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An Analysis Framework for Quantitatively Characterizing Collaboration in Tabletop Based CSCW Environments

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Abstract: **Interactive tabletop systems have shown great potential in fostering collaboration. We investigate the question of a suitable methodology for measuring, modeling and quantitatively characterizing real-world face-to-face interactions in tabletop environments while also focusing on the mutual influence of these real-world interactions / usage patterns and the IT environment. In our contribution, key aspects of the characteristics of tabletop collaboration (including related interaction patterns outside the IT environment) are quantitatively measured with the help of a dedicated tracking environment. We conducted an experiment, where participants used our creativity support system to create new ideas while their actions, motions and communication were recorded. We use several different creativity techniques in order to cover a spectrum of interaction variants within the limits of our application. We give a brief introduction of the application, followed by an overview of the tracking environment and the various types of data recorded during the user sessions. We present and discuss some examples from the possible range of results that can be derived from this data.**
Keywords: Creativity, Creativity Support System, Tabletop, Creativity Techniques, Multi-User Collaboration, CSCW

I. Introduction

Recent developments in multi-touch tabletop technologies have enabled novel interaction paradigms for Computer Supported Collaborative Work (CSCW). Those devices combine the general advantages of IT-support (such as permanent recording and sustained and parallel manipulability of collaborative artifacts) with the advantages of added face-to-face collaboration such as body language and the immediacy of verbal and nonverbal communication [9]. This way, tabletop devices support a more social- and situation-sensitive style of IT-supported collaboration. This "true" computer-mediated human-to-human interaction contrasts to traditional human-computer interaction [9], where the computer often acts as a barrier between team members due to the missing support of social context parameters [25].

Consequently, research on tabletop-mediated human-to-human interaction should also pay attention to the social aspects of this interaction that "happen outside" of the immediate actual IT environment. Those aspects have mostly been investigated qualitatively, in contrast to those that can be measured and quantitatively modeled within the IT application (e.g. territoriality [17]). Thus, it should be the goal to acquire an all encompassing quantitative model of social interaction in tabletop environments and perceive it as dynamic social context for those environments. The model will allow for inferences on how social interaction complements and influences the user's interactions with the IT system.

We want to focus on data sources which are simple to retrieve, yet precise enough for further automatic processing. Hence, we aim to establish a minimal set of expressive properties to measure the social context / the social interactions of actors in such environments. Promising data sources are audio signals and measurements of interaction geometries as will be explained in the next chapter.

Thus, we pose the following research question: *In collaborative settings combining (a) real-world face-to-face interactions with (b) tabletop based IT applications and innovative user-interface approaches for collaboration support: What is a suitable methodology-framework for measuring, modeling and* quantitatively *characterizing (a) and its influence on (b)? What are limits and chances of such a framework?*

One goal of such research can be to improve the respective IT-applications and user interface (UI) concepts in view of the social situation in which it is used. The holistic quantitative model of dynamic social context may even be used to support the collaboration in real-time (see [21]). Another goal is to gain new insight on general social influence factors of collaboratively using IT-systems, such as collaborative tabletop systems and situative CSCW. Example studies giving evidence with respect to chances and limits of such methods should be conducted.

In our contribution, first a literature review resulting in a set of collaboration characteristics on and around tabletop displays will be presented. Derived from those characteristics, a tracking environment as a means of quantitatively analyzing e.g. interaction geometry will then be introduced. Following that, an evaluation using the aforementioned tracking environment and being conducted in the application field of creativity support will be presented. Therefore, the underlying creativity support system with its main entities/elements and usage patterns as well as the evaluation setting will be described. Finally an overview about and a discussion of the most important results of the evaluation will be given and conclusions be drawn.

II. Characteristics of Co-Located Collaboration in Tabletop Environments

As pointed out in [3, p.1], "*information sharing, knowledge of group and individual activity, and coordination are central to successful collaboration*". In this regard, verbal and nonverbal communication can be seen as the key components of social interaction [22]. The fact that both are possible when working in tabletop-based IT environments makes those systems especially promising for supporting co-located collaboration [13, 9]. Although pure verbal communication obviously takes an important role in co-located settings, recent studies also "*confirm that the nonverbal behavior plays a major role in shaping the perception of social situations*" [24, p.3]. This happens through a wide spectrum of nonverbal behavioral cues that are often perceived and displayed unconsciously while producing social awareness. In tabletop environments some important cues about the nonverbal behavior manifest in the way people are interacting on the workspace of the application itself (e.g. in regard to the interaction with (virtual) objects) while others get reflected in the way how people collaborate in the physical space around the tabletop display. This chapter will provide a literature review about those characteristics which influence and express collaboration in tabletop IT environments.

A. Collaboration on Tabletop Displays

Territoriality

Territoriality, in the meaning of the placement of (virtual) objects on tabletop workspaces, helps to mediate and coordinate (social) interactions. [17] identified three types of possible tabletop territories:

- **Personal territories** provide each user with a dedicated space for performing independent activities (e.g. changing the content of a virtual object). Scott's study showed, that although no area was specifically reserved to any person, at most 13% of all performed actions took place in the other collaborators' territories. "*It appears that understood social norms dictate that the tabletop area directly in front of someone should be reserved for use by that person*" [17, p.297].
- **Group territories** fill the remaining space (the one which is not occupied by the personal territories) and therefore are generally considered available for all group members. Main activities that take place in those areas are arrangement and discussion. They also serve as a place to share resources with others. The interaction with objects in the group territories involves more communication and negotiation activity than with those in the personal territories.
- **Storage territories** originate from stacking resources on piles and can emerge on multiple locations and even overlay personal and group territories. It was revealed in Scott's study that the location of each pile also exerted an influence on who was utilizing the resources: when a pile was in a central zone, people started sharing the resources. Otherwise, when it was close to someone's personal territory, the respective user started being responsible for distributing the resources to others.

Orientation and Sharing of Virtual Objects

The orientation of virtual objects is in a close relation to workspace territories. Changing the orientation of an object, e.g. by performing a rotate gesture, can be used for collaborative activity [16]. According to [10], the orientation and rotation of virtual objects can take three main roles:

- **Comprehension:** Tabletop items mostly get rotated to improve their readability, to move them to a position which is best to complete a task or to gain an alternative perspective on the item. Rotating an item for comprehension is not only performed for a user's own purpose, but also to help others.
- **Coordination:** The orientation of items can be used to establish territories and to communicate ownership or accessibility [10]. Thus it plays a mediating role in the coordination of actions between individuals [20]. E.g. for personal territories, virtual objects get oriented in direction of the corresponding user. This obviously makes them less usable by others. Consequently, the orientation of items reflects the way how they get shared. Another way of sharing an object is to slide it to another user's personal territory. Transferring objects therefore also indicates successful coordination [12].
- **Communication:** According to [10], changing the orientation of an object to another person / group signals that the object, the person's talk, and any accompanying gestures are being directed towards that particular person / group for communicative purposes. Consequently, an object being placed at a compromised angle usually results in discussion or close collaboration activity.

B. Collaboration in the Physical Space Around Tabletop Displays

In contrast to the related work presented above, in which collaboration characteristics on the tabletop display itself are regarded, there are also characteristics which are situated in the physical environment around such a display: "*During tabletop collaboration, people sit or stand around a table at a variety of locations, both in relation to the table and in relation to other group members*" [16, p.11]. Hence, our properties of

interest are the positions of each user (in the two-dimensional space as seen from above the tabletop), the interpersonal distances (calculated directly from the positions) and the body orientation (direction or angle in/at which someone is facing).
We limited ourselves to measure those geometric properties and did not perform an additional sentiment analysis in regard to gestural and facial expression. As will be discussed in the following sections, geometric information can give sufficient insight into the social context of collaboration and the people involved [5]. Additionally these measurements are rather simple to interpret.
However, in addition to geometry, we also recorded the verbal communication between the participants. Using geometric as well as acoustic information to measure the social dynamics in co-located meetings was also proposed in [21].

Verbal Communication

We decided to give a rough quantified estimate of the participant's verbal communication by recording audio. For the analysis, both the relative duration of each participant's speaking time and the flow of communication between collaborators are of particular interest.
As pointed out in [21] the plain speaking time indicates the flow of control in a conversation and therefore the influence of the speaker on others. This may help identifying verbally dominant or disengaged persons. The flow of conversation reflects on the social dynamics within a group [21], such as the current speaker selecting the next one, e.g. by addressing him/her via verbal and nonverbal signals. Secondly a speaker may also select him/herself: if the current speaker has finished, one of the other participants may take the turn. This way we gain a characterization of the dialog between participants which also contributes evidence on when people interact and when not.

Spatial Arrangement of Actors in Tabletop Environments

Positioning: People tend to position themselves depending on the social interactions necessary to perform specific tasks [15] (see figure 1; circles denote empty positions while the"x" indicates those that are taken). The choice of a position at a table can also reflect the personality of a person: dominant and higher status individuals tend to seat themselves at the shorter side of rectangular tables, or in the middle of the longer sides as both positions ensure high visibility and provide easier control of the information flow [11]. Physical properties of the table, such as its size or shape, can also influence seating positions [16].

Proxemics, which was introduced by Edward T. Hall, is the study of set measurable distances between people as they interact. According to [7], the social distance between people is reliably correlated with their physical distance and can be divided into four different concentric zones around a person: the intimate zone (up to 0.5m interpersonal distance), the casual-personal zone (0.5m - 1.2m), the socio-consultive zone (1.2m - 2.0m) and the public zone (>2.0m).
Normally, people have the tendency to avoid the intimate zone of others. "*Group members may temporarily be permitted to interact within a person's "intimate" space, but interaction at this distance for prolonged periods will often feel socially awkward*" [16, p. 12]. The casual-personal zone is the typical distance people favor towards friends or colleagues (people they are familiar with). This zone is about an "arm's length", in which people generally feel comfortable working since this preserves their personal space [7].
Since these distances are mainly dependent on the social relationships people have with respect to each other, psychological characteristics also play an important role: extrovert people, for example, tend to prefer an arrangement that minimizes interpersonal distances, while introvert ones do the opposite [15].

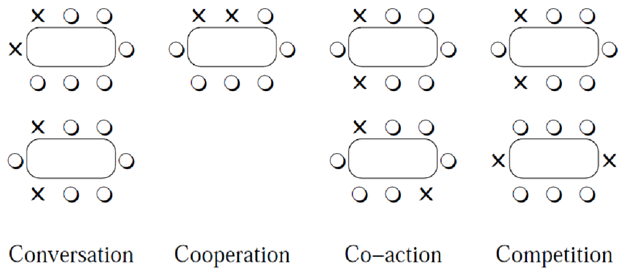

Figure. 1: Preferred positions (around a table) for different kinds of social interactions [15]

Body Orientation: The orientation of a person relates to the direction or angle in/at which someone is facing other persons or objects. This orientation may be represented by the shoulder-line and can be seen as one way of nonverbal communication. "*For example, facing in the opposite direction with respect to others is a clear sign of non-inclusion.* [...] *Face-to-face interactions are in general more active and engaging* [...]*, while people sitting parallel to each other tend to be either buddies or less mutually interested.*" [24, p.8].

In summary, many aspects in and around a tabletop application need to be taken into account in order to describe collaborative behavior of users holistically. Some of those characteristics are independent, some dependent from each other. For example the way how objects get rotated or moved is dependent on the body orientation and location of the users outside the IT environment. By measuring the body orientation and location outside of the IT environment quantitatively, e.g. the human target(s) of such a rotation or a slide may be determined automatically. This can open new ways for an in-depth analysis of collaboration patterns.
From what we have discussed concerning the characteristics of interaction "inside" and "outside" of tabletop applications, it can be concluded that both views are intimately interrelated. Thus, a quantitative modeling of these contexts is essential for understanding interdependencies and for using them inside the applications in a context-sensitive way. In the next chapter we will regard such a tracking environment for automatically and quantitatively measuring the characteristics presented above. Furthermore, we will present approaches to post-process the gathered data.

III. Tracking Environment

We assembled a set of devices and tools to track and record the introduced characteristics for further automated analysis. The setting, our so called tracking environment, is visualized schematically in figure 2 and will be further described within this section.

We used a commercial infrared camera-based tracking system (ARTrack2 from Advanced Realtime Tracking) to measure and record the geometrical parameters of interpersonal distances, the positioning of the body center and the torso orientation. The system has already been successfully applied for quantitatively measuring social interactions on small temporal and spatial scales based on body center and torso orientation as interaction geometry [5].
The cameras (figure 2, item 1) were mounted on the ceiling, each at a corner of a rectangular setup. They emit and detect IR light that is reflected by the surface of small spheres. These spheres are arranged in a unique spatial arrangement and attached to a plastic beacon (figure 2, item 2). Such a beacon is roughly the size of a human hand. The beacon is carried on the right shoulder and defines the body axes of each user. The system tracks the spatial location and orientation matrix of a beacon (and therefore a user) with an accuracy of < 1mm and $< 1°$. This accuracy was determined by the manual and own calibration measurement.
We used the tracked spatial locations of each user to calculate the *interpersonal distances* between them for each recorded time frame. We assume that the average as well as the minimum and maximum distance would be the most interesting information. Additionally we combined the tracked positions and the orientations to generate an animation of the users' movement. Finally, we generated heat maps of each user's *area of movement* to find out where a user is standing which amount of time (cp. figure 5 for still-frame of the animation, as well as the heat maps).

For recording the participants' verbal communication, we used MP3-recorders that were worn on a cord around their necks (figure 2, item 4). Our approach to measure the plain speaking time and the flow of conversation comprises two techniques of audio analysis.
The first technique is used to calculate the plain speaking time. It tracks spectral changes [6] in the signal that happen above the threshold of the averaged loudness at a certain period of time. These events of spectral change are then clustered within a time frame (of minimal size), thus segmenting the recording into a set of time frames. Those have been identified as carrying events of significant change of information in regard to preceding events in the audio signal. The segments obtained from all participants are then evaluated for overlapping regions in time that exist in the recording of several participants. For each of these overlapping regions the power of the signal is calculated. Since the power of the sound propagation falls off quadratically with growing distance the power is deemed to separate the speaking person wearing the respective MP3-recorder from other speakers as well as background noise. Such regions are subtracted from the original segments except for the one overlapping region with the maximum power. This is successively repeated. As a result only segments of the recording of a participant are obtained that are classified as carrying different information and having the most loudness. Since the permutation of successive subtractions defines the segments left that may overlap in each computation step, the second phase is repeated as fixed point iteration (also to speed up computation) using a different permutation. The averaged sum of all segments of a recording is then used to roughly estimate the amount (length) of verbal communication of each participant.
The second technique is used to gain a view on the flow of conversation. Therefore, an algorithm was devised that converts the results into a graph structure (cp. figure 6). It connects segments as nodes by edges indicating the timely order of these segments, thus constituting a path for a single user. Such paths are then connected pairwise if there exist segments/nodes in both paths that are denoted to have happened in the same time-frame. The amount of such interconnecting edges is then used to estimate how much communication is carried out per participant in dialog in comparison to the edges solely in the path.

Although it is obvious that for real-life scenarios the set-up with tracking beacons and neck-worn MP3-recorders is too invasive, we considered this technological equipment suitable for an evaluation conducted in a laboratory setting. We assessed the automatically tracked data from the physical environment by human validation of additional video recordings.

From a UI perspective, we recorded all relevant and available interaction data: Raw touch points and user-attributed interaction-paths. Those were then used to construct touch maps similar to VisTACO [19]. Furthermore the data was used to determine individual and group territories more precisely. Therefore we calculated interaction heat maps as they are common in the usability analysis of e.g. web interfaces (cp. [2]). Those heat maps can help identifying hot spots of the users' interactions similar to the activity plots proposed by [17]. This way we gained several separate and partially overlapping views on territoriality. We also tracked changes of orientation and positions of idea cards in order to examine how they are *shared* between users over time. Finally, we recorded "CRUD"[1]-operations to assess the participation level for each user.

IV. Evaluation

A. Application

For the evaluation of our tracking-environment we used a tabletop-based creativity support system (CSS). As pointed out by [18] such systems "*are especially potent in supporting group collaboration and social creativity*". Collaborative creative problem solving with its core requirements of communication, coordination and interpretation [1] makes this application field ideal for being supported by tabletop devices [9].
Our specific application is based on a generic (computer-) model for creativity techniques [4]. Those techniques try to

[1]create, update, delete

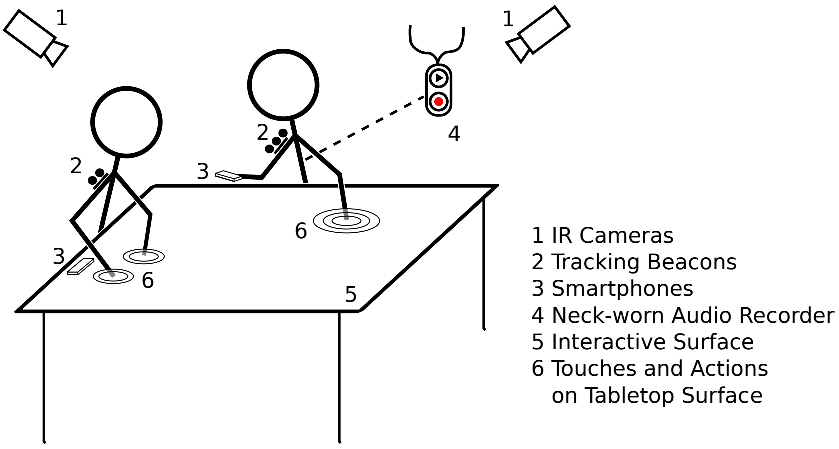

Figure. 2: The Tracking Environment

encourage creative actions (e.g. original thoughts and divergent thinking) by guiding the creative process based on certain rules, activities and constraints. Popular and practically used examples of creativity techniques are Brainstorming and -writing, Mind mapping or the Six-Thinking-Hats [23]. A typical workflow in our application is composed of a sequence of one or more arbitrary creativity techniques in which the users can either generate new ideas (divergent phases) or rate previously created ones (convergent phases).

Figure. 3: Tabletop widgets and iPhone interface. Clockwise from top left: control widget, idea card with two aspects (top one being moved), empty idea card, coupled iPhone app for text entry.

The user interface of the application is composed of widgets, from which the most central one is an idea card, consisting of different segments, so called (textual) aspects. Aspects in such idea cards can be selected for manipulation (e.g. to edit, reorder, move or delete an aspect) by a drag and drop mechanism (cp. figure 3 for all available widgets).
To start such an action, each user is provided with a control widget (figure 3 - top left corner). Each control widget contains buttons for creating / editing / deleting idea cards and their aspects. E.g. for editing an idea, a user has to press the edit-button ("screwdriver icon") and perform a drag gesture to the respective area he wants to edit. While a user is editing the text of an aspect, the aspect is locked so that no other user is able to change its content during this period. Using graphical widgets to trigger events instead of, e.g., gestures has the advantage of providing visual hints for the user. Conflicts over a shared resource for control are avoided, as each participant has an own individual control widget. Moreover, the control widgets were needed to assign actions to specific users. This was needed for example to record the contributions of users (to do a fine grained evaluation).
For the input of textual contents (e.g. when editing an aspect), we used a coupled iPhone for each participant (also cp. figure 3). This wireless input method allowed for a higher degree of freedom while using the system, as prepositioned and space-consuming on-screen keyboards would have bound the users to specific physical positions and limited the space on the screen. The tabletop interface is still needed for more invasive and collaborative actions (e.g. creating, merging, deleting and regarding ideas). Each iPhone is visually linked to a specific control widget by color coding (e.g. the widget, text interface and editing indicator are all blue in figure 3). To provide awareness to each participant, the text input is instantaneously synchronized with the selected aspect on the tabletop display. An image of the final application used in the evaluation can be seen in figure 4.

B. Setting

For the experiment, we selected a total of 31 computer science students as participants and divided them into 8 different, randomly composed groups. Following an introductory 15 minute training session to get familiar with the handling of the tabletop application and the iPhone-based text-input, each group had to find ideas to the given problem "How can academic tuition fees be used to maximize the students' benefits?". The public discussion about this topic has been ongoing in Germany for years leading to controversial results. Consequently, we aimed to stimulate this discussion by encouraging students to bring in creative (and more radical) suggestions.

Therefore, a three phase idea generation process was provided, with each phase following a different creativity technique: Brainwriting, Unrelated Stimuli and Forced Combination. While Brainwriting encourages the group

Figure. 4: The Evaluation: Creativity Support System "IdeaStream"

members to generate as much ideas as possible (with criticism not being allowed), the Unrelated Stimuli technique provides a set of stimulus terms (in our case "lawnmower", "water", and "outer space") to find associations which should lead to more novel and radical ideas. Finally, the Forced Combination technique instructs the group to merge ideas together. This way, the group members get encouraged to deal with the others' ideas, leading to a stronger collaboration and communication. We applied those different techniques to gain a broader range of possible collaboration situations to evaluate our tracking-environment in.

The time spent for each creativity technique was 10 minutes, so every group member spent roughly 30 minutes for idea generation, which is typical for creative problem solving sessions [8, 14]. Finally, a survey was handed out for each participant to find out more about the personal perception of our application and the overall group process. The photo shown in figure 4 was taken at the experiment.

V. Results

For all sessions, we conducted an extensive analysis of the users' collaboration by applying all instruments of the tracking environment presented above. In the following, the results of the automatic approaches to analyze the retrieved data will be presented.

A. Proxemics, Positioning and Body Orientation

In accordance with the theoretical background, only three pairs of users (out of 48 possible combinations) positioned themselves at a distance of less than 500 mm (intimate zone) during the experiment. Table 1 shows the minimum, maximum and average values for each creativity technique, again averaged over all 8 sessions. The interpersonal distances remained in between the range of the casual-personal zone (minimum and average values) and the socio-consultive zone (maximum values). As minimal distances of less than 500 mm occured only rarely, Scott's statement that "*group members may temporarily be permitted to interact within a person's "intimate" space, but interaction at this distance for prolonged periods will often feel socially awkward*" [16] can be supported. Regarding the creativity techniques, the averaged minimal distances slightly decreased in the Forced Combination technique. This could be explained by more inter-territorial and inter-personal activity taking place, moving the tracking beacons closer together.

	Brain-writing	Unrelated Stimuli	Forced Comb.	Total
Min.	818,81	808,32	698,20	775,11
Max.	1772,73	1600,40	1608,11	1660,41
Avg.	1202,67	1169,52	1101,98	1158,06

Table 1: Averaged distances between the users [in mm]

Figure 5 shows an example of a session, where users did not leave their initial positions throughout the various creativity techniques. While this was true for all 4 user sessions, we also experienced two 3 user sessions, where we could observe more movement. In those, one user temporarily switched to the unoccupied side of the table. As sessions with 4 users had all sides of the table occupied from the beginning, this might imply that a side is regarded as a user's own physical territory. Another reason which could have prevented a more active physical interaction in our setting is the (relatively) small size of the tabletop display we used (cp. figure 4).

map of user movement around the tabletop (example from session 3)

An evaluation of the body orientation also did not show unexpected results. In most cases, the orientation of the users was mainly parallel to the tabletop's edges. Nevertheless, the statistics of body angles allowed to analyze the frequency of certain spatial orientation constellations between users. In very few cases, people at the corner of the table were oriented towards each other, as can be also seen in figure 5 - for beacons 3 and 5. The observation pointed towards an increased social interaction during this period. Those cases lasted for short time periods only. The main maxima of the relative body orientation were at $\pm\pi/2$ and $\pm\pi$ with only small deviations which is in accordance to the table's geometry and general findings in [5].

In summary, our approach to track and visualize positions and orientations of users worked well and accurately. Especially heat maps provide for a meaningful tool to gain global insight into the temporally accumulated territorial behavior of actors around a tabletop display. In those heat maps also the information about proxemics becomes apparent as closer hotspots of different users also reflect on their average interpersonal distances.
Usually in non-laboratory settings off-table interaction that is task related but not immediately concentrated on the IT environment may also play a substantial role. Hence, it can be of interest to detect and model such off-table social situations [5] in order to e.g. invite users from those situations to enter their (presumably valuable) off-table discussion results into the IT-application. More hands-on applications of individual context might include rotating UI elements according to a user's position and orientation.

B. Verbal Communication

By applying the audio analysis approach presented in section "Tracking Environment", it was revealed that in about half of the recorded sessions one user dominated the verbal communication. Table 2 gives an example of resulting data. We also experienced participants (roughly a quarter) which were significantly disengaged from the act of verbal communication within their group. This result is based on the amount of relative speaking time and supported by the constructed communication graph having no or very few edges connecting the participant's path of communication to others. Regarding the relation to the activities carried out on the system (see section "Participation and Survey"), they have been either performing significantly above or below the amount of average group actions. Nevertheless, such a degree of social isolation does not necessarily mean disengagement from the group task.

User	Brainwriting	Unrelated Stimuli	Forced Combination
9	15,00%	21,30%	11,80%
10	5,25%	5,50%	5,30%
11	38,00%	23,80%	41,00%
12	6,50%	15,00%	19,80%

Table 2: Amount of verbal communication by each user / phase, relative to the length of the recording (example from session 3)

Concerning the differences between the creativity techniques, Brainwriting surprisingly attracted most of the communication in the form of individual segments. Although the Forced Combination technique involved fewer of those individual segments, they were of a longer duration than in the other creativity techniques.
Besides this, no other causal relation between the verbal communication and the activities on (and around) the system showed up. On the one hand this is clearly rooted in the shortcoming of the quality of the recorded material as we used only directional microphones of low quality. On the other hand, this may emphasize that collaboration is such a dynamic process that it seamlessly adapts to various individual interaction styles and social situations that this quantifying approach in the audio analysis is inappropriate.
An application of this analysis could give users feedback on

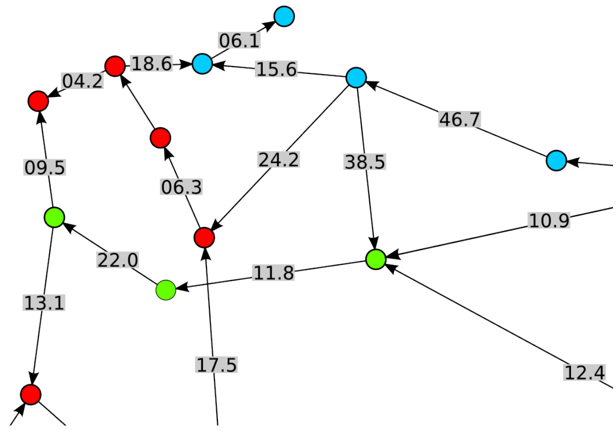

Figure. 6: Communication graph, colors identify individual users, labels indicate the duration between segments (excerpt from the first 10 minutes of session 1) - compare section "Tracking Environment"

their shares of communication [21] (e.g. as a means of automatic moderation to enforce the regulations of certain creativity techniques). Another scenario could be to adapt the workflow of the application to the intensity and extension of the discussion, e.g. in choosing creativity techniques according to the inferred level of discussion intensity or balancing the IT represented parts of the interaction with the non-IT represented parts. Off-table social situation detection for balancing these tasks requires an integration of various logical sensors such as orientation / position and verbal communication. Furthermore analyzing the discourse structure (and thus the potential collaboration structure) as in figure 6 may give the UI hints on how to automatically rotate widgets that are pushed from one user into the direction of several other users.

C. Territoriality and Position / Orientation of Objects on the Tabletop

Our approach to visualize and detect territoriality on the tabletop's surface is shown in figure 7. *Row 1* shows the heat map of the users' on-table territories coded by color opacity determined from the relative intensity distribution of their actions. We took into account all actions performed via the control-widget as those can be associated with a particular user. To further frame the users' territories, we calculated the convex hull of the start- and end-points of those actions. The screenshots in *row 2* were taken from a screen-recording and display the tabletop's surface at the end of each creativity technique. Finally, in *row 3*, a plot of the raw touch events is shown. Initial touches, of e.g. a drag and drop gesture, are drawn bigger than others.
Comparing rows 1 and 2, it can be seen that the individual territories are reflected by the orientation of the idea cards, as almost all the ideas in a user's personal space are oriented towards his position. This observation proved to be true over all sessions. In addition, we observed that when a user was moving an idea into his territory, he adjusted its orientation in direction to his physical position. However, we also noticed some users were editing ideas upside down. This was probably due to the fact that the iPhone application, which

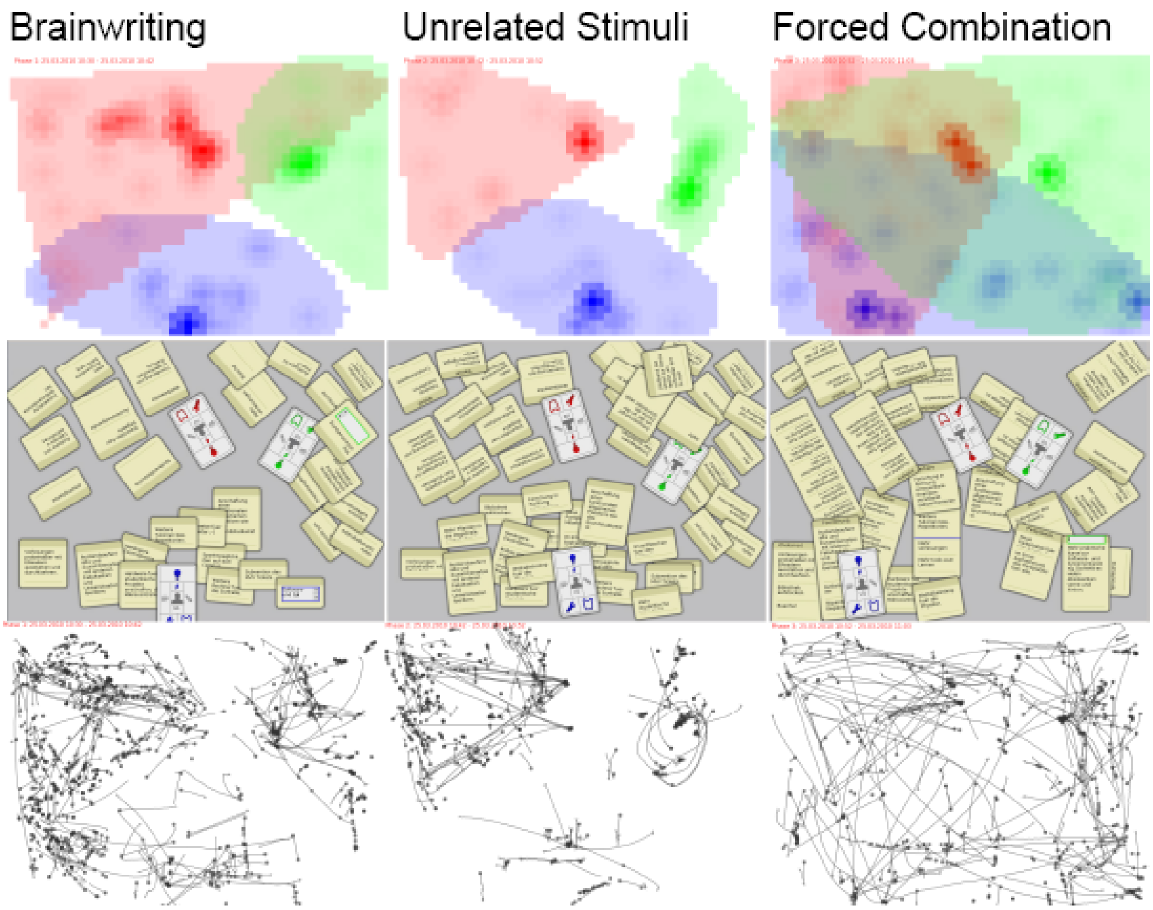

Figure. 7: Territorial heat-maps, screenshots and touch-maps for the different creativity techniques (example from session 5)

was used for text entry, allowed a user to see the text in the right orientation anyways while editing it. Therefore some avoided the additional effort for rotating the ideas towards themselves. Consequently, the orientation of the ideas can only provide an estimate of the individual territories within our evaluation setting.

Comparing the derived territories for each creativity technique, it appears that in the Brainwriting and Unrelated Stimuli technique, mostly isolated personal territories can be accounted for, whereas in the Forced Combination technique individual territories loose their strength and tend to increasingly overlap, thus forming larger group territories. These observations hold true for most of our sessions, as only the users of one session showed a different behavior: In this session, even for Brainwriting and Unrelated Stimuli, group territories were favored. However, in contrast to other sessions, the involved users all knew each other before, so crossing the border to another user's territory seemed to be less invasive.

Group territories formed along the borders of the personal territories of adjacent users, whereas much less cooperation (expressed by smaller overlapping areas) occurred between users standing on opposing sides of the table. This might directly relate to the preferred positions (around a table) for different kinds of social interactions described in figure 1, meaning that opposing users are regarded as competitors.

These assumptions are further supported by the number of ideas moved between different territories and the number of ideas rotated by 90° / 180°, as shown in table 3. Most territory changes and rotations occurred during the Forced Combination technique, wherefore the assumption that more interchange of ideas takes place within this technique can be further supported.

	Territory Changes	Rot. 90°	Rot. 180°
Brainwriting	26,17%	35,52%	29,17%
Unrelated Stimuli	30,63%	24,40%	14,58%
Forced Combination	43,20%	40,08%	56,25%
Total	493	507	93

Table 3: Territory changes and rotations over all sessions

Analyzing the quantitative correlation between a user's off-table body orientation and on-table widgets (stated qualitatively by [10]) can be used to e.g. infer (via an appropriate classifier) which widgets are currently "associated" to which user. Inaccuracies may be posed by coupled display input as explained above. Because our technique allows for incorporating longer sequences of actions into e.g. models of territoriality (which is not possible with a mere qualitative video analysis), individual user actions may be interpreted more accurately and in real-time with respect to these models. Earlier qualitative findings (e.g. [10, 17]) may thus be quantitatively proved .

D. Participation and Survey

In a last step, we analyzed all recorded actions for each creativity technique. As result, we gained an average of **104 actions** for **Brainwriting**, **73 actions** for **Unrelated Stimuli** and **82 actions** for **Forced Combination**. In 6 out of 8 sessions, one user took the lead, with a percentage of actions larger than 40%. In one session, one user even was responsibly for 70% of all performed actions. It also showed up, that in half of all sessions, during the Unrelated Stimuli technique a different user contributed most (refer table 4 for an example). As the stimuli provided in this technique may trigger different thinking patterns, this may be one reason for this observation.

User	Brain-writing	Unrelated Stimuli	Forced Comb.	Total	Perc.
19	38	54	22	114	34,86%
20	34	18	27	79	24,16%
21	46	19	69	134	40,98%
Total	118	91	118	327	

Table 4: Number of actions performed by each user / phase (example from session 5)

In the survey handed out after the experiment, we wanted to get an impression about the users' perception of the application as well as the group interaction. Summarizing the results of the survey, the users felt mostly positive and comfortable about using the application collaboratively. The size of the tabletop workspace was stated as appropriate for the given number of users, although a very few complained about not having enough space for expressing all of their ideas. Even though we observed no significant movement around the tabletop device, the liberty of action gained from using a tabletop application was seen as an improvement in comparison to single-user PCs. The perception of the group was also assessed positively, as distraction by or conflicts with others were not quoted by any of the participants.

VI. Conclusion

The research question that we pursue with this contribution was: *In collaborative settings combining (a) real-world face-to-face interactions with (b) tabletop based IT applications and innovative user-interface approaches for collaboration support: What is a suitable methodology-framework for measuring, modeling and* quantitatively *characterizing (a) and its influence on (b)? What are limits and chances of such a framework?.*

With respect to this research question, the quantitative evaluations gained from the measured parameters show that position (and derived interpersonal distance) and orientation plus audio recordings allow for an expressive characterization of real-world face-to-face interactions that have a relation to the tabletop interaction. These parameters are, in general easy to measure and allow for a quantitative analysis of real-world-interactions and real-world-IT-interactions. For a more unobtrusive measurement alternative, the use of standard mobile devices (e.g. modern smartphones) of the users or coupled display input devices as used in our evaluation is possible and should be further investigated [5]. Their integrated sensors such as as gyros, compass, microphones etc. provide manifold alternatives for measuring.

Combining "on-table" and "off-table" characterizations of social and individual context, solid data can be produced which e.g. allows for identifying weaknesses and strengths of tabletop applications. Future research will concentrate on how measurements of the real-world social context of using a tabletop environment may be used in the application itself to make it more socially and situation sensitive. We will also apply the developed techniques to other types of collaborative tabletop applications like a music production application that bridges the gap between single user oriented music composition and collaborative jamming.

Furthermore, we will investigate limits and changes of coupled display supplements for intensifying the coupling between "on-table" and "off-table" collaborative activity.

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