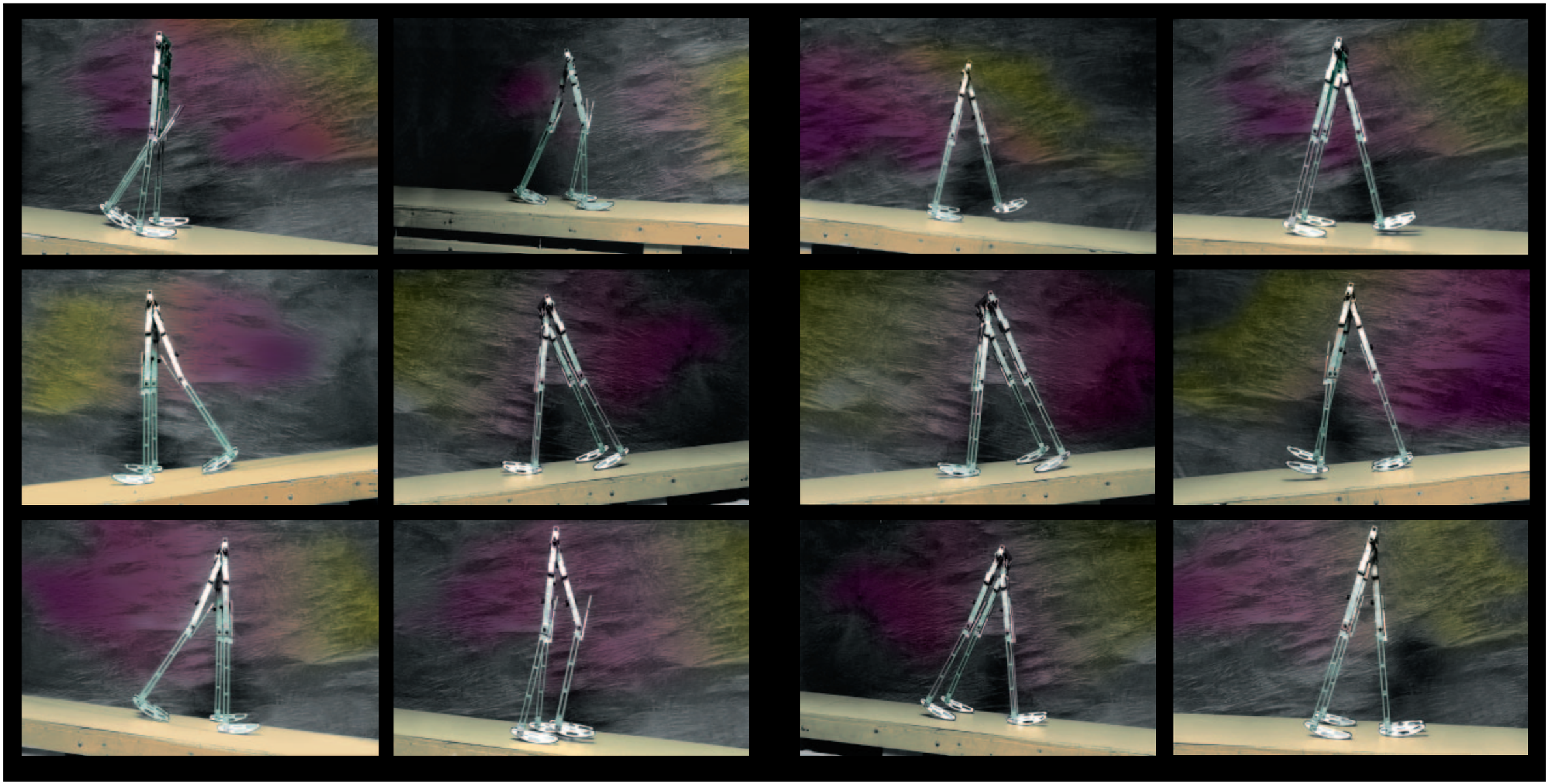
Human Locomotion

Andy Ruina's students explore the mechanics of movement

BY BETH SAULNIER



PHOTOGRAPHS BY FRANK DIMEO, UP / DIGITAL ILLUSTRATION BY CAROL TERRIZZI

So this must be where bicycles go to die. On the third floor of Kimball, a nondescript door opens on a scene out of a Schwinn's worst nightmare. Bikes hang from the ceiling like sides of beef in an abattoir. Dismembered parts—wheels and pedals, chains and bits of frame—are strewn about, odd little gizmos that once went somewhere.

But though these bikes may have departed to that big velodrome in the sky, this research room is going places. For a decade, the Human Power Lab has been a place to study what makes Sammy run—and jump, and row, and pedal, and walk. It was founded as the Bicycle Lab in 1986, but research here has since taken a broader view of locomotion. Along with the skeletons of dissected bikes are rowing machines in various states of assembly and the lab's de facto mascot "Junior," a prototype of a walking robot.

"It's interesting to learn how the human body works, to think of it as a machine," says Andy Ruina, associate professor of theoretical and applied mechanics (T&AM), one of the lab's founders. "Our approach to the human machine is off in a little corner of engineering that a lot of people don't study."

The mission of the Human Power Lab is simple: to understand the ele-gant, clever vehicle that is the human body. And out of that understanding, Ruina and his students hope to accomplish a pair of goals. The first is to better harness the body's power: to row faster, bike farther, exercise more efficiently. The second is to use the design of the human form as a basis for creating superior gadgetry. "Usually, the engineer designs the machine," says T&AM graduate student Mariano Garcia. "But when it comes to the human body, it's been designed already. The question is *how* it's been designed. It's sort of a backward approach. We're studying something that's been built already, by building something else."

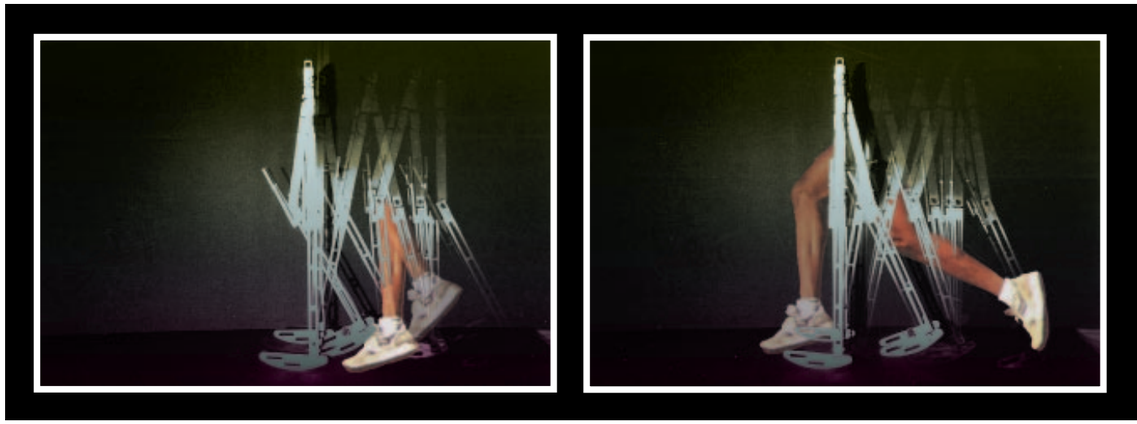
There's no mantra posted in 306 Kimball, but if there were, it would be this: "Avoid negative work." That's a guiding principal in a laboratory devoted to squeezing every ounce of energy out of the human form. Negative work means energy wasted: the recoil on a rowing machine, the effort of keeping your feet on the pedals of a bike. How to accentuate the positive? One approach is constraint, constraint, constraint. Keep the motion isolated, and you can concentrate all your efforts on the task at hand. As any cyclist can tell you, you can go faster and farther if your feet are clipped to the pedals. And bodybuilders know that you can bench press more pounds with a Nautilus machine than with free weights. Why? You don't have to waste energy trying to balance the weights and keep proper form; the machine does it for you. "All you have to worry about," says M.Eng. student Jason Cortell, "is putting as much power into it as possible."

Cortell is standing in front of his pet project, a prototype of a new kind of rowing machine he's been working on since last summer. Made of bright green metal, the monolithic gadget stands next to an earlier incarnation, crafted of wood. The original constrained rower looks like something out of the Marquis de Sade's rec room: two-by-fours and metal sheets cobbled together, all ready for the torturer and his hapless houseguest. But fear not: These aren't instruments of pain—at least not any more than your average Stairmaster. They're specially souped-up rowers that wrap around the user's body, shoulders to toes, to take advantage of every ripple of motion. "The idea," Ruina says, "is to design a machine that gets more power out of the human body than anybody has ever gotten before." Once it's finished, Cortell is looking forward to trying it out, maybe rowing his way into the record books. "We're trying to use most of the body's large muscle groups," he says. "We want to get the maximum amount of power out of the human body in a short period of time."

The lab was originally founded to study bicycles, and though two-wheeled transport is no longer its main focus, bikes still dominate its decor. And the Human Power Lab remains a magnet for biking fanatics; several of the graduate students are serious racers, and Ruina himself has been having a love affair with pedal power ever since he was a child. "I thought bikes were neat, but all kids think bikes are neat. Even after I got my driver's license, I still thought it was cool to ride," he says. "In the future, bicycling and walking will be more important that they are now. In the long run, the world can't support so many cars. And for health reasons, if nothing else, people have got to use their bodies to get around."

Over the years, 306 Kimball has become a showcase of curiosities—relics inherited from other programs, designs leftover from earlier lab projects, and miscellaneous objects of interest to the lab's inhabitants. a sign reading UNSAFE—DO NOT RIDE. A hot-pink model, suspended from the ceiling, looks fairly normal—until you realize its pedals are next to each other, rather than offset 180 degrees. And then there's a radial-gear mountain bike, with novel shifting and braking systems. "Separate from basic science-like questions," Ruina says, "it's fun to think about contraptions and novel designs."

Vehicular environment notwithstanding, the lab's current main attraction has no wheels at all. It has feet—four of them, to be exact. His name is Junior, and he's the crown prince



PHOTOGRAPHS BY JOHN CAMP / DIGITAL ILLUSTRATION BY CAROL TERRIZZI

One of the most unusual items, hanging from the wall like a piece of modern art, is a bicycle encased in a clear plastic dome: the ultimate weapon against wind resistance. Other oddities include a "folding bicycle" whose tiny wheels make it look like something out of a circus act. Another bike, missing its back wheel, is hooked up to a complicated contraption and labeled with of this curious collection of gizmos and gadgets. Junior is a walking robot, the second generation of his family. He's the spiritual son of Dynamite, who was created by the forefather of passive-walking robotics, the ingenious Canadian researcher Tad McGeer. (Dynamite, now retired, rests in a corner—the elder statesman of walking robots.)

Even when Junior is standing still, there's something strangely human about him—a metallic critter, less than a yard tall and jerry-built of aluminum and steel, suction cups and duct tape. But when he walks, the anthropomorphic effect is uncanny, conjuring up sci-fi matinee images of C3P0 and The Terminator. On a blustery fall day, as wind rattles the third-floor windows, Garcia, a fourth-year graduate student, puts Junior through his paces, positioning him at the top of the gently sloping plywood ramp that serves as his playground and giving him a few well-timed boosts. The two center legs are connected so they step together, and as Garcia tilts the walker, the two outer limbs swing gracefully around the inner ones.

Garcia lets go, and Junior ambles down the ramp, like a well-coordinated team in a three-legged race. With every step, a pair of suction cups—essentially, Junior's knees—catches and then releases, courtesy of the slow leaks factored into the design. "Real walking doesn't use muscles very much," says Garcia. "The

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legs swing in just the right way so that it doesn't waste energy."

Junior's design exploits that principal: the concept that, surprisingly enough, normal human walking uses relatively little energy, in this case *without* a lot of constraint. It's as easy, you might say, as tumbling off a log. "We're falling off one foot onto the other," says M.Eng. student John Camp, demonstrating the point with his own feet. "Just like we are, with each step, the robot's falling."

Sometimes, literally. As Junior struts down the ramp, Garcia follows at his side like an anxious nanny. Depending on a variety of factors—the launch, how the weights are adjusted, the rate at which the suction cups give way—Junior sometimes veers off the ramp, like a wayward toddler. But other times, the robot marches to the end of his runway with the confidence of an ROTC veteran. "It's sort of a subtle thing, where you put the weights so it works just right," Garcia says. "There was a lot of trial and error. And it turns out that most of the weights are around the hip area, just like the human body."

So the research comes full circle: the scientists use principals of human walking to design a robot—which helps them understand how people walk in the first place. "Is it a coincidence that this thing that mimics human movement can walk in this passive way? Probably not," says graduate student Mike Coleman, whose been known to build visual aids out of Tinkertoys and Legos.

When Junior's on a successful trot, the acute similarity to a person walking seems to endow him with all sorts of human—even childlike—qualities. It's impossible not to root for him, and when he stumbles, to want to console him as if he's some skinny-legged urchin with bruised knees. But the ultimate goal is to design a walker that never commits a *faux pas*, never steps wrong. To do that, you have to understand just how human walking works, and how the little robot's metallic gait departs from it. "Anything that makes things different from the ideal model," Camp says, "could be a potential point for disaster."

The creature that now struts across the lab on metal limbs was born in the ones and zeros of the electronic netherworld. Work on Junior began with countless hours of computer simulations; until very recently, this research would have been extremely time consuming, if not impossible. "If you do it in the real world, you can do one configuration, or maybe two, before you get really tired," Cortell says. "On a computer, you can do dozens." But to do those simulations, the researchers first had to develop a procedure for measuring the parameters, using such variables as the center of mass and the moment of inertia. "The idea is to understand how the different parameters affect the motion," Garcia says. "What happens to the efficiency? What happens to the mobility? Can the thing walk at all, or does it fall over?"

With assisance from a couple of colleagues, Camp built Junior when he was an undergraduate in the Sibley School of Mechanical and Aerospace Engineering, immortalizing his work in a poster entitled "Knee Jointed Passive Dynamic Walking," complete with time-lapse strobe photographs of the robot strutting his stuff. For the project, he teamed up with Garcia, who did the computer work as part of his Ph.D. dissertation. Camp graduated last year and stayed on for his M.Eng. in mechanical engineering. His master's project, again a collaboration with Garcia, takes Junior one step further: walking on a flat surface, rather than downhill. "We're teaming up again—the Dynamic Duo," Camp laughs. "I guess I'm the Boy Wonder and he's Batman."

As kid, Camp used to mentally dissect the science—or pseudo-science—behind science fiction. But he was never particularly skeptical of the robotic denizens in movies like S*tar Wars*. "I don't know if I ever even questioned it," he says, "because it never seemed that far-fetched to me."

He keeps the plans for his latest project in a raft of well-thumbed graph-paper notebooks with the seemingly nonsensical title of "Powered Passive Dynamic Walking." Powered *and* passive? The theory, a take-off on Junior's design, harkens back to Camp's description of human walking. If people essentially tumble from one step to the next in a controlled free-fall, Camp wonders, can that concept be used to make a robot that walks on flat ground with very little power?

"We can understand the dynamic, and use it to our advantage," Camp says. "From the ankles up, I'd like to fool the walker into thinking it's walking down a slope. As I see it, it's a thoughtful solution to powering it, because it's still passive. I can visualize the virtual slope. It seems really right to me." One hint he's on the right track: When Camp turned in his initial work on the project, his M.Eng. advisor thought he'd bungled the power calculations. "He thought I made a mistake," he says. "He was shocked at how low the energy consumption was."

Power is only one of the major issues the designers are pondering; the other is control. And there, too, the human model is a step ahead of the game. "The idea," Garcia says, "is that maybe motion is more the brain taking advantage of Newton's laws than the brain thinking out every action." In other words, not only is human walking a low-power proposition, it's low-maintenance, too. "We'd like to model walking as a passive process, just a set of tasks," Camp says.

Researchers devoted to the study of robotics spend a lot of time on control theory: how to tell the machine to put one foot in front of the other. But in the Human Power Lab, the imperative instead is to design a robot that's physically suited to walking, an artificial life form for whom walking comes naturally. "For useful walking, the world is not totally flat and smooth," Camp says. "In the end, if we want to have a Terminator-style walker, it would have to have actuators in each joint. Like a person walking across a stream with irregularly spaced stones—if you want to put your foot there, you have to tell it." Theoretically, such a robot would only require small adjustments while in motion, and therefore use much less power. "There's this idea that walking is inherently unstable," says Coleman, "but maybe there are only some small controls that make it stable."

But the irony is, the folks in the Human Power Lab aren't much interested in designing the first Terminator, or the C3P0s of the future. While work in the lab is firmly grounded in metal and rubber, its goals are more theoretical than applied. The constrained rower, for example, is purely a research project; don't expect a version of it to show up at your local gym.

"We're not really interested in making robots walk," Camp says. "We're interested in system dynamics." Ruina, too, stresses that designing walking robots is a means of study, not an end. "I don't think walking robots will be very useful," he says, his bicycle affinity showing through. "It's easier to do things with wheels."

There's a veritable flock of Juniors in the lab, earlier incarnations crafted of wood, hanging from the ceiling. Even so, the robot is not so much a product as a by-product, an exercise in applied theory. There won't be a full-sized model serving drinks à *la* Woody Allen in *Sleeper* anytime soon. But Ruina and Camp have considered that the miniature version, some six inches high, could be a Slinky for the next generation. "A Nature Company toy," Ruina chuckles.

Another, less whimsical application for the lab's study of human walking might be to help build better prosthetics, designed to minimize work for the wearer. And Junior actually has something in common with a patient in rehab who's learning to walk again between parallel bars; he can also only go in two directions, backwards and forwards. With his tripod stance, it's nearly impossible for him to topple over sideways, unless he falls off the ramp.

Although that makes for a more stable robot, it's an imperfect copy of human motion. Coleman is in the midst of more computer modeling, to figure out a way for Junior to walk on just two legs, allowing more freedom of movement but requiring side to side balance. "Right now, we just want to see if we can get the walking going," Camp says, "one step at a time."

http://tam.cornell.edu/programs/humanpower/humanpower
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