MEASURING SYMMETRY AS AN INDICATOR OF COLLABORATION AROUND A TABLETOP

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ABSTRACT
Tabletop technology offers the potential for new ways to support rich collaboration. This paper describes a theoretical foundation for a new approach to help people learn to collaborate more effectively at a tabletop. We focus on cases where the people have equal status and should all contribute to the collaborative task. The core of our approach exploits the digital footprints of the users' activity at the tabletop. To interpret this data, we have built upon a theory of symmetry of action, knowledge and status. We illustrate how this theory can be used to define measures of symmetry of interaction at a tabletop, with a case study based on concept mapping, a technique that is in wide use, particularly in educational settings, for externalising knowledge. We describe the measures that we have created, based on the theory. They are cosine distance and Gini coefficient. The key contribution of this work is the formulation of a new theoretical foundation for the analysis of collaborative interaction at a tabletop. This can be used as a basis for social translucence displays, so providing people with insights into the way that they are collaborating. This can serve as a valuable basis for learning how to collaborate more effectively.

Author Keywords
Information interfaces and presentation, Interaction styles, Collaborative learning.

ACM Classification Keywords
H5.2. Information interfaces and presentation: User Interfaces. - Graphical user interfaces, Input devices and strategies, Interaction styles, Theory and methods.

INTRODUCTION
There are many situations where people need to work collaboratively in small groups, both in the workplace and in informal settings as well as for education. In many cases, all members of the group should be active in the collaboration: for example, to draw upon the different expertise and background of each member or to find solutions to problems by negotiation and discussion of competing possibilities. This paper aims to gain measures of the effectiveness of collaboration within small groups of people who have equal status and roles and who collaborate to share their understanding, discuss it with peers and come to an agreed understanding for the group, where that may mean that the group identifies aspects that they all agree on as well as ones where they disagree.

It is challenging for people to learn to collaborate effectively. One approach that has proved effective in supporting such learning is to promote social translucence, an external representation of the nature of the collaboration. This has been shown to have benefits for improving collaboration and supporting people in learning to collaborate (Erickson & Kellog, 2000). Its strength is that it helps people see objective measures of their collaboration behaviour, enabling them to monitor whether their actual actions match what they intended, and to modify their behaviour to achieve this.

Tabletops offer the promise of supporting rich face-to-face collaboration. Importantly, they can capture digital footprints of the users' activity. Similar data has been used to create social translucence interfaces for chat (Erickson et al. 1999). We aim to establish a theoretical foundation for interpreting the data available from tabletop interaction, to create similar interfaces for them.

Drawing on the considerable work on collaborative learning (Dillenbourg, 1998), one important indicator of collaboration is the notion of symmetry. We build upon that work, and constructivist theories of group cognition (Stahl, 2006) to create a theoretical model of symmetry of action and symmetry of knowledge as indicators of collaboration at a tabletop. We also draw on the broad body of research on collaborative learning at desktop computers (Jeong, 2010). The key contribution of this work is the formulation of a new theoretical foundation for scaffolding new ways to improve collaboration at a tabletop. We illustrate how this theoretical model and the methodological basis can be used to define measures of symmetry of interaction with a case study.

Symmetry and the theory of group cognition
Group cognition theory builds on many other theories based on the concept of constructing meaning through language and social interactions (Stahl, 2006). Following these theories, a group of people working collaboratively externalise and negotiate their different viewpoints. Sometimes the flux of interactions results in external artefacts such as, texts, conceptual maps, diagrams, sculptures and other objects. These social artefacts embody the group’s understanding. Figure 1 depicts our basic model, representing the elements in this process; it builds from Stahl’s (2006) model, but focuses on the ways that symmetry in the collaborative action relates to the...
other elements. This model has two main “cycles”: the personal understanding (1) that occurs inside individuals’ minds and the social knowledge building cycle (2) which includes all the sub-processes that may be present when building social understanding. In face-to-face interactions, this process can generate a huge quantity of cognitive artefacts in short periods of time. Group members have to articulate their thoughts to convince others or to explain their point of view. They externalise their thoughts to other participants and, potentially, leave digital traces of this process. When a person negotiates shares or revises their standpoint, they may appropriate artefacts to support this, leaving more digital evidence of the collaboration. It is these digital tracks of the process of the interaction that we aim to make use of.

Our concept of symmetry has three distinct, but related, dimensions associated with the dynamics of the group. Accordingly with Dillenbourg (1998) they are: symmetry of action, symmetry of knowledge and symmetry of status. Symmetry of action is the degree to which users perform the same range of actions; this is the aspect that we can capture from actions at the tabletop. Symmetry of knowledge refers to the extent to which users have the same level of skills or knowledge, even if they have different viewpoints on the topic; this clearly is not available easily at the tabletop but our goal of social translucence means that the user can take it into account when interpreting the symmetry measures. However the symmetry of knowledge is highly related to what the user has internalised before the group interactions. When available, information about the user’s prior knowledge can therefore be used. In Figure 1 we depict these two dimensions of symmetry as being related directly to the group knowledge building. Finally, symmetry of status is associated to the relative position that each user has in the community.

Our theoretical model of symmetry needs an associated methodology for interpreting the available digital information about the collaboration and converting it into estimates for the symmetry measures. We have identified four measures of actions that can be automatically registered. These are: verbal intervention time, number of verbal interventions, total time of interaction with the tabletop and number of touches on the tabletop. We can collect all these metrics from two sources: the logs of touches from the application and the recorded conversations, which can automatically be obtained by microphones (see Bachour et al. 2008). Given this information, we need a way to measure the symmetry of action. We use the Gini Coefficient, a measurement of statistical dispersion which has been successfully used to estimate equity of participation for comparing single touch and multi touch devices (Harris et al., 2009). The Gini Coefficient is a number between 0 and 1, where 0 indicates total asymmetry and 1 indicates high symmetry. The essence of our methodology requires a way to translate the four measures of action described above into a Gini Coefficient.

Measuring symmetry of knowledge is highly dependent on the task that the group is working on. Stahl (2006) suggests use of pre-tests but that would impose undesirable limits on the generality of the approach. Instead, we exploit analysis of the artifacts that each user brings to the collaboration, comparing these with the final outcome. Our methodology makes use of a cosine measure. This means that the artifacts must be translated into a vector of elements, with a 1 for an attribute that is present and 0 when it is absent. Then, we can compare these for each individual’s initial artifact and the final one. A high value suggests the initial artifact was more similar to the final collaboration result while a low value indicates that this user’s initial artifact was very different from the final one. The difference could be due to the level of initial knowledge or willingness to concede to the views of others in the group.

As we focus on the important class of collaboration where all participants have equal roles, measuring the symmetry of status was not a concern. However we will see in the case study that there are some factors that influence the symmetry of status such as the language background and other personal characteristics. We now illustrate how we have applied this theory and methodology in the case of a particular collaborative task at a tabletop.

CASE STUDY: CMATE EXPERIMENT
Following the theoretical model described above we designed a real world case of study based on a multi-touch tabletop interface. Two key aspects to take into account for studying collaborative learning are the context and the task itself (Morgan and Butler, 2009). For this reason we have chosen the well supported technique of concept mapping (Novak 1990) as the artefact to be built at the tabletop. One of the advantages of the concept maps is that through these tools learners can construct understanding in their own terms, discuss relationships between concepts and reflect on alternative perspectives.

We describe the key features of the project with a scenario: three learners, Alicia, Bob and Carol studied the same text called: Recycling, cost-benefit analysis. Each one is asked to create a concept map capturing their own understanding on the topic and using their personal ontologies. They are requested to give an answer to the focus question: does recycling help the environment? These initial individual artefacts are built on desktop computers and preloaded into Cmate (Martinez et al., 2010), a tabletop application designed for collaborative concept mapping. A visualisation of the interface is shown in Figure 2.

Figure 1: Simplified model of collaborative knowledge building adapted from (Stahl, 2006).
When Cmate starts, the three participants share two menus, partly visible at the lower left and upper right of Figure 2, as well as two blue destructor objects at the other two corners. The application presents a central empty mapping area, showing just blue concentric circles, which helps the learners lay out concepts at the levels that reflect their judgement of the generality of the concept. The design alters the classic layout of concept maps (Novak, 1990), to account for the different orientation around the table. In Cmate, the most general concept is placed in the centre. After the group has discussed their individual maps, Alicia begins placing concepts onto the combined map. Alicia first selects the green menu item to indicate that she will be including objects from her map. Then she uses a circular gesture (similar to a 6) and Cmate presents a menu with her list of concepts. Alicia selects the concept, “recycling”, which she places at the centre of the table, because all the students agree it is the most general. Bob then takes over and places some of the concepts following similar sequence of actions. Carol then creates some links between them, defining the propositions. She selects the orange menu item, then draws an orange line between the two concepts and Cmate displays a menu with a list of the linking words that she used in her own concept map. If they don’t find the exact words which describe a concept or the relationship between two of them they can touch the word and a keyboard appears in the screen to edit the phrase.

At this point, Alicia, Bob and Carol discuss about which concepts and propositions should be included in the final artefact by presenting arguments to the others and performing different actions on the tabletop. They have 30 minutes to build the concept map and 5 additional minutes to round the ideas and formalise which propositions will remain in the map. In this scenario, the tabletop application is acting as a mediator of interaction, mirroring the different parts that have been added by each participant using different colours for the links and concepts regarding on which user used it in its individual concept map. It was designed following the model of the collaborative knowledge building process of Figure 1. We collected the following data: personal information about each participant, the logs of physical interactions on the tabletop, the verbal interventions measured by the presence of voice, the individual artefacts and the final social artefact. In the next subsections each dimension of symmetry is objectively observed based on this collected data, with the exception of the symmetry of status which is not relevant to this case since the participants all had exactly the same position in the group.

**Symmetry of action**

Table 1 summarises these metrics. For example, Alicia talked effectively for 8 minutes 32 seconds, divided in 121 interventions; the effective time in which Alicia kept any of her fingers on the tabletop was 2 minutes 16 seconds and she performed 107 different independent touches. Every verbal intervention is separated by at least 1 second of silence. In this example, the Gini coefficients indicate that the group actions are far from being symmetric. By normalising the magnitudes of each feature and drawing a map of symmetry (drawn in Figure 3) we easily observe indeed that one user (Bob) dominated in all the dimensions of equity and even more in the physical participation (overlapping blue and yellow triangles in the figure).

<table>
<thead>
<tr>
<th>Gini C</th>
<th>V.I. time</th>
<th>V.I. (#)</th>
<th>T.I. time</th>
<th>T.I. (#)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alicia</td>
<td>0.2439</td>
<td>0:06:58</td>
<td>0:01:42</td>
<td>74</td>
</tr>
<tr>
<td>Bob</td>
<td>0.2161</td>
<td>121</td>
<td>204</td>
<td>75</td>
</tr>
<tr>
<td>Carol</td>
<td>0.3174</td>
<td>0:06:58</td>
<td>0:01:42</td>
<td>75</td>
</tr>
</tbody>
</table>

**Symmetry of knowledge**

The definition of collaboration is that the work is done by the whole group as a unit (Dillenbourg, 1998); hence, the group artefact (the concept map built on the tabletop) cannot be attributed to the mental processes of one individual learner. We measured the distance between the final artefact (concept map) and each participant’s initial artefact. Taricani and Clariana, (2001) reported a technique to automatically measure the distance between two concept maps based on the propositions that they share and the physical distances between the concepts. This method can be really useful for further research but in this work we explored the use of cosine similarity to measure the distance between each pair of concept maps. We created one master vector in which each feature corresponded to each of the concepts and propositions drawn in the final concept map. Then we created 3 more vectors, one for each participant, indicating for each concept or proposition if it was initially included in the personal concept map. After these, we measured the similarity between the vectors using cosine distances. The results of such process are shown in Table 2. The same technique can be used to compare each participant’s
artefact to know how close the individual artefacts were from each other. However, in this trial the individual artefacts were very different to each other because we did not impose any constraint on the ontology that the participants used.

<table>
<thead>
<tr>
<th>Group</th>
<th>Alicia's artefact</th>
<th>Bob's artefact</th>
<th>Carol's artefact</th>
</tr>
</thead>
<tbody>
<tr>
<td>artefact</td>
<td>0.354</td>
<td>0.775</td>
<td>0.223</td>
</tr>
</tbody>
</table>

Table 2. Cosine similarity for symmetry of knowledge

DISCUSSION

These symmetry measures served as a starting point for understanding the collaborative behaviour of people that participated in the illustrative case of study. In the symmetry of action Bob dominated in quantity and duration in both dimensions of participation: verbal and physical. Accordingly, in the measurement of symmetry of knowledge, we also can notice that the distance between the final artefact and Bob’s artefact (0.775) is much closer than the final artefact and the other two participants’ ones.

Additionally to these results we video recorded the whole trial and precisely we identified that Carol and Alicia participated during the beginning of the trial but once Bob began to explain his point he guided others’ ideas to accept most of the propositions that he included in his personal concept map. Five minutes before the end of the trial Bob realised that most of the final concept map looked yellow (Bob’s colour) indicating that most of the concepts and links included in the concept map were reflecting his own ideas. Then he tried unsuccessfully to include Carol ideas into the group map but it was too late. This suggests that the use of explicit symmetry visualisations, such as the one in Figure 2, may possibly be useful for student reflection and self-regulation early on in the group work.

Moreover, we observed that contextual information of the trial, such as leadership, participant’s native language or even physical situations like the position of the learner on the table with respect of its shape, should be taken into account as a part of the symmetry of status of the group. In the trial, even when all the participants where students and read the same text, their individual artefacts and actions may have been affected by personal characteristics, for example, the fact that Bob is aiming for a higher degree than Carol and Alicia, or that Carol’s first language is not English. We felt that these particularities had a role to play in the trial.

Finally, we perceived that the participants intended to use their personal gestures to interact with the tabletop for building the artefact, but the application did not recognise such intentions. We consider that it is really important to exactly recognise what the participants intend to do while collaborating; consequently, proper heuristics evaluations or walkthroughs should be conducted in order to improve the design of this kind of interfaces.

CONCLUSIONS

In this paper we outlined the special theoretical aspects of collaborative learning through the mediation of a tabletop. Based on the discussion of this model we proposed a method to automatically identify nature and degree of collaboration at a tabletop using the notion of symmetry as an indicator, with the aim to offer support for the learning activity in real time. There are many paths for future work. Based on the logs obtained from the tabletop or from the presence of voice during the building knowledge process, further research can focus on modelling and understanding the process that occurs when learners meet on the tabletop. Furthermore, high levels of key interaction mechanisms can be explored. Mechanisms such as turn taking, overlapping, dominance, or even higher semantics, like negotiation, grounding, or internalisation, can be investigated. At this point Machine Learning techniques may become key tools to explore the entrails of the collaborative knowledge building process.

REFERENCES

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