Teaching a New Dog Old Tricks

Boston Dynamics, famous for their robot quadruped dog "Spot," takes new inspiration from some "not-so-new" sources.

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DOI: DOI:10.1145/3611685

Boston Dynamics has more than 1,000 Spots out in the world, moving around in human spaces. Spot, a quadruped "robot dog," has found purpose as a versatile tool in areas like industrial inspection, robotics research, entertainment, and even venturing into dangerous locations such as nuclear power plants. While the concept of robots coexisting with humans has long been a subject of fascination in literature, films, and video games, the reality of that interaction is still in its very early stages and the conventions of human–robot interaction (HRI) are actively being explored and evolving.

It is quite common for individuals to feel a sense of discomfort or unease when encountering this new class of creatures, particularly during initial interactions. There may be a vague feeling of being unsafe, not necessarily in a mortal sense, but more on a psychological level. Such reactions are often observed with new technologies, and they are further fueled by the dystopian robot narratives portrayed in movies. This unease is not only limited to moment-to-moment encounters in close physical proximity, but extends to a broader concern about the implications of their presence for our future and the questions it raises concerning the direction in which it is all heading.

At Boston Dynamics, our primary HRI challenge revolves around not only showcasing the impressive capabilities of our robots but also creating a sense of comfort, familiarity, and control. By leveraging familiar interaction patterns and exploring new ideas that take cues from existing disciplines, we hope to lead the way to interactive robots that behave in highly transparent and predictable ways.

THE LIMITS OF BIOMIMICRY IN HRI—COPYING FROM NATURE

Spot is frequently referred to as a "robot dog" but apart from having four legs and being roughly canine sized, there is little else that actually warrants the association. When we engage with a real dog, we have an innate

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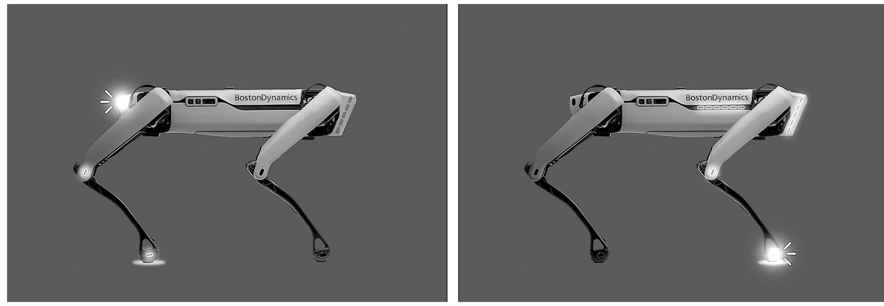
ability to interpret the information it communicates through its behavior, body language, and facial expressions. Signals such as wagging tails, display of teeth, and position of ears convey crucial information about the dog's mental state; over time, we develop intuitions around these signals, which make the interaction feel transparent and predictable. As a result, we feel confident in making predictions about the dog's future actions and our overall safety in its presence.

As Spot has already incorporated design cues from biology, the question arises about whether it should have a face or tail and to what extent HRI should leverage this biomimetic aspect. Faces, ears, and tails are expressive features of real-life dogs, and mimicking them in design could theoretically trigger familiarity and comfort. Some may even suggest turning indicator sounds into "barks" or referring to low battery as "hungry" mode. But there is a point where this approach can feel artificial, shallow, and insincere, which most people would agree is undesirable in HRI. Truthfully, Spot is more of a power tool that happens to be quadrupedal and has an excellent sense of balance.

To many, the level of biomimicry involved in copying real-life dog cues for their triggering effect feels superficial and dishonest when applied to a robotic dog like Spot, as these cues do not correspond to any meaningful or genuine internal representation. The

Figure 1. Embedded backup lights and foot turn signals externalize spatial cues to anticipate Spots next move.



factors that need to be surfaced to create predictability and transparency in Spot, the robot dog, are distinct and separate from those associated with real dogs.

DEEPENING HUMAN-ROBOT CONNECTIONS THROUGH PURPOSE AND PREDICTABILITY

Any successful robot interaction starts with a purpose or value a robot provides that makes us want or need it to share our space. The robot then must make us feel psychologically safe in that shared proximity by demonstrating its predictability and transparency and by surfacing the information about its inner state, which is important for us to understand. Only once we feel comfortable will a deeper connection be possible.

Social robots frequently get this equation almost exactly backwards. Many social robot creations have started with the general assumption that people crave human-like or creature-like connections with the robots and that by replicating emotional cues found in facial expressions and body language, a natural connection, friendship, and potentially even love will follow.

The problem is those surface face and body cues cribbed from real life do not map to any real, meaningful, or truthful inner state of a robot. Using these cues superficially to trigger an emotional connection that ultimately maps to no relevant core means most adults will perceive the interaction as an illusion and lose interest after a short period. So far, most social robots haven't provided much value and have ultimately failed in the marketplace.

ROBOT INSPIRATION FOR PREDICTABLE AND TRANSPARENT BEHAVIOR

Roomba, the world's most successful consumer robot product to date, provides an interesting example of a

Figure 2. Using projector for spatial direction symbol.

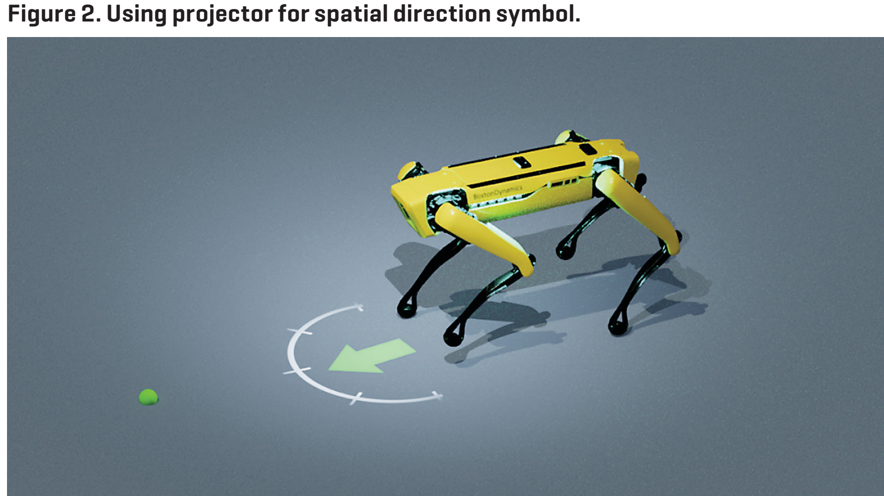


Figure 3. Projecting the real-time inner representation generated by Spot's perception system onto the ground so anyone nearby understands what the robot can "see."

successful HRI approach for making a robot's behavior predictable and transparent on its own terms. More than 40 million are around the world earning their keep by automatically performing a task we mostly dislike. But if you take a moment to watch a Roomba in action, you also see behavior that follows a basic biological pattern that our brains can understand.

An operating Roomba "learns" about the world by curiously bumping its body into our walls and furniture. After pausing to "think" about how this new information fits into what it already knows, it uses the new data to plan its next move. Turning its body in the direction of its new exploration, it signals what direction it will move next so we can plan accordingly. It repeats this simple loop until the task is complete.

If a study by iRobot is to be believed, over time it is common for Roomba owners to think of their utilitarian robot vacuums as semi-sentient members of the family. They connect to and perceive a personality in its tiny set of turns, beeps, and blinks.

Roomba is a great example of truthful, spare HRI. All behavioral cues surfaced allow our brains to construct an "inner life" that explains its actions in a predictable and transparent way. Personality and connection can emerge, but as a byproduct, not a starting point.

To identify Spot's relevant inner life, we first identify the information that is important for understanding Spot's behavior and then find the best way to surface it. There are three key aspects of Spots inner representation of the world that are relevant and need to be clearly and visually externalized for the human observer to see:

1. Clear spatial cues to show where it plans to move next and when.
2. Indications of what its perception system is seeing and hearing.
3. Visibility into its current state, current task, and current status.

EXTERNALIZING CLEAR SPATIAL CUES WITH LIGHTS AND SOUND

The automotive industry has successfully established conventions to externalize the intentions of the human brain inside a vehicle. For instance, blinking lights on the left or right side of a car provide clear indications of its intended turning direction. Similarly, a car with all lights flashing signifies that it is disabled, prompting other drivers to adapt their behavior accordingly.

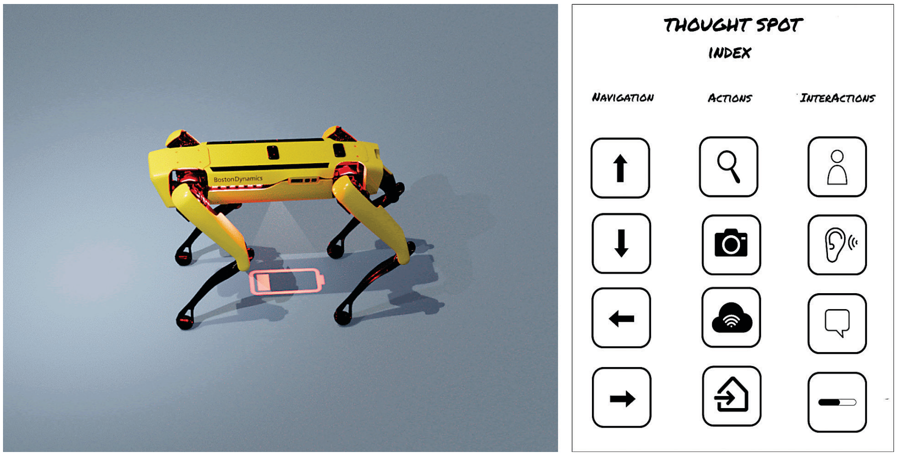
Spot can utilize its external body surfaces to display its spatial information by using lights and sound to mimic some of these same established conventions, such as flashing backup lights before moving in reverse. Lights embedded in Spot's feet could behave like turn signals to visually show the direction of Spot's next move (see Figures 1 and 2).

PROJECTING CURRENT PERCEPTION AND STATE DATA INTO THE WORLD

The integration of informational interfaces with simulated characters in virtual worlds has been a fundamental aspect of video gaming for several decades. We are accustomed to seeing relevant information displayed as part of the user interface (UI) at the edges of our screens or projected onto the ground near characters' feet to convey things like health status, time remaining, warnings, or specific actions that need to be taken.

Porting this mechanic over from the virtual world by introducing a projection system to display real-time information about Spot's internal representation of the world could greatly

Figure 4. The robot can project symbols for explicit state and status information, such as battery charge.



enhance transparency and understanding of its actions. By projecting Spot's "internal visualization" onto the ground in front of it, nearby individuals can observe the objects that Spot sees in its path, including humans, and how Spot uses these internal representations to navigate safely (see Figure 3). This transparency helps bridge the gap between Spot's internal understanding of the world and the human observer's perception.

The concept we call "Thought Spot" (see Figure 4) is another promising application of projecting traditional UI elements, like icons and fill bars, into the world to give explicit information about the robot's current state, such as: What type of action is the robot performing at this moment? How much of the action is complete? What's the battery charge level?

This mechanism can also be used with directional arrows to reinforce spatial cues by syncing it up with the lights and sounds. Projecting in this way allows visibility into the robot state without requiring specialized equipment like an AR/VR headset or a tablet. Sounds can be used in simple ways, such as accompanying the projection of a camera icon with the sound of a camera's shutter during an image capture event.

CONTROLLING BEHAVIOR AND MOVEMENT

Leveraging principles from disciplines like animation and motion design can bring expressiveness and clarity to the way Spot moves and interacts with its environment. Well-designed motion can both be used to guide effectively attention to enhance other signals, such as lights and sounds, as well as to provide cues to anticipate large actions before they happen. For example, incorporating anticipatory actions, such as a small move back just before a big move forward, provides a motion cue that allows the human observer to be prepared for this big action before it occurs (see Figure 5). Or anticipating how a pivot to the left by tapping the ground with the foot will lead the bigger action just before it makes its big turn, which provides a signal that anyone nearby can understand to anticipate what's coming next.

Any successful robot interaction starts with a purpose or value a robot provides that makes us want or need it to share our space.

CONCLUSION AND FUTURE WORK

While there are unpredictable outcomes with any new technology, embodied AI itself is not evil, "out of control," or necessarily dangerous. What is dangerous is how we decide to use and deploy it. Can we understand it and align it with our priorities? It's up to us, as robot designers, to make principled decisions about how we will usher this new category of product into shared spaces.

Driven by the need for greater transparency in robotics and AI, Boston Dynamics' approach to both the visual and interactive design of robots is to be honest and straightforward about the robot's true capabilities and communicate those clearly. At Boston Dynamics, our HRI team is an integrated design group that incorporates the practices of HRI, UI, user experience (UX), and industrial design. Our focus is on designing robots that are simple to understand and intuitive to use. We shy away from designs that overpromise and underdeliver, especially on long-term usability and we relentlessly test our robots to ensure they are reliable for thousands of days of operation. All of this adds up to building a sense of trust in our robots' abilities to do useful work and integrate into a team and work environment.

By deploying more than 1,000 robots, we have learned so much from being out there "in the wild," and are grateful for the feedback and input we've received from customers, partners, and bystanders. When we design, we think about all of the user

Figure 5. Using the "look left, look right, look left again" movement pattern for a crosswalk behavior.

personas—including people who are not using the robot for their job, but are going to be around it at work. These key people need to clearly understand what the robot is doing because the opposite feeling, or a lack of transparency, could easily lead to discomfort and unease.

This article shared our approach to making robots more transparent by externalizing their inner worlds in three ways using projected light, sounds, and body movements. We've described specific examples as they apply to Spot, our quadrupedal robot dog, but the framework is generalizable to all robots that want to be easily understood. The very first step toward making people feel comfortable around robots is to consider the following working hypothesis, a formulation on peoples' general perception of robots: Perception of a robot = robot's appearance + robot's behavior + people's associations (to previously seen real or imaginary robots).

As an integrated HRI design team, we can control the robot's appearance through industrial design and the robot's behavior through HRI design, but we can't directly control people's prior experience or memories of robots (even imaginary ones). However, we can think about what folks (freely) associate with a particular robot design being proposed. We're always curious about their first impressions as well as their visceral and emotional reactions to what's being presented. As we strive to understand user preferences, we also are paying attention to how we can differentiate our designs from what's already out there and guide all of our work through a product development process with critical input from the industries and users we serve. We then refine our designs through a series of comprehensive engineering and user testing rounds until we reach the inevitable solution.

Toward creating more explainable, simple to understand, and intuitive to use robots, we're operationalizing the Thought Spot to inform anyone observing what the robot's current navigation intent is, what the robot's perception system is sensing, and what the current task is. Old tricks from video games, animation, and newer findings in neuroscience are being combined into ongoing, deployed HRI experiments that are gaining traction and reconfirming this direction. We're also seeing this framework expanding into safety-critical signaling on autonomous vehicles and are looking forward to other implementations that help remove opacity in favor of more transparent and trustworthy AI products.

As society continues to adopt embodied AI, we're taking a careful approach to ensuring people understand that our goal in creating interfaces for robots is to strike a balance between autonomous behavior and human control. As with every new technology, there are real challenges around legacy culture thinking and it's our responsibility to take these concerns seriously and empathize with them. Given that the majority of the population has not yet had interactions with real robots, their imaginations and mental models of robots weigh heavily. Our approach is to meet this situation head-on and promote robot literacy or a deeper understanding of what the robot is actually doing and capable of doing. So far, we're encouraged to know that providing a window (thought bubble) into the robot's simplified mental model is already conveying the information people need to decide if they want to engage and effectively make use of a technology built to serve them. All of us at Boston Dynamics thrive on the challenges associated with innovation and we hope to continue using a mix of engineering know-how, HRI, and product design and development processes to bring trustworthy and useful robots into the world.

It's up to us, as robot designers, to make principled decisions about how we will usher this new category of product into shared spaces.

Biographies

Leland Hepler heads up product design for the Spot robot at Boston Dynamics. He got his start in robotics as Director of User Experience for Rethink Robotics, the collaborative manufacturing robot company in Boston founded by Rodney Brooks. He is particularly interested in how robots can be made more transparent, predictable, and safe and believes a lot can be learned by exploring methods from his earlier work in video game development and animation. He holds a BFA from Rhode Island School of Design.

David Robert is the Director of Human–Robot Interaction, a transdisciplinary design group at Boston Dynamics that integrates UX, UI and industrial design practices. David's graduate research at the MIT Media Lab's Personal Robots Group focused on creating blended reality robot/characters for informal learning environments under the supervision of Cynthia Breazeal (MIT) and Joseph Blatt of the Harvard Graduate School of Education. He's a tech-ethicist who advises EU policy makers on the pro-social design of embodied AI, a passionate educator, social venture mentor, and robot literacy advocate.

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