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A GENERIC TOOL TO STUDY HUMAN DESIGN ACTIVITIES

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ABSTRACT
This paper reports on the results of using an ontologically-based generic approach to carry out protocol analyses of designers. The Function-Behavior-Structure (FBS) ontology has been proposed as the basis of a generic coding scheme that transcends the domain of application, the task being studied, and the number of designers being studied. This paper presents results of testing this generic coding scheme in both in vitro and in situ conditions. After coding, these protocols was analyzed using descriptive statistics and Markov chains and the results compared. This work demonstrates the applicability of using the FBS coding scheme as a foundation for studying human design activities.

Keywords: protocol coding, generic coding, protocol analysis, design ontology.

1 INTRODUCTION
Over the past three decades, protocol analysis has become one of the most widely used methods to study human design activities and cognitive design processes. 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 researchers, educators, designers and tool builders. The papers from the DTRS2 [1] and DTRS7 [2] are examples of the diversity of study methods and coding schemes. This paper explores the feasibility and applicability of using a generic coding scheme in different situations by applying it to three disparate sets of protocol data.

2 PROTOCOL ANALYSIS AND DESIGNING
Ericsson and Simon [3] laid the foundation for the use of verbal protocols with concurrent reporting, as quantitative data for studying thought processes. Eastman [4] conducted the first published formal protocol analysis that studied designing. Protocol analysis has been used to identify different design activities [5], reveal different mental models and knowledge structures of designers [6], and to investigate the perceptual aspects of sketching and designing [7]. The unit of analysis varies according to the objectives of the study, but, the procedures for studying the protocols are similar. van Someren et al. [8] classified the procedures into five steps: conducting experiments, transcribing protocols, parsing segments, encoding according to a coding scheme, and interpreting the encoded protocols.
In parsing segments, different ways for segmenting protocols have been used, 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 [3] suggested that appropriate cues for segmentation are pauses, intonation, and contours, which correspond to their information processing model. Gunther et al. [9] and Dorst and Dijkhuis [10] 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; additional criteria are required to handle these cases. Another way to segment protocols relates to the designers' lines of intentions, actions or moves [7, 11, 12]. Within this scheme, there are also differences in whether the categorization of codes affects the segmentation. In Gero and McNeill [12], one sub-category of code corresponds to one segment. On the other hand, Suwa et al. [7] proposed that one segment might contain several sub-categories of codes. Code categories are defined by an a priori coding scheme. Many coding schemes

have been developed for use with design protocols. All such schemes are based on particular views of the activity of designing. Many of these schemes are unique to the data to which they are applied. In reviewing current protocol studies of designers there is no standardization of segmenting and coding, hence there is no foundation for validating and comparing different studies.

2.1 FBS Ontology

In order to establish a common ground to study design activities, we propose to use an ontology as an overarching principle to guide the protocol study. Gruber [13] define ontology, apart from philosophy that account of existence, as an explicit specification of a conceptualization. Knowledge of a domain is represented in a declarative formalism in terms of a set of objects and their relationships. A design ontology is described by defining the representational terms and their relationships. Gero [14] viewed design – within an information processing model – as a purposeful act with the goal to improve the human condition. Gero [14] stated:

> "The meta-goal of design is to transform requirements, more generally termed *functions* which embody the expectations of the purposes of the resulting artefact, into design descriptions. The result of the activity of designing is a design description."

This view centers design around the creation of artefacts. Anything that is not related to the resulting artefacts are not considered within this framework. For example, those supportive activities such as planning and scheduling are not being considered under this framework. People can spend all the time planning and scheduling but do not produce any design description.

The FBS design ontology [14], as a formal model, models designing in terms of three fundamental classes of variables: function, behavior, and structure; along with two external classes: design descriptions and requirements. 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 (Be) or derived (Bs) from the structure (S) that 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.

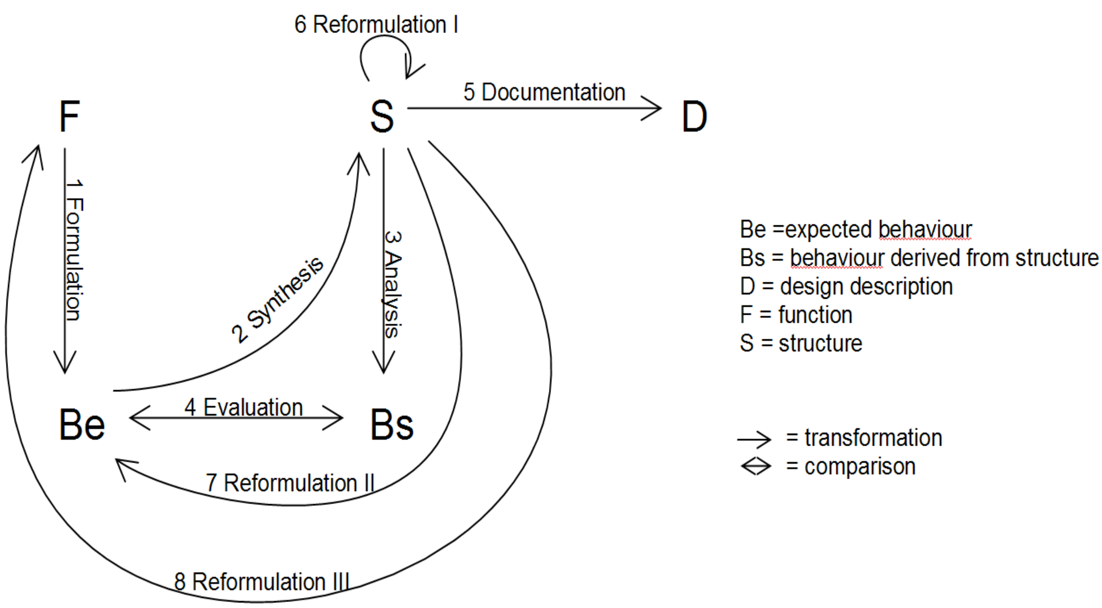

Figure 1. The FBS ontology of designing

2.2 Proposed Generic Coding Scheme

The proposed generic coding scheme consists only of the function (F), expected behavior (Be), behavior derived from structure (Bs), structure (S), documentation (D) and requirement (R). The protocols are segmented strictly according to these six categories. Those utterances that do not fall into these categories will not be coded; these may include jokes, social communication, management, etc. Examples of these codings are given in Table 1 in Section 5. This general framework does not assume any domain of designing nor does it assume the number of participants being studied. It only codes and describes the state of affairs of designing, in terms of FBS, at any point of time. With this generic coding scheme, although simple, we hope to capture the essence of designing which will form a foundation for further analysis. In this paper we apply Markov analysis to the coding results to illustrate the effects of using this generic coding scheme.

3 USING MARKOV CHAINS TO DESCRIBE THE FBS TRANSITION

Traditional protocol analysis is based heavily on statistical analysis and often contains the assumption that each segment is an independent event. Markov analysis, examines the sequence of events; Markov chains analyze or describe the probability of one event leading to another. In mathematical terms, a first order 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 analyze writers' manuscripts and to generate dummy text [15]; for the ranking of web pages by Google [16]; and to capture music compositions and synthesize scores based on the analyses [17]. Each code of a segment is considered as an event. The purpose is to investigate the probability of the next event occurring given the previous events. McNeill et al. [18], treating analysis, synthesis and evaluation as Markov states, found that the most likely event to follow analysis is a synthesis event. Also the most likely event after synthesis is an evaluation event but the most likely event after an evaluation event is a synthesis event.

3.1 FBS Transition Matrix

A transition or probability matrix is used to describe a Markov chain. It is a square matrix. Under the FBS framework it consists of six rows and six columns (the six code categories) with each row summing to one. Equation 1 shows the general form of the FBS transition matrix where $P_{i,j}$ is the probability of one state leading to another. For example $P_{2,3}$ is the probability of having a *Be* event after an *F* event. This transition matrix can be obtained by observing the transition of events in a design session. It can be seen as the characteristic of a design session.

$$P=\begin{pmatrix} & R & F & Be & Bs & S & D \\ R & P_{1,1} & P_{1,2} & P_{1,3} & P_{1,4} & P_{1,5} & P_{1,6} \\ F & P_{2,1} & P_{2,2} & P_{2,3} & P_{2,4} & P_{2,5} & P_{2,6} \\ Be & P_{3,1} & P_{3,2} & P_{3,3} & P_{3,4} & P_{3,5} & P_{3,6} \\ Bs & P_{4,1} & P_{4,2} & P_{4,3} & P_{4,4} & P_{4,5} & P_{4,6} \\ S & P_{5,1} & P_{5,2} & P_{5,3} & P_{5,4} & P_{5,5} & P_{5,6} \\ D & P_{6,1} & P_{6,2} & P_{6,3} & P_{6,4} & P_{6,5} & P_{6,6} \end{pmatrix} \quad (1)$$

3.2 FBS First Passage Times

The mean first passage time is the average number of steps traversed before reaching a state from other states. Kemeny and Snell [19] showed that the mean passage time can be obtained from the transition matrix, which can also be represented by a matrix *M*. They gave an example of "the weather in the Land of Oz" with a three-state Markov chain. The states *R*, *N*, and *S* denote for rain, nice and snow respectively. Equation (2) shows the first passage time matrix.

$$M=\begin{pmatrix} & R & N & S \\ R & 5/2 & 4 & 10/3 \\ N & 8/3 & 5 & 8/3 \\ S & 10/3 & 4 & 5/2 \end{pmatrix} \quad (2)$$

In this example, if it is raining in the Land of Oz today the mean number of days before a nice day is 4. The mean number of days before another rainy day is 5/2; before a snowy day 10/3.
In order to derive this matrix we need to compute the probability vector α and the foundation matrix *Z.* With the transition matrix *P,* the probability vector can be obtained by equation (3).

$$\alpha P= \alpha=(a_1, a_2,..., a_n) \quad (3)$$

The foundation matrix is defined as:

$$Z=(I-(P-A))^{-1} \tag{4}$$

where I is an identity matrix, P is the transition matrix and each row of A is α.

The mean first passage matrix M is given by:

$$M=(I-Z+EZ_{dg})D \tag{5}$$

where E is a matrix with all entries of 1, D is a diagonal matrix with elements $d_{ii}=1/a_i$, and Z_{dg} is the diagonal matrix of Z.

Equation 6 is the general form of the FBS first passage times matrix where $m_{i,j}$ is the average number of steps required to get from one state to another. For example $m_{1,6}$. is the average number of steps required to move from a requirement (R) event to a design description (D) event. The mean recurrence time occurs when the starting state is the same as the stopping state, $m_{i,i}$. For example $m_{5,5}$. is the mean recurrence time of structure, S to S.

This mean first passage times matrix can be use to validate hypotheses such as design processes take longer to get from function – intention (F) to structure – a design proposal (S) than from behavior (B) to structure (S).

$$M=\begin{vmatrix} & R & F & Be & Bs & S & D \\ R & m_{1,1} & m_{1,2} & m_{1,3} & m_{1,4} & m_{1,5} & m_{1,6} \\ F & m_{2,1} & m_{2,2} & m_{2,3} & m_{2,4} & m_{2,5} & m_{2,6} \\ Be & m_{3,1} & m_{3,2} & m_{3,3} & m_{3,4} & m_{3,5} & m_{3,6} \\ Bs & m_{4,1} & m_{4,2} & m_{4,3} & m_{4,4} & m_{4,5} & P_{4,6} \\ S & m_{5,1} & m_{5,2} & m_{5,3} & m_{5,4} & m_{5,5} & m_{5,6} \\ D & m_{6,1} & m_{6,2} & m_{6,3} & m_{6,4} & m_{6,5} & m_{6,6} \end{vmatrix} \tag{6}$$

4 THE DATA AND SOME OBSERVATIONS

In this paper three sets of data were used for exploration. One set is *in-situ* data from a brainstorming session and the other two sets are from *in-vitro* architectural design sessions.

4.1 in-situ Brainstorming

This *in-situ* design meeting was distributed as part of the data to researchers for the Design Thinking Research Symposium 7. The idea behind using a common set of protocol data was to find a more rigorous way to do empirical research in design [20]. Data was film of actual design meetings taking place in a product design practice. The data is made up of a 4-camera video recording, Figure 2 shows one frame of the recording.

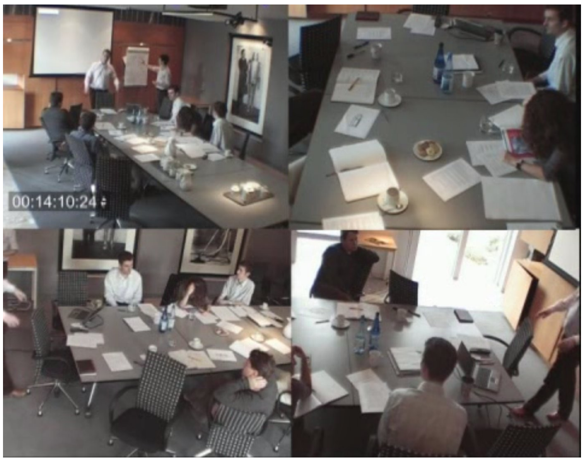

Figure 2. Four camera digital recording of the brain storming session

The design session concerned an innovative toy – a thermal printing pen as illustrated in Figure 3. The aim of this engineering brainstorming session was to obtain ideas for a prototype of the pen. This involved solving specific problems such as keeping the print head leveled with an optimum angle, activation and protection of the print head. Seven cross-disciplinary participants were involved. A business consultant acted as the moderator; three mechanical engineers, a electronics business consultant, an ergonomicist, and an industrial design student were involved. The whole session lasted for one hour and thirty-seven minutes.

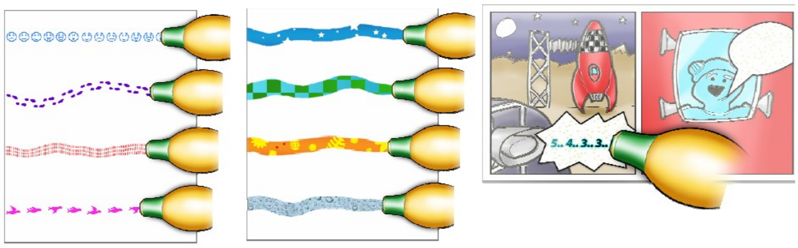

Figure 3. Illustrations of the function and behavior of the design object: thermal printing pen.

This protocol can be divided into two episodes; the first one concerned the problem of keeping the print head in contact and at the optimum angle to the media, despite wobbly arm moment. The second episode dealt with protecting the print head from abusive use and overheating. In the first episode, participants were asked to generate ideas from available products that follow a contour. Several products were mentioned, such as a sledge, snowboard, wind surfboard, shaver, snow-mobile, train, and slicer. Other concepts such as wheels, spirit level, and laser leveler were also discussed. Loosely related to those analogies, a few proposed shapes, such as a mouse-type pen, were proposed. Besides product behavior, user behavior was also considered. Figure 4 shows some of the sketches the participants used in this session. On the left is a sketch of the structure they proposed near the middle of the session; in the center is a drawing of a toy a member suggested from which to borrow ideas; and on the right is one of the proposed forms of the thermal printing pen.

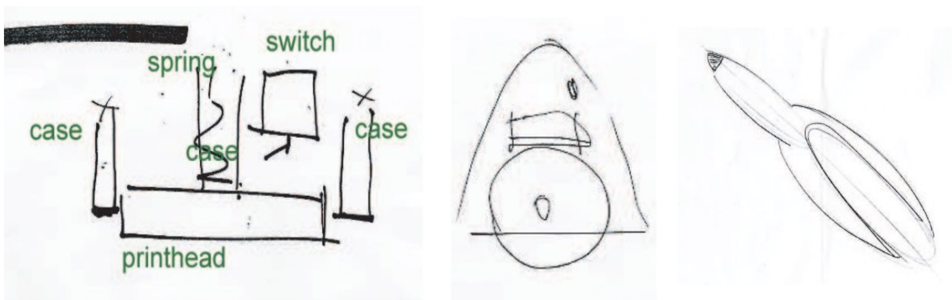

Figure 4. Sketches from the brain storming session.

4.2 in-vitro Design Sessions

These two data sets were obtained from a CRC for Construction Innovation project. In that project in-vitro studies were conducted with five pairs of designers. One pair was selected for this study. The most creative face-to-face session, judged by the design outcome, was selected for analysis. In this experiment a pair of architects, one more senior than the other, was asked to collaborate in two different settings: face-to-face and a 3D virtual world. The design tasks were to generate conceptual designs of a university student union's gallery and dance studio. Each session lasted for 30 minutes and was video recorded. Figure 5 shows the video recording of the face-to-face session and the 3D virtual world session. The screens of both designers were also recorded concurrently as shown in the right of Figure 5.

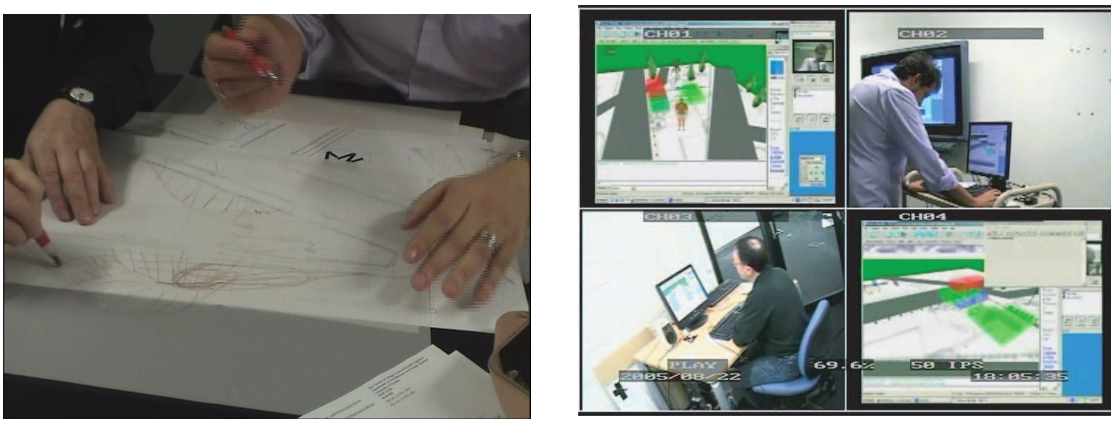

Figure 5. Left: Camera recording of the face-to-face session. Right: Four camera recording of the 3D virtual world session.

In both sessions the senior architect took the leadership role and made most of the decisions. He did most of the sketches in the face-to-face session and organized most of the activities in the virtual world session. The face-to-face session can be divided into four stages or episodes, based on the design activities. In the first episode they dealt with the brief and site (about 3.5 minutes). In the second episode they analyzed, planned and developed concepts in the plan (about 9 minutes); issues like location of main entrance and service entrance, icon to capture attention were discussed. In the third episode they developed the 3D form in elevation (about 9 minutes); ideas like “ribbon”, “hole in the middle” were suggested. In the final episode they worked on the layout, calculated the required areas, in the plan until the end (about 8.5 minutes), but they did not finish it within the 30 minutes allocated for the session.

In the 3D virtual-world session, the stages were not as well defined as in the face-to-face session; they spent less than 2 minutes with the brief before exploring and making objects. This session can be characterized as “designing through making”. Sometimes they subdivided the tasks and worked individually. They were given predefined elements—space, slab, wall, column, and beam—in various sizes. They decided to start with the biggest space element to represent the “largest” spaces, the four studios. At around 12 minutes, they discovered they could not have all the studios on one level because of the site coverage constraint. The senior architect decided to stack the blocks, the studios, and create an atrium to join them together. They tried to further develop this concept to accommodate the requirements but did not finish the design. Besides designing, time was spent on design support activities, such as discussing what elements were available and organizing what to do. Also, time was spent on the technical aspects of learning how to do things, such as changing the color of the blocks, how to “fly”, and how get out when “trapped inside” those blocks.

5 CODING AND RESULTS

Table 1 shows examples of segments from the three design sessions in relation to the coding categories. The brainstorming session is different to the architecture design sessions in terms of the domain, and method of designing. However, the FBS coding scheme is broad enough to be domain independent. For the brainstorming session the whole session (97 minutes) was coded but for the other two sessions only the first 11 minutes were coded.

There are 2030 segments in the brainstorming session and 1,239 of them contain FBS codes. Out of the 205 segments in the face-to-face session, 192 of them contain FBS code. The virtual world session contains 155 segments and 94 of them have FBS codes. Table 2 documents the frequency and distribution of codes of the three sessions.

Table 1. Examples if coding from the 3 sessions

Code	Brain Storming	Face-to-face	3D Virtual World
R Requirements	"quite important is it's about the thermal-incli-inclis ( ) pen"	(read brief) "Permanent collection is 200 and 50 meter hanging space."	"They want four studio's mate, two one hundred each."
F Function	"that's the standard plain thermal paper err and then it can draw"	"hang on, that's a public building."	"If it's a dance school it might still need a loading space."
Be Expected Behavior	"so there needs to be this contact maintained"	"Can we say this is sort of external?"	"We need to, the obvious thing we've got... the generic space..."
Bs Behavior	"( ) mmm and playing with erm hot air ( ) miraculously a colour image "	"So these guys are coming across, they will be coming across this side ."	"that's very small area, court yard terrace and rough space maybe undefined,"
S Structure	"a sledge or a snowboard a skis or snowboard"	"This is the Guggenheim"	"I don't know what size they are."
D Design Description	Figure 4 (write: sledge)	(draw arrows) (sketch)	(insert box) (move box)
Not Coded	"yeah, we'll come to that in a minute"	"How long do we have for this exercise?"	"I can't see you though"

Table 2. Frequency and percentage of codes of the three session

Code	Brain Storming (%)	Face-to-face (%)	3D Virtual World (%)
R	2 (0%)	16 (8%)	7 (5%)
F	47 (2%)	19 (9%)	2 (1%)
Be	260 (13%)	32 (16%)	5 (3%)
Bs	356 (18%)	25 (12%)	7 (5%)
S	501 (25%)	65 (32%)	53 (34%)
D	73 (4%)	35 (17%)	20 (13%)
Not Coded	791 (39%)	13 (6%)	61 (39%)
Total	2030 (100%)	205 (100%)	155 (100%)

The overall segments per minute of the brainstorming, face-to-face and virtual world sessions are 20.9, 18.6 and 14.1 respectively. This approximates the speed of activities.

The brainstorming and the virtual world sessions have high percentages of non-FBS coded segments. In the brainstorming session, all the "yeah", "OK", laugh, and unclear utterances were segmented but contain no FBS code; also, those communication control, management and planning protocol were not coded. In the virtual world session the high percentage is contributed by those discussion of technical aspects of how to do things, finding out where the other party is located and what he is doing, and organizing what to do.

The FBS segments per minute of the brainstorming, face-to-face and virtual world sessions are 12.8, 17.5 and 8.5 respectively. The face-to-face session has the highest percentage of segments with FBS codes. This is a rough indication of the rate of design activities, which shows the virtual world session has the least design activity whereas the face-to-face session has the highest. Figure 6 shows the normalized FBS code distributions of the three sessions. There are significant differences between the three sessions. The environment and settings of the sessions might also contribute to these differences.

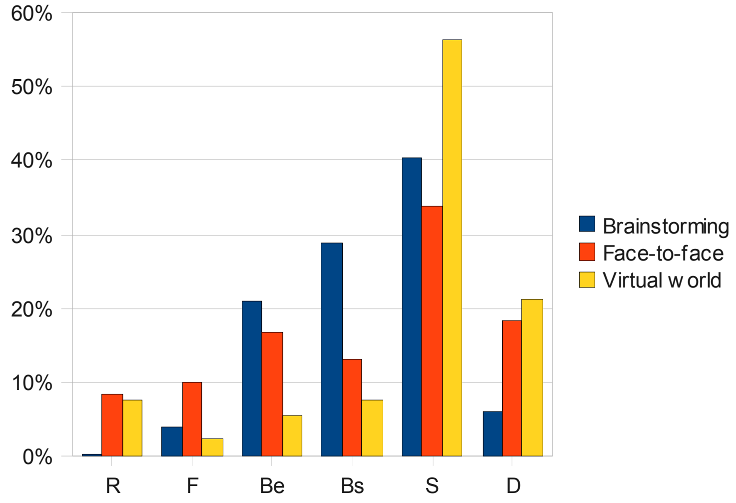

Figure 6. The FBS code distribution of the three sessions

5.1 Transition Matrix of the Three Sessions

After counting the occurrences of the consecutive FBS states of each segment, the probability of transition from one FBS state to another can be calculated. Equations 7, 8 and 9 show the transition matrix of the three sessions with the subscripts *bs, f2f,* and *3D* represent the brainstorming, face-to-face and virtual world session respectively. If we rank the probabilities, the highest is the F to Be in the virtual world session that is 1.00. This transition represents the formulation process, assuming most of the consecutive events were related. Both the brainstorming and face-to-face session have a high probability of transition from F to Be as well (0.47 and 0.45 respectively). In the brainstorming session the highest probability of transition was from D to S (0.59) and in the face-to-face session S to S (0.46). The S to S transition can be seen as type 1 reformulation. The type 2 reformulation is lower than type 1 reformulation in all the three sessions, and much lower in the virtual world session. Type 3 reformulations are very rare in all the sessions. The analysis process, S to Bs, is surprisingly low in the virtual world session; also it is low in the face-to-face session.

$$P_{bs}=\begin{pmatrix} & R & F & Be & Bs & S & D \\ R & 0.50 & 0 & 0 & 0 & 0.50 & 0 \\ F & 0 & 0.26 & 0.47 & 0.04 & 0.23 & 0 \\ Be & 0 & 0.07 & 0.33 & 0.18 & 0.38 & 0.05 \\ Bs & 0 & 0.01 & 0.20 & 0.40 & 0.34 & 0.05 \\ S & 0 & 0.03 & 0.14 & 0.30 & 0.45 & 0.08 \\ D & 0 & 0.01 & 0.14 & 0.21 & 0.59 & 0.05 \end{pmatrix} \qquad (7)$$

$$P_{f2f}=\begin{pmatrix} & R & F & Be & Bs & S & D \\ R & 0 & 0 & 0.40 & 0 & 0.40 & 0.20 \\ F & 0 & 0.18 & 0.45 & 0 & 0.27 & 0.09 \\ Be & 0 & 0.08 & 0 & 0.04 & 0.20 & 0.68 \\ Bs & 0.12 & 0 & 0.35 & 0.24 & 0.18 & 0.12 \\ S & 0.02 & 0.04 & 0.15 & 0.10 & 0.46 & 0.23 \\ D & 0.06 & 0.15 & 0.15 & 0.18 & 0.42 & 0.03 \end{pmatrix} \qquad (8)$$

$$P_{3D}=\begin{pmatrix} & R & F & Be & Bs & S & D \\ R & 0.14 & 0 & 0 & 0.43 & 0.43 & 0 \\ F & 0 & 0 & 1.00 & 0 & 0 & 0 \\ Be & 0 & 0 & 0 & 0 & 0.60 & 0.40 \\ Bs & 0.43 & 0 & 0 & 0 & 0.43 & 0.14 \\ S & 0.04 & 0.02 & 0.02 & 0.06 & 0.60 & 0.27 \\ D & 0 & 0.05 & 0.10 & 0.05 & 0.65 & 0.15 \end{pmatrix} \qquad (9)$$

Considering the eight FBS processes in Figure 1 and picking those probabilities of those transition in the three sessions, Figure 8 shows the eight FBS processes in the three sessions. For the evaluation process, we added the Bs to Be and Be to Bs transition probabilities.

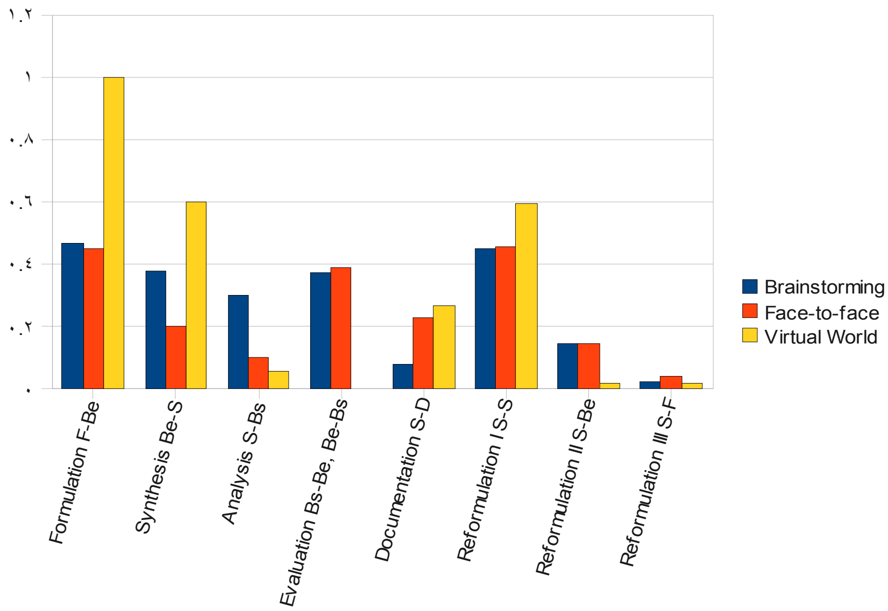

Figure 8. The eight FBS processes probability distribution of the three sessions

The distribution of the face-to-face session is different form the virtual world session but similar to the brainstorming session indicating the impact of computer mediation towards design activities. The type 2 reformulation of the virtual world session is much lower than the other two sessions; this agrees with our qualitative observations.

5.2 Mean First Passage Times of the Three Sessions

Insert equations (7), (8), (9) to equations (3) and (4) to get the foundation matrix and put it in equation (5), the mean passage matrices can be obtained. Equations (10), (11) and (12) show the mean first passage matrices of the three sessions with the subscripts *bs, f2f,* and *3D* represent the brainstorming, face-to-face and virtual world sessions respectively. In the brainstorming session there are only two recorded R events out of the 1,239 events, so the mean time for an R event to occur is close to infinite, which is a boundary condition. Other than the mean passage times for R in the brainstorming session, the longest mean passage time is from R to F (59.66) in the virtual world session and the shortest is from D to S (1.96) also in the virtual world session. On average, ignoring the R in the brainstorming session, the brainstorming session has shorter mean passage times (the average of the mean passage times is 12.6) than the other sessions, followed by the face to face session (14.72). The virtual world session has the longest average mean passage time (21.06). The minimum of this average occurs when all the events are evenly distributed, that is the transition probabilities are all equal.

$$M_{bs}=\left(\begin{array}{ccccccc} & R & F & Be & Bs & S & D \\ R & \approx\infty & \text{٣٥.٩١} & \text{٧.٦٦} & \text{٥.٧٧} & \text{٢.٣٨} & \text{١٨.٧٢} \\ F & \approx\infty & \text{٢٥.١٣} & \text{٣.٢٦} & \text{٥.٣٠} & \text{٣.٥٧} & \text{١٨.٥٢} \\ Be & \approx\infty & \text{٣٢.١٢} & \text{٤.٤٩} & \text{٤.٤٢} & \text{٣.٠٧} & \text{١٧.٤٠} \\ Bs & \approx\infty & \text{٣٤.٣٦} & \text{٥.٣٤} & \text{٣.٣٩} & \text{٣.١٦} & \text{١٧.٣٢} \\ S & \approx\infty & \text{٣٣.٩١} & \text{٥.٦٦} & \text{٣.٧٧} & \text{٢.٨٥} & \text{١٦.٧٢} \\ D & \approx\infty & \text{٣٤.٣٠} & \text{٥.٧٥} & \text{٤.١١} & \text{٢.٤٨} & \text{١٧.٠٥} \end{array}\right) \quad (10)$$

$$M_{f2f} = \begin{pmatrix} & R & F & Be & Bs & S & D \\ R & 49.96 & 16.85 & 5.38 & 10.86 & 3.24 & 4.07 \\ F & 50.32 & 14.23 & 4.86 & 11.19 & 3.74 & 4.39 \\ Be & 49.35 & 15.48 & 7.06 & 10.19 & 3.73 & 2.95 \\ Bs & 46.11 & 17.21 & 5.24 & 8.68 & 4.09 & 4.42 \\ S & 49.03 & 16.54 & 6.54 & 9.80 & 3.05 & 4.33 \\ D & 48.05 & 15.22 & 6.15 & 9.32 & 3.27 & 5.02 \end{pmatrix} \quad (11)$$

$$M_{3D} = \begin{pmatrix} & R & F & Be & Bs & S & D \\ R & 23.04 & 59.66 & 22.54 & 9.35 & 2.58 & 6.11 \\ F & 31.21 & 59.15 & 3.64 & 18.46 & 2.97 & 4.70 \\ Be & 30.21 & 58.15 & 20.85 & 17.46 & 1.97 & 3.70 \\ Bs & 20.42 & 59.33 & 22.16 & 14.37 & 2.51 & 5.52 \\ S & 28.81 & 57.65 & 20.58 & 16.26 & 2.05 & 4.37 \\ D & 29.80 & 56.40 & 18.75 & 16.76 & 1.96 & 4.75 \end{pmatrix} \quad (12)$$

In all sessions, the first passage times from Be to D is shorter than from F to D although in the brainstorming session the difference is marginal. This holds the same if we start with an R state instead of an F state. In general the mean time for an S state to occur is relatively short.

Figure 9 represents the mean first passage times in relation to the eight FBS processes. The mean passage time for the evaluation was the average of the Be-Bs and Bs-Be mean passage times. It shows the mean separation times of the two states for the FBS processes to take place. The shorter the distance, the higher the chance for that process to take place.

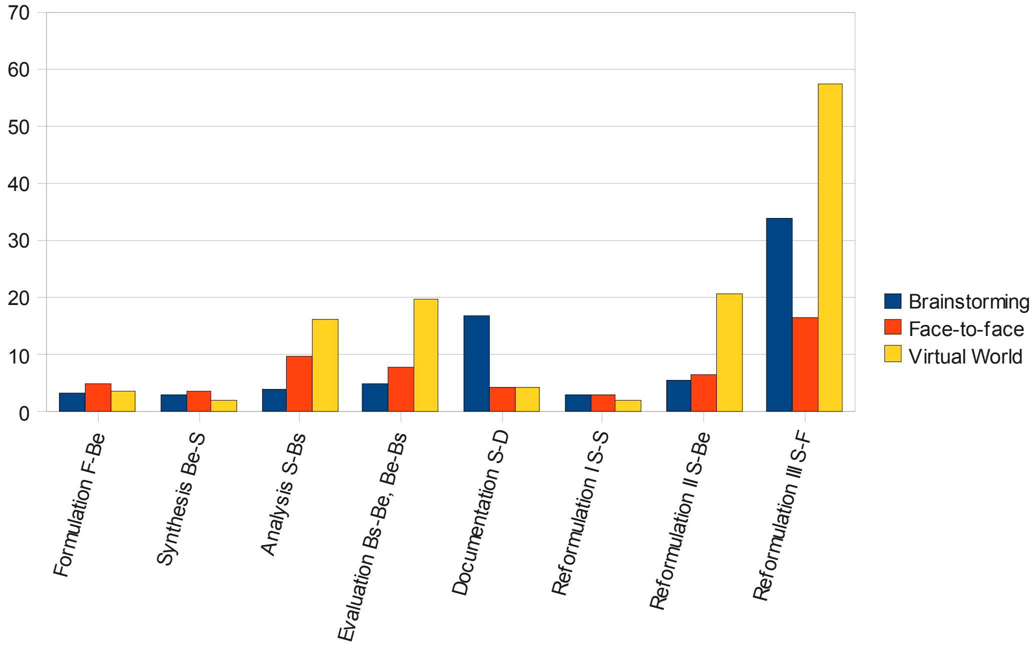

Figure 9. The mean passage time in relation to the eight FBS processes

6 DISCUSSION AND CONCLUSION

The processes from the FBS ontology are claimed to be generic for all designing. Unlike most coding schemes that 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 facilitates the comparison, as has been shown in comparing the code distributions of the three cases. This general framework does not assume any domain of designing nor does it assume the number of participants being studied. It only codes and describes the state of affairs of designing, in terms of FBS, at any point of time. This captures the essence of designing which will form the foundation for further analysis, which is not limited to descriptive statistics

Markov analysis, taking time into account, provides a way to examine design protocol data in a sequential manner. It does not assume that successive events are independent. The transition matrix can be viewed as a signature that summarizes the transitions between all the FBS events. These transitions can provide a rough idea of the distributions of the eight FBS processes by assuming that high percentages of the consecutive segments indicate a direct relation. Comparing these processes informs us of the characteristics of a session. In this case of the in-vitro sessions, the virtual world had much lower evaluation, type 2 reformulation and analysis processes. However, the first order Markov only considers the intermediate step but not the previous ideas. We expect that by constructing a linkograph, connecting related segments, we will be able to capture the design processes in more detail. The mean first passage time matrix provides another view of the design process in terms of the expectancy of FBS events. For a long design session, like the brainstorming session, it will be interesting to compare this expectancy at different stages of the session.

In this paper we have demonstrated the use of a generic design ontological coding scheme and its possible application – Markov analysis. This simple ontological coding scheme opens up the possibility to study designing using the same foundation. Hence, different sets of data can be compared and cross validated.

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