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Design Principles for Special Purpose, Embodied, Conversational Intelligence with Environmental Sensors (SPECIES) Agents

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Theory & Review

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Abstract

As information systems increase their ability to gather and analyze data from the natural environment and as computational power increases, the next generation of human-computer interfaces will be able to facilitate more lifelike and natural interactions with humans. This can be accomplished by using sensors to non-invasively gather information from the user, using artificial intelligence to interpret this information to perceive users' emotional and cognitive states, and using customized interfaces and responses based on embodied-conversational-agent (avatar) technology to respond to the user. We refer to this novel and unique class of intelligent agents as Special Purpose Embodied Conversational Intelligence with Environmental Sensors (SPECIES) agents. In this paper, we build on interpersonal communication theory to specify four essential design principles of all SPECIES agents. We also share findings of initial research that demonstrates how SPECIES agents can be deployed to augment human tasks. Results of this paper organize future research efforts in collectively studying and creating more robust, influential, and intelligent SPECIES agents.

**Keywords**: Embodied conversational agents, interpersonal sensors, system design

INTRODUCTION

The natural progression of human interactions with machines is leading to systems that can automatically and unobtrusively assess human states—such as anxiety, satisfaction, boredom, and credibility—and interact naturally with human users based on this assessment. These systems depart dramatically from the traditional systems that react to information that is manually and deliberately submitted by users (e.g., input communicated via a keyboard, mouse, touch screen, etc.). These systems utilize unobtrusive sensors, cameras, and recording devices to capture not only deliberate information such as spoken dialog, but also more subtle information such as physiological cues (e.g., fluctuation in voice, eye gaze, pulse, blood diffusion) that can be indicative of one's psychological state. In response to this information, such systems can conduct very influential, relevant, and lifelike interactions with humans. We refer to this next generation of advanced intelligent systems as Special Purpose Embodied Conversational Intelligence with Environmental Sensors (SPECIES) agents.

Due to the novelty of SPECIES agents, very little research explains how to design and build such systems. Of note, past research has looked at how agents can interact with people in a variety of team settings (Klein et al., 2004; Christoffersen and Woods, 2002). Agent-based systems have also been shown to make knowledge-based recommendations and exhibit human characteristics such as rationality, intelligence, autonomy, and environmental perception (Wooldridge and Jennings, 1995). However, rigorous design principles regarding how to assess human states and make these agents more natural, lifelike, and influential have not been posited. Hence, the purpose of this paper is to provide a framework for the study and design of SPECIES agents. To this end, we build on interpersonal communication theory to specify four design principles of all SPECIES agents. We then provide in-depth descriptions of each design principle and an example from our current research. The resulting framework will organize future efforts to collectively study and create more robust, influential, and intelligent SPECIES agents.

SPECIES AGENT DESIGN PRINCIPLES

To develop design principles for SPECIES agents and to establish a framework for future SPECIES research, we adapt the Osgood and Schramm model of interpersonal communication (hereafter referred to as the Schramm model) to the context of human-computer communication. The Schramm model (Schramm, 1954) outlines the basic components of communication between two people (Figure 1). The rationale for this adaptation is that for computerized agents to be more natural, lifelike, and influential, they must adopt the characteristics of human communication. Building on Schramm's model, we define four essential design principles for all SPECIES agents - they must be capable of: 1) engaging in purposeful communication, 2) decoding human messages through sensors, 3) interpreting sensor information to formulate a response, and 4) encoding a response. This paradigm closely relates to well-known intelligent agent activities of sensing and affecting the environment (Wooldridge, 2009, 1999). Below we discuss the four key distinctions derived from our adaptation of the Schramm model.
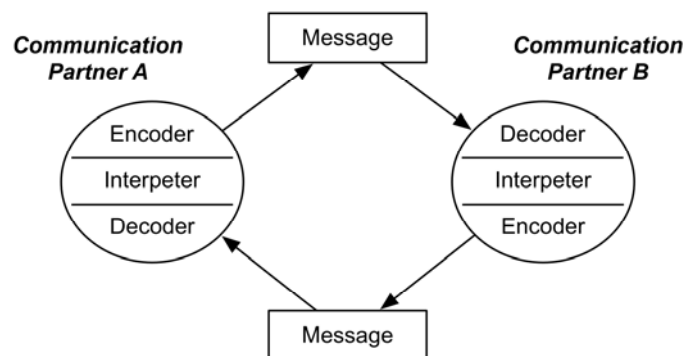
Figure 1: Schramm Model of Communication

A primary proposal of the Schramm model is that interpersonal communication occurs by the exchange of purposeful messages in a reciprocal, circular fashion. This proposition is grounded in earlier seminal communication theory (Shannon and Weaver, 1949), which explains that information is communicated in an effort to accomplish an objective. Later research has described communication as inherently strategic, purposeful, and goal-directed (Kellermann, 1992), originating from the fact that communication has structure. For example, sentences are not formed by randomly choosing meaningless words out of a bag-of-words, and facial expressions do not occur at

random intervals. Rather, words and other forms of communication are selected (albeit automatically) to communicate a meaningful message (Kellermann, 1992). Thus, the first design principle of SPECIES agents is that they must be capable of directing meaningful communication. In the context of SPECIES agents, "meaningful" is synonymous with "goal-directed." A SPECIES agent should be focused on accomplishing an embedded, discrete goal. For example, SPECIES agents could be designed to detect deception in a security context, to assess learning in an online learning context, negotiate a contract in a business context, or conduct a job interview in a hiring context.

Second, the Schramm model posits that people decode meaningful messages during communication. Decoding refers to receiving a message. In an interpersonal communication context, this is done through human senses such as hearing and sight. These nervous impulses travel to the brain where the human begins to translate them (Schramm and Roberts, 1971). It is important to note that in the Schramm model, decoding (i.e., sensing) and interpreting (i.e., making meaning of nervous impulses) occur in two separate steps. Likewise, SPECIES agents must also be capable of "sensing" information. This can be done through a variety of unobtrusive electronic sensors such as visible light cameras, thermal cameras, audio recorders, and the Laser Doppler Vibrometer. Information is gathered and stored in memory to be interpreted during the next stage of the Schramm model. To mimic a realistic and lifelike interaction, the sensors on a SPECIES agent should unobtrusively gather information without any special effort by the human communication partner. Accordingly, the use of keyboards and computer mice as the primary means of communication between humans and SPECIES agents is discouraged. In summary, the second design principle of SPECIES agents is that they must be capable of decoding information through the use of sensors.

Third, the Schramm model proposes that humans interpret the information gathered during the decoding stage. *Interpreting* can be defined as *making meaning of* sensory information (Schramm and Roberts, 1971). During a face-to-face conversation, humans will interpret sounds as recognizable words, and put the words together to make meaningful sentences. The human will also begin formulating a response in his or her cognition based on the interpretation. Similarly, SPECIES agents must have the ability to interpret sensor information. This can be done using artificial intelligence. For example, using computer vision paired with a supervised learning technique, an agent can interpret a video stream and make meaning of human movements (e.g., interpret that the human looks nervous). Using vocalic and linguistic techniques, the agent can interpret spoken words. The agent must then be capable of using these interpretations to formulate or choose a meaningful response.

Fourth, the Schramm model explains that after humans interpret nervous impulses during the previous step, they must encode meaningful messages to send to their communication partners based on the interpretation. In a face-to-face context, humans often relay spoken words to each other, display facial gestures, change their posture, move their hands, or change voice pitch. Likewise, a SPECIES agent must be capable of encoding and relaying messages to its human communication partner. These encoded messages are analogous to *effectors* in the context of intelligent agents. An effector is a device used or action taken by an artificially intelligent agent to produce a desired change in an object or environment in response to an input. The SPECIES operating environment consists primarily of humans who can be difficult to assess, represent, and influence. Thus, SPECIES agents must utilize novel effectors to affect both humans and the environment These effectors include human influence tactics, impression management techniques, communication messages, agent appearance, agent demeanor, and potentially many other interpersonal communication and persuasion strategies.
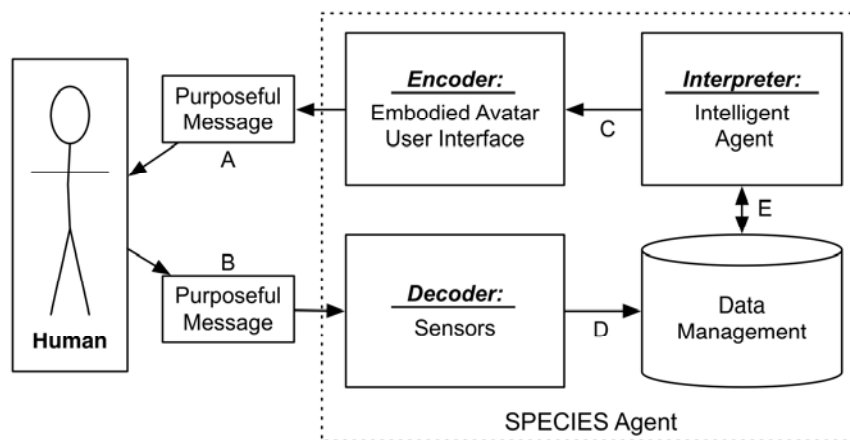
A: Embodied Agent Signals and Messages to the Human (Encoded Messages)
B: Human Behavior and Psychophysiological Signals and Messages (Decoded Messages)
C: Agent Effectors that Change Embodied Appearance and Messages (Interpretation and Embedded Goals)
D: Data Storage and Segmentation (Similar to Human Memory)
E: Data Fusion and Representation

Figure 2: Components of the SPECIES Agent Design Paradigm

We propose that by definition SPECIES agents must adhere to all four interpersonal communication principles described by the Schramm model to conduct meaningful, persuasive, and human-like communication. In summary, all SPECIES agents must be capable of: 1) engaging in purposeful communication, 2) decoding human messages through sensors, 3) interpreting sensor information to formulate responses, and 4) encoding responses to relay to the human. Figure 2 summarizes and visualizes these four components in a SPECIES agent design. In the remainder of this article, we summarize the current state of research in each of these four areas.

SPECIES Design Principle 1: Engage in Purposeful/Special Purpose Communication

Special-Purpose Communication

SPECIES agents are not general-purpose conversational agents. They must have a *special purpose*—a concrete context and purposeful communication objective. This is consistent with Task-Technology Fit theory, which explains that IT is more likely to have a positive impact on performance if it matches the task the user must perform (Goodhue and Thompson, 1995). The theory suggests two components of a successful IT implementation: complementary task characteristics and technology characteristics. In the context of SPECIES agents, one must analyze the characteristics of the task the SPECIES agent must perform and design the SPECIES agent to accomplish that special purpose. This makes them similar to high-level dialog systems focusing on a narrow band of knowledge (Schumaker et al., 2007). Examples of special purposes could include conducting an interview for a specific job, detecting deception at a border crossing, or assessing learning for an online class.

This first design principle has two benefits. First, it limits the context and interpretation requirements placed on the SPECIES agent. Unlike general purpose conversational agents, SPECIES agents are bounded in their expertise, vocabulary, and context depending on their specified purpose. This allows more manageable and in-depth interactions with human counterparts because it restricts the interpretation and conversation that must be performed. It also allows the designer to focus on the purpose of the agent. Critical design questions to determine the special purposes of SPECIES agents include:

- *What is the task this agent intends to automate?*
- *What is the goal of the agent?*
- *What is the context in which people will interact with this agent?*
- *What embedded knowledge must be included into the agent to carry out this task or reach the goal?*
- *How can this knowledge be represented?*

The second benefit of this design principle is that it provides the objective for the intelligent agent. As the agent decodes (through sensors) and encodes messages (with effectors), its embedded purpose is the driving force in the interpretive stage of communication. For example, if one agent's goal is to calm down a frustrated user and another agent's goal is to create arousal in a user, each agent will take a different action during the encoding phase.

Example from Research

A prototype SPECIES agent has been created with the special purpose of interviewing individuals as they attempt to pass through a security checkpoint. People deceive, and there are many circumstances in which rapidly detecting deception is vital for security and safety.   For example, the US border is a conglomerate of divergent issues, namely: security, immigration, and trade. Every year, over 300 million people legally pass through the United States–Mexico border. Additionally, Mexico and Canada are the largest trading partners of the United States. However, intermingled with this huge volume of legal commerce, there is the persistent problem of illegal border crossings. Clearly, one of the most challenging and important aspects of border security is to distinguish truth from deceit in interpersonal communications, while limiting interference with legal and vital commerce.

To more completely understand this pressing need, we participated in a field study with agents from US Customs and Border Protection (Office of Border Patrol and Office of Field Operations), Immigrations and Customs Enforcement, and the Federal Bureau of Investigation. The goal was to bring representatives from these agencies together where they could discuss issues they face in their daily work. All of the participants were allowed to anonymously voice their opinions. Agents indicated that they would like technology to aid in the detection of hostile intent, criminal backgrounds, and deception when interviewing people at ports of entry and suspects apprehended in the field. The SPECIES agent for automated interviewing is an outgrowth of their stated desires and interest. The goal of the agent is to naturally interact with people, conduct a screening interview, and process user responses. It evaluates physiological and behavioral deviations from group and individual baselines in order to discriminate between truthful and deceitful communication.

Given the first design principle, the agent's special purpose is to automate security-screening interviews. The goal of the agent is to discriminate between truth-tellers and deceivers. Its context is driven by screening questions and responses to interview questions. The embedded knowledge includes how avatar gender and demeanor affect users' perceptions of power, likability, and expertise (Derrick, 2011) as well as information that can be used to discern deception (Derrick et al., 2010b).

SPECIES Design Principle 2: Decode Human Messages through Environmental Sensors

One of the powerful and novel aspects of SPECIES agents is that they are able to naturally interact with a person. In an interpersonal communication context, decoding (receiving messages) is done through human senses such as hearing and sight (Schramm and Roberts, 1971). SPECIES agent "sensing" is accomplished through a variety of electronic sensors such as visible light cameras, thermal cameras, microphones, and laser Doppler vital monitoring. The sensors that should be used will vary depending on what information the SPECIES agent needs to analyze to create an appropriate response. Table 1 is a partial list of SPECIES sensors and the information that research has shown can be abstracted from humans using these sensors.

Table 1: Partial List of SPECIES Sensors

Sensor	Information that research has shown can be abstracted from humans using these sensors
Thermal Sensors	Deception (Pavlidis et al., 2002; Tsiamyrtzis et al., 2007), emotional states, blushing, embarrassment, threat responses, and surprise (Burgoon, 2009)
Cardiorespiratory Sensors	Arousal, emotional stress (Kurohar et al., 2001), and cognitive effort (Ryan et al., 2003)
Vocalic Sensors	Anxiety, arousal, emotion, and cognitive states (Rockwell et al., 1997)
Computer Vision	Arousal, emotional states, memory processes, message production, and communicator strategies (Meservy et al., 2005)
Pupilometry Sensors	Familiarity (Vrij, 2008), arousal, and stress (Lubow and Fein, 1996)

Often human states, emotions, and responses cannot be reliably detected using only one sensor. In other words, there is no "silver bullet" for deception. To accurately detect deception, data from several sensors must be combined. Hence, when deciding what sensors to implement in a SPECIES agent, one should ask the following questions:

- *What information does the SPECIES agent need to obtain from the human?*
- *What sensors can obtain that information?*
- *Are there multiple sensors that can be implemented to measure the same human state to increase the accuracy and reliability of predictions?*

Next, we briefly describe each class of sensors and then share our results regarding the integration of one of these sensors into a SPECIES agent.

Sample Indicators and Sensors

Thermal Sensors. Thermal imaging technology measures changes in regional facial blood flow, particularly around the eyes. Changes in the orbital area may reflect changes in blood flow related to the fight-or-flight response mediated by the sympathetic nervous system. Assessments of the human state are based on the temperature signal patterns identified during the interaction (Levine, et al., 2001; Pavlidis et al., 2002; Tsiamyrtzis et al., 2007). As illustrated in Table 1, thermal imaging can be used to detect deception, emotional states, blushing, embarrassment, threat responses, and surprise.

Cardiorespiratory Sensors. Pulse rate, blood pressure, and respiration rate have been shown to be reliable indicators of arousal. These measures are sensitive to emotional stress and increases in cognitive effort. Cardiovascular measures are particularly appealing because they are involuntary, even when breathing can be regulated. Despite this fact, recent studies have shown that individuals tend to inhibit breathing when faced with stress (Levine et al., 2001; Pavlidis et al., 2002; Tsiamyrtzis et al., 2007). Continuing advances in technology promise to provide additional cardiovascular indicators of stress including systolic time intervals and contractility (Ryan Jr. et al., 2003). A sensor for non-invasively capturing cardiorespiratory measurements is the Laser Doppler Vibrometer (LDV) (Derrick et al., 2010a). The LDV system uses laser imaging and Doppler sound waves to measure pulsations of the carotid artery in

a visible portion of the neck. The LDV technology is based on the theoretical concept that internal physiology has mechanical components that can be detected in the form of skin surface vibrations. The system utilizes a class-2 (medically safe) laser and the Doppler Effect to sense and measure vibrations in the carotid artery by targeting the carotid triangle. The multiple cardiorespiratory measures that are obtained are used to differentiate among stress and emotional states (Derrick et al., 2010a).

Vocalic Sensors. Vocalic cues fall into three general categories, which include time (e.g., speech length, latency), frequency (e.g., pitch), and intensity (e.g., amplitude) (Scherer, 1985). An increase in pitch or frequency has been associated with arousal (Rockwell et al., 1997; DePaulo et al., 2003), which presumably results from anxiety. Using high quality audio recording equipment and both commercial and custom vocal signal processing software, research has discriminated between emotional and cognitive states (Meservy et al., 2005).

Computer Vision. Computer vision refers to the process of extracting information from images or video. In essence, it has been described as giving computers the ability to "see." It is often used to detect kinesic movements from video, including facial expressions, gaze, head movements, posture, gestures, limb movements, and gross trunk movements. These movements have been shown to be predictive of arousal, emotional states, memory processes, message production, and communication strategies (Burgoon, 2005; DePaulo et al., 2003). Common computer vision methods include, but are not limited to, active shape modeling and blob analysis (Burgoon et al., 2010).

Pupilometry Sensor. Pupilometry is the study of changes in pupil size and movement, which has been suggested to be an orienting reflex to familiar stimulus (Vrij, 2008). Pavlov (1927) originally studied the orienting reflex during his classical conditioning experiments. This reflex orients attention to novel and familiar stimuli and is considered adaptive to the environment (Sokolov, 1963). Pupil dilation can also result from sympathetic nervous system stimulation or suppression of the parasympathetic nervous system. These peripheral nervous system responses are theorized to reflect arousal or stress, which result in pupil dilations. Difficult cognitive processes and arousal have been found to impact pupil response (Lubow and Fein, 1996). Pupilometry can be measured through the use of low-level near-infrared cameras. The infrared light is slightly outside the spectrum of visible light and therefore does not cause changes in the pupil.

Example from Research

In a theory-driven experiment to test arousal and familiarity, we decoded pupilometry characteristics. To capture the eye behavior responses, we used the EyeTech TM3 (see Figure 3). The EyeTech TM3 tracks gaze patterns and pupil dilation as people look at images. Subjects must gaze in the direction of the sensor for it to accurately capture data. Thus, because the images were displayed on a computer screen, the EyeTech TM3 was mounted directly below the computer screen.


Figure 3: EyeTech TM3

The TM3 has two near-infrared light sources that are outside of the spectrum of visible light and an integrated infrared camera. It connects via USB to a Windows computer and captures the eye gaze location (x, y coordinates) and pupil dilation at a rate of approximately 33-34 frames per second. Before the test was conducted, several participants validated the instructions and research design through a pilot test. After incorporating the feedback from the pilot test, we recruited 41 participants for this initial study. These participants included 30 European Union Border Guards and 11 MIS undergraduate students. The experimental data were collected using a straightforward two-treatment, between-group research design that required some participants to assemble a realistic, but not operational, improvised explosive device (IED). Participants in the first treatment—the control group—were in the non-bomb-making condition and therefore completely unfamiliar with the IED. Participants in the second treatment group became familiar with a simulated bomb and the bomb-making materials and then actually assembled the device. Participants were randomly assigned to treatments, and the experiment participants in the bomb-making condition received the bomb-making materials and assembly instructions that included an image of the assembled bomb (Figure 4). The instructions were as follows:

You will construct the IED pictured above with the materials provided to you. Follow the steps below in exact order to replicate the IED shown above.

Materials list:
- *Pipe*
- *Timer*
- *Battery*
- *Switch*
- *Zip ties*

1. *Orient the switch so the "1" is on the bottom. Firmly attach the switch to the left hand side of the pipe with two zip ties. Make sure the back of the switch is pressed against the white piece of Velcro already attached to the pipe. Make sure you don't break the switch module by tightening the zip ties too tight.*

2. *Attach the 9V battery to the 9V battery connector coming from the switch module.*

3. *Attach the Velcro on the 9V battery to the pipe above the switch module as shown in the picture. Make sure the connections on the battery are facing to the left (outward).*

4. *Orient the timer so the 4 digital numbers are at the bottom. Attach the timer to the pipe by placing the white Velcro on the back of the timer onto the black Velcro on the metal pipe. Position the right edge of the timer flush with the inside edge of the pipe cap.*

5. *Clip the red alligator clip coming out of the end of the pipe to the red wire coming out of the timer as shown above. Do the same with the black clip.*

6. *Clip the red alligator clip coming from the switch to the red wire coming from the left side of the timer as shown in the picture above. Do the same with the black alligator clip.*
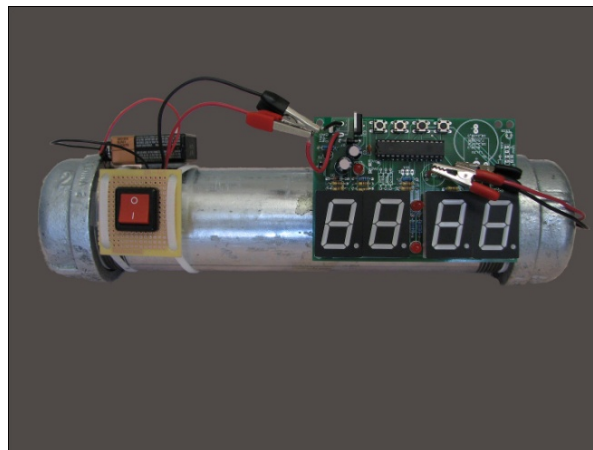
Figure 4: Completed IED

Participants took approximately 5-7 minutes to assemble the device. After the "bomb" was completed, participants packed a bag with clothes, shoes, and the IED and went to the SPECIES agent for screening. Those in the control group who did not construct an IED packed a bag with only clothes and shoes and then went directly to the SPECIES agent to begin the automated interview. At the station with the SPECIES agent, experiment personnel used a brief calibration program to calibrate the eye-tracking device to the participants' eyes. Then, the SPECIES agent communicated the following messages:

- Please state your full name.
- Are you a citizen of the United States?
- Where are you travelling from?
- What was your business there?
- Do you have anything to declare?
- Please carefully examine the following images (The following images (Figures 5, 6, and 7) were then displayed for 12 seconds each).
- Have you ever seen a device similar to this image? (Figure 6 is repeated).
- Please see the officer at the next available station. Thank you for your cooperation.

The participants were then debriefed, dismissed, and the bomb was disassembled. The first and third images were used as basic foils and to allow for task acclimation. The key image of interest was Figure 6. Please note the differences in Figures 4 and 6. Figure 4 shows the IED that the participants assembled. Figure 6 is the same device, but the button, battery, and connecting leads were removed to make this image novel to participants who assembled the device.

Figure 5: First Image Shown to Participants   **Figure 6: Second Image Shown to Participants**
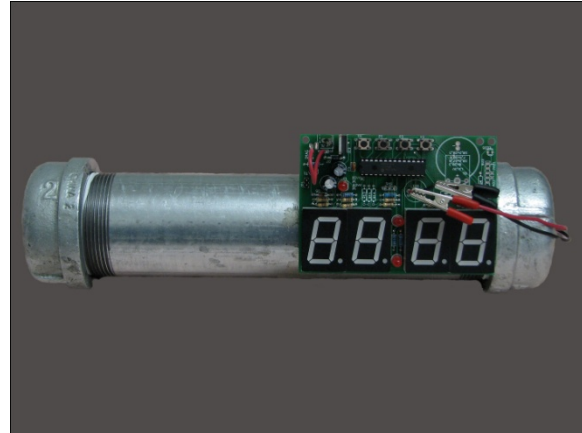
Figure 7: Third Image Shown to Participants

As previously mentioned, the images were shown for 12 seconds each and the participants' eyes were sampled at a rate of every ~30ms (33-34 samples per second). For each sample, we captured the (x, y) gaze location on the screen (in pixels) and dilation for both eyes; this six-tuple is denoted as s_n below. We captured the total number of samples for the participant denoted by set *P*. Based on the image, screen size, and resolution, we determined that the region of interest was any pixel on the x-axis less than 650 (the region where the switch was located). For every sample (s_n), we calculated the average x coordinate using the gaze position of each eye (x_{an}) and then determined if it was in the region of interest denoted by the set *I*.

$s_n = (x_{n\text{-left-eye}}, x_{n\text{-right-eye}}, y_{n\text{-left-eye}}, y_{n\text{-right-eye}}, d_{\text{right-eye}}, d_{\text{left-eye}})$
$P = \{s_1, s_2, \dots, s_n\}$
$x_{an} = (x_{n\text{-left-eye}} + x_{n\text{-right-eye}}) / 2$
$s_n \in I \text{ iff } x_{an} < 650$

We then calculated the percentage of the samples in the region of interest using the following formula: $\frac{|I|}{|P|}$.

Using this metric, we created a box plot to compare the two groups (Figure 8). The plot indicates there is a marked difference in eye gaze behavior between the two groups. The mean percentage of time the control group gazed at the

area of interest was 12.61% (*SD* = 6.46%); whereas the mean time the IED-making group gazed at the area of interest was 28.82% (*SD* = 13.67%). The participants in the bomb-making condition gazed much longer at the altered portion of the image. A Welch two-sample T-test shows that those in the aroused condition (bomb-making) viewed the image differently than those who were not familiar with the device (T = -4.956, df = 30.853, p < .001). We also analyzed the pupil diameter by comparing the dilation during the first image to the dilation during the second image, and found that those who built the bomb had a difference in pupil dilation almost twice as great as those that had not seen the bomb. The mean for the control group was .1139mm (*SD* = .1938mm) while mean of the IED-making group was .2146mm (*SD* = .2119mm.) These differences are shown in Figure 9.
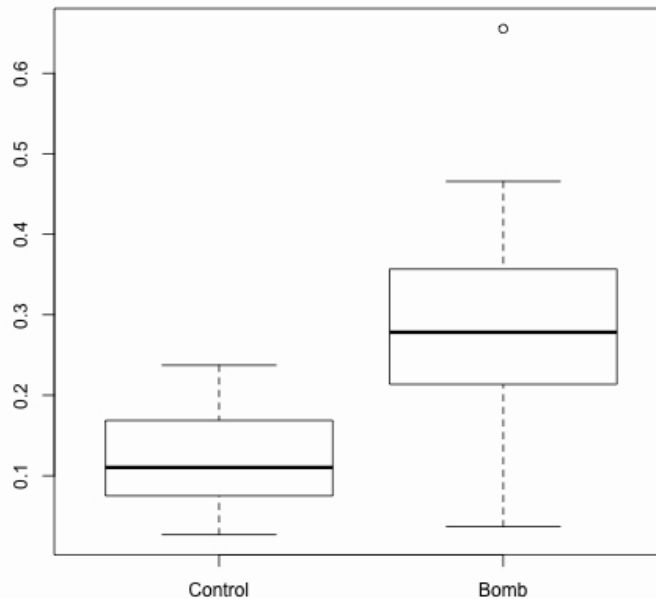
Figure 8: Percentage of Eye Gaze in Area of Interest

This study shows three important examples related to SPECIES agent design principles. First, in accordance with the first principle, the agent had a discrete context and "special purpose." Second, the SPECIES agent controlled and managed a reciprocal interaction as described by the Schramm model. Third, participant arousal and behavior were sensed by the infrared camera and interpreted by the agent given the current context.
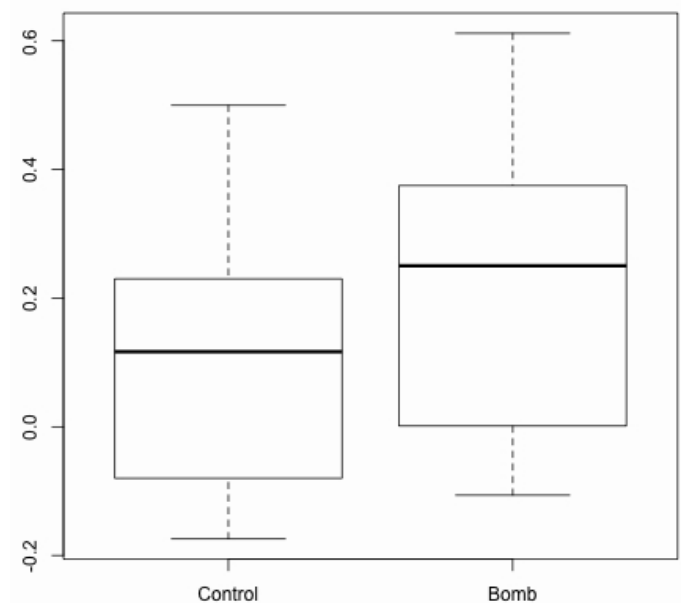

Figure 9: Pupil Dilation Differences

SPECIES Design Principle 3: Interpret Sensor Information to Formulate a Response

Signal Detection Theory

The third SPECIES design principle is to interpret the data captured by sensors to draw an intelligent conclusion. This is accomplished following the principles of signal detection theory (SDT) (Green and Swets, 1974; Stanislaw and Todorov, 1999). SDT explains an approach for identifying signals, or, in our context, human states that are sufficient to initiate a response from the SPECIES agent. For example, if a SPECIES agent "hears" the word "yes" to a question, the agent will detect that the "yes" signal is present and render an appropriate response to the human's answer. Or, if a SPECIES agent detects an increase in pupil dilation, the agent could determine the signal of "familiarity" is present and render an appropriate response to this familiarity.

A SPECIES agent will determine that a signal is present if the decision variable is greater than a specified threshold (known as the criterion). The decision variable refers to the measures obtained from the SPECIES sensors (e.g., vocalic measures, pupil diameters, vital signs, linguistic measures), which are captured and then represented in numeric format. Importantly, although a decision variable value might be greater than the criterion, it may not mean a signal is present and vice versa. For example, although a SPECIES agent might automatically transcribe the word "yes" as an answer to a question, the human might have said a similarly sounding word, such as "guess." An increased reading in pupil dilation might be due to an instrument calibration error rather than familiarity. This is consistent with popular interpersonal communication theory that claims "noise," or error, can and will interfere with decoding and interpreting information (Shannon, 1948). In SDT, a decision variable reading that is not a signal in reality is also referred to as noise. Both signal decision variables and noise decision variables are normally distributed and are referred to as the signal distribution and noise distribution accordingly. Figure 10 illustrates the signal distribution, noise distribution, criterion, and decision variable as denoted by SDT.

For SPECIES agents to correctly interpret sensor information, a criterion must be placed accurately. For example, how does a SPECIES agent know what psychophysiological indicators (e.g., pulse, eye gaze, fidgeting) indicate arousal in a human, and at what point do those indicators merit a response from the SPECIES agent? To address this, machine learning algorithms are utilized to determine the optimal placement of the criterion. Machine learning refers to algorithms that allow a computer to evolve behaviors based on empirical data, such as sensor data from the SPECIES agent. Machine learning algorithms can be described using two paradigms–supervised learning and unsupervised learning.
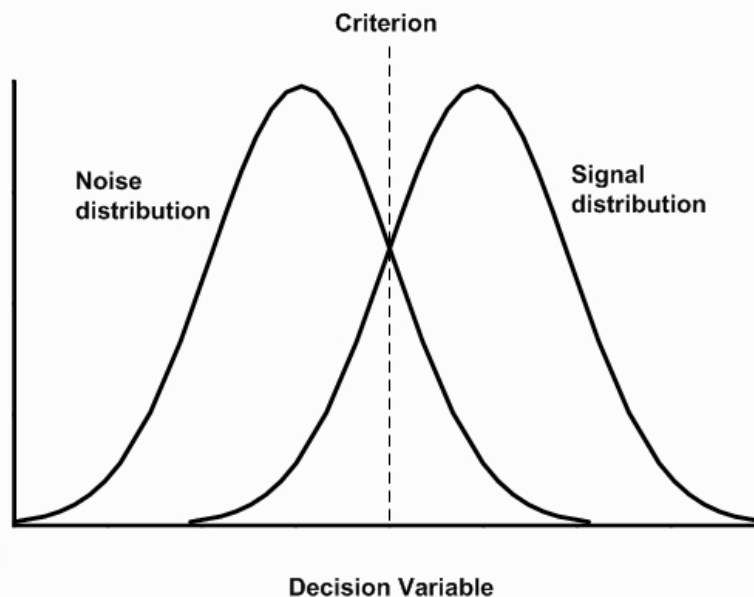

Figure 10: Illustration of Signal and Noise Distribution

Supervised learning refers to algorithms that take training examples with input/output pairs and learn how to predict the output values of future data. For example, a SPECIES agent that is trying to detect arousal from heart pulse (obtained unobtrusively through the LDV) will learn how to make this prediction using training data that contains 1) a heart pulse reading and 2) whether or not the person was aroused. Using this information, the algorithm will identify

patterns and boundaries (i.e., criterion) that predict arousal, which can be used to categorize future data. To predict sophisticated outcomes (e.g., confidence, deception, boredom, etc.) data from many simultaneous sensor streams have to be incorporated into the algorithm to make an accurate prediction. Examples of supervised learning algorithms include: support vector machines, artificial neural networks, Bayesian statistics, ID3 and C4.5 decision tree building algorithms, Gaussian process regression, statistical techniques, and naive Bayes classifiers.

Unsupervised learning refers to algorithms that take input training examples without an output value (data that has not been previously categorized). Using this data, the algorithms uncover patterns to predict output values. These can be used to create categorizations of people. For example, not all people will interact with a particular SPECIES agent in the same way; some people have computer anxiety, some people find it difficult to attribute credibility to computers, and so forth. A priori, it can be very difficult to create these categories, as many categories could exist. However, using a self-organizing map, categories of people can be created automatically from data based on how people respond to the system. A SPECIES agent can further customize responses to people based on these categories. Examples of unsupervised learning algorithms include: neural network models, self-organizing maps, and adaptive resonance theory.

Example from Research

Interpreting data from sensors that can be incorporated into SPECIES agents is a growing area of research. For example, Derrick et al. (2010) used the Laser Doppler Vibrometer (LDV) to interpret cardiovascular measures to categorize deception; Langhals et al. (2010) interpreted Active Shape Modeling data (a computer vision technique) to predict an increase in cognitive load by counting eye blinks; Jensen et al. (forthcoming) interpreted linguistic characteristics of a message to detect deception; Elkins (2010) interpreted vocalic measures to predict credibility; and Burgoon et al. (2010) measured data from an automated kinesic analysis (e.g., gestures and adapters) to measure cognitive load, nervousness, and arousal that are akin to deception.

Building on our previously discussed example of using pupilometry to detect familiarity with an IED, we created a binary decision tree for classification of familiarity based on gaze behavior and pupil changes. If the eye gaze duration was less than 23% in the area of interest and pupil diameter change was less than .28 mm, the participant was classified as in the control group, or not familiar with the IED. Based on this classification model, the results showed an overall classification rate of 87.8%. The classification matrix is shown in Table 2.

Table 2: Classification Results

	Bomb	Control
Bomb	20	3
Control	2	16

SPECIES Design Principle 4: Encode a Response to Relay to the Human

SPECIES agents must be capable of encoding a response to the human user based on the interpretation of sensor data. A SPECIES agent can respond to humans using its rendered, embodied interface and its audible responses. In our context, embodied agents refer to virtual, three-dimensional human characters that are displayed on computer screens. If an embodied agent is intended to interact with people through natural speech, it is often referred to as an Embodied Conversational Agent, or ECA (Patton, 2009). Embodied Conversational Agents are becoming more effective at engaging humans in a human-like manner. It has been proposed that Embodied Conversational Agents could be used as an interface between users and computers (Deng et al., 2006). Table 3 shows the distinctions between embodied agents and Embodied Conversational Agents (ECA) (Patton, 2009).

Table 3: Distinctions between Virtual Actors

Interface	3D Representation	Automated Control (Intelligent Agent)	Human Control	Communicates via Speech
Embodied Agent	Yes	Yes	No	No
Embodied Conversational Agents	Yes	Yes	No	Yes

There are several reasons to use an embodied face over only sound and text when communicating and interacting with individuals. People interacting with embodied agents tend to interpret both nonverbal cues and the absence of nonverbal cues. Embodied agents can effectively communicate an intended emotion through animated facial expressions (Kätsyri and Sams, 2008). The nonverbal interactions between individuals include significant conversational cues and facilitate communication. Incorporating nonverbal conversational elements into a SPECIES

agent can increase the engagement and vocal fluency of individuals interacting with the agent (Gratch et al., 2006). The agent used in the experiment described in this bomb experiment is shown in Figure 11 below.

Figure 11: Embodied Conversational Agent Used Experiment

For a SPECIES agent to successfully convey a response to a human, the SPECIES agent must be persuasive. Embodied agents can affect their environment by the persuasive messages that they deliver and persuasive behavior that they exhibit. To help address this need, the frameworks of persuasive technology presented by Oinas-Kukkonen and Harjumaa (2009) and Fogg (2003) can be adapted to the context of SPECIES agents. These frameworks help system designers generate precise requirements for system qualities that promote persuasive human-computer interactions. Oinas-Kukkonen and Harjumaa (2009) identify four categories of persuasive design principles: primary task support, dialog support, system credibility support, and social support. We describe these four categories in detail and expand upon them by proving theoretical explanations of how they influence the persuasiveness of SPECIES agents. We also give examples of how to implement each category. The following sections enumerate design principles for SPECIES agents and show how these intelligent agent systems can incorporate these persuasive technology design principles.

Primary Task Support

The first category of persuasive design that can improve the persuasiveness of systems is primary task support. *Primary task support* refers to the measures taken to aid the user in carrying out his or her primary task for using the system (Oinas-Kukkonen and Harjumaa, 2009). Its influence on persuasion can be explained through at least two mechanisms: 1) through creating positive affect and 2) through reducing biases and increasing cognitive elaboration. First, primary task support increases positive affect. When a system supports the user in completing his or her goal with the system (e.g., through reduction, tunneling, self-monitoring, simulation, and rehearsal), this increases the cost-benefit ratio of using the system (Garrity et al., 2005), resulting in positive affect (Briggs et al., 2008). Positive affect successfully yields an increase in the persuasiveness of the source (Angst and Agarwal, 2009) because, when deciding whether or not to be persuaded by a system, users subconsciously ask themselves, "how do I feel about it?" and thus affect influences their judgment (Forgas, 1995; Schwarz and Clore, 1983). In summary, positive thoughts increase confidence in the target (Garrity et al., 2005; Petty et al., 2002; Petty et al., 1993).

Table 4: Primary Task Support (adapted from Oinas-Kukkonen and Harjumaa, 2009)

Systems Design Principle	Description
Reduction	Reduce complexity of a behavior into simpler tasks
Tunneling	Guide user through experience
Tailoring	Meet the needs, interests, personality, and usage context of user
Personalization	Personalize context
Self-monitoring	Keep track of user's progress in accomplishing goal
Simulation	Show the link between cause and effect
Rehearsal	Rehearse the behavior in the real world

Dialogue Support

Dialog support entails providing feedback to users (Oinas-Kukkonen and Harjumaa, 2009). This can happen via sounds, words, graphics, and many other forms of media. Dialog support has been robustly shown to influence the persuasiveness of systems (e.g., Cable and Judge, 2003; DeBongo and Harnish, 1988; Enns et al., 2003 ; Petty et al., 1993 ; Schweidel et al., 2006 ; Westphal and Stern, 2007). This increase in persuasion is a function of people subconsciously asking themselves "how they feel about the message," and in doing so they attribute the positive affect to their judgment of confidence (Forgas, 1995 ; Schwarz and Clore, 1983). For sexample, feedback, suggestions, and expressions can improve the persuasiveness of a system by improving the clarity and correctness of one's attitude toward the message (Petrocelli et al., 2007). Positive dialog support (e.g., praise and reward) promotes positive affect or feelings (Enns et al., 2003; Petty et al., 1993; Westphal and Stern, 2007), which will influence users' confidence in the source (Briñol et al., 2007; Petrocelli et al., 2007). Negative feedback, suggestions, and expressions can also be very persuasive. For example, exchange, coalition, legitimization, and pressure tactics influence the persuasiveness of a source (Cable and Judge, 2003). These tactics increase cognitive elaboration, which increases persuasion in response to strong arguments (e.g., Cacioppo et al., 1986; Cacioppo and Petty, 1979; Karmarkar and Tormala, 2010; Petty and Cacioppo, 1981).

In the context of SPECIES agents, impression management tactics can be particularly effective and easy-to-implement dialog support techniques to improve persuasion. Table 5 provides several examples of dialog support system design principles that could influence persuasion.

Table 5: Dialog Support (adapted from Oinas-Kukkonen and Harjumaa, 2009)

Systems Design Principle	Description
Praise	Offer praise through words, sounds, images, etc.
Rewards	Reward the user based on performance
Reminders	Remind user of goals
Suggestion	Offer fitting suggestions
Social Role	Adopt a social role

System Credibility Support

Credibility can be defined as believability (Fogg and Tseng, 1999). The influence of credibility on persuasion has been the root of several theories of interpersonal persuasion, such as Source Credibility Theory (Hovland, 1953), and has been shown to be an important element of system persuasiveness (Cugelman et al., 2009 ; Fogg, 2003). It is a multidimensional construct (Burgoon, 1976; Hovland, 1953) that directly and indirectly influences persuasion (Angst and Agarwal, 2009; Petty and Cacioppo, 1986).

When users view an information system as credible, they are more persuaded that the system's message is true (Angst and Agarwal, 2009). This degree of credibility can be influenced by the system's appearance, real-world feel, and surface credibility (Angst and Agarwal, 2009; DeBongo and Harnish, 1988). This occurs because positive credibility "primes" other positive thoughts in the brain, making them easier to recall, thus influencing a user's judgment (Bower, 1981). Credibility can also be *transferred* to a system through branding, third-party endorsements, or referring to people with power (Briñol et al., 2007; Lowry et al., 2008; Stewart, 2003). This transferring of credibility is an effective way to increase persuasion (LeBoeuf and Simmons, 2010). For persuasion to occur, designers must establish a perceived link between the parties and show similarity between the source and target (Stewart, 2003).

Credibility can be manipulated through a number of design decisions. For example, credibility is influenced by the competence, character, sociability, composure, and extrovertedness of the intelligent agent (Burgoon, 1976). The demeanor, gender, ethnicity, hair color, clothing, hairstyle, and face structure of the agent can manipulate these characteristics. One study of embodied agents in a retail setting found a difference in gender preferences. Participants preferred the male embodied agent and responded negatively to the accented voice of the female agent. However, when cartoonlike agents were used, the effect was reversed and participants liked the female cartoon agent significantly more than the male cartoon (McBreen and Jack, 2001).

Emotional demeanor is an additional signal that can be manipulated to influence the credibility of a SPECIES agent. The emotional state display may be determined from the probability that desired goals will be achieved. Emotions can be expressed through the animated movements and facial expressions, which may be probabilistically determined based on the agent's expert system (McBreen and Jack, 2001). There are limitless possible renderings that may influence human perception and affect the agent's operating environment. The SPECIES models can include full physical representations, or just a part of the body such as a head and face. Research has shown that the face, especially the lower face, is critical for conveying emotions visually (Deng et al., 2006). If the face is animated poorly, animation artifacts can create negative responses in people observing them (Gratch et al., 2002). Facial expressions can be based on Eckman's facial Action Units (AUs) to simplify control and representation (Pandzic et al., 1999) or on the MPEG-4 Face Definition Parameter (FDP) feature points (Pandzic et al., 1999). Table 6 summarizes how establishing credibility can be incorporated into system design.

Table 6: System Credibility Support (adapted from Oinas-Kukkonen and Harjumaa, 2009)

Systems Design Principle	Description
Trustworthiness	Provide unbiased, fair, and truthful information
Expertise	Show information portraying knowledge, expertness, and competence
Surface Credibility	Display a competent look and feel
Real-world feel	Provide information of real organization and people behind the system
Attractiveness	Be visually appealing to the user
Authority	Refer to people of authority or act authoritative
Third-part endorsements	Show endorsements from respected third parties
Variability	Provide a means to validate accuracy

Social Support

Social support refers to leveraging social influence to persuade people (Oinas-Kukkonen and Harjumaa, 2009). Social influence refers to a change in an attitude or behavior that is caused by another person and how one views his or her relationship to the other person and society in general (Asch, 1951, 1956, 1965). Social influence can be described as peer effects (Agarwal et al., 2009) and can be intentional or unintentional (Asch, 1965).

Social support can influence persuasion because people seek favorable evaluations of themselves as well as insurance about satisfactory relations with others (Enns et al., 2003; Wood, 2000). When users see others using the system, and when the system allow users to compare the outcome of their interaction with other users' outcomes, they will feel pressured to conform their attitude to the attitude of the other users (e.g., Herath and Rao, 2009; Hsu and Lin, 2008; King et al., 2010). For example, if prior to interacting with a SPECIES agent, one has observed other users interacting with the system, and these other users have been satisfied with the feedback, one's evaluation of the SPECIES agent will more likely be anchored and skewed toward the other users' positive evaluations. Table 7 demonstrates how a system can persuade through leveraging social support.

Table 7: Social Support (adapted from Oinas-Kukkonen and Harjumaa, 2009)

Systems Design Principle	Description
Social Learning	Show others using the system and the outcomes
Social Comparison	Provide means for users to compare outcomes
Normative Influence	Provide means to gather people together with similar goals
Social Facilitation	Provide means for discerning other users
Cooperation	Facilitate cooperation
Competition	Facilitate competition
Recognition	Give public recognition

Examples from Research

There are multiple examples from research that demonstrate how an ECA encoding messages can affect human behavior. For example, Prendinger, Mori, and Ishizuka (2005) found that empathetic responses from an ECA could decrease user stress. Similarly, they showed that affective behavior from the ECA might have a positive effect on users' perception of the difficulty of a task. This study was also of note because they used physiological information as well as questionnaires. Other researchers showed that an empathetic ECA is perceived favorably and can have an effect on users' feelings (Bente et al., 2008). Wang and colleagues (2008) focused on how a pedagogical agent communicates to students. Specifically, they examined the effect of a "polite" (indirect suggestions) versus a "direct" (more challenging) agent. They found that across all students, a polite agent, compared to a direct agent, had a positive impact on students' learning outcomes. They conclude by stating that their results confirm the hypothesis that learners tend to respond to pedagogical agents as social actors, and suggest that research should focus less on the media in which agents are realized and place more emphasis on the agent's social intelligence. Mayer, Johnson, Shaw, and Sandhu (2006) sought to create understanding of the effect of a socially sensitive agent and demonstrated that the social cues from the agent were indeed perceptible to the human counterparts.

FUTURE RESEARCH AND CONCLUSION

Considerable research needs to be accomplished in each of the four design principles outlined in this paper. From the first design principle, applying SPECIES agents to new contexts is an important area of study. Potential ideas include online instruction, banking transactions, and job interviews. There is a vast potential for design and implementation of SPECIES agents in meaningful contexts that can augment human tasks, and this design principle directly relates to the relevance requirement of the design science methodology. Second, decoding human states and messages requires substantial additional research. Evaluation of new sensors with the focus on analyzing the dynamic world for agents is needed and can be linked with the expanding field of NeuroIS. Research can be done in the development of new sensors, algorithms, and technologies that can be used in this context to improve human-computer interaction using SPECIES agents. Research based on the third design principle can focus on using the sensor data to make the SPECIES agents more adaptive, dynamic, and useful. The core of interpreting the sensor data and "making sense" of the inputs provides numerous opportunities for algorithm development and new models. Fourth, the encoding of agent responses and how it affects users' perceptions of the agent must be evaluated. Potential questions include the impact of embodied gender, demeanor, voice, and appearance on human perceptions of the agent. Formulating new responses and dynamic communication provides opportunities for exploration and development.

In addition to the numerous research opportunities within each of the four SPECIES design principles outlined in this paper, future research should consider the organizational and societal impacts of SPECIES agents. For example, the advent of SPECIES agents raises ethical concerns regarding what and how much information the agents are allowed to collect through sensors. Is it ethical, for example, to collect information about people's health through unobtrusively monitoring cardiovascular statistics? Finally, another area of future research is to examine the technology adoption of SPECIES agents, especially in situations in which such agents might augment or replace human workers.

This paper provides some formal guidance to aid in the design of SPECIES agents—intelligent agents that can assess human states and provide appropriate responses based on this assessment. In this paper we first built on interpersonal communication theory to specify four design principles that all SPECIES agents must have. Second, we summarized the research progress in each of these areas. We then recommended that future research use these design principles and best practices as an integral part of design science research for SPECIES agents.

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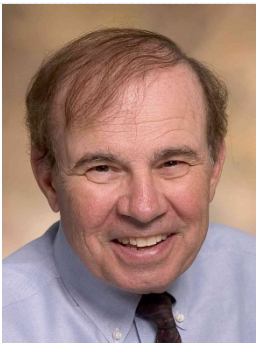
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