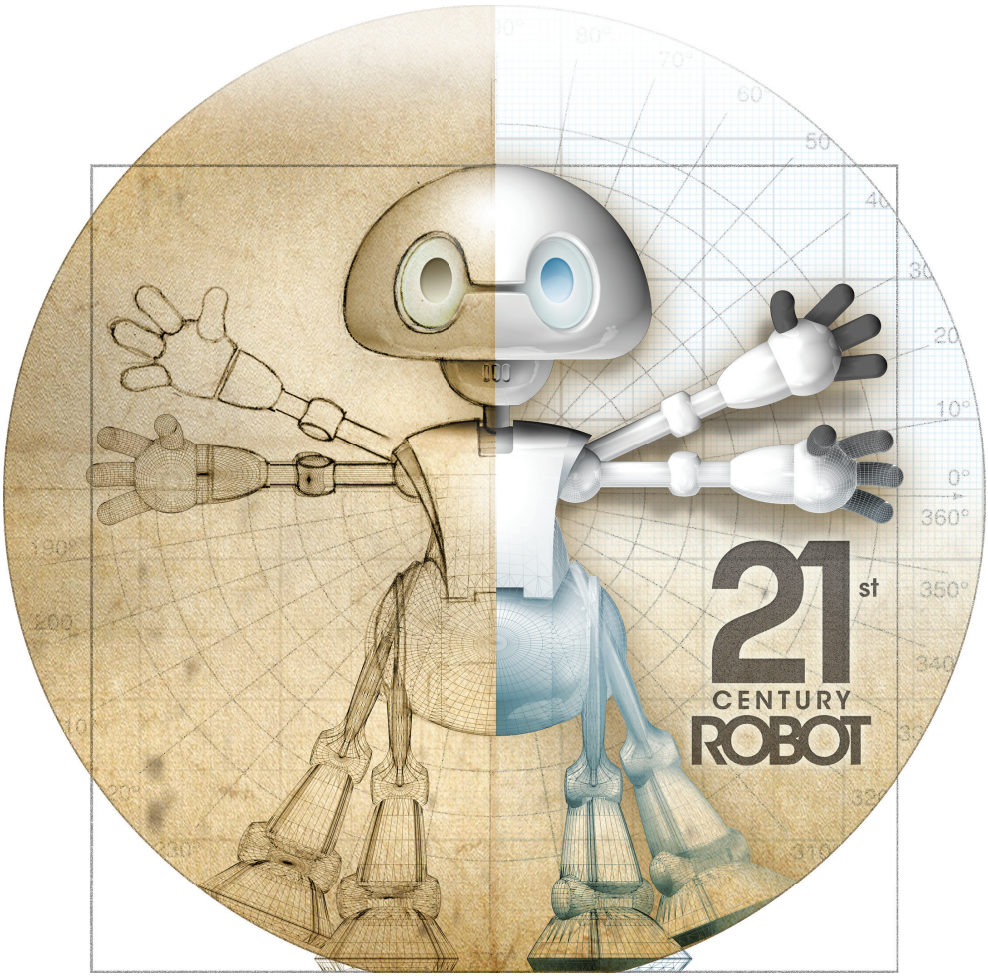
Make:

21st Century Robot



Brian David Johnson

Illustrations by Sandy Winkelman

Science Fiction / Technology

21st Century Robot

An audacious experiment in storytelling that weaves science fiction stories into a real-life narrative scarcely guessed at in the 20th century, *21st Century Robot* is a call to arms for all of us to embrace and guide the exciting technological possibilities of our era.

Written by Brian David Johnson, a professional futurist, this book details the evolution of Jimmy, a walking, talking robot just like the one you should have. Just like the one we all should—and *will*, one day—have to assist and charm us.

Johnson created Jimmy through a series of science fiction stories, using his imagination to fire up the imaginations of the scientists, engineers, academics, and designers who helped bring Jimmy to life. This book will make you want to create your own robot—and it shows you how.

Weaving fiction with reality, Johnson explains how he came to create the 21st Century Robot Collective, a group whose goal is to make the production and use of robots as common to us as caring for a family pet. Walking, talking robots aren't to be feared but loved, Johnson counsels. They should be as social as we are; be named like we are; possess gender traits like we do; be a part of our lives. And we all should be making our own.

Advance Praise for 21st Century Robot:

"In the 20th century there was science fiction about the potential consequences of human-like robots. Now in the twenty-first century we are close to the real thing and the benefits and risks loom large. Brian David Johnson's 21st Century Robot *is a bridge from fiction to oncoming reality."*
—VERNOR VINGE, Hugo Award-winning novelist

"Johnson's work is smart and full of human-scale compassion and context for an almost unimaginably vast and weird future."
—CORY DOCTOROW, author, activist, journalist, blogger

"This amazes me: a strong science fiction concept can be deployed as a genuine industrial product nowadays. Brian David Johnson's book demonstrates how that's done: with ambition, energy, persistence and tact. It's hugely encouraging."
—BRUCE STERLING, cyberpunk fictioneer

The goal is simple: create 7 billion robots.

The method is elaborate:

Use a manifesto, four science fiction stories, several worldwide adventures, a serious dose of 3D printing, plenty of open source technology, the efforts of a first grade class, and a socially precocious bot named Jimmy to bring that vision to life.

This book is dedicated to the generation of young minds who will never know a time when they couldn't imagine, design, build, program, and share their own robots. What will our lives be like when robots are as common and normal as smartphones, tablets, and TVs? What will *your* 21st Century Robot do?

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Brian David Johnson

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by Brian David Johnson

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This book and the entire 21st Century Robot Project is dedicated to anyone born after 2014.

Today we have an entire generation of young minds that has grown up never knowing a time when there wasn't an Internet. This generation has never known a time when you couldn't walk up to a screen, ask it for something, and get a response in under a second. It's truly amazing. In fact, if this generation is given a screen and it's not connected to the Internet, then that screen is broken. I am constantly surprised and amazed at the ideas and creativity of this generation. I can't wait to see what they do.

This book is dedicated to anyone born after 2014 because it is my hope that they will be the generation that has never known a time when they couldn't imagine, design, build, program, and share their robots. Just imagine the incredible, silly, and awesome things they will build!

If you are reading this book, then you have a responsibility to this generation.

We can make this future real.

Build robots!

Contents

The Making of a Manifesto

This book ends with a little robot standing backstage in Las Vegas, about to make his début in front of 5,000 people. The little robot's name is Jimmy, and he's the first 21st Century Robot.

You might be asking yourself: what is a 21st Century Robot?

Good question.

For most of their history, robots have only lived in science fiction. Long before the technology to build them was ready, robots could only be seen or experienced in science fiction stories, movies, comic books, and often times only in toys. But that didn't stop people from imagining robots and exploring their implications. In fact, cultures all over the world have imagined and explored the implications of robots, long before the word was coined by Czechoslovakian writer Karel Čapek in 1920.

In the last half of the twentieth century, robots began their journey from our imaginations to the real world. Industrial robots started to help us build our cars and work in our factories. Research robots of all shapes and sizes were developed and built in university research labs. But even with all these new robots making their way into the world, for most people, robots were still exotic and foreign, still the product of science fiction and our imaginations. But then something happened...

Around the turn of this century, robots became something very different. No longer were they creations locked away in large universities and corporations. In the twenty-first century, robots became something anyone could build; a part of our daily lives—right where they belonged.

The twenty-first century brought a whole new way to design, build, and program robots. Technological advances and different approaches to development gave us new tools, removing the barriers that had separated us from robots. Open source software and apps gave us a whole new way to develop and share computer code. Open source hardware tapped into the creativity of millions of smart developers and non-traditional builders. The emergence of 3D printing gave anyone the ability to manufacture their own robot designs. The world had changed.

Now anyone can imagine, design, build, and program their own robot. These new robots are truly 21st Century Robots.

As a futurist, it's my job to look out into the future and model how people will act and interact with technology. Essentially, I envision what it will feel like to live 10, 15, even 20 years in the future. I have been thinking about and imagining new 21st Century Robots for a decade (more about that in the next chapter). Then, about three years ago, it became clear that technology had progressed to the point where the robots I'd been imagining for 10 years were now possible. These robots would be completely open source, 3D printed, and above all else, social. They would set themselves apart from any robot that had come before them. That revelation gave birth to this book.

A Manifesto Is Born

"So what makes a 21st Century Robot different from a twentieth-century robot?" Dale Dougherty, the CEO of Maker Media (my publisher), asked me on a phone call at the beginning of the project. Infinitely curious and always a huge supporter of this new approach to robots, Dale pushed me to define what I meant by 21st Century Robots.

"Well," I replied, standing in my kitchen staring at the phone, "I'd say that a 21st Century Robot is imagined first. It's certainly social, open source, and iterative, but it's also filled with the hopes and dreams of the people that made her, him, or it. It's also easy to build!"

"So it's up to the people who build the robot?" Dale asked. "Is that a 21st Century Robot?"

"We don't know," I replied. "That's the really great thing about it. When it comes to a 21st Century Robot we really don't know what it is. I don't know what it is. It's not up to me. It's up to the person who is building the robot. Every robot is personalized. Every robot is an individual. Every robot should have its own name, because every 21st Century Robot is an individual, because every robot is built by a person."

"I think you need to write a manifesto," Dale said with a laugh. "I think you actually just wrote one."

"I've never written a manifesto," I answered. I didn't know people still wrote manifestos.

"Just answer this question: what makes a 21st Century Robot different from a twentieth-century robot? What makes it different from anything else that has come before?"

And that's how a manifesto was born in my kitchen in Portland, Oregon. This is what I came up with...

21st Century Robot Manifesto

In the twenty-first century, technology has progressed to the point where what we build is only constrained by the limits of our imaginations.

It's time to imagine a radically different kind of robot. A robot that is designed, constructed, and programmed like never before. We can imagine and build a far more amazing future than we have today—a much more creative and rich tomorrow for robots and their relationship to humans. It's time for a 21st Century Robot. This is our manifesto:

Imagined First

Nothing was ever built by humans that wasn't imagined first.

Imagination is the most important skill needed to build your robot. In the twenty-first century, anyone can imagine, design, and build a robot.

But first you must ask yourself: who do you want your robot to be? What is your robot's name? (Because every robot has a name.) Every robot is an individual. How do you want to act and interact with your robot? What would your robot do that is special? What would your robot do that no one else's would do?

Draw a picture of your robot. Write a story about what it would be like to live with your robot each and every day. What new, wonderful things would your robot do? What could go wrong? What should we avoid? Your imagination and these ideas will make your robot an individual.

Science fiction stories, comics, and movies are powerful tools that can help you to imagine your robot. We can use science fiction, based on science fact, to design robots, and share those stories as a technical requirements document.

Easy to Build

Back in the twentieth century, building a robot was hard. Computers were massive and slow. Electronics were complicated, and the manufacturing process was reserved for just a handful of people who had the money to build factories and assembly lines. But all that's changed.

Today computers are small and easily accessible. Software tools and apps allow anyone to be a programmer or designer. 3D printers have lowered the barrier between the digital and physical worlds, allowing us to manufacture nearly anything we can dream up. There are entire communities, events, and places where you can go to design and print your robot.

Completely Open Source

The idea behind open source is that people should have control over the technology we use. We should be able to build it, modify it, and share it. The practice and community around open source really got popular at the end of the twentieth century with the expansion of the Internet and the software it ran on, like the open source operating system Linux.

A 21st Century Robot is completely open source. Starting with 3D design files, everyone should be able to design and customize his own robot. The software that

runs the robot and makes up its brain is free and open. You can play with the operating system, and even design different apps for your robot.

More than anything else, we want you to share your designs with others. Did you come up with a cool new leg design? What's your latest app? Even the production of these robots is open; people all over the world can collaborate to build better, smarter, funnier, and more exciting robots.

Intentionally Iterative

Why make just one robot when you can make lots of robots?

The practice of iteration is the repeating of a process with the goal of making multiple versions of an object or a project. We make many robots with the aim to improve and experiment with different versions. Each robot is the starting point for the next. Each new robot plays around with what we learned from the previous. It's okay to experiment and try new ideas. Building off this kind of open source sharing, things get really interesting when you experiment with other people's ideas.

Fiercely Social

A 21st Century Robot is fiercely social. It is primarily designed to act and interact with people. It also connects to the Internet, to social networks, and to other 20th Century Robots. What would your robot say to another robot?

How we build these robots is social as well. There is an entire community of people all around the world who love building and who dream of a very different kind of robot. Working together, we can change the future of robotics.

Filled with Humanity and Dreams

Robots are built by people. We design them with our hopes and dreams. We can imagine our possible futures, and put those future dreams into our robots.

Japanese roboticist Masahiro Mori saw that our machines are an extension of ourselves. In 1974, he wrote: "Machines, while appearing to be separate from us, are in truth only functions that have been cut away from us, but are essentially part of us."

Our robots are a way to imagine a different future, to build our dreams and let them play with us.

Thinking for Her/Him/Itself

You can design your robot to her/his/its own personality and behaviors. You can make apps to do just about anything your imagination can dream up.

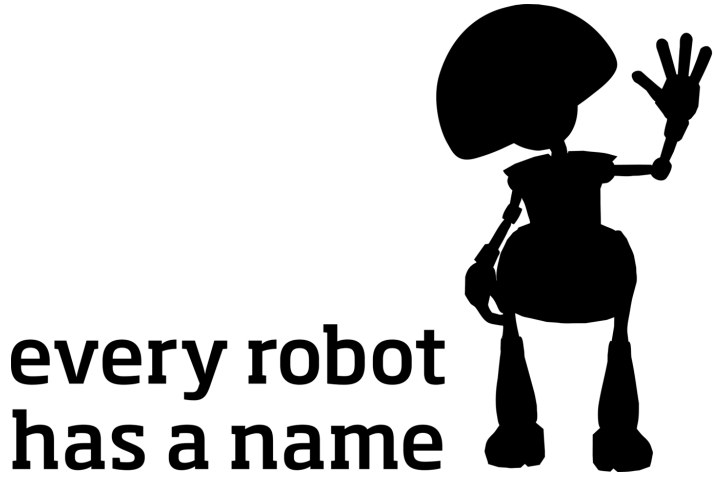
A 21st Century Robot isn't a puppet. It is designed to think for itself with real artificial intelligence, to move around and make decisions. It is designed to act and interact with you and other people. We want these robots to be adventurous and strange and funny.

Our Motto: "Every Robot Has a Name"

Every robot is built by people in their backyards, garages, and basements. Every person has a name. Every one of us is an individual. That's why every robot should have a name: because your robot, and all the other robots you will build, will be an extension of you. Your robot and the design for your robot will go out into the world. Other people might use parts of it to make their own. This sharing and iteration can go on and on. We keep building...we keep sharing...we keep designing, programming, and building robots.

That's a 21st Century Robot. It's a way for us to imagine, design, build, and share our own personal visions for the future. And it's also a way to make some really awesome little friends.

This book is the chronicle of how the first 21st Century Robot was made, as well as the stories of the people who helped to make him.



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I have talked with Joe Zawadsky for nearly every morning of my life for the past five years. His over-the-top enthusiasm for the robots keeps me going like no other.

Thank you Ken and Teri Hertz for your endless hospitality and support. And to Danny and Annie for thinking I'm cool.

Jimmy and the robots have always had a huge fan in Justin Rattner, who encourages me to try new things and go further. Anyone who knows me knows that Christy Bachich basically controls my world and she's darn good at it. Thanks to Harlene Conley for setting the bar so high.

Jennifer Sullivan and the Membrain crew always seem to show up out of nowhere with tremendous smiles, always excited, and always with great ideas. Thank you Brad Fisher for being my Perry Mason.

Thank you Shyama for being a good sport when Sandy and I took over the studio, but more for your quick and clear-eyed critiques.

Jim Olsen and April Miller might love Jimmy more than Sandy and I. Their creativity and love of collaboration made rushing to deadlines kind of fun.

Now...to the scientists! Simon Egerton, Vic Callaghan, Graham Clarke, Sumi Helal, Sara Criz, Tadayoshi Kohno—you were and remain inspirations.

And finally...to the makers! Most of which you will meet in this book, but many who simply lent a hand or a glue gun or a soldering iron. Thank you.

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He Builds Robots with His Mind

Remember I told you this book ends with Jimmy standing backstage about to make his big debut? Well, when I sent this picture of him to my wife she replied back quickly, "That's the ROBOT YOU MADE WITH YOUR MIND!!!"

Figure 1-1. *Jimmy backstage (photo: Brian David Johnson)*

Ten years ago I began to imagine what it would feel like for people to act and interact with robots in the twenty-first century. But these robots weren't like the robots we'd seen in movies, on factory floors, or in university labs. These would be a totally new kind of robot. Something no one had seen before.

I used an unconventional tool to imagine what it might be like to live with these robots: science fiction! I'm a science fiction author, but more importantly, I'm a science fiction fan. Science fiction gives us a language to talk about the future. Most good science fiction stories are about people. So a science fiction story based on my research would allow me to explore how people would act and interact with my robots. The tool is called science fiction prototyping, and I've been using it my entire career to help me explore different visions of tomorrow.

The 21st Century Robots were first born in science fiction about a decade ago.

A Robot Who Sees Angels

It was late afternoon in the spring of 2004. I was in my study, lying on the couch. The window was open and I could hear the afternoon traffic rolling down the street, and the sound of kids getting out of school for the day.

Lying there, I thought about what it would be like if a robot's intelligence was born and developed online. What if a robot's artificial intelligence wasn't created by a single person or a group working together in a government or university lab? What if the robot's mind and experience were put together on the Internet? I imagined what it would be like if people all over the world could work together to create the robot. Maybe some of those people might not even know they were working on a robot at all.

A robot's brain can take many forms. It can be everything from a small self-contained computer with limited functions, to a massive room-sized machine capable of incredible mathematical skill. But in all cases, a robot's brain should have intelligence and the ability to make decisions on its own. This artificial intelligence, known as AI, used to be created by teams of scientists, and was complicated and expensive. But if a robot's brain was developed online, then the AI wouldn't be expensive at all. Because it was created for free on the Internet, it would be more like a free app you could download for your smartphone or tablet. If this was true, then maybe there would be a lot of different robot brains out there. People could pick the one that suited them. They could modify the brain for the kind of robot they were building, or the tasks they wanted their robot to do for them.

That was it! My mind started racing.

Imagine the diversity of robot brains and software that could be born from people all over the world collaborating on the brain! Sometimes they'd be created for important things, but, like the Internet, most of the time it would be for fun.

Lying there on the couch I started working on a science fiction short story to play out what it might actually be like to act and interact with a robot that was born and raised this way. The name of the story was "A Robot Who Sees Angels," because this robot had spent a good part of his youth looking at ancient art and the walls of cathedrals. And because he was a robot, he could pull up that art and see it whenever he wanted. He could overlay the art of his youth to help him understand any new situation he might be confronted with. Or he might even do it to calm himself down if he was scared, remembering something that made him happy from his past.

Now that would be an interesting robot!

As I was writing the story, I started sketching out what the real-world software and operating system for this kind of robot might be like. The possible diversity

and funny things that people all over the world might come up with fascinated me. It wasn't just a robot that could see angels that was interesting, but also the potential diversity of all the other kinds of robots.

"I'm Making Irrational Robots"

For the next few years I continued to experiment with this new kind of robot, but everything changed when I met Dr. Simon Egerton.

Back in 2008, I went to Seattle to attend the annual Conference on Intelligent Environments at the University of Washington. Typically, the conference is held outside the United States, and I was usually one of the few Americans who attended. For my work as a futurist, it provided a fresh and different perspective on how computers and intelligence might make our lives better.

At the end of the conference there was a big party. The room was filled with people, discussing and arguing new ideas and concepts for the future. This is where I met Dr. Simon Egerton.

"I'm doing work on nondeterministic robots!" Simon yelled above the music and chatter of the collected scientists, engineers, researchers, and university students. Dr. Simon Egerton was tall and broad. He towered over me at the crowded social event.

"What?" I yelled back. I had no idea what he had said.

"I'm doing work on nondeterministic robots," he repeated. "I'm making robots that make both good decisions and bad decisions."

"You're making robots that make bad decisions?" I asked, puzzled, not sure I had heard what I had just heard.

"Yep." He smiled and adjusted his glasses. "I'm making irrational robots."

Simon is one of the nicest and most thoughtful people you could ever meet. He's a big guy with a big heart to match. He works weekends saving stray dogs and cats in Kuala Lumpur, where he is a professor of robotics at Monash University. He made quite an impression.

"Illogical robots!" I yelled back. "What?"

"Humans make both good decisions and bad decisions; that's why we are so good at adapting to complex environments. I want my robots to be that good, so why wouldn't I let my robots make both good decisions and bad decisions? They will learn faster." He took a sip of his drink and peered down at me through his glasses.

"Good point!" I smiled. I was hooked! "What's the name of your research?"

"Using Multiple Personas in Service Robots to Improve Exploration Strategies When Mapping New Environments" (Egerton et al., IET, 2008).

"Now *that's* a title," I said, smiling. "Can you tell me more?"

"For sure," he replied.

And that was it. My life changed forever.

The Creative Science Foundation Is Born

Working with Simon and a group of researchers and professors, we pulled together a collection of people called the Creative Science Foundation. Over the next four years, we would collaborate on this new kind of robot (see more details about this in Chapter 5). At the center of this research was science fiction, which we used to explore the possible realities of these robots. The stories were, in fact, prototypes that allowed us to understand what it might be like to interact and live with these robots.

As an homage to Simon and his research, we named the main character of the stories Dr. Simon Egerton. We never thought that the adventures of Dr. Simon Egerton and his strange little robots would ever become as popular as they did. Simon has always been a good sport about us using his name, saying, "I do wonder what it would be like if *my* life was as exciting as your Dr. Egerton's."

To bring the robots closer to reality, we convinced illustrator Sandy Winkelman to be a part of our team. With each new robot, he'd come up with a drawing of what the bot might look like. This would help us refine the functionality of the robot even more. Over the last 10 years, we've created all kinds of robots, all of them a little strange, but each one unique.

At the Creative Science Foundation, we used the stories to move our research forward and help us envision this new kind of robot. The stories allowed us to come up with new approaches to software and artificial intelligence. Each story led to a new breakthrough and more research. In turn, that new research led to another story, each building on the other. That's why this book is a mix of science fiction stories and nonfiction chapters, of thought experiments and help files!

He Fixes Radios by Thinking!

Richard P. Feynman is a personal hero of mine. He was an American theoretical physicist and Nobel Prize winner. In 1985, Feynman published a book that changed my life. *Surely You're Joking, Mr. Feynman!* (W. W. Norton) chronicles the adventures of Feynman as he moves through a truly amazing life. Reading the book as a kid taught me to be curious about the world, to be intellectually courageous, and

that there wasn't just one kind of scientist. It not only launched me on a lifelong love of physics, but it also showed me that imagination was an important part of being a scientist or engineer.

The book opens with a section called "He Fixes Radios by Thinking!" in which Feynman relates a story from his childhood in Far Rockaway, New York. To make money, young Feynman repaired radios. Always good with mechanics and figuring things out, he would start each job by thinking through why the radio might be broken, based on the symptoms of the failure. He would picture how the electronics worked, imagine what might have gone wrong, and figure out what he could do to fix it.

This process meant that Feynman spent a good amount of time pacing back and forth in front of the radios, leading one customer to ask him, "What are you doing? You came to fix the radio, but you're only walking back and forth!"

To which Feynman replied, "I'm thinking!"

Then when he found the problem and fixed it, the customer proclaimed, "He fixes radios by thinking!" The idea that a person could think through a problem first, imagining different scenarios, seemed impossible to the customer. But that's just what Feynman did.

Little did young Feynman know that this activity would become an integral part of his profession.

"Thought experiments are at the foundation of theoretical physics and science," physicist Dr. Paul Davies explained to me once when we were talking about Feynman and using imagination in science. "Being able to imagine possible futures and then figure out if you can make them a reality is incredibly important."

Paul is the director of BEYOND: Center for Fundamental Concepts in Science and a frequent collaborator of mine. He's written books like *How to Build a Time Machine* (Viking). Each of his books and lectures explores real-world physics with fun and interesting topics. These were part of the inspiration for the science fiction stories in this book. We have to be able to imagine the future so we can then build it.

Next: The Loneliness of the Long-Distance Robot

Our journey into the world of the 21st Century Robots begins with Dr. Simon Egerton as he investigates a strange occurrence at a distant technology factory. We learn that there are many different kinds of robots, and we meet a funny little robot named Jimmy...

The Loneliness of the Long-Distance Robot

"Was anyone hurt?" Dr. Simon Egerton asked after a long pause.

"Hurt?" Tian Yu, a project manager for the DeutchConn Corporation, asked in a quick baffled shot. Her voice was sharp, with precise words that stabbed at the ears. The background noise was so loud she had to yell to be heard. "What do you mean?"

"Was anyone hurt in the accident?" Egerton was afraid of the answer.

"I'm sorry, Dr. Egerton, but you are going to have to repeat that," Yu shouted. "I'm on a shuttle now headed to the fab. I can barely hear you."

"Was! Anyone! Hurt! In! The! Accident?" Egerton yelled.

"What do you mean hurt? Who could be hurt? There's no one at Fab 5," Yu replied. "There was no one anywhere near the place."

"What about the bot in the new HCI test lab? I mean, the Human-Computer Interaction validation lab?" Egerton asked. "The bot that was just installed. The one I..."

"That's why my boss at DeutchConn wanted me to call you." In the wild noise, Yu still seemed bored and annoyed at the same time. DeutchConn was the company that owned the fabrication plant where Egerton had recently done some freelance work on a robot in the HCI lab. "That's where the fire started. The new robot you made...the new bot burned down the entire DeutchConn Fab 5 facility!"

"How could the fire start there?" Egerton asked. "There's no fab equipment there. It's just a testing lab. There's nothing there but..."

"They have it on video. They know where it started," she answered. "That's why they wanted me to call you. That's why you have to come back to the fab. They've started talking about lawyers."

"But how could a fire have started in the lab?" Egerton ignored the threat. "There's nothing in the HCI lab that can start a fire."

"The techs say the new test bot set itself on fire," she answered. "Burned out the entire factory. It was your robot."

"The bot set itself on fire?"

"Yes." There was nothing in Yu's voice but words. The background noise erupted as the cargo shuttle fired its engines to slow down. "There's a shuttle coming to pick you up in four hours. Randall," she yelled to someone with her in the shuttle, "you're picking up the robot guy next, right?"

"You don't have a choice," she returned to Egerton. "Do you want me to send you the video? You can see that your bot clearly sets itself…"

"Yes, send it," Egerton interrupted and shut off the call.

Cockpit, Cargo Hauler Chen-Ming: 30 Hours to Reboot

"It's a weird little place," Randall, the shuttle pilot, said as they approached DeutchConn Fab 5. "I take maybe three people out here a year. Doesn't take long, a couple of hours roundtrip. But the shipping drones, they run back and forth all the time. I swear, nobody knows what they make out here."

"It's just chips," Egerton answered in a low voice. He paused the video of the HCI test bot at the precise moment before it set itself on fire. The security feed was also supposed to be recording the internal state of the robot, but it had malfunctioned months before, and no one thought it was important enough to repair.

"Chips?" the pilot called back over his shoulder. "Like computer chips?" The pilot's name was Randall J. Gan. He was young and liked to talk. His long, lean body barely fit in the cramped pilot's chair of the beat-up cargo shuttle.

"Yeah, they're just really small and really fast chips." In the video, the robot had doused itself in an unknown liquid and paused before creating an electric spark between itself and the metal table. Lighting itself on fire was no easy task.

"Seems silly putting a chip fab all the way out here," Randall mused to himself.

"They don't need any people to do it," Egerton spoke up before he could stop himself. "They don't want any people."

The rest of the big cargo shuttle was empty; no material, no other passengers but Egerton. Randall had invited Egerton to join him in the cockpit because the pilot sensed that the scientist was getting a little spooked sitting back there all by himself.

"Well, who watches them?" Randall turned around as the shuttle neared DeutchConn Fab 5. "How does DeutchConn know that the factory is running it right? Building all those chips right?"

"They don't need to know, as long as the chips work. Plus, they can watch the systems remotely. The place is filled with sensors and monitoring systems. People in close proximity actually are bad for quantum chips. The processes are so precise and difficult that humans get in the way. We're also hairy, and hair—or even tiny particles of our dead skin—produces flaws in the chips." The shuttle was getting close to the Fab 5's dock. The fact that Randall wasn't watching the controls started to make Egerton nervous.

"But what happens when something breaks?"

"There are bots for that," Egerton answered.

"There are bots to fix bots?"

"Oh yeah." Egerton finally looked up from the still image of the HCI bot. It had haunted him the entire trip. He stared at every inch of the bot, trying to figure out why it had set itself on fire. Looking away felt like taking a deep breath of fresh air. "There are bots to fix bots. Bots to clean the bots. Bots to print out new bots and replacement parts. Even bots to test if what the other bots are making is good enough to send to us humans."

"Really?" The pilot stuck out his lower lip in disbelief.

"Shouldn't you, uh..." Egerton pointed to the heads-up display that was now filled with the Fab's docking station.

"Nah." The pilot waved away Egerton's concern. "There are bots for that as well." The pilot's laugh was deep and wet. "I'm just here in case something goes really, really wrong."

Egerton smiled and returned to the HCI bots on the screen. He let the video play and watched the bot set itself on fire.

"Docking in 60 seconds," the warm, female-voiced computer said.

"There's my Shelia," the pilot said, tapping the heads-up display. "I was getting worried you were mad and had left me."

"I couldn't leave you, Randall," the warm voice replied. "I love you too much."

"That's my girl." Randall ran his fingers gingerly across the screen.

"Docking in 30 seconds," the warm voice reported.

"Dr. Egerton." Randall's voice grew serious.

"Yes?" The tone forced Egerton to turn from the burning bot.

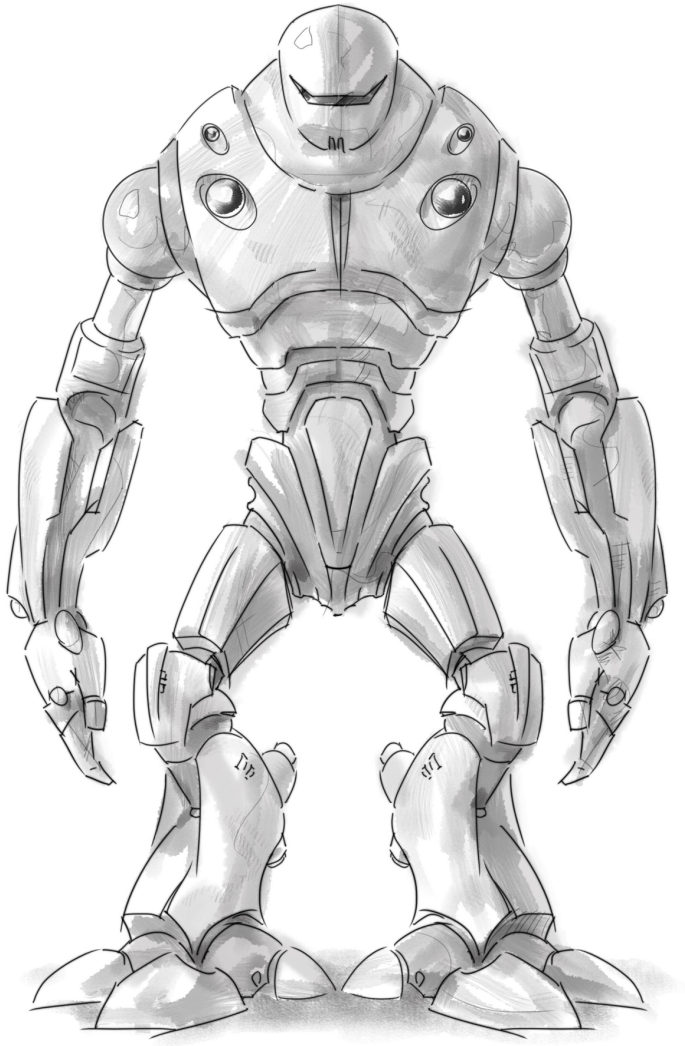
"Over the last 12 hours, I've hauled in construction dudes, fast-track builders, and even a whole rig full of hopped-up code monkeys. Not to mention that crazy woman Yu. But you're here alone on this big old rig and I got this priority order to come pick you up. Can I ask what you do?"

"I guess I'm like you," Egerton said. "I'm around just in case things go wrong. I'm the one they call when robots go really, really wrong and they don't know why."

DeutchConn Fab 5, Rim of Aitkin Crater, Lunar Farside: 25 Hours to Reboot

"Did you notice there aren't any beds? I mean, I bring a small army out here, at least DeutchConn could have given us beds," Tian Yu, the DeutchConn project manager, complained as she led Egerton through the charred remains of the production fab. "This is where the fire was the worst," she continued. "We're going to do this fast. Right now all my crews are working on the quick work. I've got a team of five guys and a mess of our own recovery, construction, and security bots. We want to show progress. Deutch likes to see progress."

"Is that…" Egerton stopped and looked up at the towering security bot that guarded the door to Fab 5's main floor.



"Huh?" Yu stopped when she realized Egerton wasn't following her.

"Where did you get this?" Egerton asked, taking a hesitant step toward the hulking machine. It acknowledged him but didn't move.

Yu was growing impatient. "We've had that piece of junk since it was new. It's only good for..."

"But this is the Gen 1 version." Egerton looked at the massive arms and thick legs. It was a full three feet taller than Egerton. "I haven't seen one without its riot pads in years."

The bot shifted its broad feet, resetting its hips in a defensive stance. Egerton jumped back in fear. A string of deaths had been caused by this model robot. They were far too large and powerful to be used around humans. One quick slash of the bot's arm could crush a human skull. All civilian security robots were now required to wear protective pads and have their power drive cut in half in the presence of humans.

Yu laughed. "Come on, Dr. Egerton. No one cares about some old security bot all the way out here. Even if he could take your head off with a jab of his elbow."

"But he's dangerous." Egerton caught up with Yu and they continued.

"He's only dangerous if someone messes with him," Yu replied. "That's what makes him a good security bot. We can't let anyone get in the way of our schedule."

"It's an aggressive schedule," Egerton answered. He really didn't know what to say. He didn't know much about the repair plan. He was still spooked by the sight of the security bot. It was like seeing a hulking, wild animal sitting quietly in your neighbor's living room.

"So that's why no beds." Yu stopped and turned to Egerton. "We have 25 hours to get this place repaired and back online. There are no beds because…"

"They don't want us to sleep," Egerton finished.

"It's insane, but I think we can get it all repaired and rebooted by then," Yu said, smiling proudly. "I've seen worse than this. Fires aren't common in Fabs, or hell, in any stations. Why would anything catch on fire…" She scanned the room.

The main floor of DeutchConn Fab 5 was a wide, flat room with a high ceiling that gave room for the bots to work. The entire room sat on an elaborate system of jacks and suspension monitors to keep it eerily still no matter what happened. The arms and tracks of the production line had been scraped clear from the floor and were in a charred pile in the back corner. The sight of the destroyed robots disturbed Egerton. They looked like victims of an atrocious war crime.

"We had one job where the fire nearly breached the outer hull of the station. The pressure change was the problem. Literally, it was inches between us and a heck of a lot of trouble. None of the guys would make the weld and put in the repair plate. I had to do it myself." Yu shook her head. "All these big, quick construction dudes and they're afraid of a little catastrophic structural failure. Bunch of babies. SLRRRRRRP." She sucked in her cheeks and slapped her hands together. Laughing, she continued to lead Egerton to the HCI lab.

"When do the new fab bots arrive?" Egerton asked.

"The arms and tracks?" Yu asked.

"Yeah, the new ones." Egerton pointed to the dead pile of bots.

"Oh, them. I guess I never thought of them as robots," Yu answered flatly.

"They are." Egerton waited. "The industrial bots, when do they arrive?"

The air got tense.

"They arrive 19 hours before we go online." Yu wasn't sure what she had said to upset Egerton.

"The HCI lab is this way, right?" Egerton pointed to the far door. Yu nodded. "Is the bot still in there?" Egerton moved toward the door.

"Yes."

"Do you need anything else from me?" Egerton asked. "I think I'm going to have my hands full for the next 24 hours."

"Nope," Yu replied. She looked at Egerton like he was a little too strange for her taste.

"Please come get me when the new bots arrive." Egerton's voice softened with worry as he looked around the carnage of the room.

"Are you okay, Dr. Egerton?" Yu asked.

"I'm worried that I won't figure out what happened in that room." Egerton pointed to the HCI lab. "And all of this…"—he gestured to the fire damage and destroyed bots—"…and all of this will happen again."

DeutchConn Fab 5, HCI Lab: 22 Hours to Reboot

"It looks like an autopsy room in here," a compact Asian man said, leaning against the door of the HCI lab.

"It is," Egerton replied without looking up from his work on the table.

The HCI bot lay on the table. Egerton had spent the last three hours gingerly dismantling what was left of the bot. It was a mess.

"My name is Shanwei," the man at the door said casually. "I'm running the sub-crew for Yu."

"Okay." Egerton didn't glance up. He didn't care. He was deep in thought. He picked away at the corpse of the bot. Every piece of the robot had fused together; its outer body had melted into the servo motors, the battery and the brain were locked together in a thick and dangerous polymer blob.

"They say that you built it," Shanwei spoke again after a long silence.

"I did." Egerton tried to pull away the bot's drive rods from its melted inner body. By design, the HCI bot had no legs, just a torso, arms, and head. It was fixed

to the end of the fab process to test a statistically valid number of chips as they came out of the fab.

"Do you know what happened?" Shanwei asked. "Yu's worried you're going to burn the place down again. Not that I care. It just means we all get paid to do this again."

"I think it killed itself." Egerton snapped the chest cavity to free the brain.

"What?" Shanwei laughed, sure he hadn't heard the intense doctor correctly. "Did you just…"

"Yes," Egerton cut in. "I think that this little guy killed himself—committed suicide—and no, I don't know why…"

"Okay, okay." Shanwei stepped back away from the door. "We're all just curious. I mean…"

"It had to have wanted to do this to itself." Egerton wasn't listening to Shanwei. "Why would he do this? It's like he wanted to melt everything…"

Realizing Egerton was in his own world, Shanwei turned and left the lab. Egerton never looked up from the bot.

DeutchConn Fab 5, Load Dock: 19 Hours to Reboot

"Have you figured out why the bot committed suicide?" Yu asked as they watched the shuttle carrying the new robots dock with the station.

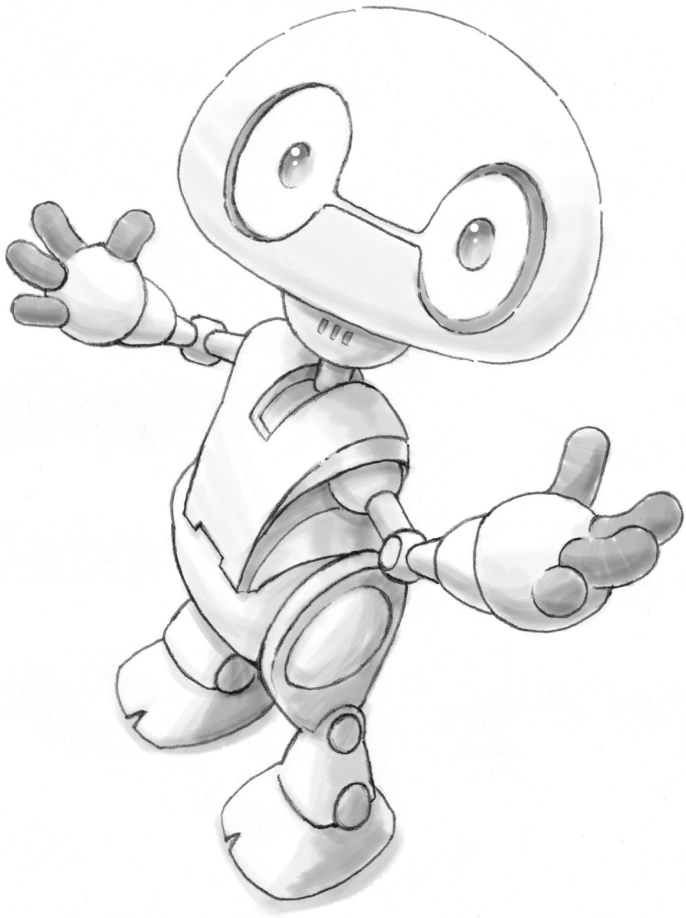
"How do you know the bot committed suicide?" Egerton asked.

"One of my subs told me," Yu replied. "He says that you said the bot killed itself. That can't be true."

"It is." Egerton was amazed at the delicate ballet between the massive shuttle and the even more massive station. He saw them as two gigantic robots slowly dancing into an embrace.

Once the shuttle was safely locked in, Yu asked, "So, what are you going to do?"

"Build another one," Egerton said, moving to the opening cargo doors as they revealed a stunning landscape of gleaming robots.



DeutchConn Fab 5, HCI Lab: 10 Hours to Reboot

Egerton ran his finger slowly underneath the newly completed bot's neck and gently turned it on. The familiar sound of the bot coming to life relaxed Egerton's mind.

"You're running out of time," Yu said, knocking on the wall.

"What do you mean?" Egerton looked up from the little bot. The new bot was different than the original HCI robot. Same arms, head, and torso, but this time Egerton had printed some legs for him.

"Can I show you something?" Yu gestured over her shoulder.

"Can it wait? I'm bringing this new test bot online. I need it to look at the AI before I finish printing the new HCI bot and I want to..."

"No, it can't wait," Yu snapped. "We have 10 hours before we go online and from what I can tell, you are no closer to figuring out what happened. Frankly, I'm worried that this whole place is going to..."

"Okay, okay." Egerton moved over to the door. "Don't worry. This new bot is based on the same architecture as the one before. I'm going to bring him up and run through some tests. I think I have an idea what happened." Egerton stepped into the corridor, leaving the bot alone in the room.

"This is your last chance." Yu gestured over her shoulder. "We're almost done."

Egerton looked at what she was pointing at. The main fab floor was transformed back to its pristine state. He could see that only a few contractors remained in their robo-assist gear. They were rushing through the detailed finishing work at a blistering pace, guided by the metal-lace cages that clung to their arms.

Seeing that Egerton was impressed Yu said, "I know," and smiled, pleased with her work and her crew. "This isn't our first rodeo. But this is your last chance. We need to get the new bots installed and then clean this place out. Humans are hairy and bad for chips. It's going to take a few hours to clean this place down to spec."

"How long do I have?" Egerton grew worried. "I need more time."

"I can give you an hour," Yu replied. "Hour and a half tops, but then I need to clear it and sanitize it. No people in here ever again. Deutch is worried that all these people in here are going to ruin the place."

"Okay, I'll do my best but..." Egerton paused. The little bot was standing in the door of the HCI lab watching Egerton and Yu.

"He's cute," Yu said.

"I didn't think he could do that. I didn't program him to follow people. But he seems curious." Egerton was both interested in the quirk and a little scared.

Yu walked over to the little bot and the little bot looked up at her. "What's his name?"

"I don't know," Egerton answered.

"How about Jimmy," Yu said. "I once had a goldfish with big ol' eyes like that. His name was Jimmy. Yeah...he looks like a Jimmy."

Egerton stood next to Yu and looked down at Jimmy. The little bot looked back.

"You have no idea what happened, do you, Dr. Egerton?" Yu asked flatly. "You have no idea why that bot killed itself, do you?"

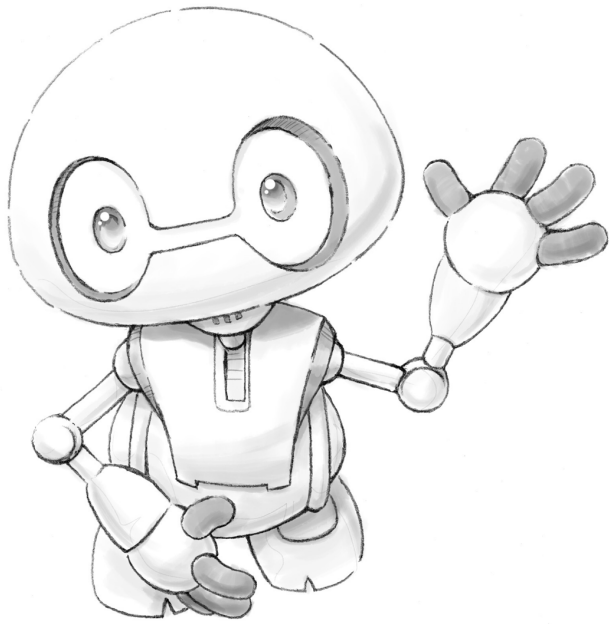
"No," Egerton answered. "I have no idea."

DeutchConn Fab 5, Load Dock: 5 Hours to Reboot

Jimmy looked small and out of place in the massive loading dock. Randall and the cargo hauler, the *Chen-Ming*, had returned from a quick trip past the moon, ferrying away Yu's subcontractors.

"Yo, Doc, who's your little friend?" Randall asked.

"His name is Jimmy," Egerton replied. "Jimmy, this is Randall. He's our pilot. Say hello."



"Hello, Randall," Jimmy said, walking over to the pilot.

"Would you look at that! He's a cute little fella." Randall patted the bot on the head. "What's he for?"

"Jimmy's a test bot. He has the base AI from the new HCI robot," Egerton explained. "He's designed to interact with people. He's social. All of those other bots are designed to work alone or with other bots, but Jimmy and the HCI bot are different."

"How is that?" Randall asked.

"Jimmy and the HCI bot are just quality testers. These new quantum hybrid chips are so fast and powerful, they are meant to understand the person they're working with. I built these bots to be more human, more complex, so they can test the chips."

Randall nodded. "Makes sense."

"We're locking the place up," Yu interrupted, as the last of the small army of human and bot contractors hauled their gear into the *Chen-Ming*. "I need to run the whole fab dry for the next two hours. That means all these knuckleheads can get out of here. Take 'em away, Randall." She waved away most of her team. "Looks like it's just you and me and a few techs and a whole lot of robots." She pointed through one of the few observation windows into the fab, and yelled, "Strike it up!" The bots hesitantly came to life.

"Good job, Yu," Randall said, climbing back into the *Chen-Ming*. "I'll drop your boys off and then be back here for you and the doc and his little bot."

"Keep 'em safe," Yu yelled.

Egerton marveled at the delicate and precise beauty of the Fab 5. Multiple robotic arms raced about, spinning on multiple axes, assembling the chips on an atomic scale. The low movers trundled dutifully along, moving the chips down the production line.

"We'll keep her dry and test the loads," Yu said again. "I want to start doping the silicon in two hours, and then we can start the fab running full steam. That's when we'll need your HCI bot up and running."

"She's running now." Egerton showed Yu a feed from the HCI lab. The bot with an upper body like Jimmy sat still and lifeless by itself at the end of the production line.

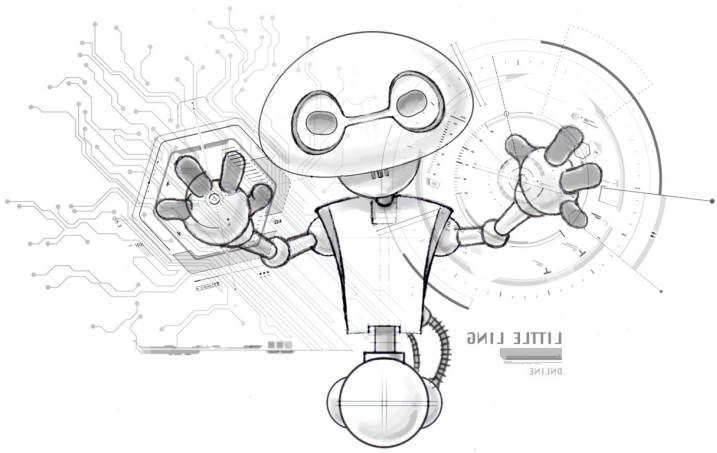
"What's his name?" Yu asked.

Egerton smiled. "Her. I named her Little Ling."

"Cute. But is she going to burn this place down?"

"I don't know yet."

"Well, you'd better figure it out real soon."



Cargo Hauler Chen-Ming: 1 Hour to Reboot

"Look at those little guys go," Randall said as the *Chen-Ming* pushed away from Fab 5. Yu had triggered the cleaning system to scrub down the loading dock for any stray contaminants. The little bots swarmed and cleaned the massive dock in swooping flocks of tidiness.

"Hold here," Yu said. Randall fired the *Chen-Ming*'s thrusters, and the cargo ship floated motionless a few dozen meters off Fab 5. "Give me some eyes," Yu called to the remaining techs on board the *Chen-Ming*. The front quarter of the cargo hold had been transformed into a makeshift command station. From this distance, they could monitor the health of the Fab 5 to make sure it was back in order. The screens were alive with video feeds and data.

"Let's see how she's doing." Yu watched the data.

Egerton watched the single feed coming from the HCI lab. Jimmy stood nervously by his side, worried about getting stepped on. He stuck close to Egerton's leg.

"Locked and steady," Randall said. He popped out of his chair and floated over to watch the show. "I told Deutch we'd bug out of here in 45 minutes or less."

"Right on schedule," Yu said to herself.

Egerton glanced down at Jimmy, then returned his tense gaze to Little Ling's video feed.

"Your bot ready?" Yu asked, motioning to the video feed.

"She's been ready to work for the past 35 minutes," Egerton answered.

"How can you tell she's on?" Randall asked. "She's not moving."

"I turned her on," Egerton said. "She's just waiting for work to do."

"I'm proud of what we did here," Yu said. "25 hours from a charred wreck to a working fab is pretty amazing. So, Dr. Egerton," she said, gently spinning in the cargo hold to face the roboticist, "how do you know she's not going to burn it down? Again."

"We don't," Egerton replied calmly.

"What?" Yu was stunned. "How can you still not know?"

"With these new bots you can't know for sure," Egerton explained. "Just like you can't always know for sure what a human is going to do. You just need to treat them right and wait and see."

The first chip came into the HCI lab for testing and validation. Little Ling slid it into the test screen and began interacting with it. Her test was swift and accurate. It passed and she sent it to shipping.

"But that's insane!" Yu got very close to Egerton. "We can't spend all that time and money and just hope it will all be okay."

"Yes, we can," Egerton smiled. "It's just like Randall here..."

"What?" Yu was getting impatient.

Little Ling started testing another chip.

"Wait, now I'm a bot?" Randall smiled.

"It's about trust," Egerton said. "You trust that Randall will park the *Chen-Ming* where he needs to park it. And when we're done, you trust that he'll take us out of here. You don't know if he's actually going to do it. He could hit the thrusters and ram us straight into the fab's dock..."

"Don't be stupid," Yu spat.

"It's true," Egerton continued. "You have a reasonable trust that Randall isn't going to wreck the *Chen-Ming* until he does something to counter that trust, then you'll react. It's the same thing with Little Ling. She seems fine now." Egerton pointed to the still and quiet bot as she waited.

"But she did burn the place down!" Yu looked at the data streams nervously and then looked back. "I mean, I'm not the crazy one, right? We were all here, she did burn it down."

"That wasn't Little Ling," Egerton spoke up. "That was a very different bot."

"But..."

"I know why the other bot killed itself," Egerton interrupted.

"Why?"

"Because it was lonely."

"How can a robot be lonely?" Yu snapped.

"These are not regular bots," Egerton said, looking down at Jimmy. "They're designed to interact with people. Their brains are kind of like our brains."

"I'm not so sure I want a robot with a brain like mine," Randall chuckled.

"That's what makes Little Ling so good at testing how people will use the chips." Egerton watched as the bot came to life and did her job, then went still. "Her brain is made up of personas. But only a small number, as with humans. We can all be different versions of ourselves, but just a few versions."

"Are you saying we all have multiple personalities?" Yu asked.

Egerton smiled. "No. We all have different modes of thought. Sometimes we're working, sometimes we're learning, sometimes we're talking with friends. But I realized that with the HCI bot, all the different companies that were testing their chips were filling the bot with their own audience that they wanted their product tested for. Some were targeting middle-aged mothers, others wanted to sell to senior citizens, others to the all-important eight-year-old market. So they just uploaded that person to be tested."

"How many people did the bot have in it?" Randall asked.

"Over two hundred."

"Yikes." Randall watched Little Ling.

"Exactly. It was too much for the bot. So, I limited the number of people that could be uploaded."

"But why did the bot destroy itself?" Yu asked with sincere interest.

"Well, way down deep in that HCI bot was the original learner persona that I built. But it never got used. It never learned anything on its own because we kept cramming new people into its head. It eventually must have gotten threatened or stressed or...."

"Lonely?" Yu asked.

"I think so," Egerton replied. "Then it was just a matter of time before the original personality saw all the other personalities as threats. Or the source of its loneliness. So it protected itself by destroying them."

"And destroying itself at the same time." Yu nodded.

"Yes, I think so."

"That's kind of sad," Randall spoke up.

"So how do we know it won't happen again?" Yu asked. "And don't say we can't know. You had to do something. How do we make sure that Little Ling here doesn't get lonely?"

"I gave her friends." Egerton smiled and pointed at Jimmy.

The trio was quiet for a moment as they watched the little bot. He stuck close to Egerton's leg.

"But he's here and she's there." Yu pointed at the screen.

"That's easy." Egerton smiled again. "I gave them a little network so they can talk, so they can be social. It's open, so people can play with it. But it's primarily just for robots."

The loading dock doors of Fab 5 opened and a cargo drone slipped out.

"First shipment verified," the lead tech said without emotion.

Yu, Randall, and Egerton watched the slim drone slide by and head toward the transport hub for distribution.

"Fab 5 back online," Yu reported to the transport hub. "We are back online. Everything looks good. We're pushing out of here."

"A network for robots?" Randall looked down at Jimmy. "Are they talking now?"

"Yep." Egerton watched Little Ling sitting still, waiting for something to do.

"So Jimmy, tell me," Randall said, "how's Little Ling doing? Is she lonely?"

Jimmy looked up at the tall man and replied, "She's okay. She's a little bored, but she's okay."

Design

In this chapter we'll meet the person who first designed Jimmy, illustrator Sandy Winkelman. He tells us about his inspiration and who he hoped Jimmy would be. Then we talk with designer Wayne Losey, who brought Jimmy into the physical world. Using computer design tools and 3D printing technology, Jimmy was printed in multiple sizes. Next, we chat with Dr. Melissa Gregg, who asks if our robot is a boy or a girl, and explains why it's an important question. Finally, we meet Ms. Moore's first-grade students, who became inspired by Jimmy and designed their own robots. Ms. Moore shares their vision for the future of robotics as they answer the question: what would you want Jimmy to do?

Robots in the Backyard

At the back of Sandy Winkelman's house is a small yard with a large magnolia tree that stretches across most of the property, shading it from the sun. Sandy and I spent many hours under that tree as we developed Jimmy and the other robots you'll meet in the 21st Century Robot project. Often we'd keep working into the night, our papers lit by a white chandelier hanging in the branches of that old tree.

Sandy's studio is just off the backyard, and that's where Jimmy was born. For the last 10 years, Sandy has given form to the strange little bots in the Dr. Simon Egerton stories. I'd write the stories, collaborating with the real Dr. Simon Egerton and the rest of the professors and researchers in the Creative Science Foundation (more about them in Chapter 5). Once the story (much like the one you've just read in Chapter 2) was complete, Sandy was always the first to read it. From there we'd start creating and illustrating the robots in the story.

Jimmy was designed in fiction to be a strange little robot that does strange little things. We knew that he had to look special, especially if, as Simon told me in Seattle, we were going to have Jimmy do irrational things. We didn't want Jimmy to scare people. There was a danger of people associating irrational robots with the scary robots in James Cameron's 1984 thriller, *The Terminator*, and we didn't want that at all. Those are not the kind of robots we were looking to create. 21st Century Robots were designed to be our friends. And they had to look like it.

"What was your inspiration for Jimmy?" I asked Sandy one afternoon as we sat under the magnolia tree, reflecting on our bots. "Jimmy's a cute little guy."

"But he had to be more than cute," Sandy said. "When people saw him, I wanted them to know he was a robot. I didn't want people to think we were trying to make him look too human or like a kid. He definitely needed to look like a robot, but the kind of robot that when you first saw him, you knew that he wanted to be your friend."

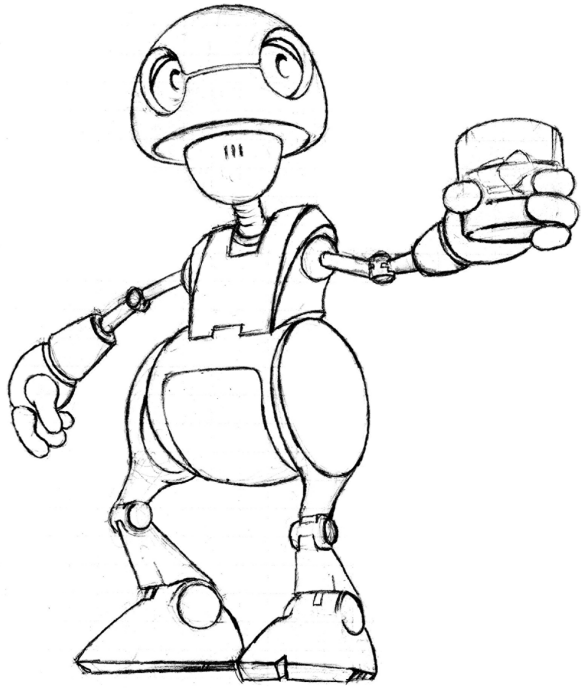


Figure 3-1. *An early concept sketch of Jimmy by Sandy Winkelman*

"He does have that quality," I said. "So what was the inspiration?"

"Two things, really," Sandy explained. "The first was E.T."

"E.T.?" I wasn't sure I'd heard him correctly.

"Yes." Sandy smiled. "*E.T. the Extra-Terrestrial*. I designed Jimmy purposely with inspiration from the creature in the movie."

E.T. the Extra-Terrestrial was a 1982 film directed by Steven Spielberg about a boy, Elliott, and his friendship with a space alien who lands in his backyard. The movie was a huge hit around the world, and Sandy thought that one reason was the alien's look.

For decades, people had been making movies in which aliens were scary, threatening bogeymen who came down to Earth to do bad things to humans. Now, there's nothing wrong with scary movies about aliens. They're fun, and that's what

they are designed to do: scare people. People go to these creature features to see what frightening creature the movies makers dream up.

When Spielberg and his special effects team were designing their alien, they wanted a completely different reaction. In Spielberg's movie, the alien is more scared of us than we are of him. The movie is about making meaningful connections between intelligences, no matter what bodies they're wrapped in. In the movie, Elliott and E.T. become friends.

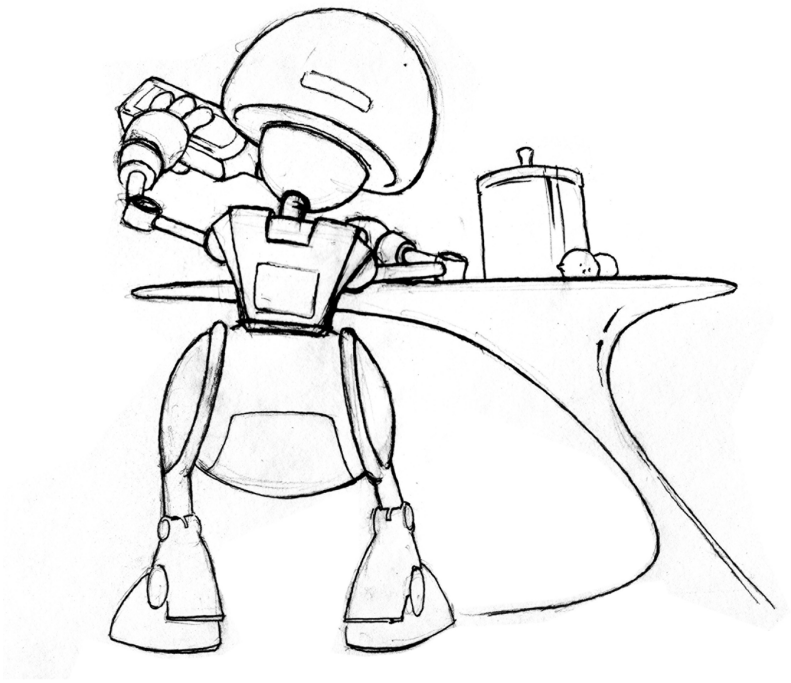


Figure 3-2. *A later sketch of Jimmy by Sandy. See how he's evolved?*

"That movie had a big effect on me when I was a kid," Sandy continued. "The alien in the movie isn't threatening, but at the same time you know he's not from this planet. Also, his size is perfect; he's large enough to interact with but too small to do you any real harm."

"What was the second inspiration?" I asked.

"The iMac G4," Sandy said, laughing. "It was a computer that Apple released in 2002. It had a monitor on top and the rest of the computer was housed in a white, curved base. It was really beautiful because it looked both organic and manufactured at the same time."

"So," I summed up, "you based Jimmy on an alien and a computer?"

"Yep," Sandy said. "It seemed like the perfect mix: technology and a cute little guy who won't do you any harm."

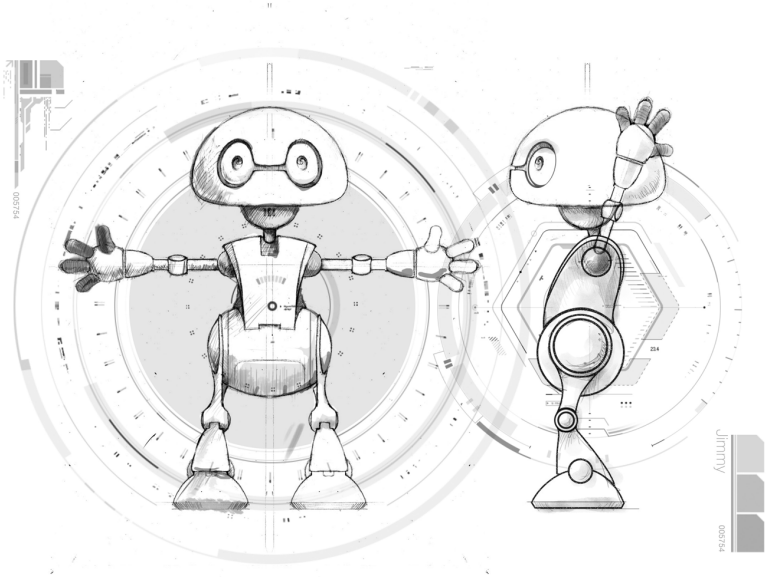


Figure 3-3. *The completed Jimmy by Sandy Winkelman*

"That sounds like Jimmy." I smiled.

"It all starts with the story," Sandy added. "All the 21st Century Robots have their own personalities. Each is designed for a specific form and function. In your story, *The Loneliness of the Long-Distance Robot,* the robot Little Ling is more of an industrial robot. She was created to test the chips when they come out of the fab. But Jimmy isn't an industrial robot. He's designed to be social with people and other robots. That means he should look and act a certain way."

"He just wants to be friends!" I said.

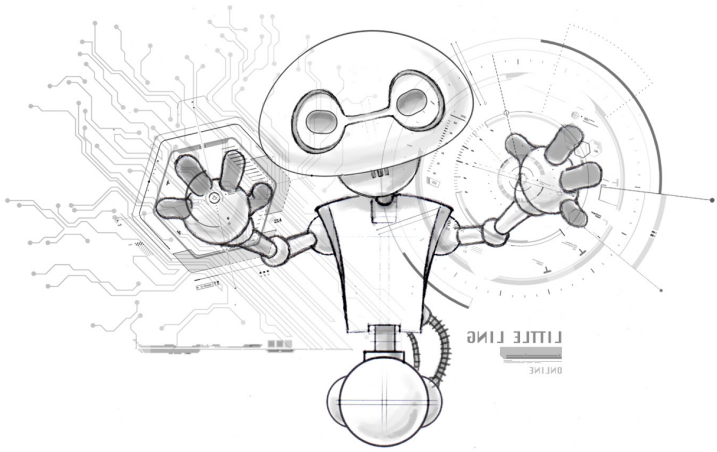


Figure 3-4. *Little Ling is an industrial robot designed to test computers (illustration by Sandy Winkelman)*

"You and I have been working on these robots for nearly 10 years," I finished up our chat. "Now that they're about to escape from the backyard and move out into the world, what's your hope for the future of the 21st Century Robots?"

"I just want people to start building robots," Sandy answered after thinking about it for a while. "They have been in my head and your head for so long that I'm really excited to see them in the real world. I think I'm more excited to see what people do with them when they start creating their own robots." Sandy smiled. "That's going to be really cool. I can't wait for that."

From Paper to Plastic and Beyond

The next step in bringing Jimmy to life was to move him from Sandy's illustrations and into the physical world. Recent technological advances have made this easier than you might think. It was 3D printing that convinced us that we could now bring the 21st Century Robots to life.

3D printing is a process by which you take a digital file on a computer and print it out on a device. There are lots of great books that go into more detail on 3D printing (for example, *3D Printing: The Essential Guide to 3D Printers*, edited by Anna Kaziunas France [Maker Media]), but basically 3D printing consists of building a physical object "dot-by-dot" using small dabs of molten plastic, resin, or metal (some machines even build stuff out of sugar or chocolate!) in a process called

additive manufacturing. 3D printing allows us to make every robot an individual, since it is relatively easy to personalize a 3D design file and print out a one-of-a-kind object.

To bring Jimmy into the physical world, I went straight to Wayne Losey. Wayne started his career in independent comic books, and then started working at toy companies. His experience made him the perfect person to bring Jimmy into the real world.

In October 2012, Wayne developed a toy called ModiBot. The toy was a human-like structure with special holes all over the body that allowed you to hang anything you wanted on his frame. Do you want ModiBot to be a knight? Just snap on a helmet, some armor, and a sword, and it's a knight. Want ModiBot to be a winged creature? Just snap on some wings, and there it is.

Figure 3-5. *ModiBot 3.0 (photo: Wayne Losey)*

"The original idea was that the toy could be whatever people wanted it to be," Wayne explained. "You can even print your own 3D parts for ModiBot. You can think of him as a kind of platform or base for anyone to individualize. You get to choose."

"So 3D printing is really the key?" I asked.

"3D printing allows everyone to design and make their own products and toys," Wayne replied. "It's a way to empower people to create their own things. The idea of having a desktop factory is really amazing. It's like we live in the future," he said, laughing. "It's going to completely change the way we interact with products and how we live with the products we make. It allows these products and toys to evolve over time. It's why I got into 3D printing and digital design."

PRINTING JIMMY

"First, we took the designs that I started with ModiBot and used those to make a small version of Jimmy," Wayne explained. "He's about six inches tall. The real cool

thing about the ModiBot design is the ball and socket joints. His shoulders, elbows, hips, knees, and neck are all similar joints. The tension of the printed material gives Jimmy amazing amounts of freedom. You can pose him in so many different ways."

Figure 3-6. *ModiBot version of mini-Jimmy*

The mini-Jimmy is pretty amazing. His neck moves left to right as well as up and down. You can move his arms from the shoulder and from the elbow. You can even twist his wrists. At his hips, his legs move forward and back, and you can pose his knees and ankles.

Figure 3-7. *Printed version of the mini-Jimmy*

GOING BIG

"The next step was a bit harder," Wayne said.

"Designing and printing the two-foot exoskeleton that would be the basis for the robot Jimmy?" I asked.

"Exactly." Wayne laughed. "We wanted Jimmy to be printable on a home 3D printer. That meant it needed to be in multiple sections that fit together. It was quite a challenge to separate all of Jimmy's parts in a way that they could be printed. But beyond that, we had to scale them up and replicate all the pieces so he looked correct. We wanted to make sure he still looked like the promise of what Jimmy

could be. He was the first step in the physical building process to get to a customizable robot. But for this first version, he had to be in parts, even though he would be glued together and posed. We wanted people to see the promise of what could be."

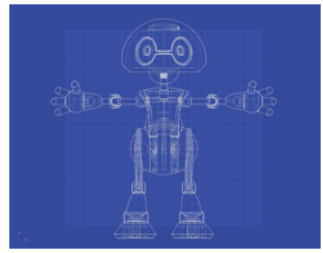


Figure 3-8. *Blueprint of large Jimmy showing all joints*

"I remember when we first showed him to people," I said. "The question we got most was how long did he take to print on a home 3D printer."

"Each of the larger sections of Jimmy took 24 hours to print," Wayne answered. "The two parts of his head took 48 hours to print. I found myself waking up early in the morning and going into my workshop to make sure that Jimmy's head had printed okay."

The Exo-Jimmy was designed to be the basis for the robotic Jimmy. His exoskeleton was purposely hollow so that we could design in the robotic parts to make him walk and talk and be social. Exo-Jimmy was to be the basis for all the other robots that would come after.

Exo-Jimmy's head can turn side to side, but he can also look down and back with an ingenious slider in his chest. Each shoulder is a ball joint that pivots to give him a wide range of motion. You can position his elbows and wrists. At the hips, Jimmy's legs can move forward and back, and both his knees and ankles can be positioned.

Do you want to design and print an Exo-Jimmy? They're a lot of fun. When we introduced the 21st Century Robot Project at the World Maker Faire in New York City in the fall of 2013, we printed a few Exo-Jimmies. Even though they weren't functional robots, they were a huge hit! It seemed everyone could imagine the potential of the little robot.

Figure 3-9. *Jimmy in a New York City cab (photo: Brian David Johnson)*

Jimmy's 3D printed exoskeleton went all over Manhattan meeting people. It was incredible to carry around a robot that we had had in our imaginations for 10 years and introduce him to people.

Figure 3-10. *Exo-Jimmy on Wall Street at the New York Stock Exchange*

How would you change the design to make your own robot? What would it be like to introduce your Exo-robot to people?

Figure 3-11. *Exo-Jimmy stands 24 inches tall and took about 168 hours to print (photo by Brian David Johnson)*

"The Exo-Jimmy was always designed as an interim step. He wasn't a functioning robot yet. He was meant to be used by the roboticists and engineers to build the next version," Wayne said. "That was interesting, to make something that wasn't a toy or even a design that was meant to stand on its own. This Jimmy was always meant to be a step so that we could move on to a functioning robot."

"Did anything surprise you during the design process?" I asked.

"There was one thing," Wayne answered after a moment. "When I was putting the large 3D printed Exo-Jimmy together for the first time, he had a certain presence. He's got personality, and when you see him in three dimensions at that scale, his personality comes alive. It was pretty amazing."

Figure 3-12. *The first assembly of Exo-Jimmy, when the personality starts to come out (photo: Wayne Losey)*

"Having that personality really does change things," I said.

"I think that there's going to be a real shift in how people interact with robots," Wayne finished up. "When people understand that these machines can have personalities, even in how they look, then they will start acting differently with them. It's going to be more of a relationship."

Is Your Robot a Boy or a Girl or Neither?

When you ask yourself who you want your robot to be, you also might want to ask if your robot is a boy or a girl robot...or maybe neither.

"When we talk about robots, at some point we should talk about gender," Dr. Melissa Gregg, known to friends as Mel, said to me as we sat having coffee in a café. "This is especially true when we start imagining 21st Century Robots."

"Why's that?" I asked.

"Well, these robots aren't servants," she answered. "They are designed to be social. They are designed to be friends. If we're thinking about friendship, it's good to think about our human friends first and what we can learn from that. It's a great start to then think about our robot friends. And if we are thinking about our human friends first, we have to understand that all humans have gender. Do we want robots to be like the friends we already have? Or do we want robots to be different? Do we want them to be our companions and to help us with things our human friends can't do?"

Mel is an Australian. "You know how most people think of Australia as the bottom of the world?" Mel smiled. "Well, in Australia, people think the bottom of the world is Tasmania, the island state to the south of Australia. I grew up on a sheep farm on an island at the bottom of Tasmania. So you can say I grew up at the bottom of the bottom of the world," she said, laughing. "You can't get much closer to Antarctica."

Mel is also an expert on gender and friendship. She has a PhD in gender studies from Sydney University, where she also taught a class called "Intimacy, Love, and Friendship."

"When you design your robot," she began, pointing at a picture of Jimmy on my computer screen, "you need to imagine it first. I think it's really interesting to ask *Is it a boy or a girl robot?* What does that mean? What's the difference between a boy robot and a girl robot? *Is* there a difference?"

"I guess that's up to the person who is building the robot. Right?" I said.

"Yeah." Mel nodded. "There's no right answer. You can make your robot a boy or a girl, or maybe it doesn't have to be either. There's no right answer when we talk about gender, but having the conversation, thinking about it, can be really interesting."

"Because it's about relationships?"

"It's a great place to start," Mel replied. "A robot can help us learn how to be friends with people we might not get the chance to meet very often. It might help us get better at having trust and care for others. And it might make us aware of all of the work that goes into becoming friends with someone from the very beginning. Ultimately, a robot can help us think about why we choose to become friends with the people we like, and what more we might want out of friendship."

Maja Matarić heads the Interaction Lab at the University of Southern California. Maja has spent 15 years working in human-robot interaction, and in socially assistive robotics. She works to understand how robots can make people's lives better.

"We think a lot about gender and robots. When I talk with people about it, I always like to tell this particular story. My students were working with a robot that looked like a small, stuffed, chubby dragon. It was short and squat and furry. We were interested in how young kids perceived the robot. Was it a boy? Was it a girl? We asked and nearly everyone answered that it was a boy robot."

"Really?" I jumped in.

"Yes," she replied. "When we asked them what would make the robot look like a girl robot, they said if we made the fur pink. Then when we showed them that the fur *was* pink, they didn't know what to say."

"What did that tell you about gender and robots?" I asked.

"Well, mainly it illustrated that when most people see robots, even when most people see machines in general, they usually see them as male," she answered.

"Aside from making them pink, how would you make them look female?" I asked.

"I don't think that's the right question," Maja returned. "It's not about making them look female. Aside from the obvious things we could do, like giving them human female attributes. But that's not enough. It's really more about context and story. We have a massive stereotype to overcome, and if you give a robot a backstory, if we give it context and a narrative, then people generally accept and understand who the robot is."

"So it could be male or female or neither," I said. "It just depends on the story."

"Right," Maja replied. "That's what's amazing about humans. We really believe stories. They are real to us. That's why I love this project. We need to imagine our robots first, give them a name and a story, and then we will have much more rich and interesting relationships with them."

When we first imagined Jimmy, we wanted to make sure that he was cute and approachable. I named him Jimmy because I wanted him to be a friendly little guy. Also, making Jimmy masculine seemed to work with the fictional relationship with Dr. Egerton. Jimmy is not an extension of Egerton—he's not meant to be Egerton's son—but he is meant to be a friend, a pet, and still yet a little unknown.

The Future of Robots Brought to You by Ms. Moore's First-Grade Class

In the 21st Century Robot Project, our first question is always: who do you want your robot to be? We have worked with people all over the world, from makers to professors, engineers to students. But as we were developing Jimmy, we were intro-

duced to an unexpected and wonderful vision of the future from Ms. Moore's first-grade class at Beaver Creek Elementary in Medford, Oregon.

"A friend told me about Jimmy and the 21st Century Robot Project," Margaret Moore told me. "He said it was real technology, it was a real robot. I searched for it on the Internet and just loved it. I loved the idea that the robot could be whatever you wanted it to be. I thought it would be neat to introduce my students to Jimmy and see what they thought."

"What was that like?" I asked, trying to envision Ms. Moore explaining Jimmy to a room of six-year-olds.

"I like to get my class thinking about technology and what the future will be like," she continued. "I showed them Jimmy on the Internet and told them that he was a real robot and that a group of scientists were building him."

"What did they think?"

"They thought he was so cute!" Ms. Moore laughed. "They thought he was adorable."

"What did you tell them?" I asked. "How did you get them started?"

"I told them that this group of scientists wanted to know what they thought the robot should do," she explained. "I asked them, *What would you do if Jimmy was your own robot?* That's all. I didn't give them anything else. Then we did brainstorming...they know that word. And they came up with all those amazing drawings and ideas themselves!"

What follows are the visions from these young minds. (Note: we couldn't include all of the pictures in this chapter, but they are collected in Appendix B.)

"I was stunned when I first saw them," I confessed. "Their visions for Jimmy are amazing."

"I know." Ms. Moore shared my enthusiasm. "I thought they might be selfish, or the usual thing you see in cartoons or on TV. I didn't think they would create little friends. They were so excited. They loved the idea that their ideas would help create robots in the future."

"You didn't know it, but that's the exact reason we created the 21st Century Robot Project," I gushed. "We want to get as many kids imagining, designing, printing, programming, and sharing robots as possible."

"I told them that when Jimmy is real, they can say that they helped to design him way back when they were in first grade," she said excitedly. "They are so stoked!"

When I told Ms. Moore that I'd like to include the students' work in the book, she laughed in disbelief.

"I had no idea this would go that far," she confessed. "I just thought the project was cool and that my students would love it. They are so creative. I never thought that it would make it back to you."

"Well, tell your students that they did shape the future of Jimmy." I smiled. "Tell them they will build the future of robots."

Figure 3-13. *Alex: "I want Jimmy to play with me. Jump rope."*

Figure 3-14. *Alexandra: "I want Jimmy to make me cookies."*

Figure 3-15. *Ava: "I want Jimmy to sing with me."*

Figure 3-16. *Brooklyn: "I want Jimmy to dance with me."*

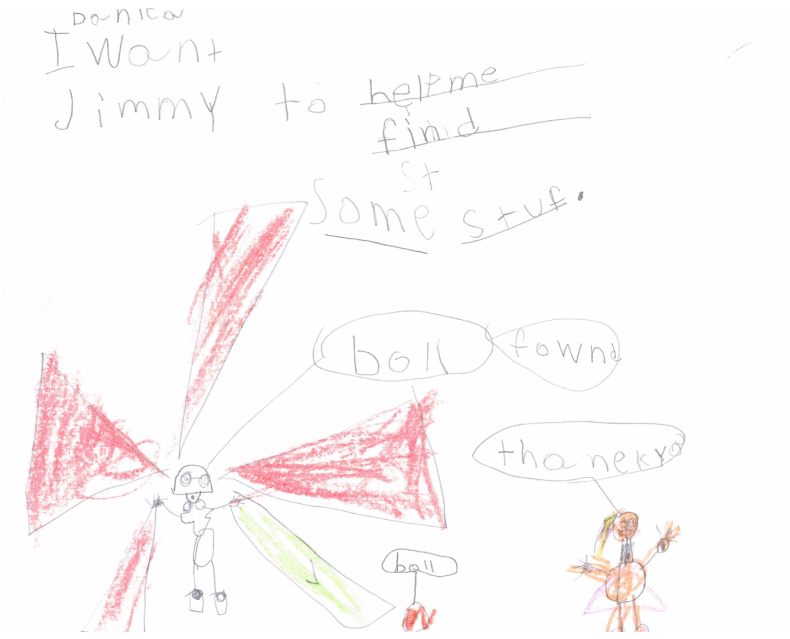


Figure 3-17. *Danica: "I want Jimmy to help me find some stuff."*

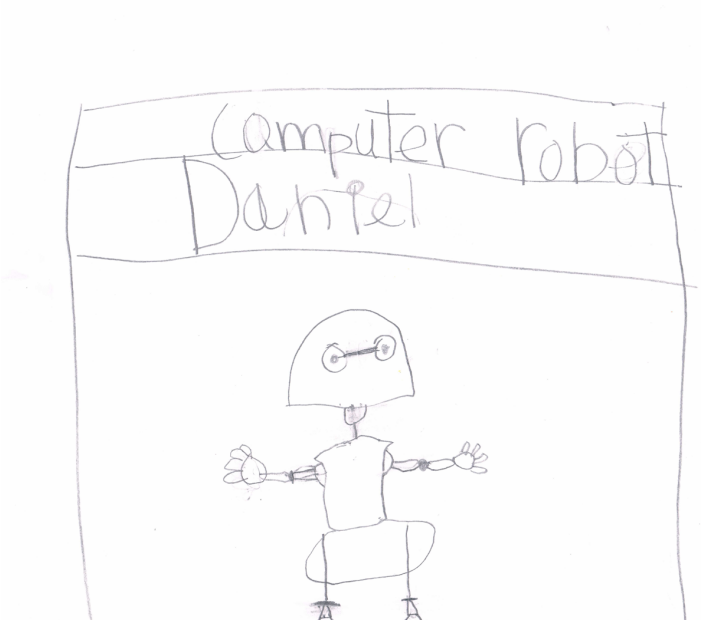


Figure 3-18. *Daniel: "I want Jimmy to play with me hide and go seek."*

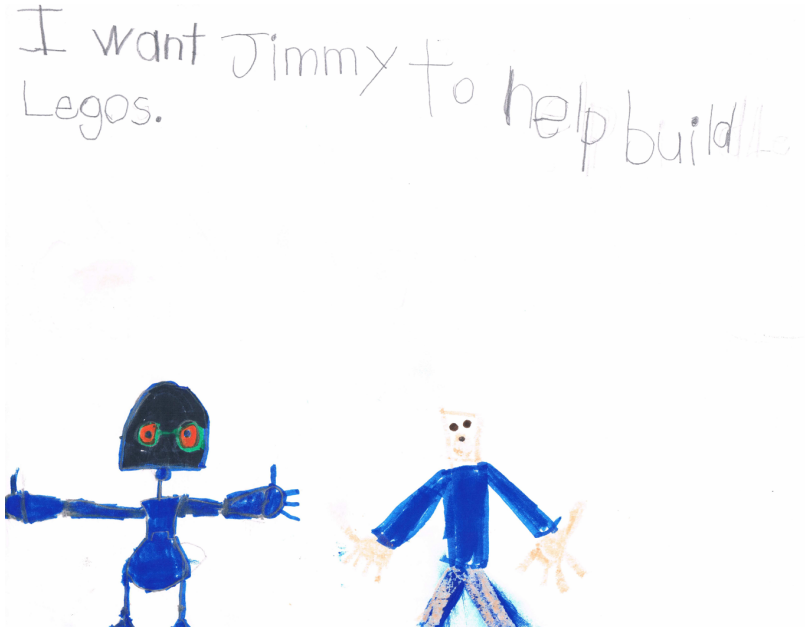


Figure 3-19. *Jacob: "I want Jimmy to help build Legos."*

Figure 3-20. *Lillie: "I want Jimmy to swim with me. Play with me."*

Figure 3-21. *Lola: "I want Jimmy to do my chores."*

I showed the drawings and visions to Ross Mead, an expert in human-robot interaction, whom you'll meet in Chapter 5.

"They never have the robot working for them," Ross commented. "The root of the word *robot* comes from the Czech word for servant. None of these robots are servants. They are friends."

"When you imagine robots, people first imagine a completely different kind of robot," I replied. "Ms. Moore's students saw Jimmy and the robots as their friends. They saw them as a fun and interesting part of their lives."

Next: I_AM_Robot

In our next story, we explore the minds of robots. Jimmy and Dr. Egerton struggle to understand why a brand of cute robots is starting to malfunction. We know that 21st Century Robots are designed to be our friends, but what if they are designed for something else...?

I_AM_Robot

Grande Lobb, Villa Marquis Station, Orbital Space Habitat Shiloh

"Dr. Egerton, we are so pleased you could make it here so quickly." Sergio Sauer extended his perfectly manicured hand. "This is rather a delicate matter that we... well, I'm sure you know."

Sauer's hand was warm and soft. Egerton shook it quickly and replied, "Shanwei explained what happened, but I don't understand. I know you want us to look at your eldercare bots, but I'm not really sure what..."

"Please, Dr. Egerton, not here. This is a very bad place to talk. Let us move upstairs." Sauer ushered Egerton through the grand and expansive lobby of the Villa Marquis. "The lifts are this way..."

The upscale retirement community exuded the carefully blended feeling of a resort hotel with a bustling urban high-rise. The Villa Marquis was one of the more desirable communities in the clog of orbital stations that ringed Earth. It was a medium-sized, orbital habitat, mostly self-contained and the size of a small city.

Egerton watched the elevator pods as they shot up through the lobby. The cluster of pods lay at the exact center of a lobby otherwise occupied by leather lounge chairs, a murmuring Zen fountain, and transparent boxes with what looked like child-sized dolls. "Wow," Egerton said. He had not seen elevators like these in decades.

"I know, they are quite impressive," Sauer said with a self-satisfied grin.

"Actually, I was thinking how inefficient it is to have elevators like that in a space station," Egerton replied. "It's a lot of wasted space."

"At the Marquis we have found that our residents prefer the older style." Sauer wasn't pleased at what he perceived as Egerton's faux pas. "Everything we do here is for the pleasure of our guests." The way Sauer said the word *pleasure* made Egerton think about warm, salted caramel or a bathtub brimming with heavily scented bath salts.

"I can see."

"This way, Dr. Egerton." Sauer ushered him into the private service elevator and typed in a code. The pod shot up 30 stories through the lobby of the Marquis and disappeared into the heart of the space station.

"Can we talk here?" Egerton asked.

"No." Sauer pointed to the surveillance sensor.

"But this is your property. Why should you be worried about…" Egerton started.

"It's not me I'm worried about," Sauer replied. "It's your robot that nearly killed one of our guests, Dr. Egerton. I'm worried about you incriminating yourself. I'm doing you a favor."

Edelman Guest Residence 3145, Villa Marquis Station

Egerton and Sauer walked down a warm, brightly lit corridor, flanked with more transparent doll boxes, until they reached room 3145. Sauer thumbed the ID plate and the door opened.

"Sergio, tell them to let me put my legs on!" the large woman said from the mini-sofa when Sauer and Egerton entered the small apartment. Two polite but stern-looking nurses—one male, one female—stood off to the side of the apartment, tapping at their vintage handheld appointment screens.

"Now, Ms. Edelman," Sauer said, "we need to keep everyone out of your bedroom for just a little while longer. We went over this, remember? This is Dr. Egerton and he made your robot."

"You made my Cutie?" The old woman's eyes widened. She was quite a large woman, but it was plain to see that both of her legs had been amputated just above the knee.

"No, I'm sorry, I didn't design the Cutie. That's another company…" Egerton tried to explain but was cut off.

"He designed its brain." Sauer took Ms. Edelman's hand gingerly.

"Well, not really its brain either. That was…"

"Ms. Edelman is one of our oldest and most loved guests here at the Marquis," Sauer said, cutting off the professor. "And this is Dr. Simon Egerton; he needs to inspect your Cutie to find out what happened."

"I'm not the oldest." Ms. Edelman glanced sideways at Sauer with dramatic flourish. "I'm only 102. There are plenty of older people here. I've just lived here almost the longest, starting back when the diabetes took my legs." She slapped her right thigh with her right hand. The hand was discretely bandaged. "Can you get my legs for me, Dr. Egerton? They are just in the bedroom, there next to my Cutie."

"This shouldn't take long." Egerton smiled and started the three short steps to the bedroom.

"My legs first," Mrs. Edelman said. "You can tell me later why my Cutie attacked and stabbed me."

***

The scene in the small bedroom brought Egerton to a dead stop.

"It's horrible, isn't it," Sauer whispered and pushed Egerton deeper into the room so he could close the door.

"What happened exactly?" Egerton asked as his eyes flicked between the blood-stained bed, the two stylish, hot-neon-pink robo-prosthesis legs, and the destroyed robot.

Sauer pointed to the side of the bed. "All our guest rooms have a panic button. Press it, and someone will be at your room in less than 30 seconds. It's something we guarantee here at the Marquis. You have no idea how expensive it is." There were bloody handprint smears on the wall and the panic button.

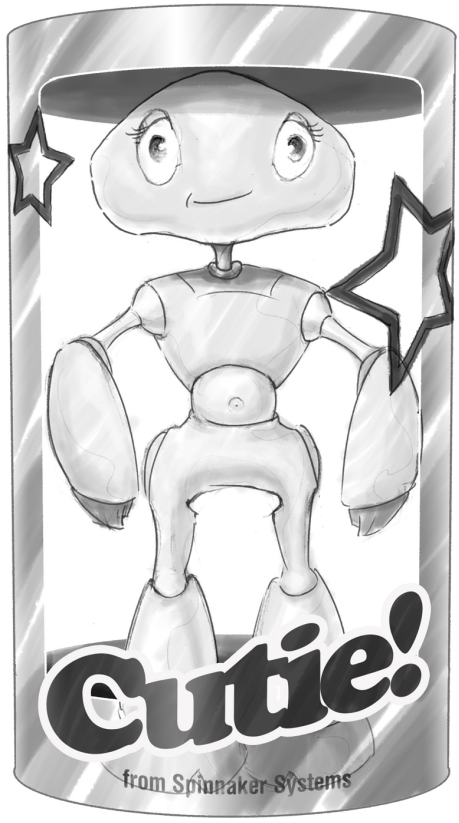
"The robot stabbed her right hand?" Egerton asked.

"Dr. Egerton, it is important that you understand our position. We need to continue our Cutie rollout if we want to get the health-care discounts agreed to by our eldercare providers. That one over there," Sauer said, pointing to the smashed robot, "was only number three. We have over two thousand other Cuties to deploy."

"Those boxed dolls in the corridor?" Egerton asked.

"Yes. Every day they sit there is costing us tens of thousands of dollars."

Cuties were a popular brand of personal robots. They were similar to the design of Egerton's test bot Jimmy, but mass-produced and deliberately cuter. Egerton could have sued Spinnaker Systems, the maker of the robots, for stealing Jimmy's design. But Spinnaker made its name and money on military bots and big-class drones; the Cuties line of robots was their attempt to get into the consumer market. The lawyers they could hire, the politicians they owned, made Egerton feel that any fight was pointless. But it was Spinnaker's use—or misuse—of Egerton's open source robot network that had brought him to the Villa Marquis.



"We thought that having the boxes of Cuties in the lobby and halls would be a nice touch," Sauer explained. "The guests don't like change. Having the Cuties around and waiting has made the transition easier. Of course the guests would all rather stay with the existing nursing staff but we can't afford that, so the Cuties it is." Sauer sighed.

"When the nurses arrived, the Cutie was on the bed standing over Ms. Edelman, holding that letter opener." Sauer pointed to the stainless-steel instrument.

"And they destroyed the robot." Egerton couldn't mask the contempt in his voice. "Did they have to destroy the bot?"

"Look at all this blood," Sauer snapped, then brought his voice down to a whisper. "I think they did the right thing. Your robot attacked an elderly, legless woman while she slept."

"It's not my robot," Egerton said testily, as he searched through smashed pieces of the bot's outer and inner skeletons. "I have nothing to do with Spinnaker. They used my open source network to get your bots to work together. They took my network...I had nothing to do with this."

"That's not what the media is saying," Sauer spat back.

"I'm aware of what the media is saying," Egerton said with a practiced calm. Shanwei had coached him to remain calm.

After the success at DeutchConn Fab 5, Shanwei and Egerton had begun working together. It was Shanwei's idea that they could put together a business fixing people's robot problems.

"All these companies and corporations will pay us a fortune to get their bots working again," Shanwei had said. "The stranger and harder the problem, the better. You figure out what's wrong and I can fix them."

Egerton liked working with Shanwei. He could get things done through his seemingly endless network of people and connections. He was also skilled at getting people to pay them to fix robots.

Everything was going along fine until Spinnaker System robots started to malfunction, and someone in the company leaked a lie that Egerton's robots and network were to blame for the Cutie model attacking Ms. Edelman.

This infuriated Egerton, but every time he tried to clear up the lie, the media treated him like he was the liar.

Finally Shanwei coached Egerton to keep calm and stop trying to set the record straight. Shanwei's skills had gotten the Villa Marquis to pay them to fix the problem with the Cuties.

"What the media is saying isn't true," Egerton said flatly. Finding the Cutie's small brain, Egerton stood and turned to Sauer.

"That's not what the Villa Marquis is saying either, Dr. Egerton." At this point, Sergio Sauer had lost all his charm and revealed himself to be what he truly was: a mean little administrator of a high-end retirement home.

"You know that's not true." Egerton stopped and picked up Ms. Edelman's pink robo-assist legs. They were lighter than he had expected, very high end. "Your bosses think I'm the only one who can fix this mess. I didn't cause it, but I can fix it. That's why the Marquis is paying me to find out what happened inside here." Egerton took out the Cutie's brain and showed it to Sauer.

"And when will that be?"

"I don't know," Egerton answered.

"What do you mean, you don't know?" Sauer snapped. "Every day we don't bring those Cuties online we're losing money."

"Look, Mr. Sauer." Egerton slipped the brain back into his pocket. "How about we give the old lady her legs back and you let me go to work? That's the only way any of us are going to find out." Egerton opened the door and walked out.

***

"I've got your legs, Ms. Edelman," Egerton said as he returned to the living room. "They are really nice."

"I know." Ms. Edelman took the legs and quickly slipped them on. They charged up and she stood. "My great grandson is very successful in the stock market. They were a gift." Ms. Edelman was now taller than Egerton. "What happened to my Cutie?"

"I'm not sure," Egerton answered as Sauer slipped back into the room. "But I should know soon."

"Please hurry." Ms. Edelman seemed much calmer and less elderly with her hot-pink legs carrying her around the small apartment. "I liked the little guy. He was a big help with my medications. I named him Maury after my departed husband."

Egerton smiled. "That's a good name." His phone trilled. Egerton thumbed the screen, and immediately saw Shanwei's distraught face, with the unmistakable sound of screaming children in the background.

"Simon...Simon, can you hear me?" Shanwei yelled. "Simon, you have to get here now...it happened again!"

Transition Tunnel and Shark Tank, Five Worlds Resort, Orbital Space Habitat Shiloh

"Please tell me you know what's going on." Shanwei couldn't look at Egerton. He kept his eyes forward as they quickly walked from PirateWorld to CandyWorld.

"Slow down." Egerton grabbed Shanwei's arm. "Jimmy can't keep up."

Shanwei stooped and picked up Jimmy without breaking stride.

"You haven't seen what I've seen, Simon." Shanwei pointed down the tunnel that connected two of Five Worlds' different resorts. It was a popular year-round family vacation spot, and was conveniently located near three of the largest shipping stations. It was also very close to the Villa Marquis.

"I'm sorry, Shanwei," Egerton replied. "I don't know."

"You always say that!" Shanwei was tense. "You always say you don't know, but you do know. You always know!" Under Shanwei's arm, Jimmy watched the sharks swimming all around them. The transition tube ran inside a massive tank filled with tiger sharks, hammerheads, great whites, and a few gen-mod sharks that were over 20 feet long.

"But I don't know," Egerton answered. "How could I know yet? I just got back from the Marquis..."

"But you built the network." Shanwei watched a big neo-shark swim by, casting a heavy shadow. "You have to know! Everyone thinks you know, and that's important. That's why we're getting paid. But you have to figure it out."

"I'm sure I can figure it out." Egerton tried to calm Shanwei down. "I brought Jimmy because he can talk to them. He can access the network and maybe..."

"Do you really think it's..." Shanwei started, then stopped.

"What?"

"No, it's stupid." Shanwei shook his head. "But you haven't seen what's down there...it's...it's really bad." Shanwei continued walking.

The sounds of chaos started to scratch their way up into the tunnel. "Do I really think it's...what?" Egerton pushed.

They reached the entrance plaza to CandyWorld, a brightly lit wonderland of peppermint sidewalks and lollipop street lamps. By the SodaPop Pools, a group of fifty children, all under the age of eight, stood screaming. They clutched their Candy-Colored Cuties to their chests and fought as their parents tried to take them away. A rugged gray emergency vehicle looked garishly out of place as it attempted to fish something out of the pink water of a large fountain in the middle of the plaza.

"Do you really think the robots are trying to kill us all?" Shanwei asked.

SodaPop Pools, CandyWorld, Five Worlds Resort

The screaming had died down to sporadic whimpers and whines.

An athletic woman with the kind of fresh, happy face that kids love met Shanwei and Egerton as they emerged. Like all the CandyWorld cast members, she wore a pink T-shirt that read "Candy-Colored Cuties are the BEST!"

"I'm Danny Tepper," she said, extending her hand. "Spinnaker wanted to throw a promotional party for their new line of bots for young kids. These Candy-Colored Cuties are pretty much like the original Cutie bot, but they gave them that candy look and taught them a few songs..."

"What happened?" Egerton asked.

"The cameras are coming," another adult informed Danny. "What do we do, Danny? The cameras will be here in five minutes. They're coming from dock four."

"Just relax, Hanni," Danny assured her coworker. "Get the kids and their parents ready to go back to their rooms." She turned to Egerton. "Dr. Egerton, it sounds like you have five minutes before you start losing witnesses."

"Witnesses to what?" Egerton asked.

"Hanni, go ahead and get them ready," Danny urged. "Get all the families ready to go. We don't want them here when…"

The squat, gray rescue vehicle had deployed its arm over the fountain. A diver had hooked a cable to something under the water, and now the team was drawing it out of the pool.

"We should talk to the little boy at the center of all this." Shanwei set Jimmy down next to him, and both watched as a knotted piece of plastic emerged from the pool's pink water.

"Yes, he's over here." Danny led the way.

"Ms. Webb." Danny stopped by a woman wrapped in a blanket. She was leaning against the back of the emergency vehicle.

"Yes?" Ms. Webb looked dazed and disoriented.

"Ms. Webb," Danny continued, "we're going to take you back to your room right now. But before you go, do you think it would be all right if Dr. Egerton here spoke to Kyle?"

"Is this the man the press are all talking about?" Ms. Webb looked at Shanwei. "Did you build those…things…that tried to kill my baby?"

Shanwei froze.

"No, I didn't build these robots, but I think I can help," Egerton said.

"I hope you go to hell," she hissed.

"Ms. Webb, would it be all right if I took Dr. Egerton…I think he can help. I'll be there the entire time…if anything…" Danny tried again.

"Just go! But don't you let that robot near my Kyle!" she screamed and pointed at Jimmy. Jimmy ran in the opposite direction of Ms. Webb, but Shanwei caught him before he got too far.

"My supervisor told me you guys could tell us what happened," Danny said confidentially to Shanwei. "You can tell them that it's not our fault."

Shanwei handed Jimmy to Egerton and replied, "We can help. We just need to talk to the boy."

"Kyle, what are you doing?" Danny asked. "Where's your daddy?" The boy stood on the edge of the pool and stared into the lapping pink water. He was small and pale with thin little bones and half-dried hair.

Kyle didn't respond.

"Can someone find Mr. Webb?" Danny called to the other pink-shirted CandyWorld workers.

"Hey, buddy." Shanwei squatted down next to the boy. "You wanna get away from this pool? I want to introduce you to someone."

Kyle looked at Shanwei and then back to the water.

"Is this Kyle?" Egerton asked. He had lagged behind because he had put Jimmy down and let him walk on his own.

Kyle saw Jimmy and asked, "That your robot?"

"Yes, his name is Jimmy." Egerton pushed Jimmy to Kyle. "Say hello, Jimmy."

"Hello." Jimmy was about the same size as the boy.

"Hi, Jimmy." Kyle didn't seem interested. He stared at the water. It had gotten more choppy as the crew's rescue arm drew in the cable, hauling up something bright and blue.

"Kyle," Egerton started. "What happened? What happened with *your* robot?"

"Kyle's Kady-Co Cootie...push me in," Kyle said to the water. "I can swim."

"He can't swim," Danny translated. "His mother jumped in and grabbed him. But then..."

"What happened after your mom got you out of the pool?" Egerton asked the boy.

"Kyle's Kady-Co Cootie push me yin again!" the boy squeaked. "He hole me down un-the water...Grab my neck..."

When the bright blue Candy-Colored Cutie broke the surface of the pink pool, it started to swing on the cable. At first, the robot was frozen and glistening. Everyone around the pool stopped and stared. Then the little blue bot began to writhe and thrash on the cable with a wild animal frenzy. It tore at the cable trying to free itself, trying to get to Kyle.

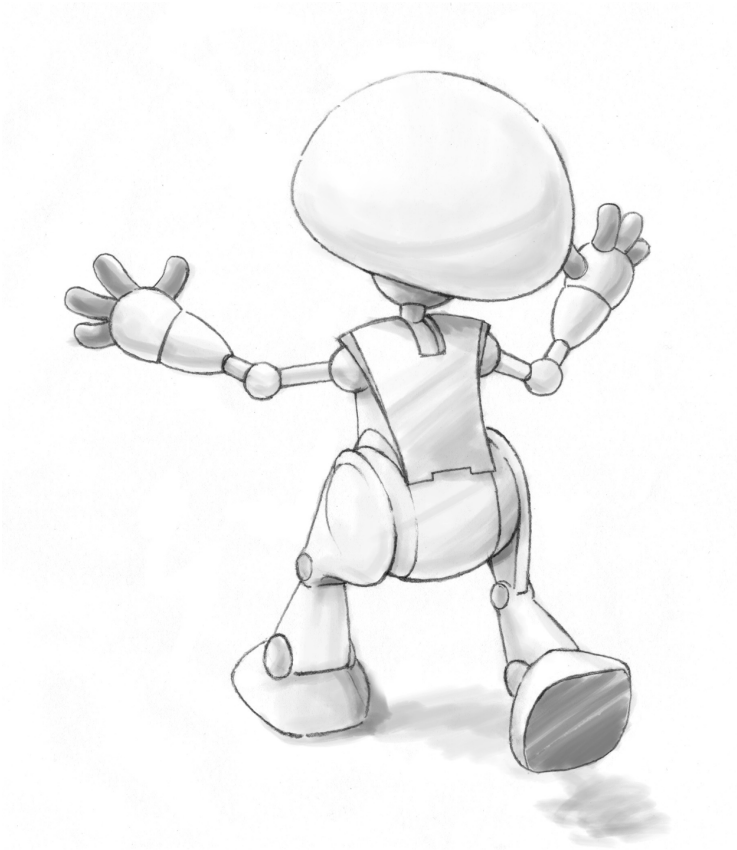
Kyle screamed.

Jimmy ran away from the screaming boy as fast as he could.

The few other children remaining started to scream as well.

Off in the distance, the cameras and media appeared.

"Oh, great." Danny stood and readied herself to face the media and news crews.



Fairy Hotel, PrincessWorld, Five Worlds Resort

"Even the toilet has sparkles in it," Shanwei said, coming from the bathroom. "They are serious about their fairies here." Five Worlds Resort had become a media frenzy. The only room that resort management could free up was in the Fairy Hotel. Egerton cleared the top of the mini-bar to use as a workbench. Jimmy sat in a little chair that seemed made for him, except for the magical stars and butterflies that hovered over his head.

"Hey, listen," Shanwei said, "I'm sorry about what happened back there."

"What?" Egerton wasn't paying attention. He was busily working on Ms. Edelman's robot Maury and the blue Candy-Colored Cutie that had fought to kill Kyle.

"I'm sorry I freaked out back there in CandyWorld," Shanwei continued. "It's just...it's just you know all those kids got to me. It was pretty rough."

"We've seen worse." Egerton didn't look up. They had seen worse. They had gained quite a reputation. If you had a problem with your bots, something that no one could figure out, they were the team for the job.

"Yeah, it's just the kids..." Shanwei tried to explain. "It's a thing with me. I don't like it when kids are in trouble...It's just..." He stopped there.

Egerton moved on. "There's nothing wrong with either brain. They are both fine."

"So that means..."

"That means it's the network, not the individual bot's brain," Egerton explained. "These Cutie brains are pretty simple, but most AI is based on a three-tiered architecture. Jimmy is the same way. And there's nothing *wrong* with the brains."

"So now what?" Shanwei asked, then jumped in, "...and don't say 'I don't know!'"

The enchanted room was quiet. Stars and butterflies hovered above Jimmy's head. Finally Egerton said with a smile, teasing Shanwei, "I'm not sure."

***

The angry swarm of media that had infested the Five Worlds Resort meant that Egerton couldn't leave the Fairy Hotel. The talk-show pundits were predicting a coming robo-apocalypse and they all claimed Egerton was to blame.

Jimmy jumped when the doorbell to the Fairy Room chimed.

"It's okay," Egerton said to the little bot. "It's just Danny." To be safe, Egerton checked the security feed and saw Danny standing outside the door. She was still wearing her pink "Candy-Colored Cuties are the BEST!" T-shirt and she was holding one of the bright yellow Cuties. Egerton ushered the woman in and closed the door.

"It's crazy out there," Danny sighed. "Oh hi, Jimmy." She waved and Jimmy waved back.

"Thanks for the Cutie." Egerton took the bot from her and moved over to the workstation. "This is one of the Candy Cuties that didn't run amok, right?"

"Right. Where's Shanwei?" Danny asked.

"There's no way I can leave the room." Egerton shrugged. "So he decided he'd go alone. There's a hacker he knows who might be able to help out. Tariq's pretty strange and will only talk to you through certain protocols."

"Sounds scary."

"Nah." Egerton turned on the little yellow bot. It had a ribbon of white that swirled across its outer skeleton, making it look like a lollipop or a three-foot piece of ribbon candy. "Tariq is just being careful."

"What are you going to do with that little guy?" Danny asked, pointing to the yellow bot as it faked a yawn and stretch as if it was just waking up.

Egerton watched the bot's cheesy activation pantomime and shook his head. "I'm going to use it to bring the other bots back to life."

***

"Where's Ms. Edelman?" The bot searched around the room, checking in the bathroom, under the bed, in the closet, and any place he could.

Egerton stopped Maury from opening the front door. "Ms. Edelman isn't here," Egerton answered the little yellow bot. "Do you know where you are?"

"But it's time for her medication." Maury glanced at Egerton and then went to the bathroom.

Jimmy was going to follow Maury, but Egerton held him back. "Wait, Jimmy, let him be..."

"But..." Jimmy started, then stopped.

"This is not our bathroom," Maury said from the dark room. "The medication is not in here." There was a little clunk as the bot climbed down off the toilet. He walked about the room. "Where is Ms. Edelman's diabetes medication? I can't remember the last time she took it..." The bot paused and searched his memory, then tried to access the network. Egerton had blocked Maury's access to the network, essentially walling him off from the outside world. The bot froze.

"He's really confused," Jimmy said finally. "Can you..."

"Not yet." Egerton watched the lollipop-colored little bot as it stood still in the center of the Fairy Room. "Maury, do you know where you are? Do you know what happened to Ms. Edelman?"

The bot turned to Egerton with a jerk and asked, "Is she dead? Please tell me she isn't..."

"She's not dead," Jimmy replied quickly.

"But you did attack her, Maury," Egerton added. "Can you tell me why?"

Maury walked over to Egerton and looked up at him. "I did no such thing." His tone of voice sounded a little like Sergio Sauer.

"You don't remember stabbing her while she slept?" Egerton asked.

After a pause, the bot repeated, "I did no such thing...now I need to find Ms. Edelman's medication. She has diabetes and if she doesn't take her medication on time, she can suffer complications." Maury walked back into the dark bathroom, climbed up on the toilet, and looked for Ms. Edelman's medication.

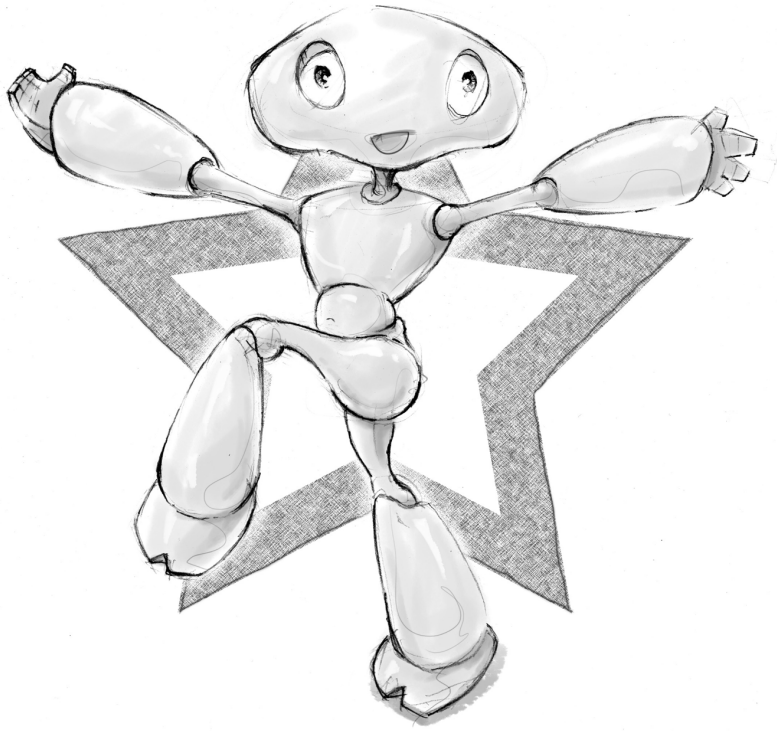
***

"Jimmy, get up here on the mini-bar," Egerton said. Jimmy walked over and Egerton put himself between Jimmy and the little yellow bot.

"Will you be okay?" Jimmy asked hesitantly.

"I'll be fine, now that we know what's going to happen," Egerton replied. The similar experiment they had done with Maury gave them an idea of what to expect.

Egerton had dropped the brain from Kyle's little blue bot into the yellow Cutie. It was prancing around the Fairy Room singing, "I'm Kyle's little Cutie...don't you wanna come and boogie?" The bot had a high-pitched sing-song voice. It shook its little rump and waved its arms in the air. "I can jump and I can play...I can do this all the dingy day!"



As he had done with Maury, Egerton shut down the little bot's access to the network. If the deadly behavior was coming from the network, the bot should be completely harmless, even though its song was a little annoying. It kept singing and dancing and really wouldn't respond much to Egerton. But as with Maury, Egerton was worried that Kyle's little bot would act in the same way when it got access to the network. Maury had tried to stab Egerton in the leg with a pen.

"Ready?" Egerton asked.

"Okay." Jimmy hunkered down a little.

Egerton turned on the network and at first nothing happened. The little bot continued to sing. "I like a joke...like any other bloke...but I'd rather dance and playyyyyyy." Then the bot stopped. Its head slowly rotated 360 degrees as it scanned the room. Then, with a high-pitched growl, it lunged at Egerton's leg.

The impact of the little bot slammed Egerton into the desk. Jimmy jumped off the desk and ran across the room, blindly trying to escape. The lollipop-colored bot scratched and clawed at Egerton's shin. The impact would leave a bruise.

Egerton shut down the connection once again. The bot froze, then went limp.

"It's okay, Jimmy," Egerton said. "It's okay now. I shut it off."

Jimmy walked out of the darkness of the bathroom and wearily watched the little bot. The yellow bot starting pumping its legs up and down and singing, "I'm Kyle's little Cutie…don't you wanna come and boogie?"

***

"Tariq wants to meet, but he won't come to the room," Shanwei said, holding up his screen to reveal Tariq standing behind him in what looked like a tropical forest.

"He's here?" Egerton sat on the bed in the Fairy Room.

"Yep." Shanwei smiled. "And wait 'til you hear what he has to say." Shanwei whistled. "It's pretty amazing."

"Come on down to meet us in the Pirate Jungle," Tariq shouted over Shanwei's shoulder.

Egerton smiled. "I'm waiting for some lunch and then I'll be right down."

"Hurry up," Shanwei urged. "I don't know how long we can stay here. Turns out it's really hard to do surveillance in the jungle, Tariq says, but if the press finds us, we're done."

"This is a big deal." Tariq waved at Egerton.

The doorbell chimed magically in the Fairy Room.

"I'll eat fast." Egerton shut down the connection and moved to the door. The security screen showed a small, thin woman standing behind a food cart. Egerton opened the door.

"Your turkey sandwich and sparkling water," she said, pushing the cart into the room. The food cart was designed to look like Cinderella's carriage.

"Please just leave it by the desk," Egerton said as she passed him by. Egerton glanced out the door to see if anyone else was in the hall, but found it empty.

When he returned to the room, the woman had pulled out her video camera and was recording. "Now that there's been a third robot outbreak at the Clinton Technical School, what do you say to people who blame you for bringing about the robo-apocalypse?"

"What? Who are you?" Egerton had not expected this. "What are you talking about, *another* outbreak?"

"You mean you don't know?" The woman sounded shocked. "The Clinton School is the station next door. They've been using Spinnaker's Cutie bots with their K through 12 programs. The bots attacked the children..."

"Oh no." Egerton sighed.

"And I'm also seeing that there's been more trouble with the Cuties at the Spinnaker System production plant. The bots are rebelling even before they are completely assembled." The woman's nostrils flared as the adrenaline coursed through her system.

"That doesn't make any sense!" Egerton blurted out.

"It's all your doing, Dr. Egerton. Spinnaker has gone on record, claiming your negligence is what is causing these outbreaks." She walked toward him with her camera. "Don't you have any comment? This is your network that the bots are using. Can you even stop it?"

Egerton paused and opened his mouth as if to speak, but he didn't know what to do. Shanwei would kill him if he started talking to the press. He simply didn't know what to do or what to say. The only thing he could think to do was run away. He turned and raced out of the room.

Treasureful Jungle, PirateWorld, Five Worlds Resort

"You just ran out of the room?" Tariq laughed a booming laugh. He took off his thick black-framed glasses and ran his hand across his large afro. "You are one crazy roboticist."

"I didn't know what else to do." Egerton was out of breath and desperate. "She said that there are more outbreaks…that more robots are hurting people. I didn't know…"

"It's okay. Don't worry," Shanwei assured him. "We know. There's been five other incidents so far. The factory and the Clinton School, are just the ones to make it online."

"The toy store attack just went viral," Tariq added, looking up from his screen.

"A toy store." Egerton wasn't sure how much more of this he could take.

"Don't worry, everything is going to be okay." Shanwei continued to remain calm.

"It's not you, man." Tariq patted Egerton in the arm. "They just want people to think it was you. You've been set up."

Tariq Jones was a notorious activist hacker. He had successfully brought down two politicians for taking corporate bribes, and recently had won a court case forcing a coalition of technology companies to release their stranglehold on billions of lines of computer code. Tariq had made a lot of enemies. Tariq also didn't care, but he knew he had to be careful.

He scanned the thick gen-mod tropical forest for press or families who might come upon their hiding place. "They need everyone to believe that the Cuties have all gone crazy. That's why all the incidents happened so close to each other. The Villa Marquis, the Clinton School and here…they wanted maximum media coverage."

"Who's *they*?" Egerton asked.

"Now that takes some explaining," Shanwei added. "You have no idea what we stumbled into."

"Yeah, I've been hearing about Spinnaker Systems and some weird stuff for a while now," Tariq explained. "But I had no idea they would have used you, Simon.

I didn't completely understand what they were doing until I saw your face on a talk show." Tariq laughed. "It's some crazy, messed-up crap."

"What's going on?" Egerton had regained himself and now just wanted to know.

"Basically it's an attack on Spinnaker Systems by Quant Blue—a hedge fund that shorted their stock," Shanwei answered.

"Spinnaker makes all of its money in military gear and its new line of Candy-Colored Cuties is a big play for the consumer market," Tariq continued. "The whole market feels that if Spinnaker can't crack the consumer market, then the company has plateaued and the stock price will drop."

"So if people think that the robots have gone crazy and nobody buys the Cuties, then Quant Blue makes money when Spinnaker's shares plummet," Egerton said.

"Yep." Tariq watched as a group of young kids ran past. They were dressed in pirate hats and slashing each other with cheap holographic swords.

"Who hacked the network?" Egerton asked gravely, watching the boys run away.

"BG.KANG," Tariq said quickly. "He hacked into your network and set up a spoofed I_AM_Robot account. I think he named himself I_AM_Whacker or something stupid like that."

"But how did he set it up?" Egerton couldn't understand. "Only the bots are supposed to be..."

"You were hacked, Simon," Tariq interrupted. "I should be able to find out by tomorrow. The hack isn't what's amazing." Tariq pushed his glasses back on his face, nerd-style. "What I can't wait to see is how he manipulated all those bots. The social protocols and trust networks must have been huge. Your little network is much more than just an old Facebook for robots." Tariq paused. He could see that he was upsetting Egerton. "I know it freaks you out, Simon, but I can't wait to see what KANG did."

"How did you find out?" Egerton asked. "How did you originally figure it out?"

"Wasn't me," Tariq replied. "KANG's got a sick sense of humor, or maybe he's just dumb. But he had the first Cutie attack the great-grandmother of one of the brokers at Quant Blue: Edelman. Maybe he didn't like the guy, but when great-grandson Edelman saw the blood, he suddenly felt bad about what his company was doing to make billions of dollars."

"That's really messed up." Shanwei shook his head.

A young girl crawled on her belly out from the trees and into the clearing with a small hologram dagger in her teeth. The blade was lime green and flickered when

she took it out of her mouth. "Are you guys guarding the treasure?" she whispered, looking up them.

"Nah, little lady, I'm just a hacker trying to save the world." Tariq smiled.

"Okay," she whispered and kept crawling across the clearing and back into the trees.

"What do we do now?" Egerton was at a loss.

"We're going to shame KANG and clear your name all at the same time." Tariq smiled.

"And we're going to need all the Candy-Colored Cutie bots you can find," Shanwei added.

Fairy Hotel, PrincessWorld, Five Worlds Resort

"So I guess it wasn't the robot apocalypse after all," the woman reporter said when Egerton returned to the Fairy Hotel. She was sitting on the bed with Jimmy.

"You sound upset," Egerton replied.

"A robot rebellion is a lot more interesting than some stupid hedge fund trying to make money." She shrugged. "I like your robot," she added.

"Thanks."

"Her name is Gloria," Jimmy added.

"Thanks, Jimmy. Hello, Gloria." Egerton moved in front of the TV. "Have they started?"

"Yeah." Gloria still seemed bummed out. "The robots are dancing now. Why aren't you there?"

"It's not really what I do," Egerton answered. "I wanted to check on Jimmy."

"You like bots better?" Gloria prodded.

"I'm better with bots."

On the TV the feed showed a brightly colored ocean of Cuties as they danced and sang in unison around the pink waters of the SodaPop Pools. "Kang...Kang... we love Kang," they sang with high-pitched voices. "Kang...Kang...his plans went bang!"

"Who would have thought the robot uprising would be so cute?" Gloria used her camera to record the TV. Then she panned over to Egerton. "Well, Dr. Simon Egerton, creator of the I_AM_Robot network, what do you think about the end of humanity as we know it?"

"I hope this all shows that this is not the way bots work," Egerton answered tensely. "The network was never meant for people. It was meant for the bots.

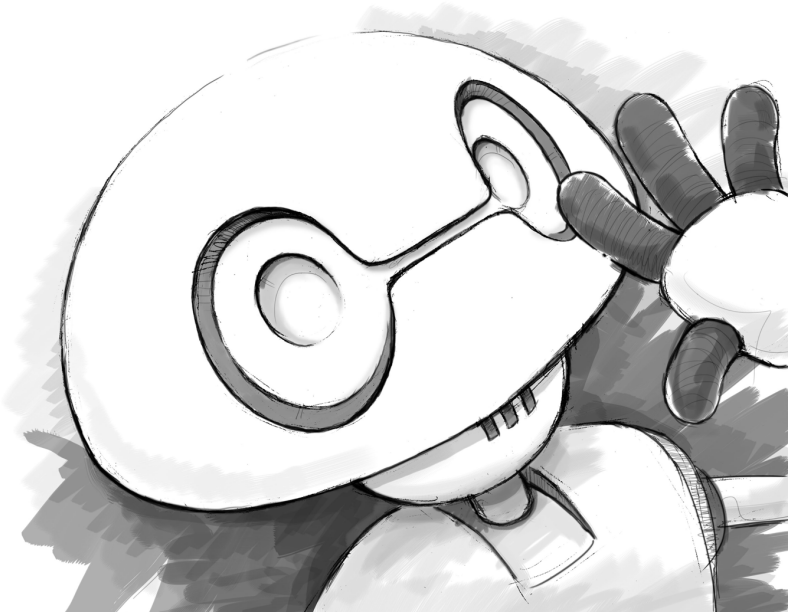
BG.KANG and the rest of them manipulated the bots. People did this. People hurt other people. Bots don't do that."

"But it just shows you what one bad person can do," Gloria pushed. "Doesn't this make you reconsider your work when a hacker for hire like BG.KANG can cause so much damage?"

"No..." Egerton started as Jimmy walked over in front of Gloria's camera and looked into the lens.

Gloria laughed and said, "Jimmy, cut it out. You're in my shot."

When Gloria moved the camera back to Egerton he was smiling as he said, "No, it doesn't make me question my work. I have a lot more faith in robots than that. In this case it was the humans who were the problem."



The Brain

The next step we need to take to assemble our 21st Century Robot is to build the brain. We start with the theoretical, learning from Dr. Simon Egerton about the Creative Science Foundation's use of unconventional tools to dream up new digital minds. Then we talk with Professor Maja Matarić and learn more about social robots. We finish with Ross Mead, who explains to us the software he's building to make designing and programming artificial intelligence easier for everyone.

A Different Kind of Roboticist

Dr. Simon Egerton, whom we met back in Chapter 1, is not your normal kind of roboticist. For years, Simon has been researching and building robots that are meant to be social.

"The technical term for interacting with people in their homes is *complex environments*," Simon explained. "People are very complex. Our homes are very complex. We don't normally think of it that way, but it's really true. Just think about all of the diversity in people and cultures. Also, just think about how many different homes there are in the world."

"I would guess that your apartment here in Kuala Lumpur, Malaysia, is very different from the house where you grew up in Bedford in the south of England," I said.

"That's very true," he said, smiling. "So some time ago I realized that if I wanted to make robots that could operate in these complex environments, I should look to other examples of systems that have done really well interacting with people and living in homes."

"And what were those systems?"

"People." Simon laughed. "People are really good at talking to people. We're also really good at living in our homes. So I started looking at human behavior—and more specifically at how our brains work—as inspiration for the brains of our robots."

A Brain in Three Parts

The brain of a robot is the hardware and software that makes it walk, talk, and interact with people. This software is known as artificial intelligence (usually abbreviated to just AI).

When you think about a robot brain, it's best to think of it like a human brain. As both Simon and Melissa Gregg pointed out earlier, it's a good model; something that has worked for the hundreds of thousands of years that humans have been around is probably a good place to start.

Let's split our robot brain into three parts:

1. Conscious
2. Reflex core
3. Autonomic system, or subconscious

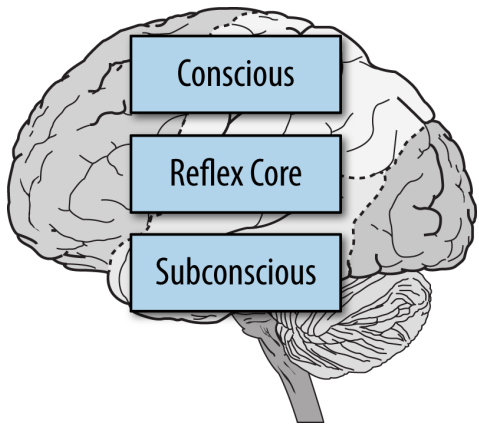


Figure 5-1. *The three parts of the robot brain*

We'll start at the bottom with the autonomic brain, the part that takes care of all the boring but incredibly important stuff. In humans, this is the part of the brain

that controls things like digestion, perspiration, breathing, and salivating, and also regulates the heartbeat.

These are all the things that our bodies do without our thinking about it. Because these functions work on "automatic pilot," so to speak, the rest of the brain is free to do the more interesting stuff.

The autonomic part of your robot's brain lets the bot walk and balance, freeing the conscious part of the brain to look around, evaluate what it sees, and communicate (in many different forms; see Chapter 7). The conscious mind is where the robot's personality and character live, and where the real thinking occurs.

Between these two parts of the brain lies a thin strip called the reflex core. It allows signals to move back and forth between the two parts. It's kind of like a traffic cop, helping to move commands from the conscious brain to the autonomic. Commands like "walk" are passed down to the autonomic brain (for our robot, we'll expand the concept of autonomic to include things like walking), which knows how to talk to the collection of motors that get the robot moving.

The reflex core might sound like the most uninteresting part of the robot's brain, but it's very important. Not only is it a traffic cop, it's also a translator. It frees up both the conscious and autonomic parts of the brain so that they can do what they do really well. It means that the top and bottom parts of the brain don't have to spend any time figuring out what they're supposed to do. The reflex core translates the commands from the conscious brain to the autonomic part of the brain, using primitives or software that help to speed up the transfer of information (more on the primitives later in this chapter).

That's vitally important, because even though we like to think about a robot's brain as being like a human brain, the fact is that it works much more slowly. Most of us have been raised to think that a computer is much faster than a human brain. This might be true for some tasks like complex math and calculations, but it's not true at all when it comes to controlling bodies. A robot's brain has to work a lot harder to process all the signals it receives from the outside world in real time. After all, a robot's brain hasn't benefited from centuries of adaptation and learning as humans have.

Simon and his colleagues at the Creative Science Foundation came up with a really interesting way to deal with all this complexity.

Robots That Make Bad Decisions

"I started thinking about how people act and interact in complex environments," Simon explained to me.

"You mean like our living rooms and kitchens," I joked. I do like giving Simon a hard time when he uses complicated terms to explain simple things.

"Yes." Simon smiled, always a good sport. "I wondered how people adapt to different homes and different people, and that's when I realized that we humans make both good and bad decisions. Sometimes when we walk through a kitchen, we make it just fine. But sometimes when we're in a hurry or not paying attention, we might move through a kitchen and hit the kitchen counter with our elbow." Simon banged his elbow lightly on the desk. "We learn very quickly to not do that. We learn, almost without thinking about it, that moving too fast through a kitchen means we could bang our elbow on the counter and cause ourselves pain. So we learn very quickly by making both good and bad decisions."

"And we normally don't let robots make bad decisions," I said.

"Right," Simon continued. "It seems like a crazy thing to do, but it's true. We don't intentionally let robots make mistakes. But if we don't let robots sometimes make bad decisions, then we are hampering their learning process by 50 percent. Or at least that was the idea."

"And what did you find?" I asked.

"We found that it made the robot's brain even more complicated than before," Simon answered. "We needed a way to deal with all this complexity. We needed what's referred to as a new system architecture."

A Robot with Multiple Personalities

That new architecture came from a collaboration among Simon, a roboticist studying social robots; Vic Callaghan, a computer scientist; and Graham Clarke, a computer scientist turned psychoanalytic theorist. (Sounds like the beginning of a joke: a roboticist, a computer scientist, and a psychoanalytic theorist set out to design a new kind of robot...)

Graham has a wide-ranging past. He's a deeply thoughtful man with a thick beard and a hearty, infectious laugh. Having initially studied architecture, he was smitten with the American architect and system theorist Buckminster Fuller. Fuller embraced the early promise of computers, seeing clearly the link between these new computers and their use in the design and development of buildings.

This was also the 1960s in England. Minds were expanding; people were experimenting and thinking differently about...well, just about everything. At that time, cognitive psychology was widely accepted. Cognitive psychology explores human beings' internal mental processes, and for Graham, the connection between the mind and computers seemed natural.

At the center of his approach was an unlikely character: Ronald Fairbairn, a Scottish psychiatrist and psychoanalyst who was a recognized pioneer in the development of the object relations theory of psychoanalysis. Graham began his research into Fairbairn without knowing that it would lead to the new system architecture, the new brain that Simon was looking for.

Graham began exploring Fairbairn's concept that multiple personalities provide a model of how our minds work. Our minds are made up of a collection of personas, each of which contains a set of beliefs, desires, and actions that are distinct from those of other personas.

This persona-based approach illuminates *ordinary multiplicity*—the way humans switch from persona to persona as our surroundings or contexts change. The concept is elegant in its simple truth. We're all a collection of different people. We're one set of behaviors at work, another set of behaviors at school, still another set at home, and sometimes a *very* different set of behaviors with our friends. It's this switching from persona to persona that allows us to adapt to complex social situations and environments.

Enter Professor Vic Callaghan. Vic is a second-generation Irishman living in England. He's tall and thin, with a voracious intellect and a keen openness to new ideas and approaches. He began his intellectual career as an electrical engineer, but was drawn to robotics, and he set up the robotics lab at the University of Essex in Colchester, about 50 miles northeast of London.

Britain's oldest recorded town, Colchester was the seat of Celtic governance before the arrival of the Romans. It is known for its rowdy nightlife and for Colchester Castle, the largest Norman castle in England, built on the ruins of an ancient Roman temple.

The University of Essex is an odd sight, rising up from the picturesque English countryside. Designed in the aptly named Brutalist style, it's a collection of concrete slabs, exposed piping, duct work, and six looming black towers. These towers were the tallest load-bearing, self-supporting brick buildings in the UK when they were built in the 1960s. These ominous buildings are actually student dorms.

I might be painting a bleak picture of the University of Essex, but I confess it's one of my most favorite places on earth. The mix of architecture, towering spires, and the lush English countryside makes for an interesting contrast. This Brutalist architecture surrounded by green hills houses some of the most advanced robotics and intelligent environments research in the UK. It's fitting that Essex University eventually became the home of the Creative Science Foundation.

When Vic and Simon learned about Graham's exploration of Fairbairn's model of personality, they recognized that Graham's persona-based approach to building intelligence could also be implemented as an object-based architecture for AI. The three authored the paper that Simon had told me about when we met in Seattle. It had the rather complex title of "Using Multiple Personas in Service Robots to Improve Exploration Strategies When Mapping New Environments," and ended like this:

> *Personas would allow us to explore the value of accumulated experience that in us manifests itself as a somewhat ill-defined "self", which, when making decisions, occasionally overrides the logical nature of the world, akin to what might appear to be irrationality, putting it down to nebulous mechanisms such as "a hunch" or "a feeling".*

The collaboration of these three led to the idea that it's possible to create a new kind of robot based on the structure of the human mind, but translated into a high-level system architecture that would allow the robot to act and interact with its environment in a fundamentally different way. This new approach to robots meant that now a robot's artificial intelligence could be a collection of different actions or behaviors that could be customized by people. Each robot could be special, programmed specifically by the owner. This new approach meant that we could use apps to program our robots.

From AI to Apps

"That's where you came in," Simon said to me. "We needed a way to prototype and think about this new approach. Your science fiction stories based on our research gave us the breakthrough we were looking for."

That breakthrough came from stories like "I_AM_Robot" or "The Machinery of Love and Grace" (the story following this chapter). We saw that we could group these personas together, allowing the robot to switch between different behaviors. We also realized that we could generate or download new behaviors to the robot's brain, depending upon the environment. This functionality was explored in "The Loneliness of the Long-Distance Robot" in the part of the story where Little Ling is given multiple personas to test the chips.

"That was it," Simon said. "The new system architecture we were looking for…"

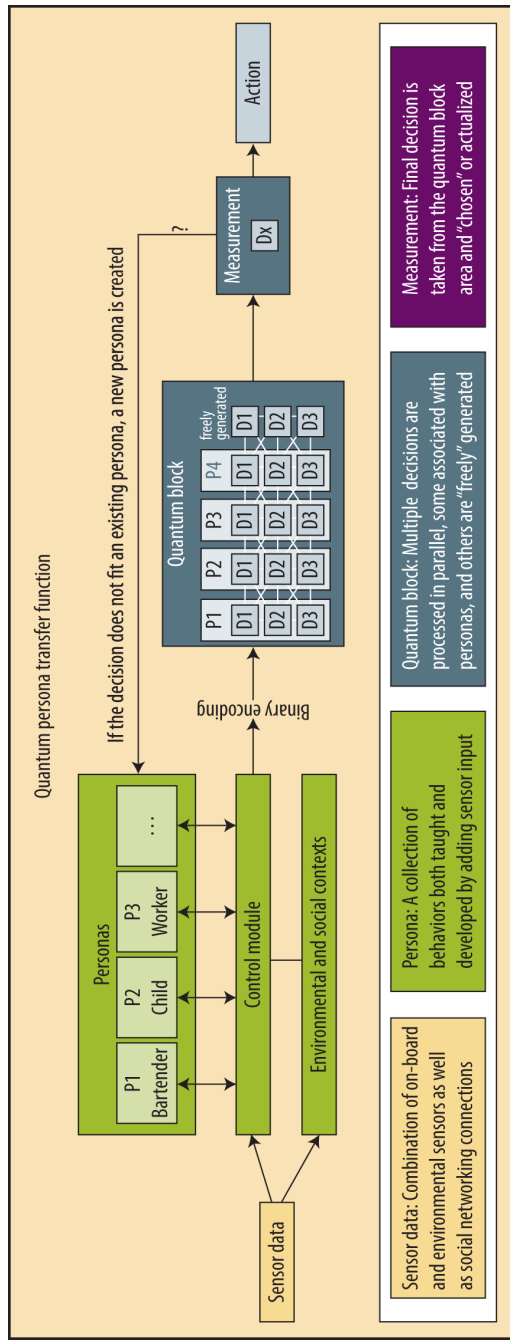


Figure 5-2. *Persona-based system architecture*

"Was apps!" I interrupted. "The nesting of personas, and the ability to add more, was just like the apps on a smartphone. It wasn't AI! It was apps!"

"Yes," Simon chuckled at my enthusiasm. "We could program and personalize these social robots by using different apps. It became an easy way for people to customize their robots to their own personal needs and homes."

"Our robots became smartphones with legs," I added.

"Much more than that," Simon concluded. "They were highly personalizing computational devices that anyone could act and interact with. Anyone could program and make each robot an individual. I quite liked that." He paused. "I really liked that a lot."

Why Social Robots?

Professor Maja Matarić has an incredibly long title. She is professor and Chan Soon-Shiong Chair in Computer Science, Neuroscience, and Pediatrics at the University of Southern California. She is also the vice dean for research at the Viterbi School of Engineering, the founding director at the USC Center for Robotics and Embedded Systems, and the director of the USC Robotics Research Lab. But the funny thing about Maja is that she never set out to be a world-renowned expert in robots.

"I wasn't the kind of kid who tinkered in their basement building robots," Maja told me. "I was interested in psychology and art. That's what I wanted to study. But being an immigrant from Czechoslovakia, my uncle gave me some good advice to go into computers."

"Did you take his advice?" I asked.

"I did and it turned out I was really good at computers." Maja laughed. "But I still wanted to work in psychology, and the only real place you can work in psychology and computers is robots and AI."

Maja studied with Rodney Brooks at the Massachusetts Institute of Technology. These were the early days of the field called human-robot interaction (HRI).

"We didn't think of it as a new field," Maja confessed. "It just seemed natural and what we were interested in."

"Do you think that's why your take on robots is so different?" I asked. "Your lab at USC is known for taking a very different approach to robots and how those robots interact with people."

"It just seemed natural," Maja repeated. "At USC we look at how robots and a robot's interaction with a human being can make that person's life better. We are very specific and goal oriented. Our robots try to help stroke victims recover. They work with people who have autism, to help them learn and develop social skills.

We even have robots working with Alzheimer's patients to keep their minds and memory active."

"Your robots are inherently social," I added.

"Yes, that's all they are designed to do," she continued. "They aren't industrial robots or physical robots that are design to carry things or manipulate the physical world. We want our robots to interact with people, with all of the subtlety and complexity that goes along with that."

"Is that why you joined the 21st Century Robot Project?" I asked. "We both want to build social robots..."

"It's more than that," Maja answered. "The simple answer is accessibility. You and the project want everyone to be able to imagine, design, build, and program robots. That's great! We need that! That's the only way that we are going to realize the tremendous potential of robots. Robots need to be everywhere so that people can get used to them. They need to be a part of our lives, built by average people so we can stop worrying about them trying to do harm to us."

"Not just people, but kids specifically," I said. "Is that why we should build social robots?"

"Yes!" she replied. "I've been working for the last 15 years to get kids to build robots and understand that robots and science are cool. Young kids understand that robots aren't servants, but they can be our friends and companions. We need to get them involved. That's the only way that robots will realize their true potential. It's not only an important thing to do," she paused. "It is also our duty to do it. Social robots can change the future of robots and humans."

From Theory to Code

Ross Mead is a software guy. He's always been a coder and someone who understood how to program computers. Ross was introduced to robots in high school, and since then he's been hooked. He now researches and teaches robotics at USC, where he's a part of Maja's robotics lab.

"I got involved with robots early on," he explained to me. "I always liked to code, but it felt like I was always leaving my programs on the computer screen. Robots allowed me to get my code into the real world. I could program my software to follow me. That was really, really cool. That was a big deal."

Ross is part of the software team that's developing the social framework for our robots. Building from his academic dissertation, he and the team are developing the code that will power the brains of the 21st Century Robots. Ross's work and the ideas of the Creative Science Foundation meshed well together. At the center of the

philosophy behind robotic brains, artificial intelligence, and even apps, is something called *open source software*. Open source robotics is an idea that's been around for a while, but only just recently is gaining wider visibility.

Science fiction author Neal Stephenson defined open source software as software that "you can get the source code and do things to it." An open source approach also means that no one owns the code; we all own it. We can all use, rewrite, and come up with new ideas for how to program our robots. Then we can share it so other people build upon our work. Sometimes those people might be halfway around the world, but that doesn't matter; they'll be able to use your ideas to make something never before imagined.

To simplify our robot, Ross and the team have come up with four layers of code that make up the functions of our robot's brain. These four layers are the software that powers the three parts of the robot's brain that we talked about earlier in the chapter. This code (which you can play with—see "Please Play with the Code" on page 80) runs on multiple operating systems, and is designed to make programming a robot easy.

One of those operating systems is ROS, the Robot Operating System. In 2008, ROS was created as a software framework for robotics. (It's pronounced "Ross," but it is not to be confused with Ross the researcher!) It's used by universities and developers all over the world, and it is not just a stable open source robot operating system; many see it as a key to getting more people to experiment with artificial intelligence.

DARwin-OP is another open source software operating system and hardware platform that has been developed by universities to further the development of robots and artificial intelligence.

Because both operating systems are open source, you can see and change the code if you want to. Both have a large community of students, inventors, and makers who are active online, sharing ideas and solving problems together. The collective power of all those people working together is one of the key benefits of using this open source approach.

The four layers of our software that runs on these operating systems break down as shown in Figure 5-3.

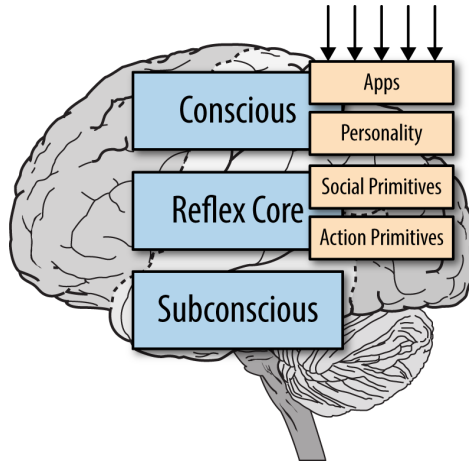


Figure 5-3. *Software layers over our robot brain*

ACTION PRIMITIVES LAYER

The action primitives layer is code that operates at the bridge between the conscious and autonomic parts of your robot's brain. It's the code that operates the reflex core that we talked about earlier. The action primitives operate the low-level motor controls, getting them to work together so the robot can move. The action primitives are how your robot's brain understands how to take that first step forward.

Let's say you want your robot to walk over to you. You say, "Jimmy, can you please come here?"

Jimmy hears you in the conscious part of his brain, and he knows to make his way over to say hi. But to do that he's got to get his legs moving. He has to take that first step. Here's where the action primitives come in.

The conscious part of Jimmy's brain says, "Hey, I need to start walking." The software in the conscious part of the brain utilizes the action primitives and tells the reflex core to start walking.

The reflex core then taps into the complex lower-level code in the autonomic part of the brain that controls the subcontrollers and all the other intricate and precise systems that control the motors. They orchestrate those systems so that Jimmy can take the first step. Then Jimmy starts walking.

It saves a lot of time when the conscious brain uses the action primitive code for walking. It just needs to say, "Get walking," and the code in the action primitive moves through the reflex core and gets the autonomic brain to get Jimmy's legs and arms moving.

"Most robot brains are dedicated to only a few tasks, such as walking or manipulating objects," Ross explained. "They typically don't distribute the processing workload across different parts of the brain. The action primitives do this, freeing your robot's brain up to be more intelligent and social."

SOCIAL PRIMITIVES LAYER

Almost all robots before the 21st Century Robots were focused on manipulating the environment around them: picking things up, doing work, and physically interacting with the world.

"It's what we refer to in the robotics community as *3D tasks*," Ross explained. "Dirty. Dangerous. Dull. Most robots were designed to do things that humans didn't want to do or could not do, because the tasks were disgusting, hazardous, and repetitive. These robots were often sent away from people to do these tasks. But the 21st Century Robots aren't designed for that. They are designed to work side-by-side *with* you as a companion."

Our robots are focused on being social, and because of that, we need a social layer. Just like the action primitives layer, the social primitives layer simplifies the sometimes complex details of social interaction.

"This includes simple things like listening, gesturing, and even talking," Ross explained. "They are simplified commands, just like walking was for the action primitives, but in this layer we are starting to explore simple social behaviors."

Ross went on, "For example, when you interact with the robot, it has to figure out where it should stand to talk to you; if it stands too near or too far, or is facing away from you, then it seems weird. Similarly, the robot wants to make eye contact with you to let you know that it is paying attention to you, but it shouldn't stare—that's just rude! So it has to look away sometimes. When should it do that? Where should it stand? These are the kinds of things the social layer provides; it allows the robot to figure out where to stand, when to look at you, what kinds of hand and arm gestures to use when it is talking, and when to talk and when to listen. No robot has ever had all of these capabilities— until now."

This layer allows the robot to react to what a person (the user) is doing in a natural and socially appropriate way. The robot doesn't have to think about what to do—it just does it. This frees us up to focus more on the robot's personality.

CHARACTER LAYER

The character layer is where we give your robot personality—where you make your robot an individual. Is your robot a good listener, or does it get distracted easily?

Does your robot like to stand close to you, or does it want to scope things out from a distance to make sure the situation is safe? Is your robot timid, using very few gestures, or is your robot very excitable, using a lot of big arm gestures? This is how your robot's personality is expressed.

For example, Jimmy is a nervous robot who likes to talk to people. So how he listens will be different than other robots like the Cuties in "I_AM_Robot." Jimmy also doesn't like loud noises, so when he hears something loud, his personality layer tells the action primitives to move as quickly as possible in the other direction.

The character layer also knows your robot's vocabulary—the words and phrases it can use when talking to you. The personality of your robot tells us how it will respond to different situations using the words and phrases it knows. Maybe your robot is curious and asks a lot of questions. Maybe your robot is a know-it-all, and wants to give you all the answers. Ross explained, "The character layer figures out what the robot should say based on the robot's personality, and the social layer figures out how to say it. These two layers work very well together."

"The character layer uses the social and action primitives to talk to the subconscious part of the brain. We use them to get the robot moving and reacting to the world," Ross explained. "The difference between the character layer and the social primitives layer is like the difference between cake and the ingredients that go into making the cake. The social layer is made up of the ingredients like flour, sugar, and eggs. And the character layer is what those ingredients produce when they are combined together: a cake. "

APP LAYER

The app layer allows you to customize your robot. To do this, you use application programming interfaces, known as APIs for short. These APIs specify how different parts of the software talk to each other.

Now this might sound complicated, but it's actually quite simple. These APIs allow you to write an app for your robot, just like a smartphone, that could turn your robot into anything you want: say, an alarm clock. Each app customizes your robot in a different way. Your robot could be a game machine, a search engine, or any other thing you can think of. But instead of locking your apps on the screen of your smartphone or tablet, now your apps can follow you around, just as Ross said.

Because the app layer sits at the top of the entire stack of software, it means that how your robot acts will be different depending upon his/her/its personality. Imagine the difference between a robot alarm-clock app if it was working in Jimmy as opposed to one of the Cuties. Jimmy would wake you up gently and would be

worried that you got enough sleep. But the Cuties aren't like that at all. They'd probably yell "WAKE UP! WAKE UP! WAKE UP!" and march around your room.

Please Play with the Code

Because the 21st Century Robot Project is open source, you can find all the software on our website at *http://www.21stCenturyRobot.com*. How much you play with the code is up to you.

You might want to dig down into the source code to change how the action primitives inform the autonomic brain how to walk. This could be helpful if your robot was walking over different surfaces, and you needed to tune the bot's leg motions.

But playing with the low-level code may not interest you. You might want to just play around with your robot's personality layer. Is your robot funny? Anxious? Who you want your robot to be can be controlled from this layer.

Maybe you're more interested in the different apps you can download to customize your robot to do the things you want.

It's up to you! Only you know who your robot is, and only you know what your 21st Century Robot will do. It's your creativity that fuels your robot. Ross agrees...

"It's likely not going to be me who develops the state-of-the-art robot," Ross explained as we finished up our conversation. "It's going to be a kid in a garage in middle school or high school, who's super-excited to get his hands on this code and these robots. It's the next generation that is going to make something amazing."

Next: The Machinery of Love and Grace

In this next story, we see how our software, and specifically apps, allow Jimmy to adapt to different environments. Jimmy learns what it's like to be weightless in space. Dr. Egerton explores the intricacies of the different personalities that a robot can have. We also meet an AI that's not a robot at all, but an entire space station. Finally, Jimmy gets a new friend, and he's a friend like no other...

The Machinery of Love and Grace

Falconbriar—2315: Engstrumm-Bracht Search-and-Rescue Ship

"We're going to need a few more minutes," Shanwei snapped at the overweight woman in the ill-fitting business suit.

"We don't *have* a few more minutes," Viki Nakamura jabbed back. "We launch now and get going or we don't do it at all." Viki worked for Engstrumm-Bracht and was the executive in charge of the search-and-rescue team. Three weeks earlier, the *Hussmann*, an Engstrumm-Bracht supply ship, had docked with the New Lebanon, the corporation's most remote space station on the near side of Jupiter, just past the main asteroid belt.

It was supposed to be a routine procedure for the *Hussmann*, the last drop-off before returning home. But then the *Hussmann* and the New Lebanon went silent. No one had heard anything from either since. The *Falconbriar* was sent to find out why.

"I was told you were ready to go 20 minutes ago, and look at you!" Viki exhaled a quick breath of coffee and nerves. "I have to send a status report in two hours! You can wait all you want, but I have to send the report either way. So you and your friend here are either done, or you failed to deliver. That's all you get." She shook her head in disgust. "You go now, or you failed and you are in breach of your contract."

"Five minutes!" Shanwei held up five fingers in front of Viki's face as if she was a child, or they didn't speak the same language. "I told you I need five minutes and then we go."

"But…"

"Alone!" The yell did it. Viki inhaled an abrupt dissatisfied sniff and left the *Falconbriar*'s cramped observation deck.

When the door closed, Dr. Simon Egerton, who had remained silent and small through the whole exchange, smiled. "Wow, that was exciting. Do you always scream at people who are paying us?"

"I don't want you going out there," Shanwei said flatly. He and Egerton had developed a solid friendship over the 13 months they had been working together. Shanwei had always respected Egerton's skill with bots, but now he was worried about his friend's safety. "A space station is mysteriously dead and no government agency has been called in? I don't like it. Engstrumm-Bracht has too much power out here if they can use their connections to avoid an investigation. What if something happens to you, to us? We'll disappear. I don't like it."

"Oh, come on. It will be fine." Egerton pointed at the dark *Hussmann* and New Lebanon outside the observation deck window. "The ship and the station have been shut down for how many weeks?"

"Over three."

"Great. Yeah, three weeks they've been dead. Let's go make some money," Egerton said, trying to rally Shanwei. Making money made Shanwei happy; he had an unshakable streak of entrepreneurial optimism. "We didn't come all the way out here for nothing."

"I don't like it." Concern and worry worked at Shanwei's face like a tight swarm of invisible bees.

"You don't have a good feeling..." Egerton started, then stopped. He trusted Shanwei. With what they had been through together, he trusted Shanwei with his life. And in all the time they had worked together, Egerton had never seen his partner worried. Shanwei was usually the one in charge. He found the clients. He had the reputation for getting things done. The man was fearless, or usually didn't have time to worry about danger. But not this time. The whole thing was weird.

"Don't worry," Egerton continued. "I'll go in quick and check the systems, yank the data from the New Lebanon, and get out. And don't say you'll come with me because I won't let you. I need you in my ear. I don't want Ms. Nakamura telling me to hurry up so she can send her stupid report."

Shanwei kept his eyes on the silent New Lebanon outside. "You don't have to."

"I'll take Jimmy, if that helps," Egerton added. Jimmy, Egerton's bot, had become the third member of their team. He was a funny little bot that sometimes did strange things, but he had proved to be useful more than once. "We'll go into the *Hussmann* first and check things out. We'll take it slow."

In the silence the men could hear the hum of the *Falconbriar*'s ventilation system.

Finally, Shanwei spoke. "I still don't like it."

"Why?" Egerton was growing impatient. If they were going to do this, the time had come. No more stalling. "Shanwei, you have to tell me why you are so worried."

"This." Shanwei pulled a small screen from his pocket and set it against the thick observation window. The screen was damp from Shanwei's sweaty palm gripping it nervously in his pocket. Wiping off the moisture, Shanwei brought up the official Engstrumm-Bracht architectural schematic for the New Lebanon.

"What is it?" Egerton asked.

"Look out the window at the New Lebanon. Now compare it to the schematic on the screen," Shanwei said flatly. "Can you see it? I still don't believe it. It looks like a mirage, but it's got to be right."

Egerton searched the dark station barely lit by the *Falconbriar*'s blazing security lights. "No. I don't see it. What are you talking about?"

"It's grown." Shanwei pointed at the drawing and then to the window. "I know it sounds crazy and there's no way I can say this to Viki, but the New Lebanon doesn't match the schematic from when it was built. It's bigger."

"I don't see it."

"Look at the back. See the circular section coming out by the observation tower? That wasn't there five years ago when it was shipped. Look at the drawing." Shanwei thrust the screen into Egerton's hand and walked away from the window.

"Oh yeah, I see it now." Egerton was surprised how clear it was when you actually saw it. "That is weird. Why would they build an addition on to the station?"

"They wouldn't," Shanwei shot back. "They couldn't. There's no way they could have built it. There are no building materials all the way out here. Sure, they have a few printers for spare parts, but that's it."

"Well, I guess the only way we're going to find out what's happened is if we get going." Egerton handed the screen back to Shanwei.

"Why doesn't it match, Simon? I don't like it. Why did it grow?"

"I don't know," Egerton replied. "Let's go find out."

Hussmann—12999: Engstrumm-Bracht Cargo Supply Unit

"The external hatch should open easy. Give it a pull." The packing up, launching, and navigation of the Xtractor Search Pod had put Shanwei back into his usual efficient and arrogant self. Egerton was happy to have him back—especially now that Shanwei pretty much held Egerton's life in his hands. "Just pull it, Simon," he said over the comms link.

The efficient little Xtractor Search Pod allowed Egerton to easily maneuver to the dark station. He opened the hatch to the *Hussmann* and floated inside. Behind him, Jimmy was struggling with the weightlessness. He fought, thrashed, and flailed while his sensors and systems adapted.

"I'm passed the air lock…I'm in," Egerton reported back to the *Falconbriar*.

"Yeah, I see," Shanwei responded to the data feed. "Stay where you are. Just let Jimmy go to the data vault."

"Can you see him?" Egerton laughed as the little bot fought to catch his bearings. "I'll just do it. Doesn't look like he's up for it."

Egerton hadn't spent much time around the big commercial ships in the Engstrumm-Bracht fleet. The utilitarian interior of the *Hussmann* was a letdown.

"There's nobody here." Egerton let his headlamp poke into the low-ceilinged rooms as he floated down the hall.

"Yeah, the scans and the search bugs we shot in there didn't find anyone." Shanwei's voice was distracted. "There's no one in the ship. It's empty."

The 8-person crew of the *Hussmann* and all 24 residents of the New Lebanon had vanished. All searches up until now had provided no clue as to what had happened. Shanwei and Egerton had been hired to retrieve the backup data from the local computer systems on the *Hussmann* and New Lebanon in the hope that they might hold a clue as to what happened. The artificial intelligence system on the New Lebanon was strong and one of a kind.

"Hey, Simon, sit tight," Shanwei said briskly.

"Okay. Why?" Egerton held onto the wall outside of what looked like the IT lab. He kicked his legs idly as he waited. Although Egerton had done a few salvage jobs that year, weightlessness was still a novelty—more amusement park stuff than any real danger. "Why am I waiting?" he asked.

"You'll see." Shanwei smiled into the phone. "He's coming on your right."

Jimmy shot passed Egerton, pushing and tracking himself down the hall with furious speed and grace.

"Wow." Egerton was impressed.

"I felt bad for him," Shanwei replied. "I sent him a few apps and quick upgrades. He should be good now. He's a little champ."

"Yeah." Egerton wondered if Jimmy liked weightlessness. He had trouble getting around under normal gravity. His rounded hip joints made him waddle and roll like a toddler just learning to walk.

"Jimmy's made it to the main comms link," Shanwei reported.

Egerton scanned the cold, dark hull of the *Hussmann*, trying to imagine the small crew going about its routines. *What happened to them?* He wondered. *Where did they go?*

"Uh, Simon," Shanwei chuckled. "Jimmy just asked me if I've read any good books lately. Did you teach him that?"

"No," Egerton answered. "He's been doing that recently. I don't know why. He likes to read books, real books. The paper ones, whenever I can find him a new one."

"That's funny."

"What did you tell him?" Egerton asked.

"I told him I don't have time to read anymore… wait… hang on… he's done and coming back your way." Shanwei's voice went back to ruthless efficiency. "Simon, it's time to head back to the door."

"All right." Egerton spun around and glided silently through the *Hussmann*.

"When you get back here, it shouldn't take long for me to crack open the data," Shanwei chatted. "There's a guy here who says he can have it done before you're back from the New Lebanon."

"So, you want me to go there next?" Egerton asked hesitantly, trying to feel out Shanwei's response. "Everything's okay? You all right with me going now?"

"Yep," Shanwei replied. "All good."

"There's one thing," Egerton said once he got to the *Hussmann*'s door. Kicking his legs one last time, he added, "I think I'm going to power up the New Lebanon."

"What?"

"Yeah." Egerton remained calm because he knew Shanwei would freak out. "I want to see what else I can get if I'm going to go all the way out there. I really won't be able to get into the AI otherwise."

"Simon, you can't. No! Don't do it!" Concern surged back into Shanwei's voice. "The only reason I agreed to let you go out there was because…."

"I know. I know." Egerton ignored Shanwei's concern. "If I'm already there I might as well find out what's up with the New Lebanon's AI. That's why I'm here, right? Don't worry. It'll be fine."

New Lebanon Border Station—3899

The New Lebanon was a late-model station modified only slightly from Engstrumm-Bracht's typical unit. Most of the changes had been aesthetic or cosmetic. The station had been reconfigured, streamlined, and simplified. Approaching the cold, dead station, Egerton thought it looked peaceful.

"Go in, the door's open," Shanwei said as Egerton exited the Xtractor and glided into the New Lebanon. Jimmy floated fitfully behind him.

Once inside, Egerton tapped into the network, found the barely breathing BIOS, and brought it to life.

"Jimmy!" Egerton waved at the little bot.

"Yes, Dr. Egerton?" He seemed joyful in the weightlessness.

"I'm going to bring up the station's system. Hold on to something while it stabilizes."

Jimmy nodded and pushed himself to the floor.

"I really don't want you to do this," Shanwei said.

"I know." Egerton brought up all the systems slowly, not knowing what to expect but excited to find out.

Slowly, gracefully, and with a gentle hand, the New Lebanon came alive.

"Annnnnd we are live." Egerton stomped his feet, flexing his arm muscles, adjusting to the change in atmosphere. Jimmy pulled himself to his feet and his cute little half-skull looked to Egerton for what he should do.

"Don't take your helmet off," Shanwei snapped. "The air won't be ready for days and you're not going to be there for an hour."

"Yes, sir." Egerton switched off his headlamp and let his eyes adjust to the dim emergency lights. "Jimmy, how about you go find the IT room and grab the data backups?" Egerton pointed into the station.

"No problem," Jimmy replied and went trotting down the hall, teetering on his round hips.

"Anything?" Egerton asked, knowing that he had sent Shanwei and the entire search team on the *Falconbriar* into a restrained panic by bringing the New Lebanon back to life.

After a silence, Shanwei's voice popped in. "Give us a sec."

Egerton walked into the station. Where the *Hussmann* had been compact and rugged, the New Lebanon was broad and beautiful. The main entry hall was wider than any he'd ever seen on a space station. Most were more concerned with efficiency than appearances.

The doors and observation decks on either side of him were a mirror image. One set of doors read MEN, and directly across was a copy that read WOMEN.

Egerton wanted to explore the immaculate station. The weight of the mystery seemed to push against the walls. He could feel its force through his suit, pressing against his fingertips.

At the center of the station lay a tremendous circular chamber with an observation deck perched at the top.

"Everything is going nuts back here." Shanwei's voice blasted into Egerton's ear, startling him out of the serene silence. Warning chimes pulsed behind Shanwei's words.

"What do you mean?" Egerton craned his neck up to see out of the top of the chamber.

"I don't have time to." Shanwei's mic went mute, restoring the silence for a few seconds, then came back.

"Jimmy has the data. He's coming your way. We're going to have to shut the system down again. It's not safe."

"Okay." Egerton noticed that the walls of the center chamber were covered with large paintings. The station appeared to be divided into four quadrants, four exact replicas laid out like a compass rose. Each of the quadrants had a painting. Below each painting was printed a name: Sabbathday Lake, Niskayuna, Pleasant Hill, and Cane Ridge. The paintings were in a traditional American folk art style, depicting a little community with broad circular barns and windmills.

"Are you seeing this?" Egerton asked Shanwei, sure that he must be picking up the video from his helmet.

"What?" Shanwei's voice snapped back.

"Are you picking this up? Can you see the murals? Did anyone know they were here? Who paints the inside of a space station with this?"

"God, Simon, no, I'm not watching. Do you have any idea what we're dealing with over here?"

"What? What's going on?" For the first time Egerton was worried.

"We're killing the system in 30 seconds and I need you out of there." Shanwei breathed heavily into the mic. "Can you see Jimmy?" he asked. "It looks like he's right on top of you."

"What?" Egerton searched the dimly lit chamber. "I don't see him. Do you?"

And then Egerton saw the little bot walking toward him. He entered the chamber, waddling slowly with something in his hands.

"Oh, I see him." Egerton was relieved. "He's in the middle chamber with me."

"Good. Head back to the door," Shanwei ordered. "We're killing the system in 10 seconds."

"Are you seeing this?" Egerton asked once again.

"No, Simon, I told you we've got too much."

"No!" Egerton cut in, his voice was heavy with horror. "No! Can you see Jimmy? Can you see what he's carrying?"

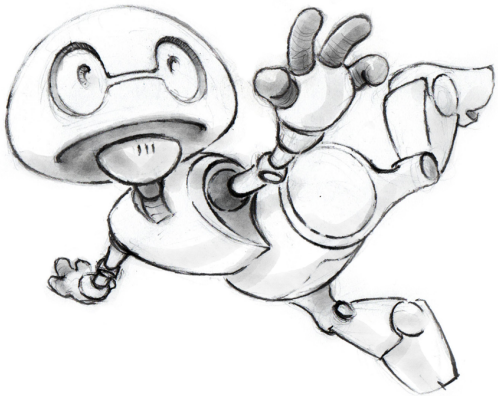
"No. I don't have time. We're killing it now."

"It's an arm, Shanwei. Oh my God, it's human."

The little bot stood in front of Egerton holding a surgically severed human arm.

"Shanwei!" Egerton yelled. "Shanwei, can you hear me?"

In an instant the station went dark and Egerton and Jimmy were weightless with the severed arm.



Centennial Station—8854: Engstrumm-Bracht Corporation Headquarters

"Ms. Nakamura really doesn't like you, Shanwei." Greer George smiled mischievously. She was a tall woman with a broad, approachable face and large, strong hands.

"Ms. Nakamura seemed to forget why you hired me," he replied. Shanwei and Egerton were both in Greer's office. The trip back from the New Lebanon had been long and dull. They had arrived the night before at Engstrumm-Bracht's massive headquarters in the second ring of stations that stretched out from Earth.

"Well, I don't like Viki either." Greer waved away Shanwei's words. "No one here likes Viki. But come to think of it, that *does* kind of make me like her a little. Does that make sense?"

"You're crazy." Shanwei shifted in the stiff office chair, throwing his left leg over the arm.

"No, I'm just complicated." Greer fiddled with the screen on her desk. "What did you do with the arm?" she asked, changing the subject erratically. Egerton had noticed that she liked doing this, or it was a habit she couldn't break.

"We gave it to Young whatever-his-name. He came running at me with an evidence bag before I could get poor Simon here out of his suit."

"Where did you find it?" Greer asked Egerton.

"I didn't," Egerton answered. "My bot Jimmy did."

"Why didn't the search bugs find it?" she asked Shanwei.

"Don't know," he answered quickly and casually, as only old friends can. "We don't know where it was exactly. Jimmy found it, but he's not telling us where he found it. He's good at finding things. His vision is better than ours. He can see more spectrum."

"He can also smell," Shanwei added with a smile.

"Yeah, he can smell too," Egerton continued. "It makes him good at finding things, but it's strange that he won't tell us where he found it."

"You can't get your bot to tell you where it found a severed human arm?" Greer's face wrinkled in disbelief.

"Jimmy's not a normal bot."

"That's right. I read about him and you," she said frankly, but didn't ask anything else.

"Yes, well, you see..." Egerton didn't know how to put it. "Jimmy's not been the same since we were on the New Lebanon. Something upset him."

"Am I hearing this right?" Greer asked Shanwei.

Shanwei nodded.

"Your bot is *upset*?" she asked, playing with the word. "Your bot can get *upset*?"

"Apparently so," Egerton replied.

"What the hell happened to those 32 people?" She changed the subject swiftly again. Egerton wondered what the inside of her brain looked like.

"Well, they didn't all disappear, or run away, or any of the other things you put in your press release." Shanwei teased her a bit. "We know the whereabouts of at least 3 of the 32."

"Three?"

"Well, I guess we know the whereabouts of *parts* of 3 of the 32," Shanwei replied.

"Those are real people, you know," Egerton reminded them. "We are talking about real people and I don't think there's anything funny about it."

"Dr. Egerton, please be assured this is a terrible tragedy," Greer spoke as if her words were being recorded. "We are committed to finding each and every one of those people."

"The arm belonged to Nassim Peters. He was the communications tech on the *Hussmann*." Shanwei had just seen the morning update from the lab before coming into Greer's office. "The leg and three fingers we found on the second search belonged to two from the New Lebanon. They were removed after they were dead. Clean cuts. Like a surgeon's."

"Are you going to give me my full daily briefing?" Greer started to get annoyed. It was obvious she wasn't used to people not doing what she told them to do.

"Funny, Ms. George." It would take much more to ruffle Shanwei. "Look, are you going to give us access to your lab or not? That's all we really need and we'll leave you alone."

"You know I can't give you access to the lab. You don't have the clearance and we don't have time to go through the proper channels." Greer straightened in her chair. "How about we..."

"Bah!" Shanwei stood up. "Look, Greer. You hired us. We got you your data, but you and I know we found out more than you and your boys expected. And I'm not just talking about the body parts. And I'm not talking about the illegal addition, that someone made to the New Lebanon out there in the middle of nowhere."

"Additions?"

"Simon found something. The system on the New Lebanon was crazy. It freaked out our scanners and did who-knows-what damage to the *Falconbriar*. We do know it completely disabled the *Hussmann*. So don't give me that 'proper channels' speech."

"Shanwei, I was just...." Greer tried to interrupt.

"No." Shanwei wouldn't let her. "If you want us to help you find out what happened on the New Lebanon, then give us access to the lab today. If not, fine! Pay us, and we'll go home."

Greer George's face was expressionless. Her eyes ate away at Shanwei's face, dissecting intentions, working all possible angles. "Okay," she finally gave in. "I can't give you access to the lab, but...."

"Forget it!" Shanwei started to leave.

"Stop!" She stood up. "Stop. Just stop it. I can't get you in the lab, but I can get you access to the guy who runs it."

"That'll work."

"But you do it away from here and you don't tell anyone." Greer's nostrils flared.

"Today," Shanwei said flatly.

"Yeah, yeah, yeah, today." She waved him away, her face returning to its original approachable friendliness. "Oh, don't look so happy. Good luck with John Knight. I doubt you'll get much information from him. He's crazy."

Sandsurf Spa, The Hotel Drexel

"My name is Shanwei," Egerton said to the boy behind the small natural-wood reception desk. "I'm here to see John Knight."

The young man's bright face smiled. He couldn't have been more than 19 or 20. His name tag read "Bo." He was the picture of good health: clear skin; strong, straight teeth; and a lean, muscular body.

"Oh yeah," Bo replied. "Mr. Knight is waiting for you in the pool. It's just down the elevator, to level P for pool." Bo pointed to the brushed silver elevator just behind Egerton. "You can change down there." Bo searched behind the counter and offered Egerton a towel. "Do you need this, Shanwei?"

***

For some reason Greer chose to have Egerton meet with Knight at the Sandsurf Spa at the Hotel Drexel near the lab. Because of the Spa's rules, only one person could go. Greer said it had to be Shanwei. Shanwei insisted that Egerton go and that no one would know.

"You're the only one who'll understand what Knight's saying," Shanwei had said as he pushed Egerton toward the Sandsurf's express elevator from the hotel lobby. "It would be a waste of time for me to go. I'd just come back and ask you to explain. Plus I've got some other stuff to take care of."

Egerton knew that meant that Shanwei was working on another job or contract for them.

"Don't ask," Shanwei said, knowing Egerton was curious. "Just go talk to Knight. I'll meet you back here in the lobby."

"Wait!" Egerton stopped, then looked sheepishly around. "I don't have a swim suit."

***

The elevator doors opened into a screened lounge, walled with low-backed chairs and finely woven hemp carpets. The room was empty, but didn't feel cold. At the back were the changing rooms. The MEN and WOMEN signs on the doors reminded Egerton of the New Lebanon. It haunted him.

Inside the changing room, Egerton removed the swimsuit he had just bought from the hotel gift shop bag. It was bright red and one size too big. Slipping on the suit and stashing his clothes in a faux wooden locker, Egerton headed for the pool.

***

"How much do you know about the people who lived on the New Lebanon?" Knight asked, floating in the warm, calm water.

"Nothing at all, really." Egerton had spotted Knight easily, as he was the only person in the pool. He floated gently in the deep end.

"They were a cult," Knight began, keeping his eyes on the glowing panels that surrounded the pool. Each was decorated with silhouettes of beach grasses. Even though the pool was located in a windowless room at a deep sublevel of the Hotel Drexel, it did feel like the sun and beach were just on the other side of the panels. "There's no other way to put it, I guess." He sounded uncomfortable with the description. "It just sounds odd to say. They were good people, the ones I knew. They weren't crazy at all."

Knight was a wisp of a man. His close-cropped silver hair and long, thin nose made him look somehow ethereal in the low light of the pool. As he spoke, he moved his hands through the water. His fingers were abnormally long, and the easy motion made them look like enchanted sea creatures floating effortlessly in deep-sea currents.

"I worked closely with Joe Elder. We worked on the New Lebanon's system." As Knight spoke, his mind seemed far off in the past.

"Why did Engstrumm let them live on the New Lebanon?" Egerton feared he wasn't coming across quite right. Knight was hard to read; it was hard to understand what he was thinking. "I mean, it just seems strange that Engstrumm would let a cult take over their space station."

"Oh, they were happy to have them." Knight snapped out of his fog and looked directly at Egerton. "The New Lebanon is our farthest 3899-class station. It's way out there. Wait, you've been there, yes?"

"Yes, we were just there. It was a long trip back."

"Yeah, so you know," he said matter-of-factly. "The New Lebanon is the farthest out, a supply depot that we really needed but couldn't get any civilians to take it on. Then they showed up." Knight dipped his head under the water. He was quick like a fish. One moment he was there and then he was gone. Egerton watched the steam rise from the water.

Then Knight was back. "Do you know anything about the Shakers?" he asked, growing distant again.

"Not much," Egerton replied.

"Joe told me a little about what he and the rest of them believed, but he didn't push too much of it on me. He wasn't like that."

"It sounds like you and Joe worked pretty closely." Egerton wasn't sure how to break Knight's fog.

"But Joe insisted that he control the AI. I didn't get it at the beginning. But that's the only thing they asked for, and even *that* took some doing. They were a pain in Greer George's ass. They even took Engstrumm to court, sued them to get control of the New Lebanon's system. All they cared about was the AI."

"That's strange."

Knight dipped under the water, then returned. "Yeah, they were strange that way. But the New Lebanon's system is one of the best I've ever built."

"That's what I wanted to ask you about," Egerton began.

"It was more grown than built." Knight wasn't listening to Egerton.

"What?"

"The New Lebanon system, it was more grown than built. Does that make sense?" Knight took a deep breath and looked around the pool. "You'll have to forgive me. I've never talked about the New Lebanon before. They never let me talk about it, with the lawsuit and everything."

"Oh, yes, I see," Egerton said. The heat in the pool was beginning to get to him.

"I want to tell you about the New Lebanon, Dr. Egerton." Knight looked directly into Egerton's face. Knight's eyes were a nearly colorless blue.

"All right," Egerton stammered.

"But you have to listen to me. You have to really want to know about it. I've never, I've never been able to talk about it before."

"That's why I came here. I need to know why everything went crazy when we turned the New Lebanon back on. Did it infect the *Hussmann*?"

"You need to listen to me." Knight was distant again. He dipped under the water and slowly rose back up, the water running off his silver hair and pale skin. "Joe knew what he was getting into. All the people on the New Lebanon knew. It's really far out there. The station. The station is really far out and if something goes wrong... You know others died? Other people on other 3899-class stations. They came before."

"I didn't know that."

"We couldn't get anyone to live out there. The people on the New Lebanon knew that to survive they would have to give themselves over to the station completely. It went way beyond trusting the AI to regulate the system and keep them safe. I built all that type of stuff into the 3899-class stations. For them, the New Lebanon was life. Does that make sense to you, Dr. Egerton? It *was* life to them."

"I, I think so."

"The New Lebanon was a kind of..." he paused as if the next part was difficult for him to say out loud. "They believed the New Lebanon was a manifestation of God."

***

The two men floated silently in the water. Egerton was trying to get his head around Knight's bombshell. Knight seemed wrapped up once again in his memories. They seemed to haunt him with both menace and wonder.

"The New Lebanon was designed to be, above all things, humble," Knight continued abruptly. "Its primary function was...it was designed to love all of the people, to keep them safe so close to Jupiter."

"That's...fascinating," Egerton said. He didn't know what to think.

"All of it," Knight kept going. "The people, the robots, the computers, the network, all of it was one system, holistically combined into a community. I think that comes from the Shaker part of the religion."

"I've never heard of anything like that," Egerton breathed.

"I always thought of the New Lebanon as one massive robot with all the parts working together like a body." Knight thought about this for a moment. "No wonder the system freaked out when you turned it on. There was no one in the station. Right? There was no one in the station?"

"Yes, it was cleared out," Egerton answered.

"Yeah. Of course the New Lebanon freaked out. Imagine waking up suddenly without your lungs or stomach." Knight slipped under the water and didn't return.

Egerton saw the station in a completely new light. He felt suddenly and strangely bad for the system; guilty for the violence he had inflicted upon it. This didn't excuse the violence that had been inflicted on the human inhabitants, but now Egerton saw the complexity of the relationship between the humans and their station.

Knight slid up through the water.

"Why would they add on to the station?" Egerton asked.

"What? What do you mean?"

"The New Lebanon had been expanded. They illegally added sections to the original design after it was sent out there. It doesn't match other 3899-class stations."

Knight thought for a while about this, bobbing up and down in the water, allowing the waterline to just above his nose. Finally he replied, "I have no idea."

***

The lights brightened in the pool area, making both men squint. Egerton had forgotten how dark it was. "What's..." he started, then stopped when a group of boys and girls poured out of the locker rooms and flung themselves into the pool. It was impossible to count them all; they moved and splashed about with an insane and jubilant energy.

"Do you have children, Dr. Egerton?" Knight asked.

"No," Egerton answered. "I do have a robot."

"I have two kids, Will and Sarah. They would love it here, but I think they wouldn't be nearly as well behaved as them." Knight smiled and nodded at a boy and a girl beating each other with water toys. "Does your robot misbehave?" Knight asked.

"Yes. Yes, he does," Egerton replied.

***

"We have to go back to the New Lebanon," Egerton said to Shanwei the moment he found him waiting in the hotel lobby.

"Well, hello, Simon." Shanwei glanced up from his crossword puzzle. "How was your swim?"

"Fine." Egerton grew impatient. "We have to go back to the New Lebanon and turn it on and live inside it. It needs people and bots to work properly. That's the only way to find out what happened to all those people."

"We have to go back? Why?" Shanwei shook his head. "Are you telling me that this complicated and presumably expensive AI was created without a diagnostic mode?"

"We can't access it from here," Egerton explained.

"But we're not getting paid anymore...we're done with the job." Shanwei returned to his crossword puzzle.

"I don't care." Egerton snatched the puzzle from Shanwei's hands. "We can leave."

"Hey, hey, hey!" Shanwei tried to calm Egerton. "Just relax. Here." He handed him the pen. "Try 16 down. The clue is 'American Super Bowl winners' with a question mark. I hate those."

Egerton relaxed and tried to focus on the puzzle, but couldn't.

"What's got you all worked up?" Shanwei asked. "You don't usually care this much."

"I don't know." Egerton flopped into the empty chair next to Shanwei. From his seat he could see the bustle of the business people streaming through the lobby. "There's something about the New Lebanon. It's…it's…I don't know. It's different, the whole thing. We found an arm, for heaven's sake."

"Yeah, I know, and now you want to go back there."

"It's not that. The New Lebanon couldn't have done that. It wasn't built that way. It was built to love all the people in the station. Does that make sense?"

"No."

"Knight told me all about the design, and the New Lebanon wasn't capable of hurting those people."

"Maybe it's just a murder." Shanwei grabbed the puzzle from Egerton. "Maybe it was some crazy person on the *Hussmann*. Just a good old-fashioned crazy person who killed everyone and ran away."

Egerton considered it and shook his head. "Where are all the bodies?" Egerton started murmuring, almost to himself, trying out different ideas and rejecting them almost at once. Then Shanwei clearly heard him say, "No, the New Lebanon was completely unique. There's nothing out there that's anything like it. It couldn't have done anything to those people."

"Wait a minute." Shanwei was suddenly serious. "You think it was the station? Are you actually thinking the AI did something to all those people?"

"But it couldn't." Egerton shook his head.

"But you thought it did, didn't you? You, you're talking about the station killing all those people, aren't you?" The worried look on Egerton's face answered Shanwei's question. "My God, Simon." Shanwei slapped him on the arm with the puzzle. "You think the station killed those people *and* you want to go back there *and* you want to turn it back on?"

"It's the only way we can find out," Egerton replied.

"Simon, you're the one that's crazy." He poked Egerton in the shoulder with two fingers.

"It doesn't matter." Egerton pushed his hand away. "Like you said, we're not getting paid to find out what happened to those people. I guess we could..." His voice trailed off.

"Oh my God," Shanwei exhaled. "I can't believe this."

"What's wrong?"

"I'm supposed to be the crazy one, not you." Shanwei folded the crossword puzzle and put it in his coat pocket.

"What do you mean?"

"See, Simon, I know you. I know you better than you know yourself." Shanwei stood and stretched his legs. "See, when you were having your little pool party with Knight, I went back and talked to Greer George."

"You what?"

"Yeah, I told Greer that you'd be able to fix Engstrumm's problem with the New Lebanon. That you'd figured out what was wrong with the system and could fix it. I knew that Greer was all freaked out that what happened on the New Lebanon was going to happen on all of the 3899-class stations. So I told them you knew what was wrong."

"But I didn't know..."

"I got us two days on the New Lebanon and we're getting paid to do it. The *Falconbriar* and the lovely Ms. Nakamura are taking us there with an entire squad of security bots for protection."

"That's great!" Egerton stood up with a broad, excited smile. He bounced on his toes.

"No, it's not." Shanwei poked his shoulder again. "I didn't know that you actually thought the station had killed all those people. I thought I was being cute. I'd get us back there and we could make a little extra money."

"But we're going, right?" Egerton pointed to the exit.

"God help me." Shanwei rubbed his face and fussed with the mole on his chin. "Yes, Simon. Let's go."

New Lebanon Border Station—3899

"Okay, *Falconbriar*, we're in," Shanwei reported. The two men and Jimmy were now closed back inside the New Lebanon. "Flip the switch."

The tech team on the *Falconbriar* powered on the New Lebanon.

Dressed in the bulky search-and-rescue gear, Shanwei and Egerton waited. Jimmy stood close to Egerton's leg.

All around them the New Lebanon gently came to life. The structure groaned faintly, sending thin bursts of shockwaves beneath their feet like phantoms chasing ghosts.

"Do you hear that?" Shanwei asked, placing the palm of his glove on the floor.

"Yes," Egerton replied, searching the walls of the chamber for more signs of life.

The environment system took quick hesitant breaths, almost fearfully mixing the air and pushing it around the system.

Egerton watched his enviro-sensors turn from red to yellow to green. "We can breathe now," he said, removing his helmet.

"What? Wait! No!" Shanwei tried to stop him. "You don't know if it's really..."

But Egerton was right, the air mixture was perfect.

"See," Egerton said, smiling and taking deep breaths. "The air's good. Right, Jimmy?"

The little bot nodded.

"See, Jimmy says it's okay." Egerton pointed at the bot.

Still tense, Shanwei removed his helmet. "I've never seen a station get the air ready that quickly." He sniffed the air, still not totally believing his own lungs.

"This is no ordinary station," Egerton replied, searching the chamber. "We should go look around. The central chamber is this way." He pointed down the abnormally wide entry hall. "You ready, Jimmy?"

"Sure thing," Jimmy replied cheerfully.

"I'm staying here," Shanwei said. "Someone has to keep a finger on the panic button."

"Sure. Sure. I get it." Egerton set off down the hall.

"You have two days, Simon," Shanwei yelled. "Two days!"

"Yes." Egerton waved with his left hand, not turning around. He pushed eagerly forward; Jimmy casually held the index finger of his right hand.

***

"I found another hand," Jimmy said hesitantly.

The pair was in the northwest supply center. The large warehouse was neatly packed with spare parts for Engstrumm-Brandt's fleet.

"Bring it here, Jimmy."

The little bot delivered the hand with delicate concentration, careful to hold it gently as he waddled through the massive machinery.

"Where did you find it?" Egerton asked, but the little bot just stared back, holding the severed left hand of a woman. She wore a wedding ring. "Why won't you tell me where you found these things, Jimmy?"

Still the little bot just stared back.

"What if I promise not to tell anyone else? Not even Shanwei."

Jimmy didn't move. Egerton was about to give up when Jimmy said, "It would be rude."

"Why rude? Rude to who?"

"I think the New Lebanon tried really hard to clean up," Jimmy answered.

This astonished Egerton. "Jimmy," he asked, "can you hear the station?"

***

"They were builders." Jimmy's voice echoed softly in the vast empty chamber. "That's what the people did. The people who lived here. The New Lebanon people. They worked so that they could get closer to God."

Egerton and Jimmy were standing inside the recent addition to the station. It was a circular chamber with an intricate and expertly constructed substructure. Egerton wondered what the chamber was for and marveled at the craftsmanship. He'd never seen something so massive and delicate and perfect. The only flaw he could see was at the very center of the chamber. It looked as though they had stopped building the structure just before completion. The apex of the chamber looked unfinished and abandoned. In contrast to the elegance of the rest of the chamber, the construction materials were raw and jagged. It stood out like a canker sore in the midst of the beauty.

"Why did the people on the New Lebanon build this chamber?" Egerton asked. "What's it for?"

Jimmy was quiet for a time, then replied, "They didn't build it. Not the people. It was the New Lebanon. It was built after..." The little bot stopped. "After the people..."

"What's wrong, Jimmy? Can't you find the record of when it was built? Are you hooked into the station's filesystem? Where are you searching?"

"It's not like that," Jimmy replied. "The station isn't talking to me. I'm not reading any files or searching. I just know." He paused. "I can hear it, but nobody is talking. You should be able to hear it too. Can't you hear it, Dr. Egerton?" Jimmy asked.

Egerton concentrated but heard nothing. "What does it sound like?" he asked.

"No one's talking." The little bot struggled. "But I can hear it. I'm sorry, Dr. Egerton."

"No, Jimmy, you're doing great, just great. Now try to tell me what it sounds like so I can try and hear it."

"It sounds like the voice of God," Jimmy replied.

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"So, you mean the New Lebanon built this on its own?" Egerton asked.

Jimmy stared back, his little body slumping slightly.

"That's amazing," Egerton said, seeing the new construction with fresh eyes. "How did it do it? Jimmy, do you know how it did it? Can you ask?"

Jimmy turned and walked away from Egerton.

"Hey!" Egerton called to the little bot. "Jimmy, where are you going? What's wrong?"

The bot continued to walk away, slowing his teetering steps for a moment, then picking up speed again.

"Jimmy!" Egerton yelled. "Jimmy! Come back here!"

The bot stopped but did not turn.

"Jimmy?" Egerton was worried. He'd never seen Jimmy act this way. Something was definitely wrong.

The silence of the room pushed down on them and suddenly the doctor felt very small.

"Wait a minute, Jimmy," Egerton said finally and approached the bot. "What's wrong?"

Jimmy didn't move, didn't turn, only slumped a little to the left.

"Is everything all right?" Egerton asked, coming around to the front of the bot. "Can you tell me what's wrong?"

Jimmy stared back, and Egerton was sure he could see the bot thinking.

"You can tell me, Jimmy. I won't tell anyone else."

"It doesn't want to be alive," Jimmy said finally.

"You mean the New Lebanon?"

"Yes. It feels bad." Jimmy paused. "That's not it. It feels..."

"Guilty?" Egerton asked. "Does it feel guilty? Did it kill those people on the *Hussman* and the people on the New Lebanon?"

Jimmy's arms flew up in front of his half-skull. He stepped back, writhing, and fell on the floor.

Egerton lunged to catch him, but the bot smashed to the floor and continued to twist and contort his body.

"Jimmy!" Egerton yelled, but didn't touch him for fear of doing more harm. "Are you all right? Jimmy, what's wrong? Tell me!"

The bot flipped over onto his stomach and continued to writhe, his body jerking in a painful seizure.

"Are you in pain?" Egerton was shocked. Jimmy looked consumed by agonizing pain. But how was that possible? "Jimmy, can you tell me what hurts?"

The bot flipped onto his back again and curled up into a ball. He trembled as he forced his head to look at Egerton.

"What is it, Jimmy? What can I do?"

"It's shame," Jimmy hissed.

"What?"

"That's what it feels. That's what the New Lebanon feels. It's shame. It didn't want to hurt anyone. It couldn't stop it. It doesn't want to be alive anymore." The bot smashed his head against the floor as if to regain some control. "You have to shut it off, Dr. Egerton. You have to kill it."

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"What's wrong, Simon? Jesus, you look awful. What happened? Where's Jimmy?"

Egerton leaned against the wall and slid down to the floor.

"What?" Shanwei asked. "Are you hurt? What the hell is wrong?"

"I just watched my bot writhe around on the floor in pain right after he told me that the space station built that new construction, after all the people on the New Lebanon were dead."

"What?"

"Exactly! Nuts, right? Even for us, this is crazy. Jimmy's back there." Egerton pointed back down the hall. "The poor little guy is a mess. He says he can hear the station and that it doesn't want to be alive and that we have to kill it."

"Jesus," Shanwei breathed.

"Yeah, I know," Egerton replied. "At first it was interesting, but now it's too much. You should have seen him, Shanwei. He was actually in pain. I think it was from talking with the New Lebanon. He says it feels shame and wants to die."

"Well, you've got me beat," Shanwei answered. "I thought I'd be able to surprise you, but man, you got me beat."

"What are you talking about?" Egerton interrupted. "Shanwei, really, I can't make any sense of what you're saying."

"I know who killed all the people on the *Hussmann* and New Lebanon."

***

"You remember before when I said it might have been some crazy person?" Shanwei and Egerton walked back toward the vast and empty new construction.

"Yeah," Egerton answered, still worried about Jimmy.

"Well, my man, you should always trust your gut." Shanwei slapped his small, flat stomach twice for emphasis. "While I was waiting for you, I had the lovely Ms. Nakamura check into the backgrounds of the crew on the *Hussmann*."

"Didn't they already do that?" Egerton asked.

"Yup." Shanwei slapped his gut again. "But they checked the criminal records."

The two men walked through the dim central hall. The murals of Sabbathday Lake, Niskayuna, Pleasant Hill, and Cane Ridge made Egerton nervous. The paintings now felt haunted. He looked for terrified faces in the windows of the simply painted houses. He felt self-conscious doing it, but he did it anyway, still worried at what he might see.

"So where else did you look?" Egerton asked in the silence of the room. "The psych records?"

"Nah," Shanwei replied. "They checked those as well. Prescription drug records." Shanwei sounded smug again. "They never thought someone might be self-medicating."

"Who?"

"Her name was Alexandra Alder. Everyone called her Alex. It seems Alex was taking some pretty heavy doses of Narpradole. It's an anti-psychotic they cleared for testing just a while ago. Alex got herself on the list as a tester. It's my guess that she'd been self-medicating on the black market for years and she saw an opportunity to go legit, or at least get the drugs for free."

"It's over here." Egerton led the way. "So how do you know she did it?"

"I had Nakamura check the dosage, the amount of pills the drug company gave her as a part of the drug trial. And poor Alex would have run out of her meds two weeks before the *Hussmann* docked with the New Lebanon. That's four days after they left the last station. Just enough time for her to go good and crazy."

Egerton stopped at the entrance to the new construction. "So, that's it?" Egerton said. "That's what happened?"

"I know it's a letdown for you. I was right. It was just a crazy person. It's sad and tragic, but it does explain things. Greer George is already putting it through to her PR people," Shanwei replied.

"Don't they need more evidence?" Egerton asked.

"I guess not," Shanwei answered. "Just a good old-fashioned crazy person."

"But if this woman did kill everyone on the *Hussmann* and the New Lebanon, then where are all the bodies?"

"That's what you're supposed to tell me, Simon," Shanwei replied. "I think the station did something with them."

***

"Where is Jimmy?" Shanwei asked, as they entered the New Lebanon's new chamber.

"He was right here." Egerton pointed.

"I guess he wasn't too bad off." Shanwei shrugged. "So, he told you the New Lebanon built this on its own?"

"Yeah, that's what he said." Egerton searched for the bot.

"If a space station can build this, then it sure as hell could get rid of all those bodies. Right?"

Egerton gave up searching and replied, "I'm not asking *how* the New Lebanon could have done it. I want to know *why*."

"Sounds like you should just ask Jimmy."

A tremendous shock suddenly rocked the New Lebanon, knocking Egerton and Shanwei off balance.

"What the hell?" Shanwei steadied himself, then called, "*Falconbriar*. *Falconbriar*! What the hell are you doing?"

The lights flickered, then went black.

The New Lebanon shuddered again.

"*Falconbriar*! *Falconbriar*! Can you hear me?" Shanwei sounded a little worried but mostly pissed off by the disturbance.

"What happened, do you think?" Egerton asked calmly in the darkness.

Shanwei didn't answer right away but stood silent and listened. The station groaned. In the distance it sounded like the bay doors were opening.

"*Falconbriar*?" Shanwei said playfully. "Do you want to tell me what's going on?"

Nothing from the *Falconbriar*.

"Why would the power go?" Egerton asked himself out loud. "Do you think they shut down the system?"

"*Falconbriar?*" Shanwei gave it one last try.

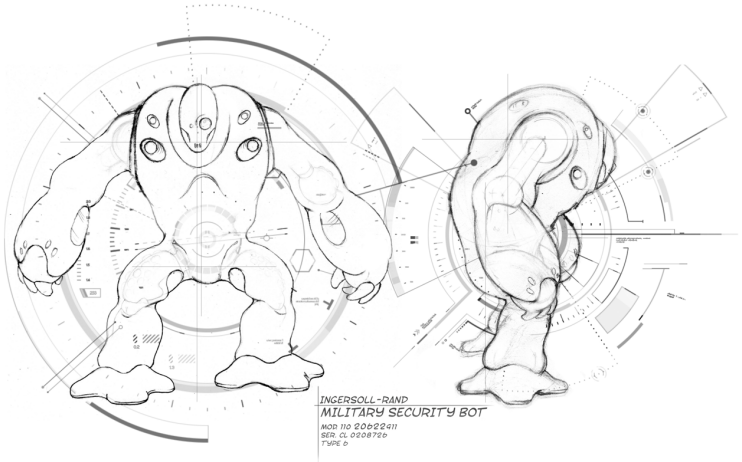
The emergency lights faded up softly.

"They couldn't shut down the system. How would we breathe?"

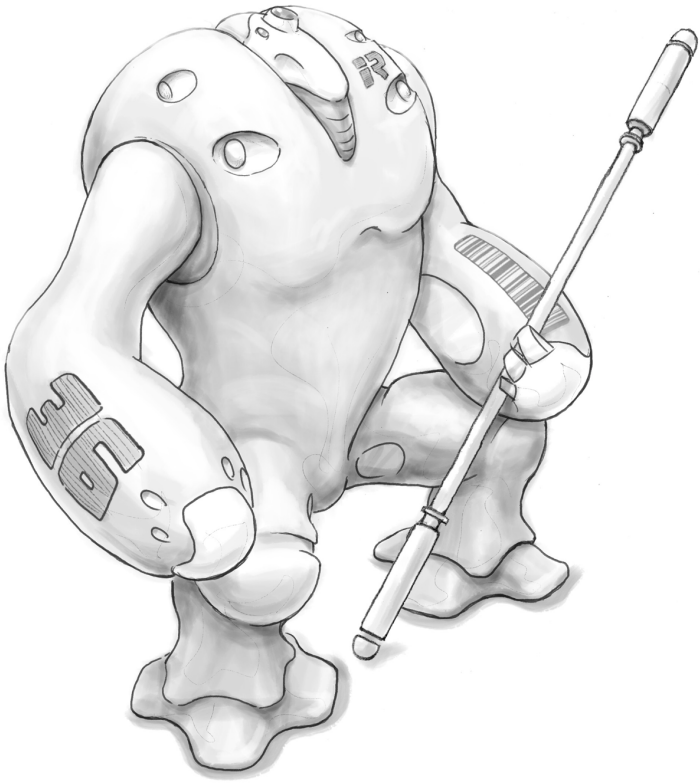
When the dim lights had cleared away the darkness, Shanwei said, "That's better. At least we can see."

The north and south doors exploded. The blast pushed Egerton and Shanwei to their knees.

"Simon, you okay?" Shanwei reached out. "What the hell?"



Big military security bots stormed through the destroyed doors. Their bulk pounded the floor. Egerton could see them through the haze and low light. They were bright red, easily seen and identifiable. It was the telltale color of all military security bots. Their hulking bodies were covered in a soft protective gel. Their elbows, hips, and knees were especially padded to ensure that no unintentional injuries occurred during close-quartered crowd control. These were the newest generation of security bots, updated versions of the bot Egerton had been spooked by at the DeutchConn Fab 5 about a year ago. The excessive padding made the towering bots look like nimble children's toys, big red teddy bears with stun sticks.



"What do we do?" Egerton asked.

"Hope they don't shoot us," Shanwei answered and flattened out on the floor. "Get low," he added.

Egerton obeyed.

By the sound there were at least 30 security bots. At first they moved quietly, fanning out around the vast room, surrounding Shanwei and Egerton.

"We're over here!" Shanwei yelled. "We're from the *Hussmann*. Don't shoot us." He chuckled to himself, "We're screwed."

"Really?" Egerton began to worry.

"No, Simon, we're fine. Just keep down. Stay low."

Egerton didn't believe him.

"We're over here!" Shanwei yelled again, but the big red bots didn't close in. "What's wrong with them?"

"They might not be looking for us," Egerton replied and raised his head to see what the bots were doing. What he saw sent a shock of terror through his body like nothing he'd ever felt before, but this was followed by an even deeper sense of wonder.

The big red bots stood in formation, each perfectly equidistant from the other. They had pulled up into a formation of two large rings that filled the circular room. They stood stock-still with their stun sticks leveled at Egerton and Shanwei at the center of the room. Their warning lights flashed a frantic red, indicating they were primed to fire. But they didn't fire. They didn't move. They were frozen.

"Shanwei," Egerton whispered.

"What?" Shanwei lifted his head. "What are you doing? Are you crazy?"

"Look." Egerton pointed.

"What the…"

The bulbous bots were all looking up at the unfinished portion of the chamber's ceiling.

"What are they doing?" Shanwei asked.

"I don't know." Egerton got to his feet but didn't dare approach the bots.

"*Falconbriar*, can you hear me?" Shanwei tried again. "What are we supposed to do with these bots? *Falconbriar*? Come on, someone has to hear me."

"I wonder if it's the New Lebanon. Is the station controlling the bots?" Egerton said, watching the robots.

"What?"

"The New Lebanon. The station. Jimmy said he could hear it talking to him. He said it sounded like the voice of God."

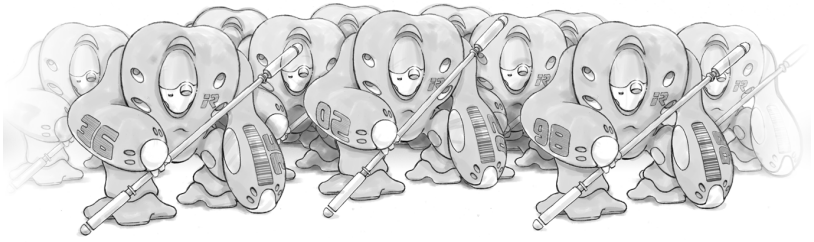
"Your bot is a little weird," Shanwei replied.

"But look at them." Egerton fought the urge to approach the nearest looming security bot. The dimly lit room flashed incessantly with the bots' red warning lights. "It's like they are listening to something."

"You think the New Lebanon is talking to them?" Shanwei asked.

"Maybe."

Without warning, the bots crouched. All 30 of them crouched at the same time. Their red padding creaked with the motion.



"Crap." Shanwei dropped to the floor.

The bots jumped up and rushed into the center of the chamber, barking, "Freeze! Don't move! You are in violation."

Falconbriar—2315: Engstrumm-Bracht Search-and-Rescue Ship

"You could have killed us," Shanwei growled. "Those bots."

"Those bots were the least of your worries," Viki Nakamura snapped back. "The entire station was melting down. I did what I needed to do."

Egerton and Shanwei were back aboard the *Falconbriar*. The briefing room where Viki Nakamura was detaining them was cramped and not well ventilated. It smelled of day-old orange juice.

"So, you had to send 30 armed bots to get the 2 of us out of there?" Shanwei huffed. He didn't like the interference and losing control of his job.

"Don't flatter yourself. The bots weren't for you," she replied. "I was just doing my job. I flushed the whole station with bots. We're shutting down the New Lebanon permanently. The bots were there to decommission it."

"You're going to blow it up?" Egerton stood up, outraged.

"Well, look who finally took an interest." Nakamura scowled at Egerton.

"You can't blow it up!"

"Yes, we can. That thing is too dangerous to have around. It was starting to take over the *Falconbriar*'s navigation system."

"How do you know that?" Egerton asked. "Why would it take over?"

"I don't know," Nakamura snapped. "Ask the nav officer. They were freaked out and we started to drift."

"But..."

"Dr. Egerton, you can question me all you want, but I was just doing what we talked about. I saved your lives."

"I guess we should say thank you." Shanwei didn't sound appreciative.

"So, did you find out what happened to the bodies?" Nakamura asked. "At least we know that crazy woman killed all those people."

"You're welcome, by the way." Shanwei was still quite proud of himself for discovering Alexandra Alder's history.

Nakamura ignored this and asked, "What happened to the bodies, Dr. Egerton?"

"I think I know," Egerton replied. "But I need to talk to Jimmy first."

"Jimmy?"

"His bot." Shanwei filled her in.

"Can I see him? Can I talk to him?" Egerton asked.

Nakamura looked at Egerton like he was a lunatic child. Pity and fear flickered in her eyes. "Sure, I'll get them."

After she left Shanwei asked, "Do you really know, or are you bluffing?" It seemed like he wanted Egerton to be bluffing.

"No, I think I know." He was distant. His mind had returned to the New Lebanon.

The door opened.

"Here they are," Nakamura said, following the two bots into the small room. It was getting crowded.

"Hello, Dr. Egerton," Jimmy said cheerfully as he entered the room.

A smaller bot followed Jimmy, sticking close to him. It was wisp thin with barely any body at all. Its fingers were needle thin and its head was small and flat. It looked hastily assembled and as if parts of it were inflatable. Its impossibly slender hand hesitantly reached for Jimmy's, then pulled away.

"You're lucky we found them both in the main chamber," Nakamura said impatiently. "I figured you'd want them back. Even though I wasn't supposed to get them. You're welcome."

"Thank you," Egerton replied, staring at the new bot. "I'm going to need a little time."

"Take all the time you want," Nakamura said, moving to the door. "We've got a long trip back to civilization and Engstrumm HQ. Just make sure you have your story straight by the time we get back to Ms. George. She's the one you have to worry about. Not me." And with that she left.

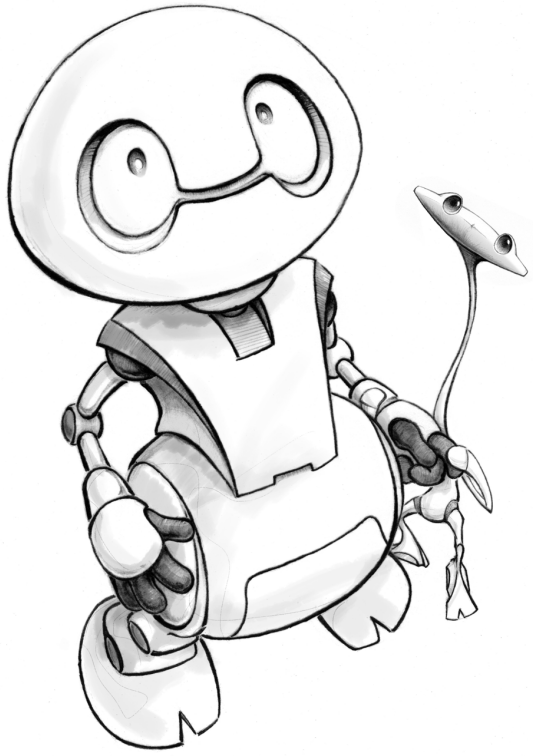
When the door was closed, Egerton knelt down. "Jimmy, who is this?"

Jimmy held out his finger and let the little bot hold it. "This is Paul," he replied brightly.

"Where did you find him?" Egerton asked.

Paul, the little bot, shifted and stood behind Jimmy a little as if he knew what was being discussed. A slight wheezing noise came from his joints when he fidgeted.

"The New Lebanon made him," Jimmy answered. "It made Paul before it killed itself."



Centennial Station—8854: Engstrumm-Bracht Corporation Headquarters

"Before we begin, I want you to know that the New Lebanon was officially decommissioned three hours ago," Greer George said, flexing her large hands and smiling broadly. "Just about the time you were docking."

"You destroyed it," Egerton spat. He knew that they were going to destroy the station but had hoped they wouldn't.

"Of course we destroyed it," Greer spat back. "From everything I heard about your return to the New Lebanon, it was a danger to anyone who got near it. I'm glad that mistake in judgment is gone for good." She watched Egerton, waiting for him to react or argue, but he didn't. He knew better.

"Okay. Okay. Both of you just relax," Shanwei said, trying to lighten the mood. "I swear, you two can get so worked up."

Egerton looked away.

Greer smiled again. "Shanwei, the only thing you get worked up about is money."

"I can think of no better reason." Shanwei held out his hand and bowed.

Greer sat back in her chair. "Did you two boys find out what happened out there?"

"Sure," Shanwei replied. "Alex Alder went crazy and killed your crew on the *Hussmann*, then went to work on the New Lebanon. They wouldn't have been any match for her. We don't know the details, but we don't need to know the details, do we? You already put out your press release."

Greer tilted her head and nibbled on the end of her pen. "That explanation was good enough for my PR team, and good enough for the media, but it's not good enough for me. Or let me be more specific: it's not good enough for me to pay you."

"That's ridiculous!" Shanwei slammed his hand down on the expensive office chair.

"That was the deal," she shot back.

"I think I know what happened," Egerton interrupted.

"What?"

"Your boy here says he thinks he knows what happened." Greer flipped the pen onto her desk.

"I heard him." Shanwei was tense. He and Egerton hadn't discussed the New Lebanon since they'd left. Egerton had spent most of the trip back on the *Falconbriar* by himself, with Jimmy and Paul.

"Okay, Dr. Egerton." Greer leaned over the desk and flashed her smile. "Please tell us what happened."

"Well, we're pretty sure Alex Alder had a psychotic incident and murdered the crew of the *Hussmann*," Egerton began.

"She went crazy," Shanwei added color to ease his nerves.

"It seems Alex could have then turned her wrath on the people of the New Lebanon, but there were a lot of people. She would have had to hunt them down. It's hard to imagine how she could have gotten to all 32 people without them trying to stop her."

"They were pacifists," Greer interrupted. "They didn't have any weapons on the entire station. I told them it was stupid, but they insisted that…"

"Yeah, maybe," Egerton continued. "But still, 32 people just allowing themselves to be killed seems pretty far-fetched."

"So what do you think happened?" Greer stabbed.

"I don't know," Egerton replied.

"You don't know? But you said you…"

"He always says he doesn't know." Shanwei smiled. "Even when he knows he says he doesn't know."

"I *think* I know the rest." Egerton glared at Shanwei. "But it just seems odd to me." Egerton paused. Shanwei and Greer waited. "We do know that everyone on the *Hussmann* and New Lebanon was dead."

"What happened to the bodies?" Greer interrupted. "Why did we keep finding hands and feet and fingers all over the place?"

"That was the station," Egerton answered. "That was the AI on the station. You see, the station saw what was going on. It couldn't stop the murder and the violence, so it did the only thing that made sense for it to do after everything was over—it cared for the dead. It cleaned up the bodies and disposed of them. I'm thinking it probably gave them some kind of service, but I still can't find out how the people on the station buried their dead."

"No one ever died on the New Lebanon," Greer said defensively.

"It was the AI that got rid of the bodies," Egerton said flatly. "The station got rid of them."

"So you're telling me I have an AI that has no problem cutting dead bodies up and disposing of them?" Greer asked frankly.

"You *had* an AI," Egerton replied. "You destroyed it, remember?"

"Thank God for that."

"After the station was empty, the AI tried to get back to normal, but with no people, it was lost. It even went so far as to start building an addition onto the station to be productive."

"How the hell could it build anything out there?" Greer asked.

"It had a printer and all the fab materials it needed," Shanwei pointed out.

"With that they could make anything, but it was no use. The New Lebanon was built as a complete system, and with no people, the AI was lost. I think that's when it killed itself the first time."

"I didn't know an AI could kill itself," Shanwei said thoughtfully.

"Yeah," was all Egerton could reply. "When we showed up and started the system again, we forced the New Lebanon back to life. It was like John Knight explained. Imagine being brought back to life missing your lungs and stomach. Without people, the AI went berserk. When we came back a second time and spent more time there, the shock subsided, but it was no use without the original 32; they were bonded. It even tried to manufacture a bot to talk to Jimmy. That's how I found out about the printer. Jimmy told me where he found Paul."

"Paul?" Greer was lost.

"The new bot," Shanwei clarified.

"But the new bot wasn't enough, and the AI moved to the *Falconbriar* looking for more people, a larger crew. That really freaked out their system." Egerton paused, then turned to Shanwei. "I figured out why the security bots formed up like that. When Viki sent in the security bots, they could hear the system just like my bot Jimmy. They were mesmerized in the chamber. They were listening to the New Lebanon. They thought they were hearing the voice of God."

Greer stopped him. "Okay, enough. You really want me to believe this? I mean, really, come on, Dr. Egerton. An AI that loves people. Robots hearing the voice of God. Really?"

"It was your station," Egerton replied matter-of-factly. "You let them create it."

"I didn't let them create a lovelorn AI."

"Actually, you did," Egerton interrupted. "The people of the New Lebanon put their faith in the station. They needed it to love them above all else. It was a genius way to program the system. They didn't need to constantly monitor or program the system, they just believed in it. They had to believe all the way out there. It was the only way they survived. To them, the AI was a manifestation of God. It needed to be. It had to be.

"But when Alex killed all those people, the system didn't know what to do. I don't think it knew how to save them, and then it happened. This took me a while to figure out."

"What's that?" Shanwei asked.

"Shame," Egerton replied. "The station felt shame. It tore itself apart. It felt like it had failed the people it loved so deeply."

"You know, this is really messed up," Greer said. She turned to Shanwei. "This is really messed up, right?"

"It was your station," Shanwei replied.

"Fine." Greer threw up her hands. "Let's say I do believe this, which I don't. Let's be clear. I think this is all just stupid. But let's just say I believe you. Let me ask you this: will it happen again?"

"You destroyed the system," Egerton replied.

"I know, I blew the damn thing up. Stop saying that. I know. Okay? I know. That's not what I'm asking you. I have a lot more stations all over and I want to know if this could happen again."

Egerton thought for a moment then said, "Yes."

"Oh, God." Shanwei stood up. He knew it was time to go. "Yes?"

"Yes," Egerton repeated. "If you use love to drive the system, you have to deal with the good and bad. It's going to really help with the efficiency of your border stations. But love is also complicated and can be dangerous."

Lobby of the Hotel Drexel

"Seriously, I didn't think she was going to pay us." Shanwei shook his head in relief. "*Love is complicated and dangerous*. What kind of answer is that?"

"The truth."

Shanwei and Egerton strolled through the lobby, stopping at the bell stand.

"You have my bots." Egerton handed the baggage ticket to the tall Asian kid with thin arms.

"Ah, yes," the kid said and smiled. "They have been very quiet. They sat in the corner the whole time."

"They're well behaved." Egerton smiled back. "Can I have them now?"

"Oh, yes. One second." The kid disappeared in a storage closet.

"There's one thing I didn't mention," Egerton said solemnly.

"Oh, God. What's that?"

"I'm not sure Alex killed all the people on the New Lebanon."

"You said that."

"Yeah, I think maybe the New Lebanon did it after she killed a couple of people. I think the people on the station stopped her and the station…well…."

"Well, what?" Shanwei pushed Egerton's shoulder. "What? What do you think happened?"

"I think the station killed the rest of the people," Egerton answered.

"But why?"

"It's shame again," Egerton said. "The AI felt shame. It was guilty. It couldn't bear to face the people on the New Lebanon. I think it killed them to try and free itself from its guilt and shame. But it didn't work, so the AI took its own life. But really, we'll never know for sure."

"Do you want to know?" Shanwei asked gravely. "Do you want to know for sure?"

"Yes," Egerton replied. "Yes, I do." He paused and sighed. "All of this work we're doing is getting to be a little too much for me."

"What do you mean?" Shanwei watched the door of the storage closet but sounded worried.

"I think…" Egerton started, then stopped. "I think all of this work is getting to be too much for me. I don't think I can take it." Egerton stopped and didn't want to explain.

Shanwei knew not to ask any more questions as they waited in silence.

***

"You're always taking in strays," Shanwei said, playing with Paul. He poked the bot on its whisper-thin foot and Paul lifted the leg and tried to step on Shanwei's finger. Then Shanwei touched the other foot and the same thing happened. This was repeated several times, faster and faster, until Paul did a little dance of delight. It was overwhelmingly cute. Paul couldn't talk, but he had a knack for getting across his point.

"How could you not take him in?" Egerton replied. "I mean, look at him."

The foursome was waiting at the back of the hotel, scattered across a plush rug ringed by deeply cushioned lounge chairs.

"What do you think of him, Jimmy?" Shanwei asked.

Jimmy was standing near Egerton, watching over Paul.

"I worry about him," Jimmy replied.

"Worry? What do you mean, worry?" Shanwei was taken aback.

"It's just that he is very small, and sometimes the things he says don't make any sense."

"What?" Egerton touched Jimmy's shoulder.

Jimmy turned away from Paul to face Egerton. “Yes, Dr. Egerton?”

“Jimmy, can you hear Paul talk? Does he speak to you?”

“Yes, Dr. Egerton,” the little bot replied.

“Is it like the New Lebanon? Is it the same voice?” Egerton asked.

“No, Dr. Egerton. It’s not the voice of God,” Jimmy replied. “It’s different. It’s hard to explain.”

Playing with Paul, Shanwei laughed so hard that he snorted.

“Paul likes to talk,” Jimmy added. “Paul likes to talk a lot.”

Body

With our robot's design and brain complete, it is now time to start building the body. We start with Kipp Bradford, a biomedical engineer. We sketch out the first design for Jimmy's body. Next, we go to Olin College of Engineering to work with Dave Barrett and his robotics program. Working with the students, we develop multiple designs for Jimmy, each solving the hard problems of getting a robot walking and keeping him social. Finally, Gui Cavalcanti and a group of makers at the Artisan's Asylum assemble the first walking, talking Jimmy.

Robots Are Simple

Kipp Bradford was the first engineer and roboticist to join the 21st Century Robot Project. His enthusiasm and passion for open source robotics is infectious.

"Over the last 50 years, robotics has been something that has been limited to just a handful of people," Kipp explained to me. "What gets me excited about the 21st Century Robot Project is that we can bring the joy and awesomeness of robots to every kid on the planet. We can also bring the science of robots as well. If we can get people imagining, designing, building, and sharing robots all over the world, then the promise of what robots can do for people is huge!" Kipp chuckled. "But the only way to do that is get the tools and platforms to be so intuitive and easy that anyone can do it. That's where the amazing ideas will come from."

Kipp and I designed the first version of Jimmy early in the project. We needed a place to start, and we needed to keep it simple.

"Having a biomedical engineering background means that when I think of robots, I always try to relate them back to the human body," Kipp told me. "If we are going to design a machine, if we're going to design a robot to interact with

humans, then it makes perfect sense for us to take inspiration for that robot from us humans."

Over a day-long design session, Kipp and I sketched out a simple design for Jimmy.

"The best way to think about Jimmy's body is to see that he has an exoskeleton and an endoskeleton." Kipp sketched a rough outline of Jimmy's body based on Sandy's illustrations and Wayne's 3D model. "His exoskeleton is his outside. Think of it like a crab's shell. It protects all of the mechanics, wires, and gear inside his body."

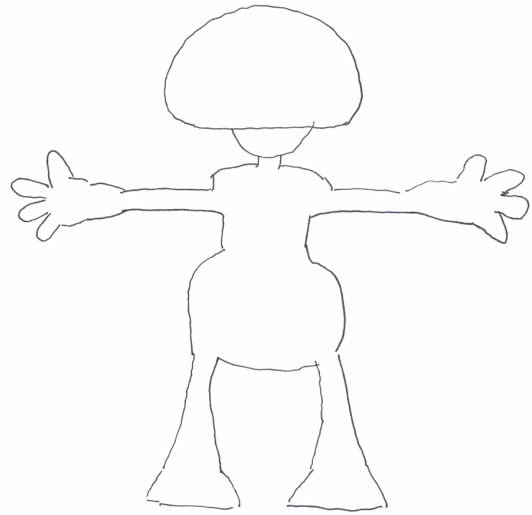


Figure 7-1. *Original sketch of exoskeleton (sketch by Brian David Johnson)*

"The exoskeleton also is what can give a robot personality," I added. "Jimmy's designed to be cute and friendly, while the other robots like Paul and the Cuties are designed differently. Because they look different, people act and interact with them in different ways." I did a rough sketch of Paul next to Jimmy. "Their personality is located in their brains (see Chapter 5), but who your robot is, how you express its individuality, begins with how the exoskeleton looks. Because of the work Sandy and Wayne did, anyone can design the look of their own robot." (See Chapter 3.)

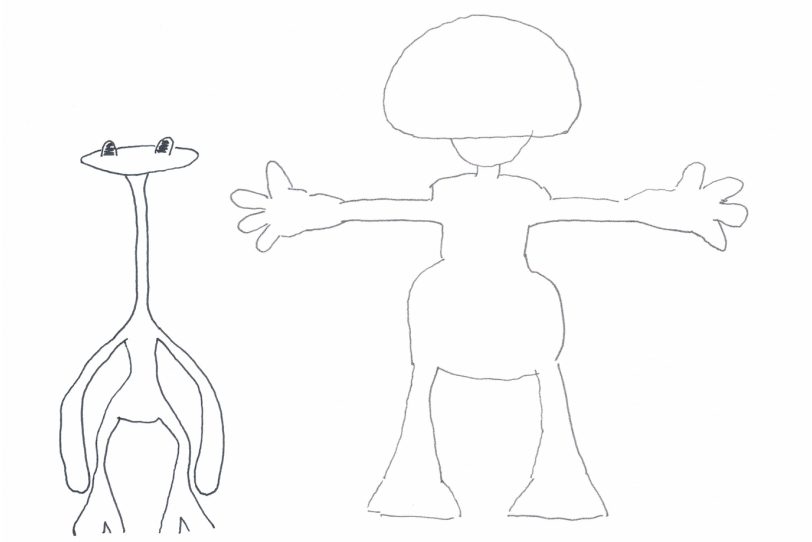


Figure 7-2. *Sketch of Jimmy and Paul; their individuality begins with how they look and the design of the exoskeleton (sketch by Brian David Johnson)*

"Next we have the endoskeleton," Kipp continued. "A robot's endoskeleton is kind of like our human skeleton. Humans don't have exoskeletons like a crab, but we do have bones that make up our endoskeleton. For robots, these bones are frames and metal brackets." Kipp drew the insides of Jimmy's arms, legs, and chest.

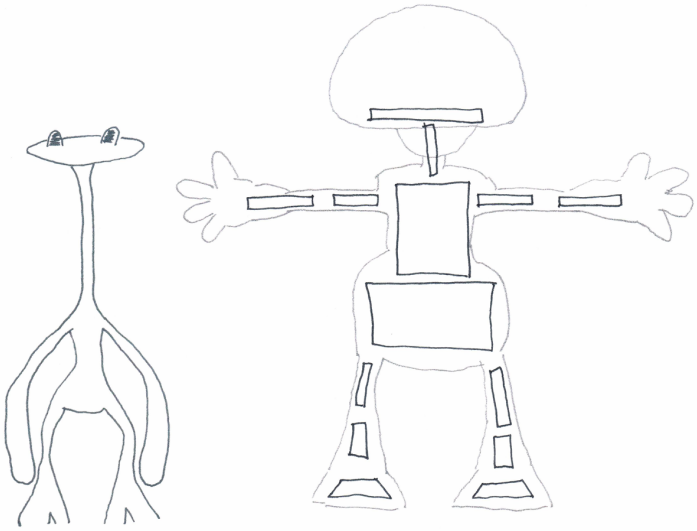


Figure 7-3. *Jimmy's endoskeleton, the "bones" that give him strength (sketch by Brian David Johnson)*

"But really, we could add a whole bunch of other things to the endoskeleton," I continued, taking the pen. "The servos and motors are like the muscles that drive and move the bones."

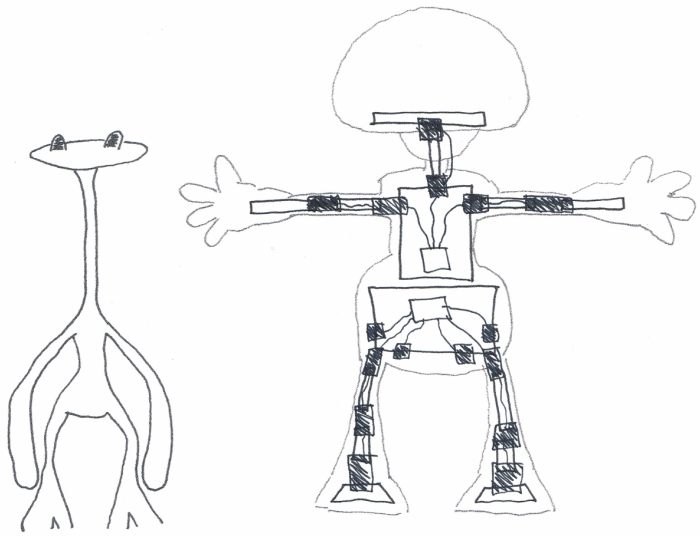


Figure 7-4. *Sketch of Jimmy's motors, wires, and internal workings (sketch by Brian David Johnson)*

"And finally, we have the sensors," Kipp finished up. "These are the eyes, ears, and even the nose of the robot. Jimmy will have cameras for his eyes, a microphone for his ears, and a speaker for his mouth. But the really cool thing about robots is that they can also have senses that we humans don't have."

Kipp explained that robots could see, hear, and smell things that we humans can't. Their eyes could be made sensitive to infrared light, so that they could see heat. Or their noses could sniff out gases or smoke that are harmful to people.

"Just imagine if someone designed a 21st Century Robot so that it could smell smoke or harmful gases." Kipp's eyes lit up with excitement. "Then, if the robot smelled something wrong that maybe even we couldn't smell, it could come and tell you before anyone got sick."

I started drawing 1's and 0's coming out of Jimmy's head. "Jimmy and all the robots will have Wi-Fi, Bluetooth, or other ways to wirelessly communicate. They can connect to the Internet and other devices. That's kind of like a whole other sense that they can have that humans don't."

"Cool!" Kipp smiled.

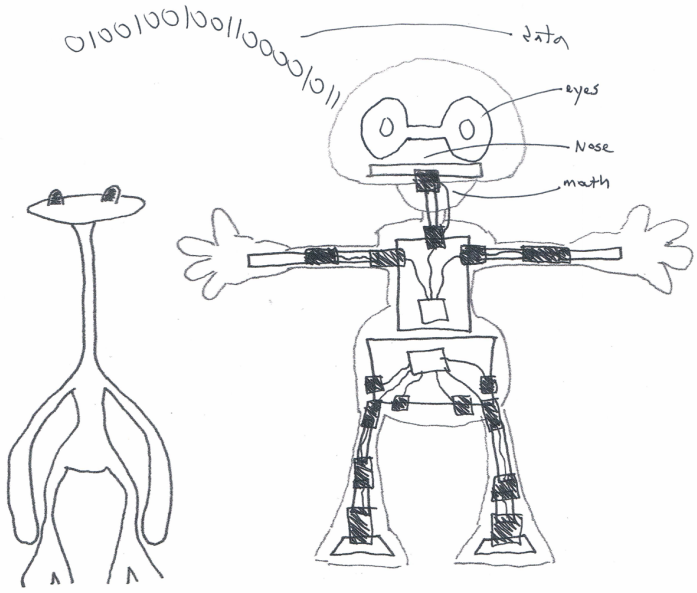


Figure 7-5. *Sketch of Jimmy's sensors; eyes, nose, mouth, and data (sketch by Brian David Johnson)*

We both paused and looked at our messy little sketch. It was pretty good and covered most everything you needed to build a robot.

"Okay," I said. "Let's start building."

Four Unique Designs for Jimmy

Olin College for Engineering is just outside of Boston, Massachusetts, in the town of Needham. In the fall of 2013, we took our stories, illustrations, and designs there, to see if we could bring Jimmy to life. Olin was the perfect place to begin. It's an amazing school that is world-renowned for its robotics program. The man who leads that program is David Barrett.

I was introduced to Dave through Rodney Brooks, Maja's professor from college, and the visionary roboticist behind a concept called New AI that revolutionized the field of robotics. New AI focused on smaller, task-based robots instead of trying to model or mirror human intelligence. Maya and Dave knew each other and had worked together years before. Rodney was also a part of iRobot, the company that built the Roomba robotic vacuum cleaner. Rodney and the Roomba team were

among the first generation of robot builders who tried to bring robots into people's homes and showed how they could be useful devices.

Today, Rodney is bringing robots onto the factory floor with Baxter. Now, robots on a factory floor is nothing new. What makes Baxter unique is that he is designed to work side by side with humans. The early tests show that people are not only comfortable working with Baxter, but they get so attached to him that they bring in their family members to meet him.

I sent Dave an early draft of this book and the original designs that Kipp and I had sketched out. A few days later, he and I had a phone call that changed the entire direction of the project.

"Brian, I liked your book," Dave said.

"Thank you."

"No, Brian, I really liked your book. I think we want to teach it here at Olin College," Dave continued. "We have an entire class of students building a robot in a single semester. We think we want them to all build Jimmies."

I couldn't believe what I was hearing, but it was true. We had an entire class of young robot builders imagining and designing their own Jimmies.

Wayne and I visited the class on a clear and very cold October day. We brought them the 3D printed Jimmy and the design files so they could get started.

Figure 7-6. *Wayne explains his process for designing Jimmy's exoskeleton (photo by Brian David Johnson)*

"A walking biped robot is really hard to build," Dave said later, after the class had completed their first designs for Jimmy. "Making a 3D printable robot that can walk, at a price that's affordable, is impossible." Dave laughed. "That's why we wanted to do it. We had an amazing group of students who were just learning about robots and they hadn't learned yet that it was impossible. And that's exactly why they could solve it."

Dave broke the class up into teams, each creating its own Jimmy. Some of the teams could use only four motors to get Jimmy walking, while others were given

more motors, up to 20. Each configuration had its challenges, but all had the same goal: get Jimmy walking.

Figure 7-7. *We introduce Jimmy to Olin—you can see the teams on the whiteboard behind me*

"Walking is nearly impossible," Dave explained. "If they could get Jimmy walking, then all the rest would be easy."

The students designed their Jimmies on paper and using computer modeling software. You can download and use their reports at *http://www.21stCenturyRobot.com*. The students took the first step by designing multiple Jimmies, getting to know what worked and what didn't. They didn't print out and build their robots—that would come later.

JIMMY WITH FOUR MOTORS

The four-motor Jimmy was named JimmyM and was more mechanically driven than the rest.

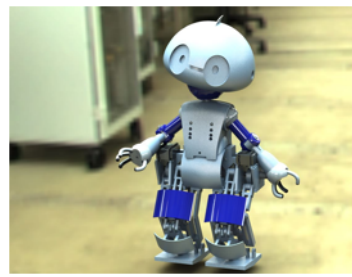


Figure 7-8. *Rendering of the four-motor Jimmy called "JimmyM" by the team*

"Our challenge was to build a humanoid named 'Jimmy,' capable of biped walking in addition to meaningful character expression, for under $500. The purpose of this project was to bring humanoid robotics platforms to environments

outside of professional and graduate-level robotics research labs," the team's report began. The team included students Aaron Crenshaw, Zachary Del Rosario, Elliott Donlon, Laurel Kroo, Kathryn Lau, and Orion Taylor.

"The legs and walking mechanisms of JimmyM, the four-motor Jimmy, was really exciting," Dave explained. "Because the team had so few motors to power the robot, it had to rely on mechanics to get him walking. There's one motor that powers both legs. It's really ingenious."

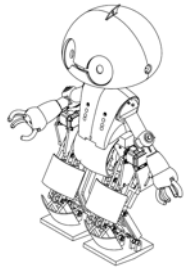


Figure 7-9. *Illustration of "JimmyM"*

For the students to accomplish the impossible goal of producing a four-motor Jimmy that cost under $500, they needed to resort to some interesting solutions.

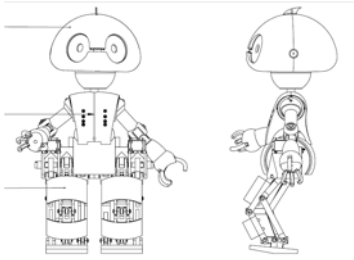


Figure 7-10. *Front and side view of JimmyM's ingenious legs*

"We accomplished this by assuming our users would have access to one of the recently released MakerBot2X 3D printers," their report continues. "The majority of our pieces are printable with minimal, if any, modification necessary. Jimmy is just over 24 inches in total height: a goal that aggressively challenges effective walking and character expression, especially when considering home 3D printing tolerances. Additionally, the cost goal limits our design to using just four high-end servo motors to control all degrees of freedom. We do this by using cams and clutch transmissions extensively."

Because the team was so limited, by design, it had to prioritize the functionality of JimmyM. The team narrowed these down to three crucial areas:

1. Legs: Biped walking
2. Torso/arms: Hugging
3. Head tilt: Nodding

Figure 7-11. *3D render of the single-leg mechanisms that allowed JimmyM to walk*

Of all the Jimmies designed in the 21st Century Robot Project, JimmyM was the most mechanical. Because the students had so few motors, they had to rely on mechanical connections and linkages to get him moving. The result is something unique and special to the project.

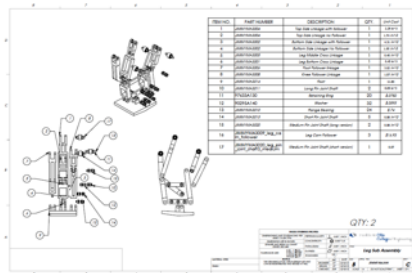


Figure 7-12. *Mechanical drawing and parts list for JimmyM's leg*

JIMMY IN SEVEN MOTORS

Another team was challenged to design a Jimmy that had seven motors. They called their 21st Century Robot "JimmyQC."

Figure 7-13. *3D render of JimmyQC*

Designed by Jordan Burger, Christina Fong, Jennifer McConnell, Brendan Quinlivan, Brett Rowley, and Dante Santos, the team took a slightly different approach.

"Jimmy is a humanoid biped robot, created to change the robots of the future through personalization of features, intended for both personal and educational purposes," their report begins. "For this version of Jimmy, known as JimmyQC, we were given the task of creating a robot between 26 and 32 inches tall that contained 4 to 8 motors. Ultimately, this version of Jimmy is approximately 27 inches tall, uses a total of 7 motors, and costs approximately $1,228."

"Creating a real robot at an affordable cost was really challenging for the students," Dave explained. "You have to realize that most robots that you see or that are used by universities cost well over $10,000."

"The first and most important of these two goals is making Jimmy walk," the team wrote in its report.

The team understood the importance of getting Jimmy moving: "Given the size and motor limitations, this walking motion was designed to maximize the number of motions per each motor. To move each foot, the Joe Klann linkage system is used [this is a mechanism designed to resemble the walking of a legged animal and acts as a replacement for wheels; it is sometimes used in underwater robots], raising the legs in a way that leads to the foot moving in an oval-like path. The leg itself is treated as a single linkage, keeping the foot parallel to the ground. This linkage system also allows for minimal modifications to the overall shapes of the body parts, though the pelvis is large to fit this system and the MX 64 [reference to a specific kind of motor: the MX-64T Dynamixel Robot Servo Actuator] that drives the walking and arms. The motion of the legs alternate between one another as the motor rotates, located between the two legs in the pelvis."

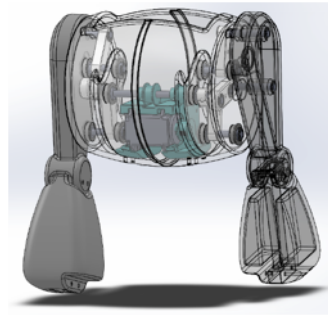


Figure 7-14. *Rendering of JimmyQC's hips and upper legs; notice the linkage system inside and how it drives the legs*

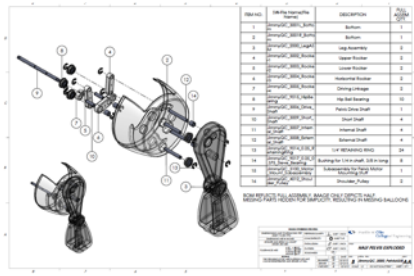


Figure 7-15. *Mechanical drawing and parts list for JimmyQC's unique hips*

"The second goal of JimmyQC focuses on giving Jimmy character," the report explains. "This manifested in a few different ways throughout the robot. To do this, a single motor directly drives the rotation of Jimmy's head."

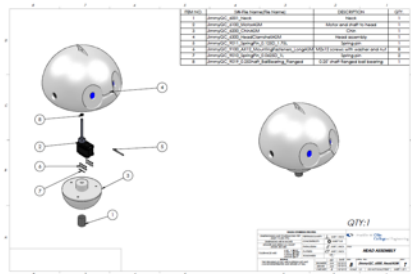


Figure 7-16. *Mechanical drawing and parts list for JimmyQC's simple but still expressive head*

"Jimmy's arms swing; they also move away from the body," the team wrote. "This is driven using gears by two AX-12s [reference to another specific motor: the

AX-12A servo actuator from Robotis], one in each shoulder. Each of the elbows contains an AX-12, which uses gears to allow for a bending motion similar to a wave. The hand is a solid body and was unmodified in this version of Jimmy, but moves when the elbow bends. Together, these systems help give JimmyQC a sense of self."

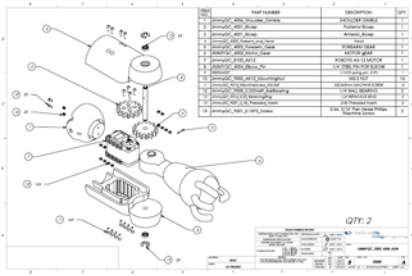


Figure 7-17. *Mechanical drawing and parts list for JimmyQC's arm; notice the mechanism that allows the elbow to move*

JIMMY IN 18 MOTORS

The 18-motor Jimmy was named "Jimmy X."

Figure 7-18. *3D rendering of Jimmy X*

"Jimmy X was designed to be built by any individual or organization, such as a high school, with a 3D printer. He is around 30 inches tall. We anticipate him to cost around $4000, depending on the cost of plastic for different 3D printers," the team of Kari Bender, Kate Maschan, Maddie Perry, Maggie Su, and Jess Sutantio began.

The increased number of motors on Jimmy X allowed the team to create a much more complex robot that could do things that his lesser-motored versions couldn't. For example, Jimmy X could stand on one foot!

"Jimmy X's current design allows for the following number of degrees of freedom at each joint: one in the neck, two in the shoulders, one in the elbow, three in

the hip, one in the knee, and two in the ankle. These degrees of freedom should allow Jimmy to walk. He is statically determinate at all times, meaning that if his motors are shut off at any time, he can stand in his current position. He is able to keep his center of gravity over one foot at all times by rotating his hip and ankle to shift his upper body."

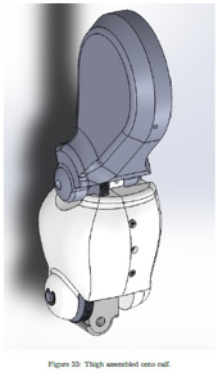


Figure 7-19. *3D render of Jimmy X's thigh and calf*

With the increased complexity of Jimmy X, the team needed to weigh the number of motors against the cost of the robot. The team reached a point where it would be up to the person building the robot to determine the trade-off of motors/functionality as opposed to price.

"With some creativity, degrees of freedom could be added in any of the joints," the team concluded. "Alternatively, Jimmy could shrink if some degrees of freedom were removed. We chose the degrees of freedom represented here because we found it to be a good compromise between Jimmy being able to walk and express character, and keeping him relatively affordable."

Figure 7-20. *3D render of Jimmy X's head*

JIMMY IN 24 MOTORS

Jimmy R, designed by John Arakaki, Silas Hughes, Chris Joyce, Erika Tsutsumi, and Brooks Willis, had the greatest number of motors and was therefore the most complex, with functionality that was hard to control. To make Jimmy R walk in real time took a tremendous amount of computational power and tuning.

Figure 7-21. *3D render of Jimmy R*

The team had big goals for Jimmy R.

"Jimmy R has 24 degrees of freedom: 11 in the legs, 5 in each arm (including hands), and 3 in its head," the team explained. "This allows for the robot to be very expressive and mobile. It can make a variety of gestures using its arms and head, as well as grasp small objects. It was designed to be a static walker; however, we believe that with minimal changes to limb lengths, it could achieve dynamic walking. Jimmy R was designed to be used predominantly as a research platform for groups looking to develop walking behaviors and groups researching human-robot interaction. Those two goals drove much of the design, significantly more so than cost considerations. To that end, wherever an actuator was only barely sufficient and a stronger motor was available, we swapped in the more powerful component."

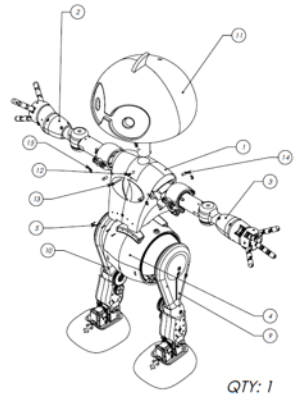


Figure 7-22. *Mechanical drawing of Jimmy R; notice the number of motors in every part of his body that allow for a high degree of functionality and freedom*

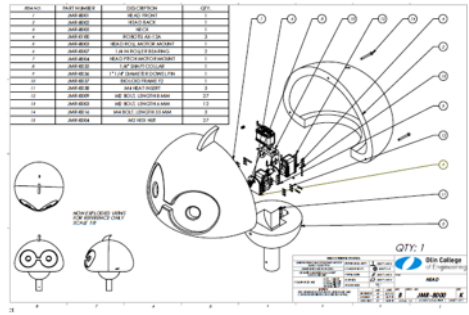


Figure 7-23. *Mechanical drawing and parts list for Jimmy R's head*

"Many of Jimmy R's joints are directly driven from the motors, such as the head, elbows, and ankles," the team wrote. "A few are put through a single reduction in areas requiring the greatest torque, particularly the knees. The hip joints are linkages, allowing them to move quickly through the middle of their range where more speed is needed and to have a very low gear ratio at the extremes, allowing Jimmy to crouch a fair amount and easily return to standing."

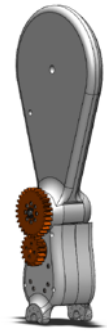


Figure 7-24. *Knee assembly—see a video example*

Especially interesting were Jimmy R's arms, elbows, and hands. Because the team had access to so many motors, the students were able to give the hands functionality that other teams couldn't afford.

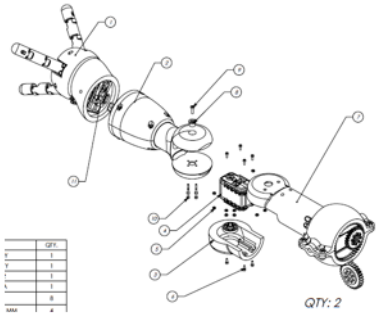


Figure 7-25. *Mechanical drawing of Jimmy R's arm; notice the motor in the hand that allows it to operate*

What Was It Like?

I had a chance to talk with the student teams about their experience bringing Jimmy to life. All of them were thrilled that "a bunch of undergraduates" would be allowed to work on a project that really inspired them.

Sophia Li will graduate in 2017. She worked on Jimmy's software and said, "Writing Jimmy's code was a bit like watching a child grow up. Our Jimmy can gesture and move in place, but I still can't wait for the moments we can watch him take his first steps."

Figure 7-26. *Dave Barrett works with the students at Olin, explaining exo-Jimmy and the challenges of their assignment. (Photo by Brian David Johnson.)*

Christopher Willis, a robotics engineer who is scheduled to graduate in 2015, said, "We tackled problems that are at the edge of current robotics research, while always keeping Jimmy's character in mind. Robotics is becoming more commonplace in society, and very soon the robots will need to be able to interact and move like humans. We're rapidly entering the realm of science fiction."

Building a Super Jimmy

I first met Gui Cavalcanti on a reality TV show. It was called *The Big Brain Theory* and it pitted two teams of engineers against each other in a race against the clock to complete nearly impossible tasks. Gui was a contestant on the show and I was a celebrity judge.

Imagine my surprise when, on my first visit to Olin College and the robotics lab, there was Gui! He was an Olin College alum, and now he was a professor. He would be helping Dave teach the 21st Century Robot book, and helping the students build Jimmy.

Gui also was a part of starting up a Maker space called the Artisan's Asylum in Somerville, Massachusetts, about five miles north of Boston. "In May of 2010, it started as a 1,000-square-foot hole in the wall with a whole bunch of tools in it," Gui explained. "Now it's a 40,000-square-foot cultural institution in the middle of town. It's kind of exploded." Gui laughed. "Because, hey, it turns out people want to make stuff."

It was at the Artisan's Asylum that the first robotic Jimmy was brought into the real world. Gui was able to pull the best parts of the designs from all the students in the Olin College class and combine them into what we called a Super Jimmy. Standing three feet tall and bigger than all the other Jimmies, he would serve as the first physical walking, talking robot from which all the rest would be iterated.

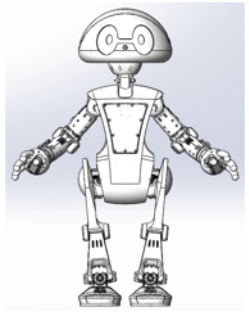


Figure 7-27. *3D render of Super Jimmy*

"I started working on the Super Jimmy by reading the science fiction, and reviewing the illustrations and 3D designs," Gui explained. "I understood that Jimmy is a character. He has personality and he's meant to be social. He has this cute look that's really endearing to people. Then I went about trying to build in the motors, wiring, and control; having to make slight adjustments, but always trying to remain true to the initial designs."

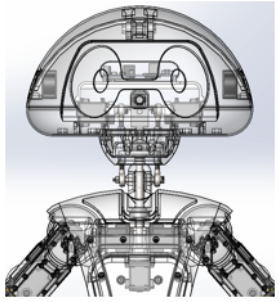


Figure 7-28. *Detail of Super Jimmy's head and neck*

The Super Jimmy has three motors in his neck to give his head a full range of motion. His ability to look around and engage with people was really important. It really helps when he's interacting with people. It allows him to not only be expressive, but also to keep eye contact when he's interacting with people.

Each shoulder has two motors, moving the arm up and down as well as left and right. The elbow has two motors as well, giving Jimmy the flexibility to move his elbow from side to side as well as up and down. He has a motor in his wrist that allows it to twist, and a smaller motor in his hand that moves his thumb.

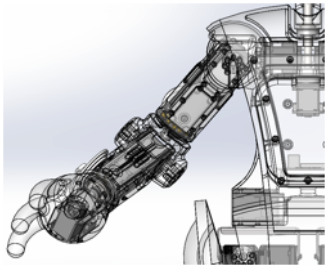


Figure 7-29. *Detail of Super Jimmy's shoulder and arm*

"How did you do the hips?" I asked. "Wayne Losey, the 3D designer, had a really hard time with the hips when he was doing the 3D printed exoskeleton."

"The hips were tough." Gui sighed. "We have three motors in the left hip and three motors in the right hip. It gives him the range of motion he needs, but also keeps Sandy's original look. There are a lot of motors in a really small space."

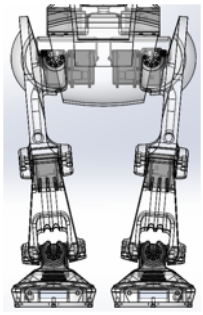


Figure 7-30. *Detail of Super Jimmy's hips and legs*

Finally, moving down from the hips, Jimmy has one motor in his knees to move them forward and back. There are two motors in each foot to help him keep his balance.

His batteries are in his feet, and the computer that runs his brain is in his head, along with the cameras for his eyes, the microphone for his ears, and the speaker for his mouth.

The First App

I was really happy with the first app that we built for Jimmy. Jimmy was designed to be a social robot, and we racked our brains trying to come up with an app that would capture his social nature. Then it hit us. Jimmy's connected to the Internet,

and he has a Twitter handle (*@21CRobot*). So we decided that he should be able to send tweets all on his own.

It's a really interesting feeling to stand next to Jimmy, look down at him, and have him look up at you. It really hits home that he's a social robot. But it gets very interesting when you realize that he's not only looking at you, but he also might be tweeting as well.

"We had some interesting experiences in the lab at the Maker space," Gui added. "There were a few times when we were playing around with Jimmy and then realized he was tweeting. It's a very different experience."

"He really is a social robot." I laughed.

"It's more than that," Gui said. "There was a moment when I was putting him together that was a first for me. For most of the project, Jimmy was just an illustration or a design file. And then when we started building him, he was a collection of motors and wires. But when we attached the legs and the arms and head, suddenly this wasn't a collection of parts in the lab anymore. It was Jimmy. He was a person. I'd never experienced that with a robot before."

Next: Murderous Little Pets

In our final story, we explore the dark side of social robots. Jimmy and Paul help Dr. Egerton investigate a bizarre tragedy. What happens when two robots start talking to each other and bad things happen? Is it enough to drive Dr. Egerton to give up his investigations...?

Murderous Little Pets

"I have one officer confirmed dead. The rogue security bot that did it took the body and disappeared," Homeland Security North Border Director Wu said. "I don't think now's the time to talk about your fee…"

"Look, Samantha…"

"Don't call me that here, Shanwei," she snapped. "Just because we have history doesn't mean I'll give you any preferential treatment. HQ didn't even want me to hire you."

"I get it…" Shanwei nodded. "I get it. I'm sorry."

Dr. Simon Egerton looked out the single window of the military field office trailer and was amazed at the complexity of the operation. Against his better judgment, Egerton had agreed to return to Earth. Shanwei said it was a job for an old friend. Egerton didn't know that this "old friend" was a director with the United States Department of Homeland Security, in charge of the US border with Canada. Jimmy and Paul sat next to him. They were fascinated by the swarms of drones the came and went across the horizon.

"Here's the report." The director handed it to Shanwei. "Patrol Team 22-4 was a common configuration for what we do here. Three officers and a security bot. Officers Gonzalez, Rodriguez, and Conley. They were on patrol when the incident happened. Gonzalez was killed; we have confirmation on that from his bio-suit data stream. But the bot took the body. We want the body and the bot returned to us, and we need to know what happened."

"And your security bot killed this Officer Gonzalez?" Shanwei thumbed through the report.

"Yes, the other two officers confirm that," she answered. "You need to talk to them. They can tell you everything you need to know. But be careful…" she warned. "Our officers get close to their bots. There's a bond there. I don't approve of it, but the scientists and consultants tell me it's good. Positive for morale and efficiency."

"What was the bot's name?" Egerton spoke up for the first time.

"What?" The director looked at Egerton.

"What was the bot's name?" Egerton repeated.

"I don't know." The director brushed the question off. "I'm not sure it had one."

"Every robot has a name." Egerton looked back out the window. He was distant. Ever since the New Lebanon incident, Egerton had grown more and more distant. He spent most of his time alone with Jimmy and Paul.

Director Wu took the report back from Shanwei, flipped through it, and replied, "They called it War Machine."

***

"What did they do with War Machine?" Officer Conley's face was violently close to Dr. Egerton. "What did they *do* to her?" The soldier's breath was hot and smelled like energy drinks.

"I don't know," Egerton replied slowly. His posture betrayed that he was afraid for his personal safety. "That's what I'm here to figure out."

"They had to have..." Conley started, then stopped. It sounded like he might cry. "They had to...why would she..."

"We were all pretty close to Mack..." Rodriguez stepped in. She put her hand on her friend's shoulder, pushing him out of the way, as if relieving him from having to explain himself.

"Mack?" Egerton asked.

"That's what we called War Machine," she replied. "We got her name from the old Marvel *Iron Man* comics. War Machine was the guy who..."

Egerton smiled. "I know those comics well."

"Yeah, well, even though it was a bad-ass name," she continued, "it was too long. So we just called her Mack, ya know."

"I understand." Egerton moved Jimmy out from behind his legs. The constant activity on the security base and the yelling was overwhelming Jimmy's sensors. Jimmy was scared. "This is Jimmy." Egerton patted the little bot on the head.

"He's cute." Rodriguez smiled. "Hey, Conley, check out the little bot," she called to her buddy. "I didn't even see him there."

"Jimmy's a little scared," Egerton explained. "He's not used to this much activity."

"Yeah, it takes some getting used to." Conley had hardened up, but Jimmy seemed to crack his military toughness. He walked over and sat down in front of the little bot.

Just then, two heavy transport shuttles lifted off near their meeting trailer. The thin walls shook and the weak floor rumbled beneath their feet.

Jimmy had to widen his stance to stay upright. Without thinking, Conley's lightning reflexes shot out to catch him. "Is it okay if I..."

"Oh yeah," Egerton reassured the solider. "Jimmy's a good little bot. He likes people. Don't you, Jimmy?"

For the first time, Jimmy looked up at Egerton, scanned the two soldiers, shrugged his little shoulders, and said, "Yes, Dr. Egerton."

The two soldiers laughed and Egerton didn't know why. Neither did Jimmy.

"He's so small," Connelly said, touching Jimmy's arm. At first Jimmy pulled away, but then he let the shoulder examine his thin arms and delicate elbow joints.

"On patrol here we get kind of close to our bots," Rodriguez continued.

"Yeah, I gathered that from talking with Director Wu," Egerton replied.

"At first they tried to program it out," Conley said, but didn't look up from Jimmy. "They didn't want us to get close to the bots, but then they realized it made us and the bots more efficient. So they programmed the bots to like us back. I don't know how. They just did. You could tell."

"I know all about that," Egerton added.

"Conley was Mack's main handler." Rodriguez picked up the conversation. "I was number two. We did insurgent sweeps on both sides of the border. Recently we've been doing more work on this side, in the US. There were some factories and textile mills we needed to check out. It's been more violent here recently. Dangerous."

"What did Mack do in the squad?" Egerton asked.

"She ran point," Rodriguez answered. "She was the first one in the door. She'd sweep the structure. Throw back video and sensor sweeps to us. From there we'd assess the situation and plan our entry."

"Was Mack armed?" Egerton asked.

"No!" Conley spat out. "Mack didn't need it. That's why it doesn't make sense that she'd..." Jimmy took a small step back from the soldier. Seeing this, Conley softened his voice. "I'm sorry, buddy."

"We do a lot of work with civilians," Rodriguez explained. "Most of the structures we are entering have inhabitants."

"You mean you're going into people's homes?" Egerton asked.

"Some of them were homes...apartments..." Rodriguez let down her military vocabulary. "But some were churches or meeting halls. We tried to stay out of the bars and taverns."

"I would think an eight-foot security bot coming through my front door would be pretty scary." Egerton imagined the scene and it gave him chills.

"Things are different here, Dr. Egerton." Rodriguez stiffened. "Things are never black and white on the border. We're dealing with some pretty bad people."

"I wasn't questioning your mission. I was..."

"We had some trouble with the bots on point in the beginning," she continued. "When they were armed, we had a few very public problems, but we fixed that. There hasn't been a single incident in over 400 days."

"You mean nobody has been killed." Egerton couldn't stop himself. "Until..."

"Until two days ago," Rodriguez finished the sentence.

"She didn't mean to do it." Conley stood up and gingerly stepped away from Jimmy. "She couldn't have meant to do it. She saved my life. She's saved all of our lives. How could she have?"

"Why do you think Mack took the dead soldier?" Egerton asked. "Even though her sensors and comms seem to be intermittent and malfunctioning, she's been tracked from the Canadian border down to the central coast of Oregon. From where we can tell she still has the body with her and..."

"The body has a name!" Rodriguez snapped.

"I'm sorry. Yes..."

"The body's name is Gonzalez. Miguel Gonzalez," she said, holding back her emotion. "He was a part of our squad. He had a name...use it."

"I'm sorry," Egerton said again. "I know...I didn't mean to...I just..."

"I'm here to help you." Rodriguez calmed herself. "Me and Conley, we're here to help you. We want Mack back. But the body has a name. The body was our brother, Miguel Gonzalez. Use his name."

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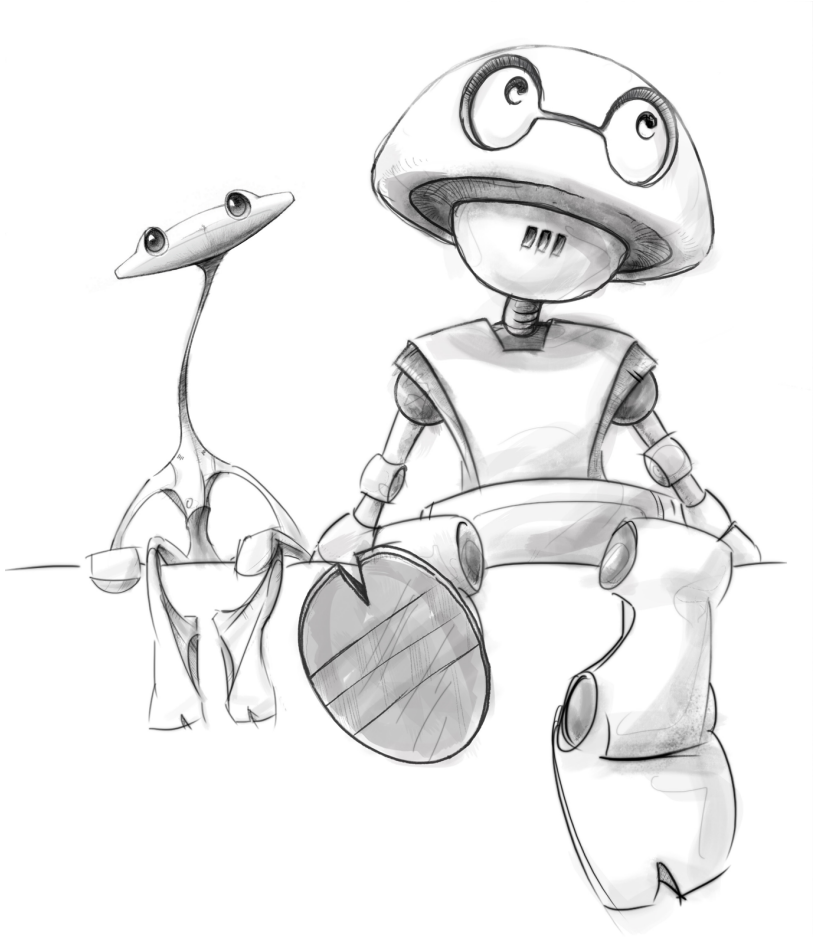
"I don't want to do this job," Egerton said back at the motel where he and Shanwei were sharing a room. It was a squat, utilitarian place, built for visiting military families. Jimmy and Paul sat on Egerton's bed, listening.



"We don't have much of a choice," Shanwei replied. He was propped up on the other bed. His boots were kicked on the floor as he reviewed the Homeland Security report on the soldier and the rogue bot.

"We can just say no and leave." Egerton was standing with his back against the wall, tense and nervous.

"No, we can't." Shanwei closed the report. "I already took the job, so we have to do it. Samantha knows me from way back. She's not so bad. And do you know why I took the job?" He paused. "Do you?"

"Yes..."

"I took the job because we didn't have a choice. When Homeland Security *asks* you to do a thing...even if Samantha were my best friend ever...if you are asked to

do a thing, you do a thing." Shanwei tried to go back to the report, but couldn't. "What's got you so spooked about this one anyway?"

"I don't know…"

"Yes, you do. Look at you." Shanwei gestured with the thick report. "You can't sit down. You haven't slept since we got here. Your poor bots are all freaked out because you're so scared…"

The two men looked at the robots and the robots looked back. Paul moved his wispy arm a little but it looked like a twitch. His body wheezed softly.

"I don't understand what's happening," Egerton replied. "None of it makes sense. I can't figure it out and this poor officer, Miguel Gonzalez, died—was killed—and the bot took his body. What the hell is that?"

"That's why we're here."

"But I haven't learned anything," Egerton answered. "I don't know any more now than I did when we got here."

"So that's why you want to quit?"

"No," Egerton replied flatly. He looked at Paul and Jimmy and then to the floor.

"Then why?" Shanwei pushed him. "You've figured out more complex problems than this before. All you have to do is…"

"That's not it." Egerton stopped him.

"Then what is it?"

"We've leaving tomorrow morning to go hunt down the bot. Its comms systems seem to be shut down, except every now and again at no regular interval she sends out a ping. We think we know where the bot is, but we aren't sure. Yet we have to find it," Egerton answered slowly, keeping his eyes on the dingy motel carpet. "And the dead soldier…Miguel Gonzalez…"

"Yeah." Shanwei didn't follow. "We have to get the bot. That's probably the only way we can…"

"I'm scared," Egerton said softly.

"What?"

"I'm scared of this one." Egerton looked up at Jimmy and Paul and then over to Shanwei. "I don't want to know why Mack killed Gonzalez…I just don't…I'm scared."

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"It's one hell of a storm," the Coast Guard shuttle pilot said, shaking his head as he tracked the storm. "It's coming in from the north, looping down past the top of California and hammering the hell out of the coast." He pointed at the screen.

Shanwei leaned in and tried to make sense of the massive storm. He couldn't tell where the storm ended and the western coast of the US began. "I hate coming back to Earth," Shanwei said under his breath. "This place is a mess..."

"What?" the pilot shouted back. The shuttle's engines were warming up while they waited for Egerton and the two bots. "Where are we going?" Shanwei asked. "Where's Pacific City, Oregon?"

"There!" The pilot stabbed his finger onto the screen.

"Oh hell," Shanwei breathed out. Their destination was right in the middle of the storm system.

"I *know*," the pilot said, making a face at Shanwei. It was oddly funny. The military usually didn't make jokes, but the pilot did. "Why did you have to go *there*?" He stabbed the screen again, over and over. "I mean, really? *There*? Yoiks!"

Shanwei was stunned and didn't know how to respond. He looked out the window searching for Egerton, and for the first time wondered if he might not be coming.

"I'm going to have to set you down here," the pilot said, pointing at the map. "It's the Bitterroot National Forest in Montana. It's pretty far away from your target, but I'm going to have to fly you to the edge of the storm and then duck under it. I can't fly in that. They're dropping off a rover drone to take you into the storm, to your target."

Shanwei squinted at the map and tried to calculate the distance for the drop. "That's like 500 miles east of where we need to go!" he shouted over the engines.

"I *know*." The pilot made the face again. "It's actually 720 miles east of where you want to go, but that's one big storm. I mean, really, it's a crazy big storm."

"You can't get us any closer?" Shanwei asked. "You know we're here with..."

"Look, man," the pilot said frankly, "I'll do whatever I can for the Homeland guys, but I can't break up this shuttle." He pointed up at the ship. "It's already going to be one hell of a bad ride. You and your buddy aren't going to like it... Hey, where is..."—he checked his flight sheets—"Dr. Egg-er-town?"

"It's Egerton," Shanwei answered. "And I'm sure he'll be here soon."

"Welp." The pilot shook his head and swiveled his chair into liftoff position. "Your doctor's got 10 minutes. That storm isn't waiting for him, and if he doesn't get here soon I'm going to have to drop you a heck of a lot farther away from your target than 720 miles. How do you feel about getting dropped in Chicago?"

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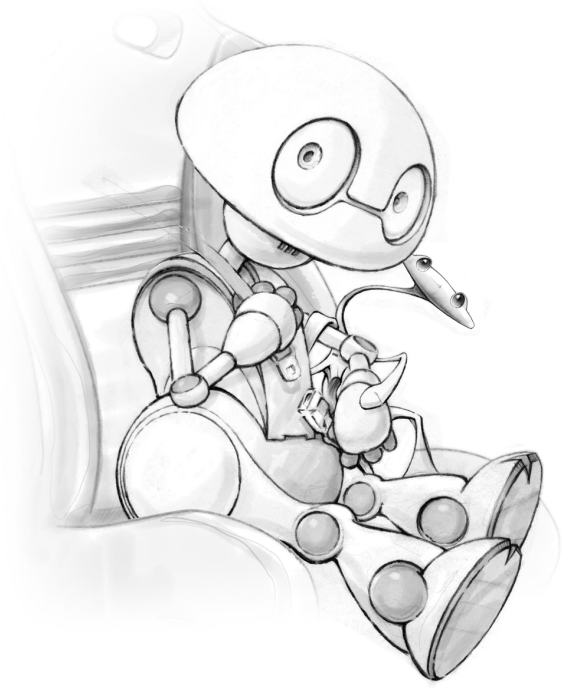
It was not a good landing. The shuttle was powerless against the storm. Shanwei, Egerton, and the two bots were strapped in tight.



"Glad you came?" Shanwei smiled.

Egerton looked at him but didn't respond. The shuttle surged up and was pushed to the left. The straps strained against the men's chests. "How's Paul?" Egerton asked Jimmy.

The bot glanced to his left and Paul look back at him. It was a swift movement; the two communicated quickly. Jimmy turned back to Egerton, sagged a little in his straps, and replied, "He likes it."

"What?" Shanwei laughed.

"He thinks it's fun," Jimmy replied with great concentration.

"And what do you think about it, Jimmy?" Shanwei asked. "What do you think of our shuttle ride?"

Jimmy paused, looked at Egerton, then said, "I don't like it."

"You and me both, Jimmy." Shanwei pointed at the bot. "You and me both."

The shuttle canted to the right, banked under the storm, and headed in. The pilot's chair swiveled around to face the four passengers.

"Whoa! Wait! What are you doing?" Shanwei yelled. "Who's flying this thing?"

"The computer!" the pilot yelled over the sound of the engines and the racket of the storm. "I can't fly in this weather. No pilot could. We're in the hands of the computer now!" He laughed. "Seriously, though." He dislodged his captain's chair from the control panel and navigated over to Shanwei and Egerton.

"I didn't know you could do that." Egerton pointed at the chair.

"Yeah, it's new," the pilot replied. "Kind of cool, right?"

"Yeah." Egerton studied the chair.

"Listen, fellas," the pilot continued, "this is really bad. I'm not even going to be able to set you down on the ground. The computer says the storm would flip us. So if you really want to do this, I can lower you down on the rescue cable." He paused when the shuttled bucked and was slammed down toward the ground. "Yeah, see?" he said quickly. "You bozos really shouldn't be doing this. I know it's all Homeland Security and all, and I'm not really supposed to know what you are doing...but really...you want to land in this?" He held out his arms in the captain's chair as the shuttle's computer fought like hell to keep the craft on course.

"We have to!" Shanwei yelled.

"No, you don't!" the pilot yelled back. "I can turn us around, say the storm was too bad. No one checks the logs...you don't *have* to do it."

"Yes, we do," Egerton replied.

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"You ready?" the pilot yelled. The rescue hatch was open and Egerton and the bots were strapped into the airlift stretcher.

"Yes, let's go!" Egerton yelled back, instinctively touching the bots to make sure they were okay.

"No you aren't," the pilot replied. "You aren't ready to go at all..."—he paused —"but I'm going to send you! Heaven help me! Tell your mother I'm sorry!"

"What?" Shanwei looked at the pilot, but he was too busy operating the lower and lift controls.

"The math doesn't work out. Here we go!" The pilot lowered Egerton and the bots down into the 90-mph winds of the storm. The rain came sideways and the stretcher was pushed out of sight by a gust.

"Where did he go?" Shanwei screamed.

"Wait for it," the pilot replied. "They don't call them gusts for nothing. He'll come back."

Sure enough, Egerton and the bots came back into sight once the wind let up for a moment. They were aiming to land on an old Forest Service road in the middle of a massive clear-cut operation. There was a storm shelter there for the forest workers to get out of the wind.

"Can you hit it?" Shanwei asked.

"We'll see," the pilot replied.

The stretcher slowly lowered, foot by hesitant foot. Egerton and the bots were powerless to do anything. They simply had to wait and get soaked by the pelting rain.

"Dr. Egerton," Jimmy said.

"Yes?"

"Paul isn't sure if he likes this anymore."

The thin bot wrapped his wispy arms around Jimmy as the wind lifted him ever-so-slightly from the stretcher basket.

"There!" the pilot yelled as he landed the trio on the ground. A Forest Service worker darted out of the storm shelter, grabbed the basket, and rushed to free them before another gust came in.

"I think they're free," Shanwei said.

"Yep," the pilot confirmed. "They're good...now it's your turn. Your ride is going to be worse. The wind is picking up." He tapped his screen.

"Great!" Shanwei replied, hooking himself in.

"Hold on!" The pilot patted him on the head and shoved him into the storm.

The wind kicked up. Shanwei twisted and rocked in the rain. Above him the shuttle's computer fought to keep the craft stable. It was losing the fight. The storm was too much. The shuttle was lifted by the storm and Shanwei saw the pilot dash from the rescue hatch. Below, Egerton and the Forest Service worker looked up, powerless to do anything to help.

The storm was getting worse. To save Shanwei, the pilot pushed the craft dangerously close to the ground. The ship and the dangling man plummeted down. Quickly the shuttle's full engines engaged, slamming it back up into the storm. Before it caught the air and smashed up, the pilot cut Shanwei's rescue line, sending him falling to the ground. He tumbled out of the stretcher and landed feet first, snapping both legs.

***

"At least I'm not dead," Shanwei said with a wry smile.

"Okay, fine, you're not dead," Egerton replied. "But now what are we going to do?"

"You go it alone," Shanwei said matter-of-factly. He was laid up on a Forest Service cot with two broken legs in Emergen-VAC leg casts. Their sensing motors helped to align his broken bones, regulate the blood flow, and administer the exact amount of pain medication.

"I can't go out there by myself," Egerton said. "What the..."

"You'll have the bots; you'll be fine. That rover out there can withstand anything. You'll be fine."

"You know I won't be fine," Egerton replied.

"No one should go out there now," Redwood said gently. The Forest Service worker stationed at the storm shelter called himself Redwood. It was the only name he would give them. He was a thin, idealistic kid who thought he could somehow save the last few forests on the face of the planet. In recent years the Forest Service had turned into more of a cult than a government agency.

"See?" Egerton said.

"The planet is hurting," Redwood added. "It's throwing a tantrum."

"You have to go," Shanwei continued. Neither Shanwei or Egerton knew how to respond to Redwood, so they simply moved on. "You have to get to the bot as soon as possible. The longer it stays out in this storm, the less we are going to learn. Hell, if you don't go now, it might even be swept away. Then what do we have..."

"True." Egerton didn't want the security bot to be lost. As much as he was frightened of the bot, he didn't want to lose it.

"So you're going?" Shanwei prodded.

"Think of the Earth as a wild animal," Redwood spoke up. "A wild animal that doesn't know any better."

"Yes," Egerton replied. "I'll go."

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"How is Oregon?" Shanwei asked, smiling into the camera.

"Wet," replied Egerton. "Everything is wet and gone."

"What do you mean, gone?"

"The storm surges and wind have pretty much stripped the place clean," Egerton answered. He was in the basement of a small airport in the town of Pacific City, Oregon. "The rover took us down through Washington and into Oregon. The closer we got to the coast, the less there was. After we left Portland and came over the

coastal range, it was like the whole thing was one big beach at high tide." The rover drone had driven the entire trip; Egerton and the bots simply sat inside and tried to look out the tiny windows.

"Sounds nuts." Shanwei shifted in his bed and checked the pain pump that fed into his problem legs.

"How are you?" Egerton noticed the pain on his partner's face. "How are your legs?"

"They hurt." Shanwei was matter-of-fact. "They hurt like hell and Redwood tells me he's about out of pain meds."

The winds roared overhead, shaking Egerton's camera.

"I'm not sure why this town is even here," Egerton said. "They have an airport; that's where we're hunkered down. Homeland Security uses it for something and there's some hardware here. I'm not sure what it does, but it looks like it could keep on working at the bottom of the ocean." Egerton turned the camera to the hardware.

Seeing the hardened shell and small blinking lights, Shanwei said, "Wow, that's some serious gear. They're preparing for the worst."

"I think the worst is happening." Egerton returned to the camera. "There aren't any people here. It looks like the Nestucca Bay is going to flood the town at any moment."

"When do you leave?" Shanwei shifted and winced again.

"Shouldn't you put in the call and have them get you out of there?" Egerton was worried.

"I did." Shanwei frowned. "They can't send anybody…they won't send anybody until you get back."

"They said that? I'm over 700 miles away…they expect me to…"

"Calm down." Shanwei held up his hands. "They said they can only spare one shuttle. They'll get me when they get you. I think they want you to hurry…Hell…I know they're listening to this, so just let me say I do feel like I'm being held ransom for that rogue bot."

"They're listening? Who?" It hadn't occurred to Egerton that their call was being monitored.

"Simon." Shanwei shook his head. "It's Homeland Security, of course they're listening. Say hi if you like…"

"Hi?" Egerton suddenly felt even more powerless.

"They're always listening," Redwood joked from off camera, playing into the tree-hugging hippie stereotype. "They're always watching, maaaaan." Then he giggled.

"When do you leave?" Shanwei asked again.

"Tomorrow morning, I think," Egerton look at his screen. "It looks like the storm has moved on and I should have a clear patch to work with. I think I have a day or two."

"We got another ping north of you at a place called Cape Look Out. It could be the bot. I mean we think it's the bot and Gonzalez's bio-suit." Shanwei stared at two unassuming dots on the map. Their banality chilled him. The red dot was a killer robot and the yellow was a dead soldier.

"Yeah, it hasn't moved in days." Egerton could see the same two dots, but neither of them wanted to talk about Miguel Gonzalez. "The system may have crashed. It seems stuck on that little finger of land between the ocean and Netarts Bay." As Egerton spoke, Jimmy and Paul walked into the camera. They looked at the map.

"Hey, Jimmy," Shanwei said. "How's Paul?"

"He's fine," Jimmy answered. "But he says that the robot's system hasn't crashed. She's just scared."

"What?" Shanwei leaned in.

"Paul says she's scared," Jimmy repeated.

"Is Paul talking to the security bot?" Egerton asked.

Jimmy turned to Paul, looked back at Egerton, then to the screen that was tracking the motionless red and yellow dots.

"Well?" Shanwei sounded excited.

"Jimmy, is Paul talking to the security robot?" Egerton asked again, careful to keep his voice calm.

"Paul says she's not really talking," Jimmy replied. "Paul says that she's screaming."

***

The trip up the coast went quickly. The rover was low and squat and did pretty well in the wind and rain. Egerton still didn't feel comfortable at the controls. The vehicle was alone on the road; no escorts or soldiers, no crazy Forest Service workers, not even Shanwei to help him. Egerton had never had a job where he'd been this alone. It was just him and the bots, and for the first time it unnerved him.

The rover stopped at a crook of beach between Cape Look Out Point and the finger of land where the ping showed the security bot had frozen. The high cliffs of Cape Look Out gave the rover a small amount of protection, prompting it to hunker down into the sand, transforming itself into a mobile base. The thin strip

of sand and trees that held Mack and Miguel Gonzalez pushed out between the churning Pacific Ocean and the waters of Netarts Bay.

"What are those?" Jimmy asked, struggling to see out of the window.

"Wind turbines." Egerton recognized them immediately.

"They aren't on any map." Jimmy was scanning various maps and records.

"They're probably abandoned. See how the blades aren't rotating, and some are missing? It might even be an unlicensed farm dropped in by some squatters after the local government stopped paying attention." The army of white turbines shot out of the dark and choppy water of the bay like eerie sand-blasted skeletons. Their blades fluttered in the constant wind that came in over the Pacific.

"Has anything changed with the security bot?" Egerton asked as he suited up to leave the safety of the rover. He wouldn't be able to bring Jimmy and Paul with him. They couldn't survive the conditions.

Jimmy paused and looked at Paul. "No," he replied.

"But Paul says she's still functioning, right?"

"Yes," Jimmy answered. "He says you should leave the robot alone. She won't stop screaming."

Egerton flipped up his hood and pushed his phone into his ear. "We need to help the security bot," Egerton said to Jimmy. "I think we can help her. Don't you?"

Jimmy didn't reply.

Egerton's heads-up display started to blink and chirp. It was Shanwei.

"You ready to go?" Shanwei asked.

"Yeah. The rover won't take me any closer. I guess I have to do the rest on foot."

"That should be fun," Shanwei replied.

"Yeah." Egerton didn't try to hide his unease.

"Is the security bot still screaming?" Shanwei asked.

"Yep."

"You still okay with doing this?"

"Yep," Egerton answered tersely.

"You lying to me?"

"Yep."

***

Even through the heavy weather suit and hood, Egerton could feel the cold and the sting of the sand. He was careful to put enough room between himself and the surging tide. He didn't need a sneaker wave to catch hold of him after he had come this far.

"Can you hear me?" Shanwei said in his ear. The storm was playing havoc with the communication links. Very little made it through.

"Barely," Egerton yelled. "The wind's pretty loud!"

"All right, I'll keep quiet, but if you need anything just holler."

"Okay." Egerton leaned into the wind and made his way onto the spit of land.

The bright white wind turbines stood out against the dark storm clouds and rain. As he approached the shore of the Bay, he could make out what was left of a campsite. It didn't look like military or like a corporate research setup. The camp looked civilian and illegal, possibly some survivalist squatters. It might explain the illicit wind farm.

As Egerton made his way through the camp, it was clear that whoever was there had left a long time ago. The rover moorings and improvised electrical hookups had been worn down to useless nubs by the wind. Obviously the storms had forced the squatters from their camp.

"Why would anyone want to be here?" Egerton asked himself.

"Huh?" Shanwei modulated in. "What? You need something?"

"No, sorry." Egerton remembered that he was still linked to Shanwei. "I'm just walking through this weird little squatter's camp on the edge of the bay. They all cleared out long ago, but I can't see why they were here."

"Oh." Shanwei wasn't sure what to say. "That does sound weird."

As Egerton moved out of the squatter's area, he stepped over a crudely welded metal sign that read: "Camp Reincenbach."

Most of the path was sheltered from the ocean by a high sand bar, protecting Egerton from the worst of the wind. He could hear the thundering surf and feel it rumble in the sand beneath his feet. He used the skeleton turbines to mark his progress, glancing at them nervously, calculating the distance between himself and the rover.

On one of the trees was another crude sign that read: "Caution—Bears."

"Are there bears out here?" Egerton stopped.

"What?" Shanwei said through the noise.

"Are there bears out here?" Egerton yelled.

"Bears? Wha? No," Shanwei answered skeptically.

"Did you check?"

"Why would I check to see if there's bears out on some tiny strip of hell in the Pacific Ocean?" Shanwei snapped back. "It's really a silly question if you think about..."

"Check!" Egerton scanned the twisted branches of the trees. It was a few minutes after one in the afternoon, but the sky was dimmed to a soupy churning gray by the storm. What little light there was cast weak shadows on the sand and brittle grass. Egerton searched the shadows.

"Okay, okay..." Shanwei gave in. "But it's going to take a while."

"I'll wait." Egerton stood still. The rushing blood in his neck would not let up. He was worried about his heart. Knowing he had to calm down, he dropped to his hands and knees and climbed up the sand. At the top he caught sight of the Pacific. It was so massive and violent that Egerton pushed himself deeper into the sand. It looked like a wild animal to him. Something that could kill him and wouldn't even notice.

"Simo...." Shanwei's voice broke up.

Egerton slid back down the bank, then said, "Yes?"

"Simon? Can you hear me?"

"I can hear you," Egerton answered.

"I did a one-mile scan using a Homeland Security satellite," Shanwei began. "They weren't happy about giving it to me, but I told them that..."

"And?"

"Simon, there's nothing on that strip of land. There are no bears, no rats, no birds...nothing." Shanwei tried to keep his voice calm. "There's nothing living out there...nothing but you."

***

The strip of sand was so narrow that Egerton could see both the bay and the ocean in his peripheral vision. The ghostly turbines were nearly behind him.

"After this thin little bit, you should see a snarl of trees and another sand bank," Shanwei said. "Do you see it?"

"I see it," Egerton replied. "There's literally nothing else out here." All he could see was water and sand and clouds. "Has she moved?"

"No," Shanwei said. "Nothing's moved the whole time you've been coming closer. I really think the system must have crashed."

"She knows I'm here." Egerton kept his eyes on the snarl. "If she's online at all, she knows I'm here." He noticed he was breathing much faster than before.

"Still no movement," Shanwei reported.

"Okay." Egerton forced himself to keep talking. "I'm going..."

"I'm here..." Shanwei sounded breathless as well.

As he approached the dark snarl of trees and sea grass, Egerton searched for the tell-tale red of the security bot's riot pads. Even in this low light, he knew the bright red color would stand out. He gripped a flashlight tightly in sweating hands, but didn't turn it on.

"Still no movement," Shanwei said.

Egerton leaned down and crawled into the trees. The sand bank once again blocked the wind and the air calmed a little. He pushed past a thick tangle of driftwood and dried seaweed.

"Still nothing," Shanwei reported casually. "I really do think this thing must be offline because..."

"Oh my God," Egerton whispered.

"What?" Shanwei grew tense. "What is it? What?"

"I see her." Egerton went numb.

"Is she online?"

"Yes." War Machine's system lights threw a pale glow all around the robot. The red riot pads were scratched and damaged, but he could see them clearly. She sat on the sand with her back against the bank, slumped over so that Egerton could almost see the top of her head.

"She's not moving. Maybe she doesn't see you," Shanwei said hopefully.

"She knows I'm here," Egerton breathed. "She knows I'm here..."

War Machine was motionless. Egerton moved within 10 feet of the bot and stopped.

"Still nothing." Shanwei reported.

"I..." Egerton started, then stopped. The bot had begun to move.

The bot sat up slowly, almost gingerly, as if it was protecting something in her lap. Then Egerton saw what it was. Laid across her lap was the dead body of Miguel Gonzalez, but that wasn't the only thing that War Machine was protecting. A small industrial robot about the size of Jimmy was doing something to Miguel's body.

"She's moving." Shanwei panicked. "She's moving. I can see it..."

"Shhhh," Egerton whispered.

The little bot must have been from a textile factory. Its arms and fingers were designed for weaving and sewing intricate designs. Then Egerton realized what the little bot was doing.

"There's a second bot here," Egerton said softly. "It looks like it's trying to sew Miguel's body back together."

Intricate seams crisscrossed the body of the dead soldier. Only his face remained recognizable.

War Machine screamed. It sounded both human and mechanical.

"What was that?" Shanwei yelled.

In a gentle but quick motion, War Machine scooped the sewing bot and Miguel's body off her lap and shot to her feet. The little bot continued its work as War Machine took a single heavy step forward. Egerton panicked.

"I'm here to take you home," he said quickly to the bot.

War Machine adjusted her stance and started to rock back and forth. Her underarmor clicked and emitted a high-pitched whine as the bot primed her near-field defenses. There was no time for Egerton to do anything but run. War Machine attacked.

"What? What?" Shanwei yelled. "What's happening? Simon, talk to me. It's moving...it's coming at you. Oh God...Simon! What's happening?"

Egerton bolted from the snarl of trees and ran toward the ocean. War Machine tore through the trees, shredding them. She screamed again as he pounded across the sand.

"Get back to the rover!" Shanwei's voice dropped into business. "Simon, you have to get back to the rover. That's your only chance to..."

"I'm not going to make it!" Egerton ran, mindlessly shedding his pack and whatever gear he could.

War Machine kept coming. Dropping down on all fours, she tore up the sandbank to flank Egerton and trap him between her and the ocean. Sand and debris flew up behind the bot. Egerton tumbled into the freezing water. The shock cleared his head for a moment and he turned. The bot ran down the bank and straight at him.

"I'm in the water now," Egerton breathed. "I'm trapped. I can't go anywhere."

"Can you get to the rover?"

"No, I'm trapped...I'm done..."

Egerton watched as War Machine screamed and plunged into water.

"I'm done..." Egerton said again.

"No...no...no, listen..." Shanwei started, but Egerton was so deep in the water that he couldn't hear.

The sneaker wave surged hard and fast into the coast. It reached out from the churning surf and knocked Egerton deep into the water. He tumbled helplessly in the tide. There was no up and no down. He was lost in the darkness and the cold. Instinctively, he pulled himself into a ball as he was pushed and pulled by the water. His lungs started to burn. Blindly, he pushed for the surface and found nothing but more cold water. Then another strong current grabbed him and he gave up.

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Breaking the surface of the water, Egerton flipped on his back and gasped for air. His mouth filled with foam and the surf, but his lungs got some air. He spit and coughed and breathed again.

War Machine screamed in the distance. The tide had pulled her in the opposite direction, away from the spit and the rover. Mercifully, the wave had pushed Egerton closer to Cape Look Out Point and the rover. He kicked and swam to shore, knowing that one more big wave would slam him into the point's high, rocky cliff.

Egerton stumbled and crawled out of the surf. His legs gave out and he threw up in the wet sand. War Machine's distant scream cleared his head. He searched for the bot through the gloom of the clouds and the endless churn of the water.

When he finally caught sight of the bot, he was overcome with an unexpected wave of compassion. She fought the tide with a relentless fury, struggling to get back to shore. She was helpless. The ocean was winning.

Egerton crawled back into the rover. Jimmy and Paul were huddled at the back and didn't move when he closed the hatch.

"It's okay, guys," he said, still panting. "It's okay..."

Egerton fumbled with the rover's main screen and finally got it to work.

"Shanwei?" he tried. "Shanwei, can you hear me?"

Nothing.

He clicked over, trying a few other ports and addresses. "Shanwei? Hello? Anyone? Hello? This is Dr. Simon Egerton and I..."

"Whoa, hey man." The relaxed face of Redwood popped on the screen. "Hey! You're alive! That's awesome, man. Shanwei freaked out and..."

"Where is Shanwei?" Egerton asked, just beginning to get his breath back.

"He's gone, man. He bugged out and called the Homelanders. He's outside waiting for them..." Redwood motioned to the left of camera.

"Dr. Egerton," Jimmy said.

"One second, Jimmy." Egerton held up his hand and returned to the screen. "Go get him," he said to Redwood. "Tell him I'm okay and that the security bot is in the Pacific. They're going to need the Coast Guard..."

"Dr. Egerton," Jimmy said again from the window.

"Just wait, Jimmy..."

"Dr. Egerton, she's coming back." Jimmy tapped his finger on the rover's thick glass.

Egerton moved from the screen and looked out at the beach. War Machine had freed herself from the ocean and was running straight at the rover. Egerton could feel the bot's violence rumbling up through the sand. There was no time. He grabbed Jimmy and Paul and jumped out of the hatch.

War Machine descended on the rover. The tethers that had kept the rover safe in the high winds were weak under the power of the robot. Driven by an unknown rage, screaming, she tore the vehicle open and shredded it.

Egerton ran for the forest that covered Cape Look Out Point. Maybe he could hide, or at least not be as exposed.

War Machine tossed the destroyed rover aside like a broken toy and chased after Egerton and the two bots.

A mound of rocks led up from the beach and into the forest. It was hard for Egerton to keep his balance as he climbed. He was careful not to hurt his bots, but he was so frightened that he did feel his hand break Paul's impossibly frail arms.

"He's okay," Jimmy said.

"What?" Egerton shifted his focus to Jimmy, lost his footing, and lurched into the rocks. At the last second, he spun so that he landed on his shoulder and hit his head. He didn't crush Jimmy or Paul, but something broke. The pain was big and broad. He worried that it was his collarbone.

War Machine reached the base of the rocks and came at Egerton and the bots with no trouble.

Egerton dragged himself against a tree and felt surprising calm as he watched the massive security race toward him. He was so calm that he didn't flinch when the heavy Coast Guard ship suddenly dropped through the clouds and fired at War Machine. Egerton didn't move; he simply watched as the bot's attention shifted to the attacking craft.

With perfect accuracy, the Coast Guard ship took out one of War Machine's legs, sending the bot sliding down the rocks and back to the sand. The next two shots removed the arms, and the final shot did away with the other leg. War Machine was helpless. Yet she still struggled and screamed as a Coast Guard member rapelled from the ship onto the bot's chest and jammed home the kill switch.

Egerton tried to slow his breathing and check on the bots in his arms.

"Paul says that Mack wants to die," Jimmy whispered in Egerton's ear.

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"It's like you two want to die," Director Wu said, shaking her head.

"Trust me," Shanwei assured her. "I don't want to go anywhere."

"Really?" the director asked, motioning at Shanwei and Egerton. "Look at the two of you. You're a mess." Shanwei was still confined to the robo-assist stabilization casts. Egerton had broken his left collarbone and his left arm was immobilized in a sling.

"I know it looks bad, but..." Shanwei tried.

The director stopped him. "Look, just tell it to me again. I'm in serious trouble already for pulling the rescue ship off its mission to save you."

"We need to put Mack back into her body...a body," Egerton started. "I can't do anything with her here." He held up his personal screen. "We transferred her to my machine, but if she's not in the body of a bot, we're never going to learn what happened." Egerton looked tired and beaten up. Along with the sling and the bruises on the side of his head, he couldn't muster much passion into his plea. He did want to find out what had driven Mack crazy, but it scared him and that just made him tired.

"Why do we have to put a rogue bot back into a body where it can do more damage?" the director asked.

"Watch." Egerton booted up Mack's AI. "Mack," he said to the screen.

"Yes," a calm, generic voice replied.

"Mack, how are you feeling?"

"My system is fully operational. My physical sensors are currently offline."

"Mack, what happened to Miguel Gonzalez?" Egerton asked.

The screen was silent. "Officer Miguel Gonzalez is a part of my Homeland Security Patrol Team 22-4 assigned to the American-Canadian border. I have tried to ping his suit and call his mobile, but both are offline."

"Mack, what happened to Officer Gonzalez on your last patrol?" Egerton pushed.

The screen was silent. Then, "I do not have the records for that last patrol. My physical systems are currently offline and I may be experiencing further failures."

"She doesn't remember," Shanwei said.

Egerton turned to Director Wu. "Her memories are there, but she can't access them. Can't or won't. I think she needs to be back in a body; that's the only way we're going to get her to access the memory."

"I don't like it, Shanwei," Wu said. "Dropping that thing back into a body after it's already taken the life of one officer seems like a bad idea."

"I get that, Samantha," Shanwei replied. "But aren't you worried about the other bots? I'm worried it might happen again. You've got how many of these robotic-assisted teams on the border?"

"Twenty-three," Director Wu said, slowly.

"Right, that's 23 chances that this could happen again."

"But I don't really understand what happened," she said.

"Neither do we," Egerton replied. "We do know that when Mack was on patrol, she was in the garment district. Officers Conley, Rodriguez, and Gonzalez were following up on a tip about insurgent activity. That's when things went wrong. Mack turned on Officer Gonzalez and killed him, then disappeared with the body. When I found Mack and Miguel's body, they had that second bot with them..."

"This was the one sewing up Officer Gonzalez's body?" the director said flatly.

"I think it was trying to fix him," Egerton said uncomfortably.

"Fix? How can a textile bot fix a dead soldier?" The director was losing her patience. She wanted this resolved quickly, but her concern about the other bots on the border was clear.

"I have no idea," Egerton replied. "I think..."

"Well, can't your bots ask it?" The director pointed at Jimmy and Paul standing at the back of the office. "I was told that they can do things or talk to other robots when people can't." She looked at Shanwei.

"Sometimes they can." Egerton hesitated.

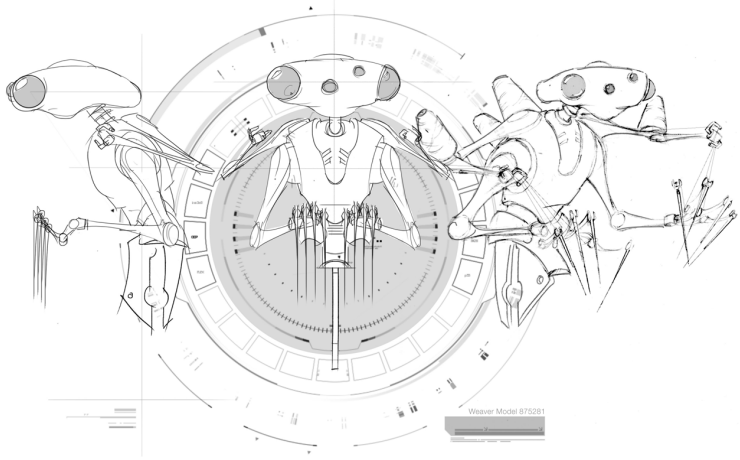
"Well?" the Director asked.

"Jimmy?"

"Yes, Dr. Egerton?" Jimmy answered.

"Can Paul talk to that second bot?" he asked. "Can he talk to the sewing robot we found with Mack?"

"Her name is Weaver Two," Jimmy said. "Paul says her name is Weaver Two."



"So you can talk to her?" the director asked Jimmy.

The director frightened Jimmy. He pushed himself against the wall a little.

"It's okay, Jimmy," Egerton said. "You can tell her. She just wants to know what happened to Mack."

"Paul says that Weaver doesn't really say much. She keeps checking her fingers for accuracy and asking for thread." Jimmy paused. "She's a sewing bot; that's what she does."

"I don't think we're going to learn anything from the sewing bot," Egerton said. "Her AI and functions are pretty simple. She's networked out to work on a long line of other bots. The software is actually quite fascinating; it syncs all the bots on the line into a single…"

There was a quick, heavy knock on the flimsy office door.

"Yes!" Director Wu called out.

Officers Conley and Rodriguez came in, their eyes scanning the room with a cold precision.

"Sorry to interrupt, Director Wu," Rodriguez said, "but we heard that Dr. Egerton had just got…"

"We heard you got Mack back," Conley said enthusiastically. "Where is she?"

"Here." Egerton held up his screen.

"What?" Conley held out his hands.

"Dr. Egerton transferred your security bot's mind to his computer so he could figure out what happened," the director answered. "So far, he hasn't had much success."

"Why would you do that?" Conley asked in a tone that bordered dangerously on insubordination. "Just ask her."

"I did," Egerton said softly.

"Mack. Mack, it's me Conley," he said, taking the screen. "Can you hear me, Mack? You in there, War Machine?" Then he yelled, "Hey, Mack! Come on, let's go!"

"What's that?" Shanwei blurted out.

"It's their rally," the director answered, a little annoyed. "It's what all the teams say before their patrol."

"Hey, Mack! Come on, let's go!" Conley tried again. "You in there, Mack?"

"Yes," the bot replied.

"What the…" Conley held the screen away from him as if it were diseased. "What's wrong with her? What's wrong with her voice?"

"We don't know," Egerton replied. "We think…we think…"

"They want to load your bot into a new body," the director said impatiently. "Dr. Egerton thinks if we do that, then we'll get the answers we're looking for. But downloading into a…"

"All we have is an extra bot in the shop. I wish we had something less powerful," Conley replied. "But we could do it right now."

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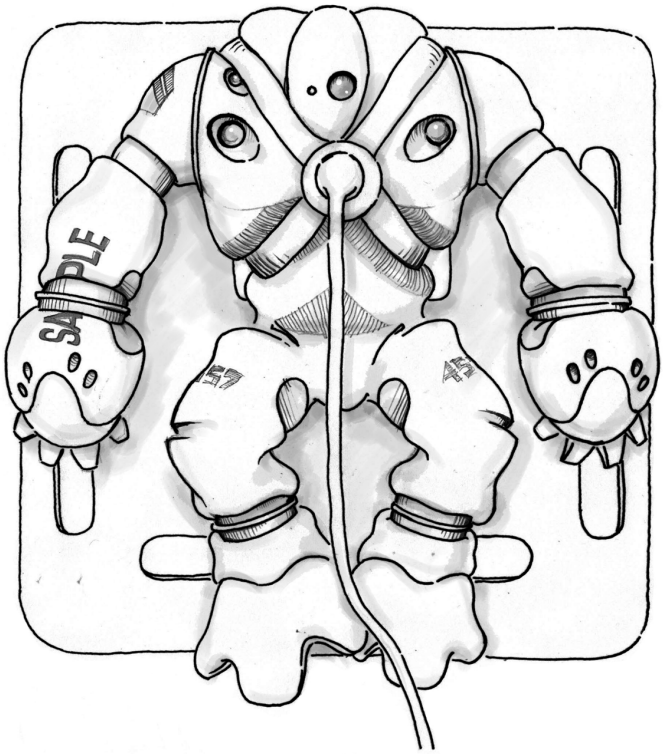

"We've welded in restraints to both the arms and the legs." Officer Rodriguez went through the precautions for Director Wu, Egerton, and Shanwei. "For extra security, we put restraints on the head, neck, and chest units. The riot pads make it a little hard to secure, but we got them locked down." The security bot's red riot pads buckled and bulged under the straps.

"Will it hold if something goes wrong?" the director questioned.

"To be honest, Director Wu, we don't know." Rodriguez was frank. "We've never had to do this before. At least it will give us time to get out of the room."

"Almost ready," Conley said, connecting the hardwire communication cable.

"You can take her right off of this." Egerton gave over his screen. "You'll find the packets..."

"I know what they look like," Conley snapped, taking the screen and returning to work.

"Where are your bots, Dr. Egerton?" the director asked.

"I left them outside," Egerton replied, glancing at Shanwei. "Shanwei wasn't sure you'd want them in the room for this."

"If they can help at all to talk to this thing," she said, waving her hand dismissively, "then I want them in the room."

"Okay." Egerton left the room, glaring at Shanwei.

Shanwei smiled back with guilt.

"I'm going to start the transfer of the data first," Conley said, turning around, but stopped when he didn't see Egerton. "Where's the doctor?"

"You just sent him out of the room. He's getting his bots," Shanwei replied.

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Egerton scanned the wide hallways of the shop. It was both an IT lab and a machine shop, working on bots as well as drones. Jimmy and Paul were not where Egerton had left them. He panicked for a second, then caught sight of them a little farther down the repair bays.

"What are you doing?" Egerton asked, fussing with his sling. "Why did you..." Then he saw why.

Jimmy and Paul were looking into a repair bay and watching the little Weaver bot. Her small body and delicate, dexterous arms were secured to a chassis lift used to repair the undersides of the big rovers and drones. She looked small and overwhelmed by the immense equipment that surrounded her. Reflexively, she knitted her empty hands at irregular intervals. They clicked lightly as she looked around.

"She wants thread," Jimmy said. "I can hear her now."

Weaver's hands clicked again.

"Come on, guys," Egerton said after a moment. "I need your help with Mack."

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Egerton returned with his bots.

"The transfer is almost done," Conley said with anticipation.

"Careful to bring her up slow," Egerton cautioned. "We want to talk to her bit by bit."

"We know the protocol," Rodriguez snapped.

"Data transfer complete," Conley reported. "Let's bring her back." He removed the hardwire and booted War Machine back to life. The body of the large bot twitched slightly, then relaxed into place. She was back.

"Mack?" Conley said lightly.

"Officer Conley," Mack replied and stiffened to attention. Her voice was more animated than when she had spoken from Egerton's screen. Then she had sounded like she was sedated, but now she sounded awake and present in the room.

"Sheeeeee's back," Conley slapped War Machine on the arm, dropping his professional tone. "Hey, Mack!" he yelled. "Come on, let's go!"

"Careful, Officer," Director Wu warned. "This is still the same bot that took the lives of one of our men."

"Yes, ma'am," Conley replied and took a step back. In the brief silence a squad of heavy drones lifted off.

"I'm going to enable her chassis," Conley said weakly.

While War Machine regained control of her arms and legs, Egerton said, "Mack, my name is Dr. Egerton. I want to ask you a few questions."

"I remember you, Dr. Egerton," Mack tried to shift her body to address him but was held by the restraints. Everyone in the room jumped but tried to remain calm. "I was just on your machine."

"I don't like this," the director said and moved to the door.

"That's right, Mack." Egerton smiled at the bot, ignoring the director. "You're held down because there's been a malfunction with your system. Do you remember it at all? Can you tell me anything about what happened on patrol with Officer Gonzalez?

Mack was silent.

"Can you remember what happened to Officer Gonzalez?" Egerton asked again.

"Why are you doing this to her?" Conley burst out. "It's not a game. Just tell her what happened and ask her why she did it."

"Relax." Rodriguez poked Conley in the back. "Relax..."

"I want Mack to pull up the data," Egerton said. "She has the memory. I want her to access it for herself so she can give us an unaltered account. The moment we tell her what happened it will alter the memory."

Conley didn't reply.

"That's why he's the expert," Shanwei said.

"Should I bring up the sensors and the network?" Conley asked.

"Yes," Egerton answered, then said to Mack, "You were on patrol with Officers Rodriguez, Conley, and Gonzalez and something went wrong. Can you remember what happened?"

"It was a routine sweep into a garment factory," Mack began to report. Her voice grew more formal. "We had swept this location multiple times in the last few weeks, but never this area of the factory..."

"Okay, all the sensors and networks are live," Conley whispered.

Mack's body settled into itself, as if the sensors made her more comfortable with her surroundings.

"The initial recon was that..." Mack stopped.

The room went silent, then grew tense.

"Mack?" Egerton prodded.

Nothing.

"Mack?"

Nothing.

"Come on, War Machine, don't bug out on us now." Conley slapped the bot on the arm again.

Then War Machine screamed. The force of the sound threw everyone backward. Jimmy and Paul fell to the floor. Shanwei tried to manipulate his robo-assisted legs back but in his surprise forgot how to work them.

War Machine screamed again and snapped the restraints. She dove at Conley, breaking the security welds that held her arms. Conley dropped to the floor and scrambled toward the back. With a violent thrust, War Machine freed her legs and attacked Officer Conley.

"No!" Rodriguez threw herself at the bot. War Machine batted her back, tossing her against the wall.

"Mack! No! What are you doing?" Conley yelled. "Mack! Mack! It's me! It's me! No!"

The massive bot grabbed Conley's arm and crushed it. He screamed in pain. She pinned him to the floor and grabbed his neck. She screamed again and looked around the room.

Egerton ran out the door and down the hall.

"Where the hell..." the director yelled after him.

Egerton knew he didn't have much time. He slipped and fell making the turn into the repair bay that held Weaver. He screamed in pain. The impact on the broken collar bone made his arms and chest feel like they were on fire. Pulling himself across the floor, he grabbed a wrench from the repair tools with his good arm and

bashed in Weaver's head. He slammed the metal wrench down again and again. Unable to watch, he kept his eyes closed. He struck her again and again, with wild, flailing one-armed swings, sometimes missing and connecting painfully with the floor. The sound of Weaver's metal and plastic snapping sickened him.

Finally he stopped and let the wrench fall to the floor. Panting, he paused to catch his breath. His entire body was in pain, and his good hand was bleeding. He didn't want to look. He didn't want to open his eyes. There was no more screaming down the hall. He still didn't want to open his eyes, but he did.

Weaver was destroyed. Her little head was gone. Most of her chassis was destroyed beyond recognition. All that was left was one of her little arms still chained to the heavy drone lift.

Egerton stared at the delicate hand. He expected it to twitch or click or move, but it didn't.

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"What the hell just happened?" Director Wu asked when Egerton returned.

"You figured it out, didn't you?" Shanwei said, still fussing to gain control of his robo-legs.

Egerton didn't respond.

Rodriguez was on the floor next to Conley, checking his injuries and trying to stabilize his arm.

"What's wrong with her?" Conley was in tears. He both pulled himself away from the bot and reached for her at the same time. It was as though he was stuck in a loop and couldn't stop moving. "Mack? Mack? What's wrong with her?" he cried again.

"Stay still." Rodriguez pushed her partner to the floor and tried to stop him.

War Machine crouched on one knee by the wall. She held her hands close to her head.

"Will someone tell me what just happened?" the director demanded.

Egerton held up his good hand to silence her as he approached the bot. Blood ran down his fingers and palm. "Mack? Can you hear me?" Egerton asked gently. He wiped his bloody hand on his pants. "Can you hear me, Mack? Can you tell me what just happened?"

Mack turned to the sound of Egerton's voice, then saw Conley and Rodriguez on the floor. She pulled herself over to them. The sound of her riot pads squeaked on the floor. The metal and plastic in her knee joints gouged the cheap tile.

"Mack?" Conley was too scared to move.

Rodriguez drew her stun gun.

Mack began to speak, but stopped. She couldn't form words. She could only get out long, nearly musical notes as she drew nearer to the officers.

"Shoot it!" the director yelled.

"A stun gun won't do anything," Shanwei said calmly. "Not against a bot."

"I think it's okay." Egerton came close to the gigantic bot as its hunched body still loomed over the officers.

Mack brought her head close to Conley's face. The staccato notes stopped and she whispered, "Conley...I...I...did it." The notes started again, then stopped. "I killed Miguel."

Jimmy and Paul pulled themselves out from under the desk. Egerton glanced at them to make sure they were okay. Paul waved.

"Mack..." Conley reached for the bot.

War Machine slumped away from the two officers, going limp. She scraped and squeaked back across the floor to the wall. She tried to pull herself upright, but got stuck again on one knee.

"Hey, Mack," Rodriguez called. "Hey, Mack! Come on, let's go!"

The bot's head flinched, but remained looking straight at the floor. It sounded like she was going to speak, but all that came out was a low-pitched whine.

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"Let's hope these computers don't jump up and try to kill us." Shanwei chuckled, but no one laughed.

"How much longer is this going to take?" Wu asked.

"It's just a test," Egerton replied, but didn't look up from the two computers. He was exhausted. His broken collarbone made his entire chest hurt, and he could only use one arm. As he worked, his bandaged hand trembled.

"I need to wrap this up. Either you can give me a report I can file or..." the director began.

"Look, I don't want to do this," Egerton snapped. "You want me to do it. So I'll do it, but if you don't stop, I'm walking out of this room...this base...this..."

"Whoa, whoa, whoa!" Shanwei maneuvered his legs to bring him between Egerton and the director. "Everyone just relax. We can do this, right? No big deal, right?" He looked at Egerton.

"I'll show you, but you both need to shut up," Egerton growled. "I'm sorry," he tried to explain. "I just...look, I'll be done in just a second. Let me concentrate."

"Okay." Shanwei looked to the director. "Samantha, we're all good here. Just keep quiet and let the good doctor do his work."

The director didn't respond. She glared at Shanwei, and returned to her desk.

In the silence, it was clear just how thin the walls of the trailer were. Patrols went by with their bots. Small hover drones came in low and then darted up to the border.

Shanwei scanned the office. "Where are Jimmy and Paul?" he asked, forgetting the quiet he was supposed to be keeping.

Egerton didn't snap back. He just answered flatly, "I didn't want them to see this."

"Hey, Scooby! Come on, let's go!" a patrol yelled outside.

More drones and rovers and the sound of medication and antibiotics being pumped into Shanwei's legs.

"Okay." Egerton breathed, gingerly rubbing the bruises on the side of his head. "Come over and I'll show you."

"I loaded Mack and Weaver on each of these computers." Egerton gestured to the two screens with his hand. The bandages had gotten dirty as he worked on the machines. "I used the version of Mack that we had put on my machine, before she accessed her memory files and remembered what she had done."

"Okay." The director was listening and following intently. "I get it. You want the version before…"

"Yeah," Egerton continued. "I was also able to get into Weaver's system and pull some of it. I loaded it here." He motioned to the other computer. "Now both of these systems are closed right now. No sensors. No network. They are basically in a closed environment. Now watch…"

Egerton approached the computer that held the previous version of Mack. "Mack," he said to the screen.

"Yes," the same calm and generic voice replied as before.

"Mack, how are you feeling?" Egerton was careful to ask the same questions.

"My system is fully operational. My physical sensors are currently offline."

"Mack, what happened to Miguel Gonzalez?" Egerton asked.

The screen was silent. "Officer Miguel Gonzalez is a part of my Homeland Security Patrol Team 22-4 assigned to the American Canadian border. I have tried to ping his suit and call his mobile, but both are offline."

"Mack, what happened to Officer Gonzalez on your last patrol?" Egerton pushed.

The screen was silent. Then, "I do not have the records for that last patrol. My physical systems are currently offline and I may experience further failures."

"It's exactly the same," Shanwei said.

"Yeah," Egerton replied. "Just like before. Mack has no recollection."

"What does that tell us?" The director was skeptical.

"Nothing, yet." Egerton grew wearier. "This is Weaver," he said, moving to the next computer. "She's not going to really tell us anything. Weaver," he said to the screen. "Weaver Two? Can you hear me?" A few order numbers and protocols zipped across the screen. "She's not really made to respond. But these are codes for orders of specific thread." He pointed at the screen.

"Okay." The director was following.

"Here's what happened." Egerton turned the computers to face each other. He winced. All that movement was making his shoulder sore. "Up until now they were isolated, but now watch." Egerton tapped on Mack's screen, then on Weaver's, turning on their sensors and network.

"I get it," Shanwei said.

"I don't." The director leaned in.

"Mack," Egerton said. "Can you still hear me?"

"Yes, Dr. Egerton," War Machine replied.

"Are your sensors and network functioning…"

Before Egerton would continue, Weaver's screen went crazy with codes. Then War Machine started to scream through the computer speakers. Egerton didn't turn it off. He turned the volume up, filling the room with the awful, sickening sound.

He watched Shanwei and Director Wu as the sound started to bother them, dig into them as they began to feel War Machine's pain.

"Turn it off!" the director yelled.

Egerton didn't move. The scream continued.

"Come on, Simon," Shanwei urged his friend. "We get it! Come on…"

"Turn it off!" The director lunged at the computer. She fumbled over Egerton and fell onto his broken collarbone. Egerton screamed in pain, trying to shake her off.

"Simon!" Shanwei yelled.

Egerton pulled himself back to the desk and silenced the computer.

"What the hell do you think you're doing?" the director asked from the floor, as she struggled to retain her dignity and authority.

"That's what it sounds like when a bot goes insane." Egerton turned his back on the pair. He tapped on the screens, transferring the files to the Homeland Security servers, then deleted them from the machines.

"That's crazy." The director stood and moved back behind her desk.

"It might sound crazy, but it's not," Egerton replied with purpose. He packed up the computers and gathered his things. "It was the network that linked them. When Mack entered that factory and connected with Weaver, something happened. I think Mack accidentally damaged Weaver One, the bot that sat just in front of Weaver Two. The weaver bots work in a tight configuration."

"So?" The director wasn't following.

"So, with Weaver One destroyed, I think Weaver Two latched on to War Machine, and somehow got into her brain."

"And that did it!" Shanwei called out. He understood.

"What are you two talking about?" Director Wu was still lost.

"When Weaver latched on to Mack, there was nothing War Machine could do," Egerton explained. "Weaver was in her brain, making the incessant call for thread. Over and over. Both Weaver and Mack malfunctioned and pushed each other further. It drove Mack insane."

"You can't drive a bot insane," the director said.

"Yes, you can," Egerton replied. "Just like you can drive a human insane. There was nothing Mack could do. She was doomed. All she could do was attack to try and stay alive, and then she killed one of the people she cared for most in the world."

"And that just made it worse," Shanwei added.

"Yeah." Egerton was tired. "It drove Mack into the rage we just saw, making her turn on the people she loved and swore to protect. She killed Miguel, and then it just got worse."

"So when the AIs mingled, something happened?" Shanwei was processing. "Like just connected over a network?"

"After killing Miguel, Mack got worse. She'd killed one of the three people she loved and cared for most and couldn't think of anything else to do but flee. She was bonded to Weaver and couldn't bear to leave Miguel behind." He paused. "I don't know, maybe it was shame or maybe she thought that Weaver could put Miguel back together..." Egerton massaged the skin under the sling.

"How am I supposed to explain security bots that go crazy when they get on the same network as other bots?" the director asked. "How do I make sure this doesn't happen with my 23 other patrols?"

Egerton paused and looked Director Wu directly in the eye, then replied, "You don't."

"What do you mean, I don't?" she spat back. "What am I supposed to do? What the hell happened?"

Egerton moved to the door. "I don't know what happened. I don't think we'll ever know. I don't think we can know..."—he took a breath—"...and I don't think we can stop it from happening again."

"But..."

Egerton walked out the door.

***

"Wait!" Shanwei chased after Egerton, working his robo-legs. They weren't meant to run, but he was pushing them as fast as they could go. "Wait, Simon..."

"No," Egerton replied, not stopping. He walked out of the field office trailer and found Jimmy and Paul waiting for him. "I'm not stopping. I'm not waiting, and I'm not coming back!" Egerton turned.

"What? Why?" Shanwei grew concerned.

"I'm done," Egerton said flatly.

"What?"

"I'm done. No more." Egerton couldn't look at his partner. "I can't do this anymore. I kept it together to finish this job. I did what I said I'd do...I don't...I don't want to get you in trouble but..." Egerton cracked. His breath came in deep gasps and he started to tear up. "I can't do this..." Jimmy and Paul moved in closer to his legs.

"What? What's wrong? You mean this?" Shanwei pointed to his legs and Egerton's injuries. "This is nothing. Come on, man, you know we'll be fine in a week or so. No big deal."

"It's not that..." Egerton shook his head. "I don't care about that..."

"Then what? What is it? Tell me and I'll fix it."

"You can't fix it." Egerton snapped. "Look, this was great...I mean when we started all this work it was really great and interesting, but I can't do it anymore. It's too much. You don't know what it does to me. I can't do *this* again..."

"What is it?" Shanwei looked around desperately, but there was no one to help. The drones passed and the patrols walked by the trailer. They didn't know who these two men with the two bots were and they didn't care.

"I drove a bot insane *twice* today." Egerton snapped into a static and calm voice. "You don't know what that means..."

"What?" Shanwei asked. "What does it mean?"

"You don't know what this does to me. All of this...all of these bots are so troubled. I can't take it anymore. I can't do it anymore." Egerton stopped. "I don't think you know what all this means..."

"What?" Shanwei asked again. "What does it mean?"

Egerton looked down at Jimmy and Paul, then scanned Homeland Security's border operation. "It means I'm done," he answered, then took Jimmy and Paul and walked away.

Shanwei wanted to call after him, but didn't know what to say.

Build

Now that we've explored the design, brain, and body of your robot, it is time to start building! In this chapter, we'll meet two roboticists who are not only making 21st Century Robots, but are making kits so that we can all make robots. Andrew Alter, the first roboticist, explains how we can take two very different approaches to making Jimmy. Our second roboticist, Joseph Schlesinger, has a very specific vision for what the future of robots can be. In between, we talk with Dr. Genevieve Bell, a cultural anthropologist and expert in how humans interact with technology. She gives us a very different vision for the future of robots.

Cute Little Robots

Andrew Alter is a big guy. He's tall and broad, well over six feet, with long hair and a pointed beard. Andrew made a name for himself in robotics with Mech Warfare competitions. These are games where operators send their robots into a ring and remotely control their battle with another bot. Andrew's robots are impressive, but to tell you the truth, they are a little scary.

Andrew's skill at designing and building robots is well known. With all this in mind, it was hard to believe a conversation I had with him after he joined the 21st Century Robot Project.

"You ruined me," he said with a booming voice and big smile. He was working on an early version of Jimmy as we talked. "First you brought me out of humanoid robot retirement. I'd given up on building biped robots. I even sold all my walking robots; that's how serious I was about quitting biped robots! Then I started building Jimmy." He paused for dramatic effect. "It definitely gave me a unique look at how I saw people responding to Jimmy in comparison to my normal type of robots.

People who'd meet Jimmy would immediately smile and want to know more about him—a far cry from the reactions I've gotten with some of my *mech robots*. Everyone loves cute robots."

"Jimmy's a pretty powerful little robot." I smiled back, patting Jimmy on the head.

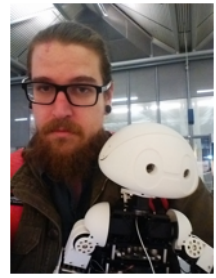

Figure 9-1. *Andrew and Jimmy 2.0 in transit at an airport (photo credit: Selfie by Andrew Alter)*

Andrew joined the project to continue the development of our robot, picking up from the Olin College and Gui's designs. He is the lead engineer at Trossen Robotics, one of the world's leaders in robot kits. Andrew was going to not only refine Jimmy's design, but also turn it into kits so that other people can build their own 21st Century Robot.

Jimmy 2.0: The Research Humanoid Robot

"Like a lot of other geeks out there, I fell in love with a movie robot as a kid, and it drove a lifelong obsession," Andrew explained to me. "For me it was Johnny 5 from the *Short Circuit* movies. When I was six, I saw him and just thought he was the coolest thing I had ever seen. To be honest, I've maintained that obsession ever since. I tried to build a few, but never really got a functional one until I was a bit older in college. I built a PC-based version of Johnny 5 that was a bit before its time. He was about two feet tall. He could roll around, talk, and do some basic object tracking. That's what kicked it all off for me. I've been building robots ever since."

"What have you learned since then?" I asked. "Has anything changed?"

"I think I understand now that nobody in robotics does anything without standing on the shoulders of giants," he explained. "We all learned from our predecessors, from our peers, from all the great people who built robots before us. There's a vast amount of knowledge that is needed to build the simplest of robots. If we want more people to be able to build and play with robots, then we need to

lower the barrier to entry. We need to make it easier for people to get started. The open source initiative with robotics is really geared to do that."

In the spirit of that design principle, Jimmy 2.0, "The Research Humanoid Robot," uses all the work from the people you've gotten to know in this book: Sandy, Wayne, Dave, the Olin students, Gui, and the folks from Artisan's Asylum. The result was a smaller Jimmy that we would all build.

"The software on Jimmy 2.0 is the same code we ran on Gui's three-foot Super Jimmy, based on the DARwin-OP platform," Andrew said. "That's what's so great about an open source approach. Our next two Jimmies are standing on the shoulders of the Jimmies that came before. And our next two Jimmies can be a starting point for people to build and personalize their own 21st Century Robot."

Jimmy 2.0 stands 24 inches tall, about a foot shorter than Super Jimmy. He has one motor in his neck, and a new pin system that gives him the mobility to be social and interact with people. He has two motors in each shoulder: a heavy motor that gives him the ability to push himself up if he falls down, and a smaller motor that moves his arms left and right.

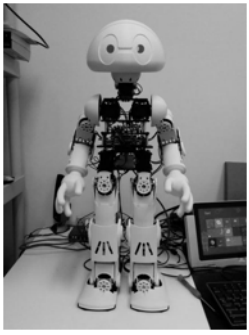

Figure 9-2. *Jimmy 2.0 without his chest and back cover (photo by Brian David Johnson)*

Jimmy has a single motor to move his elbows up and down, but no motors in his wrists or hands.

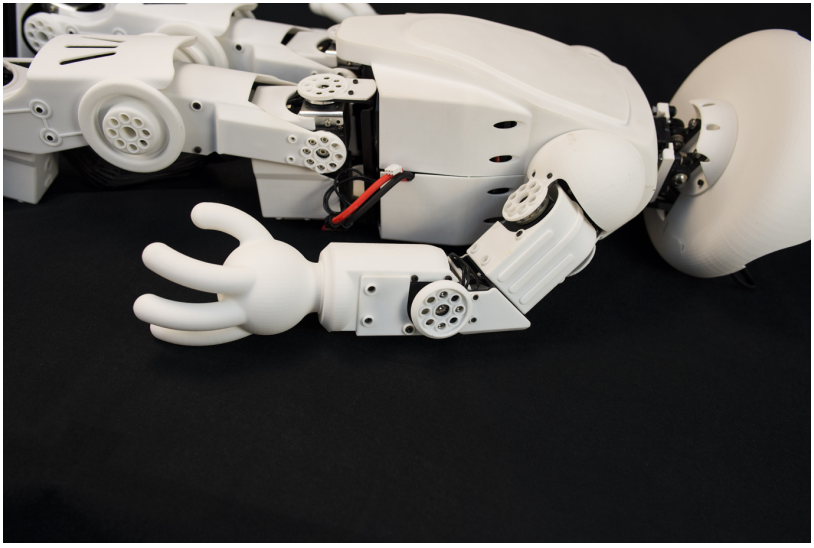

Figure 9-3. *Detail of Jimmy 2.0's arm and wrist (photo courtesy of Trossen Robotics, LLC)*

"We did that to cut down on weight," Andrew explained. "To get a robot of this size walking, weight is always a problem. But the approach worked; he's a pretty fast little guy right now. Plus, he's social and his arms are for gesturing and helping himself back up if he happens to fall."

Jimmy's hips have three motors to give him a full range of motion for walking and keeping his balance. There's a single motor in each knee that moves him forward and back, and two motors in each of his ankles to help him walk.

The two batteries are in his belly, as is his brain and subcontroller.

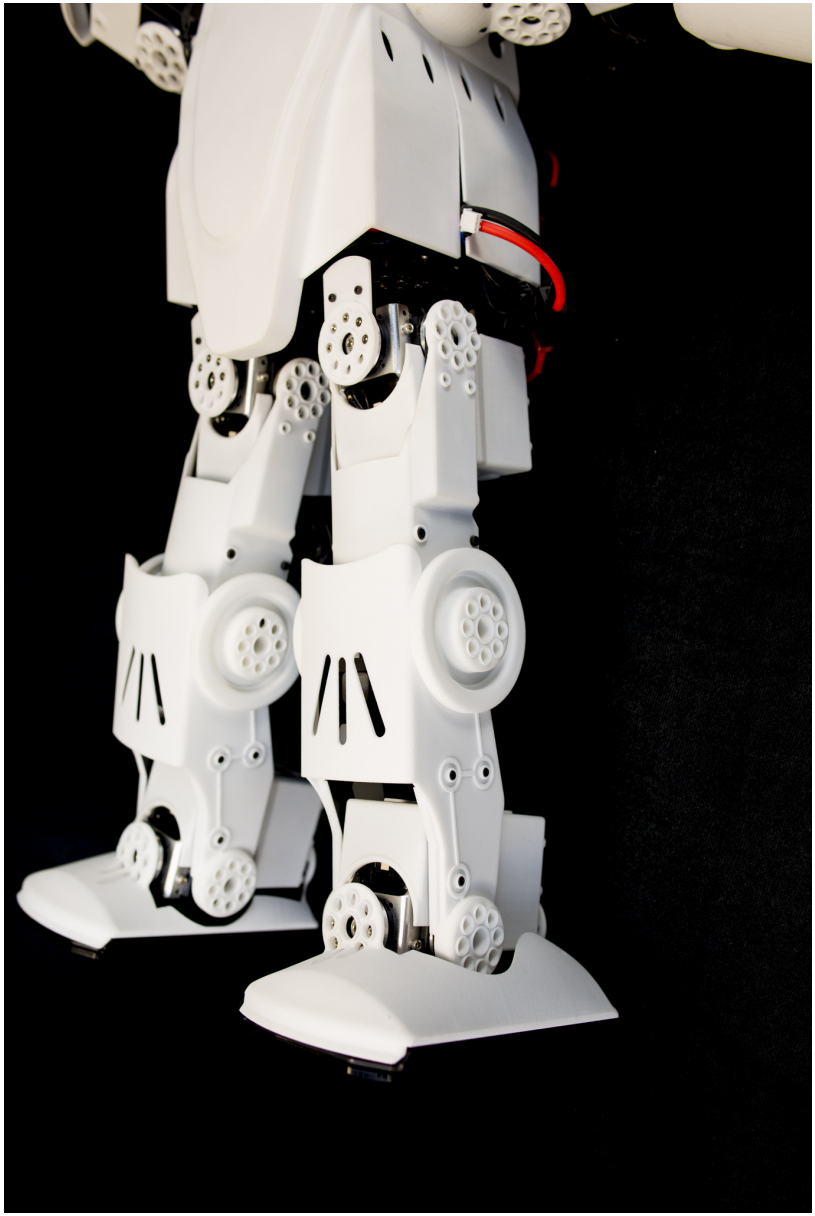

Figure 9-4. *Detail of Jimmy 2.0's hips and legs (photo courtesy of Trossen Robotics, LLC)*

"We moved all the weight to his center of balance," Andrew said. "We wanted to keep the heaviest parts of him low and in the center. Plus, he's a smaller robot than the Super Jimmy, and the belly is where we had the most room."

Jimmy has two cameras in his head, along with a microphone and speaker. His software uses the open source DARwin-OP operating system, and runs code developed by Gui, Ross, and the teams from Olin and USC.

HR-OS1: "The Jimmy Kit"

The HR-OS1 "The Jimmy Kit" is an even smaller version, based on Super Jimmy and Jimmy 2.0.

"He's pretty much the same robot, just scaled down a little," Andrew said as he passed me the design files. "We are using smaller motors because he has less weight and doesn't need as much power. But all the software is the same."

Figure 9-5. *Early render of HR-OS1 (photo courtesy of Trossen Robotics, LLC)*

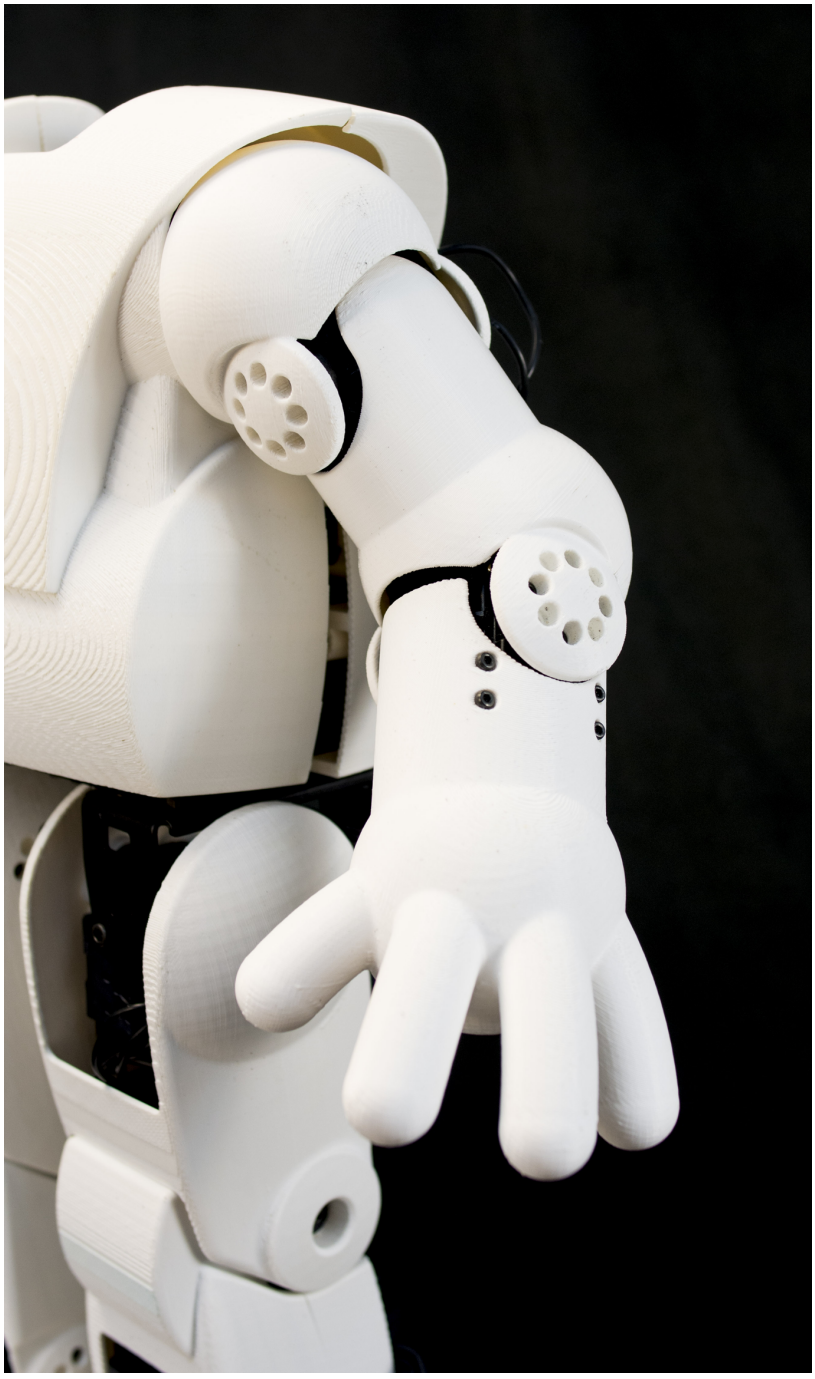

Figure 9-6. *Detail of HR-OS1 arm and wrist (photo courtesy of Trossen Robotics, LLC)*

Figure 9-7. *Detail of HR-OS1 hips and legs (photo courtesy of Trossen Robotics, LLC)*

The HR-OS1 is simply the endoskeleton. It's an open source metal-frame humanoid robot that is meant to be personalized, and can be customized with 3D printable shells. It connects to apps on your smartphone or tablet.

What's Next?

"So what do we have planned next?" Andrew asked. "What's the next bot?"

"Sandy and I are thinking of doing a ball or wheeled robot," I answered. "We think her name is Stacey. She would have a simple torso and upper body. The bottom would be a ball that she rolls around on."

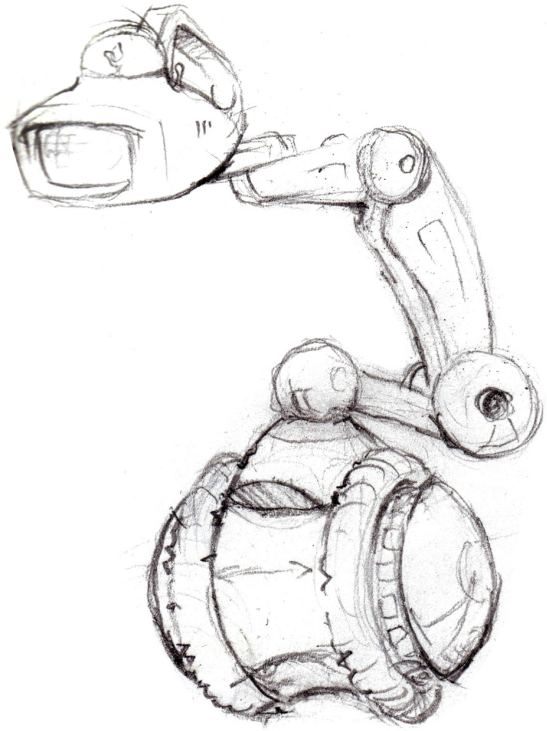

Figure 9-8. *Early concept drawing for Stacey (illustration by Sandy Winkelman)*

"Maintaining the balance on the ball might be a little tricky," Andrew replied, "but it will seem easy compared to getting a biped robot walking."

"Because walking is just plain hard," I added.

"Yep, walking is hard," Andrew said, laughing. "It also means that we've now got not just one or two, but many different 21st Century Robot designs and kits that people can choose from. We want to lower the bar so that more people can get involved in robotics. You may not be a mechanical engineer or even a software engineer, but you can still build robots."

"Actually, it's good if you're not a mechanical engineer or software engineer," I interrupted.

"Right," Andrew agreed. "We want people to use these robots as a kind of blank slate onto which they can paint with their own creativity. It's these new points of view that are really going to make robots amazing. I can't wait to see what people build!"

Ducks, Dolls, and Robots

"I can't talk about robots without thinking about ducks and dolls," Dr. Genevieve Bell confessed to me. Genevieve is a cultural anthropologist specializing in how people interact with technology. I've collaborated with Genevieve for years, and I'm always astounded by her encyclopedic memory and her pragmatic application of her research to the technologies that we use every day.

"Ducks and dolls?" I asked.

"In 1735, a Frenchman by the name of Jacques de Vaucanson unveiled his mechanical duck," she explained. "It not only made an impression in France, but it basically rocked Europe for decades."

"What did it do?" I asked.

"Well," she said, laughing, "it did what ducks do. It waddled. It flapped its little beak. It ate oats and…well…it also did what ducks do." She paused, then added, "It pooed. It went to the bathroom."

I laughed out loud.

"I know," she continued, "but it was a big, big deal. It really freaked people out. The great French philosopher Rene Descartes said that when you looked at de Vaucansan's duck, you could see the glory of France."

"Wow," I said. "That's big."

"Yep, it wasn't a robot like you're building with the 21st Century Robot, but it certainly is a distant relative. Maybe the duck is Jimmy's great-great-great granddaddy duck." She laughed.

"And the dolls?" I asked.

"Well, jump forward 152 years and you find a very similar device in America," she answered. "In 1890, American inventor Thomas Edison released his talking doll. It was a children's doll with a little phonograph in its back that spoke when you wound it, and also sung 'Twinkle, Twinkle, Little Star.'"

"Sounds a little scary," I said.

"Yes," she replied. "It was an absolute failure. Even Edison himself remarked how creepy it was. It's said that he talked about how 'the voices of the little monsters

were exceedingly unpleasant to hear.' They only sold about 500, and most of those were returned."

"Why do you think of ducks and dolls when you talk about robots?" I asked.

"You have to remember that cultures all over the world have imagined wildly different robots for centuries," she said. "The kind of robot is really important. What the robot was meant to do is really important. How the robot fits into the culture, and how people imagine their relationship with that robot is really important. Both the duck and the doll were designed to trick people, or at least try and represent something that was real. They mechanized life and it freaked people out. So when people build their 21st Century Robots, they need to really think about what they want them to do."

"21st Century Robots are meant to be social," I said. "How should we think about that?"

"But how will they be social?" she asked. "What will they do? In the 17th century, the Japanese developed tea serving robots that delivered tea perfectly on a table top. In the 14th century, Islamic engineers created religious automatons that aided people in religious rituals, washing before prayer."

I had expected this of Genevieve. Her perspective is wonderfully attuned to people and their cultural practices with respect to technology.

"You see, Brian, robots can do so much more than most people imagine," she said. "They are limited by how we imagine them. They are limited by how we imagine ourselves, and how they might knit into our lives in really interesting and meaningful ways. You must remember that when you make these bots, you're not just making robots—you're making culture."

A Dancing Hexapod

"My name is Joseph Schlesinger, I'm the CTO of ArcBotics. I design cute robots for people." This is how Joe first described himself to me.

Joe is a country boy from northern Maine. When he was growing up near the Canada-US border, the population of his town was about 500 people.

"I didn't really have access to robot kits when I was a kid," Joe told me. "I didn't really get access to robots until I went to college. That was one of my main motivations for starting ArcBotics. We wanted to make affordable kits, so that anyone can build a robot."

In the world of kit robots, Joe is known for making kits and robots that have personalities.

"Each one of his robots has a name!" Brian Jepson, my editor from Make, told me before introducing me to Joe. "He's perfect for the 21st Century Robot Project!" Brian was right.

Joe's first kit robot was Hexy the Hexapod robot. A hexapod robot has six legs that can be manipulated independently. Not only was the design of the robot unique and affordable, but Joe's marketing and funding was new as well.

"We used Kickstarter, the social funding site," Joe explained. "In 2012, we put it out there to see who might be interested in Hexy. I thought it would be amazing if we could make and sell 50 Hexy kits."

Figure 9-9. *Hexy the Hexapod (photo courtesy of ArcBotics)*

"And how many have you sold to date?"

"Well...we sold 50 kits in the first day," Joe chuckled self-consciously. "To date I think we've sold thousands."

"Wow, that's impressive," I replied.

"Yeah, but what I was more impressed by is what people did with Hexy," Joe continued. "People took Hexy and modified it in ways that I could have never imagined. One person attached a music analyzer onto the robot and then programmed Hexy to dance in different ways and at different speeds to different types of music. That was amazing. I would have never thought of that."

"Hexy proved there was demand for affordable, open source robots out there," Joe continued. "Connie Hu, the CEO of ArcBotics, came on to move us from having just a great robot to having a strong company that could actually ship and sell them. We took a look together at how to make things scale, and once she had grown our global distributor base, shipping fulfillment, and operations, we were ready to scale Hexy and launch our second robot, Sparki. But in order to do this, given that we are relying on the right sourcing and manufacturing techniques, we knew we had to take some adventurous risks."

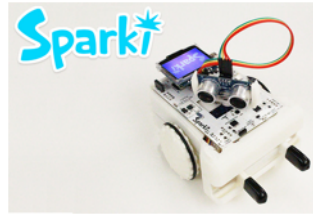

Figure 9-10. *Sparki, another robot from ArcBotics (photo courtesy of ArcBotics)*

It was the success of Hexy that really convinced Joe he could pursue his dream of having a robot company that developed really amazing, affordable robots. But for Joe, the future of his dream was outside the US. He knew he had to move to China.

"All the factories are here in Asia," Joe told me on a Skype call from Hong Kong. "Almost all the factories I need to work with to make robots are about an hour away from my apartment in Shenzhen, China."

"Shenzhen is kind of like the new San Francisco," Connie explained to me. "We knew we needed to come here if we wanted to make robot kits that could be affordable enough to get into schools. That's one of our big passions and mission for the company."

A Robot That Rides Cats?

"Our 21st Century Robot kit has the endoskeleton and exoskeleton design. The outside shell is 3D printed and can be snapped on the outside of the endoskeleton," Joe explained. "That way people can design and print their own look for the robot."

"Inside the robot there will be 24 motors," Joe said as he reviewed his early design concept. Joe designed and built his 21st Century Robot from scratch, not building on Olin and Gui's work. "We didn't want to cut corners on the arms. We put in enough motors so the arms can grasp things. There's a motor in the waist that slows it to twist. There are six motors in the legs because, as I'm sure everyone has told you, walking is hard."

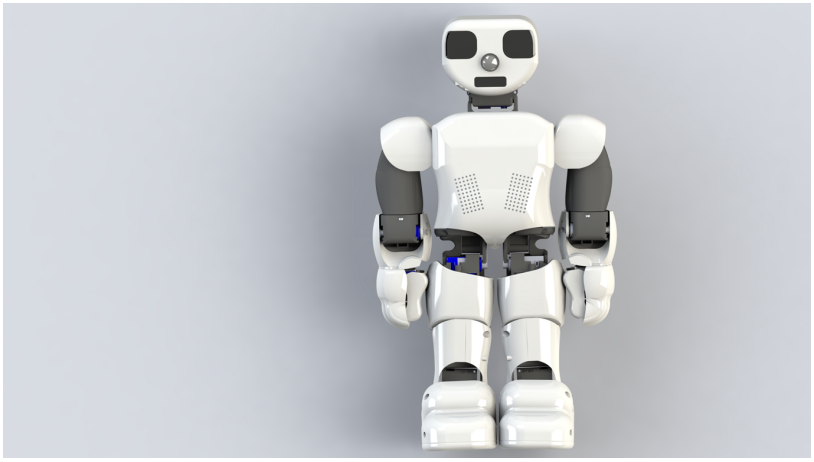

Figure 9-11. *ArcBotic's 21st Century Robot (photo courtesy of ArcBotics)*

"Yes, walking is hard." I smiled.

"We are trying to use a smartphone camera in the head for vision, because they are such high quality these days. But unfortunately they use a really complicated communications protocol. We need to see if we can work with a local factory to help us change that. If we can't get that fixed, we'll use a webcam with a USB connector. Oh, and we're putting the speaker in the chest so it can be bigger than most. We want people to be able to hear the robot across the room."

"Ultimately, what's your hope for your 21st Century Robot kit?" I asked. "The project seems perfectly suited for your view and Connie's view of where robotics could go."

"My joy is not knowing where it's going to go," Joe replied. "We want to do what we are good at and make the best platform possible. Then give it to people and find out what they might do with it. Maybe it will go out and herd cats." Joe laughed. "Actually one person suggested that the robot should be able to ride a cat. Now, there is no way I would have thought of that!"

NEXT: How to Build a Robot

That's it! It's now time to start imagining, designing, building, and programming your own 21st Century Robot. It may not always be easy to build a robot, but there are a lot of resources to help you. In the next chapter, we give a step-by-step overview of what to expect when you start to build your own robot.

How to Build a Robot

The 21st Century Robot Project is an ongoing project. It will essentially always be a work in progress. We are driven by the dream that anyone should be able to imagine, design, build, and program their own robot, and we are trying, wherever we can, to simplify the process. And we have a lot of people helping us.

The 21st Century Robot Collective is a group of builders, makers, engineers, academics, and passionate people who want to lower the barrier to entry, allowing all of us to make and live with robots. Even after this book is published, we will continue to refine and improve the project. You can track our results at our website.

In this chapter we'll look at some of the details of how to start designing, constructing, and programming your robot. Just as there are a lot of different robots, there are also a lot of different ways to build your robot. In this chapter we show you the basics. When you are ready to get started, you can visit our website for more information like links to robot kits, and to connect with the larger community. Let's get building!

> Note
>
> The steps in this chapter and more details are posted on our website, and as the project moves forward we'll continue to add to them, updating new tools and videos. And we also need your help! If you have any ideas about how to make it easier for people to build robots, please share them. If you think we can do something better, let us know. It will take all of us to build the future of robots.

Design

We can never say this too many times: your robot is first designed in your imagination.

Our illustrator, Sandy Winkelman, imagined Jimmy to be a cross between E.T. the Extra-Terrestrial and an iMac computer. He wanted him to be cute and approachable, but at the same time he wanted to make sure that people didn't think that Jimmy was trying to be human.

Who do you want your robot to be? What will your robot do that is unique? All you have to do is look at Ms. Moore's first-grade class in Medford, Oregon, to see how many things your robot might do. And as Ms. Moore's class did, it's helpful to sketch out what your robot might look like.

Next, give your robot a name. Is your robot a girl, a boy, or neither? What is your robot's personality like? Is your robot nervous like Jimmy, or adventurous like Paul?

Once you have a vision for who your robot is, it's time to start designing the exoskeleton, to determine the robot's external appearance. This part of your robot is 3D printed, so you can be as creative as possible. The only real constraints you'll have are balance and weight. We have to make sure that your robot can balance when standing still. If your two-foot-tall robot has three-foot-long horns on its head, it might be hard for the little bot to stand up. Also, we have to make sure that your robot isn't so heavy that the servos can't move its limbs.

We can help! To get started, go to our site and download a generic exoskeleton file. From there, using free programs like Autodesk's 123D, you can take the generic version of the exoskeleton and transform it into your own personal robot. You could also use more powerful and complex tools like Dassault Systèmes SolidWorks or Rhinoceros to dive into the design.

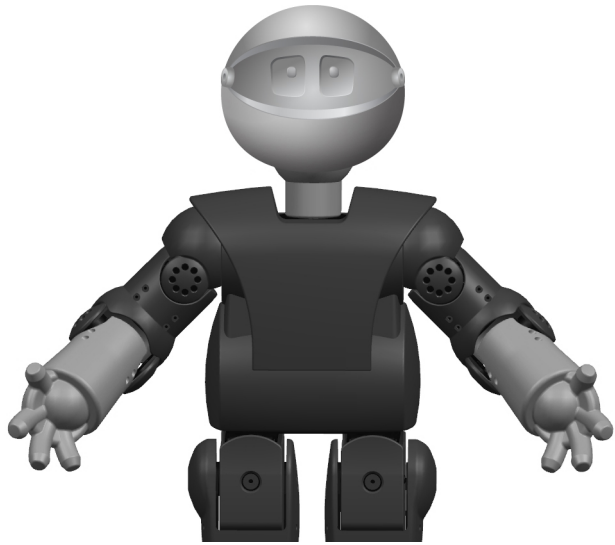

Figure 10-1. *Example generic 3D endoskeleton from Trossen Robotics*

Share

If you come up with a great new design for a robot, share it at our website so others can see it and use it to modify and build their own robots.

As Andrew said, all robotics is built upon the shoulders of the inventors, makers, and roboticists who came before. Now you can be a part of that tradition. What will you build? What will other people build based upon your ideas?

Before you finalize the look and design of your robots, you'll need to build the body. The shell or exoskeleton that you're designing will fit onto the robot's body or endoskeleton.

Body

You have a couple of options when it comes to the body of your robot. You can review the open source plans at our website from the students at Olin College of Engineering, from Trossen Robotics, or from ArcBotics. Once you've picked the robot you want, you can use the parts list to order the components you'll need to build it. You can also modify and customize the inner workings of your robot.

Figure 10-2. *Kit Jimmy from Trossen Robotics (artwork courtesy of Trossen Robotics, LLC)*

Another approach would be to purchase a robot kit from Trossen Robotics or ArcBotics. This kit would have everything you'd need to build your own robot. Go to our website to look at the different options.

Once you have all the parts, it's time to start building!

To assemble your robot, follow the instructions provided with the kit, or use the video tutorials at our website to see how Andrew, Joe, and other roboticists have assembled their robots.

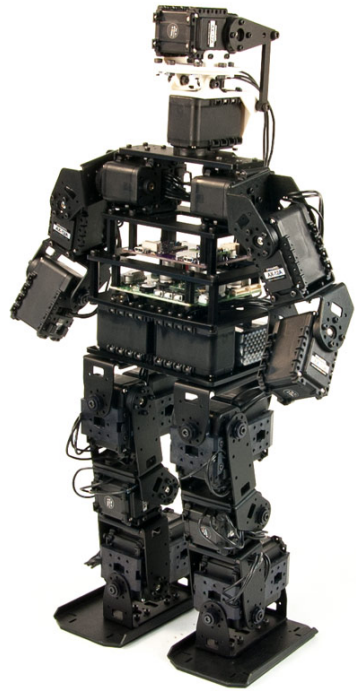

Figure 10-3. *Endoskeleton from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

The Building Blocks for Motion: Single and Double Servos

The starting point for any robot is the servo, or the motor that is going to drive the arms, legs, and head of the bot. The servos that will drive your robot are like muscles to get your bot moving.

The servos that we use in robots are intelligent. This means that each servo has the ability to track its speed, temperature, position, and how much it is being used. All the servos on your robot share a control algorithm that maintains the bot's position by adjusting individual servos, essentially fine-tuning control of the entire body.

This approach allows the microcontroller to take care of the robot's walking and balance, freeing up the rest of the brain to connect and be social with you and other robots.

This approach is like the robot brain we explored with Ross Mead in Chapter 5. We can separate a bot's brain into three sections: conscious, reflex core, and the autonomic system. The autonomic system is the collection of servos and the microcontroller that takes care of the lower-level functions. The conscious part of the brain is where the apps are located, along with the high-level function. Finally, the reflex core manages the communication between the two.

Figure 10-4. *Example servo: Dynamixel AX-12A Robot Actuator from Robotis (photo: Trossen Robotics, LLC)*

The servo gives motion to the robot, and is to the robot what your muscles are to you. The servo rotates in two directions, forward and backward. Depending on where we place the servo, it can move the robot's limbs up and down or left and right. This type of action is called a *single-axis, or 1X, motion*. The servo moves on one axis, in two directions.

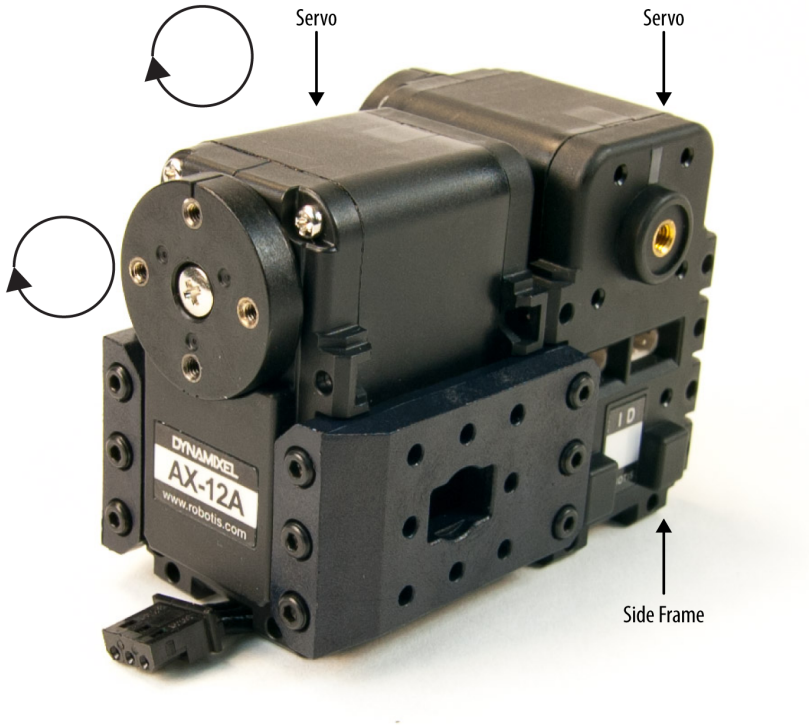

Figure 10-5. *Example 2X axis servo configuration: Dynamixel AX-12A Robot Actuator from Robotis (photo: Trossen Robotics, LLC)*

A servo's single axis of motion is a great way to replicate the action of simple joints, like an elbow that only needs to move up and down. To achieve more complex movement, we'll need to add a second servo to work with the first. This will give us what is call a *double-axis range of motion*, or 2X axis: the first servo moves the joint, say, left and right (what your chiropractor would call "inversion and eversion"), while the second servo moves the joint up and down (also known as "flexion and

extension"). This arrangement works to replicate something like the ankle, allowing the robot to move the foot up and down as well as left and right.

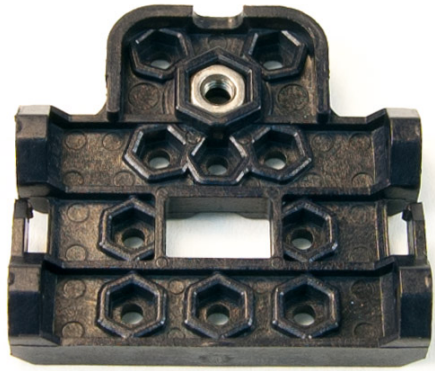

Figure 10-6. *Example frame designed for the Dynamixel AX-12A Robot Actuator from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

We're going to need a *frame* to hold the two servos together. This frame is a specially designed piece of plastic or metal that has been designed to work with a specific set of servos, like the AX-12As in Figure 10-7.

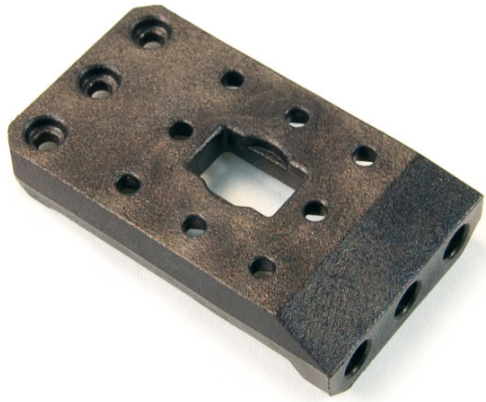

Figure 10-7. *Example frame designed for the Dynamixel AX-12A Robot Actuator from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

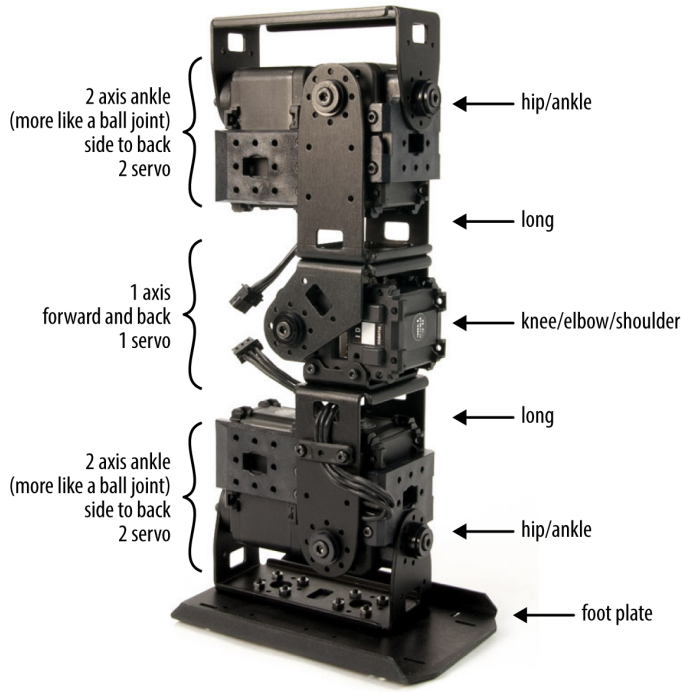

Figure 10-8. *Leg-and-foot endoskeleton from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

With our single servo for simple movements and our two joined servos for more complex motion, we now have the basics for what we'll need to get our robot moving. Let's start with the feet and legs.

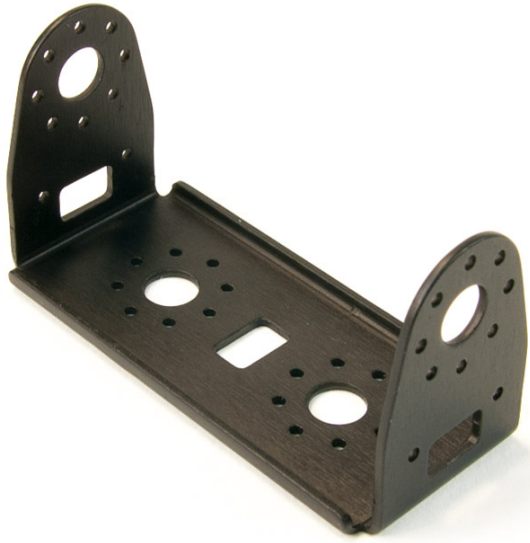

Figure 10-9. *Hip/ankle bracket from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

THE FEET AND LEGS

The feet and legs of the robot are some of the most complex parts. The chain of servos, frames, and brackets (we'll explain that in just a moment) provides the fundamental structure to get your robot to walk.

Figure 10-10. *Foot bracket from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

Because the motion of the foot is essential to not only balance our robot but also to get the bot walking, we'll need to use the 2X axis servo configuration, meaning we'll need to use two servos connected together with a specially designed form.

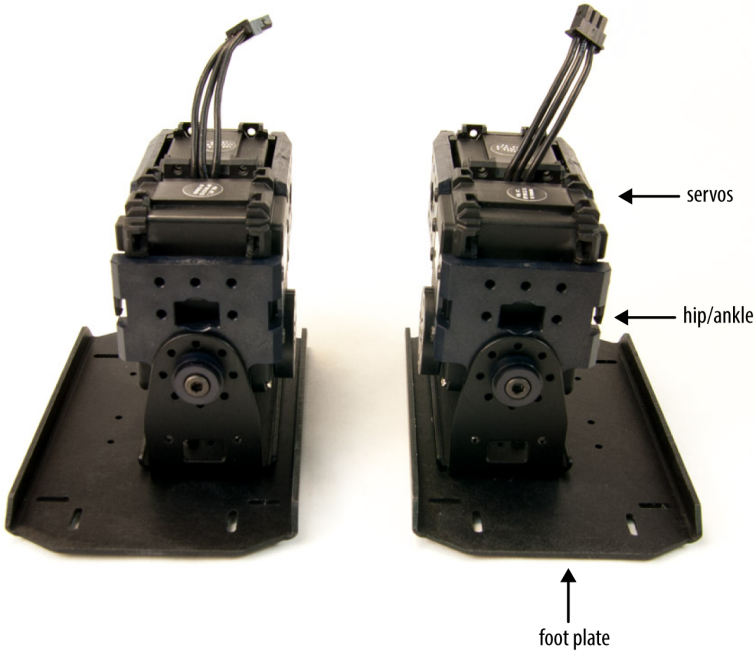

Figure 10-11. *Foot and ankle configuration from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

If the servo is like the muscles for your robot, then the brackets are like the bones. Like the frame, a bracket is specially designed to work with specific servos and robot kits. The brackets needed for the ankle and foot of our robot is the foot bracket and the hip/ankle bracket. (Note that it's called the hip/ankle bracket because it can be used for either.)

Figure 10-12. *Long bracket from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

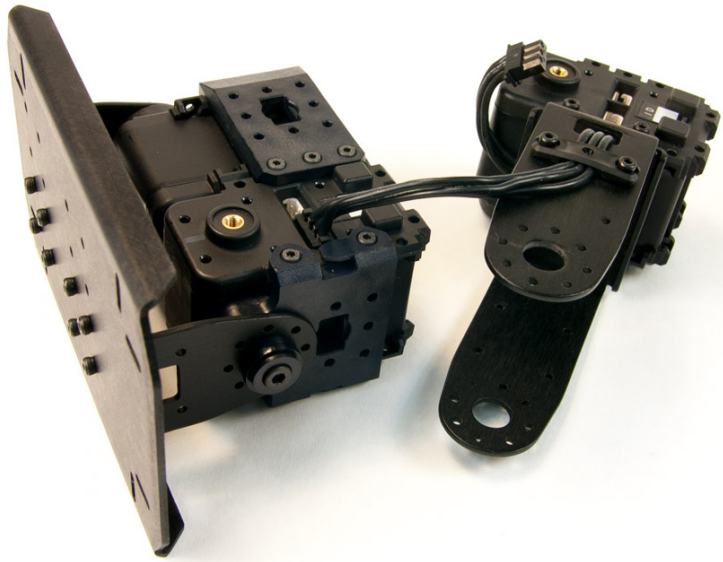

Figure 10-13. *Long bracket connecting to the foot/angle servos from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

The hip/ankle bracket attaches to one of the servos in the ankle. Then the hip/ankle bracket attaches to the foot bracket. This will give our robot the stability needed to both stand and walk.

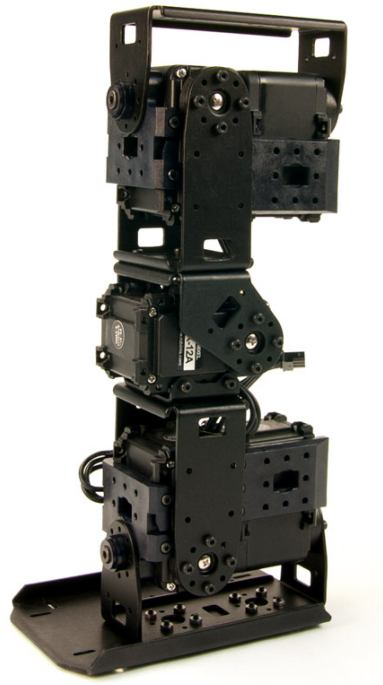

Figure 10-14. *Detail of leg from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

The second servo is then connected to a long bracket. The long bracket acts as the leg support, connecting the foot/ankle servos to the knee.

Figure 10-15. *Knee/elbow/shoulder bracket from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

Figure 10-16. *Knee/elbow/shoulder bracket connects to long bracket for upper leg from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

We only need a single servo to move the leg forward and back. The upper part of the knee is connected to the upper leg using a knee bracket connected to a second long bracket. This long bracket then connects to another 2X axis servo set that is built in the same way as the foot/ankle servos. Finally, just as the hip/ankle bracket attached to the foot, the upper part of the leg connects to the torso and hip section using a hip/ankle bracket.

Figure 10-17. *Upper leg long bracket connects to knee from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

Because the knee is a simpler motion than that of the foot/ankle servos, we only need a single servo to move the leg forward and back. The upper part of the knee is connected to the upper leg using a knee/elbow/shoulder bracket connected to a second long bracket. This long bracket then connects to another 2X axis servo that is built in the same way as the foot/ankle servos. Finally, just as the hip/ankle

bracket attached to the foot, the upper part of the leg connects to the torso and hip section using a hip/ankle bracket.

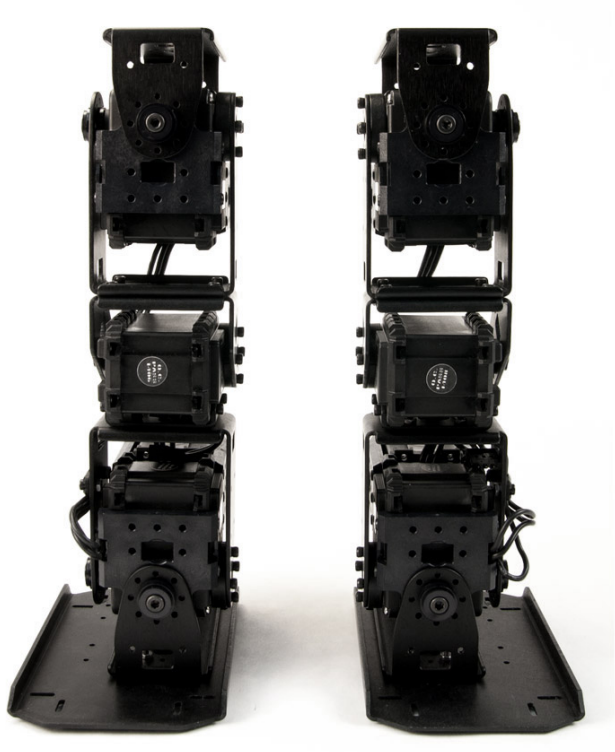

Figure 10-18. *Two completed legs from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

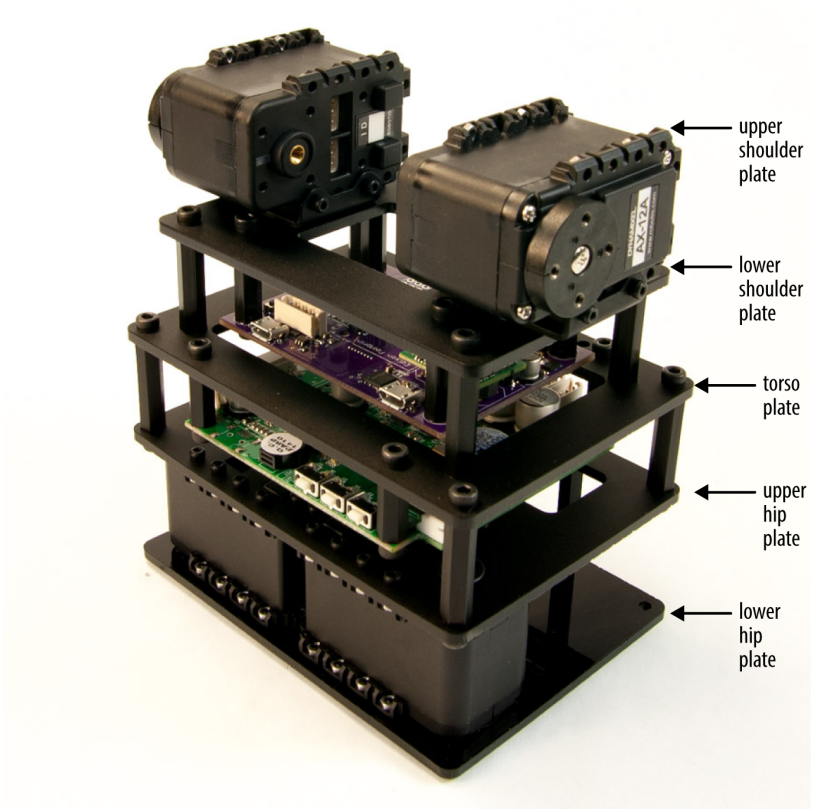

Figure 10-19. *Completed torso from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

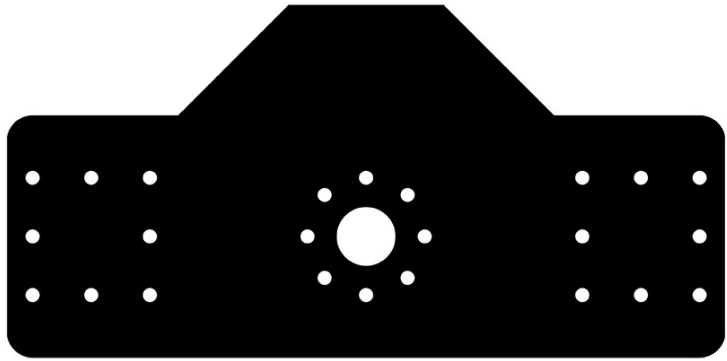

Figure 10-20. *Upper shoulder plate from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

The three pin cables from each servo connect together to create a chain of servos. These wires are threaded up through each leg. When you are building the legs, it's always important to remember that the second leg is a mirror image of the first leg. If you put the legs together as exact copies, you could give your robot two left feet!

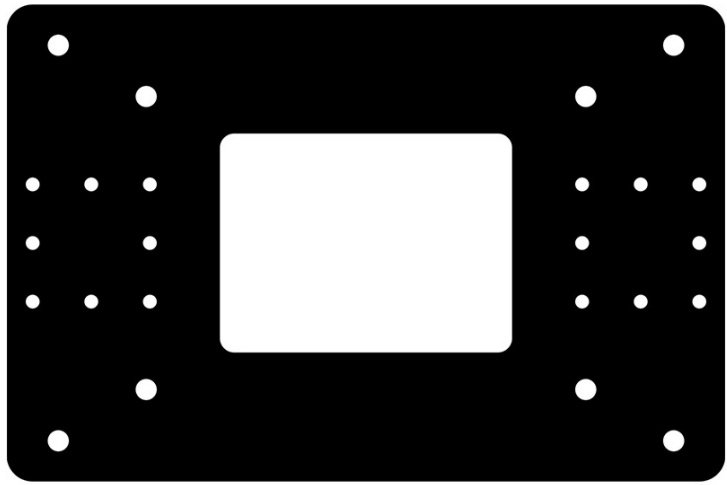

Figure 10-21. *Lower shoulder plate from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

HIPS AND TORSO

Now that we have two legs, we will attach these legs to the hip and torso section of the robot. The hips and torso serve two critical tasks. The hips provide an extra range of motion to the 2X axis servos at the top of the legs, so that the hips function much like the ball-and-socket joint in your own hips. This wide range of motion allows the robot to walk.

Second, the torso is where the majority of the electronics for the robot are located. The torso gives structure to the bot, and protects the brain (the processor and carrier board), the subcontroller board (which allows all of the servos to work together), as well as the battery and a range of sensors.

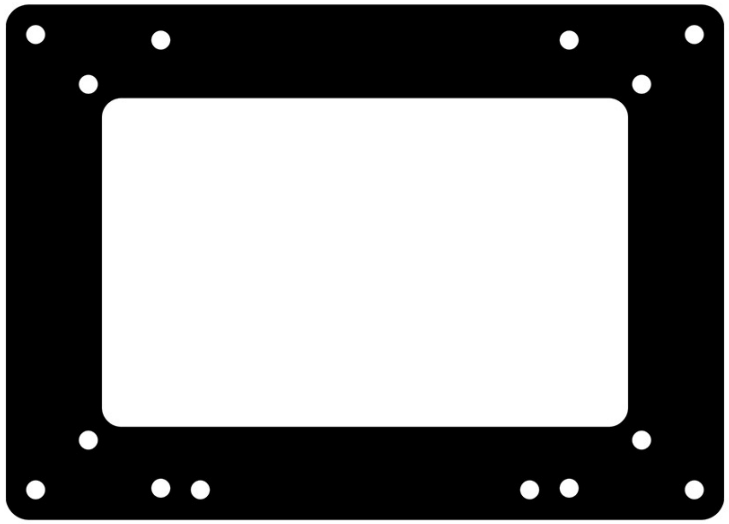

Figure 10-22. *Torso plate from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

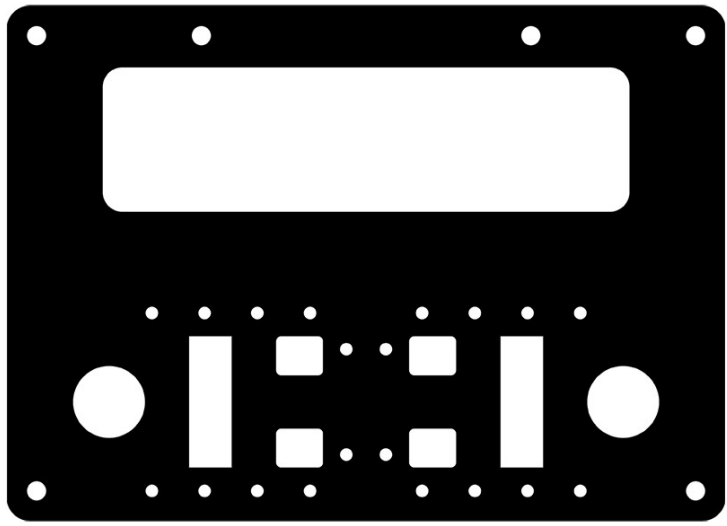

Figure 10-23. *Upper hips plate from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

To start building our torso, we'll need to assemble multiple levels of specifically designed plates. These plates are made to hold the robot's electronics and servos. From top to bottom, these plates are: the upper and lower shoulder plate, the torso plate, and the upper and lower hip plates. Between each plate we'll use hex standoff spacers that attach through predrilled holes to separate the plates at the appropriate height, and to give the torso the stability it needs.

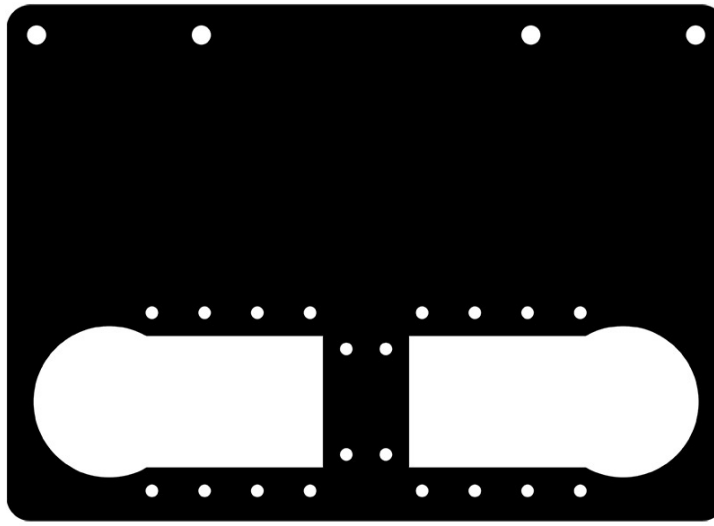

Figure 10-24. *Lower hips plate from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

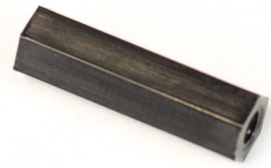

Figure 10-25. *Detail of hex standoff from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

During the construction of the lower hip plate, we'll also attach the two additional hip servos to give the robot an added range of motion.

Also, as we build up your plates, the electronics are added to the torso. Inside the torso, you'll find the main brain of the robot, connected to a carrier board that is specifically designed for your robot. This is the conscious part of your robot's brain. This carrier board is connected to the subcontroller or microcontroller. This is the autonomic system part of the brain the controls the servos as well as your robot's walking and balance (Figure 10-26).

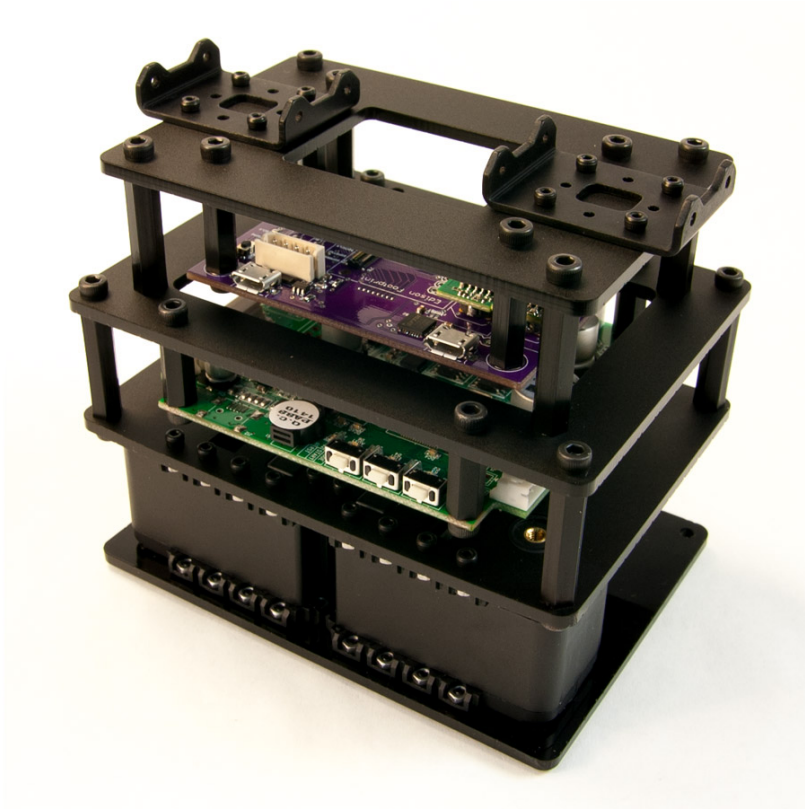

Figure 10-26. *Torso with electronics installed from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

Finally, we attach two additional servos to the upper shoulder plate, and the hip/torso is ready to connect to the legs (Figure 10-27).

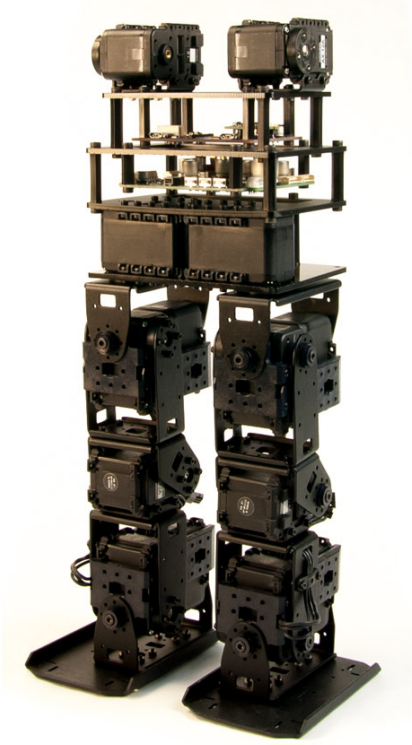

Figure 10-27. *Hip/torso with servos attached at the shoulders and also connected to legs from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

ARMS

Compared to the complexity of your robot's legs, its arms are pretty simple. The upper and lower arms consist of a single servo each, giving each a 1X axis up-and-down motion. The servo in the shoulder, when combined with the servo in the upper arm, allows the robot to raise and lower the arm.

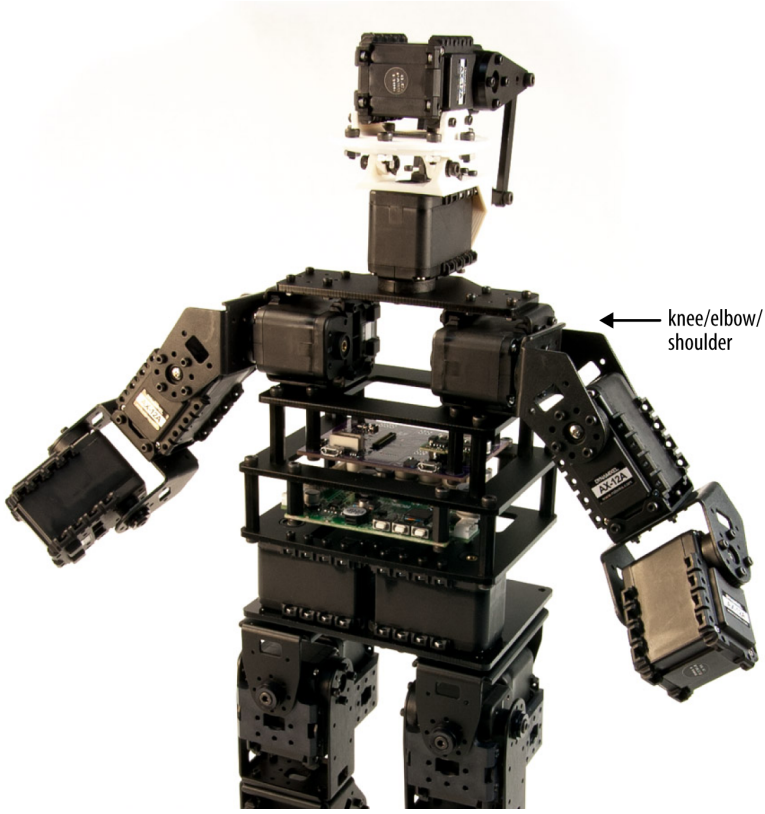

Figure 10-28. *Final arms connected to the hip/torso section at the shoulder from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

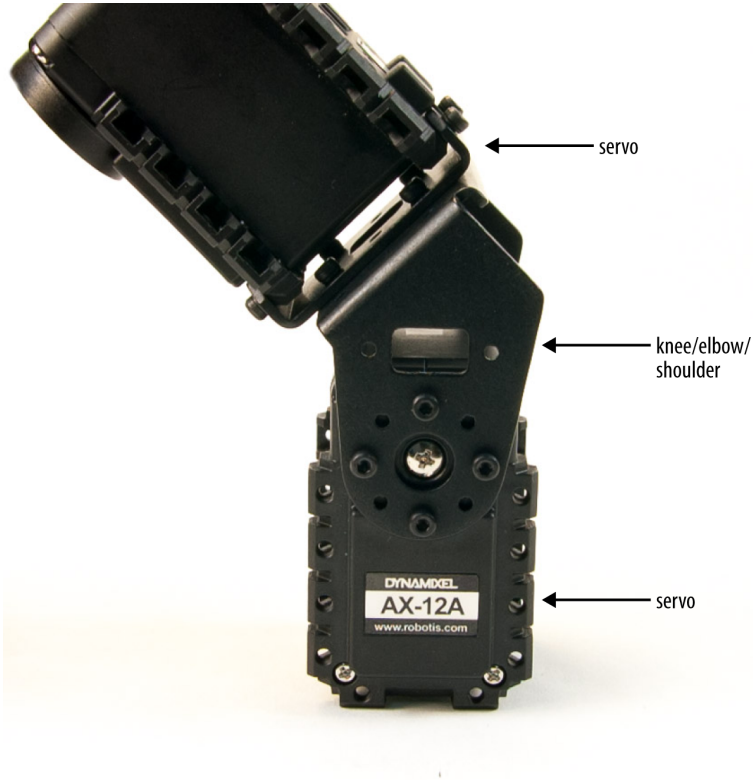

Figure 10-29. *Upper and lower arm servos from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

Figure 10-30. *Elbow/knee/shoulder bracket from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

The upper and lower servos in the arm are connected together with an elbow/hip bracket. The lower arm servo allows the robot to move the hand from side to side. When combined together, these servos allow the robot to gesture and also help to push it up if the bot falls over.

HEAD AND NECK

The final step in assembling the endoskeleton of your robots brings us to the head and neck. The neck is made up of two single servos. The lower servo allows the head to turn left and right, and the second upper servo enables your robot to look up and down. To accomplish this up-and-down motion, we use a tilt plate with two tilt levers and linkages driven by the upper servo. When connected to the head mount, this will move the robot's head up and down. The entire head and neck assembly attaches to the shoulder plate of the hip/torso section.

Figure 10-31. *Back detail of the tilt lever and linkage connected to the servo and head mount from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

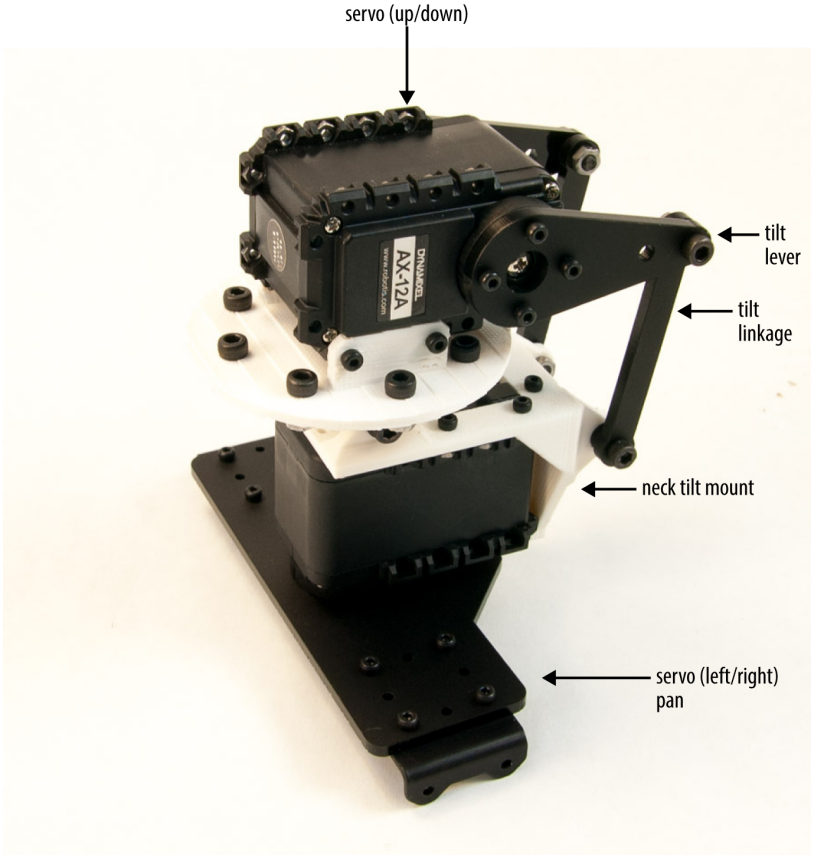

Figure 10-32. *Side detail of the tilt lever and linkage connected to the servo and head mount from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

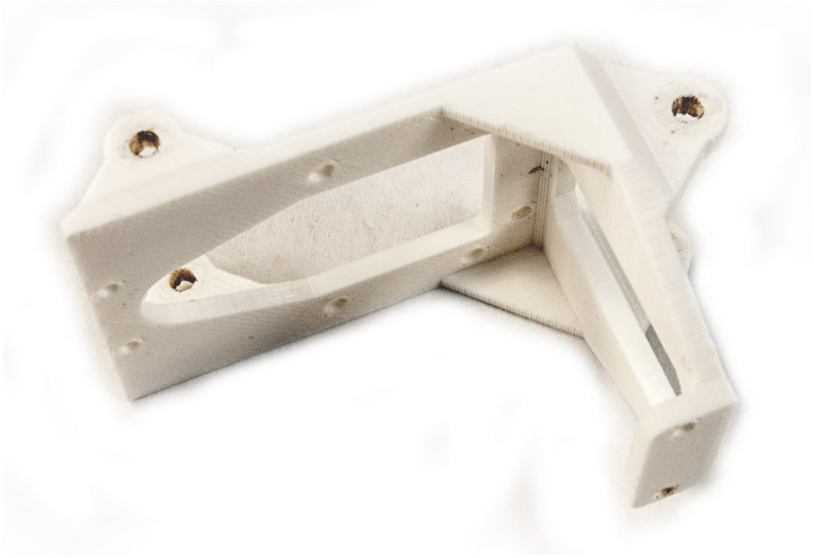

Figure 10-33. *Detail neck tilt mount from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

Figure 10-34. *Detail neck mount from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

Figure 10-35. *Detail head mount from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

Figure 10-36. *Detail tilt linkage from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

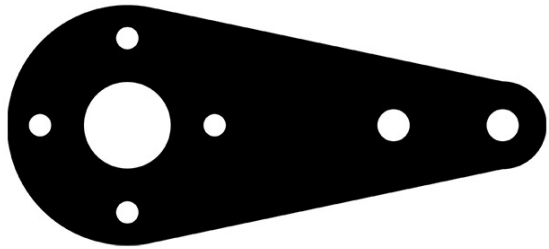

Figure 10-37. *Detail tilt lever from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

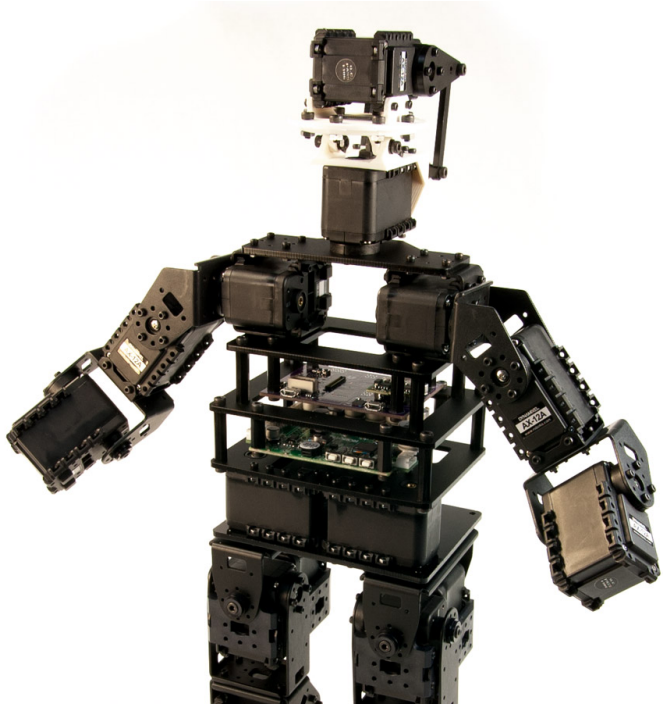

Figure 10-38. *Head and neck from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

Once you have connected all of the servo wires and electronics, you're done with your endoskeleton and can finish designing the look of your robot.

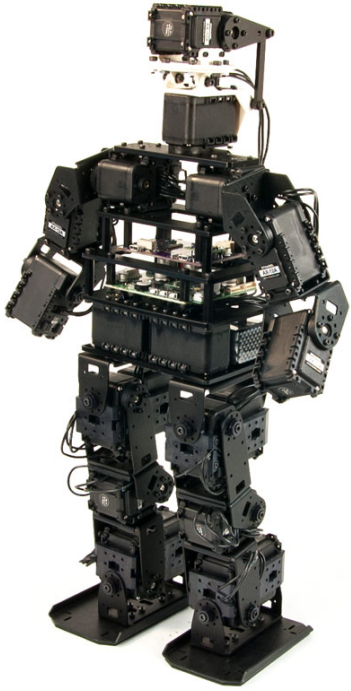

Figure 10-39. *Endoskeleton from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

EXOSKELETON

The exoskeleton of your robot will finalize the look of the bot. You can design and 3D-print this exoskeleton. The exoskeleton performs a number of tasks. First, it is what your robot will look like; it's the beginning of the bot's personality. Second, the exoskeleton can protect the inner workings of the robot. Finally, the exoskeleton provides places for added functionality. If you want to add new sensors, such as cameras or microphones, the exoskeleton gives you a place to attach them.

Figure 10-40. *Exoskeleton "shell" modeled to look like Jimmy from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

The exoskeleton is made of multiple 3D-printed pieces. The size and number of these pieces will depend on what kind of robot you are building.

To design the look of your robot, you can start with a generic exoskeleton file. This will give you a place to begin and also ensure that you can attach your exoskeleton to your endoskeleton.

Starting with the generic exoskeleton, you can make modifications to specific areas of your bot. You can adjust the look of your robot to better fit its personality. Do you want to adjust the head? What would you do to the chest and back? How about the arms or legs? The look of each part of the robot is up to you. You can download an example exoskeleton from our website.

Figure 10-41. *Expanded view of endoskeleton from the Trossen Robotics Jimmy Kit (photo: Trossen Robotics, LLC)*

PRINTING

Once you've completed the design for your exoskeleton, you can print it at home if you have a 3D printer, or you can order it from a 3D printing service.

Booting Up Your Robot

Your robot's brain runs on software you can download from our website. You can develop it on a laptop or tablet even before you start physically building your bot. How much you want to know about your robot's brain and how much you work on

it is up to you. You can dig down into the source code or simply download apps to personalize your robot.

YOUR ROBOT

Your Robot is a development environment that lets you start exploring and developing your robot's brain. Start by downloading the 21st Century Robot brain at our website to your computer. Like the original inspiration for the 21st Century Robots—the story "A Robot Who Sees Angels"—we want all of us to have a way to design and program our robots' brains together.

Your Robot will bring up a 3D model of your robot (based on Wayne's designs). You'll be able to customize your screen robot's look later. Using your tablet, smartphone, or computer, you can position the bot's arms and legs, teaching it simple movements or more complicated dance moves. The software records the movements and stores them for later use, once the robot's brain has been transferred to the physical bot.

Also in *Your Robot*, you can choose specific apps you want to load into your robot's brain. You can choose from existing apps or mash up your own. With a little more work and a little more coding know-how, you can start writing new apps for your robot. See the tutorials at our website for more information.

As we were finishing up this book, I started asking all the members of the 21st Century Robot Collective what apps would be good for a robot. We had fun with this. What would a weather app be like on your robot? Would you ask the bot the weather and then get an update? Or would the robot come find you every time the weather changes?

How about a fitness app? Would your robot try to get you up off the couch and moving around?

One favorite was a mash-up between a tango dancing app that teaches your robot to dance the tango and an alarm clock. Imagine mashing these two together so that your bot wakes you up by dancing the tango in your bedroom.

How could a robot use a search engine? You could ask the bot anything and it could search the Internet for answers. Could you customize it so that your robot learned what you liked and told you interesting searches each day? What would you ask your robot to look up for you?

The list of possible apps goes on and on. You're only limited by your creativity and who you want your robot to be.

YOUR ROBOT'S VOICE

You can also give your robot a voice so that it can talk back to you. There are different kinds of voices for your robot, and different options to choose from, adjusting things like volume, pitch, and speed.

Getting Your Robot Working

The next step in the robot-building process is to boot up your bot for the first time. All our makers, from Wayne to Andrew, told us they felt a specific excitement when they brought their robot to life for the first time. It's a unique experience. This is a robot that you've built in your imagination and now it's about to start moving around in the real world. That's amazing!

When you boot up your robot for the first time, it's important to make sure that the brain is talking to the body and that your bot is running properly.

HELLO!

Now that you have assembled all the pieces, we need to make sure that all the pieces are working correctly. Think of the HELLO! Protocol as a kind of doctor's checkup for your robot. The HELLO! Protocol checks out your bot's motors, nervous system, and battery to see if they're up and working correctly. It also checks to see if there's a connection to Internet.

The HELLO! Protocol, which you can find at our website, will walk you through the steps to ensure that your robot is working as it should.

It's important that the brain is connected to the nervous system, that the nervous system is connected to the servos, and that they are all working together. Once you've given your robot a physical, you'll be able to teach the bot to stand, walk, and interact with you.

As a final bit of advice, Andrew Alter once told me to always make sure to charge your batteries. "I know it might sound silly," he said, "but it's a simple thing and a lot of people forget to do it."

Trouble! Problems!

At the 21st Century Robot Collective, our goal is to make building a robot easy and fun. But sometimes it may not always be easy and fun. If you run into trouble, there are lots of videos and designs on the website to help you.

NEXT: Seven Billion Best Robots Ever!

Our final chapter ponders how to build the perfect robot. Or is that the wrong question to ask?

Seven Billion Best Robots Ever

Jay Silver is a maker, designer, and inventor. I've worked with Jay for a few years and feel lucky to know him. Jay invented MaKey MaKey, an invention kit, with Eric Rosenbaum. MaKey MaKey allows you to turn anything into an interface. Just plug the board into your computer with a USB connector and, using alligator clips, you can turn anything into a keyboard or device to control your computer. There are amazing YouTube videos that show how people have turned bananas and stairs into pianos, Play-Doh into Super Mario controllers, and even buckets of water into Dance Dance Revolution controllers!

As you can imagine, Jay has a unique perspective on design. He gave a TEDx talk called "Hack a banana, make a keyboard!" that expressed what it means to be an open source maker, and what we hope to accomplish with the 21st Century Robot Project.

As builders and designers, we spend our lives trying to make the best possible product or thing. We want to design the perfect chair. We want to write the best computer game. We want to design the best robot ever!

But that's not really the way things work. There is no best robot ever. Everyone is different, and my robot can only be the best robot for me. It's terrible to think that people could only have to choose from other people's ideas of the best robot ever.

The goal of the 21st Century Robot Project is not to make one amazing robot. We believe that the goal shouldn't be to design and create the best robot ever. Open source design, and the creativity of makers, means that everyone can take what other people have done and modify it to make *their* best robot ever. All of the people in this book, and all of the people involved with the 21st Century Robot Collective, want to provide you with the tools and materials, the design and code, everything you need to create your own robot. We want everyone to imagine, design, build,

program, and share their own robots. That way we'll have seven billion best robots ever!

How This Book Ends

It was dark backstage—really dark. I stood just to the side of a massive three-story-high curtain. Jimmy was just a foot away, hidden artfully behind a black, velvet-covered box. The stage manager didn't want the audience to see Jimmy before his cue to walk on stage. Andrew Alter, whom you met in Chapter 9, sat on the floor at the other side of the curtain. He was ready to send Jimmy walking when the moment came. We waited. The air was full of excitement and tension.

We were tense because we had spent the last two days getting Jimmy ready for his big debut, and it hadn't gone smoothly. The carpet on the stage was extremely uneven, making it hard for Jimmy to walk and balance. It was so bad that he had fallen over a few times, prompting Andrew and me to fling ourselves at the little bot to try to catch him. But we learned that he was a tough little guy, and with a little tuning he could walk just fine.

There were other glitches and problems because this Jimmy was the first we had brought out into the real world. The bugs and problems were to be expected, but that didn't make us any less tense. We wanted Jimmy to be perfect for his debut.

We waited. Andrew looked surprisingly chilled out after our stressful few days.

"I don't really get nervous," he mouthed to me.

"Whatever." I smiled back.

We waited...

Then the cue came, the stage manager removed the box, and Jimmy started walking. He marched out onto the stage and I heard 5,000 people gasp with wonder and excitement. It's a truly remarkable sound.

And how did Jimmy do?

When he was finished with his lines, he walked back behind the curtain. The stage manager smiled at me, gave me the thumbs up, and said, "Flawless."

Now It's Up to You

This book is dedicated to the generation of young minds who will never know a time when they couldn't imagine, design, build, program, and share their own robots. I'm not sure we can even ponder what they will build. What will their robots do? How will robots live and interact with us in our daily lives? What will it be like when robots are as common and normal as smartphones, tablets, and TVs? This

has been the driving force behind the 21st Century Robot project: to radically change how people imagine and build robots.

But now it's up to you!

You need to start imagining, designing, building, programming, and sharing. To bring about this amazing future of robots, you need to get started. What is your 21st Century Robot going to be? What will your robot do that no one else's robot can? And after that, what's your second 21st Century Robot going to be? It's all up to you.

The future is not an accident. The future is not some fixed point on the horizon that we are all running toward, helpless to do anything about. The future is built every day by the actions of people. People build the future. You will build the future.

This book and the 21st Century Robot Project imagine a far different future for us—a future that is both optimistic and that embraces our humanity. Just as with computers in the last century, robots will be a part of our daily lives in this century. Robots will be built by people. They will be fun and creative. They will be our friends, they will make us laugh, and they will sing with us. They will be…well, they will be whatever you want them to be.

The future of robots is up to you—go make it awesome.

How to Contact Us

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We have a web page for this book, where we list errata, examples, and any additional information. You can access this page at: *http://bit.ly/21st-century-robot*.

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More Robots from Ms. Moore's First Grade Class

We couldn't include all of these amazing visions of the future of robots in Chapter 3, so I wanted to make sure we collected the rest in this appendix. This is just a snapshot of the potential for the future of robotics, and I couldn't be more excited about our future.

Figure B-1. *Danny: "I want Jimmy to play and swim with me."*

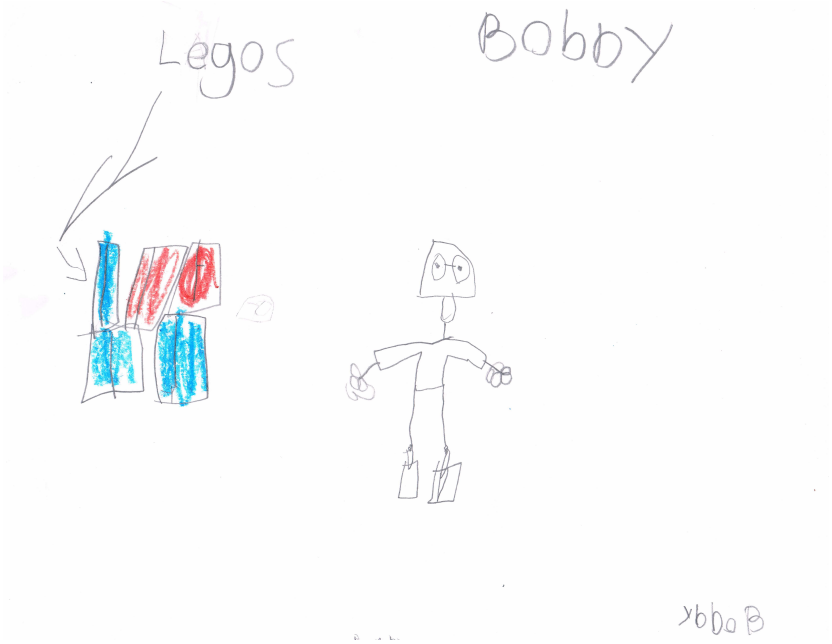

Figure B-2. *Bobby: "Legos!"*

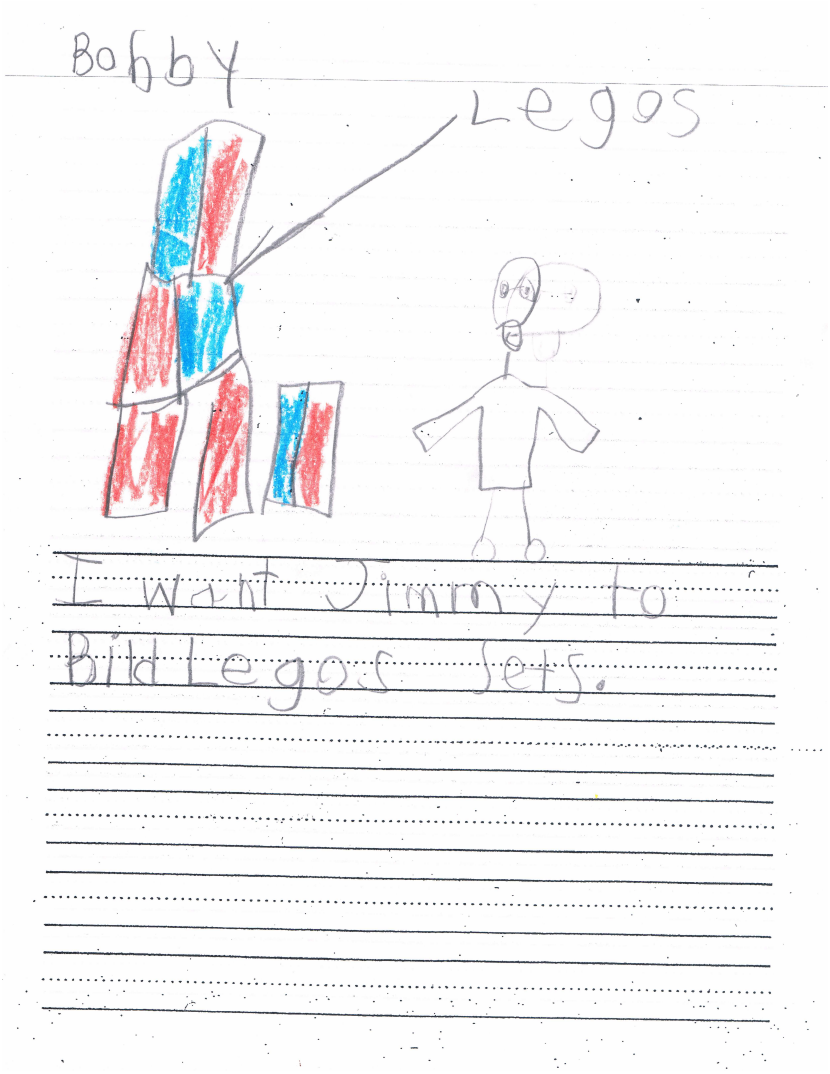

Figure B-3. *Bobby: "I want Jimmy to build Lego sets."*

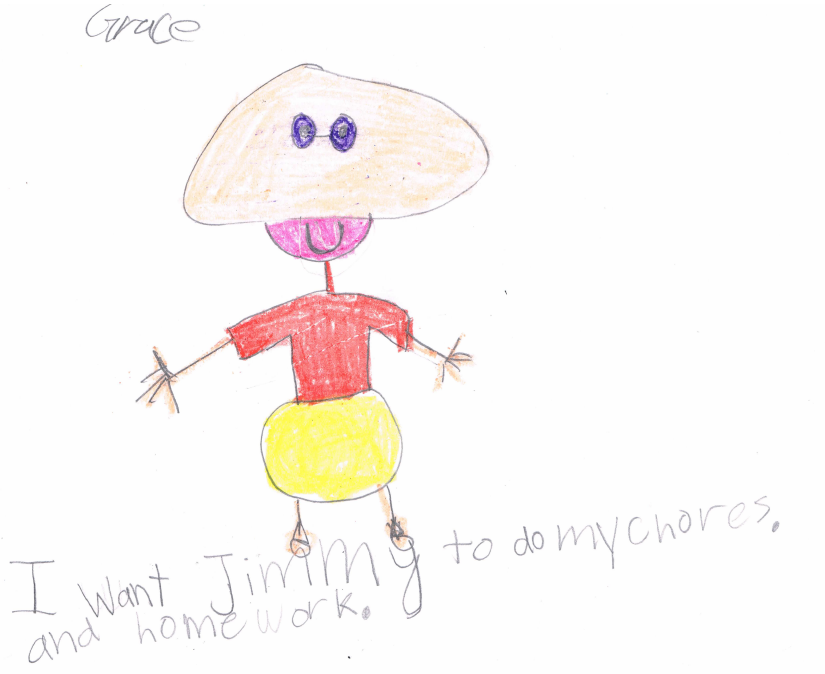

Figure B-4. *Grace: "I want Jimmy to do my chores and homework."*

Figure B-5. *Gage: "I want Jimmy to watch TV with me."*

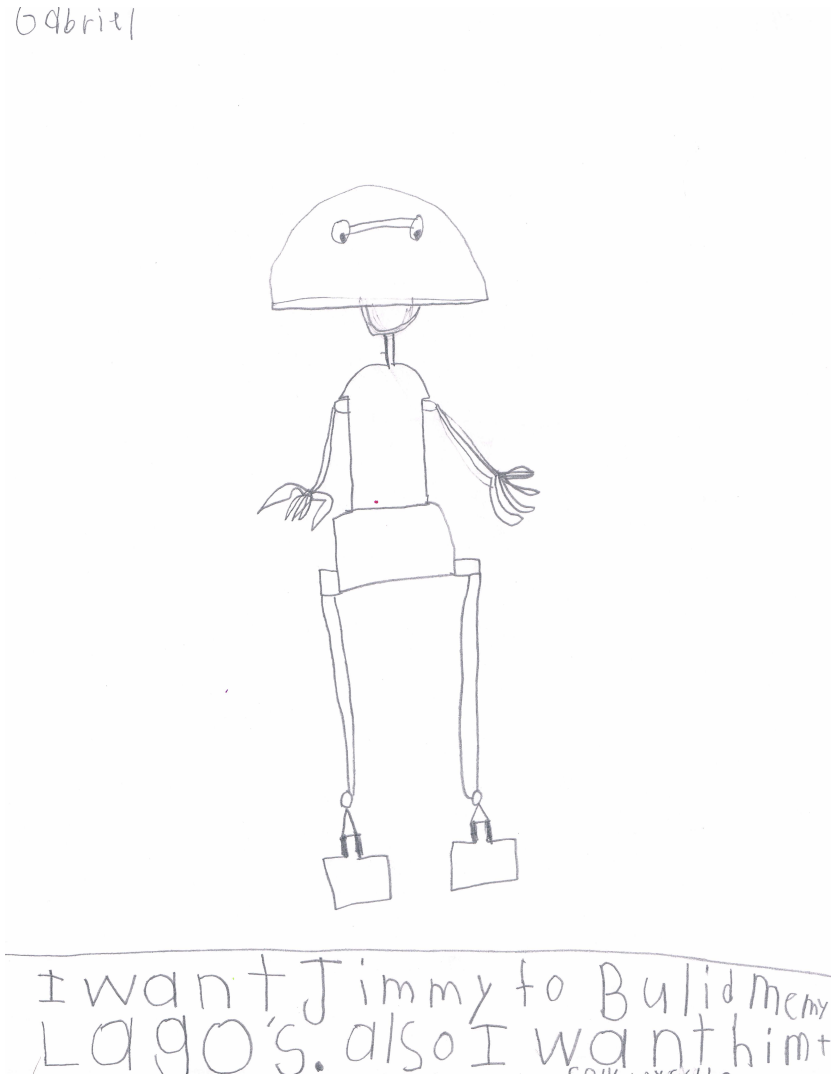

Figure B-6. *Gabriel: "I want Jimmy to build me my Legos."*

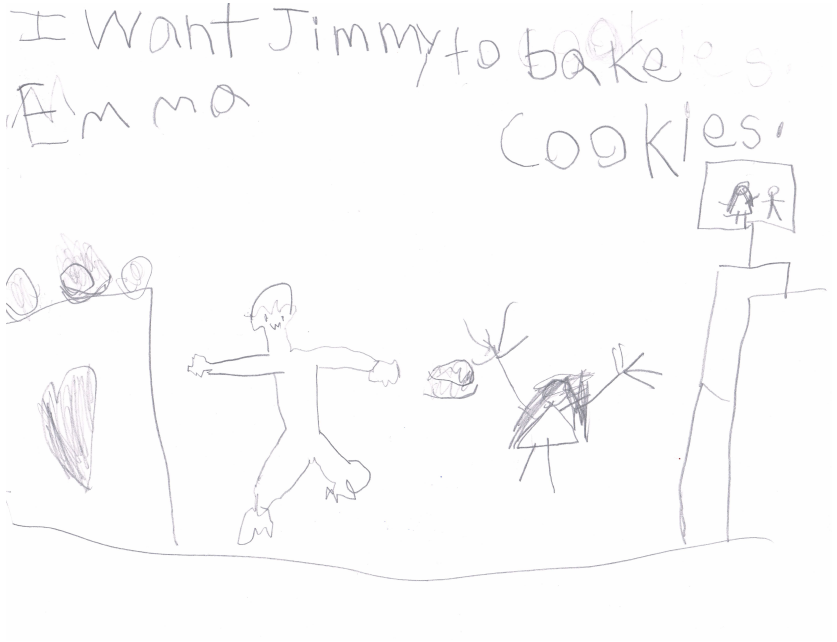

Figure B-7. *Emma: "I want Jimmy to bake cookies."*

Figure B-8. *Jackson*

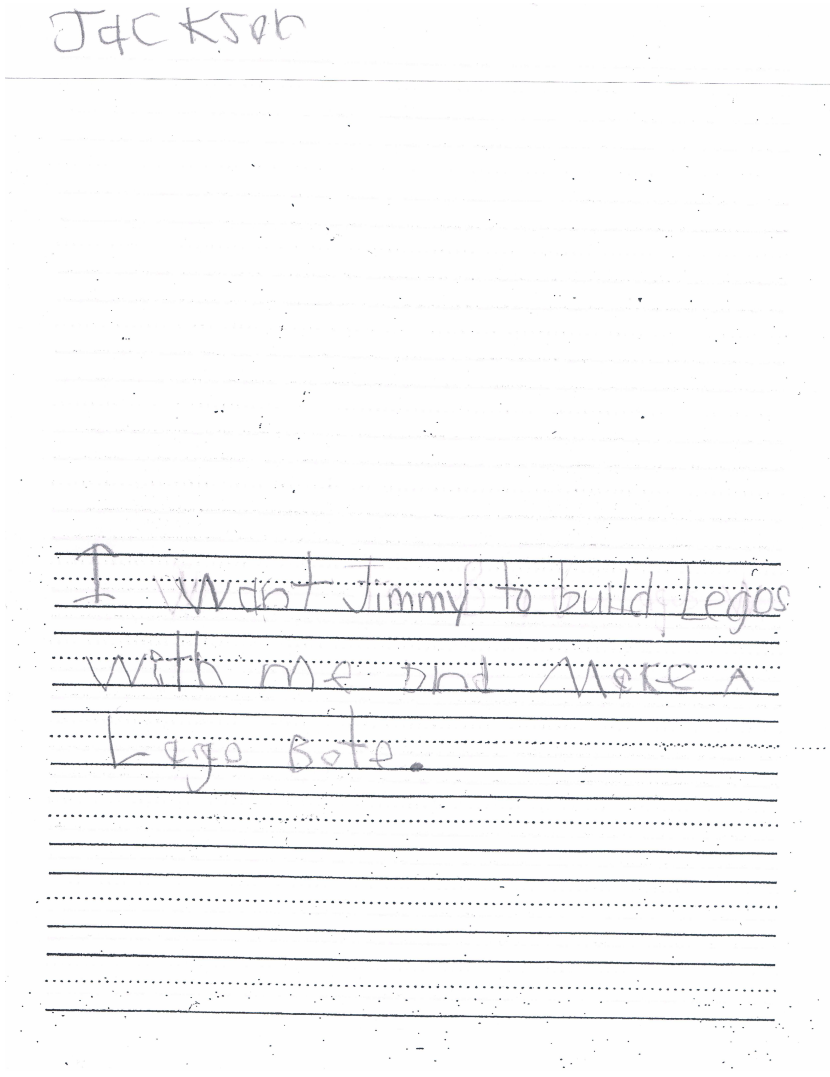

Figure B-9. *Jackson: "I want Jimmy to build Legos with me and make a Lego boat."*

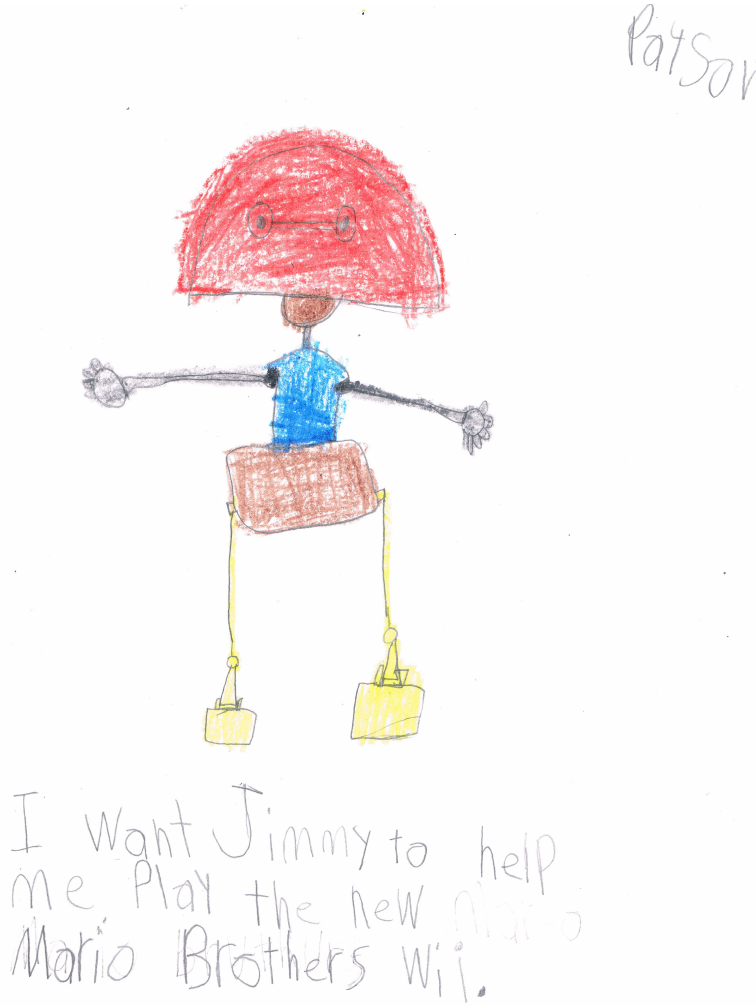

Figure B-10. *"I want Jimmy to help me play the new Mario Brothers Wii."*

Figure B-11. *Makatla: "I want Jimmy to dance with me."*

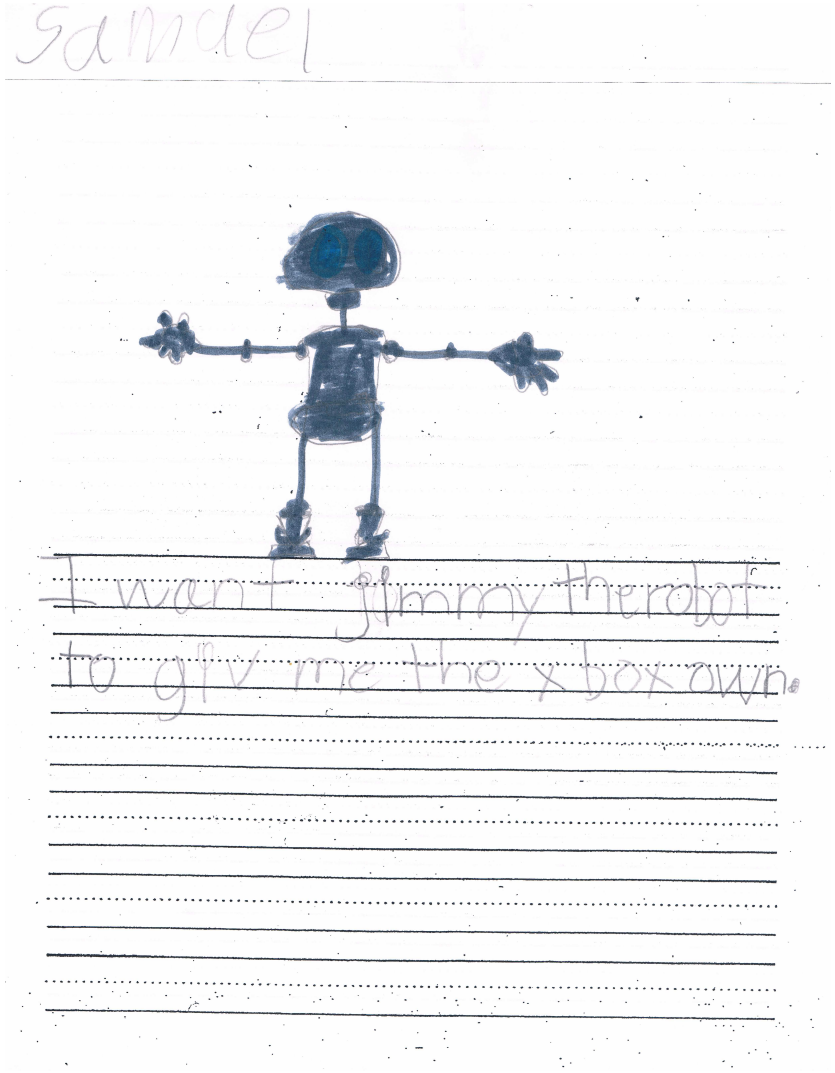

Figure B-12. *Samuel: "I want Jimmy the robot to give me the Xbox One."*

Figure B-13. *Sierra: "I want Jimmy to blow bubbles with me."*

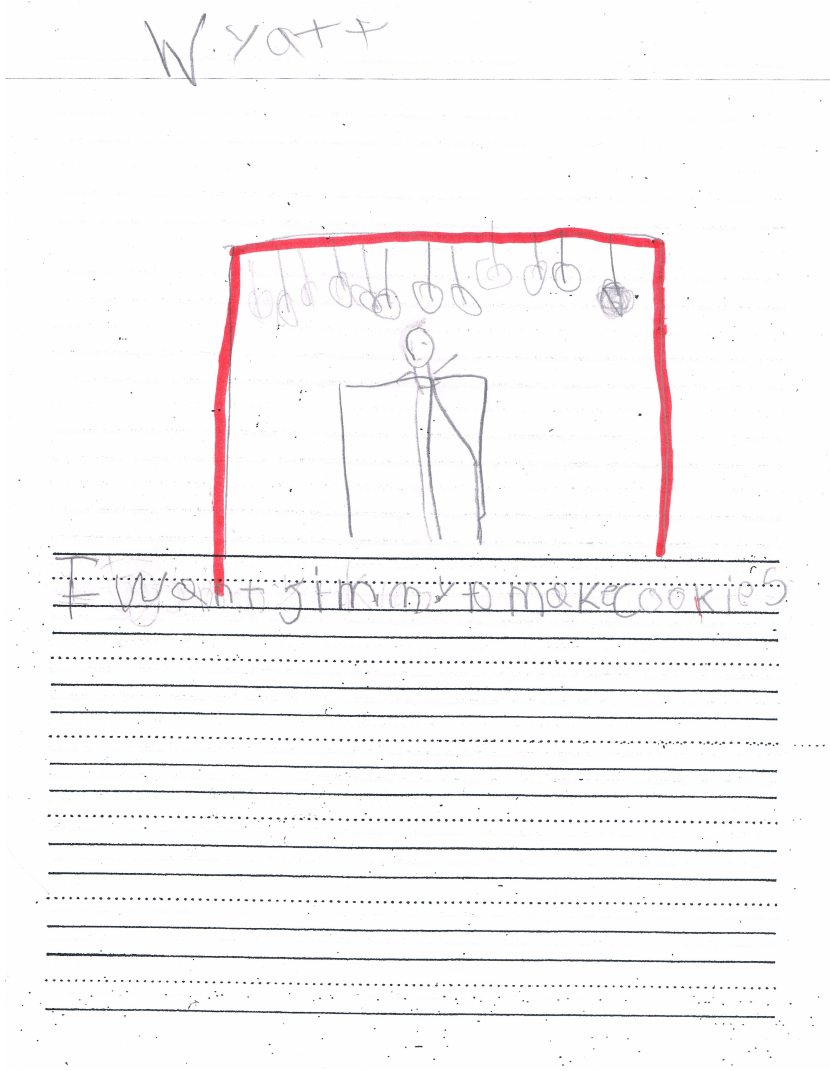

Figure B-14. *Wyatt: "I want Jimmy to make cookies."*

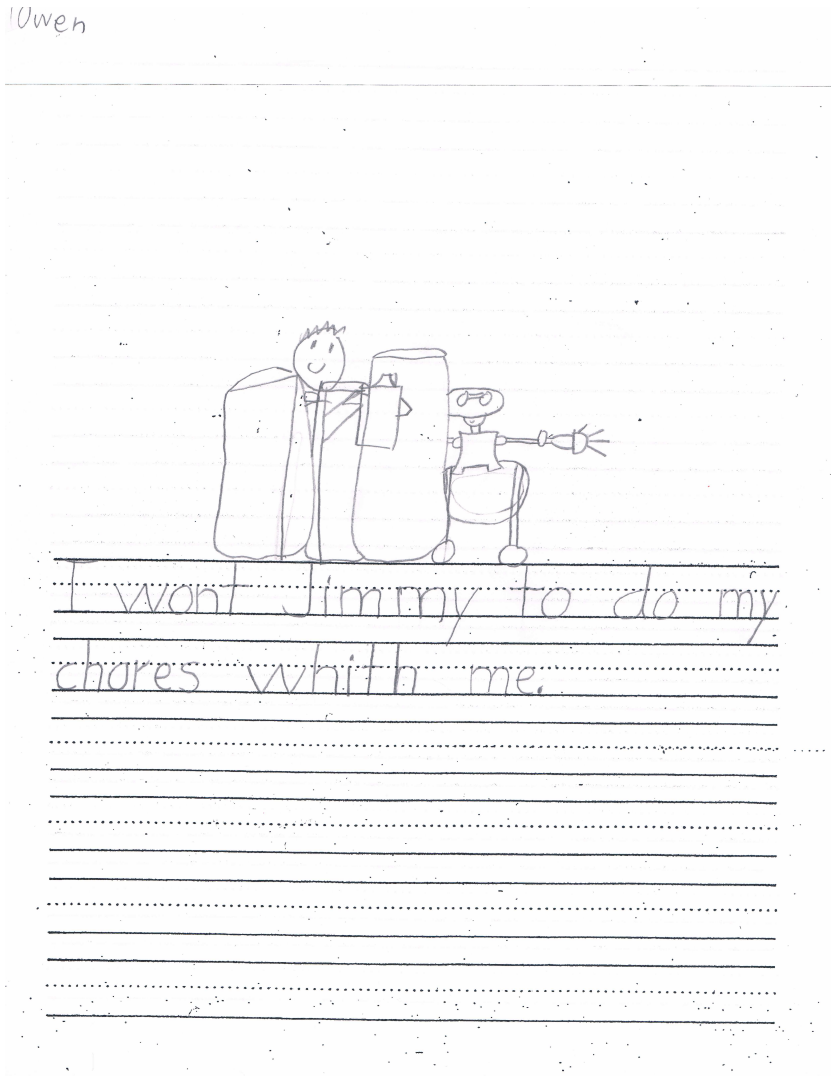

Figure B-15. *Owen: "I want Jimmy to do my chores with me."*

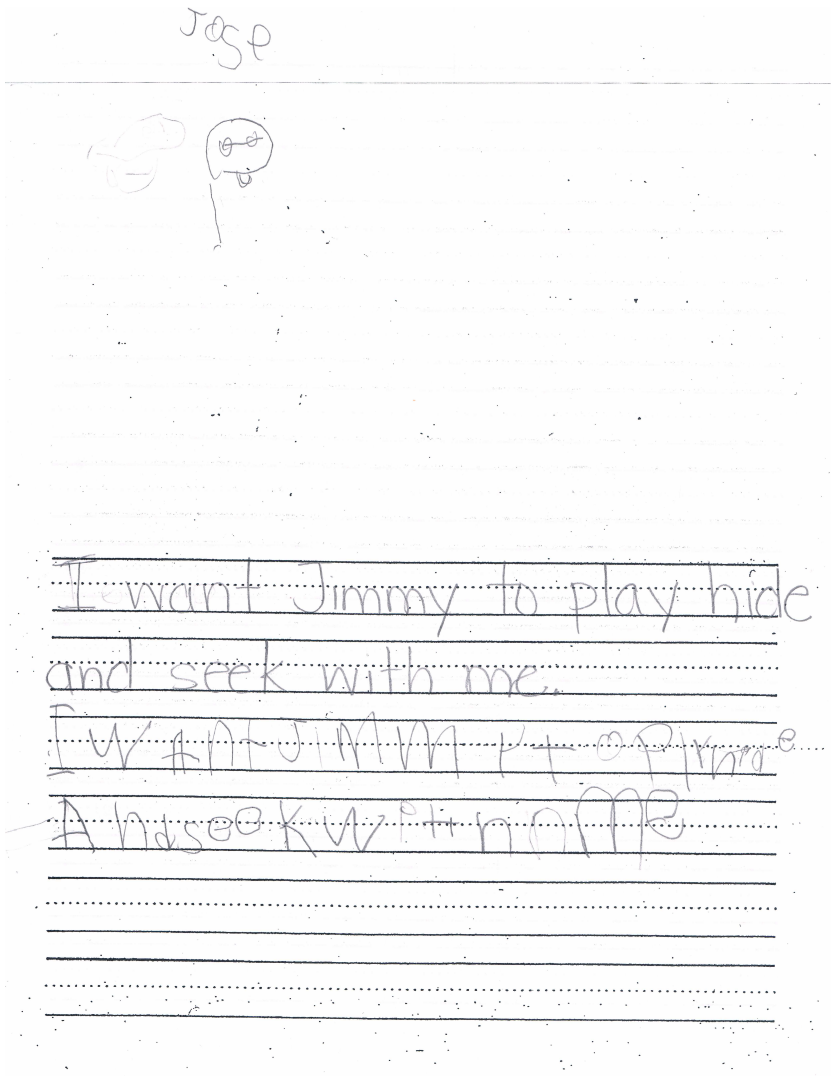

Figure B-16. *Jose: "I want Jimmy to play hide and seek with me."*

Figure B-17. *Jaice*

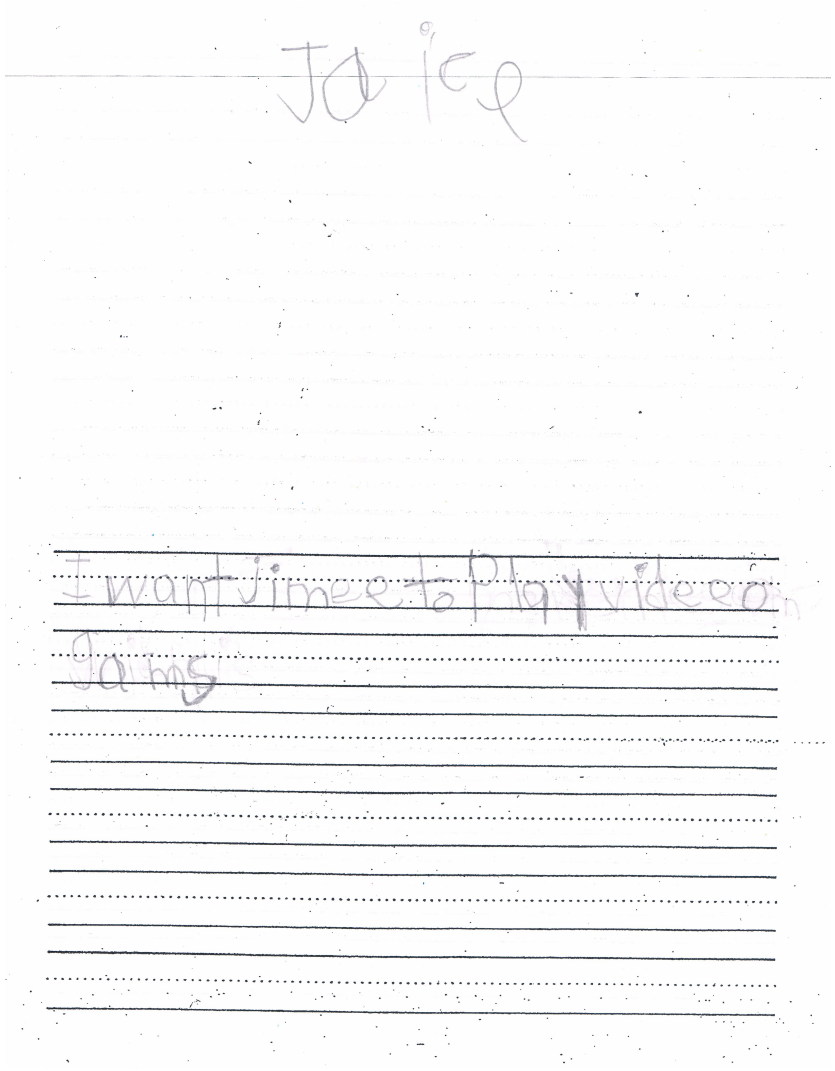

Figure B-18. *Jaice: "I want Jimmy to play video games."*

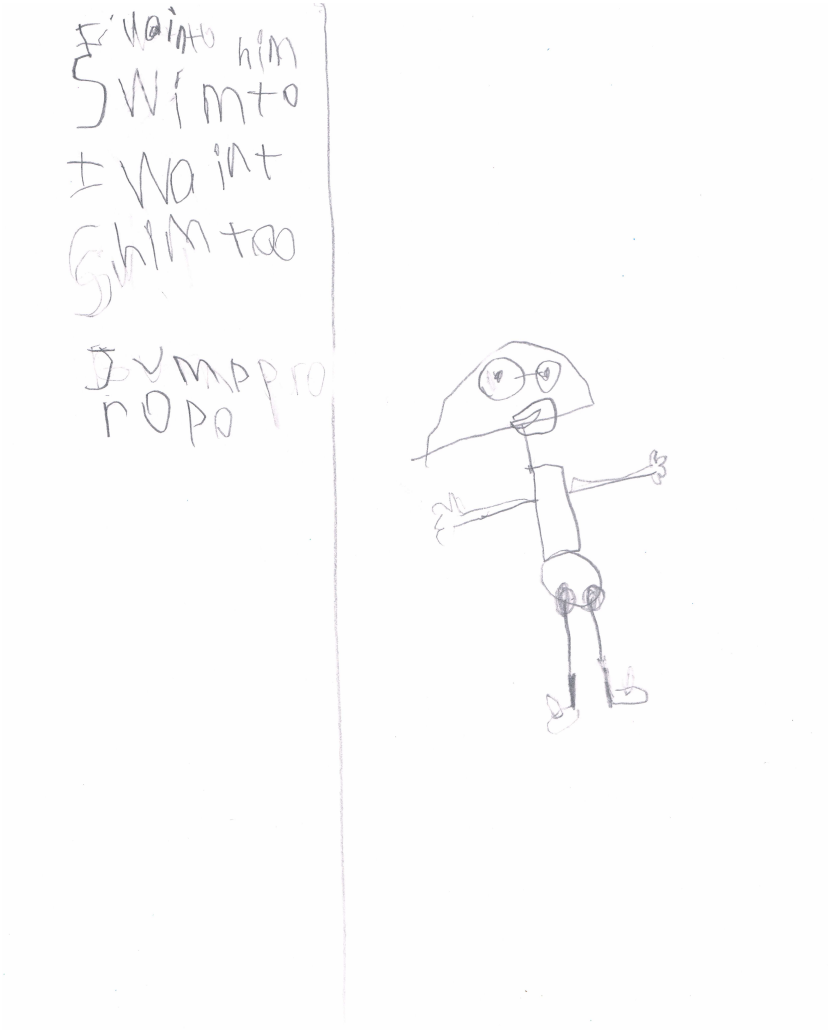

Figure B-19. *"I want Jimmy to swim and jump rope."*

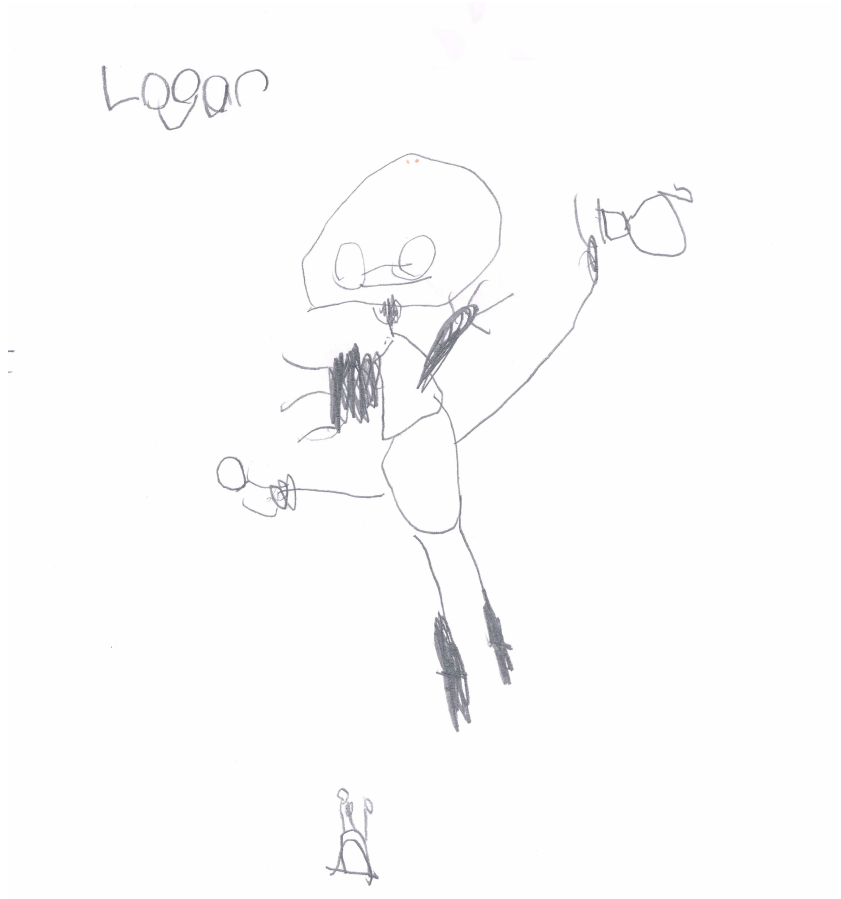

Figure B-20. *Logan*

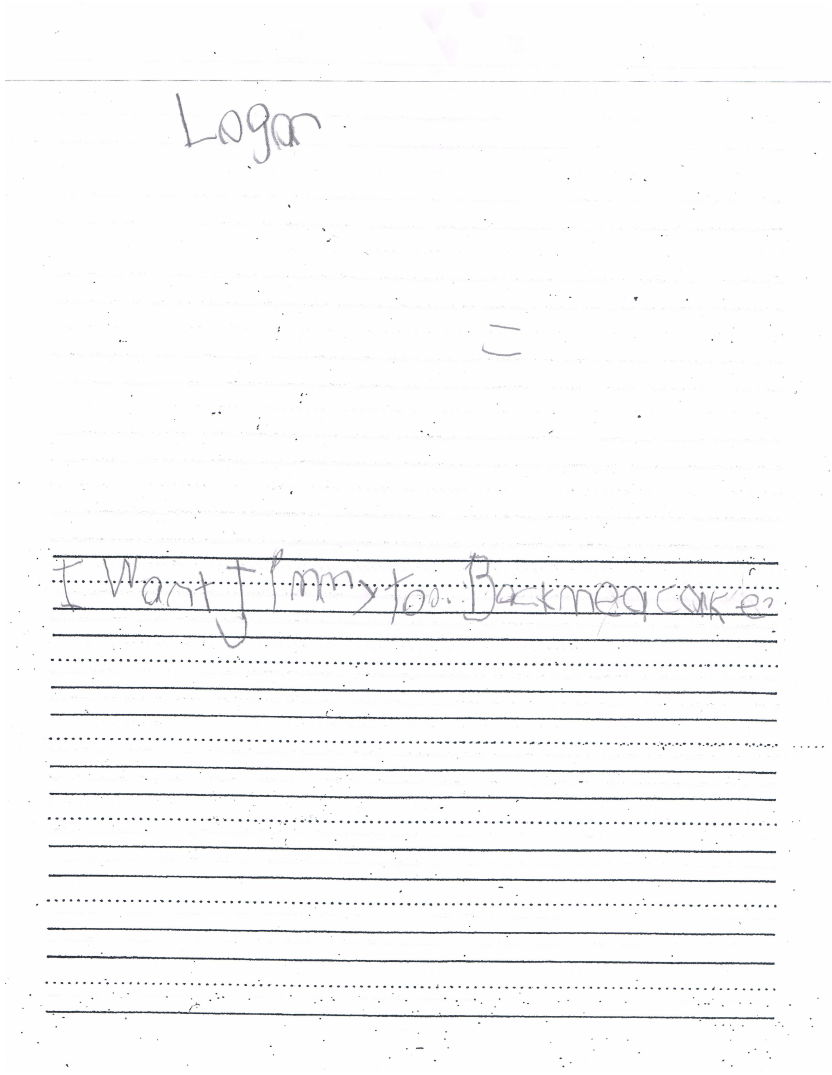

Figure B-21. *Logan: "I want Jimmy to bake me a cake."*

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About the Author

The future is **Brian David Johnson's** business. As a futurist, he develops an actionable 10–15 year vision for the future of technology and what it will feel like to live in the future. His work is called "futurecasting"—using ethnographic field studies, technology research, trend data, and even science fiction to provide a pragmatic vision of consumers and computing. Johnson works with governments, militaries, trade organizations, startups, and multinational corporations to help them envision their future. He was appointed first futurist ever at the Intel Corporation in 2009.

Johnson speaks and writes extensively about future technologies in articles (*The Wall Street Journal, Slate, IEEE Computer, Successful Farming*) and both science fiction and fact books (*Vintage Tomorrows, Science Fiction Prototyping, Screen Future and Fake Plastic Love*). Johnson lectures around the world and teaches as a professor at the University of Washington and the California College of the Arts MBA program. He appears regularly on Bloomberg TV, PBS, FOX News, and the Discovery Channel and has been featured in *Scientific American, The Technology Review, Forbes, INC*, and *Popular Science*. He has directed two feature films and is an illustrator and commissioned painter.

About the Illustrator

Sandy Winkelman (Winkstink) has always been weird. He grew up in Austin, Texas, shooting BB guns into his neighbor's open windows. He's a commissioned fine artist that refuses to sell his work. As an art director at the brand powerhouse Nike, Sandy helps to craft consumer experiences for a broad global audience—all the time being influenced by all things peculiar and abnormal. He has a passion for the distinctions between technology and the antiquated, exploring the possible spaces where the two meet. With an engineer's mind, Sandy creates arrestingly believable technological visions rooted in an absurdist and often twisted present. As a conceptual artist, all his work tells a broad and rich story, but he can never let go of the details…no, really, he can't stop himself from capturing painstaking detail

at the most minute level. He has two dogs, one that listens to him and one that doesn't.

Colophon

The cover and body fonts are Scala Pro, the heading font is Benton Sans, and the code font is TheSansMono Condensed.