How People Use Orientation on Tables: Comprehension, Coordination and Communication

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ABSTRACT
In order to support co-located collaboration, many researchers are now investigating how to effectively augment tabletops with electronic displays. As far back as 1988, *orientation* was recognized as a significant human factor issue that must be addressed by electronic tabletop designers. As with traditional tables, when people stand at different positions around a horizontal display they will be viewing the contents from different angles. One common solution to this problem is to have the software reorient objects so that any given individual can view them 'right way up.' Yet is this the best approach? If not, how do people actually use orientation on tables? To answer these questions, we conducted an observational study of collaborative activity on a traditional table. Our results show that the strategy of reorienting objects to a person's view is overly simplistic: while important, it is an incomplete view of how people exploit their ability to reorient objects. Orientation proves critical in how individuals comprehend information, how collaborators coordinate their actions, and how they mediate communication. The coordinating role of orientation is evident in how people establish personal and group spaces, and how they signal ownership of objects. In terms of communication, orientation is useful in initiating communicative exchanges and in continuing to speak to individuals about particular objects and work patterns as collaboration progresses. The three roles of orientation have significant implications for the design of tabletop software and the assessment of existing tabletop systems.

Categories and Subject Descriptors
H.5.3 [**Information Interfaces and Presentation**]: Group and Organization Interfaces – *collaborative computing, computer-supported cooperative work, theory and models.*

General Terms
Design, Experimentation, Human Factors.

Keywords
Tabletop display, orientation, rotation, observational study.

GROUP'03, November 9–12, 2003, Sanibel Island, Florida, USA.

1. INTRODUCTION
When people collaborate in face-to-face settings, they often use tools such as pens, pencils, paper, and printouts, and work over some sort of supporting surface or table. They share information placed on this surface, use objects on the table as conversational props, or develop ideas and work products [2, 19]. In contrast, desktop computers may inhibit the group interaction, even though they potentially allow access to information and productivity tools pertinent to the task at hand. For example, adults are forced to sit closer than is socially comfortable [8], and people resort to a turn-taking interaction style because they cannot interact in their typically synchronous manner [15]. In fact, Luff et al. [13] found that desktop computers are often abandoned for traditional tools during co-located collaboration.

Many researchers are now interested in combining the advantages of computers and tables through the development of *tabletop displays*. The technology is nearly in place: high quality projectors, flat panel and plasma displays, and touch-sensitive surfaces mean that it is now fairly straight-forward to construct a tabletop display. The challenge is one of design: electronic tables should at least maintain those characteristics of traditional tables that prove particularly useful for collaboration, such as awareness of other participants' actions, the possibility of simultaneous interaction, and affordances for sharing [12]. Of course, there are restrictions imposed by physical tables that electronic ones may mitigate or bypass altogether. For example, two people seated at different sides of a table will see the same object at different orientations. Electronic tables may provide additional functionality to enable collaborators at different viewpoints to see the same object 'right way up;' for instance, by providing multiple copies of information. When pertinent information is upside down or sideways, people may have more difficulty understanding it, or may miss it altogether. It is this issue of object orientation and its role in collaboration that is the focus of this paper.

Our goal is to understand how the orientation of artifacts affects collaboration at a horizontal workspace and the implications this has for the design of collaborative tabletop displays. In the next section, we describe how existing designs of tabletop systems address orientation. Then, based on an observational study and subsequent video analysis, we identify and discuss three roles that orientation plays in the collaborative process: *comprehension*, *coordination*, and *communication*. Finally, we discuss the implications these roles of orientation have for the design and evaluation of tabletop interfaces.

Cite as:
Kruger, R., Carpendale, S., Scott, S. and Greenberg, S. (2003). How People Use Orientation on Tables: Comprehension, Coordination and Communication. Proceedings of the ACM Group 2003 International Conference on Supporting Group Work (November 9-12), ACM Press.

2. RELATED WORK

There are several basic approaches that are used to handle orientation in existing tabletop display systems.

Fixed orientation. Some systems assume a single orientation, and that participants will sit side-by-side instead of on different sides of the table. An example is the Café Table [3], where a small semi-circular electronic display, embedded in one end of an oval espresso table, is configured for side-by-side seating. The main workspace of the table display orients all items to the near end of the table.

Manual orientation. Conceptually, the simplest way to manage orientation is to let users manually rotate their own information items on the tabletop. This is, of course, a direct analog of how people now interact with traditional media, such as paper, on a table. While people have considerable experience rotating traditional media, manually rotating digital objects can be more difficult. Rotation is clumsy in electronic settings, likely because current input devices (e.g., mouse, keyboard, and stylus) provide few degrees of freedom compared to the easy manipulations possible with one's hand on a physical object. Extra controls are typically needed, such as the rotation mode and "handle" provided by Microsoft PowerPoint® for free rotation, or a menu to rotate an object a set amount. To facilitate manual orientation, several tables with pen-based input now provide users with lightweight rotation mechanisms, such as the circular pen gesture employed by the InteracTable [17] and the ConnecTable [18].

Person-based automatic orientation. A few designers have tried to minimize manual rotations by automatically orienting information items in the tabletop workspace. In the person-based approach, information is oriented towards the person who has most recently accessed the information. This strategy assumes that the person manipulating the item benefits most from the 'best view' of the information. For example, people seated at the InfoTable [14] can access items on the tabletop display by using the pointing device on their respective laptops (also located on the table). When a person drags a tabletop item to "their" side of the table, the item automatically rotates toward the table edge closest to their laptop.

Environment-based automatic orientation. A limitation of the person-based approach is that tabletop systems often do not know exactly where the person manipulating the item is located; thus, the information may be automatically oriented towards the wrong side of the table. This problem may soon be solved, for several new technologies now provide more accurate person-location detection [6, 9]. Still, some have questioned whether it is always appropriate to orient the information toward the person manipulating the information, for appropriateness often depends on the intent of the manipulation.

Thus, another tactic is to use an environment-based approach where the system orients information based on its location in the tabletop environment. This strategy typically assumes that the person who is closest to the information—regardless of who has selected it—would be the one most likely to benefit from the 'best view' of the information. For example, the Personal Digital Historian system [16] automatically adjusts the orientation of tabletop information items towards the edge of the circular workspace. This means that any item directly in front of a person will always be oriented toward that person, regardless of who is manipulating it. Likewise, icons on the perimeter of the Café Table [3] flow along the edge automatically, and as they flow they are oriented orthogonally to the edge (although as stated previously the main display has a fixed orientation). The InteracTable system automatically rotates objects as a consequence of a person "tossing" an information item to the other side of the table using a pen gesture. As the item moves across the table it automatically rotates until it stops on the other side of the table, fully oriented towards the closest table edge [17].

It is unclear which, if any, of these approaches suffice. There is relatively little prior work on orientation in tabletop interaction. Thus there is no basis to inform decisions about how best to present orientation-dependent information (e.g. text, menus, and icons) to collaborators working at a table. Existing design assumptions are likely too simplistic. For example, automated orientation mechanisms assume that readability of the item is critical. However, one of the few observational studies that considered orientation in collaborative tabletop interactions suggests otherwise. In particular, while Tang [1] noted the familiar problems of information at odd angles causing reading and annotating difficulties, he also noted conditions where variant orientation served as a collaborative resource:

- Using someone else's alignment conveyed support,
- Orientation could establish the intended audience, and
- Orientation was also used to create a personal space.

Another exploratory study, performed by Fitzmaurice et al. [7], investigated the manipulation of artwork during the drawing process. Large variations were found in drawing styles between participants. Yet all participants used variant (i.e., non-orthogonal) orientation of their drawing canvas and many continued to vary the orientation of the canvas as they worked. Rotation of the canvas appeared to be performed for ergonomic (e.g., comfort), performance, and comprehensive (e.g., evaluative) reasons during both the writing and drawing tasks performed by their participants. While their focus was on supporting a single user drawing on a pen-based tablet-style computer, many of their recommendations may be applicable to handling orientation issues during tabletop collaboration. In particular, they discuss the need for full variation in orientation angle, and suggest the use of self-rotating and self-orienting user interaction elements.

3. THE IMPACT OF ORIENTATION ON COLLABORATION

In our own efforts developing collaborative tabletop interfaces, we realized there were still many unresolved research questions concerning orientation of digital information on horizontal displays. As mentioned above, previous person-based and environment-based approaches assume that the most significant orientation issue is that of readability (i.e. comprehension). Furthermore, these approaches assume that the critical question is how to know whom an object should be oriented towards at any moment. Intrigued by Tang's observations and motivated by the importance of resolving this issue for the design of our own tabletop interfaces, we set out to improve our understanding of the roles orientation can play in collaboration.

We began a series of explorations into the impact of orientation on collaborative activities and interaction in general. These explorations involved gathering data from a variety of sources including prior art:

- HCI and CSCW literature describing existing digital tabletop systems, e.g., [3, 6, 9, 14, 16, 17, 18],
- HCI and CSCW literature involving qualitative and quantitative studies focused on tabletop collaboration or single-user tabletop interaction, e.g., [7, 19].

Because no body of work has tackled orientation head-on, we also conducted our own formative investigations. These included formative pilot studies, involving a series of design sessions on the granularity of rotation and variations in angular freedom [10], and an observational study of collaboration on displays of various orientations [11].

Analyses of these formative studies revealed that rotation and orientation appear to have complex and subtle effects on the process of tabletop collaboration. In order to further understand these effects, we performed an in-depth video analysis of one condition of the observational study, which involved tabletop collaboration using traditional paper-based media.

3.1 Video Analysis of Tabletop Collaboration

The video data from this condition consisted of approximately 50 minutes of five adult pairs constructing puzzles with strongly oriented content (i.e., a passage of text). While participants also constructed puzzles containing non-oriented content (i.e. geometric shapes), we restricted our analyses to sessions involving oriented content in light of the time-intensive effort required for in-depth video analysis. Given our purpose of understanding the effects of orientation on collaboration, we felt the sessions involving the passage of text would be more beneficial for achieving this goal.

During the tabletop collaboration sessions, participants sat directly across the table (76x124cm) from each other with the puzzle on the table between them (see Figure 1). In order to complete the puzzle, participants were provided a white, rectangular piece of cardboard (19x19cm) on which to construct the puzzle from 25 puzzle pieces. Participants were also provided a preview image showing what the completed puzzle would look like. Participants were free to position all puzzle-related items anywhere on the table. In general, pairs took less than ten minutes to correctly assemble the complete passage of text.

We chose the puzzle task as it shares attributes common to many collaborative construction tasks performed over tabletops: a single shared artifact that is the 'product' (the puzzle); individual components that are manipulated for individual work (one's selected puzzle pieces); and objects for joint action (sharing of puzzle pieces as well as the puzzle-in-progress). The fact that puzzle pieces and the completed puzzle also have a visual up/down orientation meant that we could also analyze orientation as a variable.

3.2 Three Roles of Orientation

Through critical analysis of the prior art, results of our formative studies, and the in-depth analysis of tabletop collaboration, we have identified three key roles of orientation that impact collaboration and have implications for the design of tabletop interfaces: *comprehension*, *coordination*, and *communication*. We can break down each of these key roles of orientation into several more specific roles (Table 1). The next three sections will describe each of these orientation roles in turn and provide supporting examples from our data sources.

4. COMPREHENSION

The most obvious use of orientation is comprehension. In practice, people often rotate tabletop items to help themselves read (or draw or write on) the item. We will also see in Section 6 that people also rotate items to help *others* read/draw/write on the item.

The role of orienting items for comprehension is fairly basic, as we know that it is often difficult to interpret something that includes text or symbols unless it is oriented correctly. Yet while it may seem that there is only one 'correct' or 'best' orientation for an individual viewing an item, people also rotate items to different angles to help them understand or interact with the content. These nuances are discussed below.

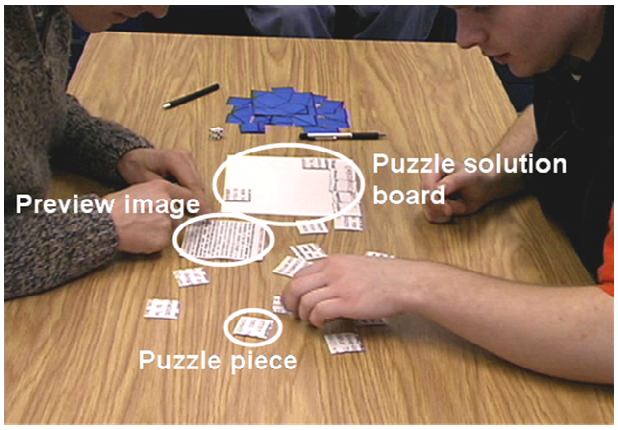

Figure 1. Setup for collaborative puzzle construction.

Table 1. Roles of orientation

Comprehension
Ease of reading
Ease of task
Alternate perspective
Coordination
Establishment of personal spaces
Establishment of group spaces
Ownership of objects
Communication
Intentional communication
Independence of orientation

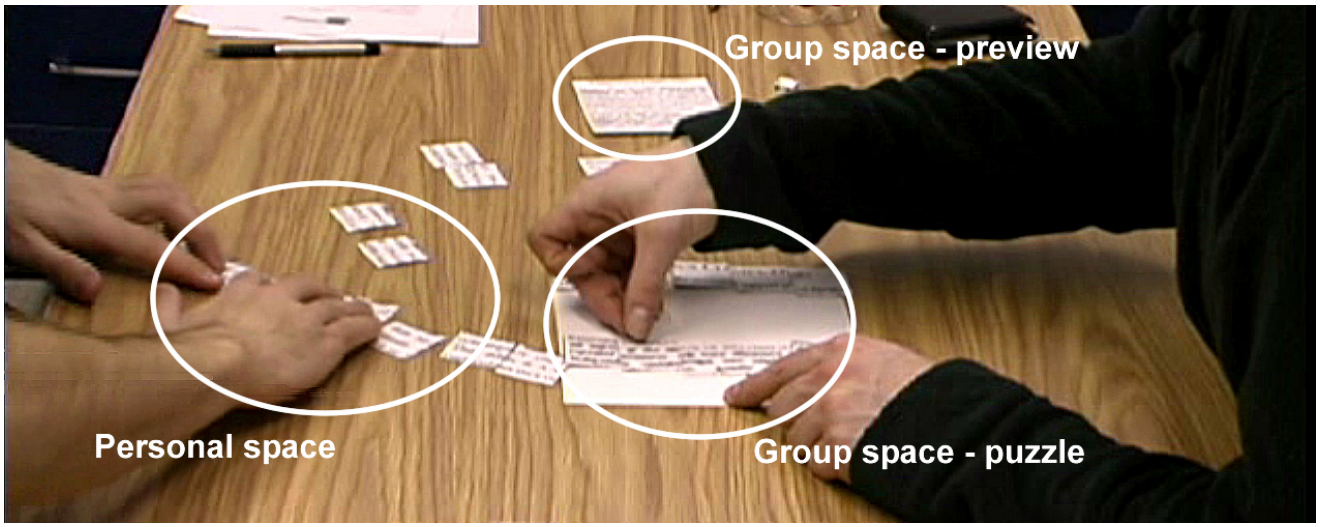

Figure 2. An example of personal and group spaces.

4.1 Ease of Reading

People often orient objects so that they are most readable for themselves. Usually this involves turning the object so that it is the 'right way up' in that words and symbols are easily read and interpreted. This role of orientation is recognized by most tabletop technology designers, who often try to orient an object the 'right way up' for the user who is either currently accessing it or is closest to it [14, 16].

However, our data revealed that the 'right way up' does not necessarily mean that items face the edge of the table where a person is seated, as is often done in both person-based and environment-based automatic orientation strategies (Section 2). Instead, the items could be oriented tangential to how the person is looking at the item, i.e., how they move their head and eye gaze towards the item. Figure 2 gives an example, where we see an image extracted from a video of two people collaborating on a puzzle. The person on the left is sitting somewhat sideways to the table, and consequently he has aligned his pieces towards himself (and the best viewing angle), rather than to the table's edge.

4.2 Ease of Task

People may also rotate items on the table to a position that provides the best angle for completing a given task. For example, Fitzmaurice et al., [7] reports on various studies of artists that describe: how they operate within an articulation comfort range as they draw; how they rotate artwork so their hand does not obscure the key area of the drawing; and how they are careful to position the drawing so as not to smear or damage sensitive parts of the drawing, e.g., those with wet paint. These angles may, of course, differ from the reading orientation. For example, we know that people may use a tangential orientation for reading, but a different 'slanted' orientation when writing for comfort.

4.3 Alternative Perspective

People also rotate items in various ways to help them understand its content. These rotations provide people with alternative perspectives of the item, especially if the item has multiple orientations or is not strongly oriented. Obtaining alternate perspectives is accomplished by rotating items on the table, or by a person moving to a different location at the table. This happens, for example, when a chess player walks around a chess table.

5. COORDINATION

Tang [1] observed that orientation appears to play a mediating role in the coordination of actions between individuals in a collaborative setting. To understand how this happens, we observed and analyzed the subtleties of how people use orientation as a coordinative act. In particular, we saw that orientation of items is used by people to establish different categories of personal and group spaces on a table, and to communicate *ownership* or accessibility of these items.

5.1 Establishment of Spaces

A horizontal display serves as both a shared space for doing group work, and a personal space for doing individual work. Yet there is usually no explicit demarcation on the surface itself as to what comprises the personal *vs.* the group space. Consequently, people divide the space through other means, e.g., explicit verbal demarcation (this is mine, this is yours), or implicit demarcation in terms of where people place objects and how they are oriented. In practice, orientation proves an important cue to others in how personal and group spaces are created and communicated and how subsequent actions over the display occur.

Establishment of a personal space through orientation. One way we saw that people established their personal space was to orient objects in an area of the tabletop so that they were 'just right' for their own use (Section 4). This in turn creates a space less usable by others and where others tend not to perform actions. Typically, personal objects are kept close to the person they belong to (see also [1]) and are oriented appropriately for him or her. This makes objects easier for that person to see, read and use for one's task, and harder for others to see, read and use.

In our puzzle study, most people created their own personal space by orienting puzzle pieces appropriately in the area directly in front of them. Figure 2 shows this for the participant seated on the left, where he has clearly organized his collection of puzzle pieces both by proximity and by tangential orientation; this creates a spatial region that suggests these items are for his own use in the current task. Note that items around this personal zone are oriented differently from other items in the workspace.

Establishment of a group space through orientation. A group space is one or more spaces in which more than one person feels

free to work. While this may occur as either an implicit or explicit group decision process, it usually takes place with great ease. Unlike the personal space where both proximity and orientation favors a particular person, a group space may compromise some or all participants because the space is typically located somewhat centrally on the table, and because items may be 'upside down.' Yet people willingly and gracefully accept this compromise.

In the puzzle study, we saw that all groups easily and quickly established a group orientation at the beginning of the puzzle task. No one said they minded what their relationship would be to the established group orientation. In fact, some people were proud of their skill at working with items that were 'upside down' for them.

We also saw that multiple group spaces can co-exist, and each can have a different orientation. In particular, we saw some people establish two group orientations for the puzzle task. The first was the orientation of how the puzzle would be assembled (the primary task), and the second was the orientation of the preview image (see Figure 2). These orientations were usually done quickly, where only a handful of physical actions and interpersonal negotiations established the group orientation.

Establishing group orientation proved to be a very social act. In every case, the person responsible for establishing the group orientation attempted to favor the other person by aligning the puzzle right side up for their collaborator. Figure 3 gives an almost comical example of the lengthiest negotiation we saw for establishing the orientation of the preview image. In frame A, Participant 1 (on the right) initially suggests an orientation that makes the image right-way up for Participant 2 (the bottom of the image is indicated by a thick black line). In frame B, Participant 2 counters by rotating it so that it is right-way up for Participant 1. This back-and-forth continues, until Participant 1 suggests a compromise between the two orientations in frame D, which is then flipped by Participant 2 and accepted by both in the final frame.

Once established, the group orientation had a significant effect on the completion of the puzzle. For example, approximately two-thirds of all rotations were to turn pieces to the same orientation of the puzzle; this makes sense, as the primary goal of participants was to fit the pieces into the puzzle. However, other rotations were done with respect to the preview image, i.e., so a person could get a sense of how and where their piece would eventually fit into the completed puzzle.

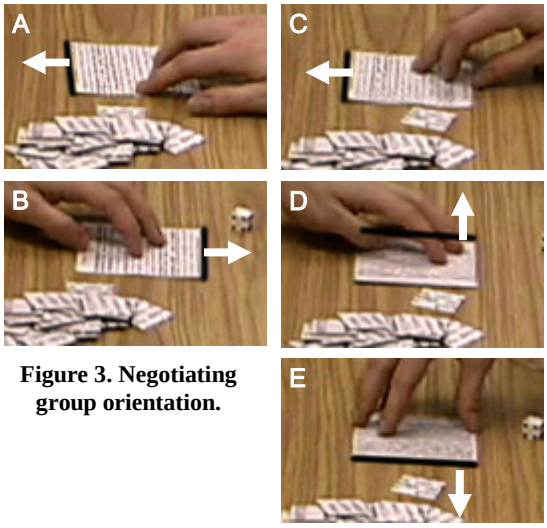

Figure 3. Negotiating group orientation.

Finally, we should add that the distinction between personal and group orientation is not necessarily permanent; one group altered the preview image from a group orientation to a more personal orientation. The image then fluctuated between being both a group and personal resource.

5.2 Ownership of Objects

Groupware systems often have a strong notion of ownership, where the system dictates access control and restricts who can do what. In real life, however, ownership and control is often a socially mediated process, determined by implicit subtleties such as proximity, the history of who has used an object, and so on. Because ownership can change rapidly during collaboration, the heavyweight notions of access control often found in groupware may be inappropriate for co-located collaborative settings.

Orientation also serves to mediate ownership of tabletop objects. In particular, our data revealed two ways that orientation dictated who 'owned' a particular object, and how others were willing to respect that ownership.

- ***Orientation for picking up/using objects.*** People are much more likely to pick up and use objects that are oriented towards themselves or at a compromised angle.
- ***Placing oriented objects for availability.*** The way people place an object suggests personal ownership/access if the object is oriented towards themselves, and shared ownership/access if it is oriented towards others or placed at a compromised angle.

Our video analysis suggests that the control and ownership of items within a personal space was rarely in dispute. In particular, we counted how people picked up and put down puzzle pieces with respect to their orientation. First, in all cases, only the 'creator' of the personal space (similar to the one illustrated in Figure 2) would rotate or access the pieces within that space. Second, out of 116 observed actions, people picked up pieces facing them about 33% (39/116) of the time, pieces oriented at a compromised angle about 53% (61/116) of the time, and pieces oriented towards others 14% (16/116) of the time. That is, a person is much more likely to pick up objects that are set according to a compromised orientation or that are oriented for themselves. A person is much less likely to pick up a piece oriented directly towards someone else.

Our data also suggest that people place pieces on the table at these angles as an indication of ownership and/or how the item should be shared. For example, if people did not think communally, we would expect them to predominantly place objects in an orientation that was suitable for them. Yet this happened only about 24% of the time. We saw that people were very likely to place pieces at an angle that was either compromised (49%) or directed towards the other person (27%). We also saw that if people picked up pieces oriented to the group orientation, they usually put them down in the same orientation. This indicates that people replace shareable objects in a way that tells others that the object is still communally owned and publicly accessible.

6. COMMUNICATION

Orientation also plays a mediating role in communication between individuals in a collaborative setting. In particular, orientation is used as an intentional communicative act and is independent from other patterns of communication.

6.1 Intentional Communication

Intentional communication is prevalent between people as an explicit mechanism for gathering and exchanging information [4]. We usually see this in face-to-face discussions via people's intentional verbal exchanges and by the explicit hand and body gestures that accompany and accentuate talk [1]. This also occurs over workspaces via talk and deictic gestures [1]. Our observations of tabletop collaboration suggest that how people orient objects when working over tabletops also serves a role in intentional communication.

- ***Orienting an object to oneself*** signals no intentional communication; the person is doing their own personal work.
- ***Orienting an object to another person*** signals that the object, the person's talk, and any accompanying gestures are being directed towards a particular person for communicative purposes. If the item is oriented directly towards the other person, this typically establishes an audience or indicates relinquishment of turn. If the item is oriented at some compromised angle, this almost invariably initiates a response in the form of discussion and a period of close collaboration.
- ***Orienting an object to the group*** is similar, except that the objects and any accompanying talk and gestures are now being directed towards the group (or sub-group).

Our observations confirm the role of orientation in intentional communication. People intentionally rotated objects as part of their communicative acts after they had established their personal and group orientation spaces. About one-third of all orientations were to oneself, signaling no communication. This was recognized by others: they left those objects alone and any gestures or adjustments made to them were ignored or not noticed.

About another third of people's rotations involved directly orienting an item to another person's perspective. This alignment of an object so that it was 'right way up' for the other person proved to be one way of directing communication towards them. We also noticed that when people shared an item with another person by passing it to them, the giver always oriented the item according to the orientation of the person receiving the piece.

The remaining one-third of all acts involved rotating items to a compromised angle, i.e., an orientation that made the item visible to both people but which was not aligned well for any one person (e.g., as in the group workspace, Figure 2). This clearly signaled to others that the item was to be a focus of discussion or engagement for both parties. This partial rotation is of particular interest in the collaborative process. When a rotation is made to an orientation that is compromised but possible for both people to view, it appears to be a very compelling communicative gesture. In our study, this action always initiated discussion and seemed to be a well-understood method for starting immediate collaboration. As well, we observed a reciprocal head tilt by the receiving person to indicate a willingness to read at a compromised angle. Both of these actions seemed quite compelling. Moreover, we have

Participant 1 (left) reads the preview image. Participant 2 (right) looks at puzzle pieces.

Participant 1 rotates the preview image to an angle that is very compromised for him and slightly compromised for Participant 2. Participant 2 immediately responds by tilting his head.

Collaboration is established and the two participants proceed to work together. The image is now completely oriented towards Participant 2.

Figure 4. Images show two people establishing collaboration using object orientation.

noticed this action-response pairing in a variety of situations during our day-to-day interactions.

The sequence of images in Figure 4 illustrates this process. In Figure 4a, both participants are doing their own work and Participant 1 (on the left) is looking at the preview image, which is 'right way up' for him. In 4b, Participant 1 rotates the preview image towards Participant 2. Participant 2 notices and tilts his head in response. In 4c the collaboration is well in hand: Participant 1 is reading, though the text is now upside down for him, and Participant 2 is assembling pieces that match.

6.2 Independence of Orientation

Non-verbal conversational acts are often tied to other intentional communication as a way to explain or clarify that person's intentions, or to remove ambiguity. For example, talk and gestures often work together, e.g., as in deictic references. Orientation, however, proves to be an understandable stand-alone act that does not require additional communication in the following cases.

- ***Orientation independence as one repositions an object.*** As people pick up, use, and reorient objects, they rarely comment or add gestures to explain such rotation actions.
- ***Orientation independence of objects already positioned.*** For an object already placed on the table, its orientation informs others as to whether or not it is available. No further requests for information are needed.

Our analysis of orientation during tabletop use showed that people rarely accompanied a rotational act with a directed comment or additional gesture to another person (only about 15% of the time) – and when they did, more than half of these were comments made when the group initially established the group orientation. Thus, the vast majority of rotations (85%) did not involve any directed comments whatsoever. Accompanying gestures were rarely seen. Hence, rotation is a relatively "lightweight" communication activity that people do naturally, quickly, intuitively, and without explicit consideration. Similarly, people rarely asked for explanations or commented on items already positioned on the table. That is, the meaning of the orientation was self-explanatory.

Thus, people appear to be aware of the meaning of orientation changes both as they happen and afterwards. The orientation act and object position are usually sufficient for communicating to others about who 'owns' what, what one is currently using, and what one is finished with.

Because of this independence of orientation, the alignment of items left as a result of the work progression continues to inform the participants. This effect can be described as the residual communication of objects already positioned. That is, for an object already placed on the table, its orientation informs others as to whether or not it is available. No further request for information is needed.

7. THE MECHANISMS OF ORIENTATION

We have just discussed how orientation plays several important roles in tabletop collaboration. As will be discussed in Section 8, we believe that digital tabletops should be designed to facilitate how people make use of these various roles of orientation, and that people should be provided with suitable interaction techniques for orientating objects. Consequently, we articulate orientation mechanisms exhibited by collaborators during the course of our study to inform the development of such interaction techniques.

Analysis of our observational data revealed several basic mechanisms that contribute to the comprehensive, coordinative, and communicative roles of orientation. These include the angle or degree of rotation (orthogonality), the duration of rotation, and the location of rotation.

Orthogonality. As previously discussed, many current solutions to tabletop orientation position on-screen items orthogonally to the table edge, usually aligned with whichever edge the system believes the user is located. If users are located on different sides of the table, this positioning typically favours only one person at the table.

Our study analysis revealed that collaborators made both orthogonal and non-orthogonal rotations of objects. Influenced by collaborators' tendency to establish personal and group workspaces, we re-define an *orthogonal rotation* as a rotation in which the item was aligned to any established personal or group space as well as any table edge.

Even with this liberal interpretation of orthogonality, only slightly more than half the rotations resulted in alignment with an established orientation. The remaining rotations resulted in non-orthogonal alignment. This strongly indicates that tabletop software needs to handle *both* variant and orthogonal orientations. For example, once associated orientations have been established in personal and group spaces, it may be possible to provide automatic orientation as items move into these spaces. Yet since variant rotations occurred in all spaces, it should be easy to override automatic rotations to allow an object to be oriented at any desired angle.

Duration. Another question relates to the temporal nature of rotations. As previously mentioned, one of the more powerful communicative uses of orientation is when a person shows a collaborator an item held at a compromised angle. It is during the actual act of rotation that communication is typically initiated (Figure 4). While the rotation used to initiate the communication is often temporary, we found a decided tendency to leave items in their last position when the discussion ended. Rather than just being untidy, the orientation of the items continued to inform people about which items were available for use (see Section 6.2). As a result, the vast majority of rotations were non-temporary (93%). Hence, the ability to effortlessly rotate objects while communicating, as well as the ability to stop that rotation at any point, may be important to support in a tabletop interface.

Locations of interaction. For the tabletop interface designer, it is important to know if the various uses of orientation were parts of interaction that occurred directly on the tabletop surface or in the space above the table. Orientation-related actions taking place on the surface of the table are much more accessible for supporting in software. Actions taking place above the table require additional interactional support, such as the inclusion of support for gestures or tangible interface components. In our study, about half of all rotations were performed on the tabletop surface. As well, it should be noted that these rotations were used for all three purposes of orientation: comprehension, communication and coordination. Hence, it seems likely that tabletop software can be designed to leverage people's familiarity with two-dimensional

rotation. However, the fact that almost half of all rotations took place above the table's surface does raise design questions regarding the importance of non-traditional input.

8. IMPLICATIONS FOR DESIGN

Generations of people have gathered around tables in boardrooms, meeting rooms, and cafés for a variety of collaborative activities. These activities range from games and leisure activities to design and planning activities. Consequently, most people will have preconceptions about the types of activities possible on a digital tabletop display and the collaborative benefits of using a tabletop workspace. Therefore, in order to preserve the benefits of using a tabletop environment for collaboration, the comprehensive, coordinative, and communicative roles of orientation must be supported in the information layout strategies and rotation interaction techniques of a tabletop interface.

Our observational data has several implications for the design of such layout and interaction techniques as outlined below.

Free rotation must be supported. The observational data showed many instances of both full and partial rotations, as well as orthogonal and non-orthogonal rotations. A system that provides techniques to rotate objects to any angle would allow people to perform all such rotations. It would also allow people to place objects correctly in already established oriented spaces, such as group or personal spaces.

Rotation techniques must be lightweight. Participants in our study performed numerous and rapid object rotations during their tabletop collaborations. These would be inhibited if interaction techniques were heavyweight, such as those typically seen in conventional object-drawing packages. Instead, we need lightweight interaction techniques that place minimal overhead on performing a rotation operation; this would minimize interference with the comprehensive, coordinative, and communicative roles for which the rotations are being used. Lightweight interaction techniques would also allow users to establish or change the orientation associated with personal and group spaces quickly.

Orientation of user-positioned items must be maintained. Our observational data suggest that whether an item is currently available for use depends both on its current location (e.g., in which oriented space it is located) and its current orientation (e.g., Person A may have rotated an item towards Person B). A tabletop system should avoid reorienting such items without the user's (implicit or explicit) permission to avoid inadvertently changing the information being communicated about an item's availability to other users at the table. Such system action could interfere with the coordination of the collaborative activities.

Rotation actions must have clear feedthrough. In order to preserve the non-verbal communicative role of orientation, it must be obvious to others when a user is performing a rotation action. Otherwise, the action may be missed. Yet, many groupware systems have historically removed or stylized fine-grained actions associated with object movement for the sake of system performance. Other systems provide single-step rotations (e.g., through a menu selection) that could easily be missed by other participants. To provide the long-term communicative effects of orientation (e.g., conveying the ownership or availability of an item), the system should also clearly show an item's orientation both during and after the rotation action.

Automatic support for rotation and orientation must be handled carefully and allow easy user override. One way to go beyond conventional tabletops is to support automatic rotation, ostensibly to minimize an individual's work. While our results clearly show that there are areas on the table that suggest an orientation, there are also many times where people choose variant orientations in these areas. Thus, any automated rotation performed by the system must be carefully designed to balance the comprehensive needs of individuals viewing tabletop items and the group coordination and communication needs essential to the collaborative process. Rotations performed automatically by the system should provide users lightweight mechanisms to override these system actions so they can position items to meet their current needs.

9. IMPLICATIONS FOR ASSESSMENT

Understanding the roles that orientation plays during tabletop collaboration provides a means to compare existing approaches to orientation. Current tabletop systems can be evaluated based on how well they support the various roles of orientation. The design implications presented in the previous section can be used to guide such evaluations. From these assessments, we can leverage the strengths of each approach to create more effective rotation and orientation solutions.

To illustrate how both the roles of orientation and their design implications can be used to evaluate existing digital tabletop systems, we present a brief comparison of five existing systems previously introduced in Section 2: the ConnecTable [18], the InfoTable [14], the Personal Digital Historian (PDH) [16], the Café Table [3], and the InteracTable [17]. A summary of this comparison is presented in Tables 2 and 3. In these tables a checkmark (✓) indicates that, for the most part, a system addresses the roles of orientation or the design criteria. If it does not appear to sufficiently address the roles or design criteria, we indicate this with an '✗'. In some cases, only certain rotation or orientation techniques provided by a system address the roles or design criteria; this is indicated by a hybrid symbol (✓/✗) in the tables. Finally, in the case of the Ease of Task role, it was difficult to determine whether a system addressed this role if no real applications exist for the system (as discussed below); this case is indicated by a question mark (?).

To preface our evaluations, we acknowledge that most tabletop systems (e.g. ConnecTable, InfoTable, and InteracTable) are prototype interfaces that generally demonstrate simple operations on primitive tabletop items, such as images, sketches, and icons. In contrast, PDH and the Café Table offer more complex applications designed for specific purposes, story-sharing and information viewing and sharing, respectively. Hence, certain design decisions have been made in these systems to provide specific functionality, which sometimes limits their ability to flexibly address orientation.

Overall, the emphasis of these systems has been on orienting objects in an attempt to align them 'right way up' for individuals. While clearly attempting to address the comprehensive role of orientation, the coordinative and communicative roles of orientation have been less universally supported.

First, we examine how the five tabletop systems address the design criteria suggested by our design implications. Then, we discuss the interplay between these design criteria and the roles of

Table 2. Comparison of existing systems based on the Design Criteria suggested by the implications

Design Criteria	Tabletop Systems				
	Connec-Table	Info-Table	PDH	Café Table	Interac-Table
Free rotation	✓	✓	✓	×	✓
Lightweight	✓	✓	✓/×	×	✓
Orientation maintained	✓	✓	×	✓	✓
Feedthrough	✓	✓	×	×	✓
Override	×	×	×	×	×

orientation as it relates to developing tabletop systems which facilitate collaboration.

Of the five systems, the Café Table is the only system that does not allow free rotation. Of the other four systems, the InfoTable, InteracTable, and ConnecTable provide relatively lightweight rotation mechanisms via circular gestures, while PDH requires a heavyweight, multi-step approach. PDH, however, does allow for lightweight rotations aimed at comprehension (for instance, rotations where the entire circular display rotates, like a "lazy-susan"). Similarly, the InteracTable provides a lightweight "toss" gesture to quickly move an item from one side of the table to another.

In general, most of these systems maintain the orientation of an object until someone acts on it further. However, the global rotation actions in PDH, such as the "lazy-susan" workspace rotation and a "magnet view" rotation (i.e., all items orient towards a particular spot on the workspace edge), indiscriminately rotate all tabletop items, affecting the orientation of user-positioned items on the table.

Table 3. Comparison of existing systems based on the Roles of Orientation

Roles	Tabletop Systems				
	Connec-Table	Info-Table	PDH	Café Table	Interac-Table
Comprehension					
Reading	✓	✓	✓	✓	✓
Task	?	?	✓	✓	?
Perspective	✓	✓	✓	×	✓
Coordination					
Personal Spaces	✓	✓	×	×	✓
Group Spaces	×	✓	✓	✓	✓
Ownership	✓	✓	×	×	✓
Communication					
Intentional	×	✓	✓/×	×	✓
Independence	✓	✓	×	✓	✓

The rotation gesture, combined with the animated rotation of the item being acted upon in the InfoTable, ConnecTable, and InteracTable systems, provides clear indications of feedthrough. In contrast, PDH provides rotation mechanisms that are menu-based and globally applied; hence, they may not provide clear feedthrough.

No system provides adequate user override mechanisms for automated rotation and orientation strategies. Peripheral icons on the Café Table continuously scroll around the workspace, aligned by the system orthogonally to the curved table edge. The user has no way of changing the orientation of these items. Nor can a user of PDH exempt certain tabletop items from being included by global actions, such as a workspace rotation or view change.

While several design criteria map directly onto the roles of orientation they support (e.g. providing free rotation supports both the ease of reading and alternate perspective roles) there is some subtle interplay between others, as well as additional design factors which influence the roles of orientation. For example, while the ConnecTable addresses all design criteria except allowing user-overrides, its small, tiled display makes it difficult for users to simultaneously maintain personal and group spaces. Its form factor, consisting of two connected personal displays, favours multiple personal spaces, especially since the physical seam between displays is located in the natural centre of the group space. The connected displays also prevent a person from interacting with objects in a collaborator's display space, inhibiting intentional communication in this area.

Similarly, the form factor of the Café Table limits its ability to completely address the roles of orientation. It provides a small, semi-circular display that, besides the scrolling peripheral icons mentioned above, provides only a fixed group orientation.

In contrast, both the InfoTable and InteracTable systems provide large, seamless workspaces that allow people to maintain personal and group spaces. The InfoTable also allows users to move objects between their laptop displays and the table display, providing an extended personal space for independent work while allowing easy sharing of items when appropriate.

Evaluating PDH against the roles of orientation highlights some fundamental assumptions underlying its design. PDH provides users with a large "group" workspace. The global orientation mechanisms, such as its "lazy-susan" and magnet rotations, provide workspace-wide orientation changes. These changes may interfere with residual effects of a rotation action, such as indication of ownership and establishment of a personal space. This approach assumes that story-sharing is a continually tightly-coupled activity, where people do not work independently. Given the variety of collaboration styles that people often employ during group work [5], applying this assumption generally to all tasks does not appear reasonable.

It must also be mentioned that a number of systems (e.g., ConnecTable, InteracTable) have attempted to address orientation by using multiple copies of information. While this addresses comprehension, this approach can compromise coordination and communication. In particular, using an object's orientation to help indicate personal or group spaces or the ownership of specific objects is considerably degraded when multiple copies of the same object exist. Likewise, using an object's orientation for intentional communication or to speak to individuals without

additional comments or gestures is appreciably hindered without the shared focus inherent to a single set of objects.

In summary, this comparison highlights several useful and versatile approaches to rotation and orientation, such as lightweight, free rotation gestures. It also emphasizes several deficiencies in current tabletop systems for supporting the multiple facets of orientation areas which need further research. In particular, more user control is needed in systems which provide automated support for orientation. While these systems can facilitate interaction, it is difficult for the computer to predict the intentions of the user and, thus, may interfere with the collaborative process unless flexible automatic and manual rotation capabilities are provided.

10. CONCLUSIONS

The main contribution of this paper is to expand our understanding of the roles that orientation plays in collaboration. The main roles are:

- Comprehension,
- Coordination, and
- Communication.

We saw that orientation plays a significant role in the establishment and maintenance of personal and group workspaces. This, in turn, helps inform collaborators about who is currently using which items, and which items are available for group use. We also saw that a partial rotation towards a fellow collaborator is a particularly compelling communicative gesture that invites immediate collaboration. Finally, the long-term effect of the orientation of various items communicates to collaborators about the history of their work processes.

The second contribution of this paper is a set of design criteria for the design and evaluation of tabletop systems implied by this improved understanding of the roles of orientation. We plan to use these combined insights to develop new orientation and rotation techniques for tabletop displays.

11. ACKNOWLEDGMENTS

This research was supported in part by the Natural Sciences and Engineering Research Council of Canada (NSERC), Alberta Informatics Circle of Excellence (iCORE) and Intel Inc. We thank Tony Tang for editing help and, more generally, the members of the Interactions Lab for their insightful comments.

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