Jean-François Rousseau, a plant engineer at Montreal-based Etalex, had a problem that he could not solve the usual way.

Etalex makes custom metal shelving and storage systems. To thrive, the company needs fast turnarounds and low total costs to offset its high labor costs. That means adding automation, and Rousseau has installed 30 robots since 2003.

Each robotic cell is unique. Some do potentially dangerous jobs, like loading or removing sharp-edged strips of metal from hydraulic presses. Others assemble and weld parts. One even combines part removal with spot welding. All add automated efficiency where needed, without forcing Rousseau to redesign his entire production line. And, as he notes, each robot puts in a 16-hour day without a break.

Rousseau’s problem was the massive, 12-foot-long hydraulic punch located at the front of his plant. Rousseau wanted to automate it, but it was only 6 feet from the factory’s main aisle. That posed a problem. Robotic arms are fast, powerful, and stupid. They cannot tell when people are near. They could pummel anyone straying into their path, and most conventional robots have no sensors to tell them they have hit anything as soft and pliant as a human. They would continue moving, potentially crushing an arm or a rib, or trapping someone against the surrounding machinery.

To prevent this, engineers build fences around robots. When someone walks through the gate, he or she steps on a pressure mat or breaks a laser or light beam. This triggers the robot to stop.

“We didn’t have any space to put in a safety guard, and forklifts and employees pass down that aisle all day long. We didn’t want to move the press, because it is such a big setup,” Rousseau said.

Now Another Option

Five years ago, Rousseau would have had no alternative but to shut down part of his plant and relocate the press. Now he had another option. He could install a collaborative robot designed to work safely around people.

Universal Robots introduced the first collaborative robot, the UR5, named after its 5 kg load capacity, in 2009. It is a device called a power and force limiting robot, one that handles only light payloads at low speeds. This limits its potential for hurting nearby workers.

Also, each of the articulated arm’s six joints contains dual sensors. They measure the slightest impact and trigger the robot to stop within milliseconds. At worst, a blunt robot-worker collision feels like a friendly punch delivered by an overly enthusiastic friend.

Vendors often refer to these low-powered robots as inherently safe.

Rousseau decided to install Universal’s 10 kg model, the UR10. He liked its precision and smooth motion, which resembled the behavior of the 30 conventional Fanuc indus-
trial robots he had installed over the past decade.

The UR10 proved easier to install than the Fanuc. Rousseau, who integrates his robots in-house, handed the task to a junior engineer. He trained the robot by moving the arm where he wanted it, then programmed additional instructions for turning on the grippers. One month later, the robot was removing and stacking metal strips as they came out of the punch.

Occasionally, a worker walks up to take quality measurements or remove a cart of stacked parts. A laser scanner notes when workers approach, and the UR10 reduces its speed by 30 percent. Workers feel safer when the robot recognizes them by slowing down, Rousseau said.

Eliminating fences also makes it easier to change tooling. With conventional robots, Rousseau had to take down the fence and remove the robot so a forklift carrying the massive tooling could approach the press. Now he simply unlatches a bracket and slides the robot to the side to access the press’s tooling.

Rousseau is not alone. Glidewell Laboratories, Newport Beach, CA, used a UR5 to reconfigure its manufacturing process. The company makes dental crowns. In the past, it sent instructions to a worker, who sorted colored blanks to match tooth color and loaded them in a fixture for batch milling. Now, Glidewell sends instructions directly to the robot, which loads each blank individually. By going to single-part flow, the company slashed three hours off its process and significantly reduced returns for mistakes in color or crown shape.

Du-Co Ceramics, Saxonburg, PA, is using a Baxter robot from Rethink Robotics to pick partially finished ceramics off a line and place them in a fixture for sintering.

“We can look at production runs we could never automate before, because the time required to set up the work cell wouldn’t have justified it. In the past, we would have done it with people. Now, we can create a versatile cell that we can move from machine to machine,” said Du-Co process engineer Josh Rupp.

All three are thinking about adding more collaborative robots to their shops. The robots cost one-third as much as a conventional robot to buy, install, and program. Because they do not require fences, engineers can insert these robots anywhere without having to redesign the entire process.

Many users report returns on investment of less than one year. This combination of properties makes it possible to automate and improve productivity of tasks that would have been uneconomical with conventional robots. It could prove a seismic change in manufacturing.

Universal has sold more than 4,000 UR robots since 2009, said CEO Enrico Iversen. Last year, the company’s revenues rose 70 percent and it moved into a facility large enough to manufacture 35,000 robots annually.

Rethink Robotics entered the field in 2012 with Baxter, a more flexible but less precise robot. This past spring, it launched a smaller, more precise robot, Sawyer. Rethink is led by iRobot founder Rodney Brooks, a visionary whose Roomba vacuum cleaners and military systems made robots part of our consciousness.

**Inherently Safe**

More recently, established industrial robot companies have begun selling power and force limiting robots. ABB recently introduced YuMi (as in “You-Me”), an inherently safe collaborative robot. It also acquired Gomtec, a small German company whose robots resemble Universal’s UR series.

Germany’s KUKA recently rolled out its LBR iiwa. It gets its unwieldy name from a mashup of “Leichtbauroboter” (German for lightweight robot) and “intelligent industrial work assistant.” In the United States, Precise Automation offers about 30 different articulated, SCARA, and Cartesian robots to the healthcare industry to handle everything from test kits to samples.

Meanwhile, Yaskawa Motoman and other established producers have begun to instrument fast and powerful industrial robots to work safely around humans.

Applications are multiplying. Today, one of the common uses for collaborative robots is picking parts from a line or cart and placing them in fixtures for further processing or boxes for shipping, said Scott Mabie, general manager of Universal’s U.S. operations. Machine tending, managing the flow of parts in and out of machines, is also common.
Manufacturers also use cooperative robots to bolt, screw, glue or weld pieces together, and to pack or palletize final products. Baxter’s elastic joints, force sensors, and embedded video enable it to see and feel its way in, so it can align circuit board holes with testing equipment. Some Universal’s robots distribute pepperoni on frozen pizzas.

“Today, you can put a robot alongside a person in a job done previously by people without having to carve out that work and move it elsewhere in the plant. What was once all manual work is now people-robot work, where both work on the same process,” said Julie Shah, who heads MIT’s Interactive Robotics Group.

Shah says keeping production lines together and dividing tasks improves productivity, but existing applications are not very collaborative. Today, robots work alone. Humans enter their space only to take measurements or tend supplies.

The Next Step
The next step might be working on tasks together. In Spartanburg, SC, BMW’s factory is looking at ways to do that. It has shown videos of Universal robots sealing sunroofs, and the plant’s vice president of assembly, Richard Morris, said they help in installation as well. BMW is also testing autonomous vehicles that will cruise up and down the line, resupplying workers with parts.

More interesting is the use of robots to help install a foil water barrier over electronics in the door. The task now requires workers to push the glue onto the door under constant pressure, which is difficult and has led to repetitive stress injuries. Morris is testing whether a robot could do the same job with greater precision, while humans do the more dexterous task of fitting the foil onto the door.

The application would take advantage of what humans and robots do best. As Rethink’s Brooks notes, there are no truly dexterous robots.

One of those researchers is Aaron Bobick, founder of the Georgia Institute of Technology’s School of Interactive Computing and the new dean of engineering and applied science at Washington University.

Bobick and Shah use similar words to describe their research goals: creating robots that interact seamlessly with humans, doing the right thing for the right person at the right time in the right way.

This is clearly not as easy as it sounds. Humans, Bobick explains, have had tens of thousands of years of evolution and decades of individual experience learning to interact with one another. The better a robot mimics this, the more comfortable humans feel and the less training it takes to teach them to work with a robot.

Bobick points to Rethink’s Baxter robot as an example of “lightweight” anthropomorphism. A display sits atop Baxter’s body. It looks like a face and features two animated eyes.

“Why does it have a face? It doesn’t use those eyes to see. Instead, those eyes show you what it is looking at,” Bobick said.

This way, workers are not surprised by the robot’s actions. The challenge, Bobick said, is making this work in
the other direction, from human to robot.

“When we are standing near each other and I shake something, I want you to look at it. If robots find salient the same things that humans do, it will be easy to teach robots what we want,” he said.

Bobick’s approach is to teach robots a work grammar, a base sequence of events in an operation.

“A system trained on how to recognize the actions of the human can try to figure out what steps are being done and when, so the robot does the right thing at the right time,” Bobick said.

Yet even simple tasks, like screwing two parts together, can get complex: choosing and acquiring parts, aligning surfaces, inserting a screw, clasping a screwdriver, and, finally, screwing in the screw.

Humans have no problem identifying these steps. A robot, on the other hand, sees a stream of information that it must parse and interpret, Bobick explained. It must also react to variations that would not upset humans but might puzzle robots, such as whether workers do something fast or slow, use their left or right hand, alter their stance or angle of attack, or simply stop to tie their shoelaces.

Understanding those nuances will enable robots to go from reactive, where they stop if a human approaches, to participatory.

“It has to recognize that you are going to need a tool in four seconds, so it has to get that tool now in order to hand it to you then. It needs to be fluid,” Bobick said.

Shah agrees. “Robots use repetitive motion, but people don’t,” she said. “They go a little faster or slower, so a robot cooperating with them is starting and stopping a lot, and it loses its economic benefit if it does that.”

Rather than build a grammar of different work motions, Shah has opted for a more general way to predict the motion of a human arm. She starts with a biomechanical model of the arm. When a worker moves his or her arm, her robot compares it with the model and predicts how the motion that has already occurred will limit the arm joints degrees of freedom in the future.

“Within 400 milliseconds, we could predict which of four quadrants you can reach to,” Shah said. This includes sensing a person, calculating its distance in space, and calculating how the robot should change its path.

Not Fast Enough
This sounds fast, but it was not fast enough. Shah is interested in instrumenting fast and powerful industrial robots, the type that can hurt workers if they make a mistake, to measure speed and separation between humans and machine. Fortunately, one of her students was able to slash the time it takes to receive and process the data. Now, the robot can make predictions that are 95 percent accurate within 5 milliseconds, and 99 percent accurate inside 12 milliseconds. Such rapid calculations are the only guarantee of safety, Shah said.

Collaborative robots promise major productivity improvements. Their low cost and ease of deployment will enable factories to automate production runs of a few hundred or thousand parts. The resulting gains in productivity could drive costs down for custom and semi custom parts, making early adapters more competitive internationally.

To get there, collaborative robots must pass several hurdles. The first goes to the heart of what control engineers
do: they create deterministic processes that work the same way, every time, no matter what. A learning robot that adapts to its environment and interprets events to anticipate future actions is not going to be as deterministic as, say, a feeder inserting a blank into a mill.

“Manufacturers already know they have hundreds of non-deterministic machines running around the assembly area. They’re called people, and robots are far more repeatable,” Bobick said.

Yet he admits this will be a challenge.

“Semi-autonomy is always much harder than full autonomy. If all cars on the road are autonomous, they can count on each other to behave in a certain way. If there is semi-autonomy, there is an agreement between the car and the driver. The human has to trust the car, and yet the car has to yield to the human. It’s not as clear cut, which is why it is always harder to build collaborative systems than fully autonomous ones, Bobick said.

Integration exacerbates the problem, added Jeremy Marvel, a project leader at the Intelligent Systems Division of the National Institute of Science & Technology (NIST). He noted that warehouse robots, which combine an autonomous ground vehicle (AGVs) body and a robotic arm, injure “a lot of people.”

Unexpected Behaviors

The problem is that the arm and AGV are often made by different manufacturers and they follow different safety rules. This leads to unexpected behaviors.

“For example, if the arm gets too close to a person, it will shut down and require a manual restart, while the AGV will reset itself. So the AGV could start moving while someone is working with the arm,” Marvel said.

NIST, he added, is trying to identify possible standards issues and develop better ways to ensure both components operate in a safe and repeatable manner.

Standards are a primary concern of General Motors’ principal robot engineer, Marty Linn. He would like to add robots to his assembly lines. The problem, he said, is that GM cannot certify its installation because there are no standards for safe robot-worker interaction.

This lack of standards prompts Linn to question the safety of “inherently safe” robots. A robot bumping into someone while moving a 5 kg load might hurt a little. On the other hand, the same force could slash or stab a worker if the robot was holding a thin piece of metal with sharp edges. It all depends on the jobs and individuals, Linn said.

A new standard, ISO 15066, Safety Requirements for Industrial Robots—Collaborative Operation, hopes to address those issues. It outlines four strategies that robots can use to work safely around humans.

The first is the one adapted by Universal, Rethink, and the new generation of collaborative robots, power and force limiting. At Germany’s University of Mainz, researchers have gone into overtime on a program that evaluates pain and injury thresholds. The work is complex, and has slowed the adoption of ISO’s collaborative robot standard.

The second approach is the safety-rated monitored stop. This involves monitoring the area around a robot. When a worker triggers a sensor, the robot stops. It resumes where it left off once the human leaves.

The third is hand guiding. This will allow workers to train a robot while it is in live automatic mode. This will greatly simplify the programming of industrial robots.

Fourth is speed and separation monitoring, the most radical departure from existing practice. It uses sensors to track workers. The robot continues to work around the person, and slows or even stops when humans come too close.

Many industrial robots are already equipped with these safety-rated sensors.

“The major industrial robot makers have been doing functional safety for more than four years,” said Erik Nieves, technology director for Yaskawa Motoman. Engineers could retrofit them to work more closely with humans.

Robots today offer high productivity in applications that require brute strength and precision, like welding automobile frames. Tomorrow’s robots will help human workers perform assembly tasks more productively. They might carry out tasks that do not require full-time workers, such as machine tending, or pieces of tasks that are ergonomically challenging, like applying sealant to a door. They may one day deliver parts where needed, or lift and position parts for more dexterous human beings.

That may be only the start. The factory is a test bed. Assembly routines are already highly structured. They are the types of tasks where robots can learn to know and anticipate human needs. Engineers will use that knowledge to create robots that can handle less structured tasks.

If the boy is father to the man, then perhaps today’s collaborative robots are the progenitors of robots that will clean our homes and cook our dinner tomorrow.