Guided Play: Automatic Stereotypical Behavior Analysis and Intervention during Play

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CHI PLAY'16 Extended Abstracts, October 16–19, 2016, Austin, TX, USA.
ACM ISBN 978-1-4503-4458-6/16/10.
http://dx.doi.org/10.1145/2968120.2987727

Abstract
Restricted and repetitive behaviors (RRB) are a core symptom and an early marker of Autism Spectrum Disorder (ASD). Despite technologies for detecting certain forms of RRB, assessment and intervention for RRB still heavily rely on professional experience and effort.

This paper presents an ongoing investigation of a technology that uses instrumented games or toys as platforms to assess RRB and facilitate behavior intervention during play. The design and implementation of a prototype for the iPad are discussed. The same technology can be applied to tangible objects such as smart toys for a natural player-computer interface.

Author Keywords
Autism; Restricted and repetitive behavior; Assessment; Intervention; Technology

ACM Classification Keywords
J.4 [Computer Applications]: Social and Behavioral Sciences—*Psychology*

Introduction
Autism, or Autism Spectrum Disorder (ASD), is a developmental disorder that impairs an individual's social communication, sensory processing, and behavior. Early

diagnosis and intensive intervention are critical to lowering treatment cost and improving prognosis. Unfortunately, it often requires enormous professional experience and effort to identify and treat symptoms of ASD [21]. Hence there has been a great interest in technology that can recognize and measure symptoms of ASD and even facilitate interventions.

Restricted and Repetitive Behaviors (RRB) are one of the core symptoms and diagnostic criteria of ASD [1]. Although no single type of RRB is unique to autism, a pattern of multiple types of RRB can be an early indicator of ASD [2, 13]. RRBs are also a frequent target of behavioral interventions. The most widely used intervention technique is Applied Behavior Analysis (ABA). ABA principles including building response repertoires, prompting variability, and reinforcing variability have been found effective for increasing behavior variability in individuals with autism [21].

Among RRBs, stereotypical motor movements (SMM) refer to repetitive, non-functional motor behaviors (e.g., body rocking and hand flapping). Sensors, such as accelerometers [11, 7, 20, 9] and video cameras [3, 6], can help recognize and measure SMMs, and provide valuable data for identifying markers of ASD and assessing treatment progress.

However, not all RRBs exhibit significant acceleration or visual patterns. For example, when playing with toys, many children with ASD tend to play in stereotypical ways (e.g., stacking and lining up toys). Another challenge is that when a RRB is identified, it still requires human professionals to implement the interventions. To our knowledge, few technologies can facilitate or even implement behavioral interventions.

As our world becomes increasingly machine dense (including both hardware and software), traditionally analog and centralized ecosystems are becoming digital and distributed. As an example, healthcare instead of being delivered only in hospitals can now be accessed where we are, and can be personalized to our own data available through mobile sensors. Our next generation will also benefit from such a transformation. We believe that machines can provide more insight into a child's development and become a helper in their lives.

We attempt to push forward the technology to not only recognizing and assessing RRBs, but also delivering behavioral interventions within the context of play. Instead of SMMs, we target a subtle form of RRB – invariance in object manipulation. Our technology, Guided Play, implements an intelligent agent that transforms games and smart toys into behavior co-therapists. It observes a child's play, measures his/her behavior variability, detects repetitive patterns, and joins the play to increase behavior variability and repertoire. This paper introduces a digital building block game that runs on the iPad as part of our ongoing effort to develop technologies that can help identify symptoms of ASD and facilitate behavior interventions.

Related Work

A large body of existing studies of RRB detection and measurement focus on SMM, given that body motions often emit significant acceleration or visual signals recognizable by sensors.

One such line of research uses wearable accelerometers to measure body movements and machine learning algorithms to classify the movements as SMM or non-SMM [7, 11, 6, 16]. Another approach is to track body motion in videos and use computer vision to detect motion patterns [5, 14, 3] as well as other behavioral elements such as facial expression, eye gaze, engagement, etc [15, 8].

In addition to stereotypical body motions, children with ASD often exhibit unusual and prolonged object exploratory behaviors during play [2, 13]. Several "smart toys" with embedded wireless sensors have been created [20, 9] to track and identify stereotypical body movements in play such as shaking, spinning, banging, etc.

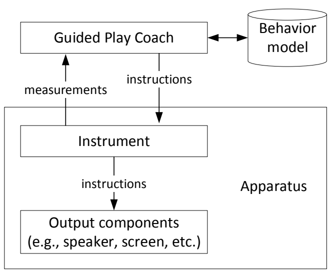


Figure 1: System architecture.

Our work is different in that it addresses a subtle form of RRB not fully supported by exiting technology – invariance in object manipulation and also supports behavior intervention using principles of Applied Behavior Analysis (ABA).

Guided Play

This section details the design and implementation of the Guided Play system.

Overview

Guided Play is an intelligent agent behind a game or smart toy that transforms it into a platform for behavioral assessment and intervention. We call such a game or toy *apparatus*. As illustrated by Figure 1, Guided Play inserts an *instrument* into the apparatus as a sensing and communication plug-in. An instrument can be a wireless sensor embedded in a smart toy similar to those used in Westeyn et al. [20] or a software component running inside a computer game.

Inspired by the principles of ABA, Guided Play embodies the following steps:

- *Observing*. The instrument continuously reads and sends behavioral data to Guided Play Coach, the decision making component of the system, which then measures various aspects of the behavior, including variability and size of repertoire.
- *Detecting*. When a RRB is detected based on pre-defined percentile thresholds, Guided Play Coach via the instrument gives instructions to the apparatus to start behavior shaping.
- *Joining*. The apparatus will then play *with* the child (prompting next move, taking turns, etc.) instead of being played *by* the child (without any intervention of the child's behavior).
- *Guiding*. Following the best practices of improving behavior variability [21], Guided Play Coach instructs the apparatus to expand the player's behavior repertoire by modeling new responses and to vary his/her responses by giving prompts.
- *Reinforcing*. When desired behavior is observed, the apparatus will deliver individualized reinforcements to promote and maintain behavior variability.

Guided Play Blocks

To test the efficacy of our approach, we created a prototype using a building block game on the iPad as the apparatus [1]. Our hypothesis is that a child with RRB in a real-life activity may also exhibit similar patterns in a digital replica of the activity, and interventions carried out in the digital activity may have impact on his/her behavior in real-life.

[1]Guided Play app is available at http://guidedplay.toys

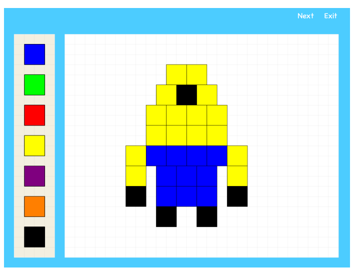


Figure 2: A screenshot of Guided Play Blocks.

We chose a block game for several reasons. First, the level of block play is highly related to the stages of child development, including spatial cognition, fine-motor skills, classification, math, and social skills [19]. Second, blocks have been successfully used in previous studies of RRB interventions [12]. From a technical point of view, block play is structured, and computers can understand the dynamics of block play behavior.

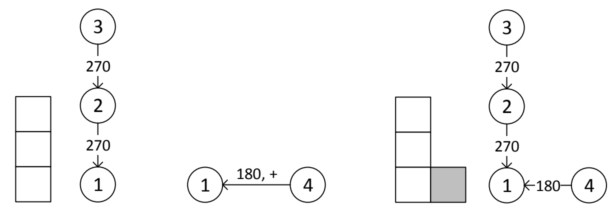
Figure 2 gives a screenshot of the game running on an iPad. On the left-hand side, there is a *blocks panel* supplying blocks in various colors. All blocks are of the same size and shape at the initial level. Higher levels will provide different sizes and shapes. A player can move the blocks one at a time from the blocks panel to the center *canvas* using drag-and-drop gestures. The supply of blocks is unlimited. When a block is placed on the canvas, it will be aligned with existing blocks on the canvas automatically to accommodate young children's inaccurate gestures, and a new one will be created to fill the empty spot left on the blocks panel. Sound and animation effects are given to the movements to make the blocks lifelike.

Behavior Modeling and Analysis

We use a graph-based formalism to model dynamic building operations and static construction structures. Each block movement will generate an *operation graph* representing the operation and a *structure graph* as a snapshot of the block structure updated by the operation. A (node-edge) graph is a set of nodes connected by edges. As an example, Figure 3(a) shows a block structure and its corresponding structure graph after the *i*-th operation. Figure 3(b) represents the *i+1*-th operation that transforms structure *i* into structure *i+1* shown in Figure 3(c).

In the graphs, a node always represents a block. In an operation graph, e.g., the one shown in Figure 3(b), the edge indicates the operation, annotated by its action ("*": new block, "+": connect to, "-": disconnect from, etc.) and orientation (e.g., connect block 4 to the right of block 1). In a structure graph, an edge represents the connection between two blocks. The orientation of an edge is denoted as a degree in the polar coordinate system. For example, in Figure 3(a), the edge from node 3 to node 2 indicates that node 3 is connected to node 2 from the top (270 degrees).

The system maintains a history of all the operations and structure snapshots. Based on the graph model, the system computes the following measures.



(a) Structure *i* (b) Operation *i+1* (c) Structure *i+1*

Figure 3: Graph-based modeling.

- *Variability* consists of *operational variability* and *structural variability*. Operational variability measures the variability of block operations (e.g., stacking on top, connecting to left, disconnecting, etc.). Similar to Napolitano et al. [12], it is measured as the average difference between the operation graphs within a given time window. Structural variability is the variability of completed block structures. It is calculated as the average difference between the structure graphs within a given time window.

- *Complexity* measures the complicatedness of the blocks and their relationships. It is based on the following block complexity metrics: dimensions (height and width), size (number of blocks and connections), symmetry (reflectional and rotational), dimensionality (0D, 1D, 2D, and 3D), and stage complexity (line, cross, enclosure, and bridge) [17, 18].

- *Structural categories*. We are also interested in the categories of the structures a child has made, which represents his/her skill repertoire. To measure that, the system groups similar block structures into a category using a hierarchical clustering algorithm [10].

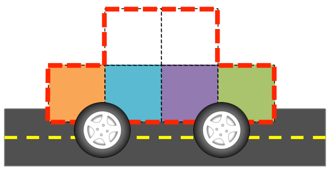


Figure 4: An example of the Guided Play mode.

Behavior Shaping

Guided Play works in two modes. *Free play* mode allows a player to choose a target object and build it using the blocks without interventions from the system. The system quietly tracks a player's interactions with the game except that it provides sound and visual effects to block movements in order to keep the player engaged.

The system may decide to switch to *guided play* mode when the player's percentage of the behavior variability among all same-aged players falls below a certain threshold. Caregivers and professionals may manually override the system's decision. In the guided play mode, the system uses the following proven methods [21] to increase a player's behavior variability.

- *Building repertoire*. Limited response repertoires is one of the reasons for low variability in the behavior of individuals with ASD [21]. Guided Play attempts to expand a player's construction structures by modeling similar but different responses (new objects to build). It maintains a library of constructions collected from all the players and grouped by age. Based on a child's current repertoire of block structures, it finds a structure in the library that is closest to yet different from the child's constructions as a suggested object to build next.

- *Prompting variability*. Apart from the prompts from caregivers and therapists, the system can independently prompt the player to build a new structure using background and shape outlines, as shown in Figure 4. The background is relevant to the theme of the target object or object category. The outline prompts the player to finish the object by "filling in the blanks". When the system detects that the player is not following the prompt, it may generate a next move for the player by adding a missing block to the outline until the player comes back to the game or the structure is completed.

- *Reinforcing variability*. In ABA, differential reinforcement refers to reinforcing (rewarding) desired behavior and not reinforcing undesired behavior. Studies have shown that differential reinforcement reliably increases the diversity of behaviors including those in block play [21].

  Guided Play gives immediate rewards (sound and visual) when a player connects blocks. Finishing a construction generates an animation relevant to the object (car running in the case of Figure 4). The rewards are pre-identified for each individual using preference testing [12]. To promote variability, timing of the rewards can be controlled by reinforcement schedules, such as percentile schedule [4].

Conclusions and Future Work

We have presented the design and implementation of Guided Play, a system that evaluates invariance in play behavior and promotes behavior variability.

The initial version of the app is now available on the iOS app store, and supports the free play mode and data analytics. Other features such as the guided play mode are under development. We are also interested in applying the technology to digitally enhanced physical blocks [9].

In collaboration with behavioral scientists, we are currently conducting a study to test the effectiveness of Guided Play for increasing variability in block play behavior. The study will enroll 3 cohorts of 3 children aged between 2 and 5 years old with ASD, who will each receive approximately 6 hours of access to the app, with sessions ranging between 30 and 60 minutes. The study will use a multiple-baseline across-subjects design in which several free play to guided play phase changes occur in staggered fashion across multiple participants in order to determine if the application of Guided Play causes change in behavior. Expected measurable changes include increased variability in block structures and operations and increased construction complexity.

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