The EventTable Technique: Distributed Fiducial Markers

Alissa N. Antle, Nima Motamedi, Karen Tanenbaum, Zhen (Lesley) Xie
School of Interactive Arts and Technology
Simon Fraser University
Surrey, B.C., Canada
{aantle; nimam; ktanenba; zxie}@sfu.ca

ABSTRACT
The EventTable technique is a tangible object tracking technique implemented on a camera vision based tabletop platform. The technique supports an event-driven – rather than object centric – tracking technique. Fiducial markers are distributed between objects. When objects are brought into a proximal or connected relationship, a whole marker is formed and recognized by the tracking system. Thus, rather than tracking each individual object, the system tracks user-driven events that occur when two or more objects are proximal. The technique can be used in addition to individual object tracking and touch tracking. This approach provides a reliable and flexible approach to tabletop object tracking for a wide variety of tabletop activities. We describe three prototype applications to illustrate how the distributed marker technique can be applied. We describe the advantages and limitations of this approach. We conclude with a brief discussion of how the EventTable technique enables a shift in human computer interaction research from an information-centric to an action-centric epistemological view on how users' create meaning.

Author Keywords
Tangible interaction, visual marker tracking, fiducial markers, distributed markers, reacTIVision.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Advances in sensing and camera vision technologies have resulted in a plethora of digital tabletop research conducted on a variety of systems. Digital tabletop prototypes utilizing objects may be implemented with different sensing methods (e.g., object tracking, visual marker tracking, ultrasonic sensing). These new digital tabletop techniques and technologies afford new forms of interaction. Research related to user interaction on tabletops is gaining momentum as evidenced by a dedicated forum for digital tabletop research, the IEEE Workshop on Tabletops and Interactive Surfaces series, as well as increasing numbers of papers on tabletop research at ACM UIST[1], ACM TEI[2] and ACM CHI[3] conferences (e.g.,[3, 9, 12, 15]). A review of tabletop papers presented at these conferences reveals most research on interaction is conducted on commercially available tables (e.g., MERL Diamond Touch [5], Microsoft Surface[15], Philips Entertaible [3]) or unique, one-off, prototyping platforms (e.g., SmartSkin [12], TViews [9, 10], SenseTable [11]). All of these tabletop systems have been designed to track individual objects or touches. We present a tracking technique that shifts attention from an object space to an *event* space by tracking the connections between objects.

EventTable is based on the successful reacTIVision approach which tracks visual markers, initially introduced by Bencina *et al.* [4]. However, instead of tagging individual objects, we distribute visual markers across objects. A reliable tracking approach is achieved by distributing markers between sets of physical objects. The system recognizes complete markers when two or more objects bearing parts of a whole marker come into contact. For example, a marker may be distributed across several jigsaw puzzle pieces (Figure 1). The many jigsaw puzzle pieces are not tracked individually. This facilitates users working with objects offline in the interaction space and not burdening the system with tracking large numbers of objects in real time. However, when the user connects two pieces, a complete marker is made, and the system recognizes the marker and responds to this user driven event.

[1] Symposium on User Interface Software and Technology

[2] International Conference on Tangible and Embedded Interaction

[3] SIGCHI Conference on Human Factors in Computing Systems

In this paper, we provide the design goals for our original EventTable prototype followed by a description of our system implementation and three variations of distributed marker tracking. We illustrate our technique by describing three examples of object tracking designs which utilize distributed markers implemented on EventTable. Two of these examples use our distributed marker technique alongside traditional tracking of individual objects tagged with whole markers. We then discuss the advantages of this technique in terms of technical reliability and prototyping flexibility. We conclude with new directions for tabletop research based on an event-based approach.

Figure 1. Unique markers are distributed across pieces.

EVENTTABLE

The EventTable tangible tabletop system is an object-based system that uses an infrared camera to track fiducial markers placed on the underside of physical objects (e.g., jigsaw puzzle pieces, tools, game pieces). Markers are distributed across multiple pieces reflecting proximity and/or connection relationships between objects and/or between the representations embodied by those objects.

The EventTable tangible tabletop system was developed to meet the need for an object-based tabletop prototype that could be used to implement a tangible jigsaw puzzle activity for children [16]. One of the issues in building such a system was the initial requirement to track one hundred individual jigsaw puzzle pieces. While it is possible to implement such a strategy, tracking one hundred pieces in real time requires significant processing power and elegant algorithms. An alternative solution was to track only the connections between pieces (i.e., user-based events) rather than each piece. This approach is suitable for cases where individual object information (e.g., identity, location, orientation) is not required until pieces come into direct contact with other pieces.

Design Requirements

In our exploration of a suitable digital tabletop platform for a tangible jigsaw puzzle for children, we identified several requirements needed for the development of an extensible tangible tabletop prototyping platform that could support rapid prototyping in an iterative process:

- Ability to reliably track and process unique configurations of large numbers of objects (e.g., 100 piece jigsaw puzzle)
- Ability to efficiently add and delete new objects (e.g., implement new puzzles)
- Portability of objects between tabletops (e.g., replace lost pieces from pieces at another table)
- Extensibility of application space in order to quickly prototype other activities.

System Architecture

Like most camera vision based tabletop platforms, EventTable is composed of four basic elements:

- Form: a self-contained, easily assembled wood table-box enclosure, 55 cm high, 58 cm in width and 88 cm in length;
- Tracking: a infrared camera based system and application for real time object tracking (supported by reacTIVision computer vision framework [4]);
- Display: a short throw projection system rear projected on a scalable and scratch resistant horizontal display surface and two concealed speakers;
- Application: a customizable application program(s) written in either Processing, PureData or Java.

In addition, EventTable has an extensible application layer that facilitates *connection event* tracking by supplementing the reacTIVision object tracking framework with code that recognizes and responses to object connection events designated by the sensing of complete markers. For readers interested in building their own version of EventTable, appropriate details of the system design and implementation are described in a technical report available online [2].

Object Tracking

Tracking in EventTable is implemented with an infrared camera located beneath a translucent table surface in order to avoid any type of occlusion. Fingers, objects and events are tracked with the same system. Tracking objects provides the ability to identify and relate unique interactional objects with different functions within an application. Objects are marked with amoeba fiducial markers (Figure 1). An object may be marked in a number of ways. Traditionally, a single object is marked with a single marker as demonstrated in the original reacTable system [8]. However, several different ways of distributing markers across objects are possible as described in the next section. We discuss these distribution methods based on our successes with amoeba markers, however, other pattern systems can also be used with these strategies (e.g., AR Toolkit, Domino).

Marker Distribution Methods

An amoeba fiducial marker can be distributed across objects to form unique markers, multiplexed markers or combinations of whole and distributed markers.

Unique Marker Distribution

First, and most simply, a marker can be cut into several pieces and distributed between several objects as shown in Figure 1. When the objects are connected or placed into a proximal relationship, the two or more marker pieces are also connected. The result is the formation of a whole marker (as shown on the right in Figure 1). This style of marker distribution was used to implement event tracking in a tangible jigsaw puzzle. When a whole marker is formed it is detected and interpreted by the reacTIVision engine. In the example shown, a puzzle piece may be marked with up to four partial markers, one for each of the four sides of the puzzle piece (two male and two female connectors).

This method works for cases where there is only one unique "correct" way for a user to connect related objects.

Multiplex Marker Distribution

It is sometimes desirable to enable users to connect one object to more than one other object. This is facilitated by the amoeba marker design in which portions of a marker are common to more than one whole marker. The two whole markers in Figure 2 (BC and AC) both have a black portion containing three small while circles. Part of this common pattern (C) can be combined with two or more other partial markers (A, B). Each combination forms a unique whole marker. Thus an object marked C can be combined with an object half marked with B to form a whole marker BC. The same object marked with C can alternatively be combined an object marked with half marker A to form a different whole marker AC. In this way, object C can be combined with object B to form one marker (and system interpretation) and also combined with object A to form another marker.

This method works for cases where there is a requirement for one object to connect to more than one other object.

Figure 2. Multiplex: half markers A and B both can connect to half marker C to create whole markers AC and BC.

Combination: Whole + Distributed

It is also possible to place a whole marker and a portion of a distributed marker on a single object (as shown in Figure 3). This method of combining whole markers with distributed markers can be used when a single object is to be used in different ways, one of which involves being connected to another object.

Figure 3. Combined whole and distributed markers.

SAMPLE APPLICATIONS

In this section we describe three prototype applications that illustrate the EventTable distributed marker technique.

Tangible Jigsaw Puzzle

A tangible jigsaw puzzle was the first activity implemented with the EventTable, as described in [16] and shown in Figure 4. It was implemented with the unique distributed marker technique which facilitated tracking the connections between the many puzzle pieces in real time in a reliable manner. The amoeba fiducial markers were distributed along the edges of intersecting pieces. The system recognized user triggered events, which occurred when a correct physical connection was made between two or more puzzle pieces. In response to these connection events, a logic program, controlled visual and audio feedback. A puzzle image was projected on the surface of the tabletop system. When pieces were assembled correctly, the corresponding locations on the projected image were blacked out. The system also played a laser sound effect signifying a correct connection. The prototype was a tangible user interface to the physical jigsaw puzzle that embodied the properties and functions of both traditional and GUI puzzles. It was created as a research instrument for a semi-experimental comparison of interface styles.

Tangible Concept Mapping System

The tangible concept map (TCM) system (Figure 5) was implemented on the EventTable table using the combination of whole and unique marker distribution methods. The combination of whole and distributed markers facilitated rapid prototyping of tangible objects that served two functions. The advantage of this approach was that the tangible objects were designed so that their physical form constrained possible connections to correct ones. At the same time, the objects could be used as individual control objects.

The goal of the project was to investigate how a tangible tabletop approach could support users to create, manipulate, revise and save a concept map which could then be used as input to digital user models in learning applications, as described in [13]. The concept map nodes (circle) and links (lines) are displayed on the table surface and manipulated with two tangible event objects, called pucks, shown on the right edge of the table in Figure 5. Each puck was marked with a whole marker and a portion of a unique marker (Figure 3). The form of the pucks with their V-shaped connection makes the link creation mechanism visible, physically representing one of the problem constraints. The concepts are linked by connecting the pucks which then creates a complete marker on the underside of the pucks. Only when the two pucks are properly connected is the whole marker recognized and feedback given to the user. Here the advantage of unique marker distribution is that the two pucks must be physically connected in a particular way. While this may have been possible using whole markers, a whole marker cannot easily fit onto the triangular connector

Figure 4. Tangible jigsaw puzzle on EventTable.

Figure 5. Tangible concept mapping system on EventTable.

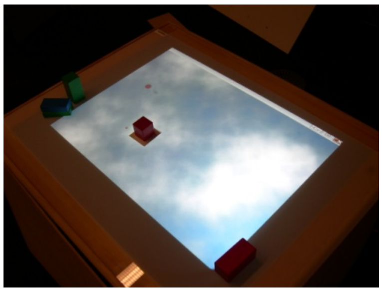

Figure 6. Marble drop game on EventTable.

portions of the pucks. A distributed marker can easily be split to fit on a variety of male-female connection shapes.

The same two pucks were also individually used to implement the labeling links. When near the right edge of the tabletop, a puck's whole marker was recognized by the tracking system. One puck turned the link label menu on by being rotated to the appropriate position. The second puck was rotated to scroll through the available labels. A third whole marker puck was used to signify map completion.

Tangible Marble Track Game

The marble track game is an early prototype currently under development implemented on the EventTable (Figure 6). The goal of the game is to help children, aged 7 to 9 years, learn about Newton's Laws of Motion through experimenting with a tangible marble track type game. The gravitational field strength tool (GFS) is a parametric tool which was created using the multiplex distribution method. Using the game, children try to control the fall of digital marbles down physical ramps by changing ramp angles and locations and by varying parameters related to GFS (e.g., weak/moon, regular/earth), friction (e.g., smooth, rough) and mass (e.g., ball size). The GFS tool has two possible values related to gravitational field strength on the moon and on the earth. It was created with three block objects and two markers using the multiplex marker distribution method (Figure 2). The main portion of GFS is a cardboard object marked with a half marker (C). The gravitational field strength parameter value of the tool is set by combining this object with one of the two other cardboard "parameter value" objects (A or B). The AC combination creates a whole marker signifying that the entire system is operating under a weak gravitational field strength (e.g., on the surface of the moon). The BC combination creates a second whole marker signifying that the entire system is operating under a "normal" gravitational field strength (e.g., on the surface of the earth).

The three objects that comprise the parametric tool are physically connected through magnets (instead of male-female connectors). The magnetic force that holds the parameter value to the tool object is chosen based on the value of the parameter value. For example, the magnets that hold pieces A and C together (i.e., moon value) is weaker than the magnetic force that holds B and C pieces together (i.e., earth value). In this way the users' tactile experience of setting the parameter for the GFS tool is analogous to values of the field strength parameter. The use of the multiplex distribution method described above facilitates the creation of this type of parametric tangible tool. While the same functionality could be created with two whole markers, the tangible object would have to be twice the size (to accommodate two markers) and the connection shape would be limited to side by side (versus various kinds of connectors which constrain and support correct connectivity (as above in the TCM system). In addition, this approach may require fewer markers than an implementation with whole markers, which may be important when the number of required markers exceeds available markers.

ADVANTAGES

The EventTable applications described above utilize whole and distributed markers to instantiate simple yet powerful approaches to tangible interaction. The use of visual markers supports reliable, flexible and easily extensible prototyping. Unlike other visual marker approaches that use whole markers, our event-based approach can be used in several innovative ways. They can be used to manage large numbers of objects for cases when connection events are of interest. They can be placed onto the confined space of physical connectors between objects. They can be multiplexed to create multiple functionalities or representations using fewer markers on smaller objects.

Technical Reliability

A reliable tracking approach is achieved by distributing amoeba fiducial markers between sets of physical objects. System events are triggered when objects are connected or become proximal. There are several reliability advantages to distributing markers across objects in an event-based approach. First, objects with partial markers are not sensed until they are formed into a whole marker. This eliminates the need to track individual objects while "waiting" for two objects to be placed proximal to each other. The processing time of marker detection and decoding programs is highly dependent on the number of markers visible to the system at one time [17]. Thus, tracking fewer markers both reduces processing time and reduces the probability of error occurring since fewer markers are tracked. Second, the approach eliminates the need to search for legal pairs (or triplets, quartets etc.) *every time* two adjacent markers are detected. With paired whole markers, an algorithmic search must occur every time two or more objects are placed adjacent to each other. Conversely, with the distributed approach, only legal connections result in a sensed event. This also eliminated the need to determine “closeness” thresholds for adjacent markers. Illegal or close matches are simply ignored, freeing up system resources. This approach is computationally more efficient and may reduce system response latency effects. Third, by distributing pieces, smaller contiguous object surface areas are required. For example, it is difficult to fit a single marker on a jigsaw puzzle piece. However, portions of four markers can easily be accommodated on a single piece allowing for larger markers. Larger markers are tracked more accurately than smaller ones. Multiplexed markers also reduce the number of required markers. Taken together, these advantages make the EventTable distributed marker approach more reliable than commensurate whole marker approaches.

Prototyping Flexibility

We propose that a user-driven event strategy in object tracking can be utilized for many kinds of activities. Ullmer and Ishii presented the notion that tangible interfaces tend to combine systems of physical objects in one of three major interpretations: spatial, relational, and constructive [14]. Our event-driven tracking approach is flexible enough to accommodate activities that require each of these interpretations of the configurations of interactional objects.

The event of correctly connecting pieces in a jigsaw puzzle is an example of both the spatial and constructive modes of interpretation. The visual image represented in the puzzle is encoded in the spatial adjacency relationships between puzzle pieces. Thus, the spatial connection of pieces is visually meaningful. The puzzle image is encoded directly in the spatial relationship between pieces, which is then formed into a complete whole when the user connects the set of pieces into a finished puzzle. In this case, the unique marker distribution method is used to encode both spatial and constructive information.

The event of connecting two nodes in a concept map using pucks is an example of a relational interpretation. The physical connection of two pucks signifies a conceptual relationship between the two concepts currently attached to the objects. This relationship is then encoded digitally in a concept map data file. If the two pucks are used separately along the edges of the table, they are interpreted spatially in relation to the menu control functions. In this case, the combined whole and distributed marker method is used to encode both spatial and constructive information.

The parametric GFS tool is an example of relational and constructive interpretations. The user sets the parameter value through physical construction of a complete tool (tool object + parameter value object). The physical (magnetic) relation between the tool and parameter value pieces helps the user interpret the relationship between parameter values and system responses. In this case, the multiplex marker distribution method is used to encode both relational and constructive information.

While an event driven approach might at first seem limiting, many more examples are possible for cases where proximity events form the basis for a significant proportion of interaction. Examples include: concatenating digital photographs or video frames into a sequence; using controller objects to operate on various representational objects; connecting objects in construction type toys, landscaping or architecture applications; and moving game pieces into adjacent board positions. While proximity events have limitations and certainly cannot account for all types of desired interactions, they can be useful in a significant number of cases. A distributed approach can also be used alongside a whole marker approach to accommodate proximity events with other kinds of tracked events (e.g., location, orientation of a single object) as required.

RELATED WORK

Researchers have experimented with adapting existing technologies to form digital tabletops. For example, the SenseTable system is based on Wacom’s tablet and pen technology [11]. The Interface Currents tabletop is based on a SmartBoard system [7]. However, both the Sensetable and Interface Current’s performance is reduced when tracking a large number of objects. In addition, objects are continually tracked which precludes offline manipulation of pieces in the interaction space. EventTable can accommodate tracking large numbers of objects when the proximal relations between them are paramount to user interaction.

The reacTable system [8] uses amoeba markers. However, the large size of whole markers limits their use in situations that require small or irregular shaped pieces. For objects that are meant to be connected, designing the physical affordances of the pieces to constrain connections to correct one is beneficial. The distributed marker approach facilitates attaching markers to small, irregular or custom shaped connectors between objects.

TViews is a one-off system created to enable tracking of large numbers of objects [10]. However, the ultrasonic sensing approach requires power, circuitry and passive sensors embedded in interactional objects, inhibiting the rapid creation of new objects or applications. The EventTable technique can be achieved by printing out visual markers, cutting them and then simply attaching them to objects.

EPISTEMOLOGICAL IMPLICATIONS

From a philosophical perspective, EventTable enables a shift from an information-centric to an action-centric epistemological view on how users’ create meaning in human computer interaction research. This is achieved through a focus on user driven events as resources for design rather than a focus on possible actions and spatial properties of objects (e.g., location, orientation). It also provides built in support for physical constraints on action-object couplings. We propose that working with a tangible prototyping environment that includes event-space may shift designers' focus from what is *possible* (actions on objects) to what is *meaningful* (events). This shift is in line with recent developments in tangible and embedded interaction research which focuses on how users make meaning through embodied processes (e.g., [1, 6]).

Through connection, the physical objects embody a physical state of the system. Their physical configuration can be coupled to the digital state of the system they represent. In the jigsaw puzzle this coupling is tight and literal. The connection of two physical pieces is coupled to their digital representations, which also become connected in the computational puzzle model. In the concept mapping application, the connection of the two pucks is symbolic. It represents the connection of two concept nodes through a link. As these examples show, the design of event-based applications requires the designer to consider the meaning created when two or more objects are acted upon and moved into a specific relationship. The design space of possible actions on objects becomes focused on meaning-making events.

CONCLUSION

We presented the EventTable tracking technique on a tangible digital tabletop prototyping platform. By distributing visual markers across objects, a fast and reliable visual marker tracking approach is facilitated. While the technical advantages of marker distribution are only garnered for object proximity events, we have presented three functional prototypes that illustrate the flexibility of our approach for a variety of tangible applications.

We envision future work that focuses on exploring different couplings and user driven interpretations of actions affecting the relations between interactional objects. This work is in line with an embodied view of cognition in which meaning making occurs through action, and a phenomenological view of interpretation which suggests that ultimately users not designers create meaning. We view the technique presented in this paper as incremental advance in enabling technologies that make such investigations possible.

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REFERENCES

1. Antle, A.N., Corness, G. and Droumeva, M. What the body knows: Exploring the benefits of embodied metaphors in hybrid physical digital environments, *Interacting with Computers: Special Issue on Physicality*, Elsevier, 2009, (in press, available at http://dx.doi.org/10.1016/j.intcom.2008.10.005).
2. Antle, A.N. and Motamedi, N. EventTable, Technical Report 2008-01, School of Interactive Arts and Technology, Simon Fraser University, Surrey, B.C., Canada, 2008, 1-16. Available at http://www.antle.iat.sfu.ca/EventTable/
3. Bakker, S., Vorstenbosch, D., Hoven, E.v.d., Hollemans, G. and Bergman, T. Weathergods: Tangible interaction in a digital tabletop game. In *Proc. TEI 2007*, ACM Press *(*2007), 151-152.
4. Bencina, R., Kaltenbrunner, M. and Jorda, S., Improved Topological Fiducial Tracking in the reacTIVision System. In *Proc. CVPR 2005,* IEEE (2005), 99-107.
5. Dietz, P. and Leigh, D., DiamondTouch: A multi-user touch technology. In *Proc. UIST 2001*, ACM Press (2001)*,* 219-226.
6. Fernaeus, Y., Tholander, J. and Jonsson, M., Towards a new set of ideals: Consequences of the practice turn in tangible interaction. In *Proc.TEI 2008,* ACM Press (2008), 223-230.
7. Hinrichs, U., Carpendale, S. and Scott, S.D. Evaluating the effects of fluid interface components on tabletop collaboration. In *Proc. Advanced Visual Interfaces 2006*, ACM Press (2006), 27-34.
8. Jordà, S., Geiger, G., Alonso, M. and Kaltenbrunner, M., The reacTable: Exploring the synergy between live music performance and tabletop tangible interfaces. In *Proc. TEI 2007,* ACM Press (2007), 139-146.
9. Mazalek, A., Reynolds, M. and Davenport, G., The TViews table in the home. In *Proc. Workshop on Horizontal Interactive Human-Computer Systems 2007*, IEEE (2007), 52-59.
10. Mazalek, A., Reynolds, M. and Davenport, G. TViews: An extensible architecture for multiuser digital media tables. *Computer Graphics and Applications 26,* 5, (2006), 47-55.
11. Patten, J., Ishii, H., Hines, J. and Pangaro, G., Sensetable: A wireless object tracking platform for tangible user interfaces. In *Proc.CHI 2001*, ACM Press (2001), 253-260.
12. Rekimoto, J. SmartSkin: an infrastructure for freehand manipulation on interactive surfaces. In *Proc.CHI 2002,* ACM Press (200), 113-120.
13. Tanenbaum, K. and Antle, A.N. Using physical constraints to augment concept mapping on a tangible tabletop. (Eds.) S. I. Ao, Craig Douglas, W.S. Grundfest, Lee Schruben and Jon Burgstone, *World Congress on Engineering and Computer Science, International Conference on Education and Information Technology,* (2008) IAENG, San Francisco, USA. Lecture Notes in Engineering and Computer Science, 539-547.
14. Ullmer, B. and Ishii, H. Emerging frameworks for tangible user interfaces. *IBM Systems Journal*, *39*, 3/4, (2000). Available at http://www.research.ibm.com/ journal/sj/393/part3/ullmer.html.

15. Wilson, A.D., Play Anywhere: A compact interactive tabletop projection-vision system. In *Proc. UIST 2005,* ACM Press (2005), 83-92.
16. Xie, L., Antle, A.N. and Motamedi, N. Are tangibles more fun? Comparing children's enjoyment and engagement using physical, graphical and tangible user interfaces. In *Proc. TEI*, ACM Press (2008), 191-198.
17. Zhang, X., Fronz, S. and Navab, N., Visual marker detection and decoding in AR systems: A comparative study. In *Proc. ISMAR 2002*, IEEE (2002), 97-107.