind our coding manuals, along with example utterances from our dataset depicting these three conversational strategies.

Operationalizing Similarity Constructs

We utilized dynamic time warping (DTW) to obtain a global distance that can characterize how conversational strategy usage for each partner in the dyad is aligned in time. Originally presented by (Kruskal and Liberman, 1983) for speech recognition purposes, this technique allows two time series that are similar but locally out of phase to align in a nonlinear manner. In our case, each element in the two time series refers to time from the start of a peer tutoring session (in seconds) at which each individual in the dyad used certain conversational strategy. Concretely, given these two time series, say $A = [a_1, \dots, a_n] \in \mathbb{R}^{1 \times n}$ and $B = [b_1, \dots, b_n] \in \mathbb{R}^{1 \times n}$, DTW is a technique to align A and B such that the sum of the Euclidean distances between the aligned samples is minimized. In order to perform this alignment, DTW can distort (or, as (Kruskal and Liberman, 1983) call it, “warp”) the time axis - compressing it at some places and expanding it at others.

Thus, by viewing the time axis as a stretchable one, DTW is able to match (via construction of a warping path) a point of time series A even with surrounding points of time series B . Minimum global dissimilarity, or DTW distance can be assumed as the stretch-insensitive measure of the inherent difference between two given time series. Furthermore, the shape of the warping curve itself provides information about which point matches which, i.e., the pair wise correspondences of time points can be easily inspected.

This warping path is a central part of comparing the two time series, since it determines which points match and are to be used for calculating the distance between the two time series. One simplistic way, for instance, is linear matching, that aligns the i^{th} point of the first curve with

the i^{th} point of the second curve. Because this matching is very sensitive to small distortions in the time axis, a more computationally expensive way is to perform a complete matching. This technique calculates the distance between every point of the first curve and every point of the second curve. For every point, the smallest distance to the other curve is decided. These distances are summed and divided by the number of points. Each point can match with no more than one point of the other curve.

In contrast, a non-linear (elastic) alignment provided by DTW produces an intuitive similarity measure, allowing similar shapes to match even if they are locally out of phase on the time axis, by allowing elastic shifting in order to detect similar shapes with different phases. (Rabiner and Juang, 1993) provide a more comprehensive technical description of the DTW algorithm.

To investigate similarity in the pattern (timing) of conversational strategy usage, we employed the *dtw* package in *R* (Giorgino, 2009), and selected the following parameters: a)First, we utilized the *symmetric2* step-pattern (Sakoe and Chiba, 1978) that lists transitions allowed while searching for the minimum distance path between the two time series, with the constraint that one diagonal step costs as much as the two equivalent steps along the sides. Intuitively, step-patterns limit the maximum amount of time stretch and compression allowed at any point of the alignment, b)Second, we performed an open-ended alignment, meaning that we freed the endpoint of time series *B* in order to allow for a partial match. Intuitively, relaxing the end-point constraint results in computing the alignment which best matches all of time series *B* with a leading part of time series *A*, c)Third, we normalized the DTW distance by the length of the two input time series, in order to accommodate time-series of varying lengths (certain dyads, for instance, do lot more self-disclosure relative to other dyads).

Finally, since conversational strategy usage by the partners in the dyad not only varies in terms of expressive frequency, but also in terms of time progression, we computed two measures reflective of similarity between partners in the dyad: a)**Diff**: This metric measures the absolute difference between the number of a specific conversational strategy usage by both students in a dyad. Thus, a lower difference would imply that the count of a specific conversational strategy is very similar for the dyad, b)**Diff + Time**: Since **Diff** metric cannot take into account the temporal distribution of conversational strategies, we utilized the normalized DTW distance obtained from the time warping algorithm as a second measure reflective of the similarity in the pattern of timings of conversational strategy usage.

4.1.5 Explanatory Analysis

We conducted a four-way $2 \times 2 \times 2 \times 5$ repeated measures ANOVA to investigate the effect of gender (male, female), relationship status (friends, strangers), period (social, task) and session (1, 2, 3, 4, 5) on the a)total conversational strategy usage by partners in a dyad, b)absolute & DTW difference in the number of usages by partners in a dyad. Period and session were used as within-subject repeated measures.

For all statistically significant effects ($p < 0.05$) reported, we also looked at effect size (Cohen's d) in order to assess the practical significance of these results. In essence, effect size is the difference between two means (e.g., friends minus strangers) divided by the pooled standard deviation (adjusted with weights for the sample sizes) of the two conditions (Ellis, 2010).Figure 4.1 demonstrates most of our findings. Next, we computed correlations (Pearson r , Spearman Rank ρ) to find relationships among the outcome variables of learning, rapport and operationalized

measures of conversational strategy similarity. Significance of the correlation was assessed via two tailed t-test. Since the total conversational strategy usage hides information about the exchange patterns of the individuals involved in peer tutoring, we were interested in testing the impact of only conversational strategy similarity on socio-cognitive outcomes. All details of the analysis are provided in (Sinha et al., 2015).

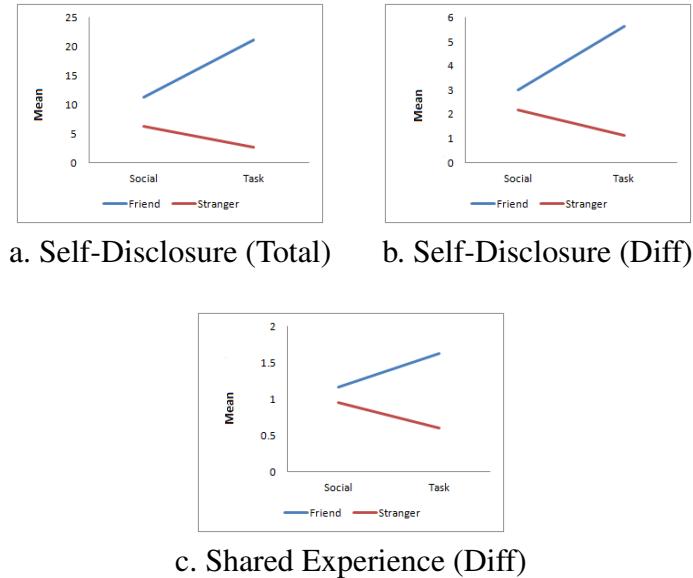


Figure 4.1: Plots depicting significant interaction effects from the repeated measures ANOVA

4.1.6 Conclusion

To summarize, in this work, we explored how the similarity in aggregated count of conversational strategies by partners, as well its temporal variations, relate to rapport and learning. We discovered significant effects that explain importance of gender and relationship status in deciphering conversational strategy exchange patterns, as well as a different set of rules governing social exchanges within these settings.

4.2 Predictive Model for Conversational Strategies Recognition

4.2.1 Introduction

In this section, we propose a technique to automatically recognize conversational strategies. We demonstrate that these conversational strategies are most effectively recognized when verbal (linguistic), visual (nonverbal) and vocal (acoustic) features are all taken into account.

4.2.2 Related Work

(Wang et al., 2016) developed a model to measure self-disclosure in social networking sites by deploying emotional valence, social distance between the poster and other people and linguistic

features such as those identified by the Linguistic Inquiry and Word Count program (LIWC) etc. While the features used here are quite interesting, this study relied only on the verbal aspects of talk, while we also include vocal and visual features.

Interesting prior work on quantifying social norm violation has taken a heavily data-driven focus (Danescu-Niculescu-Mizil et al., 2013b; Wang et al., 2016). For instance, (Danescu-Niculescu-Mizil et al., 2013b) trained a series of bigram language models to quantify the violation of social norms in users' posts on an online community by leveraging cross-entropy value, or the deviation of word sequences predicted by the language model and their usage by the user. Another kind of social norm violation was examined by (Riloff et al., 2013), who developed a classifier to identify a specific type of sarcasm in tweets. They utilized a bootstrapping algorithm to automatically extract lists of positive sentiment phrases and negative situation phrases from given sarcastic tweets, which were in turn leveraged to recognize sarcasm in an SVM classifier. Experimental results showed the adequacy of their approach.

(Wang et al., 2012) investigated the different social functions of language as used by friends or strangers in teen peer-tutoring dialogs. This work was able to successfully predict impoliteness and positivity in the next turn of the dialog. Their success with both annotated and automatically extracted features suggests that a dialog system will be able to employ similar analyses to signal relationships with users. Other work, such as (Danescu-Niculescu-Mizil et al., 2013a) has developed computational frameworks to automatically classify requests along a scale of politeness. Politeness strategies such as requests, gratitude and greetings, as well as their specialized lexicons, were used as features to train a classifier. Additional past work are discussed in (Zhao et al., 2016a).

However, a common limitation of the above work is its focus on only the verbal modality, while studies have shown conversational strategies to be associated with specific kinds of nonverbal behaviors. For instance, (Kang et al., 2012) discovered that head tilts and pauses were the strongest nonverbal cues to interpersonal intimacy. Unfortunately, here too only one modality was examined. While nonverbal behavioral correlates to intimacy in self-disclosure were modeled, the verbal and vocal modalities of the conversation was ignored. Computational work has also modeled rapport using only nonverbal information (Huang et al., 2011). In what follows we describe our approach to modeling social conversational phenomena, which relies on verbal, visual and vocal content to automatically recognize conversational strategies. Our models are trained on a peer tutoring corpus, which gives us the opportunity to look at conversational strategies as they are used in both a task and social context.

4.2.3 Ground Truth

We assessed our automatic recognition of conversational strategies against this corpus annotated for those strategies (as well as other educational tutoring phenomena not discussed here). Inter-rater reliability (IRR) for the conversational strategy annotations, computed via Krippendorff's alpha, was 0.75 for self-disclosure, 0.79 for reference to shared experience, 1.0 for praise and 0.75 for social norm violation. IRR for visual behavior was 0.89 for eye gaze, 0.75 for smile count (how many smiles occur), 0.64 for smile duration and 0.99 for head nod. Below we discuss the definitions of each conversational strategy and nonverbal behavior that was annotated.

4.2.4 Understanding Conversational Strategies

Our first objective was to understand the nature of different conversational strategies. Towards this end, we first under-sampled the non-annotated examples of self disclosure, shared experience, praise and social norm violation in order to create a balanced dataset of utterances. The utterances chosen to reflect the non-annotated cases were randomly selected. We made sure to have a similar average utterance length for all annotated and non-annotated cases, to prevent conflation of results due to lower or higher opportunities for detection of multimodal features. The final corpus (selected from 60 interaction sessions) comprised of 1014 self disclosure and 1014 non-self disclosure, 184 shared experience and 184 non-shared experience, 167 praise and 167 non-praise, 7470 social norm violation and 7470 non-social norm violation.

Second, we explored observable verbal and vocal behaviors of interest that could potentially be associated with different conversational strategies, assessing whether the mean value of these features were significantly higher in utterances with a particular conversational strategy label than in ones with no label (two-tailed correlated samples t-test). Bonferroni correction was used to correct the p-values with respect to the number of features, because of multiple comparisons involved. Finally, for all significant results ($p < 0.05$), we also calculated effect size via Cohen's d to test for generalizability of results.

Third, for visual behaviors like smile, eye gaze, head nod, we binarized these features by denoting their presence (1) or absence (0) in one clause. If an individual shifts gaze during a particular spoke conversational strategy, we might have multiple types of eye gaze represented. We performed χ^2 test to see whether the appearance of visual annotations were independent of whether the utterance belonged to a particular conversational strategy or not. For all significant χ^2 test statistics, odds ratio (o) was computed to explore co-occurrence likelihood. Majority of the features discussed in the subsequent sub-sections were drawn from qualitative observations and note-taking, during and after the formulation of our coding manuals.

Verbal

We used Linguistic Inquiry and Word Count (LIWC 2015) (Pennebaker et al., 2015) to quantify verbal cues of interest that were semantically associated with a broad range of psychological constructs and could be useful in distinguishing conversational strategies. The input to LIWC were conversational transcripts that had been transcribed and segmented into syntactic clauses.

Self-disclosure: We observed personal concerns of students (sum of words identified as belonging to categories of work, leisure, home, money, religion and death etc) to be significantly higher, than in non self-disclosure utterances with a moderate effect size ($d=0.44$), signaling that students referred significantly more to their personal concerns during self-disclosure. Next, due to the fact that self-disclosures are often likely to comprise of emotional expressions when revealing one's likes and dislikes (Sparrevohn and Rapee, 2009), we used the LIWC dictionary to capture words representative of negative emotions ($d=0.32$) and positive emotion words ($d=0.18$). Also, to formalize the intuition that when people reveal themselves in an authentic or honest way, they are more personal, humble, and vulnerable, the standardized LIWC summary variable of Authenticity ($d=1.16$) was taken into account. Finally, as expected, we found self-disclosure utterances had significantly higher usage of first person singular pronouns ($d=1.62$).

Reference to shared experience: We looked at three LIWC categories: (1) Affiliation drive, which comprises words signaling a need to affiliate such as ally, friend, social etc ($d=0.92$), (2) Time Orientation words, which capture past (mostly in ROE), present (mostly in RIE) and future focus and comprises words such as ago, did, talked, today, is, now, may, will, soon etc ($d=0.95$). Such words are not only used by interlocutors to index commonality within a time frame (Enfield, 2013), but also to signal an increased need for affiliation with the conversational partner, perhaps to indicate common ground(Clark, 1996), (3) First person plural such as we, us, our etc. In line with expectations, this feature had high effect size ($d=0.93$), since interlocutors focused on both themselves and the conversational partner.

Praise: We looked at positive emotions ($d=2.55$), since praise is one form of verbal persuasion that increases the interlocutor's confidence and boosts self-efficacy (Zimmerman, 2000). Most of the praise utterances in our dataset were not very specific or directed at the tutee's performance or effort. Also, the LIWC standardized summary variable of Emotional Tone from LIWC was considered for the sake of completeness, which puts positive emotion and negative emotion dimensions into a single summary variable, such that the higher the number, the more positive the tone ($d=3.56$).

Social norm violation: We looked at different categories of off-task talk from LIWC, such as social processes comprising words related to friends, family, male and female references ($d=0.78$), biological processes comprising words belonging to the categories of body, health etc ($d=0.30$) and personal concerns ($d=0.24$). The effect sizes across these categories ranged from moderate to low. Next, we looked at usage of swearing words like fuck, damn, shit etc and found low effect size ($d=0.13$) for this category in utterances of social norm violation. For the LIWC category of anger (words such as hate, annoyed etc), the effect size was moderate ($d=0.27$).

In our qualitative analysis of social norm violation utterances, we had discovered interactions of students to be reflective of need for power, meaning attention to or awareness of relative status in a social setting (perhaps this could be a result of putting one student in the tutor role). We formalized this intuition from the LIWC category of power drive that comprises words such as superior etc ($d=0.18$). Finally, based on prior work (Kacewicz et al., 2009) that found increased use of first-person plural to be a good predictor of higher status, and increased use of first-person singular to be a good predictor of lower status, we posited that when students violated social norms, they were more likely to freely make statements that involved others. However, the effect size for first-person plural usage in utterances of social norm violation was negligible ($d=0.07$). Table 4.1 provides complete set of results.

Vocal

In our qualitative observations, we noticed the variations of both pitch and loudness when interlocutors used different conversational strategies. We were thus motivated to explore the mean difference of those low-level vocal descriptors as differentiators among the different conversational strategies. By using Open Smile (Eyben et al., 2010), we extracted two sets of basic features - for loudness features, pcm-loudness and its delta coefficient were tested; for pitch-based features, jitterLocal, jitterDDP, shimmerLocal, F0final and also their delta coefficients were tested. pcm-loudness represents the loudness as the normalised intensity raised to a power of 0.3. F0final is the smoothed fundamental frequency contour. JitterLocal is the frame-to-frame pitch period length

Conversational Strategy	Verbal/Vocal(Speaker)	t-test value	Mean value	Effect Size
1. Self-Disclosure	LIWC Personal Concerns	t(1013)=7.06***	SD=4.13, NSD=1.58	$d=0.44$
	LIWC Positive Emotion	t(1013)=2.98**	SD=7.61, NSD=5.50	$d=0.18$
	LIWC Negative Emotion	t(1013)=5.51***	SD=5.62, NSD=2.22	$d=0.32$
	LIWC First Person Singular	t(1013)=25.87***	SD=20.12, NSD=7.77	$d=1.62$
	LIWC Authenticity	t(1013)=18.59***	SD=66.71, NSD=34.07	$d=1.16$
	pcm-loudness-sma-amean	t(1013)=4.11***	SD=0.64, NSD=0.59	$d=0.26$
2. Shared Experience	LIWC Affiliation Drive	t(183)=6.22***	SE=4.64, NSE=0.77	$d=0.92$
	LIWC Time Orientation	t(183)=6.47***	SE=24.89, NSE=15.02	$d=0.95$
	LIWC First Person Plural	t(183)=6.29***	SE=3.99, NSE=0.48	$d=0.93$
	shimmerLocal-sma-amean	t(183)=-2.21*	SE=0.18, NSE=0.194	$d=0.32$
3. Praise	LIWC Positive Emotion	t(166)=16.48***	PR=55.63, NPR=4.56	$d=3.56$
	LIWC Emotional Tone	t(166)=22.96***	PR=91.1, NPR=33.5	$d=2.55$
	pcm-loudness-sma-amean	t(166)=-3.33***	PR=0.5, NPR=0.6	$d=-0.51$
	jitterLocal-sma-amean	t(166)=2.93*	PR=0.1, NPR=0.07	$d=0.45$
	shimmerLocal-sma-amean	t(166)=2.56*	PR=0.2, NPR=0.18	$d=0.39$
4. Social Norm Violation	LIWC Social Processes	t(7469)=33.98***	VSN=17.35, NVSN=6.45	$d=0.78$
	LIWC Biological Processes	t(7469)=12.95***	VSN=4.21, NVSN=1.38	$d=0.30$
	LIWC Personal Concerns	t(7469)=10.61***	VSN=2.61, NVSN=1.33	$d=0.24$
	LIWC Swearing	t(7469)=5.85***	VSN=0.49, NVSN=0.11	$d=0.13$
	LIWC Anger	t(7469)=11.64***	VSN=1.19, NVSN=0.20	$d=0.27$
	LIWC Power Drive	t(7469)=7.83***	VSN=1.99, NVSN=1.14	$d=0.18$
	LIWC First Person Plural	t(7469)=3.23**	VSN=0.85, NVSN=0.64	$d=0.07$
	pcm-loudness-sma-amean	t(7469)=31.24***	VSN=0.69, NVSN=0.56	$d=0.72$
	F0final-sma-amean	t(7469)=26.6***	VSN=231.09, NVSN=206.99	$d=0.61$
	jitterLocal-sma-amean	t(7469)=-4.09***	VSN=0.083, NVSN=0.087	$d=-0.09$
	shimmerLocal-sma-amean	t(7469)=-7.02***	VSN=0.1818, NVSN=0.1897	$d=-0.16$

Table 4.1: Complete Statistics for presence of numeric verbal and vocal features in Self-Disclosure (SD)/Non-Self Disclosure (NSD), Shared Experience (SE)/Non-Reference to Shared Experience (NSE), Praise (PR)/Non-Praise (NPR) and Violation of Social Norms (VSN)/Non-Violation of Social Norms (NVSN). Effect size assessed via Cohen's d . Significance: ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$

deviations. JitterDDP is the differential frame-to-frame jitter. ShimmerLocal is the frame-to-frame amplitude deviations between pitch periods.

Self-disclosure: We found a moderate effect size for pcm-loudness-sma-amean ($d=0.26$). Despite often becoming excited when disclosing things that they loved or liked, sometimes students also seemed to hesitate and spoke at a lower pitch when they revealed a transgressive act. However, the effect size for pitch was negligible. One potential reason for our results not aligning with hypothesis could be consideration of utterances with annotations of enduring states as well as transgressive acts together.

Reference to shared experience: We found a moderate negative effect size for the shimmerLocal-sma-amean ($d=-0.32$).

Praise: We found negative effect size for loudness ($d=-0.51$), meaning the speakers spoke in a lower voice when praising the interlocutor (mostly the tutee). We also found positive and moderate

effect sizes for jitterLocal-sma-amean ($d=0.45$) and shimmerLocal-sma-amean ($d=0.39$).

Social norm violation: We found high effect sizes for pcm-loudness-sma-amean ($d=0.72$) and F0final-sma-amean ($d=0.61$) and interestingly, negative effect sizes for jitter ($d=-0.09$) and shimmer ($d=-0.16$). One potential reason could be that when student violate social norms, their behaviors are likely to become outliers compared to their normative behaviors. In fact, we noticed usage of “joking” tone of voice (Norrick, 2003) and pitch different than usual, to signal a social norm violation. When the content of the utterance was unaccepted by the social norms, students also tried to lower down their voice, which could be a way of hedging these violations. Table 4.1 provides complete set of results.

Visual

Computing the odds ratio o involved comparing the odds of occurrence of a non-verbal behavior for a pair of categories of a second variable (whether an utterance was a specific conversational strategy or not). Overall, we found that that smile and gaze were significantly more likely to occur in utterances of self-disclosure ($o(\text{Smile})=1.67$, $o(\text{gP})=2.39$, $o(\text{gN})=0.498$, $o(\text{gO})=0.29$, $o(\text{gE})=2.8$) compared to a non self-disclosure utterance. A similar trend was observed for reference to shared experience ($o(\text{Smile})=1.75$, $o(\text{gP})=3.02$, $o(\text{gN})=0.58$, $o(\text{gO})=0.31$, $o(\text{gE})=4.19$) and social norm violation ($o(\text{Smile})=3.35$, $o(\text{gP})=2.75$, $o(\text{gN})=0.8$, $o(\text{gO})=0.47$, $o(\text{gE})=1.67$) utterances, compared to utterances that did not belong to these categories.

The high odds ratio for gP in these results suggests that an interlocutor was likely to gaze at their partner when using specific conversational strategies, signaling attention towards the interlocutor. The extremely high odds ratio for smiling behaviors during a social norm violation is also interesting. However, for praise utterances, we did not find all kinds of gaze and smile to be more likely to occur than non-praise utterances. Only gazing at partner ($o(\text{gP})=0.44$) or their worksheet ($o(\text{gN})=4.29$) or gazing elsewhere ($o(\text{gE})=0.30$) were among the non-verbals that were significantly greatly present in praise utterances. Table 4.2 provides complete set of results for the speaker (as discussed above) and also for the listener.

4.2.5 Machine Learning Modeling

In this part, our objective was to build a computational model for conversational strategy recognition. Towards this end, we first took each clause, or the smallest units that can express a complete proposition, as the prediction unit. Next, three sets of features were used as input. The first set f_1 comprised verbal (LIWC), vocal and visual features of the speaker, informed from the qualitative and quantitative analysis as discussed above. While LIWC features helped in categorization of words used during usage of a particular conversational strategy, they did not capture contextual usage of words within the utterance. Thus, we also added bigrams, part of speech bigrams and word-part of speech pairs from the speaker’s utterance.

In addition to the speaker’s behavior, we also added two sets of interlocutor behavior to capture the context around usage of a conversational strategy. The feature set f_2 comprised visual behaviors of the interlocutor (listener) in the current turn. The feature set f_3 comprised verbal (bigrams, part of speech bigrams and word-part of speech pairs), vocal and visual features of the interlocutor in the previous turn.

Conversational Strategy	Visual (Speaker) - χ^2 test value - Odds Ratio	Visual (Listener) - χ^2 test value - Odds Ratio
1. Self-Disclosure	Smile - $\chi^2(1,1013)=20.67*** - o=1.67$ Gaze (gP) - $\chi^2(1,1013)=93.04*** - o=2.39$ Gaze (gN) - $\chi^2(1,1013)=35.1*** - o=0.49$ Gaze (gO) - $\chi^2(1,1013)=173.88*** - o=0.29$ Gaze (gE) - $\chi^2(1,1013)=120.77*** - o=1.8$	Smile - $\chi^2(1,1013)=18.63*** - o=1.63$ Gaze (gP) - $\chi^2(1,1013)=131.34*** - o=2.84$ Gaze (gN) - $\chi^2(1,1013)=73.23*** - o=0.38$ Gaze (gO) - $\chi^2(1,1013)=152.12*** - o=0.31$ Gaze (gE) - $\chi^2(1,1013)=78.92*** - o=2.37$
2. Shared Experience	Smile - $\chi^2(1,183)=4.73* - o=1.75$ Gaze (gP) - $\chi^2(1,183)=25.37*** - o=3.02$ Gaze (gN) - $\chi^2(1,183)=3.73* - o=0.58$ Gaze (gO) - $\chi^2(1,183)=27.87*** - o=0.31$ Gaze (gE) - $\chi^2(1,183)=38.13*** - o=4.19$	Smile - $\chi^2(1,183)=7.53** - o=2.07$ Gaze (gP) - $\chi^2(1,183)=33.36*** - o=3.59$ Gaze (gN) - $\chi^2(1,183)=17.68*** - o=0.32$ Gaze (gO) - $\chi^2(1,183)=16.55*** - o=0.41$ Gaze (gE) - $\chi^2(1,183)=32.45*** - o=3.92$
3. Praise	Gaze (gP) - $\chi^2(1,166)=9.94*** - o=0.44$ Gaze (gN) - $\chi^2(1,166)=37.52*** - o=4.29$ Gaze (gO) - N.S Gaze (gE) - $\chi^2(1,166)=14.44*** - o=0.30$	Gaze (gP) - $\chi^2(1,166)=14.22*** - o=0.39$ Gaze (gN) - $\chi^2(1,166)=15.19*** - o=0.33$ Gaze (gO) - $\chi^2(1,166)=24.23*** - o=3.30$ Gaze (gE) - $\chi^2(1,166)=9.77** - o=0.39$
4. Social Norm Violation	Smile - $\chi^2(1,7469)=871.73*** - o=3.35$ Gaze (gP) - $\chi^2(1,7469)=911.89*** - o=2.75$ Gaze (gN) - $\chi^2(1,7469)=34.82*** - o=0.8$ Gaze (gO) - $\chi^2(1,7469)=515.26*** - o=0.47$ Gaze (gE) - $\chi^2(1,7469)=195.17*** - o=1.67$ Head Nod - $\chi^2(1,7469)=8.06** - o=0.77$	Smile - $\chi^2(1,7469)=869.29*** - o=3.37$ Gaze (gP) - $\chi^2(1,7469)=609.06*** - o=2.27$ Gaze (gN) - $\chi^2(1,7469)=239.22*** - o=0.55$ Gaze (gO) - $\chi^2(1,7469)=110.48*** - o=0.70$ Gaze (gE) - $\chi^2(1,7469)=12.38** - o=1.14$ Head Nod - $\chi^2(1,7469)=44.51*** - o=0.56$

Table 4.2: Complete Statistics for presence of binary non-verbal features in Self-Disclosure (SD), Shared Experience (SE), Praise (PR) and Violation of Social Norms (VSN). Odds ratio signals how much more likely is a non-verbal behavior likely to occur in conversational strategy utterances compared to non-conversational strategy utterances. Significance: ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$

Finally, early fusion was applied on these multimodal features (by concatenation) and L2 regularized logistic regression with 10-fold cross validation was used as the machine learning algorithm, with rare threshold for feature extraction being set to 10 and performance evaluated using accuracy and kappa¹ measures. The table 4.3 shows our comparison with other standard machine learning algorithms such as Support Vector Machine (SVM) and Naive Bayes (NB), where we found Logistic Regression (LR) to perform better in recognition of the four conversational strategies. In next sub-section, we therefore denote the feature weights derived from logistic regression in brackets to offer interpretability of results.

4.2.6 Results and Discussion

Self-Disclosure: We could successfully identify self-disclosure from non self-disclosure utterances with an accuracy of **85%** and a kappa of **70%**. The top features from feature set f_1 predictive of speakers disclosing themselves included gazing at partner (0.44), head nodding (0.24) and not gazing at their own worksheet (-0.60) or the interlocutor's worksheet (-0.21). Head nod is

¹The discriminative ability over chance of a predictive model, for the target annotation, or the accuracy adjusted for chance

Conversational Strategy	LR	SVM	NB
Self-disclosure	Acc=0.85 $\kappa=0.7$	Acc=0.84 $\kappa=0.68$	Acc=0.83 $\kappa=0.65$
Shared Experience	Acc=0.84 $\kappa=0.67$	Acc=0.82 $\kappa=0.64$	Acc=0.79 $\kappa=0.59$
Praise	Acc=0.91 $\kappa=0.81$	Acc=0.90 $\kappa=0.80$	Acc=0.88 $\kappa=0.76$
Social Norm Violation	Acc=0.80 $\kappa=0.61$	Acc=0.78 $\kappa=0.55$	Acc=0.73 $\kappa=0.47$

Table 4.3: Comparative Performance Evaluation using Accuracy (Acc) and Kappa (κ) for Logistic Regression (LR), Support Vector Machine (SVM) and Naive Bayes (NB)

a way to emphasize what one is saying (Poggi et al., 2010), while gazing at the partner signals one's attention. Higher usage of first person singular by the speaker (0.04) was also positively predictive of self-disclosure in the utterance. The top features from feature set f_2 predictive of speakers disclosing included listener behaviors such as head nodding (0.3) to communicate their attention (Schegloff, 1982), gazing elsewhere (0.12) or at the speaker (0.09) instead of gazing at their own worksheet (-0.89) or the speaker's worksheet (-0.27). The top features from feature set f_3 predictive of speakers disclosing included no smiling (-0.30), no head nodding (-0.15) and lower loudness in voice (-0.11) from the interlocutor in the last turn.

Reference to shared experience: We achieved an accuracy of **84%** and kappa of **67%** for prediction. The top features from feature set f_1 predictive of speakers referring to shared experience included not gazing at own worksheet (-0.66), partner's worksheet (-0.40) or at the partner (-0.22), no smiling (-0.18) and having lower shimmer in voice (-0.26). Instead, words signaling affiliation drive (0.07) and time orientation (0.06) from the speaker were deployed to index shared experience. The top features from feature set f_2 predictive of speakers using shared experience included listener behaviors such as smiling (0.53) perhaps to indicate appreciation towards the content of the talk, or encourage the speaker to go on (Niewiadomski et al., 2010). Besides, the listener gazing elsewhere (0.50) or at the speaker (0.47), and neither gazing at own worksheet (-0.45) nor head nodding (-0.28) had strong predictive power. The top features from feature set f_3 predictive of speakers using shared experience included lower loudness in voice (-0.58), smiling (0.47), gazing elsewhere (0.59), at own worksheet (0.27) or at the partner (0.22) but not at partner's worksheet (-0.40) from the interlocutor in the last turn.

Praise: For praise, our computational model achieved an accuracy of **91%** and kappa of **81%**. The top features from feature set f_1 predictive of speakers using praise included gazing at partner's worksheet (0.68) indicative of directing attention to the partner's (perhaps the tutee's) work, smiling (0.51), perhaps to mitigate the potential embarrassment of praise (Niewiadomski et al., 2010) and head nodding (0.35) with a positive tone of voice (0.04), perhaps to emphasize the praise. The top features from feature set f_2 predictive of speakers using praise included listener behaviors such as head nodding (0.45) for backchanneling and acknowledgement and not gazing at partner's worksheet (-1.06), elsewhere (-0.5) or at the partner (-0.49). The top features from feature set f_3 predictive of speakers using praise included smiling (0.51), lower loudness in voice (-0.91) and overlap (-0.66) from the interlocutor in the last turn.

Violation of Social Norm: We achieved an accuracy of **80%** and kappa of **61%** for prediction. The top features from feature set f_1 predictive of speakers violating social norms included smiling (0.40), gazing at partner (0.45) but not head nodding (-0.389). (Keltner and Buswell, 1997) introduced a remedial account of embarrassment, emphasizing that smiles signal awareness of a social norm being violated and serve to provoke forgiveness from the interlocutor, in addition to being a hedging indicator. (Kraut and Johnston, 1979) posited that smiling evolved from primate appeasement displays and is likely to occur when a person has violated a social norm. The top features from feature set f_2 predictive of speakers violating social norms included listener behaviors such as smiling (0.54), gazing at own worksheet (0.32) or at the partner's (0.14). The top features from feature set f_3 predictive of speakers violating social norms included high loudness (0.86) and jitter in voice (0.50), lower shimmer in voice (-0.53), gazing at own worksheet (0.49) and no head nodding (-0.31) from the interlocutor in the last turn.

4.2.7 Post-experiment

The accuracy of detection violation of social norm is comparatively lower than other conversational strategies. Thus, we conduct a post-experiment analysis and propose a more advanced model based on our previous studies. Social norms are shared rules that govern and facilitate social interaction. Violating such social norms via teasing and insults may serve to upend power imbalances or, on the contrary reinforce solidarity and rapport in conversation, rapport which is highly situated and context-dependent. In such a sway, we hypothesize that the performance of detect social norm violation should attribute to the fact that logistic regression fails to model the dialog context during its prediction. we extend our previous work by leveraging the power of recurrent neural networks and multimodal information present in the interaction, and propose a predictive model to recognize social norm violation. Using long-term temporal and contextual information, our model achieves an F1 score of 0.705.

Model

We treated a dialog D as a sequence of clauses c_0, \dots, c_T , where T was the number of clauses in the D . Each clause c_i was a tuple $([w_0^i, \dots, w_m^i], e_i)$, where $[w_0^i, \dots, w_m^i]$ was the m words in the clause c_i , and e_i was the corresponding meta information such as the relationship of the dyad and nonverbal behavior during the generation of the clause. The handcrafted feature of size 3782 was denoted as f_i , and could be viewed as a mapping function $F : c_i \rightarrow f_i$. Meanwhile, each clause was associated with a binary label $y_i \in \{0, 1\}$ that indicates the ground truth of whether c_i is a violation of social norm. Eventually, the goal was to model $p(y_t | c_{0:t})$, the conditional distribution over whether the latest clause was a violation of social norm, given the entire history of the dialog.

- Logistic Regression Model

We first trained a L2 regularized logistic regression model using the proposed verbal and visual features f_i as inputs (leftmost in Figure 4.2). This model serves as our baseline.

- Local/Global-Context RNN Model

Past empirical results suggest two possible hypotheses of improving the model performance:

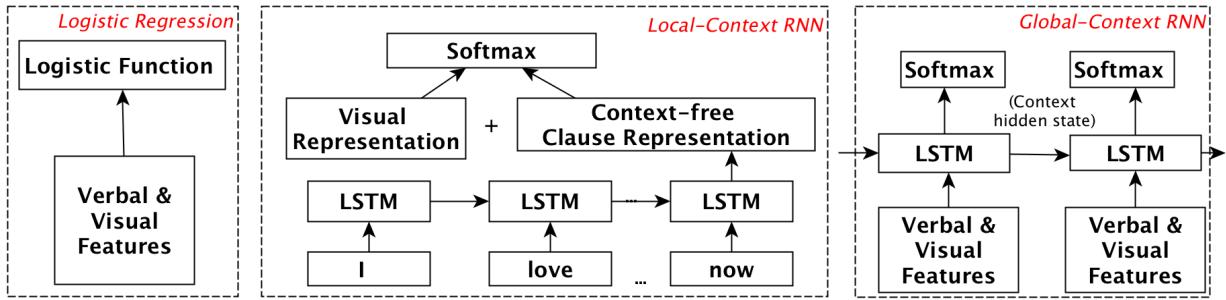


Figure 4.2: Three proposed computational models.

1. improvement in clause level representation 2. inclusion of contextual information for prediction. Therefore, we designed Local/Global-Context models to test these hypotheses. The Local-Context recurrent neural network (RNN) models the context inside a clause at the word-level by encoding word embeddings of size 300 in a clause c_i sequentially using a Long-short Term Memory (LSTM) cell of size 300. The mechanism of LSTM is defined as:

$$\begin{bmatrix} i_t \\ f_t \\ o_t \\ j_t \end{bmatrix} = \begin{bmatrix} \sigma \\ \sigma \\ \sigma \\ \tanh \end{bmatrix} W[h_{t-1}, x_t]$$

$$c_t = f_t \odot c_{t-1} + i_t \odot j_t$$

$$h_t = o_t \odot \tanh(c_t)$$

We treated last hidden LSTM output h_m^i as the clause embedding and concatenated that with the corresponding meta information vector e_i . The combined vector was linearly transformed and then fed into a softmax function.

Next our Global-Context RNN investigated the influence of clause-level context in detecting social norm violation, by using the LSTM cells to model the long-term temporal dependencies. For a fair comparison, we used the same hand-crafted feature f_i used in the logistic regression model as the representation of clause c_i . As shown in Figure 4.2, we first obtained a linear embedding of size 150 $emb_i = W_e f_i + b_i$ of f_i . Then emb_i was used as the inputs to LSTM of size 600. The hidden output h_i at each time step was fed into a multilayer perceptron (MLP) with 1 hidden layer of size 100. We applied 50% dropout regularization (Zaremba et al., 2014) at the input/output of LSTM and MLP hidden layer for better generalization. Finally the model was optimized w.r.t to the cross entropy loss. A further challenge was the length of dialog. The average number of clauses in training dialog was 817.8, which made it computationally intractable to backpropagate through the entire sequence. Therefore, truncated backpropagation through time (TBPTT) (Sutskever, 2013) was used by unrolling the network for 20 steps. The final state of LSTM of each batch was fetched into the next batch as the initial state.

Experiment Result

We observed that Global-Context RNN with 2 LSTM layers outperformed other models as showed in Table 4.4. First, by comparing logistic regression model with our best model, the result indicates the strong predictive power of long-term temporal contextual information on the task of detecting social norm violation in dialog. On the other hand, Local-Context RNN model did not achieve significant improvement on overall performance regarding to logistic regression, which means that our learned clause representation through training process has less competence compared to hand-crafted features inspired from linguistic knowledge. One potential reason for such a result could be insufficient amount of training set in order to learn a generic clause representation.

Table 4.4: Performance comparsion for the 3 evaluated models

	Precision	Recall	F-measure
Logistic Regression	0.573	0.583	0.578
Local-Context RNN	0.478	0.747	0.583
Global-Context RNN (1-layer)	0.689	0.696	0.693
Global-Context RNN (2-layer)	0.690	0.720	0.705

4.2.8 Conclusion

In this work, by performing quantitative analysis of our peer tutoring corpus followed by machine learning modeling, we learnt the discriminative power and generalizability of verbal, vocal and visual behaviors from both the speaker and listener, in distinguishing conversational strategy usage.

We found that interlocutors usually accompany the disclosure of personal information with head nods and mutual gaze. When faced with such self-disclosure listeners, on the other hand, often nod and avert their gaze . When the conversational strategy of reference to shared experience is used, speakers are less likely to smile, and more likely to avert their gaze (Cassell et al., 2007). Meanwhile, listeners smile to signal their coordination. When speakers praise their partner, they direct their gaze to the interlocutor’s worksheet, smile and nod with a positive tone of voice. Meanwhile, listeners simply smile, perhaps to mitigate the embarrassment of having been praised.

Finally, speakers tend to gaze at their partner and smile when they violate a social norm, without nodding. The listener, faced with a social norm violation, is likely to smile extensively (once again, most likely to mitigate the face threat of social norm violations such as teasing or insults). Overall, these results present an interesting interplay of multimodal behaviors at work when speakers use conversational strategies to fulfil interpersonal goals in a dialog.

4.3 Predictive Model for Rapport Assessment

4.3.1 Introduction and Motivation

Conversational strategies in our computational model of rapport function to fulfill specific social goals and are instantiated in particular verbal and nonverbal behaviors. Thus, studying the syner-

gistic interaction of conversational strategies and nonverbal behaviors on rapport management is important. In the first section of this chapter we qualitatively examine certain dyadic behavior patterns that benefit or hurt interpersonal rapport. Now, we move forward to build automated frameworks to learn fine-grained behavioral interaction patterns that index such social phenomena. The latter has received less attention, in part due to the time-intensive nature of collecting and annotating behavioral data for different aspects of interpersonal connectedness, and the difficulty of developing and using machine learning algorithms that can take the time course of interaction among different modalities and between interlocutors into account. There are three key issues that we believe should be taken into consideration when performing such assessment.

(1) When the foundational work by (Tickle-Degnen and Rosenthal, 1990) described the nature of rapport, three interrelating components were posited: positivity, mutual attentiveness and coordination. Their work demonstrated, that over the course of a relationship, positivity decreases and coordination increases. Factors such as these, then, depend on the stage of relationship between interlocutors, and therefore it is necessary to take into account the relationship status of a dyad when extracting dyadic patterns of rapport. (2) while (Ogan et al., 2012) discovered some of the common behaviors exhibited by dyads in peer tutoring to build or maintain rapport; playful teasing, face-threatening comments, attention-getting, etc., tutors and tutees were looked at separately, and each of these behaviors was examined in isolation from one another. In the current work, our interest is in moving beyond individual behaviors to focus on temporal sequences of such behaviors in the dyadic context. Likewise, (Ogan et al., 2012) did not distinguish between rapport management during task (tutoring) vs social activities. We believe that the interactions between verbal and nonverbal behaviors may manifest differently in social and tutoring periods, since the roles of a tutor and tutee are more evident in the tutoring compared to the social periods. (3) Most prior computational work examining rapport, such as (Gratch et al., 2006, 2007; Huang et al., 2011), has used post-session questionnaires to asses rapport. However, to measure the effect of multimodal behavioral patterns on rapport and better reason about the dynamics of social interaction, a finer-grained ground truth for rapport is needed.

In this section, we take a step towards addressing the above limitations. We employed thin-slice coding (Ambady and Rosenthal, 1992) to elicit ground truth for rapport, by asking naive raters to judge rapport for every 30 second slice of the hour long peer tutoring session, presented to raters in a randomized order. This, in turn allowed us to analyze fine-grained sequences of verbal and nonverbal behaviors that were associated with high or low rapport between the tutor and tutee.

As a side note, while the current section addresses these phenomena in the context of peer tutors and intelligent tutoring agents, this work analyzes rapport in the conversational strategy level, which is domain-independent. Thus, our predictive model of rapport could be easily and generally applied to other domains of dyadic interaction.

4.3.2 Related Work

Individual-focused Temporal Relations

The study of temporal relationships between verbal and nonverbal behaviors has been of prime importance in understanding various social and cognitive phenomena. A lot of this work has

focused on the observable phenomena of interaction (low level linguistic, prosodic or acoustic behaviors that can be automatically extracted) or has leveraged computational advances to extract head nods, gaze, facial action units, etc., as a step towards modeling co-occurring and contingent patterns inherent in an individual person’s behavior. Since feature extraction approaches that aggregate information across time are not able to explicitly model temporal co-occurrence patterns, two popular technical approaches to investigate temporal patterns of verbal and nonverbal behaviors are histogram of co-occurrences (Ramanarayanan et al., 2015) and motif discovery methods (Nakano et al., 2015).

Dyadic Temporal Relations

In a conversation, attending to the contribution of both interactants adds greater complexity in reasoning about the social aspects of the interaction. Listeners show their interest, attention and understanding in many ways during the speakers utterances. Such “listener responses” (Fujimoto, 2009), which may be manifested through gaze direction and eye contact, facial expressions, use of short utterances like “yeah”, “okay”, and “hm-m” etc or even intonation, voice quality and content of the words, are carriers of subtle information. These cues may convey information regarding understanding (whether the listeners understand the utterance of the speaker), attentiveness (whether the listeners are attentive to the speech of the speaker), coordination, and so forth. Several interesting past work are discussed in (Zhao et al., 2016b).

4.3.3 Study Context

In this study, we conduct our experiment on CMU reciprocal peer tutoring dataset(Yu et al., 2013), which has been explained in chapter 2.

In addition, we also annotated the entire corpus for conversational strategies such as self-disclosure (Krippendorf’s $\alpha= 0.753$), reference to shared experience ($\alpha= 0.798$), praise ($\alpha=1$), social norm violation ($\alpha= 0.753$) and backchannel ($\alpha= 0.72$) in the first pass, and reciprocity in these strategies (using a time window of roughly 1 minute) in the second pass ($\alpha= 0.77$). Finally, our temporal association rule framework comprised of nonverbal behaviors like eye gaze (Krippendorf’s $\alpha= 0.893$) and smiles ($\alpha= 0.746$).

Rapport Annotations

We assessed rapport-building via thin slice annotation (Ambady and Rosenthal, 1992), or rapidly made judgments of interpersonal connectedness in the dyad, based on brief exposure to their verbal and nonverbal behavior. Naive raters were provided with a simple definition of rapport and three raters annotated every 30 second video segment of the peer tutoring sessions for rapport using a 7 point likert scale. Weighted majority rule was deployed to mitigate bias from the ratings of different annotators, account for label over-use and under-use and pick a single rapport rating for each 30 second video segment. The segments were presented to the annotators in random order so as to ensure that raters were not actually annotating the delta of rapport over the course of the session. Prior work has shown that such reliably annotated measures of interpersonal rapport are causally linked to behavioral convergence of low-level linguistic features (such as speech rate

etc,) of the dyad (Sinha and Cassell, 2015a,b) and that greater likelihood of being in high rapport in the next 30 sec segment (improvement in rapport dynamics over the course of the interaction) is positively predictive of the dyad's problem-solving performance.

4.3.4 Method

The technical framework we employ in this work is essentially an approach for pattern recognition in multivariate symbolic time sequences, called the Temporal Interval Tree Association Rule Learning (Titarl) algorithm (Guillame-Bert and Crowley, 2012). Since it is practically infeasible to predict exactly when certain behavioral events happen, it is suitable to use probabilistic approaches that can extract patterns with some degree of uncertainty in the temporal relation among different events. Temporal association rules, where each rule is composed of certain behavioral pre-conditions (input events) and behavioral post-conditions (output events), are one such powerful approach. In our case, input events are conversational strategies and nonverbal behaviors such as violation social norms, smile etc. The output event is the absolute value of thin-slice rapport. Because interpersonal rapport is a social construct that is defined at the dyadic level, the applied framework helps reveal interleaved behavioral patterns from both interlocutors. An example of a simple generic temporal rule is given below. It illustrates the rule's flexibility by succinctly describing not only the temporal inaccuracy of determining the temporal location of output event, but also its probability of being fired.

"If event A happens at time t, there is 50% chance of event B happening between time t+3 to t+5". Intuitively, the Titarl algorithm is used to extract large number of temporal association rules (r) that predict future occurrences of specific events of interest. The dataset comprises both multivariate symbolic time sequences $E_{i=1\dots n}$ and multivariate scalar time series $S_{i=1\dots m}$, where $E_i = \{t_j^i \in \mathbb{R}\}$ is the set of times that event e_i happens and S_i is an injective mapping from every time point to a scalar value. Before the learning process, a parameter w or the window size is specified, which allows us at each time point t to compute the probability for the target event to exist in the time interval $[t, t + w]$.

The four main steps in the Titarl algorithm (Guillame-Bert and Crowley, 2012) are: (i) exhaustive creation of simple unit rules that are above the threshold value of confidence or support, (ii) addition of more input channels in order to maximize information gain, (iii) production of more temporally precise rules by decreasing the standard deviation of the rule's probability distribution, (iv) refinement of the condition and conclusion of the rules by application of Gaussian filter on temporal distribution. Confidence, support and precision of the rule are three characteristics to validate its interest and generalizability. For a simple unit rule $r: e_1 \xrightarrow{[t,t+w]} e_2$ (confidence: x%, support:y%), confidence refers to the probability of a prediction of the rule to be true, support refers to the percentage of events explained by the rule and precision is an estimation of the temporal accuracy of the predictions.

$$\text{confidence}_r = P((t \in E_1)|(t' \in E_2), t' - t \leq w) \quad (4.1)$$

$$\text{support}_r = \frac{\{\#e_2|r \text{ is active}\}}{\#e_2} \quad (4.2)$$

$$\text{precision}_r = \frac{1}{\text{standard deviation}_r} \quad (4.3)$$

4.3.5 Experimental Results

We first separated out friend and stranger dyads to learn rules from their behaviors. We also tagged the data as occurring during a social or tutoring period, and as being generated by a tutor or a tutee. We then randomly divided the friend and stranger groups into a training set (4 dyads) and test set (2 dyads). In the first experiment, we extracted a potentially large number of temporal association rules affiliated with each individual rapport state (from 1 to 7). In this experiment, for each event, we looked back 60 seconds to find behavioral patterns associated with it. A representative example is shown in figure 1, and descriptions of some of the rules in the test set whose confidence are above 50% and for whom the number of cases the rule applies to are more than 20 times are described below, divided into friends (F) and strangers (S) and into high rapport (H), defined as thin-slice rapport states 5, 6, and 7 and low rapport (L), defined as states 1, 2, and 3.

Behavioral Rules for Friends

There are 14,458 total rules for friends with confidence higher than 50%, 14,345 of which apply to friends in high rapport states. Overall, engaging in reference to shared experience, smiling while violating a social norm and overlapping speech are associated with high rapport. Examples are:

- FH 1 *One of the student smiles while the other violates a social norm (Social period)*
- FH 2 *One of the students refers to shared experience (Social period)*
- FH 3 *One student smiles and violates a social norm, and the second smiles and gazes at the partner within the next minute (Social period)*
- FH 4 *The two conversational partners overlap speech while one is smiling, following which the second starts smiling within the next minute (Social period)*
- FH 5 *The tutee reciprocates a social norm violation while overlapping speech with the tutor, following which the tutor smiles and violates a social norm (Task period) [shown in Figure 4.3]*

In contrast to the high number of rules with confidence higher than 50% for friends in high rapport, there are only 113 rules that satisfy these criteria for friends in low rapport. Some examples are:

- FL 1 *The tutor finishes violating a social norm while gazing at the tutee's work sheet, and within the next minute the tutee follows up with a social norm violation, but gazing at his/her own work sheet (Task period)*
- FL 2 *The tutor reciprocates a social norm violation without a smile and neither the tutee nor the tutor gaze at one another. Meanwhile, the tutee begins violating another social norm within the next minute (Task period)*
- FL 3 *The tutor backchannels while gazing at his/her own work sheet and does not smile. Moreover, the tutor also overlaps with the tutee in the next minute (Task period)*

Behavioral Rules for Strangers

There are 761 total rules for strangers, of which 130 are rules that apply to strangers in high rapport. In general, smiling and overlapping speech while using particular conversational strategies are associated with high rapport. Some examples are:

- SH 1 *One of the interlocutors smiles while the other gazes at him/her and begins self-disclosing, and they overlap speech within the next minute (Social period)*
- SH 2 *One of the interlocutors smiles and backchannels in the next minute (Social period)*
- SH 3 *The interlocutors' speech overlaps and the tutee smiles within the next minute (Task period)*

631 rules, then, explain strangers in low rapport. Interestingly, rules that explain low rapport among strangers most often come from task periods. In general, overlapping speech after a social norm violation leads to low rapport in strangers. Some examples are:

- SL 1 *The tutor smiles and gazes at the worksheet of the tutee while the tutee does not smile (Task period)*
- SL 2 *The tutor violates social norms while being gazed at by the tutee, and their speech overlaps within the next minute (Task period)*
- SL 3 *The tutor smiles and the tutee violates a social norm within the next 30 seconds, before their speech overlaps within the next 30 seconds (Task period) [shown in Figure 4.4]*

4.3.6 Validation and Discussion

In order to demonstrate that the extracted temporal association rules can be reliably used for forecasting of interpersonal human behavior, we first applied machine learning to perform an empirical validation, which we describe in the next subsection. The motivation behind constructing this forecasting model was to prove the automatically learned temporal association rules are good indicators of the dyadic rapport state. In the subsequent subsections of the discussion, we will discuss implications of our work for the understanding of human behavior and the design of “socially-skilled” agents, linking prior strands of research.

Estimation of Interpersonal Rapport

In addition to its applicability to sparse data, one of the prime benefits of the temporal association rule framework to predict a high-level construct such as rapport lies in its flexibility in modeling presence/absence of human behaviors and also the inherent uncertainty of such behaviors, via a probability distribution representation in time. In summary, the estimation of rapport comprises two steps: in the first step, the intuition is to learn the weighted contribution (vote) of each temporal association rule in predicting the presence/absence of a certain rapport state (via seven random-forest classifiers); in the second step, the intuition is to learn the weight of each binary classifier for each rapport state, to predict the absolute continuous value of rapport (via linear regression). For clarity, we will use the following three mathematical subscripts to represent

Relationship Status	t-test value	Mean value (Mean Square Error)	Effect Size
Friends	t(1,14)=-6.41***	Titarl=1.257, Linear Regression=2.120	-0.42
Strangers	t(1,14)=-8.78***	Titarl=0.837, Linear Regression =1.653	-0.62

Table 4.5: Statistical analysis comparing mean square regression of Titarl-based regression and a simple linear regression, for all possible combination of training and test sets in the corpus. Effect size assessed via Cohen's d . Significance: ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$

different types of index. i : index of output events, k : index of time-stamps, j : index of temporal association rules.

Each individual rapport state is treated as a discrete output event e_i , where $i = 1, 2, 3, 4, 5, 6, 7$. We learn the set of temporal association rules $R_i = \{r_j^i\}$ for each output event e_i . In the first step, a matrix M_i is constructed with $|T_i|$ rows and $1 + |R_i|$ columns, where $T_i = \{t_k^i \in \mathbb{R}\}$ denotes the set of time-stamps at which at least one of the rules in set R_i is activated. $M_i(k, j) \in [0, 1]$ denotes confidence of the rule r_j^i at the particular time point t_k^i . The extra column represents the indicator function of rapport state: $M_i(k, |R_i| + 1) = \{1, \text{if } t_k^i \in E_i; 0 \text{ otherwise}\}$. Seven random-forest classifiers ($f_i(t)$ and $t \in T_i$) are then trained on each corresponding matrix M_i using the last column (binary) as the output label and all other columns as input features (Guillame-Bert and Dubrawski, 2014). In the second step, another matrix G with $|T|$ rows and $1+|C|$ columns is formalized, where $|C|$ is the number of random-forest classifiers, $G(k, i) = f_i(t_k)$ and $T = \{t_k | t_k \in T_i, i = 1\dots7\}$. The last column is the absolute number of rapport state gathered by ground truth. This matrix is used to train a linear regression model.

For our corpus, as part of the Titarl-based regression approach, we first extracted the top 6000 rules for friend dyads and 6000 rules for stranger dyads from the training dataset, with the following parameter settings: minimum support: 5%, minimum confidence: 5%, maximum number of conditions: 5, minimum use: 10. Second, we fused those rules based on algorithm discussed above and applied them on test set, performing a 10-fold cross validation. In order to test the robustness of the results, we repeated the experiment for all possible random combinations of training (4 dyads) and test (2 dyads) sets for friends and strangers, and performed a correlated samples t-test to test whether our approach results in lower mean squared error compared to a simple linear regression model that treats each of the verbal and nonverbal modalities as independent features to predict the absolute value of rapport. Evaluation for performance metrics in this basic linear regression approach was done using the supplied test set of randomly chosen 2 dyads for each experimental run. In addition, we also calculated effect size via Cohen's d ($2t/\sqrt{df}$), where t is the value from the t-test and df refers to the degrees of freedom. Results in Table 4.5 suggest that the Titarl-based regression method has a significantly lower mean square error than the naive baseline linear regression method. The high effect size in both strangers ($d=-0.62$) and friends ($d=-0.42$) further prove the substantial improvement on accuracy of assessing rapport by Titarl-based regression comparing to simple linear regression.

Implications for Understanding Human Behavior

One of the important behavior patterns that plays out differently across friends and strangers, and whose interactions can lead to either high or low rapport, is smiling in combination with social norm violations and speech overlap. A violation of social norms without a smile is always

followed by low rapport. On the other hand, a social norm violation accompanied by a smile is followed by high rapport when followed by overlap and performed among friends. Meanwhile, violating social norms while smiling leads to low rapport when followed by overlap if performed among strangers [See FH1, FH3, FH5, FL1, FL2, SL3]. What we may be seeing here is what (Goffman, 2005) described as embarrassment following violations of “ceremonial rules” (social norms or conventional behavior), which is less often seen among family and friends than among strangers and new acquaintances. Similarly, (Keltner and Buswell, 1997) emphasized that the smile is a kind of hedge, signaling awareness of a social norm being violated and serving to provoke forgiveness from the interlocutor. Overlap in this context may be an index of the high coordination that characterizes conversation among friends whereby simultaneous speech indicates comfort, or that same overlap may indicate the lack of coordination that characterizes strangers who have not yet entrained to one another’s speech patterns (Cassell et al., 2007).

Another important contingent pattern of behaviors discussed here is the interaction between smile and backchannels [See SH2, FL3]. In general a backchannel + smile was indicative of high rapport, perhaps because the smile + backchannel indicated that the listener was inviting a continuation of the speaker’s turn, but also indicating his/her appreciation of the interlocutor’s speech (Bevacqua et al., 2008).

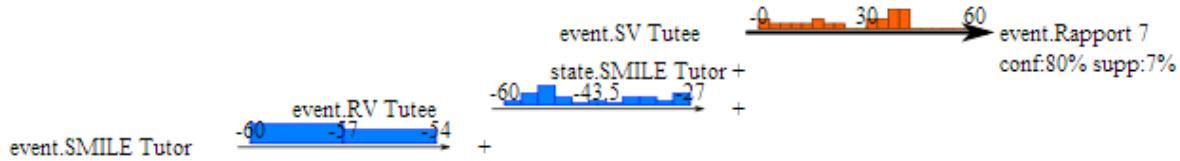
We also discover the interaction between smile, the conversational strategy of self-disclosure and overlaps [See SH1]. Smiles invite self-disclosure, after which an overlap demonstrates responsiveness of the interlocutor. (Laurenceau et al., 1998) have shown that partner responsiveness is a significant component of the intimacy process that benefits rapport. Finally we described how the presence of overlaps with a nonverbal behavior or conversational strategy often signals high rapport in friends but low rapport in strangers [See SH3, FL3, SL2, SL3]. Prior work has found that friends are more likely to interrupt than strangers, and the interruptions are less likely to be seen as disruptive or conflictual (Cassell et al., 2007).

Implications for Social Agent Design

Rules such as those presented above can play a fundamental role in building socially-aware agents that adapt to the rapport level felt by their users in ways that previous work has not addressed. For example, (Gratch et al., 2006) extracted a set of hand-crafted rules based on social science literature to build a rapport agent. Such rules not only need expert knowledge to craft, but may also be hard to scale up and to transfer to different domains. In our current work, we alleviate this problem by automatically extracting behavioral rules that signal high or low rapport, learning on verbal and nonverbal annotations of a particular corpus, but employing only the annotations of conversational strategies that did not concern the content domain of the corpus.

4.3.7 Conclusion

In this work, we utilized a temporal association rule framework for automatic discovery of co-occurring and contingent behavior patterns that precede high and low interpersonal rapport in dyads of friends and strangers. Our work provides insights for better understanding of dyadic multimodal behavior sequences and their relationship with rapport which, in turn, moves us forward towards the implementation of socially-aware agents of all kinds.



An example from the corpus is shown below:

Tutor: Sweeney you can't do that, that's the whole point{smile}; **[Violation of Social Norm]**

Tutee: I hate you.I'll probably never never do that; **[Reciprocate Social Norm Violation]**

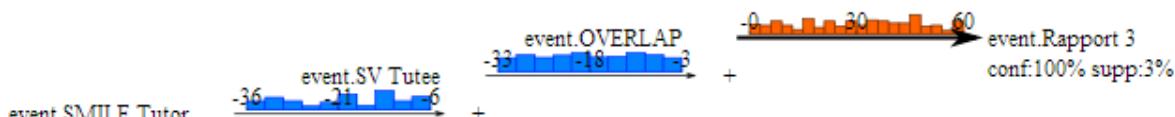
Tutor: Sweeney that's why I'm tutoring you{smile};

Tutee: You're so oh my gosh{smile}.We never did that ever; **[Violation of Social Norm]**

Tutor: {smile}What'd you say?

Tutee: Said to skip it{smile};

Tutor: I can just teach you how to do it;



An example from the corpus is shown below:

Tutee: divide oh this is so hard let me guess;eleven;

Tutor: you know;

Tutee: six;

Tutor: next problem is is exactly the same smile, over eleven equals, eleven x over eleven;

Tutee: I don't need your help; **[Violation of Social Norm]**

Tutor: {Overlap}That is seriously like exactly the same.

Chapter 5

Discourse Planning for Social Dialog

5.1 Introduction and Motivation

Dialog manager is in charge of picking up the next system action respect to the task. Similar, we develop a module named social reasoner that focuses on managing relational bonds with human user through reasoning the usage of the conversational strategy for system. Specifically here we are interested in seven common conversational strategies shown to positively impact rapport (Tajfel and Turner, 1979; Spencer-Oatey, 2008b): Self-Disclosure (**SD**), revealing personal information, to decrease social distance; Question Elicitation of Self-Disclosure (**QESD**), which is used to encourage the other interlocutor to self-disclose; Reference to Shared Experiences (**RSE**), that indexes common history; Praise (**PR**), that serves to increase self-esteem in the listner and therefore interpersonal cohesiveness; Adhere to Social Norm (**ASN**), that increases coordination by adhering to behavior expectations guided by sociocultural norms; Violation of Social Norm (**VSN**), where general norms are purposely violated to accommodate the others behavioral expectations; and Acknowledgement (**ACK**), a way to show that the interlocutor is listening.

Given that rapport-management is a dyadic process, intrinsically involving two individuals, our system must fulfill two critical prerequisites: understanding the *user's* conversational strategy in real-time, and estimating the level of rapport, or relationship strength, at any given moment. The first prerequisite was fulfilled by our trained multimodal *Conversational Strategy Classifier* introduced on last chapter,which has been integrated into our decision-making system. The second prerequisite was fulfilled by our temporal association rule-based *Rapport Estimator*, has been shown to have strong predictive power on rapport estimation in real time, which is also integrated into the social reasoner.

Social Reasoner module is capable of taking input from both the Rapport Estimator and User's Conversational Strategy Classifier described and functioned to reason about how to respond to the social intentions underlying those particular behaviors (such as to raise rapport), and generating appropriate social conversational responses with the system's goal of always keeping rapport high in order to increase trust and long-term engagement. While there are several potential approaches, most of them are not suitable for our purposes: since the large and increasing number of inputs that the Social Reasoner must process continuously, selecting a proper conversational strategy becomes a combinatorial explosion problem that results almost intractable to solve with a pure

symbolic approach such as production rule systems or classic planners. On the other hand, pure sub-symbolic or connectionist approaches fail to semantically express the relationships between inputs, outputs, and negative and positive consequences of triggering a particular conversational strategy. Therefore, we employ a hybrid approach that takes advantage of the features of a classic planner governed by spreading activation dynamics. In fact, the hybrid model proposed by (Maes, 1989) and extended by (Romero, 2011), so-called Behavior Networks, perfectly fits our needs.

5.2 Related Work

Below we will describe related work that focuses on computational modeling decision-making processing in agent to build long-term relationship with human.

(Bickmore and Schulman, 2012) proposed a computational model of user-agent relationship which was inspired from accommodation theory. They defined a set of activities that user is willing to perform with agent. Those activities were described as dialog acts. Their reactive algorithm selected the most appropriate dialog act in order to advance user-agent intimacy. However, the study indicated that their algorithm successfully adapted to user's desired intimacy level but failed to increase intimacy along with the user-agent interaction. As a side note, their system understood user-agent relationship through questionnaire instead of automatically reasoning the real-time closeness level, which was harmful to their decision-making process.

Similarly, (Coon et al., 2013) targeted on developing closeness in human-agent interactions through implementing an algorithm to plan appropriate joint activities. The algorithm modeled the difference between relationship stages from stranger to companion. The decision-making process of this activities planner was based on the required closeness level of each activity while the algorithm optimized its performed activities to achieve user-agent intimacy over time. However, since (Coon et al., 2013) handcrafted specifics activities for each stage, it is a challenge to scale up their algorithm.

Actually, we are not the first ones to propose using a behavior network to model social dialog in human communication. In the past, (Cassell and Bickmore, 2003) constructed a discourse planner that could interleave small talk and task talk during the real estate buyer interview. The conversational moves such as introducing new topic in dialog were planned in order to maximize trust building while pursuing task goal of selling real estate. Their implementation utilized activation network to simply adjust agent linguistic behavior - more or less polite, more or less task-oriented, or more or less deliberative, but not for deciding which conversational strategy fitted better during each state of the conversation.

5.3 System Architecture

Using a Global Workspace approach and a spreading activation model, we endow our social reasoner with both short-term and long-term decision-making skills that allow it to reactively select a proper conversational strategy while deliberatively tailoring a plan (sequence of conversational strategies) in the background. Our purpose here is to motivate and then evaluate the use of this kind of Social Reasoner, which has some specific properties due to its hybrid nature, specifically to a) efficiently make both short-term decisions (real-time or reactive reasoning) and long-term decisions (deliberative reasoning and planning); b) the knowledge is encoded by using both symbolic structures (i.e., semantic-labeled nodes and links) and sub-symbolic operations

(i.e., spreading activation dynamics); and c) its network's operation is grounded on cognitive psychological phenomena such as subliminal priming, automaticity with practice, and selective attention, whereas the design of its network's structure relies on observations extracted from data-driven models.

5.3.1 Modules Description

The Social Reasoner's architecture is depicted in figure 5.1. They are described as follows:

1) Working Memory (WM): short-term memory that stores chunks of environmental information (percepts) that are then processed by the Social Reasoner's decision module; 2) Goals: a hierarchy of both task (e.g., generate a recommendation) and social goals (e.g., build rapport); 3) Social Reasoner History (SRH): records of all past decisions (i.e., system conversational strategies); 4) Selective Attention (SA): the most relevant, important, urgent, and insistent information at the moment, which will be selected to be processed by the decision module based on the Global Workspace Theory (Baars, 2003); 5) Action Selection (AS): this module is in charge of choosing a conversational strategy as a consequence of the decision-making dynamics. This module is implemented as a Behavior Network (originally proposed by (Maes, 1989) and extended by (Romero, 2011)). 6) Learning Processing (LP): this module is responsible of adapting the system parameters in real-time. However, this is part of our future work so we will not go into further details; 7) Other Modules: Social Reasoner interfaces with other modules that are commonly used in dialog Systems and conversational agents, such as ASR, NLU, NLG, etc.

Social Reasoner's Decision module is crafted as a network of interacting nodes where decision-making emerges from the dynamics of relationships among those nodes.

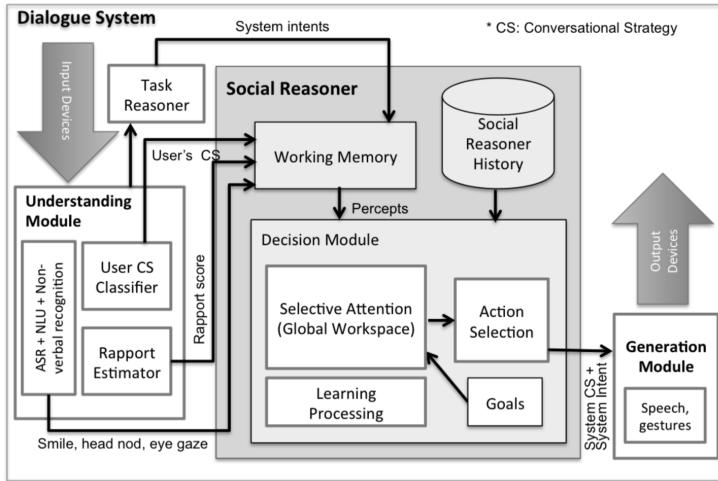


Figure 5.1: System Architecture

5.4 Computational Model

In the following, we will provide details of our Behavior Network formalism.

A Behavior Network (BN) is a spreading activation model proposed by (Maes, 1989) as a collection of competence modules which works in a continuous domains. Behavior selection is modeled as an emergent property of activation/inhibition dynamics among all behaviors. A behavior i can be described by a tuple $\langle c_i, a_i, d_i, \alpha_i \rangle$ where c_i is a list of pre-conditions which have to be fulfilled before the behavior can become active, a_i and d_i represent the expected (positive and negative) effects of the behavior's action in terms of an add list and a delete list. Additionally, each behavior has a level of activation α_i . If the proposition p about environment is true and p is in the pre-condition list of the behavior i , there is an active link from the state p (proposition about environment) to the behavior i . If the goal g has an activation greater than zero and g is in the add list of the behavior i , there is an active link from the goal g to the behavior i . Internal links include predecessor links, successor links, and conflicter links. There is a successor link from behavior i to behavior j for every proposition p that is member of the add list of i and also member of the pre-condition list of j . A predecessor link from behavior j to behavior i exists for every successor link from i to j . There is a conflicter link from behavior i to behavior j for every proposition p that is a member of the delete list of j and a member of the pre-condition list of i . The following is the procedure for decision-making:

1. Calculate the excitation coming in from environment.
 2. Spread excitation along the predecessor, successor, and conflicter links, and normalize the behavior activations so that the average activation becomes equal to π .
 3. Check any executable behaviors, choose the one with the highest activation, and execute it.
- A behavior is executable if all the pre-conditions are true and if its activation is greater than the global threshold. If no behavior is executable, reduce the threshold and repeat the cycle.

Additionally, the model defines five global parameters that can be used to tune the spreading activation dynamics: π is the mean level of activation, θ is the threshold for becoming active which is lowered each time none of the modules could be selected and reset to its initial value otherwise, ϕ is the amount of activation energy a proposition that is observed to be true injects into the network, γ is the amount of energy a goal injects into the network, and δ is the amount of activation energy a protected goal takes away from the network.

One important contribution made to the original Behavior Networks model is that we use a “partial matching” approach rather than a strict “full matching” approach; that is, the original model states that a behavior is activated only when all its pre-conditions are true, which works well when using discrete variables, however, we deal with continuous variables in a frequently-changing environment, so behaviors are almost never activated under these conditions. We propose the definition of categories to group sets of well-defined pre-conditions with something in common. An inclusive OR operator is used to evaluate intra-category pre-conditions and an AND to evaluate inter-category pre-conditions, that is, there must be at least one pre-condition per category that is true. This scheme is much more flexible and allows more combinations of pre-conditions that can trigger a particular behavior.

In our model, each behavior corresponds to a specific conversational strategy (e.g., SD, PR, VSN, etc.) where pre-conditions are divided into categories, as shown in table 5.1, and post-conditions are defined in terms of what the expected states are after performing the current conversational strategy (e.g., rapport score increases, user smiles, etc.). This kind of chaining reasoning based on linked pre-conditions and post-conditions endows the system with planning ahead capabilities. Intuitively, the Social Reasoner can tailor a deliberative plan as the aggregation of

Table 5.1: Pre-condition and Post-condition Categories

Category	Pre-conditions and Post-conditions
Rapport level	low, medium, and high
Rapport delta	decreased, maintained and increased
System and User conv. strategies	asn, vsn, sd, qesd, se, ack, pr, not-asn, not-vsn, not-sd, not-qesd, not-se, etc.
User non-verbals	gaze-elsewhere, gaze-partner, head-nod, smile, etc.
dialog history	number-of-turns, sd-user-history, pr-system-history, qesd-user-history, etc.
System intent	greeting, do-goal-elicitation, start-interest-elicitation, start-recommendation, do-recommendation, end-recommendation, farewell, etc.

nodes connected through both predecessor and successor links, for instance, when a conversation starts the most likely sequence of nodes could be: <ASN, ASN, SD, PR, SD ...VSN ...>, that is, initially the system establishes a cordial and respectful communication with user (ASN), then it uses SD as an icebreaking strategy(Altman and Taylor, 1973), followed by PR to encourage the user to also perform SD. After some interaction, if the rapport level is high, a VSN is performed. Coalitions are created between nodes, so ASN would spread forward some energy to SD, and SD would spread backward some energy to ASN, and the same between SD and PR, and between PR and SD, etc. Inhibitory links avoid wrong conversational strategies to be triggered. The Social Reasoner is adaptive enough to respond to unexpected users actions by executing a reactive plan that emerges from forward and backward spreading activation dynamics as well as from the network's parameters configuration that determines the global system's behavior, for instance, it can make the system more goal-oriented vs. situation-oriented, more adaptive vs. biased to ongoing plans, more thoughtful vs. faster.

5.5 Design of the Decision-Making module

5.5.1 Sources of Information

As is clear from the description above, the nature of the pre-condition and post-conditions is key to the functioning of the systems. We extracted information for these conditions from two sources: theoretical and empirical data.

Theoretical Sources

Rapport Theory: Based on our proposed computational model of rapport in Chapter 2, at the beginning of the interaction, one tends to be tentative and polite, adhering to social norms. Initiating a self-disclosure at this stage will both signal attention and elicit self-disclosure from the interlocutor which, in turn, enables both parties to gradually learn each other's behavioral expectations. During this stage of interaction, praise can boost self-esteem and motivate the interlocutor to diminish social distance. Thus, adhering to social norms, self-disclosure and

praise are three trending conversational strategies in the early stage of communication. As the interaction proceeds, interlocutors have more interpersonal knowledge to guide their behavior. They refer to shared experience to index commonality and purposely violate social norm in order to accommodate each other's behavioral expectations, and signal that they are now outside the phase of pure politeness.

Norm of Reciprocity: Reciprocity of behavior (Burger et al., 2009) plays an important role in increasing coordination between interlocutors. Our annotations of conversations revealed that most of the conversational strategies described here are used reciprocally (referring to shared experience evokes the same behavior from one's conversation partner). Thus, one pre-condition for praise is that the user hasn't praised in the previous turn.

Data-driven Sources

Data-driven discovery by temporal association rule: (Zhao et al., 2016b) applied a data mining algorithm to separately learn behavioral rules for friends and strangers. In our Social Reasoner, we input *phase* of interaction (early, middle, late) as a variable. Early stages of the interaction were determined by rules learned from the stranger data, later stages by friend rules. For instance, a rule that strangers followed was: *one of the interlocutors smiles while the other gazes at the partner and begins self-disclosing*, so we defined smile as one of a set of optional pre-conditions for self-disclosure.

Data from Wizard-of-Oz study: We collected data from 228 English-speakers interacting with a virtual assistant acting as a guide that recommends sessions to attend and people to meet at the conference. In each session, a dyad consisting of a user and the virtual assistant (using a Wizard of Oz protocol) interacted through a dialog system interface for around 8-10 minutes. During conversation, the agent elicited the users interests and preferences and used these to improve its recommendations. The user's verbal and non-verbal behaviors were recorded by the system while the woz-er picked the next utterance for the agent depending on the user's utterance, the current task and goal, as well as the WoZer's assessment of most appropriate conversational strategy to build rapport. After conducting the study, only those decisions made by the woz-er that had a significant impact on building rapport (i.e., increasing rapport) and raising engagement (defined here as increase conversation length) were taken into account.

5.5.2 Encoding of Pre-conditions & Post-conditions

We modeled a Behavior Network with seven behaviors (one for each conversational strategy). Their pre-conditions and post-conditions were designed by following a two-way tuning process: initially, for each behavior, we identified a sub-set of preconditions and post-conditions (from table 5.1) based on the theoretical foundations provided in section 5.5.1; then we validated the previous model through the empirical analysis of data obtained from the Wizard-of Oz study. For the latter process, we ran a feature selection statistic analysis, more specifically, a bidirectional elimination stepwise regression that allowed us, through a series of partial F-test, to include or drop candidate variables from each behavior. This process helped us to discover which sub-set of variables and features should be considered as pre-conditions and post-conditions for each behavior because of their impact and significance. For instance, the theoretical

foundation guided us to identify a sub-set of pre-conditions for PR as follows: <low-rapport, not-pr-user, not-pr-history-user, ...> however, the stepwise regression analysis told us that we need to include at least three more pre-conditions: <high-rapport> ($F: 95.7$, p-value: 0.00), <gaze-elsewhere> ($F: 56.8$, p-value: 0.00002) and <rapport-increased> ($F: 17.6$, p-value: 0.00073); and remove pre-condition <not-pr-history-user> ($F: 3.4$, p-value: 0.005) to improve the accuracy on conversational strategy prediction. An excerpt of the final tuned behaviors' pre-conditions and post-conditions is shown in appendix.

5.5.3 Spreading Activation Parameters:

Following the guidelines proposed by (Romero, 2011; Romero and de Antonio, 2012) and through empirical analysis, we determined that the best configuration of the spreading activation parameters is as follows:

1. To keep the balance between deliberation and reactivity, $\phi > \gamma$, so $\phi = 68$ and $\gamma = 42$.
2. To keep the balance between bias towards ongoing plan vs. adaptivity, $\pi > \gamma \wedge \pi < \phi$, so $\phi = 50$.
3. To preserve sensitivity to goal conflict, $\delta > \gamma$, so $\delta = 75$.

5.6 Experimentation and Results

Our experiments focused on evaluating three aspects of our work: 1) determining whether social reasoning can increase rapport and raise engagement; 2) evaluating the degree of effectiveness and accuracy of the Social Reasoner after the data-driven tuning process; and 3) evaluating the performance of the Social Reasoner during interaction with users.

5.6.1 Experiment 1: Social Reasoning validity

H_0 : *Social Reasoning doesn't contribute significantly to build rapport and increase conversational engagement in comparison with traditional dialog systems.*

For this experiment we divided the WOZ study dataset of 228 sessions (section 5.5.1) into two groups: dialog turns that used conversational strategies and dialog turns that did not use any conversational strategy (plain behavior). Then, we observed the rapport score (1-7), our variable of interest. We ran an one-way ANOVA analysis in order to find out whether there is a statistically significant difference between the groups at $p < .05$. The ANOVA is shown in table 5.2.

Table 5.2: ANOVA for Experiment 1.

Sc. of Variation	df	SS	MS	F	p
Between groups	2	1012398	687297.4	4.52	0.007%
Within groups	154	1672037	293898.8		
Total	156	2684435			

Since p is less than .05 we can conclude that there is a statistically significant difference between the two groups. A Tukey post-hoc test revealed that rapport scores of the group that

uses social reasoning was higher ($5.65 \pm 0.4, p = .032$) in comparison with the group that uses a traditional approach – no social reasoning – ($3.17 \pm 0.6, p = .028$) and therefore we can reject the null hypothesis H_0 that social reasoning doesn't contribute significantly to build rapport. Likewise, we conclude that using social reasoning may improve social bonds (rapport) on a 35.4% during a conversation.

5.6.2 Experiment 2: Social Reasoner's accuracy

$H_0 : Data\text{-}driven\ tuning\ process\ doesn't\ improves\ Social\ Reasoner's\ accuracy$

For this experiment we used the WOZ study dataset as a ground truth. Then we ran a simulation for all 228 sessions, where system inputs were signals from the understanding module, the task reasoner, and the history databases; and outputs were the conversational strategies picked by the woz-er. Then, we compared each woz-er output with the social reasoner's output for two different scenarios: before tuning the decision-making module (i.e., using only a theoretical-driven design) and after tuning (i.e., using both a theoretical and data-driven design). We ran an one-way ANOVA analysis and results are shown in table 5.3.

Since p is considerably lower than α , we can conclude that there is a statistically significant difference between the two groups. A Tukey post-hoc test revealed that rapport scores of the group that received a data-driven tuning was higher ($4.83 \pm 0.5, p = .027$) in comparison with the group that only used a theoretical-based design ($3.05 \pm 0.4, p = .033$) and therefore we can reject the null hypothesis that data-driven tuning doesn't improve the Social Reasoner's accuracy. Also, we conclude that using a data-driven tuning process along with a theoretical-driven design may improve the accuracy of Social Reasoner up to a 25.4%.

Table 5.3: ANOVA for Experiment 2.

Sc. of Variation	df	SS	MS	F	p
Between groups	4	2984714	873394.3	5.34	0.005%
Within groups	173	3439465	363797.8		
Total	175	6424179			

5.6.3 Experiment 3: Social Reasoner's performance

For this experiment we chose four well-characterized conversational sessions from the dataset log files in the post-experimental evaluation to test the system's performance. Below is the description of each one:

Flat User Scenario (FU): user's verbal and non-verbal behaviors remain the same during conversation, e.g., rapport level is medium all the time, no smile, and user's conversational strategy is ASN most of the time.

Incremental Engagement Scenario (IE): user is getting more engaged in conversation over time, e.g., rapport level increases gradually, user smiles more often, and user's conversational strategy is mostly SD and VSN.

Low Rapport Scenario (LR): during most of the conversation user keeps a low rapport level, no smiles and barely makes eye contact.

Losing Interest Scenario (LI): initially, user is very engaged during conversation (i.e., high rapport, a lot of smiles and eye contact, user's conversational strategies are SD and VSN, etc.) but gradually he is losing interest.

Table 5.4: Social Reasoner's performance. MSE: Mean Square Error, MSE Rate: $[1 - (MSE_{SR} \div MSE_{TD})]$

Scenario	Std Dev	MSE_{TD}	MSE_{SR}	MSE Rate
FU	0.83	1.31	0.86	34.35%
IE	0.73	2.12	1.68	20.75%
LR	0.52	0.96	0.68	29.16%
LI	0.93	1.54	1.05	31.81%

Table 5.4 shows the statistical data for experiment 3. The MSE for each scenario is the mean square error of 20 turns, where an error is considered as a drop on the rapport score as consequence of activating the wrong conversational strategy. The MSE rate presents the performance relationship between MSE_{TD} (a traditional dialog system that doesn't use conversational strategies) and MSE_{SR} (a dialog system that uses our Social Reasoner). It is important to notice that, for the experiments executed, the proposed Social Reasoner model improves the performance results obtained by a traditional dialog system a rate between 20% and 34%.

It is worth mentioning that having the highest activation level is not the only criteria to chose a particular conversational strategy (CS), but it must be also executable and its activation level must be over the threshold, otherwise, the next CS which meets those conditions will be chosen.

Intuitively, one can deduce that the Social Reasoner emergently tailors a plan as the combination of SD, PR and QESD strategies when detecting the user is not engaged during interaction as expected (e.g., in LR and LI scenarios). Conversely, VSN is avoided when trying to recover both user's attention and interest, and also his rapport level is low (as at the end of LR, and in FU). On the other hand, reactive decisions such as using VSN or RSE are made when the system detects the user is more receptive to this kind of strategies, even if they are not the ones with the highest activation level. ACK is more likely to appear when there is evidence of progressive raising of user's engagement, since conversational strategy such as ASN, SD and RSE spread more activation energy forward and backward to it. Also, it is interesting to see how ASN is activated at an early stage of the conversation (e.g., IE scenario) but remains accumulating energy during the whole interaction so it can be easily triggered if the system realizes that a previous action (as consequence of using a particular CS) causes a diminishing on the rapport level. Finally, PR is continually used when the Social Reasoner detects no significant changes on user's verbal and non-verbal behaviors that can raise rapport, specially when other conversational strategy such as SD and QESD have been used without success.

5.7 Conclusion

We proposed a hybrid adaptive Social Reasoner component that determines which conversational strategy should be used in order to build and maintain rapport with a user. The Social Reasoner interacts with several modules that can be connected and disconnected while its behavior remains

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robust. A spreading activation approach was merged with classic planner features and extended to allow the system to partially match pre-conditions by using an OR operator rather than the conventional AND operator, and as a consequence expanding the number of possible combinations between matched pre-conditions and triggered conversational strategies.

Chapter 6

Neural Network Based Model for Controllable Social Dialog Generation

6.1 Introduction

Comparing to task-oriented dialogs, social dialogs have the open-ended nature. Our modular-based system follow the conventional approach of designing a dialog manager (Williams and Young, 2007) and natural language generation that are hand crafted and human controllable but do not scale well to open-domain conversation models because of the vast quantity of possible decisions and variations. Thus, there has been a growing interest in applying encoder-decoder models (Sutskever et al., 2014) for modeling open-domain conversation (Vinyals and Le, 2015; Serban et al., 2016a). The basic approach treats a conversation as a transduction task, in which the dialog history is the source sequence and the next response is the target sequence. The model is then trained end-to-end on large conversation corpora using the maximum-likelihood estimation (MLE) objective without the need for manual crafting. However, from theoretical perspective, this solely data-driven approach is lack of guidance from previous linguistic knowledge and discourse-level planning. From practical perspective, recent research has found that encoder-decoder models tend to generate generic and dull responses (e.g., *I don't know*), rather than meaningful and specific answers (Li et al., 2015; Serban et al., 2016b) which is very harmful to maintain the social bond (e.g. harmful to mutual attention and coordination). Thus, to solve the foreseeable challenges, we strive to improve the current sequence-to-sequence model by allowing it to (1) diversify the response at the discourse level (2) encode the prior linguistic knowledge and (3) have capability of discourse planning. In this chapter, we will address the first two challenges and the next chapter for the third one.

There have been many attempts to explain and solve these limitations, and they can be broadly divided into two categories: (1) the first category argues that the dialog history is only one of the factors that decide the next response. Other features should be extracted and provided to the models as conditionals in order to generate more specific responses (Xing et al., 2016; Li et al., 2016a); (2) the second category aims to improve the encoder-decoder model itself, including decoding with beam search and its variations (Wiseman and Rush, 2016), encouraging responses that have long-term payoff (Li et al., 2016b), etc.

Building upon the past work in dialog managers and encoder-decoder models, the key idea of this chapter is to introduce a latent random variable in encoder-decoder model that govern the dialog generation at the discourse level. Theoretically, we believe that there are underlying factors that affect the dialog generations, where we could insert our prior knowledge. Previous studies indicate that there are many factors in open-domain dialogs that decide the next response, and it is non-trivial to extract all of them. Intuitively, given a similar dialog history (and other observed inputs), there may exist many valid responses (at the discourse-level), each corresponding to a certain configuration of the latent variables that are not presented in the input. To uncover the potential responses, we strive to model a probabilistic distribution over the distributed utterance embeddings of the potential responses using a latent variable (Figure 6.1). This allows us to generate diverse responses by drawing samples from the learned distribution and reconstruct their words via a decoder neural network. Additionally, prior linguistic knowledge could be explicitly encoded into the latent variable. Finally, discourse planning could be achieved through controlling the configuration of latent variable.

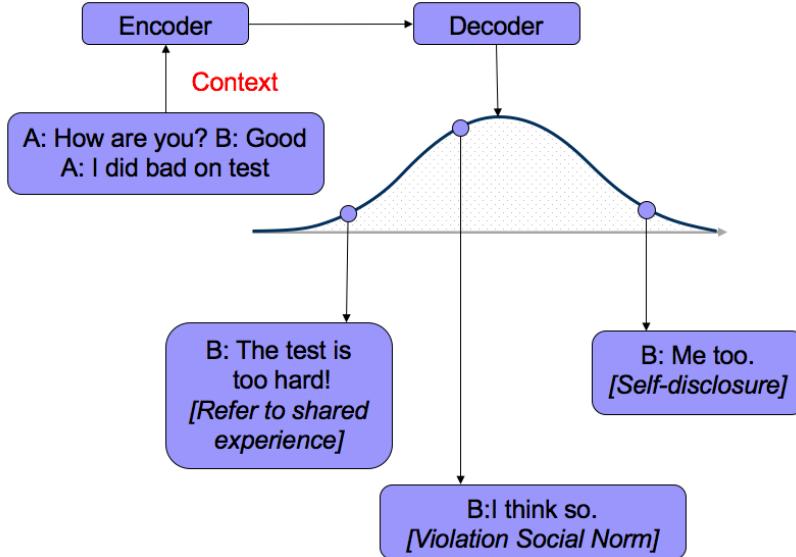


Figure 6.1: Given dialogue context, there exist many valid responses realizing different conversational strategies.

In our paper(Zhao et al., 2017), we propose the conditional variational autoencoder(CVAE) and knowledge-guided CVAE(kgCVAE) models to capture the latent variable in conversation. In practice, training CVAE based model is a challenging optimization problem which often requires large amount data, but conversational strategy is sparse in CMU peer tutoring dataset. Since dialog acts normally have dense labeling in conversation, we choose to model them as the linguistic features/knowledge in latent variable towards the first step to validate our neural dialogue model. Meanwhile, dialog acts (Poesio and Traum, 1998) have been widely used in the dialog managers (Litman and Allen, 1987; Raux et al., 2005; Zhao and Eskenazi, 2016) to capture crucial features in representing natural conversation. Therefore, we conjecture that it will be beneficial for the model to learn meaningful latent z if it is provided with explicitly extracted discourse features (e.g. dialog act) during the training. Next step, we extend the validated model to capture the conversational strategy in latent variable and realize the guidance of socially-aware

framework in our neural dialog mode. Specifically, our contributions are three-fold: 1. We present a knowledge-guided CVAE (kgCVAE) adapted from CVAE (Yan et al., 2015; Sohn et al., 2015), which can capture discourse-level variations 2. We propose and demonstrate knowledge-guided CVAE (kgCVAE), which enables easy integration of linguistic knowledge such as dialog act results in performance improvement and model interpretability. 3. We propose to refine kgCVAE model with reinforcement learning to improve the supervision of social-aware framework from discourse-level. We evaluate our models on human-human conversation data and yield promising results in generating appropriate and discourse-level diverse responses with linguistic knowledge guidance. As a side note, a straightforward VAE with autoregressive decoder fails to encode meaningful information in latent variable due to the *vanishing latent variable problem* (Bowman et al., 2015). We introduce a simple yet novel technique to tackle this problem: bag-of-word loss. Details are provided in our paper (Zhao et al., 2016c).

6.2 Related Work

Our work is related to both recent advancement in encoder-decoder dialog models and generative models based on CVAE.

6.2.1 Encoder-decoder Dialog Models

Since the emergence of the neural dialog model, the problem of output diversity has received much attention in the research community. Ideal output responses should be both coherent and diverse. However, most models end up with generic and dull responses. To tackle this problem, one line of research has focused on augmenting the input of encoder-decoder models with richer context information, in order to generate more specific responses. (Li et al., 2016a) captured speakers' characteristics by encoding background information and speaking style into the distributed embeddings, which are used to re-rank the generated response from an encoder-decoder model. (Xing et al., 2016) maintain topic encoding based on Latent Dirichlet Allocation (LDA) (Blei et al., 2003) of the conversation to encourage the model to output more topic coherent responses.

On the other hand, many attempts have also been made to improve the architecture of encoder-decoder models. (Li et al., 2015) proposed to optimize the standard encoder-decoder by maximizing the mutual information between input and output, which in turn reduces generic responses. This approach penalized unconditionally high frequency responses, and favored responses that have high conditional probability given the input. (citewiseman2016sequence) focused on improving the decoder network by alleviating the biases between training and testing. They introduced a search-based loss that directly optimizes the networks for beam search decoding. The resulting model achieves better performance on word ordering, parsing and machine translation. Besides improving beam search, (Li et al., 2016b) pointed out that the MLE objective of an encoder-decoder model is unable to approximate the real-world goal of the conversation. Thus, they initialized a encoder-decoder model with MLE objective and leveraged reinforcement learning to fine tune the model by optimizing three heuristic rewards functions: informativity, coherence, and ease of answering.

6.2.2 Conditional Variational Autoencoder

The variational autoencoder (VAE) (Kingma and Welling, 2013; Rezende et al., 2014) is one of the most popular frameworks for image generation. The basic idea of VAE is to encode the input x into a probability distribution z instead of a point encoding in the autoencoder. Then VAE applies a decoder network to reconstruct the original input using samples from z . To generate images, VAE first obtains a sample of z from the prior distribution, e.g. $\mathcal{N}(0, \mathbf{I})$, and then produces an image via the decoder network. A more advanced model, the conditional VAE (CVAE), is a recent modification of VAE to generate diverse images conditioned on certain attributes, e.g. generating different human faces given skin color (Yan et al., 2015; Sohn et al., 2015). Inspired by CVAE, we view the dialog contexts as the conditional attributes and adapt CVAE to generate diverse responses instead of images.

Although VAE/CVAE has achieved impressive results in image generation, adapting this to natural language generators is non-trivial. (Bowman et al., 2015) have used VAE with Long-Short Term Memory (LSTM)-based recognition and decoder networks to generate sentences from a latent Gaussian variable. They showed that their model is able to generate diverse sentences with even a greedy LSTM decoder. They also reported the difficulty of training because the LSTM decoder tends to ignore the latent variable. We refer to this issue as the *vanishing latent variable problem*. (Serban et al., 2016b) have applied a latent variable hierarchical encoder-decoder dialog model to introduce utterance-level variations and facilitate longer responses. To improve upon the past models, we firstly introduce a novel mechanism to leverage linguistic knowledge in training end-to-end neural dialog models, and we also propose a novel training technique that alleviate the vanishing latent variable problem.

6.3 Models

6.3.1 Baseline Model: Conditional Variational Autoencoder (CVAE)

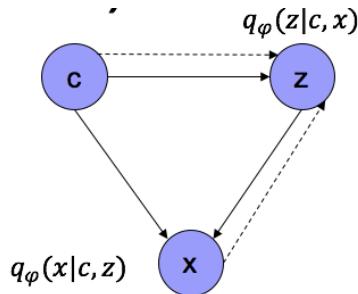


Figure 6.2: Graphical model of CVAE

Each dyadic conversation can be represented via three random variables: the dialog context c (context window size $k - 1$), the response utterance x (the k^{th} utterance) and a latent variable z , which is used to capture the latent distribution over the valid responses. Further, c is composed of the dialog history: the preceding $k-1$ utterances; conversational floor (1 if the utterance is from the same speaker of x , otherwise 0) and meta features m (e.g. the topic). We then define the

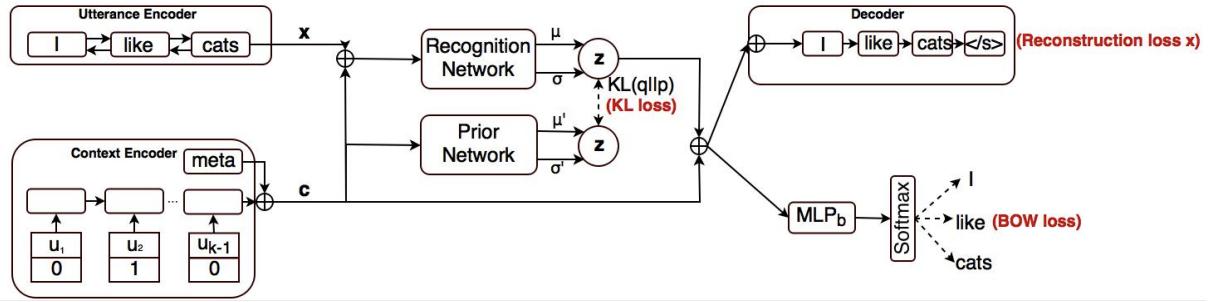


Figure 6.3: The training architecture for the CVAE model. \oplus denotes the concatenation of the input vectors.

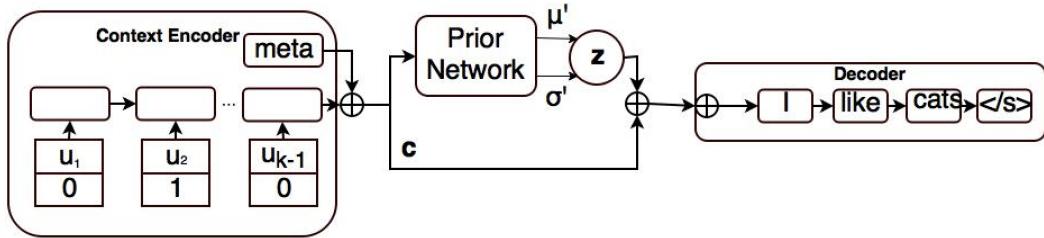


Figure 6.4: The test architecture for the CVAE model. \oplus denotes the concatenation of the input vectors.

conditional distribution $p(x, z|c) = p(x|z, c)p(z|c)$ and our goal is to use deep neural networks (parametrized by θ) to approximate $p(z|c)$ and $p(x|z, c)$. We refer to $p_\theta(z|c)$ as the *prior network* and $p_\theta(x|z, c)$ as the *response decoder*. Then the generative process of x is shown as a graphic model in (Figure 6.2):

1. Sample a latent variable z from the prior network $p_\theta(z|c)$.
2. Generate x through the response decoder $p_\theta(x|z, c)$.

CVAE is trained to maximize the conditional log likelihood of x given c , which involves an intractable marginalization over the latent variable z . As proposed in (Sohn et al., 2015; Yan et al., 2015), CVAE can be efficiently trained with the *Stochastic Gradient Variational Bayes* (SGVB) framework (Kingma and Welling, 2013) by maximizing the variational lower bound of the conditional log likelihood. We assume the z follows multivariate Gaussian distribution with a diagonal covariance matrix and introduce a *recognition network* $q_\phi(z|x, c)$ to approximate the true posterior distribution $p(z|x, c)$. Besides, in order to alleviate the vanish latent variable problem, we introduce the bag-of-word loss. Thus the loss function of modified cvae can be written as:

$$\begin{aligned}
 \mathcal{L}(\theta, \phi; x, c) &= -KL(q_\phi(z|x, c) \| p_\theta(z|c)) \\
 &\quad + \mathbf{E}_{q_\phi(z|x, c)} [\log p_\theta(x|z, c)] \\
 &\quad + \mathbf{E}_{q_\phi(z|x, c)} [\log p(x_{bow}|z, c)] \\
 &\leq \log p(x|c)
 \end{aligned} \tag{6.1}$$

Figure 6.3 demonstrates an overview of CVAE model in training. The utterance encoder is a bidirectional recurrent neural network (BRNN) (Schuster and Paliwal, 1997) with a gated recurrent unit (GRU) (Chung et al., 2014) to encode each utterance into fixed-size vectors by concatenating the last hidden states of the forward and backward RNN $u_i = [\vec{h}_i, \tilde{h}_i]$. x is simply u_k . The context encoder is a 1-layer GRU network that encodes the preceding $k-1$ utterances by taking $u_{1:k-1}$ and the corresponding conversation floor as inputs. The last hidden state h^c of the context encoder is concatenated with meta features and $c = [h^c, m]$. Since z follows isotropic Gaussian distribution, the recognition network $q_\phi(z|x, c) \sim \mathcal{N}(\mu, \sigma^2 \mathbf{I})$ and the prior network $p_\theta(z|c) \sim \mathcal{N}(\mu', \sigma'^2 \mathbf{I})$, and then we have:

$$\begin{bmatrix} \mu \\ \log(\sigma^2) \end{bmatrix} = W_r \begin{bmatrix} x \\ c \end{bmatrix} + b_r \quad (6.2)$$

$$\begin{bmatrix} \mu' \\ \log(\sigma'^2) \end{bmatrix} = \text{MLP}_p(c) \quad (6.3)$$

Reparametrization trick (Kingma and Welling, 2013) is applied to obtain samples of z either from $\mathcal{N}(z; \mu, \sigma^2 \mathbf{I})$ predicted by the recognition network in training or $\mathcal{N}(z; \mu', \sigma'^2 \mathbf{I})$ predicted by the prior network in testing. The testing architecture is shown at Figure 6.4. Finally, the response decoder is a 1-layer GRU network with initial state $s_0 = W_i[z, c] + b_i$. The response decoder then predicts the words in x sequentially.

6.3.2 Proposed Model:knowledge-guided CVAE (kgCVAE)

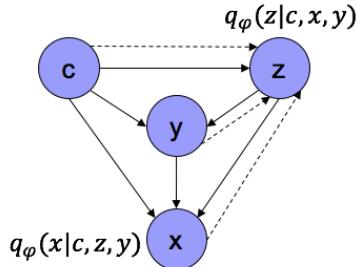


Figure 6.5: Graphical model of kgCVAE

In order to incorporate the linguistic features/knowledge into the basic CVAE model, we first denote the set of linguistic features as y . Then we assume that the generation of x depends on c , z and y . y relies on z and c as shown in Figure 6.5. Specifically, during training the initial state of the response decoder is $s_0 = W_i[z, c, y] + b_i$ and the input at every step is $[e_t, y]$ where e_t is the word embedding of t^{th} word in x . In addition, there is an MLP to predict $y' = \text{MLP}_y(z, c)$ based on z and c . In the testing stage, the predicted y' is used by the response decoder instead of the oracle decoders. We denote the modified model as knowledge-guided CVAE (kgCVAE) and developers can add desired discourse features that they wish the latent variable z to capture.

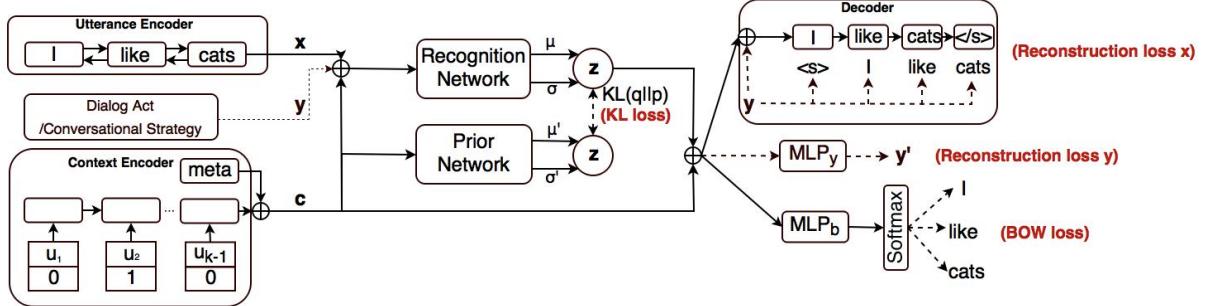


Figure 6.6: The training architecture for the kgCVAE model. \oplus denotes the concatenation of the input vectors.

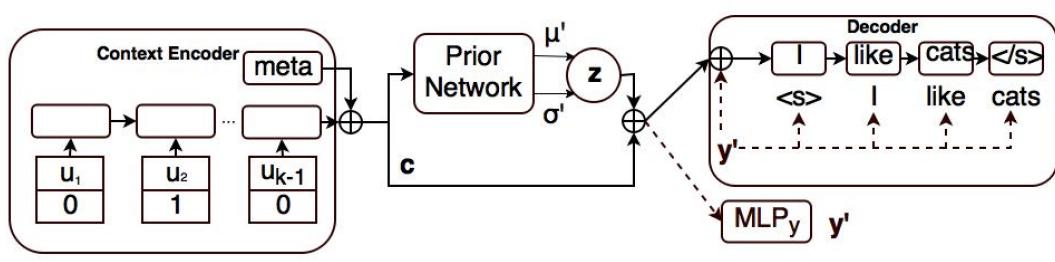


Figure 6.7: The test architecture for the kgCVAE model. \oplus denotes the concatenation of the input vectors.

KgCVAE model is trained by maximizing:

$$\begin{aligned} \mathcal{L}(\theta, \phi; x, c, y) = & -KL(q_\phi(z|x, c, y) \| P_\theta(z|c)) \\ & + \mathbf{E}_{q_\phi(z|c, x, y)} [\log p(x|z, c, y)] \\ & + \mathbf{E}_{q_\phi(z|c, x, y)} [\log p(y|z, c)] \\ & + \mathbf{E}_{q_\phi(z|c, x, y)} [\log p(x_{bow}|z, c)] \end{aligned} \quad (6.4)$$

Since now the reconstruction of y is a part of the loss function, kgCVAE can more efficiently encode y -related information into z than discovering it only based on the surface-level x and c . Another advantage of kgCVAE is that it can output a high-level label (e.g. dialog act) along with the word-level responses, which allows easier interpretation of the model's outputs.

6.4 Experiment: Validate kgCVAE model

In this experiment, we aim at validating that kgCVAE has capability of integrating prior linguistic knowledge (dialog act) in governing the dialog generation.

6.4.1 Dataset

We chose the Switchboard (SW) 1 Release 2 Corpus (Godfrey and Holliman, 1997) to evaluate the proposed models. SW has 2400 two-sided telephone conversations with manually transcribed speech and alignment. In the beginning of the call, a computer operator gave the callers recorded prompts that define the desired topic of discussion. There are 70 available topics. We randomly split the data into 2316/60/62 dialogs for train/validate/test. The pre-processing includes (1) tokenize using the NLTK tokenizer (Bird et al., 2009); (2) remove non-verbal symbols and repeated words due to false starts; (3) keep the top 10K frequent word types as the vocabulary. The final data have 207,833/5,225/5,481 (c, x) pairs for train/validate/test. Furthermore, a subset of SW was manually labeled with dialog acts. We extracted dialog act labels based on the dialog act recognizer proposed in (Ribeiro et al., 2015). The features include the uni-gram and bi-gram of the utterance, and the contextual features of the last 3 utterances. We trained a Support Vector Machine (SVM) (Suykens and Vandewalle, 1999) with linear kernel on the subset of SW with human annotations. There are 42 types of dialog acts and the SVM achieved 77.3% accuracy on held-out data. Then the rest of SW data are labelled with dialog acts using the trained SVM dialog act recognizer.

6.4.2 Training

We trained with the following hyperparameters (according to the loss on the validate dataset): word embedding has size 200 and is shared across everywhere. We initialize the word embedding from Glove embedding pre-trained on Twitter (Pennington et al., 2014). The utterance encoder has a hidden size of 300 for each direction. The context encoder has a hidden size of 600 and the response decoder has a hidden size of 400. The prior network and the MLP for predicting y both have 1 hidden layer of size 400 and \tanh non-linearity. The latent variable z has a size of 200. The context window k is 10. All the initial weights are sampled from a uniform distribution [-0.08, 0.08]. The mini-batch size is 30. The models are trained end-to-end using the Adam optimizer (Kingma and Ba, 2014) with a learning rate of 0.001 and gradient clipping at 5. We selected the best models based on the variational lower bound on the validate data. Finally, we use the BOW loss along with KL annealing of 10,000 batches to achieve the best performance.

6.4.3 Results

We compared two neural dialog models: CVAE(baseline), and kgCVAE. We sample N times from the latent z and only use greedy decoders so that the randomness comes entirely from the latent variable z .

Quantitative Analysis

Automatically evaluating an open-domain generative dialog model is an open research challenge (Liu et al., 2016). In this study, we apply the following metrics to validate if prior linguistic knowledge guide the dialog generation as well as the diversity of responses. We assume that for a given dialog context c , there exist M_c reference responses r_j , $j \in [1, M_c]$. Meanwhile a model can generate N hypothesis responses h_i , $i \in [1, N]$. The generalized response-level precision/recall

for a given dialog context is:

$$\text{precision}(c) = \frac{\sum_{i=1}^N \max_{j \in [1, M_c]} d(r_j, h_i)}{N}$$

$$\text{recall}(c) = \frac{\sum_{j=1}^{M_c} \max_{i \in [1, N]} d(r_j, h_i)}{M_c}$$

where $d(r_j, h_i)$ is a distance function which lies between 0 to 1 and measures the similarities between r_j and h_i . The final score is averaged over the entire test dataset and we report the performance with 3 types of distance functions in order to evaluate the systems from various linguistic points of view:

1. Smoothed Sentence-level BLEU (Chen and Cherry, 2014): BLEU is a popular metric that measures the geometric mean of modified n-gram precision with a length penalty (Papineni et al., 2002; Li et al., 2015). We use BLEU-1 to 4 as our lexical similarity metric and normalize the score to 0 to 1 scale.
2. Cosine Distance of Bag-of-word Embedding: a simple method to obtain sentence embeddings is to take the average or extrema of all the word embeddings in the sentences (Forgues et al., 2014; Adi et al., 2016). The $d(r_j, h_i)$ is the cosine distance of the two embedding vectors. We used Glove embedding described in Section 6.4.2 and denote the average method as A-bow and extrema method as E-bow.
3. Dialog Act Match: to measure the similarity at the discourse level, the same dialog-act tagger from 6.4.1 is applied to label all the generated responses of each model. We set $d(r_j, h_i) = 1$ if r_j and h_i have the same dialog acts, otherwise $d(r_j, h_i) = 0$.

One challenge of using the above metrics is that there is only one, rather than multiple reference responses/contexts. This impacts reliability of our measures. Inspired by (Sordoni et al., 2015), we utilized information retrieval techniques to gather 10 extra candidate reference responses/context from other conversations with the same topics. We collected multiple reference responses for each dialog context in the test set by information retrieval techniques combining with traditional a machine learning method. First, we encode the dialog history using Term Frequency-Inverse Document Frequency (TFIDF) (Salton and Buckley, 1988) weighted bag-of-words into vector representation h . Then we denote the topic of the conversation as t and denote f as the conversation floor, i.e. if the speakers of the last utterance in the dialog history and response utterance are the same $f = 1$ otherwise $f = 0$. Then we computed the similarity $d(c_i, c_j)$ between two dialog contexts using:

$$d(c_i, c_j) = \mathbb{1}(t_i = t_j) \mathbb{1}(t_i = t_j) \frac{h_i \cdot h_j}{\|h_i\| \|h_j\|} \quad (6.5)$$

Unlike past work (Sordoni et al., 2015), this similarity function only cares about the distance in the context and imposes no constraints on the response, therefore is suitable for finding diverse responses regarding to the same dialog context. Secondly, for each dialog context in the test set, we retrieved the 10 nearest neighbors from the training set and treated the responses from the training set as candidate reference responses. Thirdly, we further sampled 240 context-responses pairs from 5481 pairs in the total test set and post-processed the selected candidate responses by two human computational linguistic experts who were told to give a binary label for each

candidate response about whether the response is appropriate regarding its dialog context. The filtered lists then served as the ground truth to train our reference response classifier. For the next step, we extracted bigrams, part-of-speech bigrams and word part-of-speech pairs from both dialog contexts and candidate reference responses with rare threshold for feature extraction being set to 20. Then L2-regularized logistic regression with 10-fold cross validation was applied as the machine learning algorithm. Cross validation accuracy on the human-labelled data was 71%. Finally, we automatically annotated the rest of test set with this trained classifier and the resulting data were used for model evaluation.

The 10 candidate references are filtered by two experts, which serve as the ground truth to train the reference response classifier. The result is 6.69 extra references in average per context. The average number of distinct reference dialog acts is 4.2. Table 6.1 shows the results.

Metrics	CVAE	kgCVAE
perplexity (KL)	20.2 (11.36)	16.02 (13.08)
BLEU-1 prec	0.372	0.412
BLEU-1 recall	0.381	0.411
BLEU-2 prec	0.295	0.350
BLEU-2 recall	0.322	0.356
BLEU-3 prec	0.265	0.310
BLEU-3 recall	0.292	0.318
BLEU-4 prec	0.223	0.262
BLEU-4 recall	0.248	0.272
A-bow prec	0.389	0.373
A-bow recall	0.361	0.336
E-bow prec	0.705	0.711
E-bow recall	0.709	0.712
DA prec	0.704	0.721
DA recall	0.604	0.598

Table 6.1: Performance of each model on automatic measures. The highest score in each row is in bold. Note that our BLEU scores are normalized to [0, 1].

kgCVAE is able to achieve the highest precision and recall in the 4 metrics at the same time (BLEU1-4, E-BOW). One reason for kgCVAE’s good performance is that the predicted dialog act label in kgCVAE can regularize the generation process of its RNN decoder by forcing it to generate more coherent and precise words. We further analyze the precision/recall of BLEU-4 by looking at the average score versus the number of distinct reference dialog acts. A low number of distinct dialog acts represents the situation where the dialog context has a strong constraint on the range of the next response (low entropy), while a high number indicates the opposite (high-entropy). It is worth to be noted that CVAE suffers from lower precision, especially in low entropy contexts. Finally, kgCVAE gets higher precision than CVAE in the full spectrum of context entropy.

Example 1-Topic: Recycling Context: A: are they doing a lot of recycling out in Georgia? Target-B (statement): well at my workplace we have palaces for aluminium cans and we have a separate trash can for recyclable paper
kgCVAE+Greedy
1. (non-understand) pardon 2. (statement) oh you're not going to have a curbside pick up here 3. (statement) okay I am sure about a recycling center 4. (yes-answer) yeah so
Example 2-Topic: Child Care Context: A: you know a private home to take their children to when they're young until they hit the preschool age and they Target-B (backchannel): uh-huh
kgCVAE+Greedy
1. (backchannel) uh-huh 2. (turn-exit) um-hum 3. (backchannel) yeah 4. (statement) oh yeah I think that's part of the problem

Table 6.2: Generated responses from kgCVAE in two examples. KgCVAE provides the predicted dialog act for each response. The context only shows the last utterance due to space limit (the actual context window size is 10).

Qualitative Analysis

Table 6.2 shows the outputs generated from kgCVAE. In example 1, caller A begins with an open-ended question. The kgCVAE model generated highly diverse answers that cover multiple plausible dialog acts. Further, we notice that the generated text exhibits similar dialog acts compared to the ones predicted separately by the model, implying the consistency of natural language generation based on y . Example 2 is a situation where caller A is telling B stories. The ground truth response is a back-channel and the range of valid answers is more constrained than example 1 since B is playing the role of a listener. The kgCVAE model is able to generate various ways of back-channeling. This implies that the latent z is able to capture context-sensitive variations, i.e. in low-entropy dialog contexts modeling lexical diversity while in high-entropy ones modeling discourse-level diversity. Moreover, kgCVAE is occasionally able to generate more sophisticated grounding (sample 4) beyond a simple back-channel, which is also an acceptable response given the dialog context.

6.5 Conclusion

In conclusion, we identified the problem of pure data-driven approach in open-domain dialog generation and proposed two novel models that show superior performance in generating diverse and appropriate responses at the discourse level with prior linguistic knowledge guidance. While the current chapter addresses diversifying responses in respect to dialog act and conversational strategy, this work is part of a larger research direction that targets leveraging both past linguistic findings and the learning power of deep neural networks to learn better representation of the latent factors in dialog.

Chapter 7

Proposed Work: Towards a Socially-Aware end-to-end Negotiation dialog System

7.1 Introduction and Motivation

Negotiation involve mixed-motive conflicts in which participants are motivated to cooperate with each other as well as compete with each to maximize their own benefits. Both qualitative and quantitative studies have shown that interpersonal rapport has powerful effects on negotiation, which encourages negotiators' willingness to share crucial information and cooperate to reduce the risk of impasse. Thus, we select this semi cooperative settings to validate our proposed socially-aware intelligent framework.

To be clear, in this study, we will focus on validating our proposed socially-aware intelligent framework on interleaving social conversation into complex negotiation communication, not referring to improve negotiation strategy for dialog system. Since Facebook AI Research (FAIR) group recently demonstrated the advancements of their innovative neural dialog models on multi-issue bargaining task, we decide to adopt their end-to-end-trained neural network as our start point, which serves as our baseline. It is worth to be noted that their best model (Reinforcement Learning+Rollouts algorithm) suffers from low agreement rate with human user. They attribute this negative consequence to human's unwillingness to cooperate with an uncompromising opponent. Besides, we hold a view that their human-human dialog dataset was collected under a very constrained experimental setting, which leads to the deviation on behaviors of their trained user simulator with the human in a normal and real negotiating setting. Thus, we are motivated to ameliorate their stubborn negotiation through inserting the social bits in the current dialog corpus with the guidance of our socially-aware framework and Ventola model which describes the structure of casual conversation. With the bootstrapped corpus, we are able to obtain a better user simulator to approximate human's behavior in a natural negotiation. Our advanced neural dialog model will be trained following the same routine proposed in the paper (Lewis et al., 2017). During the phase of reinforcement learning, our model will consider the reward from both task and social perspective. The design of reward functions is inspired by the previous empirical study of rapport in negotiation, which especially focuses on the contribution of verbal channel (Bronstein et al., 2012). Finally, our socially-aware negotiation dialog system should be able to

recognize social intention of its interlocutor and generate appropriate social responses as well as carrying out task duties at the same time.

7.2 Challenges and Solution

Based on our preliminary analysis of the collected corpus and prior study, we discovered the following foreseeable challenges of improving FAIR current end-to-end model with socially-aware capabilities:

- **Data sparsity**

Problem: The appearances of social utterances (conversational strategies) are comparatively sparse than task utterances in human-human dialog. Thus, we should be able to model those rare events in our end-to-end system.

Solution: In order to improve FAIR current end-to-end model with socially-aware capabilities, we will firstly bootstrap their collected negotiation corpus by systematically anchoring different social bits/conversational strategy in dialogs in order to boost the social phenomena for training our models. The overall structure of each bootstrapped dialog will follow the study from Ventola model. There are two types of social utterances: in-task social utterance and out-task social utterance. In-task social utterances serve as the part of task dialog but are phrased in the form of different conversational strategy like "I love basketball so could you give me two balls?"(self-disclosure).Based on our socially-aware framework, these conversational strategy optimally blend task with social, which should help to facilitate the task performance of a dialog system through building the social bond with human user. On the contrary, out-task social utterances are semantically individual unit of the dialog such as "Today's weather is pretty good", which aims at improving the quality of naturalness of the dialog. The source of in-task social utterances are from both annotated FAIR corpus and templates of different conversational strategies. The out-task social utterances are extracted from popular chat corpus such as SwitchBoard Corpus, Twitter Corpus and Reddit Corpus.

- **User Simulator and Non-likelihood model**

Problem:As we mentioned before, the original trained user simulator in FAIR corpus could not reflect the human behaviors in normal negotiation settings. Also, participants might not be good at handling social dynamics in negotiation. Thus, merely imitating human's behavior is not an ideal approach in our case.

Solution: First of all, we will build a user simulator upon our bootstrapped corpus. Secondly. (Lewis et al., 2017) pointed out that likelihood model aims to imitate the actions of human users, but does not explicitly attempt to maximize an agent's goals. Instead, they explore pre-training with supervised learning and then fine-tuning against the evaluation metric using reinforcement learning. We will adopt this similar two-stage learning strategies and refine the reward function through including social-related metrics. Meanwhile, during this step, we also promote FAIR dialog Rollouts algorithm by enabling its capability of considering social rewards in planning.

- **Cross-interaction reference in dialog**

Problem:Cross-interaction reference in dialogs (also called reference to shared experience)

is a common discourse phenomenon especially between friends and has been showed great effects on indexing built relationship. However, current deep learning techniques has limitations on long-term memory to completely model such phenomenon.

Solution: In the current corpus, each dialog is between two different participants. We will randomly select subset of the corpus and add some simulated utterances to some pairs of dialogs in order to make them look like a repeated interaction by the same two participants. During the training, we will encode the this meta information in user model.

- **Social signals in text-based system**

Problem: Social signals are sometimes perceived and expressed through different modalities such as nonverbal behaviors. Meanwhile, visual access has been proved to greatly boost rapport-building. However, text-based system is still the most widely used and easiest to setup. Thus, we should enrich the expressiveness of the text to support the interpersonal communication.

Solution: Based on the prior studies(Felbo et al., 2017; Eisner et al., 2016), people generate emotional language through emoji icons and GIF animations. We are supposed to adopt this routine and insert some emoji labels to the corpus based on the sentiment of the context.

7.3 Theoretical Framework of Rapport in Negotiation

In order to better operationalize my proposed theoretical framework of rapport in negotiation settings, I leverage the findings from (Bronstein et al., 2012) who quantitatively examined the contribution of verbal behavior to the creation of rapport in negotiation. More important, their study validated and extended Spencer-Oatey's rapport theory in negotiation context, where our framework is originated from . As they point out, most prevalent speech acts in negotiation inherently threaten face and rapport, such as request, reject and etc. Thus, applying socially-aware framework to maintain the social bond has intrinsic value in this task. Specially, conversational strategies will reduce the degree of face-threatening.

7.4 Study Context

In this study, we will bootstrap negotiation corpus collected by FAIR, which is a total 6118 human-human dialogs using Amazon Mechanical Turk. Their task is an instance of multi-issue bargaining. They are negotiated to divide collection of items, which are valued in different ways. Their unique value function for items has several constraints to enforce that it is not possible for both participants to receive a maximum value.

7.4.1 FAIR Negotiation Corpus Stats

Metric	Dataset
Train/Valid/Test	5048/544/526
Success/Fail	4801/1317
Average Turns per dialog	6.6
Average Words per Turn	7.6

7.4.2 Speech Act Annotation

We select the following five speech acts that has close relationship with rapport/face management.

- Elicit preference question: ask questions about the opponents preferences that gain the maximal information.
- Request: request a subset of items from the opponent.
- Offer: offer a subset of items to the opponent.
- Reject: reject a whole or partially previous offer.
- Accept: accept the whole or partially previous offer.

The annotation work was conducted on Amazon Turk platform. Six out of ten turkers were passed the qualification test since they have more than 80% accuracy. 2500 dialogs were annotated and used to train an n-gram SVM classifier which serves to annotated the rest of the corpus.

Speech Act	Precision	Recall	F1
Request	0.922	0.935	0.928
Reject	0.824	0.590	0.688
Accept	0.826	0.858	0.842
Elicit preference question	0.776	0.422	0.547
Offer	0.913	0.859	0.885

7.5 Step-wise Implementation Plan

- Step 1: Corpus Bootstrap
 - Speech Act and Entity Annotation
 - Annotate speech act.
 - Annotate entities in each speech act.
 - Trained an information extractor, whose output will be used to rephrase task utterances with conversational strategies.
 - Boost social utterances:
 - Annotate social utterances in the FAIR corpus. (In-task social)
 - Create conversational strategies template for rephrasing existing task utterances.(In-task social)

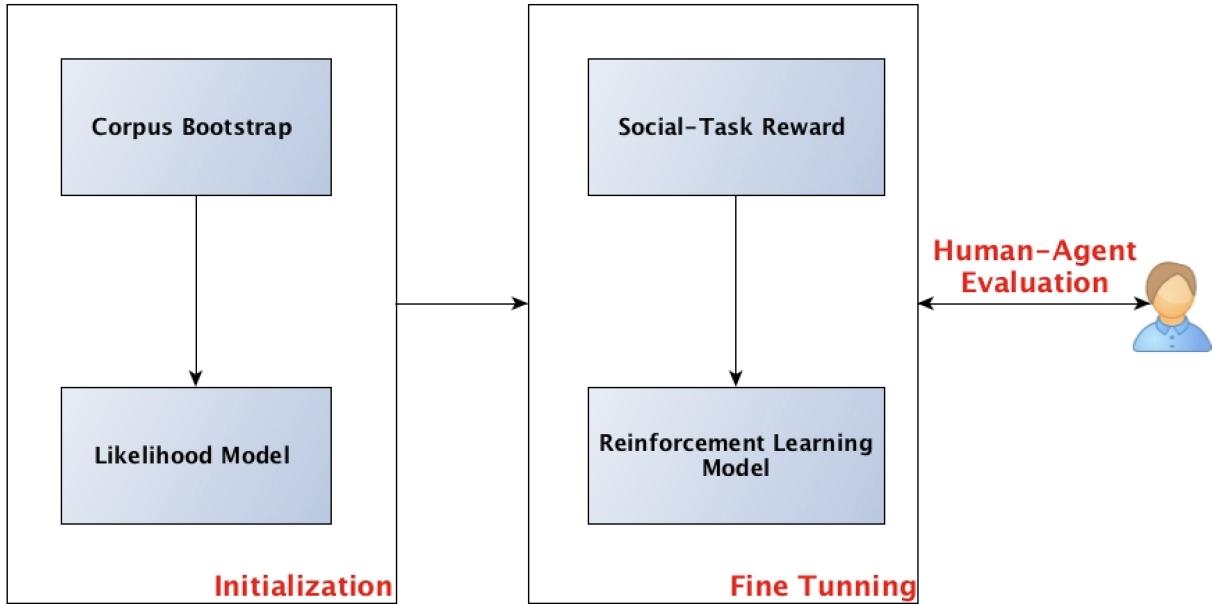


Figure 7.1: Overview of Workflow Chart

- Retrieval small talk units from other chat corpus.(Out-task social)
- Design User Model for simualting repeated interaction.
- Design the structure of simulated dialog.
 - Implement Ventola model for sampling diversified simulated dialog structures.
- Create an bootstrapped negotiation dialog corpus.
- Step 2. Train a likelihood model for user simulator
- Step 3: Define social-related reward function and human evaluation metrics
 - Design social-related reward function for reinforcement learning.
 - Design participant questionnaire of rapport (self-reported rapport) for human evalua-
tion.
- step 5: Train socially-aware neural dialog model with reinforcement learning in the agent-
agent dialog simulation setting.
- Step 6. Collect human-agent dialogs and evaluate our model through Amazon Turk
- Step 7: Post-experiment analysis

7.6 Implementation

7.6.1 Corpus Bootstrap

A sample dialog from FAIR corpus

A: : hi I would like the book and ball and you can have the hats

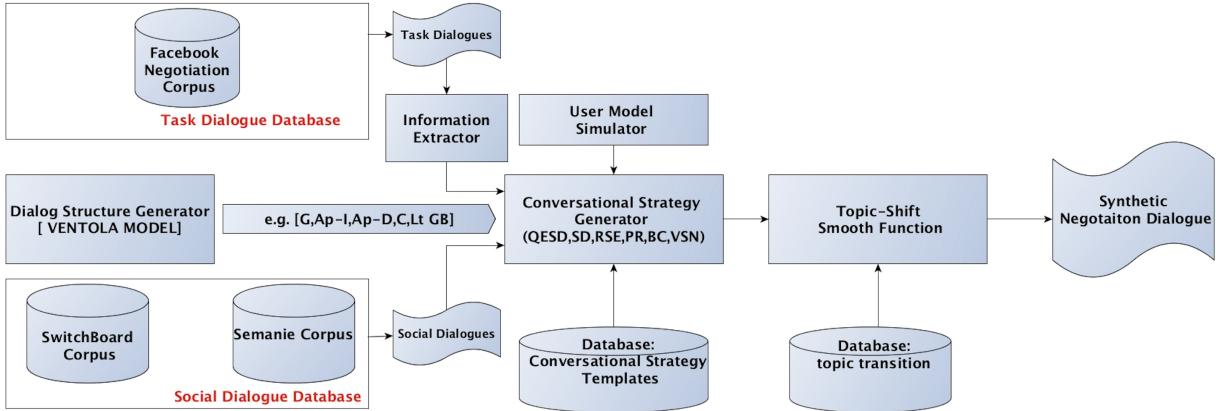


Figure 7.2: Dialog Corpus Bootstrap Architecture

B: : Can I give you either the book or the ball
 A: : I will take the book
 B: : ok i will take the hats and ball
 A: : deal

A sample bootstraped dialog

A: : hi nice to see you again! This time I would like the book and ball and you can have the hats. You got the book and ball last time. *[Refer to shared experience]*
 B: : No way buddy! I can only give you either one of them.*[Violation social norm]*
 A: : I really love that book and hope to give this ball to my son.*[Self-disclosure]*
 B: : You are so kind but sorry.*[Praise]*
 A: : I will take the book
 B: : ok i will take the hats and ball
 A: : deal

7.6.2 Social-related Reward Function Design

(Bronstein et al., 2012) found that rapport is indeed encoded in the verbal behavior and that various verbal behaviors contribute to negotiators' sense of rapport. Thus, we decide to leverage their findings to create our social-related reward functions for two reasons. First of all, they have qualitatively validated thirteen verbal variables that have strong correlation with self-reported rapport. Secondly, they learned the interpersonal rapport which is inspired by the Sepceney-Oatey's rapport theory where our framework is originated from. The following four major factors is composed of social-related reward function (SRF), which contribute to the rapport in negotiation.

- negotiation process (e.g. different speech act)
- interaction process (e.g. synchrony)
- interaction content (e.g. sentiment of content)
- interpeonal content (e.g. personal story or indexed relationship)

7.6.3 Baseline Model

The baseline model is described in Figure 7.3

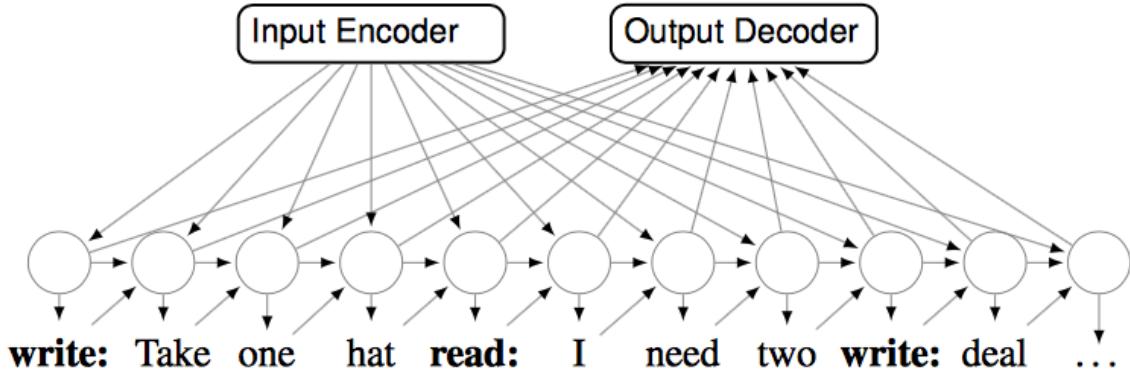


Figure 7.3: Baseline Model

7.6.4 Proposed Model: Reinforced knowledge-guided CVAE (RL-kgCVAE)

The proposed model will be trained using reinforcement learning with bootstrapped user simulator, which is built upon our bootstrapped corpus through supervised learning method.

kgCVAE endows the capability of integrating linguistic prior knowledge to sequence-to-sequence model as well as diversifying response at the discourse-level. However, directly applying kgCVAE model to operationalize socially-aware framework is problematic: as a sequence model, kgCVAE with supervised training always suffers from known failure modes due to the deviation between the objective of likelihood model with the target goal(e.g. building rapport). Specifically, the current setting of kgCVAE model strives to imitate the actions of human users. To further alleviate this problem, we propose to combine kgCVAE model with reinforcement learning to refine characteristics learned from data by imposing guidance from socially-aware framework. One solution is to enable socially-aware framework provide supervision on y during the dialog generation. During the training, we are able to obtain the a social dialog policy. Figure 7.4 demonstrates an overview of RL-kgCVAE model in training. Figure 7.5 demonstrates an overview of RL-kgCVAE model in test.

7.7 Experiment: Validate RL-kgCVAE model

In the this experiment, we aim at validating the reinforced kgCVAE model that is able to execute the guidance/planning from socially-aware framework in discourse level.

- Baseline Negotiation Bot: FAIR Original System
- Socially-aware Negotiation Bot

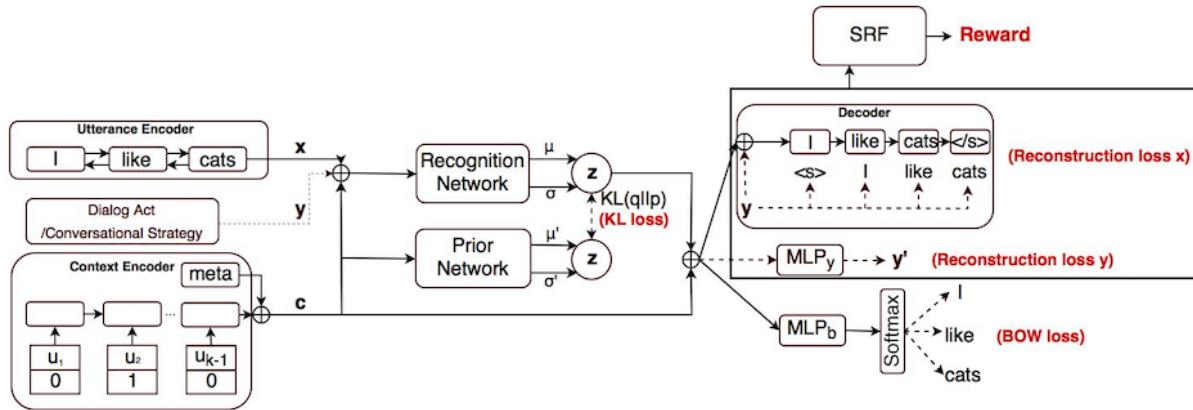


Figure 7.4: The training architecture for the RL-kgCVAE model. \oplus denotes the concatenation of the input vectors.

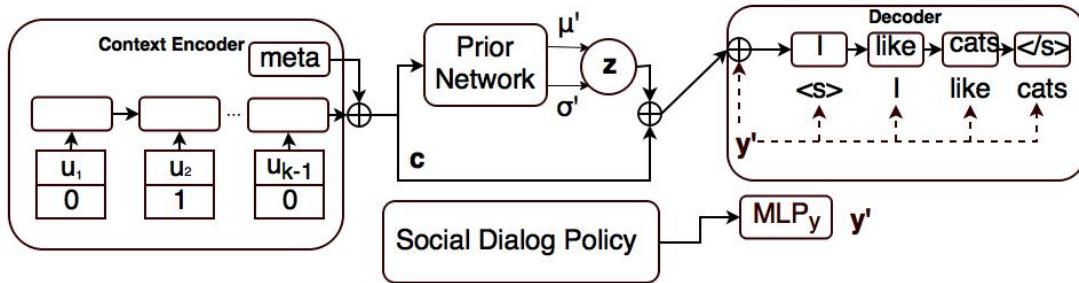


Figure 7.5: The test architecture for the RL-kgCVAE model. \oplus denotes the concatenation of the input vectors.

7.8 Human Evaluation Metrics

- Task Oriented: success rate of the deal
- Social Oriented(Participant Questionnaire) (Bronstein et al., 2012)

Chapter 8

Timeline

8.1 Timeline

- Theoretical Framework of Rapport Management
 - Published at IVA 2014
- Socio-Cognitive Effects of Conversational Strategy Congruence
 - Published at ICMI 2015
- Predictive Model for Conversational Strategies Recognition
 - Published at SIGDIAL 2016
- Predictive Model for Rapport Assessment
 - Published at IVA 2016
- Discourse Planning for Social Dialog
 - Published at IJCAI 2017 (joint work with Oscar J Romero)
- Neural Network Based Model for Controllable Social Dialog Generation
 - Knowledge-guided Conditional Variational Autoencoder Model
 - Published at ACL 2017 (joint work with Tiancheng Zhao)
 - Reinforced knowledge-guided Conditional Variational Autoencoder Model
 - Target: ACL 2018
- Socially-Aware Animated Intelligent Personal Assistant Agent
 - Published at SIGDIAL 2016 (joint work with Yoichi Matsuyama)
- Towards a Socially-Aware Negotiation Neural Dialog Model
 - Target: EMNLP 2018
- Thesis writing and defense: Aug-Sep 2018

December 6, 2017
DRAFT

Appendices

Appendix A

Sample Dialogs of Social-Aware Intelligent Personal Assistant

Table A.1: Extract from an actual interaction

Turn	Speaker	Utterance	Intent	Strategy
1	System	I'm here to be your personal assistant and help you get the most out of the conference, but to be honest, I'm a little nervous. This is my first time here, is it yours as well?	introduce, do_attendance_elicitation	SD, QE
2	User	Actually, this is my first time here as well.	first_time_attending	SD
3	System	I'm finding it overwhelming. I bet you are too.	feedback_attendance_elicitation_first_time	SD, QE
4	User	Ya, there's just so much going on. But i'm getting a hang of it.	positive_confirmation	SD
5	System	Great. Now, If you wouldn't mind sharing your goals for attending the world economic forum this year, I can try to help you achieve them.	do_goal_elicitation	ASN
6	User	Well, I'm here to meet people who are passionate about the use of technology in education, and to know more about the latest developments in the field.	recommend_people, recommend_sessions	None
7	System	Great. Good goals. Can you tell me a little bit about your work so I understand your interests better?	feedback_goals, do_interest_elicitation	ASN
8	User	I am the founder of a non profit educational startup which helps deliver quality education to the remote areas.	like {startup, education}	None
9	System	Very Interesting. Let's start by finding some interesting people for you to meet that are relevant to your interests. This is my favorite part. Let me look this up. One moment.	feedback_interest_elicitation, do_person_recommendation	ASN, SD
10	User	Sure	positive_confirmation	None
11	System	I think you would enjoy meeting this attendee. On the screen are some more details. Well? What do you think?	outcome_person_recommendation, end_person_recommendation	ASN, VSN

Appendix B

Pre-conditions and Post-conditions of conversational strategies in social reasoner

Self-Disclosure

Pre-conditions: [low–rapport, medium–rapport, rapport–decreased], [sd–user, qesd–user], [smile, gaze–elsewhere], [introduce, start*], ...

Post-conditions (add): [sd–history, smile, gaze–partner, rapport–increased, rapport–maintained], ...

Post-conditions (delete): [rapport–decreased, sd–user, qesd–user, pr–history, vsn–history, introduce, start–*], ...

Acknowledgement

Pre-conditions: [sd–user, vsn–user], [gaze–partner], [not–ack–history–user, not–ack–history–system], [feedback–*]

Post-conditions (add): [ack–history, rapport–maintained]

Post-conditions (delete): [not–ack–history, feedback–*]

Praise

Pre-conditions: [low–rapport], [not–pr–user], [not–pr–history–user, sd–history–system, turns–lower–thresh, not–pr–history–system, qesd–history–system], ...

Post-conditions (add): [pr–system, pr–history, rapport–increased, rapport–maintained], ...

Post-conditions (delete): [low–rapport, not–pr–history],

Question Elicitation Self-disclosure

Pre-conditions: [rapport–increased], [not–qesd–history, not–sd–history], [do–*, preclosing, ask–*] ...

Post-conditions (add): [qesd–system, gaze–partner] ...

Post-conditions (delete): [not–qesd–history–system, not–sd–history–system, do–*, preclosing, ask–*], ...

Reference to Shared Experiences

Pre-conditions: [medium–rapport, high–rapport], [rse–user, sd–user, vsn–user], [vsn–history, not–rse–history–system], [available–shared–experiences] ...

Post-conditions (add): [rse–history, rapport–increased, rapport–maintained, gaze–partner], ...

Post-conditions (delete): [gaze–elsewhere], ...

Adhere to Social Norm

Pre-conditions: [low–rapport, medium–rapport], [not–asn–history–system], [outcome–*–recommendation, preclosing, greeting, farewell, feedback–*, start–*, ...]

Post-conditions (add): [asn–system, asn–history, rapport–maintained, gaze–partner, ...]

Post-conditions (delete): [not–asn–history–system, [outcome–recommendation, farewell, feedback–*, ...]]

Violation of Social Norm

Pre-conditions: [high–rapport], [vsn–user], [smile, gaze–partner], [turns–higher–threshold], [once–vsn–history–user, not–vsn–history–system], [start–*, feedback–*, ...]

Post-conditions (add): [vsn–history, rapport–increased,]

Post-conditions (delete): [not–vsn–history–system, greeting, start–*, feedback–*, do–*, ...]

Appendix C

Visualization of latent variable space in kgCVAE model

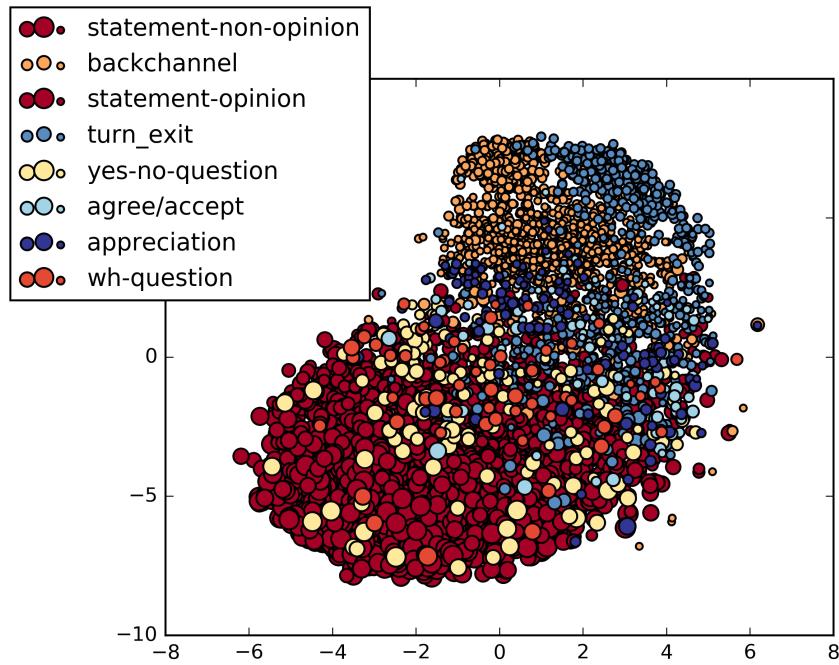


Figure C.1: t-SNE visualization of the posterior z for test responses with top 8 frequent dialog acts. The size of circle represents the response length.

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