THE EFFECT OF COMPUTER MEDIATION ON COLLABORATIVE DESIGNING

Using a Universal Coding Scheme to Study Cognitive Differences

JEFF W.. KAN, JOHN S. GERO
Krasnow Institute for Advanced Study, USA
kan.jeff@gmail.com; john@johngero.com

Abstract. There has been considerable research in studying collaborative designing using protocol analysis. However, it is not possible to compare these studies because they use different models and have their own coding schemes. A coding scheme based on the Function-Behaviour-Structure (FBS) ontology has been proposed as the basis of a universal coding scheme that transcends the domain of application, the task being studied, and the number of designers being studied. This paper presents results from using the FBS coding scheme and sequential analysis to study the differences between face-to-face design collaboration and synchronized design collaboration using NetMeeting via the internet. In this case the formulation and re-formulation processes are richer in the NetMeeting design collaboration. In the face-to-face session they are quicker in arriving at the structure of the design.

Keywords. Designing; computer mediate design collaboration; protcol analysis; design ontology.

1. Background

Increasingly design is carried out in teams rather than by individuals alone. There has been considerable research in studying computer supported co-operative work (CSCW). In the domain of design collaboration, protocol analysis techniques have been a well received tool to examine the cognitive behavior of designers. However, our ability to compare these studies has been limited by the use of different coding schemes applied to the protocols by different researchers and even different coding schemes by the same researchers studying different tasks. As a consequence there has not been an adequate basis to compare and build on such research to inform educators, designers and tool builders. The papers from the DTRS2 (Cross et al, 1996) and DTRS7 (McDonnel and Lloyd, 2007) are examples of the diversity of study methods and coding schemes.

1.1. ANALYSIS OF DESIGN PROTOCOL

In order to quantify a design protocol for analysis, it has to be segmented and coded according to certain schemes.

There are different ways to segment protocols depending on the objectives and scope of the study. For instance, protocols can be segmented according to instances of processes in order to study the frequencies of processes. Ericsson and Simon (1993) suggested that appropriate cues for segmentation are pauses, intonation, and contours, which correspond to their information processing model. Gunther et al (1996) and Dorst and Dijkhuis (1996) used a fixed 15-second time-scale. The advantage of this method is that it requires no interpretation, hence it segments the protocols quickly. However, the obvious problem with a fixed time-scale is that it may cut in the middle of a statement, which could make the coding difficult. Another way to segment protocols relates to the designers' lines of intentions, actions or moves (Goldschmidt, 1995; Gero and McNeill, 1998; Suwa et al., 1998). There are also differences in whether the categorisation affects the segmentation. In Gero and McNeill (1998), one sub-category corresponds to one segment. On the other hand, Suwa et al. (1998) proposed that one segment might contain several sub-categories.

Similarly, there is diversity in coding schemes; many coding schemes have been developed for use with design protocols. Almost every study has its own scheme, all such schemes are based on particular views of the activity of designing. Categories are added or subtracted to reflect the data. As a consequence many of these schemes are unique to the data to which they are applied. Design protocols are usually interpreted or analysed by using descriptive statistics of how designers spend their time on what they do.

1.2. FBS ONTOLOGY

The FBS ontology (Gero 1990) models designing in terms of three classes of variables: function, behavior, and structure. In this view the goal of designing is to transform a set of functions into a set of design descriptions. The function (F) of a designed object is defined as its teleology; the behavior (B) of that object is either expected or derived from the structure (S) which is the components of an object and their relationships. A design description cannot be transformed directly from the functions which undergo a series of processes among the FBS variables. Figure 1 shows the relationship among those processes and variables.

In this paper we propose to study the effects of computer mediation on collaborative designing using a protocol analysis. We commence by segmenting and coding the protocol by categorising the designers' protocol into F, B, and S classes. Section 2 will present an example of the segmentation and coding.

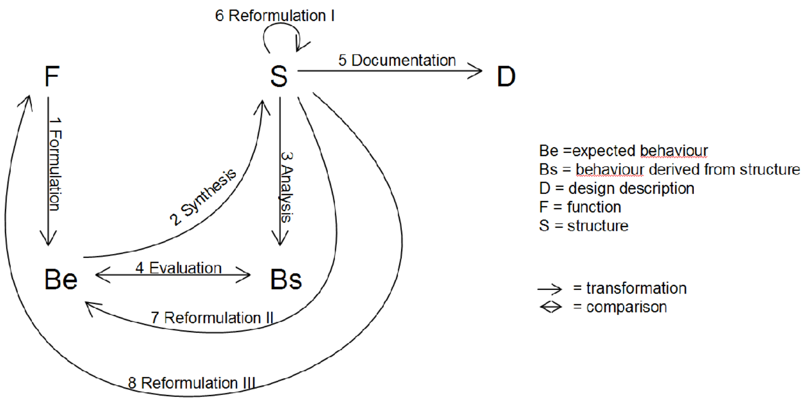

Figure 1. The FBS ontology of designing

1.3. SEQUENTIAL ANALYSIS

Markov analysis, also referred to as Markov chains, is one of the most used method to do sequential analysis. It describes the sequence of events by the probability of one event leading to another. A Markov chain is a discrete-time stochastic process with a number of states such that the next state solely depends on the present state. Markov chains have been used to analyse writers' manuscripts and to generate dummy text (Kenner and O'Rourke, 1984); for the ranking of web pages by Google (Langville and Meyer, 2006); to capture music compositions and synthesise scores based on the analyses of previous scores (Farbood and Schoner, 2001).

Traditional protocol analysis is based heavily on statistical analysis and often contains the assumption that each segment is an independent event. Markov analysis, based on the probability of relationship with the last event, provide another technique for developing insight into design activities. McNeill et al. (1998), treating *analysis*, *synthesis* and *evaluation* as Markov states, found that the most likely event to follow an *analysis* event is a *synthesis* event. Also the most likely event after a *synthesis* event is an *evaluation* event but the most likely event after an *evaluation* event is a *synthesis* event. From the FBS ontology in Figure 1, the underlying variables for these processes *analysis*, *synthesis* and *evaluation* are FBS. Therefore, in this paper, we treat the FBS coded segments as the fundamental states in the Markov analysis.

2. Data and Example of Segment and Code

The face-to-face design session video was recorded in-situ where two architects, one more senior than the other, designing a commercial building after a review session, subsequent to a client meeting. In this session the designers revisited the relationship between vertical circulation and the void areas, in order to satisfy the client's preference.

The computer-mediated session was a in-vitro design session simulating distance collaboration by using NetMeeting and tangible interfaces. NetMeeting contains a shared white-board and a video conferencing tool.

The designers, an architect and a landscaper, were asked to design an art gallery in a harbor-front triangular site with level changes. The details were documented in Kan (2008).

The design task and stage between the two sessions were very different. However, there were design activities happening in both sessions; both sessions contained the intentions of changing the existing environment and produced some descriptions that documented the proposed changes.. The communication in the face-to-face session depended on the use of gestures and tacit knowledge while the computer-mediated session contained more communication regarding the use of the technology instead of designing activities. Some of the non-verbal communications in the face-to-face session were captured while transcribing. For example in the third column of Table 1 all utterances were accompanied by non-verbal communications, recorded in bracket sets.

Table 1 is the excerpt of the protocol. In the first column, SA denotes the senior architect and A denotes the architect. The utterances were segmented according to the FBS classes, if one utterance contains more than one predominant class it will be segmented. In segment 47 the senior architect was evaluating the behavior of the lobby so it was coded as B. All the other segments in this excerpt concern the form and location of elements so they were coded as structure.

TABLE 1. Example coding of the face-to-face session.

Subjects	No.	Segment	Code
SA	47	I like that with glass under that, you walk past the sort of lobby as you come in (pointing at drawing the architect **A** just drawn)	B
A	48	and as you go up this thing jumps out....(gesturing jumps out)	S
SA	49	yeah so you could put that line there (moving over drawing)...	S
A	50	And there is your Bridges here DM (gesturing position). Bridge here bridge here either side (gesturing position).	S

For this exploratory study, only the first sheet of drawings were studied. A detailed qualitative comparison can be found in Kan (2008). The face-to-face session contains 98 segments and 91 of them contain FBS coding. The NetMeeting session has 97 segments and only 57 of them contain FBS coding.

3. FBS and Sequential Analysis

Using the FBS framework and Markov analysis we hypothesise that the design collaboration will exhibit similarities and differences in behavior quantified by the FBS variables. These similarities and differences are broken down into the following hypotheses.

3.1. HYPOTHESES

H1: With the loss of communicating through lack of gesturing because of the limitation of this computer mediation setting, the distribution of FBS states will be different between the two sessions.
H2: The distribution of transitions of the FBS states will be different in the two sessions.
H3: Any design processes, independent from modes of collaboration, take longer to get from function – intention (F) to structure – a design proposal (S) than from behavior (B) to structure (S).

Chi-square test is used to test H1. The null hypothesis here is that the two sets are similar. The frequency of FBS codes for the face-to-face and NetMeeting sessions are (F:4, B:28, S:59) and (F:11, B:26, S:20) respectively. The Chi-squared is 0.00174 and the Chi-distance is close to 1; the chance of the two sets being similar is close to zero. Therefore, the null hypothesis is adequately falsified and there is a significant difference between the distribution of FBS codes of the face-to-face session and the NetMeeting session.

3.2. STATE TRANSITIONS

To test H2, we have to count the number of occurrences of the FBS state transitions from one segment to the next segment. Table 2 records the occurrences of those events. Using Chi-square test again the Chi-distance is 1, therefore there is a significant difference between the distributions of the transitions of the FBS states of the two sessions.

TABLE 2. Occurrences of different types of transition events.

Face-to-face				**NetMeeting**			
	Next State				***Next State***		
State	***F***	***B***	***S***	***State***	***F***	***B***	***S***
F	2	0	2	***F***	4	5	2
B	1	9	17	***B***	3	13	9
S	1	18	40	***S***	4	7	9

With the observations of the transition events, these can be turned into a transition matrices *P*, Equations (1) and (2), which represent a first order Markov process. The numbers in the matrix represent the probability of an event; for example in the first row of equation (1), the probability of an F state being followed by another F state (F-F) is 0.5. The probability of an F state being followed by a B state (F-B) and S state (F-S) is 0.0 and 0.5 respectively.

$$P_{f2f} = \begin{pmatrix} & F & B & S \\ F & 0.50 & 0.00 & 0.50 \\ B & 0.04 & 0.33 & 0.63 \\ S & 0.02 & 0.31 & 0.68 \end{pmatrix} \qquad (1)$$

$$P_{nm} = \begin{array}{c} \\ F \\ B \\ S \end{array} \begin{pmatrix} F & B & S \\ 0.36 & 0.45 & 0.18 \\ 0.12 & 0.52 & 0.36 \\ 0.20 & 0.35 & 0.45 \end{pmatrix} \tag{2}$$

Examining equation (1), especially column three, the face-to-face session is dominated by *structure* because at any state of the design there is at least a 50% chance that the next state will be *structure*. Refer to the first column, in this protocol the likely state that precedes a *function* state is a *function* state. This is shared by the NetMeeting session (36% chance of F-F), first column of equation (2), but in the NetMeeting session the chances of B-F (12% vs 4%) and S-F (20% vs 2%) events are higher. This indicates that the NetMeeting had higher chance of type 3 reformulation assuming some of the S-F events are reformulations. Assuming some of the F-B events contain the formulation processes, in this first sheet of the face-to-face session there is no formulation process (F to Be) recorded. This is likely due to the stage of design they are at. The NetMeeting session has much higher chance of having the formulation processes (45% vs 0%).

3.3. FIRST PASSAGE TIMES

In order to test H3, we need to rely on one of the properties of Markov chains – first passage times. The mean first passage time is the average number of steps traversed before reaching a state from other states. Readers can refer to Kemeny and Snell (1960) for the formulas to calculate the first passage M from the transition matrix P. Equation (3) and equation (4) are first passage times of the FBS states for the face-to-face and NetMeeting sessions respectively. The first rows in the matrices signify the average steps it takes for an F, B and S state to occur after an occurrence of an F state. Similarly the second row shows the average steps for an F, B and S state to occur after an occurrence of a B state. For example in the face-to-face session, if starting with a F state the mean number of events before another F state is 22.0. The mean numbers of events before a B state and a S state are 5.4 and 2 respectively. The largest and smallest mean numbers occur when starting with an S event; on average it takes 43 events for an F event and 1.5 events for another S event to occur. If the starting state is the same as the stopping state, for example, S to S, this is called the mean recurrence time. In the NetMeeting session, the shortest mean first passage time is the mean recurrence time of a B event (2.2) and the longest mean first passage time is from B to F (6.6).

$$M_{f2f} = \begin{array}{c} \\ F \\ B \\ S \end{array} \begin{pmatrix} F & B & S \\ 22.5 & 5.4 & 2.0 \\ 42.1 & 3.3 & 1.6 \\ 43.0 & 3.4 & 1.5 \end{pmatrix} \tag{3}$$

$$M_{nm} = \begin{pmatrix} & F & B & S \\ F & 5.1 & 2.3 & 3.7 \\ B & 6.6 & 2.2 & 3.0 \\ S & 6.0 & 2.7 & 2.8 \end{pmatrix} \tag{4}$$

These equations support the hypothesis that it takes longer (more steps) to get from F to S than from B to S in both the face-to-face (2.0 vs 1.6) and the NetMeeting (3.7 vs 3.0) sessions.

To get to S from any state, the designers take longer using computer-mediated collaboration than face-to-face (from F 3.7 vs 2, from B 3 vs 1.6, and from S 2.8 vs 1.5). However, the NetMeeting collaboration has faster mean passage time form F to F (5.1 vs 22.5) and F to B (2.3 vs 5.4). This could be partially due to the different stage of design they were at. Also this might due to the lack of access to gestures and body languages that force them to dispatch semantic rich communication in order to cognitive synchronize their ideas.

4. Conclusions and Discussions

One of the major differences, observed form the raw protocol data, of the two sessions is the unavailability of communicating through gesturing in the NetMeeting session. This might cause them to take longer arrive at any *structure* states as compared to the face-to-face session. However, they seem to have more formulations and the reformulations of *function*. The distribution of FBS codes and the distribution if their transitions are very different. However, as predicted, in both sessions, the first passage time from B to S is shorter than from F to S.

The processes from FBS ontology are claimed to be fundamental for all designing. Unlike most coding schemes which allow overlapping of codes, the ontological approach requires precise discernment of one code per segment. This clear distinction converts the protocol into unambiguous segments; it quantifies the amount of effort spent in relation to function, behavior, or structure, which facilitate the comparison of different design processes.

Markov analysis, taking time into account, provides a way to examine design protocol data in a sequential manner. It does not assume successive events to be independent. The transition matrix can be viewed as a signature that summarises the transitions between all the FBS events. The mean first passage time matrix provides another view of the design process in terms of the expectancy of FBS events.

The effect of computer mediation on collaborative designing is to change the distribution of time for the activities of designing.

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References

Cross, N., Christiaans, H. and Dorst, K.: 1996, *Analysing Design Activity*, John Wiley & Son.

Dorst, K. and Dijkhuis, J.: 1996, Comparing paradigms for describing design activity, in Nigel Cross, Henri Christiaans and Kees Dorst (eds), *Analysing Design Activity*, John Wiley & Son, pp. 253–269.

Ericsson, K. A. and Simon, H. A.: 1993, *Protocol Analysis: Verbal Reports as Data*, revised edn, The MIT Press.

Farbood, M. and Schoner, B.: 2001, Analysis and synthesis of palestrina-style counterpoint using markov chains, *Proceedings of International Computer Music Conference*, Havana, Cuba.

Gero, J.S.: 1990, Design prototypes: A knowledge representation schema for design. *AI Magazine* **11**(4), 26-36.

Gero, J. S. and McNeill, T.: 1998, An approach to the analysis design protocols, *Design Studies* **19**(1): 21–61.

Goldschmidt, G.: 1995, The designer as a team of one, *Design Studies* **16**(2): 189–209.

Gottman, J. M. and Roy, A. K. : 1983, *Sequential Analysis: A Guide for Behavioral Researchers*, Cambridge University Press.

Gunther, J., Frankenberger, E. and Auer, P.: 1996, Investigation of individual and team design processes, in Nigel Cross, Henri Christiaans and Kees Dorst (eds), *Analysing Design Activity*, John Wiley & Son, pp. 117–131.

Kan, J. W. T.: 2008, *Quantitative Methods for Studying Design Protocols*, PhD Thesis, Faculty of Architecture, Design, and Planning, The University of Sydney, Sydney.

Kan, J. W. T. .and Gero, J. S.: 2007, Using the FBS ontology to capture semantic design information, in J McDonnell and P Lloyd (eds), *DTRS7*, University of the Arts, London, pp. 155-165.

Kan, J. W. T. and Gero, J. S.: 2008, Do computer-mediated tools affect team design creativity? in Nakapan et al. (eds) *CAADRIA08*, Chiang Mai, pp. 263-270.

Kemeny, J. G. and Snell, J. L.: 1960, *Finite Markov Chains*, Van Nostrand. Princeton, New Jersey.

Kenner, H and O'Rourke, J: 1984, A travesty generator for micros: Nonsense imitation can be disconcertingly recognizable, *BYTE* (12), 449–469.

Langville, A. N. and Meyer, C. D.: 2006, Updating markov chains with an eye on google's pagerank, *SIAM Journal on Matrix Analysis and Applications* **27**(4), 968 – 987.

McDonnell, J. and Lloyd, P.A.: 2007, *Design Meeting Protocols: Proceedings from Design Thinking Research Symposium 7*, 19-21 September, London.

McNeill, T., Gero, J. S. and Warren, J.: 1998, Understanding conceptual electronic design using protocol analysis, *Research in Engineering Design* **10**(3): 129–140.

Suwa, M, Purcell, T and Gero, JS: 2000, Unexpected discoveries and s-invention of design requirements: important vehicles for a design process, *Design Studies* **21**(6): 539–567.