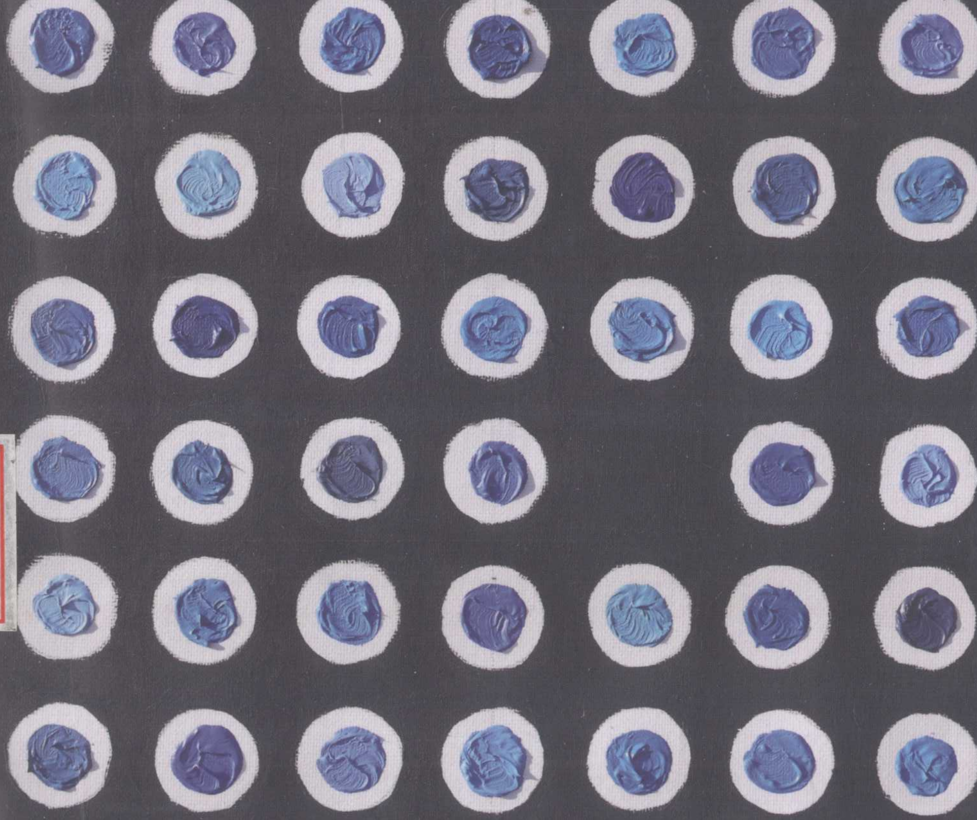
ROBOT FUTURES

ILLAH REZA NOURBAKHSH



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To Marti, Mitra and Nikou: you illuminate my life.

Acknowledgments

Many people in my life have played critical roles in encouraging me to be inquisitive and providing me with the knowledge and habits of mind that shaped my intellectual identity. I am deeply grateful to all of them, although were it not for one particular mentor, I would never have become a roboticist. Professor Michael Genesereth at Stanford University introduced me to artificial intelligence and robotics, then encouraged me to join his research group. He convinced me to change my plans following college, continue university studies, and enter the PhD program at Stanford University, and he taught me a form of academic precision and sharpness in thought, and an appreciation of societal impact, that transformed me.

My peers, friends, and family have read early versions of this book and provided invaluable guidance. They have shaped both the style and the essential content of this work: Mark Bauman, Nonie Heystek, Steve Ketchpel, Ben Louw, Tom Lauwers, Marti Louw, Matt Mason, Ofer Matan, Farhad Noorbakhsh, Alex Norbash, P. W. Singer, and Holly Yanco. Not only did Mark Bauman and P. W. Singer improve this book through their early reviews; together with Fatemeh Zarghami, my mother, they are my role models. They set a gold standard for how one educates, communicates, and informs for positive social change.

Jim DeWolf at the MIT Press has enthusiastically supported this endeavor, navigating the publication process with patience and transparency. His efforts, and the willingness of the Press to publish a work that is critical of technology and its ramifications, speak volumes about their commitment to express strong ideas of all flavors to the public.

The life of a robotics professor is mostly consumed with teaching, research, and fundraising—so much so that I cannot imagine normally finding the time and space to properly nurture a book. Carnegie Mellon University and the Robotics Institute gave me that time and space by granting a sabbatical, allowing me to leave my university responsibilities behind and travel to a distant place. On the other side of that voyage, the University of the West of England's Science Communication Unit, led by Professor Alan Winfield, welcomed Marti Louw, my wife, and I with open arms into a dual sabbatical, providing an environment for research collaboration that was warm and stimulating during our stay in Bristol. Finally there is the one person who created the most important space for me to write daily, and who served as my most regular intellectual peer in evaluating and tuning the ideas in this book—Marti Louw. Her science communication expertise and her willingness to take on the societal impact of robotic technologies have made her the ideal collaborator.

Throughout this book I describe some of my past projects. The first-person narrative can imply that I invented and built these new systems singlehandedly, but nothing could be further from the truth. The CREATE lab's thirty members—researchers, educators, administrators, and students—are the real drivers behind every one of these projects. These individuals have dedication, social empathy, creative intelligence, and technical know-how, and together they make our audacious dreams of creative technology for social change come true.

Note Regarding Jacket Art

The jacket of this book features forty-one distinct versions of the color blue (see chapter 1). To create these separate colors, I visited the Couleurs Leroux factory in Joigny, France, where original pigments and oil are combined by hand to create art quality oil paints. The forty-one colors resulted from mixing six fundamental blue pigments from Leroux together in varying proportions with titanium white: bleu de Prusse, outremer, coeruleum, bleu cyanine, indigo, and bleu de cobalt. I am grateful to Leroux and to the artist, Francisca de Beurges Rosenthal, for expert guidance.

Preface

In 1977 I walked into the first run of *Star Wars* with my parents, not knowing what to expect. Just for context, we were there because *Herbie Goes to Monte Carlo* was sold out. Two hours later I was transformed, branded with images of C-3PO and R2-D2, robots among people. This is how my love affair with robots started, and it is also how an entire generation of robotics researchers, about my age, set their eyes on robots for life. I have participated in the past two decades of robotics research, where literally thousands of research groups across the planet have worked to close the gap between the promise of science fiction's robots and the reality of commercial robotics.

As is common in a field as multidisciplinary as robotics, my own career spans many different forms of robot innovation. I have worked to improve robots' basic capabilities—a new vision system for seeing the world three-dimensionally, a new strategy for navigating indoor spaces without getting lost (Nourbakhsh et al. 1997; Nourbakhsh, Powers, and Birchfield 1995). I have also participated in the creation of robots that we have deployed around the world: a seven-foot-tall tour guide that led visitors for four years through Dinosaur Hall at the Carnegie Museum of Natural History (Nourbakhsh et al. 1999); miniature programmable

Mars rovers installed in the National Air and Space Museum; the Exploratorium and the Japan World Expo (Nourbakhsh et al. 2006). But most of all I have applied new robotic technologies to interactive devices, imbuing new products with robotic powers: a pogo stick that launches the rider meters into the air (Brown et al. 2003); a vision system used by artists to make their art respond to the viewer (Rowe, Rosenberg, and Nourbakhsh 2002); a panorama robot that turns a regular camera into a billion-pixel documentary tool (Nourbakhsh et al. 2010); a messaging system that helps kindergarteners stay in touch with their parents; a smart electric car that local mechanics can make using used car parts (Brown et al. 2012); a robot-building kit that helps middle-school students build and program any robot out of craft materials (Hamner et al. 2008).

Robotic technologies seem magical because they are transformative. A product we simply use becomes something that sees us, hears us, and responds to our needs. Robotics makes the products around us more aware and more alive, a trend that will accelerate dramatically in the next decade. This is because the ambition of robotics is no longer limited to merely copying us—making walking, talking androids that are indistinguishable from humans. Robotics has grown up and grown out of that mold.

Modern robotics is about how anything can perceive the world, make sense of its surroundings, then act to push back on the world and make change. But never ask a roboticist what a robot is. The answer changes too quickly. By the time researchers finish their most recent debate on what is and what isn't a robot, the frontier moves on as whole new interaction technologies are born.

But there is one special quality of modern robotics that is very relevant to how our world is changing: robots are a new form of living glue between our physical world and the digital universe we have created. Robots have physical sensors and motors—they can operate in the real world just as well as any software program operates on the Internet. They will be embedded in our physical spaces—our sidewalks, bedrooms, and parks—and they will have minds of their own thanks to artificial intelligence (AI). Yet robots are also fully connected to the digital world—they are far better at navigating, sharing information, and participating in the online world than humans can ever be. We have invented a new species, part material and part digital, that will eventually have superhuman qualities in both worlds at once, and the question that remains is, how will we share our world with these new creatures, and how will this new ecology change who we are and how we act?

Already, robotic technologies are the living glue connecting the physical and digital all around us. They are running through forests as giant, military robo-dogs with visual optics that use the Internet to classify everything they see. Smartphones can guess what you are doing using built-in gyros and accelerometers, and can plot your path outdoors using the GPS satellite network and indoors using wireless antennas whose positions are shared in massive online libraries. When you ask Siri a question on the iPhone, your iPhone packages your voice and sends it online, then powerful shared servers in the digital world formulate an answer. Your digitized question travels thousands of miles, and your iPhone's brain includes not only the device you hold in your hand but the entire digital realm. Tiny, flying robots can buzz around a building, find an open window, and zip in to perch on a ledge, mapping the exterior and interior in real time. Those maps can be instantly published online; experiences are not local or transient in the robot-connected world; they are packaged, published, and digested before we humans have even blinked.

To begin to understand how robotics will change us, we need to understand key areas of robotics research and innovation. We take inspiration from humans, and so the first question roboticists ask is, what makes humans intelligent? We think of human intelligence as a quality that is living and interactive, embedded in the context of the world in which we function. Therefore intelligence depends on two things: being meaningfully connected to our environment, and having internal decision-making skills to consider our circumstances and then take action. The environmental connection is two-way, and we term the inputs as *perception* and the outputs back to the world as *action*. The internal decision making that transforms our senses about the world into deliberate action is *cognition*.

Perception is the ability to collect and interpret information about the world using sensors—digital cameras, sonar rangefinders, radar, light sensors, artificial skin, and many others. Perception is easy on the Internet because everything has a digital form—online sensors are easy to build, and the signals are easy to interpret. An online artificial intelligence can play video games on par with human visitors because it can see as well as humans can online. But robot perception in the real world means recreating the sublime physical and visual processing systems we have—feeling a firm handshake, recognizing faces, animals, textures, and fleeting smiles.

Action is the power to effect change in the world. For decades, robots have acted effectively in constrained situations such as automotive assembly lines. Robots are historically hard, heavy machines with powerful motors and little flexibility. An automotive assembly plant welding robot moves with great speed and precision, repeating the same complex motion thousands of times a day, all in a steel cage that is off-limits to humans, because the robot could thoughtlessly kill with a single blow. But acting in our social, human world means moving from the constraints of the factory floor to the dynamic, unpredictable world in which we raise our families. Instead of speed and power, social robots need elasticity, pliability, and gentleness of touch. This has motivated researchers to invent new types of motors with built-in springs, and new control systems to push a shopping cart or unscrew a jar of honey.

Cognition is the ability to reason, to make decisions about what to do next. Cognition is close to the traditional AI dream of thinking like a human: if a robot can sense the world through perception and change the world through action, then cognition is about making decisions about what to do next. It is the glue that connects perception to action, just as our brains absorb information using the five senses, then make decisions about how to behave next, connecting our senses to our muscles using reflexes and thought. Cognition is also the area in which robots veer away from how all natural animals operate, with local brains that must make decisions independently. Robots have effortless access to the digital world, and in that disembodied sphere there is both massive data and superhuman processing power. Every robotic decision can be informed by everything its shared network of robot brethren have encountered, and even the decision-making process itself is subject to outsourcing—a robot can use powerful online computing services so that its own circuitry can stay lightweight and power-efficient.

From a cognitive point of view, the robot we might encounter on a sidewalk is more unknowable than any animal. We will not be able to distinguish potential Borg from homebrew 'bot. Is it one physical pawn of a massive online intelligence reinforced by vast shared experiences and knowledge libraries, or is it a four-wheeled computer running a toy program written by the precocious preteen next door?

The three core strands of robotics research inquiry—perception, action, and cognition—do not proceed perfectly apace, nor are researchers succeeding in mimicking the diversity of human abilities all at once. Rather, our research is a ragged frontier that, in some cases, already exceeds human capabilities in peculiar ways and, in other cases, seems to be refusing every effort at advancement. We are not really on a straight path to the artificial human, but rather on the road to a strange stable of mechanical creatures that have both subhuman and superhuman qualities all jumbled together, and this near future is for us, not just for our descendants.

New research is yielding major innovations ever faster, and, what's more, human-level capability has turned out not to be a special stopping point from an engineering perspective. Consider action. Researchers have already built walking robots that can walk downhill using zero energy. Soon these robots will walk more efficiently than humans. Robots will take routes on Yosemite Valley's El Capitan that no human rock climber can ever match. One Carnegie Mellon project has created new materials that adhere to walls like Gecko feet. Their prototype robots effortlessly climb walls and, shortly, ceilings (Murphy, Kim, and Sitti 2009). In the case of perception, robots will see with greater detail, and they will see not only the light that our eyes register, but also the light signals detected by insects and birds. They will detect smaller movement further away, and one day they will see even better in the dark than a spotted owl and will navigate better than a bat.

A robot moving down the street will see in all directions, not simply in front of it like humans. If that robot is connected to a network of video cameras along the street, it will see everywhere on the street, from all angles, the entire time it walks. Imagine this scenario. A not-very-clever robot walking down the street will have access to entire synthesized views of the street—up and down, behind you, down the alley, around the corner—and be able to scroll back through time with perfect fidelity. As you approach this robot, it might be cognitively much dumber than you, but it knows far more about its surroundings than you do. It stops suddenly. What do you do? There is no *common ground* established between you and this robot, just the fact that you occupy the same sidewalk. The well-referenced concept of *grounding* in communication was presented by Herbert Clark to explain how even strangers can have a productive, social interaction by relying on a shared background of beliefs, assumptions, and group experiences that bring meaning to the few words they exchange (Clark 1996; Clark and Brennan 1991). A whole new robot species will have little in common with us in terms of beliefs or experiences, and so the basis of effective communication will be simply missing. What's more, along certain dimensions these robots will be far better informed.

One certainty is that humans will be inferior to robots in some ways. Is this really important, since we are already less competent than our computers at particular tasks such as calculating, spelling, and timekeeping? After all, none of this embodied computational prowess suggests that robots will write books that we want to read, or that the conversation we have with a robot will be affective and emotionally fulfilling. But robots will share our physical, social, and cultural spaces. Eventually, we will need to read what they write, we will have to interact with them to conduct our business transactions, and we will often mediate our friendships through them. We will even compete with them, in sports, at jobs, and in business. How will this change us?

I am not a social scientist, but as a roboticist I can predict possible futures for perception, action, and cognition breakthroughs. With these predictions in hand, I can paint portraits of how such advances introduce us to new robot experiences *in the wild*, and how these experiences may change the ways we function in society. Each chapter in this book imagines an ever-further robot future in which underlying robot technologies have advanced and yielded new ways that we and robots share our common world. The chapters dwell, not on the technologies, but on the ways in which each possible future surfaces new human side effects, just like new pharmaceutical drugs. And, like drugs, the side effects that matter most reach well beyond the individual, influencing human activities and, ultimately, our culture.

The lay reader may also need an introduction to the upcoming technology innovations that will transform robots from laboratory experiments to consumer items. Embedded in chapter 2 ("Robot Smog") is a tutorial, "The Near Future Robot Primer," that I hope provides enough technical context and detail to begin imagining the pioneering robots of the 2030s.

Today most nonspecialists have little say in charting the role that robots will play in our lives. We are simply watching a new version of *Star Wars* scripted by research and business interests in real time, except that this script will become our actual world. Robotic technologies will infuse products all around us. Familiar devices will become more aware, more interactive and more proactive; and entirely new robot creatures will share our spaces, public and private, physical and digital.

The robot future will challenge our sense of privacy. It will redefine our assumptions about human autonomy and free will. As we face more intelligent robots, so we discover new forms of identity and machine intelligence. Our moral universe will be tested by robot cruelty and robot-human relations. Our sense of physical space and reach will expand thanks to robot proxies, just as our personal sense of self will be diluted into a broader and shallower digital-physical footprint. This book imagines successive milestones in robot evolution so that we can envision, discuss, and prepare for change, and so that we can influence how the robot future unfolds.

Note: I will track and blog major, relevant advances in robotics on this book's companion blog page: http://robotfutures.org.