# Realistic Virtual Characters in Treatments for Psychological Disorders
# An Extensive Agent Architecture

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## Abstract

Interactive virtual reality applications have lately been used as a complementary tool in the treatment of people with different kinds of psychological disorders. A number of these projects would benefit from a more realistic behavior of virtual characters. In this paper we describe our ongoing work on an advanced emotional agent architecture for virtual characters and propose new potential applications within the area of health care.

**Keywords:** Virtual reality, artificial intelligence, agent architectures.

## 1 Background

Computer animation is concerned with producing sequences of images that when displayed at high speed give the illusion that certain components of the image move. The aim is to produce animations that look realistic. Computer animation has typically focused on low-level locomotion problems, i.e., low-level control.

In the mid-1980s, researchers began incorporating physical principles to develop physical models for animating passive objects, such as falling and colliding objects. The idea behind this kind of model was to explicitly represent physical concepts. In the last decades, researchers started to focus on the requirement that characters in animations should behave realistically. That is, characters should be able to perform sequences of movements. This is commonly referred to as high-level control problem. Research in behavioral modelling progressed toward self-animating characters that react appropriately to stimuli perceived from the environment. The seminal work in this area was that of Reynolds [Reynolds 1987]. Tu [Tu 1999] and Terzopoulos [Terzopoulos 1999; Tu and Terzopoulos 1994] extended then that approach to dealing with some complex behaviors. One of the early attempts at virtual autonomous characters was the Improv [Perlin and Goldberg 1996] system. Improv allows for the creation of real-time behavior based animated actors using an animation engine and behavior engine to allow authors to create sophisticated rules governing how actors communicate, change, and make decisions. At the top of the modelling pyramid, cognitive modelling has emerged as the use of artificial intelligence techniques, including knowledge representation, reasoning, and planning, to produce virtual characters with some level of deliberative intelligence, see for example [Funge 1998; Funge 1999; Funge et al. 1999]. Addressing human cognitive functionality is a challenging research area in artificial intelligence (AI). Funge pioneered the use of hardcore artificial intelligence techniques in computer games and animation. His aim was to devise a system suitable for rapid prototyping and producing off-line animations. To do so, he used logical reasoning to shift most of the work for generating behavior from the animator to the animated characters. With the intention that the devised system should be easy to build, reconfigure and extend. In [Funge 1998] Funge addressed the problem of devising characters that display elaborate behavior in unpredictable and complex environments. In order to generate high-level behavior, he used the situation calculus [Reiter 1991] to model the virtual world from the animated character's point of view. The basic idea was that a character viewed its world as a sequence of snapshots known as situations. An understanding of how the world could change from one situation to another could then be given to the character by describing the effect of performing each given action. Since the world was dynamic, characters were equipped with knowledge-producing actions (like sensing). Funge's work contributed to advanced computer animation research in several ways: (i) he was the first to tackle the problem of modelling cognitive capabilities of virtual characters enabling them to represent, reason and act in their virtual world, and to perform sensing actions; (ii) to develop and implement an architecture suitable to specify the high-level control combining the advantages of a reactive and a reasoning system. The devised architecture was such that cognitive models were built on top of biomechanical, physical and kinematic models (that control for example locomotion, collisions, etc.). The interaction among the various levels in the hierarchy is achieved by communicating the actions to be performed to the lower levels where they are executed by the appropriate routines. In contrast, the function of sensing actions is to prompt the lower levels to return information about the state of the world to the cognitive level.

## 2 Research Vision and Objectives

We consider virtual, autonomous characters situated in dynamic, unpredictable, virtual worlds. To render these characters self-animated (i.e., alive) in real time performances, we need to make them able to perceive, reason and act in the world where they are situated. This goal can be achieved by ascribing characters cognitive capabilities together with reactive functionalities that implement primitive behaviors (such as avoiding collisions). Our aim is to be able to deploy autonomous characters in interactive systems and virtual reality applications. Despite several attempts to make the animated characters more autonomous and intelligent there is still a broad scope of research into the problems involved in the design and modelling of virtual characters. The growing popularity of logic-based agent architectures gives new opportunities to apply recent advances in AI to this problem. Hence, the focus of our project is to deploy state-of-the-art artificial intelligence methods into character simulation and extract and address new research issues in computer graphics and artificial intelligence in the context

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of the developed applications.

# 3 Current Agent Architecture

At present time the architecture (depicted in Fig. 1) includes the handling of emotions, an appraisal module, a simple decision module, a knowledge base and a trust module. The original design and implementation of the architecture was carried out by two diploma works [Esbjörnsson 2007; Johansson 2007]. Our system architecture needs to be modular to simplify the task of adding and editing components. The system is rather extensive and management of such a system is easily done in a modular architecture.

The system works in the following way. At each update time (preferably at not every frame as this will slow down the performance of the entire system), the simulation engine (e.g., a game engine) sends information to the XML interface. Such information may be about the whereabouts of objects, weather conditions etc. In the XML interface the information is converted to XML and sent to the knowledge base (although some specific types of information are sent directly to the Affective Appraisal module). In the knowledge base the information is added to the agent's memory (we use XSB Prolog system to store the data). The Affective Appraisal module triggers emotions and expectations depending on what happens around the agent. Emotions and trust also influence which emotion and expectation to trigger. The decision module selects which action to execute depending on the current knowledge, emotional state and trust. The selected action is sent back to the XML interface to be executed by the simulation engine.

In the following sections we will describe the different modules of our system in more detail.

## 3.1 XML for Inter-Modules Communication

To keep our agent architecture independent of simulation and rendering engines, we have developed an XML interface between the chosen simulation engine and the agent architecture. Information from the game state, no matter how it is stored there, is converted into an XML representation that the agent can process. This allows us to decouple the chosen simulation engine from the agent architecture in the way that changes in the representational language of the simulation engine are not reflected into the modules.

Communication between the different modules in the agent system is also largely done in XML. This makes modifications of the modules easier. XML is also used as a configuration language to define the settings of the different modules.

To ensure fast XML parsing we use a small DOM-based XML library named TinyXML. Because it maintains the entire XML document in memory there is no need for writing information to file. TinyXML provides ways to quickly traverse XML node trees and even with the extended checks we added to ensure well-formed documents, the system is fast.

## 3.2 Emotion Module

The original emotion module was developed in a prior diploma work [Esbjörnsson 2007]. The emotions in our system are represented as signals[1]. The set of all signals of the same type forms the corresponding emotional state. Each signal has the form of a sigmoid curve and consists of the following phases: delay, attack, sustain and decay. The sigmoid curve is defined as:

$$sigmoid(t) = \frac{g}{1 + e^{-(t+h)/s}} + v$$

where $t$ is the time, $g$ is the gain, $h$ is the horizontal shift, $s$ is the slope steepness and $v$ is the vertical shift. Being the signals parameterized, it is possible to create fairly diverse types of emotion signals.

Emotions can influence each other through a sophisticated filtering system (see Fig. 2). There are currently three types of filters: sigmoid, linear and gamma filters. They have the following mathematical definitions:

$$sigmoid(x, g, s, h, v) = \frac{g}{1 + e^{-(x+h)/s}} + v$$

$$linear(x, s, v) = x * s + v$$

$$gamma(x, g, s, v) = g * x^s + v$$

where $x$ is the input value to the filter, $g$ is gain, $h$ is the horizontal shift, $s$ is the slope steepness and $v$ is the vertical shift. Note that these functions have dynamic parameters that will change over time as the emotional states change. This provides a powerful mechanism for letting the emotional states interact with each other. The emotional states can influence all aspects of incoming signals, including intensity and phase lengths. The filtering system is completely customizable through a configuration file written in XML.

The filtering system consists of modifiers each affecting one parameter of an incoming signal of a particular emotional state. A modifier is a dynamic filter object consisting of one of the previously mentioned filter functions. Each modifier also consists of several arbiters, each affecting one parameter of the filter function of the modifier. To each arbiter, any number of emotional state can be connected with different influence values.

## 3.3 Knowledge Base

The knowledge base represents the memory of the agent. Here all information on events, expectations, etc. is maintained. The logic language (XSB, or Tabled Prolog [XSB-Prolog 2007]) we use for the knowledge base also allows for expressing reasoning although this is not yet integrated into the system. XSB allows us to store complex information in a simplified way and it also allows us to create simple rules that can be evaluated dynamically. Incoming information (represented in XML within the agent) from the game state is automatically translated into XSB statements that are asserted into the memory.

Here follows an example of how the XML information is translated into Prolog statements. Suppose that the agent receives an event from the simulation engine stating that there is a warrior at position (1.4, 2.3) holding an axe. This is represented in XML as:

```
< object id="2" type="warrior" >
    < position x="1.4" y="2.3" / >
    < holdsitem type="axe" / >
< / object >
```

The XML element above is coded into three Prolog statements:

```
object(2,warrior).
position(2,1.4,2.3).
holdsitem(2,axe).
```

[1] The signals correspond to what in neuroscience is the concentration of certain chemical substances in human brain. The signal we use is a simplified representation of the concentration levels.

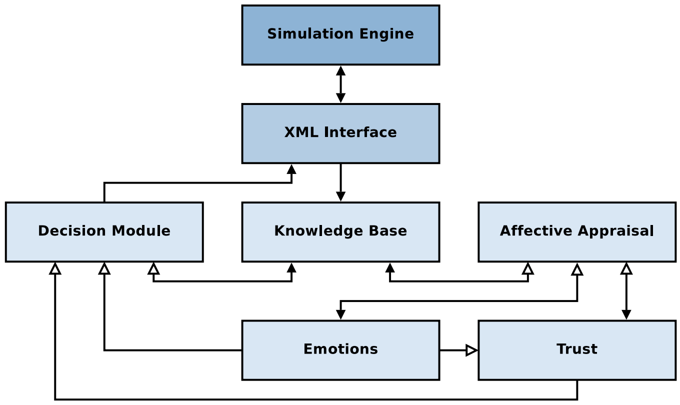


**Figure 1:** *Agent architecture*

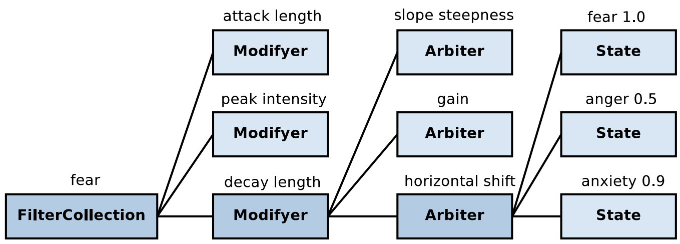


**Figure 2:** *Emotion filtering system*

The way the information is saved is highly similar to common database structures. Note that the first Prolog statement declares that there exists a warrior whose id is two. The remaining two statements, *position* and *holdsitem*, use the id of the warrior to save its position and the item held. This construction can be compared to the use of primary and foreign keys in databases. To retrieve all the objects currently holding an axe from the knowledge base the following Prolog query can be made:

```
?- object(X,_), holdsitem(X,axe).
```

The result of the query is then expressed in XML to be used by the other agent's modules:

```
< object id="2" type="warrior" >
      < holdsitem type="axe" / >
< / object >
```

The knowledge base saves the source of the information along with the information itself (this extra argument is not shown in the example above). The source in our system is an agent, either the agent itself (the event was perceived by the agent itself) or another agent. The source of information is important when determining the trust towards another agent. Should an agent provide false information it is likely to be trusted less in the future.

The time of the information acquisition is also stored in the knowledge base (not seen in example). This time of acquisition can also be used to simulate forgetfulness or the reliability of a piece of information.

### 3.4 Affective Appraisal Module

The main task of the Affective Appraisal module is to do an emotion appraisal, that is, an affective estimation of the incoming/perceived events. Depending on the events, different emotions will then be triggered. For instance, if an agent sees a wolf running towards it, the appraisal will trigger the emotion fear. The rules defining which emotion to trigger are easily customizable via XML rules:

```
< rule >
   < condition >
      < less_than threshold="80.0" >
         < new_value_from_memory variable_name="?MinDis" >
            < min_distance id1="#self" type="wolf"
            returnId="?WolfId" returnDis="?MinDis" / >
         < / new_value_from_memory >
      < / less_than >
   < / condition >
   < do >
      < trigger_emotion emotion="fear" >
      < / trigger_emotion >
   < / do >
< / rule >
```

This rule states that if the distance to the nearest wolf is less than 80 length units, then the emotion fear must be triggered.

#### 3.4.1 Triggering Secondary Emotions

When the Affective Appraisal module encounters a rule that requests the triggering of the emotion disappointment, sadness should be triggered as well. It would also be appropriate to decrease the value of happiness. Triggering these kinds of secondary emotions is done automatically in the Affective Appraisal module. To decrease happiness due to an increase in disappointment, one needs to create an emotional signal with a negative peak value. When adding this signal to the already existing happiness signals the overall value for happiness will decrease. The triggering of secondary emotions is configured through an XML document and the values can easily be tweaked for a better behavior.

### 3.4.2 Expectations

The appraisal module also handles the creation and management of expectations and (to some extent) trust. The handling of expectations is automatic and therefore hard-coded. An expectation in our agent architecture consists of several parts (defined in [Johansson 2007]):

| Parameter | Explanation |
|---|---|
| expectation | The description of the event that is expected to happen. |
| time frame | The estimated time frame in which the event is predicted to happen |
| control-factor | The perceived control over the situation. |
| benevolence | The perceived goodness of the event seen from the agent's point of view. |
| probability | The estimated probability that the event will occur. |

The expectations themselves are stored in the knowledge base. The affective appraisal module also checks for all the unfulfilled expectations and consequently the emotions that should be triggered in response.

## 3.5 Trust Module

The trust module[2] handles the agent's trust towards other agents (be they virtual or human). This module also specifies the trust-relevant personality traits of the agent. The agent can be trusting, suspicious, reactive, forgiving, etc. Personality traits can easily be changed over time to reflect the experience of the agent. For instance, if the agent has decided to trust other agents several times in the past but it always ends up badly, then the agent will likely not be so trusting in the future.

Our trust module builds upon several different trust models, in particular the ones in [Mayer et al. 1995; Zaheer et al. 1998]. It consists of four parts: *ability*, *reliability*, *predictability* and *integrity*. The overall trust is calculated as a sum of these four values. The values can also be used on their own if necessary. Different events will possibly trigger changes in these values. For instance, if an agent refuses to share information on the whereabouts of food, the other agents will most likely lower the integrity value of that agent.

One interesting aspect of this module is that it takes into consideration the values of emotions when calculating the perceived trust value for another agent. It has been shown that emotions influence our trust towards other people [Dunn and Schweitzer 2005]. This is especially true when we are not consciously aware of the source of our emotions. The way emotions affect trust is defined as:

$$
\begin{aligned}
overall\ trust &= T + EI \\
T &= ability + integrity + \\
&\quad reliability + predictability \\
EI &= \frac{OPC}{5} + \frac{WC}{10} + \frac{PC}{20} \\
OPC &= gratitude - anger \\
WC &= happiness - sadness \\
PC &= pride - shame
\end{aligned}
$$

where $T$ is emotionless trust (the trust without any influence from emotions), $EI$ is emotional influence, $OPC$ is other-person control, $WC$ is world control, $PC$ is personal control. The definition of $OPC$, $WC$ and $PC$ is based on the work of [Dunn and Schweitzer 2005]. Since our system does not store information about the source of emotions yet, we do not have to be concerned about source salience which would otherwise affect the emotional influence on trust.

## 3.6 Decision Module

The task of the decision module is to select an action that the agent needs to perform at every time stamp. Choosing the best action is a complex task that depends on the history of previous events, knowledge and the current goals/objectives of the agent. At the moment, the decision module only consists of a simple set of XML rules similar to that of the Affective Appraisal module.

All emotions have to be triggered in the Appraisal module. However, expectations can be triggered in the decision module as they are often linked to a chosen action. In fact, when the agent chooses an action, it will most likely expect a certain outcome.

Actions that can be taken are physical actions (such as running, eating or sending messages to other agents), as well as internal actions (like triggering expectations). The physical actions available are determined by the simulation engine that will execute them.

# 4 Future Developments

Several improvements are needed to create a better agent architecture. We describe the planned extensions in detail below.

## 4.1 Decision Module

The current decision module uses only simple if-then rules. The first encountered rule with true body in the decision module determines the action to be executed next. Such a behavior is very limited, and we really need to extend this module. We are considering using a behavior network based approach [Maes 1989; Maes 1991] extended with emotions.

## 4.2 Action Management

A current diploma work [Zakaria (work in progress)] focuses on action management which deals with the actions once they have been selected. This includes script enabling and physics-based animation among other things. This module is placed slightly outside the agent architecture since it is not entirely a cognitive process but instead a more physics based process.

[2] Note that trust is not used here to make decisions (this happens in the decision module). The level of trust is calculated and maintained here, and trust values are provided to other modules when needed.

### 4.3 Learning

Another important capability that we want to ascribe to our agents is the ability to learn both from observation and experience. We are going to first develop/exploit a suitable learning algorithm and test it in our agent architecture.

### 4.4 Perception Module

The perception of the agent is influenced by its current emotional state, its preferences and its prior knowledge. An example of emotional influence is when an agent is very afraid of a predator and therefore pays little attention to other things around it. This module is very complex but it would also give great rewards in form of a more realistic human behavior system.

### 4.5 Memory Management

The agent cannot remember everything forever due to memory issues. It is also inhuman to remember information for too long. Humans remember some information for a very long time, while other things are forgotten after a short while (that is, human exploits short and long term memory). Some pieces of information are only remembered under certain conditions, such as when something in the vicinity reminds us of a remembered event (associative memory). Memories should also fade gradually over time, and become less and less certain. The aim of Memory Management module is to deal with all of these issues.

## 5 Virtual Reality Exposure in the Treatment of Psychiatric/Psychological Disorders

Over the last few years, therapists have started to use virtual reality (VR) exposure in the treatment of psychiatric and psychological disorders as a complement to standard therapy treatments, e.g. cognitive-behavioral therapy (CBT). VR seems to be an effective alternative to these traditional treatments and seems to bring significant advantages by allowing exposure to several different situations that would be difficult/costly to recreate in real life. In this section, we outline a number of research approaches that use VR exposure in the treatment of psychiatric disorders focussing on social disorders and phobias.

### 5.1 Social Disorders

Several studies have been conducted regarding the use of virtual reality in the treatment of social disorders, all leading to the conclusion that virtual reality seems adequate for such treatments (see [Grillon et al. 2006] p.105 for a list of supporting references). In fact, virtual reality can offer relevant scenarios which may not be easily available in real life. For example, it would be expensive to repeatedly take a patient on an airplane in order to treat him against the fear of flight.

A psychiatric disorder that can benefit from virtual reality based clinical treatment is social phobia. [Klinger et al. 2006] for example carried out research studies using VR in the treatment of fear of public speaking. Their findings show that human subjects are sensitive to virtual environments, and that the efficacy of VR treatment compares well with traditional CBT.

A number of research groups attempted to use VR-based treatments for social skills training for people with autistic spectrum disorders (ASDs). [Tartaro and Cassell 2006] proposed the use of authorable virtual peers (AVPs) to help children with ASD since they often lack communication and social interaction skills[3]. AVPs are animated characters capable of interacting and responding to children's input. In order to do so, AVPs incorporate three interaction modes - interact, control and author - that scaffold three key interaction practices - rehearse, observe and construct. The authors also embedded into their approach techniques of collaborative storytelling.

In addressing the use of virtual environments for social skills training for people with ASD, [Sarah et al. 2006] argue that there is still a lack of realism of virtual characters in scenes, although virtual environments have progressed quite a lot in terms of how realistic the scenes appear. It seemed clear to users that the virtual figures did not have any personality but they were instead preprogrammed. Therefore the authors advocated to make the characters more human-like.

One interesting interactive application is to employ characters in virtual learning environments (VLEs). Such an application can be used for example to assist children aged 8-11 years in dealing with social problems of bullying and mobbing in schools. In fact, VLEs populated with virtual characters offer children a safe environment where they can explore and learn via experiential activities. [Hall et al. 2004] carried out a similar project by using a software package called FearNot. In their project, FearNot presented the children with a bullying scenario with few virtual characters. Based on the children' choices taken during a simple dialogue with one of the characters, the narrative of the story could have had different endings. The objectives of this project was to teach children the strategy to use to solve a specific drama. Or if the children had selected strategies that frequently did not work, the educational message to them would have been to tell the drama to someone they trust.

### 5.2 Phobias

Phobias are common forms of anxiety disorders. Phobias are typically treated by using gradual exposure therapy that consists in exposing patients to anxiety-provoking stimuli in a gradual order with the aim to attenuate their anxiety. If the anxiety decreases, a more fearful situation is created. Traditionally, those stimuli are looked for in actual physical situations (in vivo) or by having the patient imagine the stimulus (in vitro). VR and virtual environments allow for an alternative/complementary option of exposure therapy. VR has been already used in treating specific phobias such as fear of heights, fear of spiders, fear of flying and claustrophobia, as well as agoraphobia (see for example [VR_Phobias 1999; VR_Med_Center 2007]).

[Takacs and Simon 2007] describe their clinical experience in deploying VR therapy for treating a variety of psychological disorders including depression, age-related conditions, pain distraction, anger-management as well as common phobias. They address three major aspects of rehabilitation:

*cognitive rehabilitation* - where visual stimuli and exercise in virtual environments are carried out to help patients regain their cognitive capabilities (e.g. after a stroke);

*psychological rehabilitation* - to help patients overcome fear, phobias and side-effects associated with stress;

*physical rehabilitation* - designed to make patients interact with virtual objects and carry out exercise in virtual space.

The authors state that they have successfully used the system, and present clinical validity results.

[3] It is reported that children with ASD show affinity for computers [Hart 2005]

To summarize, there is evidence from clinical data that VR can help to address a number of psychological disorders, and that there is an increasing number of health-care applications where VR can play a relevant role. Furthermore, VR-based therapy techniques offer a number of advantages over traditional ones, for example, they give the possibility of treating different kinds of phobias, stimuli in virtual environments can be manipulated, and patients can be confronted with their fears in environments that are felt safer than the real one.

## 6 Discussion

Once the characters' architecture is fully implemented, we aim at developing applications that build upon it. In particular, we aim at conceiving and developing interactive applications to be made publicly available. Such applications can be developed for different public sectors ranging from entertainment to education and health. Our primary objective is both to test the agent architecture and to develop concrete applications that can be of benefit in society. We expect that deploying complex forms of reasoning and learning as well as advanced forms of perception (for example, the ones that will incorporate techniques to acquire, interpret and select sensory information) will enhance realistic behavior modelling of virtual characters. Furthermore, ascribing emotions and personality traits to virtual characters will allow us to define complex forms of human-computer interaction.

One interesting test bed for our system would be to apply virtual characters and storytelling to create improvised dramas in a virtual school. Our vision is that Hall's original project (see Section 5.1) could be expanded in a number of ways, for example, to exploit better and more advanced types of human-computer interaction as well as to provide children with more realistic scenarios. This could be possible by exploiting our results and implemented characters' architecture. Of course, this must be done along side with cognitive psychologists, medical doctors, and school teachers.

Another challenging application where we can exploit VR-based technology is one that addresses the problem of facial expression recognition. It is well-documented that facial expression perception is impaired for example in individuals diagnosed with autism or Asperger's syndrome (see [Hobson et al. 1988; Phillips 2004]). In fact, autistic people do not appear to be able to pick up facial signals and notice other people's emotions. They can't read the signals or facial expressions of emotions in a normal way. Naturally, not being able to do so affects their social interactions. Recently, an interactive computer software program called FaceSay[4] has been shown to improve the ability of children with autism spectrum disorders (ASD) to recognize faces, facial expressions and emotions, according to the results of a study conducted by psychologists at the University of Alabama at Birmingham (UAB) [ScienceDaily Jun, 2007]. We believe that by ascribing virtual characters cognitive capabilities, perception and emotions we can go one step further. In fact, we can link the virtual character's facial expressions to its internal emotional state. Furthermore, since the emotional state depends upon the virtual character's cognitive and perceptive capabilities, we can relate the facial expression recognition problem to the problem of understanding the virtual character's cognitive/mental state. For example, we can associate the gesture of smiling (denoting happiness) to the fact of having successfully carried out a certain action. In this way, the understanding of the character's mental state will help in recognizing its emotional state, and vice versa. We hope that by establishing this association will help autistic people to enhance their overall ability in recognizing emotions and ultimately to improve their social interaction skills.

One major criticism to the use of VR-based technology for treatments is that the cost of this technology may be very high, and therefore its availability will remain limited (at least for the time being). Furthermore, some patients may experience simulation sickness. However, we already have VR technology and equipments available at our institution that we can freely use.

[4]Created by Symbionica L.L.C., features interactive games that let children with ASD practice recognizing the facial expressions of an avatar. Specifically, the computer game teaches the children where to look for facial cues such as an eye gaze or a facial expression. FaceSay is available at www.facesay.com

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