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DISTINGUISHING AND MEASURING "COMMUNICATION WHILE DESIGNING" AND "DESIGN COMMUNICATION" IN TEAM DESIGN

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ABSTRACT
This paper presents empirical support for the notion that measuring communication from a design perspective produces different results to when measured from a communication perspective. Two types of communications: "communication while designing" and "design communication" can be distinguished in team design activities. In order to measure and compare the underlying structure of these two types of communication, we constructed two communication models and operationalized them into two segmentation and coding approaches. The paper presents a case study that applied these segmentation approaches to a video protocol of a team design activity. The segmented design session was firstly analyzed by examining the temporally-distributed turn-taking frequencies along the progression of the designing process. The team design activities in this case study, framed by these two different communication models, exhibited a similar overall structure. Information exchanges accelerated towards the end of the design session. The data were then analyzed with a first-order Markov model. Transitions between adjacent communication segments revealed the formation of sub-teams beneath the overall team. In addition, intra-personal design communications between different design issues seemed to be the primary contributors to the design processes of the team moderator and that inter-personal design communication is important across the entire design processes. These preliminary results indicate that simply modeling "communication" while designing is insufficient to capture the designerly nature of design communication.

Keywords: Team design, communication, first-order Markov model

1 INTRODUCTION

To deal with the increasing complexity of contemporary design problems, the design professions have moved from mainly an individual activity towards predominantly a team-based activity. Studying team design activities, in particular conversations/communications/interactions between designers as well as other stakeholders, therefore becomes one of the important emerging interests of design research. For example, the 7th Design Thinking Research Symposium (DTRS7) "analysing design meetings" [1] and the forthcoming 10th Design Thinking Research Symposium "analysing design review conversations" both focus on multidisciplinary design collaborations.

Design activities have long been considered as multifaceted, e.g., including development of design concepts (cognition) and process planning (metacognition) [2, 3]. The shift from individual's work to teamwork further introduces new dimensions beyond simply increasing the number of participants. Social issues, e.g., information sharing, collective learning and cognitive consensus, need to be considered [4]. A shared design team mental model [5, 6] is constructed as sub-models of task, process and team. Team coordination and "sharedness" of individual designer's cognition become important features of team design, distinguished from individual design activities.

Communication between designers is vital for achieving team coordination and "sharedness". As a broad definition, communication is the exchange of information between two or more parties. The same with the concept of designing, communication is multifaceted: multiple types of communication

can distinguished. This paper aims to explore two types of communication. Designing, in addition to being a generative process, is also a negotiating and social process [7]. "Communication while designing" frames the design session through the turn-taking of the conversation by members of the team, independent of the content of utterances. It could thus be seen as the structure of communication provides an environment for the acts of designing. Design cognition, which directly contributes to design conception and development, is the kernel of the designing process. Many design cognition studies explicitly exclude process planning and other social conversations (e.g., [8]). The second type of communication in team design activities is defined as "design communication", i.e., the exchanges of design issues directly concerned with the status of "design space". This could be seen as the structure of designing provides an environment for the acts of communication.

This paper hypothesizes that the structure of "design communication" is different from "communication while designing". This hypothesis was tested by comparing the temporal distribution of communication segments and then by examining the transitional probabilities of adjacent segments in the two different models of communication.

2 METHODS

2.1 Data Segmentation and Coding Methods

The protocol analysis methodology [9, 10] was applied in this study. Design protocols, based on the videoed recording of design activities, produce a particular form of qualitative data. They have to be transcribed, segmented and/or categorized in some ways and it is the transformed protocols on which the analyses are performed [11]. In order to examine the underlying structure of these two models of communication in team design activities, two segmentation and coding approaches are used to respectively transform the videoed design activities into a chronological sequence of basic communication components.

Guided by the basic principle of an inter-person communication mechanism, "communication while designing" is modelled as conversational turn-taking among more than one participant, regardless of the content of each individual's utterance. Each participant's uninterrupted, continuous utterances were considered as a single segment of communication while designing, and coded with that participant's name. When more than one person responded at the same time, the segment was labelled with "all".

"Design communication" is concerned with the design issues in design ideation, development, analysis and evaluation. The structure of "design communication" is then modeled as a sequence of design issues according to an ontologically-based segmentation and coding scheme [12]. The FBS ontology [13, 14] describes design knowledge in terms of function (F) of a designed object (its teleology); the behavior (B) of that object (either derived (Bs) or expected (Be) from the structure), and structure (S) represents the components of an object and their compositional relationships. These ontological classes are augmented by requirements (R) that come from outside the designer and description (D) that is the document of any aspect of designing. In FBS ontologically-based segmentation and coding, the basic unit of analysis is the design issue. A person's continuous utterance often contains more than one issue. As "design communication" is modeled by the turn-takings of design issues (segmented utterances), intra-personal communication is possible when a designer elaborates or reflects on his/her own design ideas.

These two data segmentation methods transform the comparisons of two communication models into the contrast between the turn-taking structures of continuous utterances of individual team members as segments with segmented utterances based on design issues.

2.2 Data Set

These data segmentation approaches were then applied in a case study, on data obtained from the DTRS7 dataset [1]. The source data was a video of design meetings taking place in a product design practice, Figure 1. The meeting lasted about one and half hours. A multidisciplinary design team was asked to brainstorm ideas for solving technical issues in the design of a thermal printing pen. Figure 2 illustrates what the thermal pen is intended to do.

The team consisted of a business consultant, who acted as the moderator (Allan), three mechanical engineers (Jack, Chad and Todd), an electronics business consultant (Tommy), an ergonomist (Sandra), and an industrial design student (Rodney). They were all from the same company and the

student, Rodney, was on an internship with the company. The details of the meeting setting can be found in McDonnell and Lloyd [1].

Figure 1. Four camera digital recording of the design session.

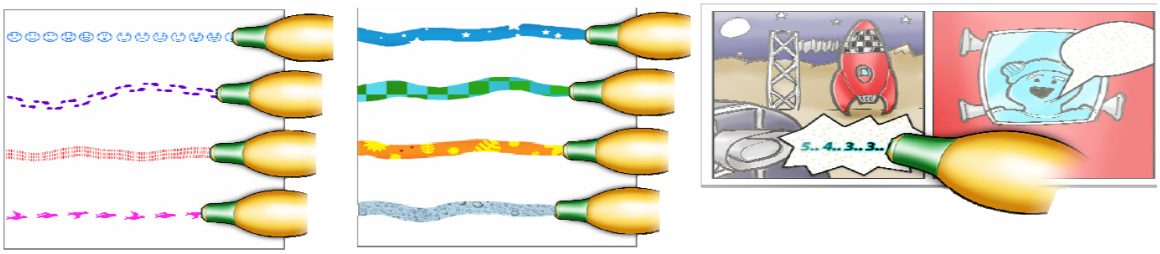

Figure 2. Illustrations used in the session showing the function and expected behavior of the thermal printing pen being designed.

2.3 Two-level Analysis

This paper is interested in the syntactic structure of communication, rather than the information content conveyed by the communication. The analysis of "design communication" differed from the regular FBS ontologically-based protocol analyses. We only utilized design issues as the basis for developing the segments used in "design communication". The ownership of the utterances was coded, but not the contents of design issues. This data preparation also facilitates the comparison with "communication while designing".

There are two levels of comparison presented here. The macroscopic analysis explores the overall structural pattern by examining frequency distributions of utterance spoken by each participant and the temporal distributions of basic components. The microscopic analysis is conducted by using a first-order Markov model, where transitional probabilities between adjacent utterances or design issues are measured.

3 RESULTS AND DISCUSSIONS

3.1 Summary of the Data Segmentation

After applying the two segmentation approaches, the videoed design session resulted in 1462 conversational turn-takings and 1280 design issues. In both segmented data sets, the most frequent speaker was Allan, the moderator, and the least active participant was Rodney, the intern designer who was the least experienced member of the team, Figure 3.

The "all" category in "communication while designing" usually contained laughs after a joke, which were excluded in the FBS ontologically-based coding for "design communication", which is why there are fewer design issue segments that turn-taking segments. To make these two sets of

segmented data comparable, we removed the "all" codes, and combined the adjacent codes if the same person continued talking after a laugh. The adjusted coding for "communication while designing" contained 1366 after removing "all" category. The removal of "all" category did not affect the turn-taking frequencies for individual persons, χ^2=0.086, p=1.000. The remaining analyses thus used the adjusted data of "communication while designing".

The Chi-square test indicated that turn-taking frequencies were statistically significantly different between "communication while designing" and "design communication", χ^2=17.812, p=0.007. Cramer's V=0.082 indicates a small effect. Residual analysis showed the frequency difference mainly lay with Sandra and Chad, two relatively less active participants, Figure 3.

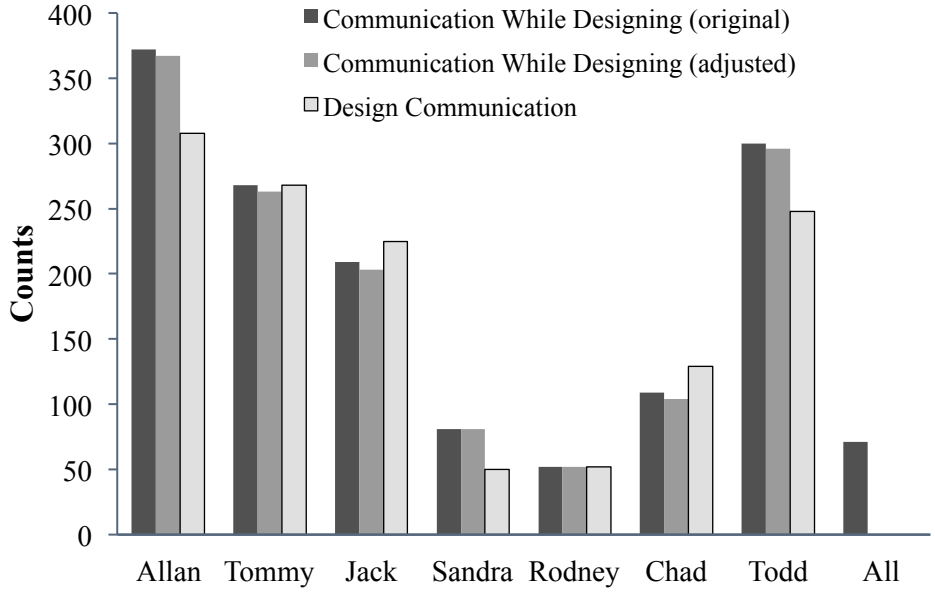

Figure 3. Turn-taking frequency distribution of each participant

3.2 Temporal Structure of Communications

Designing is dynamic in nature. Plotting the temporally distributed frequencies of utterances reveals the overall pattern of the communication structure. Figure 4 shows that, regardless of the segmentation methods applied, the turn-taking frequencies tend to increase towards to the latter stage of designing. It suggests that as the designing progresses exchanges of information occur more frequently. This increasing trend is more pronounced in "design communication", as indicated by the steeper slope of its regression line of best fit.

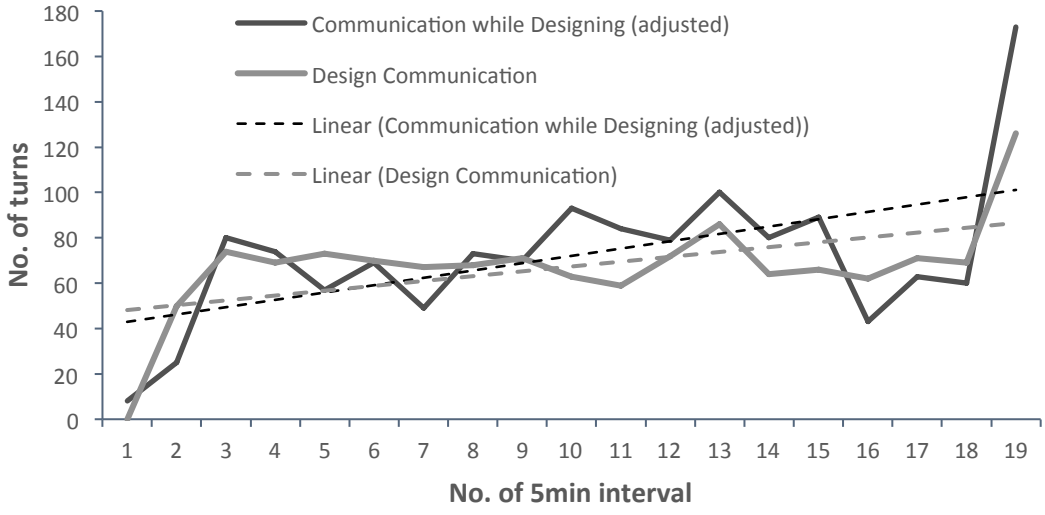

Figure 4. Temporally distributed Frequencies of Turn-taking in 5-minutes interval

3.3 Transitional Structure of Communications

Transitions between communication components provide another lens through which to explore communication structures, independent of the temporal distribution of communication segments. This paper applies the first order Markov model (only the transitions between intermediate utterance segments were considered) to extract transitions from one member (for "communication while designing") or design issue (for "design communication") to another of the whole session.

3.3.1 First-order Markov Model of "Communication while Designing"

The transitional probability matrix of the participants' continuous utterances are shown in Table 1. The horizontal rows show the transition probabilities of individual responses therefore it added up to 1. The main diagonal, the probabilities of self-recurring turn-taking, is zero. This is because, by definition, one person cannot respond to himself or herself when applying the "communication while designing" model.

Allan, the moderator, had the frequent interactions with all other participants. The probabilities of transiting to Allan (column 2) are the first or second largest number for each row. Todd had the highest chance of talking after Allan (0.28). The probabilities of Tommy and Jack's response following Allan's utterance were the same, 0.22. Chad, Sandra and Rodney were relatively not active in responding to Allan. Though lower than row average (1/6=0.167), their responding probabilities were highest compared to their communication with other participants.

Table 1. The probability of communicative transition from one member to another

	Allan	Tommy	Jack	Sandra	Rodney	Chad	Todd
Allan	0.00	0.22	0.22	0.09	0.08	0.11	0.28
Tommy	0.33	0.00	0.16	0.05	0.02	0.07	0.37
Jack	0.42	0.21	0.00	0.06	0.03	0.05	0.23
Sandra	0.37	0.21	0.16	0.00	0.02	0.09	0.15
Rodney	0.51	0.12	0.12	0.06	0.00	0.04	0.16
Chad	0.35	0.16	0.16	0.02	0.02	0.00	0.29
Todd	0.34	0.34	0.15	0.06	0.03	0.08	0.00

Figure 5 shows in graphical form the inter-personal transition probabilities in Table 1 only where the transitional probabilities are larger than the row average of 0.167. The sizes of circles corresponds to the proportion of turn-taking frequencies, Figure 3.

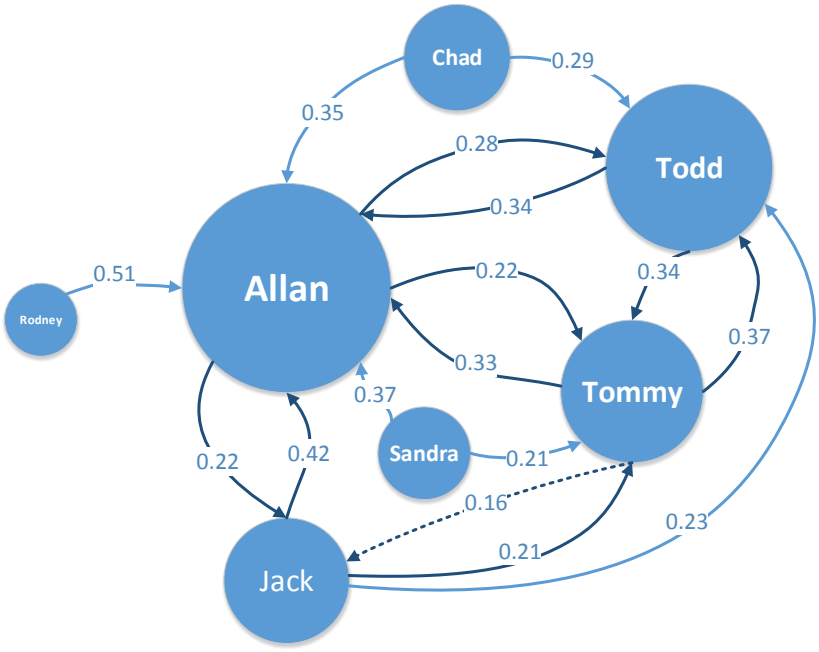

Figure 5. Transition diagram of "communication while designing"

This transitional diagram illustrates the general intensities of inter-personal communication and reveals several pairs of participants who responded to each other frequently. For example, the transitional probabilities between Tommy and Todd reach 0.37 and 0.34, those between Todd and Allan are 0.34 and 0.28, those between Jack and Allan 0.42 and 0.22, and those of Tommy and Allan 0.33 and 0.22. Gero and Kan [15] defined this phenomenon as the formation of sub-teams. Allan and Tommy, two business consultants, played a vital role in the formation of sub-teams. The mechanical engineers, Todd, Chad and Jack, mainly discussed with the business consultants, and had a few interactions within engineers in the team (e.g., "Jack to Todd", 0.23, "Chad to Todd", 0.29). Among the three engineers, Chad was relatively inactive, indicated by the low probabilities associated with his response to other participants.

Rodney (industrial design intern) and Sandra (ergonomist) were clearly not in active in this meeting. The transitions to them generally had low probabilities, all less than 0.09 (less than 0.06 when excluding the transitions from Allan). This indicates that Rodney and Sandra were not responding to anyone much during communication. In particular, they had limited communication with engineers, neither providing information to the engineers nor getting responses from them.

3.3.2 First-order Markov Model of "Design Communication"

We calculate the probability of the consecutive utterance of the participants' design issues to form the first order Markov model of "design communication". Table 2 shows the transition probabilities of participants according to their utterances of design issues. In a random scenario or if everyone has equal turns of contributing design issues, the probability of transitions will be 1/7 (i.e., 0.143).

The diagonal cells show the intra-personal design communication of individual participants. Each cell shows the probability of transition (communication) of design issues by the same person. Contrast this to the zero-value main diagonal in "communication while designing" matrix, the diagonal cells in "design communication" matrix have the highest values in their row. The intra-personal transition probability is particularly high for Tommy-Tommy and Jack-Jack (0.61), indicating over 60 percent of their responses were picking up the design issue that they started with, or they were continuing with different classes of design issues. Chad and Allan also have very high intra-personal design communication (0.56 and 0.55 respectively). Sandra has the lowest intra-personal design communication (0.36).

Table 2. The probability of transition from one member to another communicating design issues

	Allan	Tommy	Jack	Sandra	Rodney	Chad	Todd
Allan	0.55	0.09	0.09	0.03	0.04	0.07	0.11
Tommy	0.12	0.61	0.09	0.02	0.01	0.03	0.13
Jack	0.16	0.08	0.61	0.03	0.01	0.02	0.09
Sandra	0.26	0.10	0.10	0.36	0.02	0.08	0.08
Rodney	0.20	0.06	0.06	0.04	0.49	0.02	0.14
Chad	0.13	0.12	0.05	0.01	0.01	0.56	0.12
Todd	0.12	0.14	0.08	0.03	0.03	0.07	0.53

Figure 6 shows in graphical form the transitions of design issues, Table 2. Because of the high probabilities of intra-personal communications, inter-personal transition probabilities are all relatively low, the majority of them are under 0.10. Figure 6 illustrates the inter-personal transitions whose probability lies between 0.10 and the row mean of 0.143 using dotted lines. The moderator Allan is the main contributor to the team discussion, having the largest number of inter-personal transition whose probabilities are over 0.10. This figure shows that the sub-teams of Tommy and Todd, and Allan and Todd can still be observed, but their significance is reduced. The sub-teams of Allan and Tommy, and Allan and Jack, however, disappear in this diagram. The consultant Tommy was no longer a pivot in "design communication".

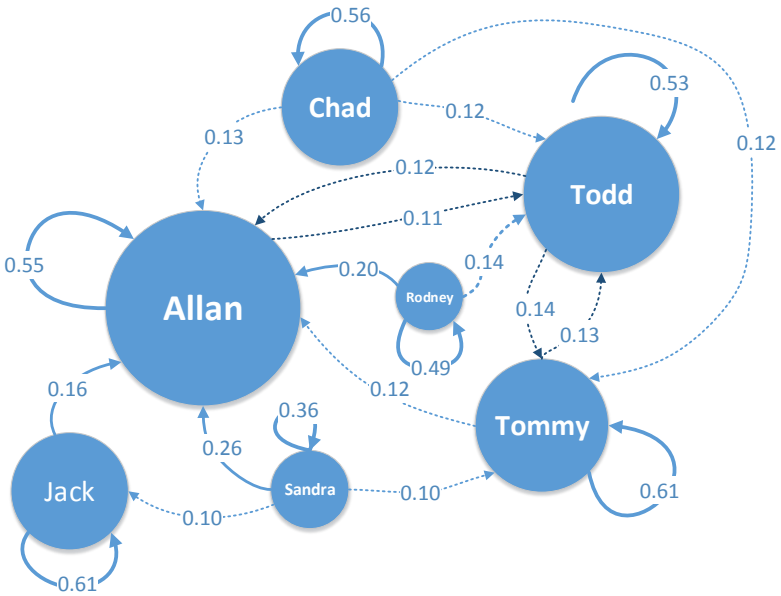

Figure 6. Transition diagram of "design communication"

Chad and Sandra were the only two participants who had three outgoing inter-personal transition probabilities that are over 0.10. Rodney seemed to have more design idea exchanges with other participants than with himself. It was also observed that the industrial design intern and ergonomist provided support and feedback to the engineers (e.g., "Rodney to Todd", 0.14; "Sandra to Jack", 0.10). These findings were not revealed in the "communication while designing" results.

4 CONCLUSION

This study aimed to measure and compare two types of communication in team design activities. Through an in-vivo case study, we found some conceptual differences between "communicating while designing" and "design communication". The difference between these two communication models suggest that measuring design protocols from a communication viewpoint fails to reveal the designerly behaviors of the participants, which can only be observed by measuring it from a design point of view. In this case, Chad and Sandra are good examples; their contributions can only be revealed by examining "design communication". The interdisciplinary collaborations between the industrial design intern and engineers, and between ergonomist and engineers were also found in the "design communication" analysis only.

This finding has important implications in future studies into designing. Conventional protocol analysis studies of designing embed design processes in the coding scheme that make it hard to study "design communication" in relation to design processes. The FBS ontologically-based data segmentation and coding method can capture the essence of "design communication" with an ontological framework.

This is only our first step to explore the structures of communication in team design activities. The generalizability of our claims await future studies to validate them.

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