

# Visualizing Patterns of Social and Communicative Behavior in Children Using Plexlines

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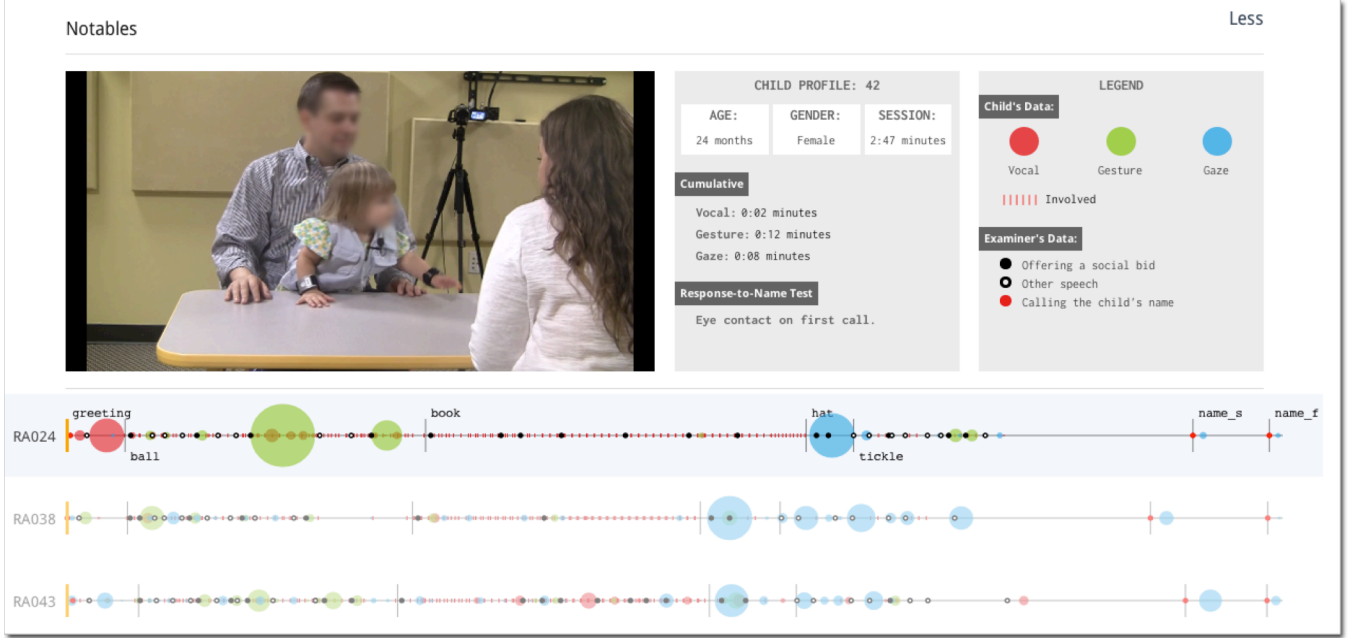


Fig. 1. The main view of Notables with one Plexline selected. Each Plexline highlights the interactions between the child and the examiner during a Rapid ABC session. The red, green, and blue circles each represent the child's gesture, gaze, and vocalization respectively, and the size of the spheres denotes the duration of each action.

**Abstract**—We present a system to visualize the annotations of videos of children engaged in a 3–5 minute interactive protocol that assesses communicative behavior, the Rapid ABC. Rapid ABC session videos are annotated to capture the child's gestures, gaze, and vocalization — important developmental indicators for a young child. From these annotations, we create a graphical fingerprint for each session. In doing so, we introduce Plexlines, a technique for visualizing multiple types of information layered compactly as timelines. Our tool highlights points of interest to probe Rapid ABC sessions that require more attention. Early feedback suggests this system has potential as a tool for communicating developmental concerns to parents and as a training tool for clinicians.

**Keywords**—Visualization, Multimedia Systems, Time series analysis

## I. INTRODUCTION

Diagnosing Autism Spectrum Disorder (ASD) is a

challenging task, requiring a significant investment of time and an experienced professional to make a diagnosis [10]. The Rapid ABC (RABC) is a semi-structured play protocol to assist a clinician in observing the social communicative behavior of a child aged 9–30 months [11]. Compared to traditional instruments—such as the Autism Diagnostic Observation Schedule and Autism Diagnostic Interview, Revised—which last hours, an RABC session can be completed in under five minutes [9]. The child and examiner go through a series of semi-structured activities while the entire interaction is recorded and observed. The RABC is short and has a consistent structure. It lends itself well to exploring new methods of data visualization to highlight patterns of behavior.

To do this, we developed Notables, an online tool designed for researchers, clinicians, and parents that allows for comparison of many RABC sessions at a glance using data gathered from video annotations. Each session is presented as a Plexline, a layered, timeline-based representation where behaviors are represented as abstract graphical elements.

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Notables was designed with three main goals: To create (1) a child-centered, time-based visualization that (2) highlights communicative behaviors known to be warning signs for developmental delay, and (3) compared across a population of children on and off the autism spectrum.<sup>1</sup> We found that abstracted visualizations are highly functional and early probes suggest clinicians and researchers are excited to explore them in their analysis process. We will explain the methodologies and techniques used to meet these goals, the feedback we have received from our preliminary evaluation, and our plans for future work.

## II. RELATED WORK

There has been extensive work visualizing time series data. In this section, we will discuss our main inspirations, though it is not an exhaustive list of work in the field. We are especially interested in social visualization, which is defined as “the visualization of social information for social purposes,” or in other words, visualizations for the everyman [3]. Time series data visualization has come a long way, from simple hand-drawn visualizations, such as Playfair’s line graphs and bar charts [14], to Chat Circles, which visualizes time series data in real-time [3]. We take an approach similar to Chronovis where data is imported into the visualization [5]. We found that the abstracted, linear graphical representations of temporal data in Loom, Chat Circles, and CloudLines were evocative and functional, so we embraced functional abstraction in presenting each child’s visualization as a personal time stream [3, 6].

In the field of medical visualizations, we were inspired by LifeLines, one of the first visualizations of medical records [12]. Its second iteration, LifeLines2, allows users to visually inspect multiple health records in a consolidated view, with additional functionality to align, rank, and zoom to examine the records [15]. Its depiction of multiple medical records of time series data as a list is perhaps the biggest inspiration for Notables.

## III. PROJECT BACKGROUND

Notables aggregates data from two instruments: the RABC, a protocol created for direct observation of social communicative behavior of young children, and ELAN, an annotation software package.

### A. Rapid ABC

RABC was developed as an easy to administer 5-minute prescreener for ASD that was designed to be accessible to all doctors and theoretically, can be conducted in a routine doctor’s visit [9]. It consists of five stages of play (greet, ball, book, hat, tickle) wherein the examiner evaluates the child’s responses to social bids (an attempt by the examiner to initiate a response) and the ease of engaging the child. This research is part of a larger research initiative, an NSF Expeditions project involving 9 universities and an autism center. The RABC data was collected as part of this effort. Over a hundred RABC sessions were recorded in a specially instrumented room containing multiple cameras, microphones, and a Kinect.

<sup>1</sup> Another paper (Han et al.) submitted to this workshop also describes a visualization tool for the same dataset. This paper focuses on visualization and understanding of the individual session, while Han et al considers the problem of being able to create understanding across multiple sessions.

Affective Q-Sensors on both the examiner and child recorded electrodermal activity (EDA), temperature, and acceleration. For our visualizations, we utilize the camera facing the child and the human coded RABC video annotations.

### B. Annotations & ELAN

The RABC videos were hand coded by three independent coders and checked for inter-rater reliability. We grouped the annotated behaviors into three categories: child’s gaze, vocalization, and gesture. Of these annotations, we highlight the ones that indicate communicative intent and interactions directed toward the examiner. We further explain this in the Annotation Taxonomy subsection.

The RABC videos were annotated using ELAN, a software tool to annotate video [16]. It allows for multimodal analysis through the creation of an annotation hierarchy. We export this ELAN data to create Plexlines.

## IV. PLEXLINES

Plexlines were developed specifically to reveal temporal patterns available in the RABC annotations. In this section, we discuss the design decisions and the framework behind the visualization.

### A. The Power of Abstraction

Visualizing one child’s data in ELAN requires the entire screen. This layout prohibits comparison of several RABC sessions at a glance. Our approach is to create a simple, legible fingerprint of each RABC session. To do this, we abstract the annotations, through the use of simple shapes and symbols, that allow us to provide a complete picture of the annotated behaviors at a glance [1].

In a way, shapes and symbols are more concrete than numbers. We perceive perceptual structure—patterns of quantities, color, relative size, and shapes [1]. The latter uses single units while the former operates as a whole, through our cognitive ability to quickly perceive visual relationships. The abstracted visualization is a concrete representation of an internal mental model of social-communication behavior. A new representation of a familiar model can also help clinicians become more attuned to spotting abnormalities, revealing patterns faster than what would typically be hidden in text and numbers [8, 17].

Our goal with Plexlines is to visualize timeline data, functionally and legibly. Plexlines capture the essence of behavior while providing a detailed picture of many types of information. In the context of this work, one Plexline visualizes over 30 different annotation codes, while still providing information on actions, duration, behavioral patterns, and initiation-response sequences.

### B. Annotation Taxonomy

We categorized the RABC annotations to create a graphical framework. To focus on interpersonal interaction, we categorized child-related annotations into primary and secondary annotations. We define primary annotations to be cases in which the child is engaged in social interaction directly with the examiner or with intent, including: gaze at examiner, responding to a question, or calling for attention. Primary

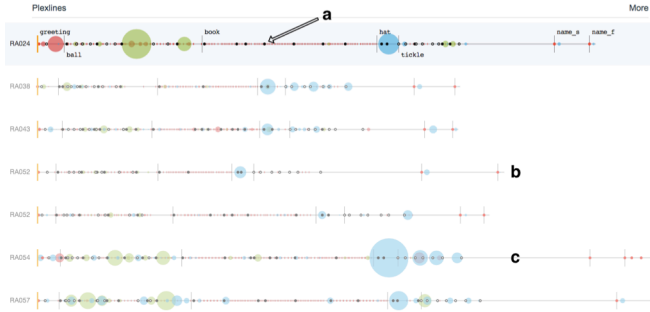


Fig. 2. A series of Plexlines. Each Plexline represents a single RABC session. (a) Instance of an examiner bid signal (b) A shorter Plexline with minimal gaze, gesture, and visualization of the child (c) A longer Plexline with instances of overlapping actions during a RABC session.

annotations are further separated into three categories: vocal, gesture, and gaze, which are color-coded red, green, and blue respectively. Secondary annotations are all other annotations not categorized as primary, representing moments in which the child is engaged in an activity, but not in direct communication with the examiner, such as turning the page of a book. This distinction between primary and secondary is necessary in designing the visual hierarchy of the Plexline. Primary information will be represented more prominently to distinguish the nuances between each child.

Annotations relative to the examiner are categorized similarly, separating annotations into two types of examiner bids or requests: those in which there is an expected reaction from the child, and all else in which there may be any number of reactions from the child. The former usually consists of a question or a demand—such as “Can you turn the page?” or “Look at my hat!”—and is marked by a filled black point. All other annotations fall into the latter category and are represented by a hollow point. Additionally, calling of the child’s name is highlighted separately from other examiner annotations because it was included in addition to the RABC.

### C. Graphical Design

Visualizations of medical records have shown that graphical time scales are one of the most intuitive approaches to telling a narrative and comparing large datasets [12, 6]. However, rather than comparing many sets of data within one child’s timeline, we are comparing different categories of information in one child, and those patterns across several children. In order to maximize screen retail while creating a legible visualization, we developed a technique for layering salient information onto one line. By layering and combining multiple types of information on one line using different stylizations of plotting symbols, we are able to display all the annotation data continuously while maintaining legibility [1, 7]. Each unit can be read individually, or as part of its group on a linear time scale.

1) *Symbolic Markers*: One of the biggest challenges of the Plexline is separating the different categories of information visually. However, legibility can be achieved through careful selection of different styles of circular plotters. Circles are used as the main representation of data for aesthetics and scalability. It lends itself well for displaying multiple units of

different sizes over a linear path of time. By using the diameter of the circle to indicate the duration of the annotation, we can create a visual pattern in which more visual density indicates more child activity.

Secondary child annotations show that the child is still participating in the activity and are aggregated and represented by small hatch marks on the Plexline so they are not emphasized as much as the primary annotations. Examiner bids signal initiation of a social interaction (See Figure 2 (a)), so they are also represented by circles to match the child, who may follow with a response. However, since the examiner is scripted and standardized (as much as is possible), the size of the examiner’s circle is fixed and does not include duration.

2) *Color*: Because this is a child-centered visualization, only the child’s primary actions are colored, drawing attention to the child’s pattern of interaction. Vocal, gesture, and gaze are also coded red, green, and blue respectively based on level of importance in identifying autistic behavior. For example, lack of vocalization or non-verbal vocalization is one of the biggest indicators of autism [10]. With the least frequent/expected action—vocal—being the most unexpected, it is coded the brightest and boldest color, red, for ease of reference. A slight transparency to each circle allows for spotting overlapping of actions since it is not unusual for a child to do all three primary interactions at once, showing high engagement at the moment.

## V. ONLINE WEBTOOL

We developed a beta of Notables, with the goal of exploring the effectiveness of the visualization. It is a fully functional system implemented primarily using D3. We will discuss the details of the tool in the following sections.

### A. Video Supplement

The Notables online tool can be seen in Figure 1. The Plexlines appear as a list below the video screen. Selecting a specific Plexline, loads its corresponding video. The Plexline then becomes both an interactive scrollbar and visualization. The video proved useful in explaining visualization patterns. For example, in Figure 3 (b), the child gazes at the examiner primarily in the middle of the session. When viewing the video, the user can see the gaze in context. The visualization’s reliability is strengthened by the ability to cross-reference points of interest with key moments in the video.

### B. Comparison

Plexlines are displayed as *small multiples*, a term Tufte coined describing a series of small visualizations with the same design structure. This “economy of perception” allow the viewer to focus on information changes within and across Plexlines [14]. For example, in Figure 2 (c), the last Plexline depicts a longer RABC session, with more gazes from the child. However, in Figure 2 (b), the RABC session is much shorter, lacks gesture and vocalization behaviors, and displays minimal gaze behavior from the child.

The default order of the visualizations is sorted by the child's ID number. To compare a small selection of children, one can reorder Plexlines by drag-and-drop. It is possible to compare one child across the entire population by comparing the Plexlines of one child to an aggregate visualization of all the rest (except that of the individual child). In this view, the Plexlines are layered on top of each other (see Figure 3 (b)). From the aggregate view, one sees that children are more likely to gesture during the initial stages of the session, a behavior missing in the first Plexline in Figure 3 (a).

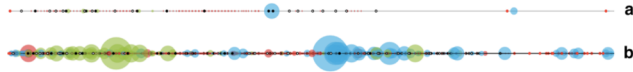


Fig. 3. Comparing one child (a) with a layered aggregate of the rest (b). A lack of green on the individual Plexline shows that this child lacks gestural engagement in the first quarter of the RABC session, which is unusual when compared to the aggregate.

## VI. INITIAL EVALUATION AND FUTURE WORK

As of the writing of this paper, 144 children have participated in the RABC recording, of which 53 sessions have been annotated. We presented a demonstration of Notables with these annotation data to a clinician and a panel of researchers. The clinician's response was enthusiastic. From this discussion, we identified key ideas to drive future development of the visualization tool.

### A. Annotating Plexlines

The clinician found the Plexlines interpretable and expressed a desire to further annotate points of interest along a Plexline. This would be useful for noting and describing specific events to parents after a session.

### B. Notables as a Training Tool

Early feedback introduced a new use case for the visualization. The clinician suggested the potential of using Notables as a training tool for clinicians. Trainees can see a series of Plexline visualizations to understand a typical session, thereby understanding the structure of the protocol and the expected behaviors.

### C. Segmenting Stages

The entire RABC session is represented continuously on one Plexline. The Plexlines are aligned at the beginning of the RABC greeting stage. The protocol, however, consists of 5 stages. Aligning the Plexlines about any of the specific stages across multiple children would provide more detailed information about that stage. That is especially helpful as children proceed through the RABC at different rates.

### D. Limitations

We realize annotations are imperfect and not inclusive of every possible behavior. Coding schemes improve iteratively over time. The features we are coding may not be optimized for our screening goals. The taxonomy for our visualization is highly influenced by the taxonomy of the existing RABC annotations. We currently distinguish between gaze, gesture,

and vocalization behaviors. Smiling is an example of an annotation that may be useful, but not yet annotated.

The time to code the RABC videos is another limitation. Ideally, a clinician may want to show a parent their child's session visualization immediately following the session. Other members of the research team are exploring vision techniques to automatically extract annotations from the RABC. Until we can reliably annotate data automatically, we depend on a less convenient, but more consistent framework through hand-coded annotations.

## VII. CONCLUSION

We presented a browser-based tool for visualizing RABC sessions using Plexlines, a new technique for visualizing multiple layers of social and behavioral interaction. We focused on understanding the child's intent and preferred patterns of communication through their gestures, gaze, and vocalization. The Plexline for each individual child can be viewed in the web browser for comparison across multiple children to identify points of interest for further examination. Early feedback suggests Plexlines are (1) interpretable, and useful in providing a quick overall summary of RABC sessions and (2) a useful tool for teaching and explaining the RABC protocol.

We continue to make the tool more robust and flexible, by integrating sorting, filtering, and semantic zoom features. A larger formal study is planned to consider how the tool is integrated into the clinicians' existing workflow in a way that is unobtrusive and useful.

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## REFERENCES

- [1] R. Arnheim, *Visual Thinking*, University of California Press: Los Angeles, 1969.
- [2] R. I. Arriaga, O. Ousley, S. Kannan, B. Van den Bogaard, G. Abowd and J. M. Rehg, Facilitating Pediatrician Buy-in: a Technological Solution for Integrating An Autism Screener into the Medical Office Work Flow, (1)Interactive Computing, Georgia Tech, Atlanta, GA, (2)Psychiatry and Behavioral Sciences, Emory University, Atlanta, GA, (3)Computer Science, Georgia Tech, Atlanta, GA.
- [3] J. Donath, K. Karahalios, and F. Viegas. Visualizing conversation. *Journal of Computer-Mediated Communication* 4.4 (1999)
- [4] A. Fathi, J. K. Hodgins, and J. M. Rehg. Social interactions: A first-person perspective. In Proc. IEEE Conference on Computer Vision and Pattern Recognition, 2012.
- [5] E. Fouse, N. Weibel, E. Hutchins, and J. D. Hollan. ChronoViz: a system for supporting navigation of time-coded data, Proceedings of the 2011 annual conference extended abstracts on Human factors in computing systems, May 07-12, 2011, Vancouver, BC, Canada.
- [6] M. Krstajic, E. Bertini, and D. Keim. CloudLines: compact display of event episodes in multiple time-series. *Trans. Visualization and Computer Graphics* 17, 12 (2011), 2432-2439.
- [7] M. Krzywinski, and B. Wong. Points of view: Plotting symbols. *Nature Methods* 10.6 (2013): 451-451.

- [8] Z. Liu, and J. Stasko. Mental models, visual reasoning and interaction in information visualization: A top-down perspective. *Visualization and Computer Graphics, IEEE Transactions on* 16.6 (2010): 999-1008.
- [9] C. Lord, M. Rutter, S. Goode, J. Heemsbergen, H. Jordan, L. Mawhood, and E. Schopler. Autism diagnostic observation schedule: A standardized observation of communicative and social behavior. In *Journal of Autism and Developmental Disorders*, vol. 19, no. 2, pp. 185–212, Jun. 1989.
- [10] P. Mundy, M. Sigman, J. Ungerer, and T. Sherman. Defining the social deficits of autism: the contribution of non-verbal communication measures. *Journal of child psychology and psychiatry*. 27.5 (1986): 657–669.
- [11] O. Y. Ousley, R. Arriaga, G. D. Abowd, and M. Morrier. Rapid assesment of social-communicative abilities in infants at risk of autism. Technical Report CBI-100, Center for Behavior Imaging, Georgia Tech, Jan 2012. Available at [www.cbi.gatech.edu/techreports](http://www.cbi.gatech.edu/techreports).
- [12] C. Plaisant, R. Mushlin, A. Snyder, J. Li, D. Heller, B. Shneiderman. LifeLines: Using Visualization to Enhance Navigation and Analysis of Patient Records Revised version appeared in 1998 American Medical Informatic Association Annual Fall Symposium (Orlando, Nov. 9-11, 1998) AMIA, Bethesda MD, pp. 76-80.
- [13] J. M. Rehg, G. D. Abowd, A. Rozga, M. Romero, M. Clements, S. Sclaroff, I. Essa, O. Y. Ousley, Y. Li, C. Kim, H. Rao, J. C. Kim, L. Lo Presti, J. Zhang, D. Lantsman, J. Bidwell, and Z. Ye. Decoding children's social behavior. In 2013 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2013.
- [14] E. Tufte. *The visual display of quantitative information*. Cheshire, CT: Graphics press, 1983.
- [15] T. Wang, C. Plaisant, A. Quinn, R. Stanchak, B. Shneiderman, and S. Murphy. Aligning Temporal Data by Sentinel Events: Discovering Patterns in Electronic Health Records, *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems* (CHI 2008).
- [16] P. Wittenburg, H. Brugman, A. Russel, A. Klassmann, and H. Sloetjes. ELAN: A professional framework for multi-modality research. In *Proceedings of LREC 2006*, 2006.
- [17] W. Worringer. *Abstraction and empathy: A contribution to the psychology of style*. Rowman & Littlefield, 1997.