

ROBOTS, AI, AND **THE FUTURE OF WORK**

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Robots, AI, and the Future of Work

BYRON AUGUSTE

Skills and Tomorrow's Jobs Report: The Usual Suspects

By Byron Auguste

Forbes | July 5, 2018

<https://www.forbes.com/sites/byronauguste/2018/07/05/skills-and-tomorrows-jobs-report-the-usual-suspects-warning-spoilers/#46f3c9f92af8>

All ready for “Jobs Day” tomorrow? If so, here are two spoilers: (1) The headline U.S. unemployment rate (“U3”) will be close to the lowest recorded. (2) Headlines and op-eds decrying or debunking “the skills gap” will follow.

As exciting as the seasonal adjustment footnotes will be for true enthusiasts, most mainstream analysis of tomorrow’s U.S. employment numbers will be entirely predictable, but not entirely convincing. After business journalists interview CEOs (big skills gap!) and economists (no skills gap!), here are three of “the usual suspects” once again to be trotted out and interrogated: Not enough school: “More jobs ‘require’ college degrees than we have college grads.” Not enough STEM: “Too many liberal arts grads; new jobs need math and science.” Not enough salary: “If companies need more skills, can’t they just pay people more?” There’s a dollop of truth in each of these narratives, but none of them explain nor even usefully frame the underlying patterns of dysfunction in the U.S. labor market, of which “the skills gap” is a symptom. Worse, they make us spectators when it’s time to act.

See also in the TTI/Vanguard archive:

- Maria Klawe: *Developing the Dream Tech Employee*, Washington, D.C., May 2009.
- Erin Dolan: *Big Undergraduate Research: The Freshman Research Initiative*, Austin, Texas, February 2016.
- Paul Daugherty: *Reimagining Work in the Age of AI*, San Francisco, California, December 2018.



LEIGH CALDWELL

Cognitive Goods, Normal Goods and the Market for Information

By Leigh Caldwell

Conference paper | January 2019

<https://www.aeaweb.org/conference/2019/preliminary/paper/sAaNh7zR>

People experience emotions—and utility—from mental states that do not relate to material outcomes. But there is something that stops us simply choosing whatever mental states make us happy. It is no use trying to model these processes simply by assigning a utility function to my relative income or my lack of awareness of health. There can be no well-behaved utility function because these are not well-behaved economic goods. Preferences over relative income cannot simultaneously obey convexity and transitivity. Lack of awareness of medical status does not obey the irrelevance axiom. And even though we may put a positive value on these mental states, they cannot be priced, because they are neither scarce nor tradable. If instead we define a new type of object, the cognitive good, we can create a model that allows these objects to be valued consistently.

See also in the TTI/Vanguard archive:

- Dan Ariely: *Reality vs. Subjective Reality*, Atlanta, Georgia, February 2008.

TIM ENWALL

Misty Robotics CEO Tim Enwall: Everyone Will Have a Home Robot in 10–20 Years

By Kyle Wiggers

VentureBeat | August 31, 2018

<https://venturebeat.com/2018/08/31/misty-robotics-ceo-tim-enwall-everyone-will-have-a-home-robot-in-10-20-years/>

In June 2017, when Misty Robotics spun out of Colorado-based startup Sphero—the folks behind the eponymous Sphero toy series, a motorized R2-D2, and a miniature replica of Lightning McQueen from Disney's Cars franchise—it announced intentions to develop a “mainstream” home robot with the help of hobbyists, enthusiasts, and crowdfunding backers. With \$11.5 million in capital from Venrock and Foundry Group in the bank, the team wasted no time in getting to work. And the startup unveiled the first fruits of its 11-month labor—a robotic development platform called Misty I—at the 2018 Consumer Electronics Show. In May, Misty Robotics took the wraps off the second iteration of its robot—Misty II.

See also in the TTI/Vanguard archive:

- Tandy Trower: *A Robot for Every Home: A Perspective on the Emerging Personal Robotics Market*, Santa Monica, California, December 2007.
- Brian David Johnson: *Jimmy the 21st-Century Robot*, Boston, Massachusetts, April 2014.
- Maja Matari: *Providing Care by Facilitating Social Interactions Rather Than Automating Physical Tasks*, Los Angeles, California, March 2018.

**RICHARD FREEMAN****Who Owns the Robots ... Redux****By Richard B. Freeman**

The economic logic that offers most insight into the long-term effects of AI robotics technologies on workers is the theory of comparative advantage. Comparative advantage holds that technological change or any other major economic development (such as trade between two countries with different factor endowments, which spawned the theory) will show up more in the type of work people do and the income they earn from work than in some apocalyptic end of work. In the case at hand, even if AI algorithms/machines dominate humans in every work task, firms will still hire humans. They will hire humans to do work tasks which we can do at lower cost than machines and hire machines to do the work they can do at lower cost than humans. The key question for newbies circa 2020s is the extent to which the machines will gain advantage in the high-skill and high-paid work activities that provide desirable career jobs.

See also in the TTI/Vanguard archive:

- Paul Daugherty: *Reimagining Work in the Age of AI*, San Francisco, California, December 2018.
- Michael Bernstein: *Crowd-Powered Systems*, San Francisco, California, December 2013.

MARTIAL HEBERT**The Dream Labs of Future Robotics****By Tanya M. Anandan**

Robotic Industries Association | October 30, 2018

https://www.robotics.org/content-detail.cfm/Industrial-Robotics-Industry-Insights/The-Dream-Labs-of-Future-Robotics/content_id/7533

Robotics is a multidisciplinary sport. The traditional areas of study, mechanical engineering, electrical engineering and computer science, have broadened into biological systems and cognitive science. Many of the top university robotics programs are attacking robotics challenges from all angles and making fascinating discoveries along the way.

See also in the TTI/Vanguard archive:

- Robert Full: *Biological Inspiration: Design Lessons from Nature*, Charlotte, North Carolina, December 2010.
- Sangbae Kim: *Design Inspirations from Biology*, Los Angeles, California, February 2011.
- Vytas SunSpiral: *Tensegrity Robots, Neuroscience, Fascia, and Space Exploration*, Atlanta, Georgia, February 2014.



DAVID HU

The Mysteries of Animal Movement

By James Gorman

New York Times | November 5, 2018

<https://www.nytimes.com/2018/11/05/science/hu-robotics.html>

A scientist's unfettered curiosity leads him to investigate the physics at work in some very odd corners of the natural world.

See also in the TTI/Vanguard archive:

- Robert Full: *Biological Inspiration: Design Lessons from Nature*, Charlotte, North Carolina, December 2010.
- Douglas Emlen: *Extreme Weapons*, Washington, D.C., September 2016.
- Todd Blackledge: *Spiders, Silk, and Webs: Biomimicry and the Role of Basic Biology*, Charlotte, North Carolina, December 2010.

JOHN LESLIE KING AND TAE WAN KIM (MODERATOR: ROBERT CHARETTE)

Evolving from Know-How to Know-What

By Robert N. Charette

IEEE Computer | March 2019

<https://ieeexplore.ieee.org/document/8677333>

Computing is experiencing a “Cambrian explosion” of new technologies that promise great societal benefits but also create opportunities for misuse and societal harm. How to reduce this potential for harm is the objective of computing codes of ethics. Given the rash of ethical lapses related to computing, we ask whether codes of ethics are effective and, if not, why not?

See also in the TTI/Vanguard archive:

- Bob Charette: *Programming in the New Risk Ecology*, Washington, D.C., September/October 2014.
- Ben Kuipers: *Robots, Trust, and Ethics*, Brooklyn, New York, June 2018.

DAVID MINDELL

What the Lion Air Crash Teaches Us About Autonomous Cars

By David Mindell

<https://www.forbes.com/sites/davidmindell/2019/02/25/what-the-lion-air-crash-teaches-us-about-autonomous-cars/#4ba5f97f5e6c>

Rhetorical emphasis, at least, now shifts toward human-centered systems, driver assists based on various monitoring technologies that augment an attentive driver. It's a familiar pattern: Unmanned aircraft took 70 years to find their niche, in part because technologies that improved their autonomy also improved the performance and safety of human operators (think automatic pilots). Autonomy plays catch up with its own augmentation of human ability.



Automated to Death: As Software Pilots More of Our Vehicles, Humans Can Pay the Ultimate Price

By Robert N. Charette

IEEE Spectrum | December 15, 2009

<https://spectrum.ieee.org/computing/software/automated-to-death>

The Flight 124 crew had fallen prey to what psychologist Lisanne Bainbridge in the early 1980s identified as the ironies and paradoxes of automation. The irony, she said, is that the more advanced the automated system, the more crucial the contribution of the human operator becomes to the successful operation of the system. Bainbridge also discusses the paradoxes of automation, the main one being that the more reliable the automation, the less the human operator may be able to contribute to that success. Consequently, operators are increasingly left out of the loop, at least until something unexpected happens. Then the operators need to get involved quickly and flawlessly.

See also in the TTI/Vanguard archive:

- Bob Charette: *Programming in the New Risk Ecology*, Washington, D.C., September/October 2014.
- Simon Tong: *Testing Autonomous Vehicles: Safety Drivers and Simulation*, Brooklyn, New York, June 2018.

MARC MISKIN

The Microbots Are on Their Way

By Kenneth Chang

New York Times | April 30, 2019

<https://www.nytimes.com/2019/04/30/science/microbots-robots-silicon-wafer.html>

Like Frankenstein, Marc Miskin's robots initially lie motionless. Then their limbs jerk to life. But these robots are the size of a speck of dust. Thousands fit side-by-side on a single silicon wafer similar to those used for computer chips, and, like Frankenstein coming to life, they pull themselves free and start crawling. "We can take your favorite piece of silicon electronics, put legs on it and then build a million of them," said Dr. Miskin, a professor of electrical and systems engineering at the University of Pennsylvania. "That's the vision."

See also in the TTI/Vanguard archive:

- Kris Pister: *Smart Dust*, Miami, Florida, September 2002.
- Andrew Hessel: *Synthetic—and Open-Source—Biology*, San Diego, February 2015.

**SANJIV SINGH****Boeing's New Prototype Cargo Drone Can Carry up to 500 Pounds****By Kyree Leary**

Futurism | January 11, 2018

<https://futurism.com/boeings-new-prototype-cargo-drone-carry-500-pounds>

Typically, when imagining a drone, one might picture something relatively small that can only carry a smartphone, camera, or another equally small object. Boeing, however, just revealed a new cargo drone that's capable of lifting 500 pounds. The unmanned cargo aerial vehicle (CAV) prototype is much larger than anything you can find in a store. It's 15 feet long, 18 feet wide, and 4 feet tall. It also weighs 747 pounds. The cargo drone will be used as a test bed to facilitate the development and testing of better autonomous technology and vehicles, such as the electric VTOL being designed by Aurora Flight Sciences (bought by Boeing in October), and whatever "urban mobility" products it explores as part of its partnership with Near Earth Autonomy.

See also in the TTI/Vanguard archive:

- Ian Glenn: *Autonomy and Industrial Drones*, Brooklyn, New York, July 2016.
- Eric Cheng and Mike Hawley: *Aerial Imaging: A Conversation and Demo*, San Francisco, California, December 2014.

JON SNODDY**Disney Imagineering Has Created Autonomous Robot Stunt Doubles****By Matthew Panzarino**

TechCrunch | June 2018

<https://techcrunch.com/2018/06/28/disney-imagineering-has-created-autonomous-robot-stunt-doubles/>

Traditionally, most animatronic figures cannot move from where they sit or stand and are pre-built to exacting show specifications. The design and programming phases of the show are closely related, so that the hero characters are efficient and durable enough to run hundreds of times a day, every day, for years. The Na'vi Shaman from Pandora: The World of Avatar, at Walt Disney World, represents the state of the art of this kind of figure. However, with the expanded universe of Disney properties including more and more dynamic and heroic figures by the year, it makes sense that they'd want to explore ways of making the robots that represent those properties in the parks more believable and active. That's where the Stuntronics project comes in. Built out of a research experiment called Stickman, which we covered a few months ago, Stuntronics are autonomous, self-correcting aerial performers that make on-the-go corrections to nail high-flying stunts every time. Basically, robotic stunt people, hence the name.

See also in the TTI/Vanguard archive:

- Nolan Bushnell: *Success and Failure—Two Sides of the Same Coin*, Washington, D.C., December 2001.
- Cynthia Breazeal and Stan Winston: *Robots on the Silver Screen and Beyond*, Pasadena, California, February 2002.

**JOHN SUH****Hyundai Is Building a Car That Can Walk on Four Legs****By Andrew J. Hawkins**

The Verge | January 9, 2019

<https://www.theverge.com/2019/1/9/18173742/hyundai-walking-car-concept-elevate-ces-2019>

CES typically attracts whacky ideas, especially from automakers that tend to use the electronics show to showcase their most outlandish and unbuildable products. Unfortunately, the 2019 show has been pretty tame by most measures, which is why it's so refreshing that Hyundai came to Las Vegas with a truly bonkers idea: a "walking car" with real, bendable legs. Like some mashup between a Boston Dynamics robot and something you might find stomping across the frozen surface of the planet Hoth, Hyundai's Elevate vehicle is an automotive concept I can't recall having seen before. Hyundai says it designed it for first responders who need to access difficult terrain. Electrically powered and modular so it can swap vehicle bodies for a variety of use cases, the South Korean automaker is calling it an "Ultimate Mobility Vehicle."

See also in the TTI/Vanguard archive:

- Marc Raibert: *Dynamic Robots*, Brooklyn, New York, July 2016.
- Dean Kamen: *Clean(er) Water and Power*, Jersey City, New Jersey, October 2009.

Skills and Tomorrow's Jobs Report: The Usual Suspects

Byron Auguste

Jul 5, 2018

<https://www.forbes.com/sites/byronauguste/2018/07/05/skills-and-tomorrows-jobs-report-the-usual-suspects-warning-spoilers/#46f3c9f92af8>



A "now hiring" sign is seen in a window of a business on July 7, 2017, in Miami, Florida. (Photo by Joe Raedle/Getty Images)

All ready for “Jobs Day” tomorrow? During my two years in the White House advising President Obama on jobs and economic policy, the first Friday of each month’s Bureau of Labor Statistics (BLS) release of its [Employment Situation](#) report felt like an 8:30 a.m. rock concert—for people who follow ‘U5’ the time series more closely than ‘U2’ the band. So, if you happen to be a labor economist (sorry!), you’ve likely already set your alarm and two snooze backups.

Oh, you’re not a labor economist? Planning to sleep in tomorrow instead? Rearrange your sock drawer? Or, I don’t know, get up and go to work, maybe? If so, here are two spoilers:

- The headline U.S. unemployment rate (‘U3’) will be close to the lowest recorded.
- Headlines and op-eds decrying or debunking “the skills gap” will follow.

As exciting as the [seasonal adjustment footnotes](#) will be for true enthusiasts, most mainstream analysis of tomorrow’s U.S. employment numbers will be entirely predictable, but not entirely convincing, like *Casablanca*’s Captain Renault raiding Rick’s Café: “I’m shocked—shocked!—to learn that gambling is going on in this establishment!” and “Round up the usual suspects!”

After business journalists interview CEOs (big skills gap!) and economists (no skills gap!), here are three of “the usual suspects” once again to be trotted out and interrogated:

- **Not enough school:** “More jobs ‘require’ college degrees than we have college grads.”
- **Not enough STEM:** “Too many liberal arts grads; new jobs need math and science.”
- **Not enough salary:** “If companies need more skills, can’t they just pay people more?”

There’s a dollop of truth in each of these narratives, but none of them explain nor even usefully frame the underlying patterns of dysfunction in the U.S. labor market, of which “the skills gap” is a symptom. Worse, they make us spectators when it’s time to act. Let’s examine each in turn.

Not Enough School?

In their outstanding 2010 book, [The Race Between Education and Technology](#), economists Claudia Goldin and Larry Katz showed convincingly that U.S. growth diminished and inequality rose when educational attainment slowed its century-long rise in the 1970s. This original rise was driven by the universal high school movement, massive expansion of public colleges and universities, the G.I. Bill and Pell grants, which expanded demand *and supply* of high-quality post-secondary education. By contrast, in the last 15 years, employers have reclassified middle-class jobs as “college graduate jobs” much faster than any rise in college degrees or notable changes to the skills obtained in college ([Burning Glass Technologies calls this “up-credentialing”](#)). When only 20% of administrative assistants have a bachelor’s degree but almost two-thirds of new job postings for admins require a B.A. to be considered, such practices make college degrees more of an arbitrary barrier than an inclusive bridge to middle-class work.

Not Enough STEM?

Should more students master STEM disciplines such as engineering, computer science and statistics? According to [LinkedIn](#), definitely yes: There’s a strong and growing job demand in these fields, although good logic, writing and listening skills go a long way, too. Nonetheless, pinning an economy-wide skills gap on STEM has a (rather ironic) problem: The numbers just don’t add up! Even by the most generous definition, “tech” jobs are less than 10% of U.S. jobs. Software developer jobs are growing fast, but demand for personal care and home health aides is growing even faster. In absolute terms, [the latest BLS 10-year projections](#) predict 10x more new nursing, personal/health aide, restaurant and janitorial jobs than app developers.

Not Enough Salary?

Three decades of [stagnating wages](#)—rising just 0.2% annually since the early 1970s, adjusted for inflation—means an economic five-alarm fire. But are wages insufficient to motivate people to skill up; or a smoking gun of the labor market irrelevance of education? No and no. Despite overall wage stagnation, the compensation gap between more and less “degreed” workers has widened, and college graduates who majored in engineering and other high-demand fields [earn much higher starting and lifetime pay](#). There is no ‘reserve army’ of data scientists waiting at home until they get a decent salary offer. However, chronic wage stagnation does reflect much deeper problems—underinvestment in both private and public sectors, institutional barriers to labor mobility (e.g., an absurd proliferation of [non-compete agreements](#)) and structural factors keeping millions of “caring

economy” jobs as low wage, precarious jobs, [even as demographic change makes them all the more essential](#) to the quality of our lives and to societal well-being.

The Show Is Over. Time to Get Serious.

Some may take comfort from replaying these “skills gap” narratives, like watching a favorite film time after time. The lead characters are a bit cartoonish but familiar: ‘Technology,’ ‘Education,’ ‘Business,’ ‘Government.’ As the story unfolds, we can watch and speculate on these heroes or villains, according to our ideological taste. Whose jobs will ‘Technology’ destroy? Will ‘Business’ invest more in people? Will ‘Education’ rise to the challenge? We just can’t wait to find out...

Scratch that: I mean we can’t just wait to find out. Showtime is over; game time is now. It’s well past time we leave our passive spectating ways behind. The U.S. has arrived at an inflection point in our economy, technology and demography that demands a reality check on the sorry state of our labor market, and the – i.e., our – institutional practices that produce it.

Our employers complain they can’t find the needed skills, but never assess the skills of most of their job applicants. We preach “meritocracy” and performance, but we practice “alma mater-ocracy” and pedigree. Policymakers say jobs are their No. 1 priority; businesses insist their most important asset is their people; we say college is essential, then rate colleges by how many applicants they can reject. Commentators stroke their chins and refer to impersonal forces of technology, markets and systems – as if these were created in some other way than cumulative and collective human choices. Our cluelessness can be comical, but its net effect is tragic: a U.S. job market that’s broken for half of Americans, in ways barely noticed by so many who make the rules. The so-called “skills gap” is really an opportunity gap, which generates a gap (chasm, in fact) in confidence and trust, dividing our country by income, education, class, gender, race and region.

Let’s get serious.

Let’s realize that the “future of work” depends on us: our choices; our actions. What institutional policies, practices we as workers, managers, educators, voters, voices and leaders in the fields of business, learning, innovation, governing and civil society organizing will we allow to persist? What new institutional supports and tools, norms and rules will we create – and for whom?



Posters and pictures of “Casablanca” movie at the Casablanca bar in Camaguey city, 600 kilometers east of Havana, on June 19, 2015. (ADALBERTO ROQUE/AFP/Getty Images)

Beautiful Friendships?

During most of *Casablanca*, both Rick and Captain Renault are committed to doing only what serves their short-term interests, bigger picture be damned. In the film's [final scene](#), they face a stark choice: they can keep hiding losing cards from each other, hoping no one calls their bluff; or join forces to reshuffle the deck. Happily, they both chose to work together for a larger cause.

It's certainly less cinematic, but the condition of our job market – i.e., the ability to make progress in America through meaningful work – is a crisis, no matter what you may read tomorrow about “a good jobs report” marred only by “a skills gap.” Don't be lulled by that lullaby. We are far from where we need to be, and we can't arrive at an innovative, inclusive ‘future of work’ by accident, nor each on our own. Fortunately, a growing cadre of executives and entrepreneurs, educators and social enterprises, technologists and trade unionists, mayors and governors are embarking on this journey: on purpose, and together. It may be the beginning of some beautiful friendships.

Cognitive goods, normal goods and the market for information

Leigh Caldwell
Irrational Agency/Inon
January 2019

Introduction

Lassie died one night. Millions of viewers, not all of them children, grieved...the mourners knew that Lassie didn't really exist...Did they enjoy the episode?

Thomas Schelling, "The Mind as a Consuming Organ"

In this essay of 1987, Schelling explores the reward and emotions generated by experiences that we know will have no actual, permanent impact on our lives. Examples are easy to find. People care about events in the news that can have no measurable effect on their own life outcomes. They care about income relative to their peer group, when (given a particular level of purchasing power for the currency) it is only absolute income that allows them to buy things. (Indeed, many of us would rather not know what our colleagues earn.) People avoid finding out medical information that could be important to optimising future health outcomes.

If I hadn't seen such riches, I could live with being poor.

James, "Sit Down"

In short, people experience emotions – and utility – from mental states that do not relate to material outcomes. But there is something that stops us simply choosing whatever mental states make us happy (Ainslie 1992).

It is no use trying to model these processes simply by assigning a utility function to Lassie's death, my relative income or my lack of awareness of health. There can be no well-behaved utility function because these are not well-behaved economic goods. A (dis)utility function over Lassie's death cannot apply if the agent has a consistent model of the world. Preferences over relative income cannot simultaneously obey convexity and transitivity¹. Lack of awareness of medical status does not obey the irrelevance axiom. And even though we may put a positive value on these mental states, they cannot be priced, because they are neither scarce nor tradable.

If instead we define a new type of object, the *cognitive good*, we can create a model that allows these objects to be valued consistently.

This paper proposes a set of axioms that cognitive goods should obey, proposes a model that obeys the axioms and allows further predictions to be made, and outlines

¹ A demonstration will be provided in a separate appendix. The only way to reconcile this with a standard utility function is to assume that people have general *disutility* for other people's income, i.e. they prefer others to earn less regardless of their own income. This is possible in theory, but seems implausible in the real world.

consequences for some key markets: the market for information, cultural goods and money. A few potential policy consequences are explored.

Examples of mental objects that meet the definition of cognitive goods include:

- Experiences of fictional events [figure 5 below]
- Self-image and identity markers [figure 6 below]
- Belief-based utility [figure 7 below]
- Desire for an income level relative to a peer group in preference to an absolute amount [figure 8 below]
- States where the absence of information is preferred to its possession [figure 9 below]
- The results of sporting events [figure 10 below]

An important step in understanding the nature of cognitive goods is exploring the constraints that stop them from being arbitrarily created. To do that, I propose a plausible mechanism by which cognitive goods might be generated and valued.

The existence of cognitive goods in turn influences how agents value, and consume, normal goods. Therefore, even aside from the direct welfare that may be generated by cognitive goods, they are important for consumer welfare theory in general.

Cognitive goods are an important modelling artefact for the emergence of *cognitive economics*, defined by Kimball (2015) as “the economics of what is in people’s minds” and by Mulgan (2017) as “the view of thought as involving inputs and outputs, costs and tradeoffs”. The concept of cognitive goods unifies these two definitions, which approach the subject from complementary angles: what is the subject matter, and what are the mechanisms that animate it.

Proposed axioms for cognitive goods

Start with the following **axioms**:

1. Mental states are internal to the state of an individual agent, and have no direct effect on any other agent
2. A weak preference relation exists: agents may prefer one mental state to another (though they can also be indifferent between particular states)
3. An agent’s mental state at time $t+1$ is a function of its mental state at t , and the agent’s inputs from the external world at time t
4. To make a choice over normal goods, an agent must change mental state at least once. This claim is based on the idea that the agent has to mentally consider the options to evaluate them, this takes a finite amount of time, and that their state of mind is different after the choice than before – if in no other respect that they now know what choice they have made.
5. An agent’s actions are determined by its mental state.
6. A *cognitive good* is defined as any part or subset of a mental state; hence, beliefs about the world are a type of cognitive good

Some immediate conclusions or lemmas can be drawn from these axioms.

Lemma 1: Agents are constrained in their ability to generate cognitive goods.

By axiom 3, mental state at any time is a function of previous mental state plus sensory input. Therefore, an agent cannot arbitrarily choose any mental state at any time.

Lemma 2: Mental states generate a continuous stream of utility or reward.

(because we prefer one mental state to another, and states change over time, any preferred state provides some kind of ongoing payoff)

Lemma 3: Mental states can affect the decisions that agents make about normal goods

From axiom 3, mental state is a function of sensory input (including sensory inputs about the goods being chosen). Also from axiom 3, mental state is a function of previous mental state. Therefore, different starting states can lead to different finishing states under the same sensory inputs. From axiom 5, the agent's actions (which includes its choices between goods) are influenced by its mental states. Therefore, a different starting mental state can lead to a different choice of goods.

Lemma 4: Beliefs can affect decisions

From lemma 3, mental state affects decisions. From axiom 6, beliefs are a type of mental state. Then, beliefs can potentially affect decisions. As a corollary, preferences – defined as the rules upon which decisions are based – can be seen as a kind of belief: the belief that “A is better than B” is equivalent to a preference for A over B.

Lemma 5: Each mental state has a natural successor state

From axiom 3, each state is a function of the preceding state plus sensory input. If no external sensory input is provided, the state is determined solely by the preceding state (up to a random error term).

Lemma 6: The absence of a cognitive good can be preferred to its existence

From axiom 2, one mental state can be preferred to another. From axiom 6, a cognitive good is part of a mental state. In principle, a mental state that does not contain the good can be preferred to one that does.

I now explore a possible mechanism that obeys these axioms and can illuminate the behaviours we would expect agents, and markets, to exhibit in the presence of cognitive goods.

[The psychological background to this model](#)

Clark (2015) and Hohwy (2013) argue that the primary function of human cognition is to predict the future. The ability to predict gives agents such immense power to make better decisions with limited resources, that this capability provides an overwhelming evolutionary advantage.

Gilbert and Wilson (2007) propose that the ability to *prospect* (imagine the future), is moreover one that people enjoy, at least in the case of positive potential outcomes; our imagined future happiness gives us pleasure, and we are motivated to engage in daydreaming and planning those potential futures.

Neuroscientists including Stachenfeld et al (2017) have examined a potential mechanism by which the brain makes predictions and acts on them: the *successor representation*. This theoretical concept, proposed by Dayan (1993) is now supported by neural and behavioural evidence (Gershman 2018). It represents potential states of the world in terms of the states that are likely to come after them. A state representing me opening my office door might be succeeded by a state that represents me stepping out into the hallway, which in turn is followed by me reaching the kitchen.

Caldwell (2017), building on arguments in Ainslie (1992), proposed that this capability to imagine, and be rewarded for imagining, the future is essential to making intertemporal tradeoffs. Future benefit cannot directly influence an agent's present choices; only the agent's present beliefs about future benefits can do so. The proposed mechanism for this is that agents are rewarded in the present for visualising and imagining future reward, and this present reward is a substitute for the reward available from immediate consumption. The ability to visualise and act on future reward is proposed as the basis of a "System 3", the counterpart to Systems 1 and 2 proposed by Stanovich and West (2000).

The causal graph model

Causal models, as described by Sloman and Lagnado (2015), are a way for agents to mentally understand the world and the relationships between events or objects within it. Pairs of objects A and B are causally related if A causes B; B can in turn cause C, implying that A indirectly causes C. Agents can use these models to predict the outcomes of their actions: if the agent takes action A, B will follow, then C in turn. Based on the agent's evaluation of outcome C, they can decide whether to proceed with A.

Learning theories discuss two kinds of representations of the world: model-free and model-based. In model-free representations, only the initial choice (A) and the ultimate outcome (C) are considered: for example, I may decide to get up from my desk and go to the shops because it is, on average, a rewarding activity (perhaps I have learned from experience that I will usually find something enjoyable there). A model-based representation instead takes into account the structure of this task and the intermediate states that I may go through before achieving an outcome. For example, I might think through my likely actions in the shop, the objects I might purchase, and try to consider whether they are worth the effort.

The successor representation is a version of model-based reasoning. However, I argue that the individual steps in the successor representation are learned in a model-free way. The

step from the desk to the door, or the door to the hallway, do not have any internal structure – they are the “atoms” of the learning process.

Each of these atoms can be thought of as a causal relationship: *if I go through the door, then I will be in the hallway. If I eat this chocolate, then I will be happy.*

In Sloman and Lagnado’s model, the whole causal network must be evaluated in order to decide whether to take the first step – it is a fully model-based representation. However, Daw and Dayan (2014) present some of the algorithmic challenges inherent in model-based reasoning, which suggests that model-based learning and reasoning must be constrained in certain ways to be computationally feasible.

I propose a constraint that can resolve this challenge: model-based reasoning and representations use *reward* to operate, and this reward in turn creates model-free caches within the overall network. An agent’s mental model of the world is composed of individual causal beliefs, each of which is a model-free “atom” in the larger causal network. Each belief has a level of reward associated with it.

Formally:

A causal graph $G = (V, E, r)$ where:

V = a set of nodes, each representing a single *interpretation of stimuli*

E = a set of edges $e_{1,2} = (v_1, v_2)$: agent’s belief that v_1 causes v_2

$r(v)$ = the reward associated with node v

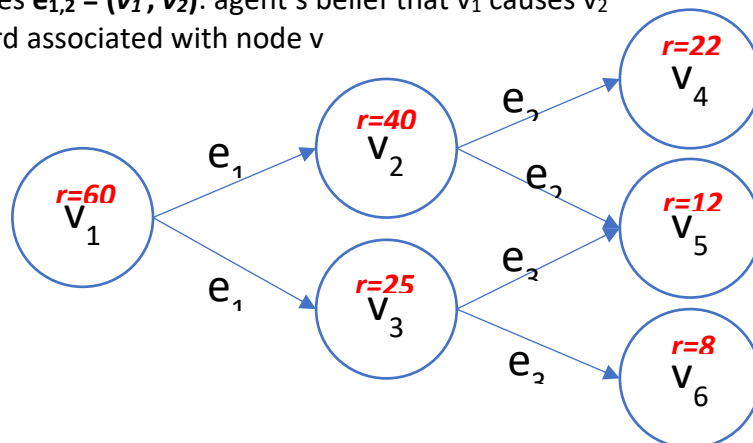


Figure 0: How a causal graph might be defined.

In order to make a decision between two options, an agent mentally simulates the causal consequences of each option. Following the causal network from the option to its immediate and successive consequences generates a certain amount of reward at each node in the network. The total reward the agent accumulates by following each option guides them in choosing the preferred option.

$$R(v) = r(v) + \sum_{e(v,b) \in E} R(b)\delta$$

Where $0 < \delta < 1$, the *causal discount rate*. In Figures 1-4, the causal discount rate is set to 1; subsequently 0.8.

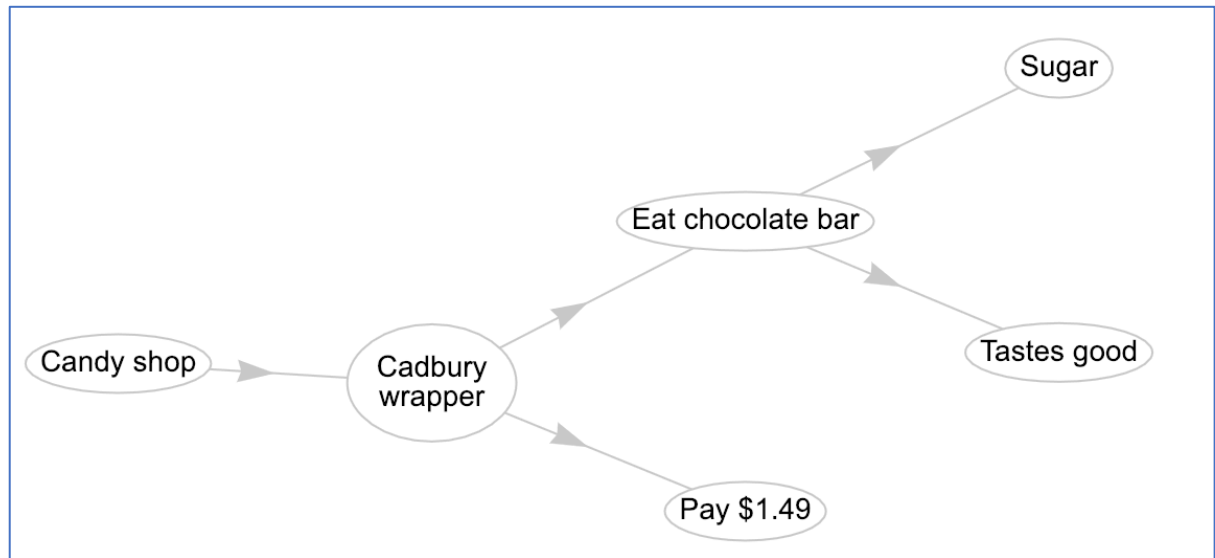


Figure 1: a graph of causal relations to do with eating chocolate

While mentally navigating this network, the agent has the opportunity to learn which nodes in the network are predictive of high reward. For example, I may visit a candy shop several times and end up with a chocolate bar, a bag of sweets, a box of Junior Mints – soon enough I will learn that the ‘candy shop’ node in my causal graph usually predicts a rewarding outcome. To save on future computation, I learn to directly associate ‘candy shop’ with reward – a model-free supplement to the model-based network. This enables me to make more efficient predictions: instead of mentally working through all the actions I could take when I go into to the shop, I only need to know that when I get there, something good will happen.

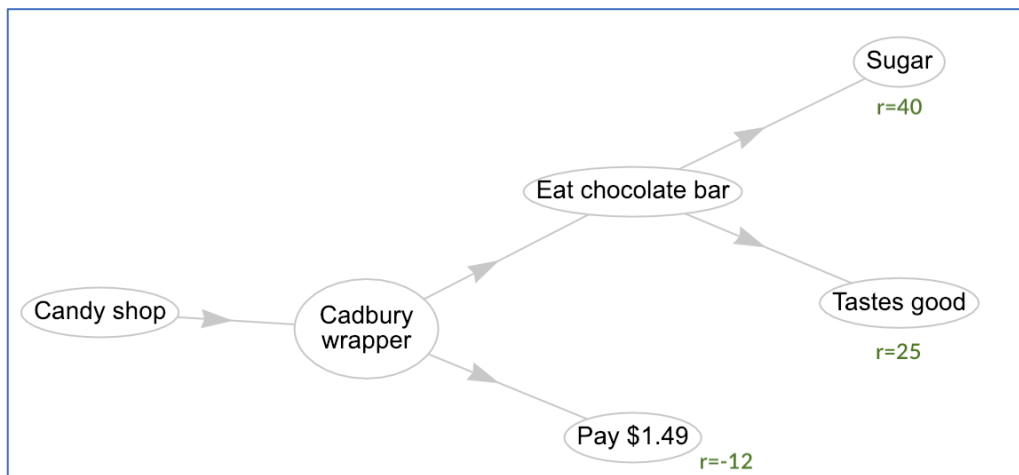


Figure 2: a graph of primary reward and the causal relations that lead to it

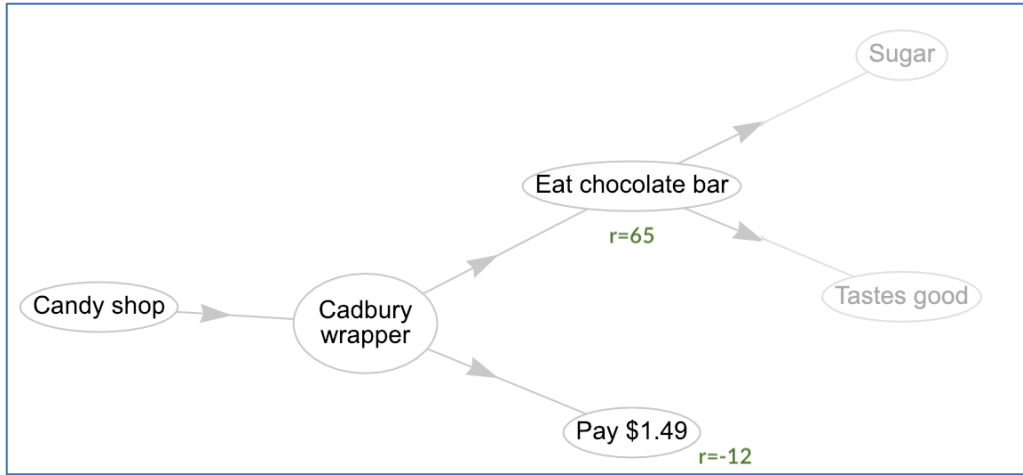


Figure 3: reward is cached one level up from the primary reward

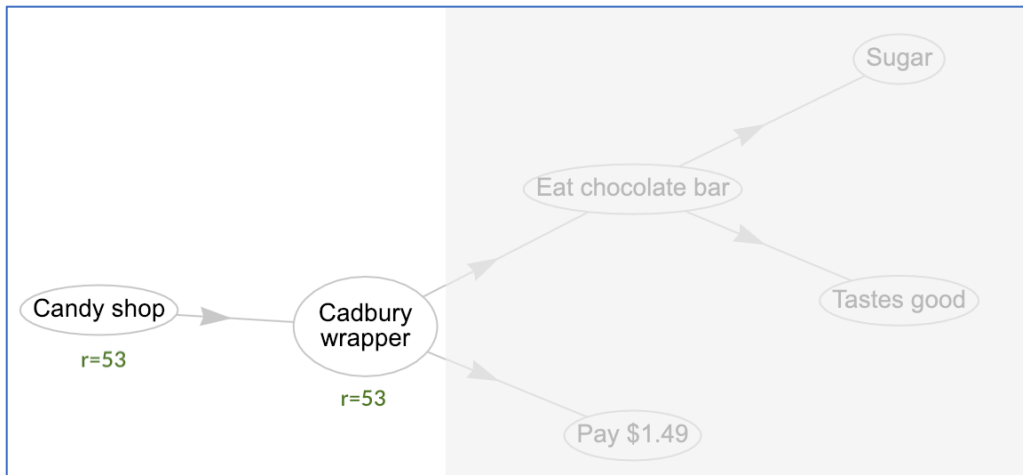


Figure 4: reward is cached two levels up and the agent learns that going to the shop is, in general, a good idea.

This process can be summarised as learning to associate rewards with intermediate states. The shop does not start out as intrinsically rewarding (only the things that happen *after* I get there are rewarding in themselves). But I learn to associate it with reward. Ultimately, I will feel happy just when I get to the shop, even before I buy, open and eat the chocolate.

Formally, if a node is not cached, the usual recursive process occurs:

$$R(v) = r(v) + \sum_{e(v,b) \in E} R(b)\delta | v \notin C$$

If the node has a cached reward value, that value is used:

$$C(v) | v \in C$$

And if the total discount is less than a cutoff value, zero reward is produced and no further evaluation takes place.

$$0 | \delta < \epsilon$$

With sufficient reinforcement, the mental state of *imagining* the candy shop can become rewarding in itself. Similarly, states like thinking about a loved one, a political belief, or watching Lassie on TV, can all become rewarding.

In this model, reward is generated whenever a node in the graph is mentally *active* – which we might see as roughly equivalent to having attention from the decision maker’s executive function. An active node automatically activates its causal successors in the graph. The agent’s external behaviour is likely to be driven by seeking out stimuli that will (directly or indirectly) activate the most rewarding nodes. Its internal processing will consist of choosing to activate nodes in the network that, insofar as it can calculate, will result in high levels of reward.

A number of key psychological questions remain about how this mechanism is likely to be implemented. These could be explored with further empirical work:

- Activation would be expected to decay as it moves through the graph; an active node will not always fully activate its successor nodes (especially if it has multiple successors, for example in cases of uncertainty)
- The learning algorithm needs to implement a cutoff in order to avoid infinite recursion through the mind. This cutoff could be based on the number of nodes navigated, the level of reward generated by the node, or some other mechanism.
- The parameters of the learning mechanism need to be measured empirically. Reinforcement learning models tend to use a variant of the Rescorla-Wagner model (see for example Miller, Barnet, Grahame 1995) which indicates that learning occurs when the reward generated from an action differs from the predicted level of reward. Implemented in this model, this would suggest that the cached reward amount at a node in the graph would gradually approach the true weighted amount of downstream reward generated from its successor nodes. However, the speed of approach may be fast or slow, and this has differing implications especially when the agent must learn in a fast-changing environments.
- Uncertainty is modelled in this graph by multiple effects for a single cause. It is unclear whether the brain’s autonomous mechanisms can represent probabilities in a fine-grained way; will all possible outcomes of an event receive equal weight in the reward calculation, or will they be weighted by likelihood (perhaps with approximation)?
- Similarly, it is not clear whether the graph can meaningfully handle quantitative calculation. Is it more rewarding to imagine four chocolate bars than three? How about forty chocolate bars? If so, how much more? I suspect the answer is that numeric weights above 2 or 3 must be imposed by a second-order calculation, perhaps through algorithmic “System 2” rules that the agent applies outside of the reward graph. However, empirical work would be needed to explore this further.
- It is unclear whether pain and reward are neurally implemented in the same ‘currency’ or there are two different neural mechanisms at play. In the current model I assume that they can be traded off against each other – sufficient pleasure can outweigh a certain amount of pain – but this may need to be revisited.
- The agent needs a mechanism to recognise external stimuli and associate them with nodes in its internal model. This mechanism may involve activating multiple nodes

simultaneously, setting off parallel reward calculation streams. The exact type of mechanism that brains might use to do this is not well-understood psychologically, but neural network models provide one possible route.

The different examples of cognitive goods given above can all be implemented in this model. Examples are shown in figures 5-11.

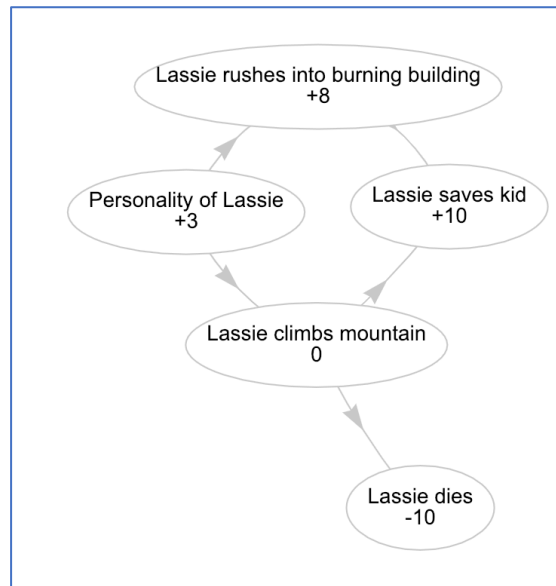


Figure 5: Reward from watching (and imagining) the adventures of Lassie. The ‘Personality of Lassie’ is the origin node of this graph, and reward ultimately accrues to the activity of imagining and understanding that personality.

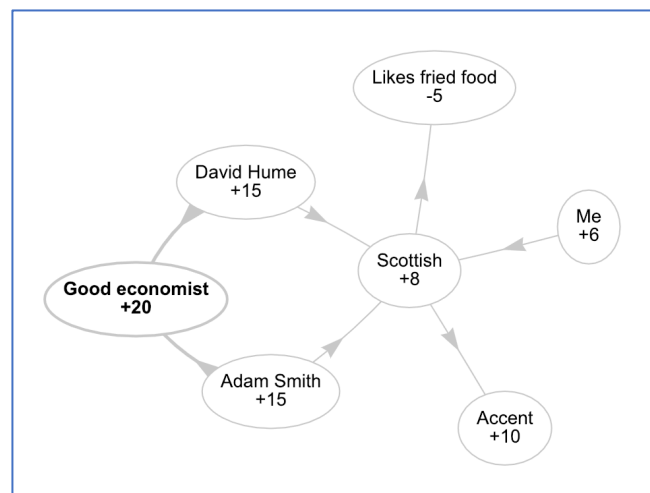


Figure 6: Reward from an identity marker – which could originate from fuzzy pattern recognition, associating the identity of being Scottish with being similar in other respects to Adam Smith or David Hume.

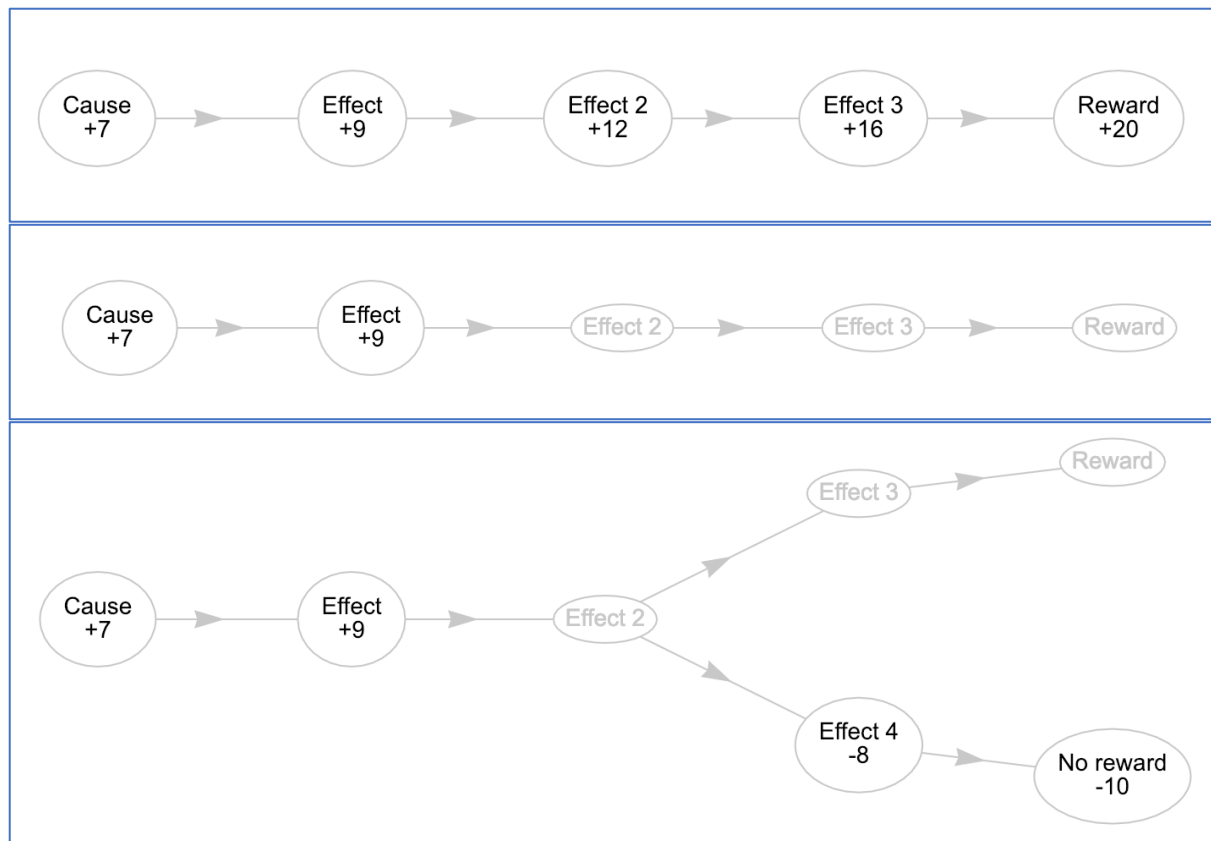


Figure 7: Belief-based utility. A belief, when first learned, is accurately associated with positive reward. The agent's mind caches reward at the original belief and truncates calculation. When new information is subsequently learned, the original belief is no longer updated.

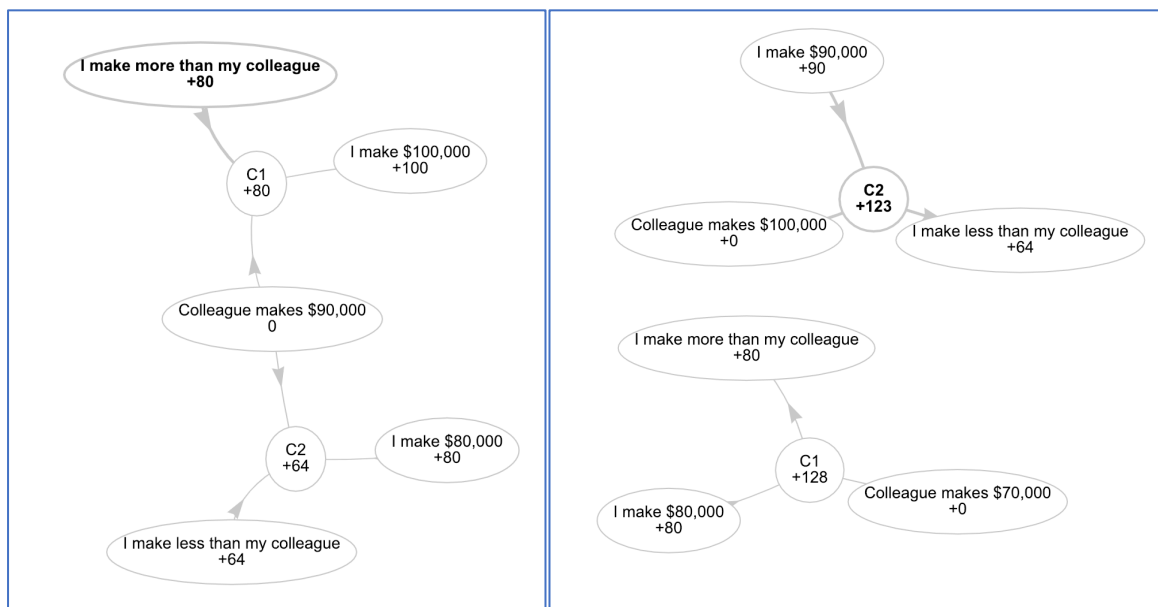


Figure 8: Relative income. If the agent first learns the value of relative income in an environment where their own income is the only variable, they may learn to attach reward to a higher relative income. In a new environment where that is not the case, this could lead to apparently irrational preferences (C1 being preferred to C2).

The definition of cognitive goods

If this process, or one like it, is indeed the origin of valuation of mental states, it has implications for the first lemma of cognitive goods: the constraints on their generation.

A *fundamental cognitive good*, in this model, is a single node of the graph – such that activation of this good produces direct reward according to solely the numeric reward value attached to that node. A *simple cognitive good* is an active connected subgraph of an agent's causal graph. A *composite cognitive good* is the union of multiple simple cognitive goods which need not be connected. A *social cognitive good* is a subgraph, a representation of which is shared between multiple agents and activates corresponding cognitive goods in each.

This terminology is partly consistent with Benjamin, Heffetz, Kimball, Szembrot 2014 (BHKS), who define fundamental aspects of welfare as those which cannot be broken down into smaller parts, composite aspects as consisting of several fundamental aspects (this includes both the 'simple' and 'composite' cognitive goods in the present definition) and public aspects, those related to a whole society's wellbeing rather than one individual's. BHKS's public aspects do not correspond directly with the social cognitive goods defined here, which could include privately owned brands or product concepts, but in practice there is likely to be an overlap between these two groups.

Normal economic goods are constrained or scarce due to their production function. The goods are made from inputs, which may be raw materials or other (intermediate) goods. The inputs are scarce, and as a consequence, production of the goods is limited.

Cognitive goods – in the model proposed here – are produced instead by activation of different parts of the causal graph that the agent holds in their mind. Although this activation consumes a small amount of energy, that is not the primary constraint. Instead, activating one part of the graph automatically activates the nodes "downstream" of this subgraph (axiom 3: mental state is a function of the previous mental state). These activated downstream nodes may not be positively rewarding. The desire to activate cognitive goods that produce only positive reward is a key constraint on the agent's consumption of mental states.

Conversely, in order to activate a subgraph of the agent's mental graph, the nodes that lie 'upstream' of it should be activated. Agents may not have sufficient knowledge of their own causal graph, or the mental self-control, to explicitly choose which nodes to activate. If so, they need to use sensory stimuli or other secondary objects to cause activation. As a result, they may buy goods or experiences that provide this stimulation. In other words, they acquire normal goods in order to indirectly manipulate the cognitive goods in their own mental state.

Cognitive goods may therefore have correspondence or similarities to normal goods, but need not always. A common class of cognitive good that does not necessarily correspond to any normal good, are goods transmitted through language instead of sensory experience. Language can activate the agent's causal graph directly, without the need for the referent

concepts in the graph to be experienced. Language – and hence information – therefore can become directly rewarding, independently of the objects it refers to.

The market for information

Information is typically seen (Stigler 1961, Allen 1990) as a very different kind of object to a normal good. Information is satiable, non-rival, non-excludable and – without artificial institutional structures such as information property rights – cannot be priced above zero.

Examining the agent's utility in terms of cognitive goods shows that information is more similar to normal goods than is usually thought.

When an agent gains new information, they update their beliefs – or equivalently, their causal graph of the world. In the traditional view, this might change the agent's choices over goods because they now know more about the goods they are choosing between, and can make more accurate decisions.

In the cognitive goods model, since agents gain value from the structure of this causal graph, new information actually changes the real value that an agent generates from the world. The information does not just help the agent better calibrate to the real world, it affects the meaningful state of that world itself. The agent may not immediately update their beliefs on exposure to new information; a learning process might be needed, especially if the information is complex or contradictory to an existing belief.

Two results of this are:

- agents may seek out information not because it is accurate but because it is rewarding

For example, curiosity (Loewenstein 1994) motivates people to find out information that they believe will reward them. For this to hold, the agent must expect that new information, on average, will be more positive than negative. A prediction from this, which could be tested empirically, is that happy people will be more curious than unhappy people.

- Agents may avoid information that would change the content of the causal graph in such a way as to reduce total reward

People are known to actively avoid information (Ho, Hagmann, Loewenstein 2018, Golman & Loewenstein 2015) and this model here provides a potential mechanism by which this would operate. It should be possible to empirically measure the underlying causal model and compare the predictions of the model with actual behaviour.

Kőszegi and Rabin (2009) find a consistent result with regard to preferences over good and bad news, and propose theoretical consequences that follow if agents receive anticipatory utility from planning their future consumption. The current model suggests a mechanism by which agents might generate that utility (although without the imposition of further

assumptions, it does not necessarily predict the same loss averse informational preferences that they rely on.)

The key prediction of the model is that people cannot consciously avoid activating specific nodes in the causal graph. If certain causes point to unrewarding effects, it may be impossible to avoid navigating to those unrewarding (painful) locations in the graph. However, if the graph does not contain any edges that point to those locations, the agent cannot accidentally navigate to them. Agents could therefore be motivated to avoid learning this information.

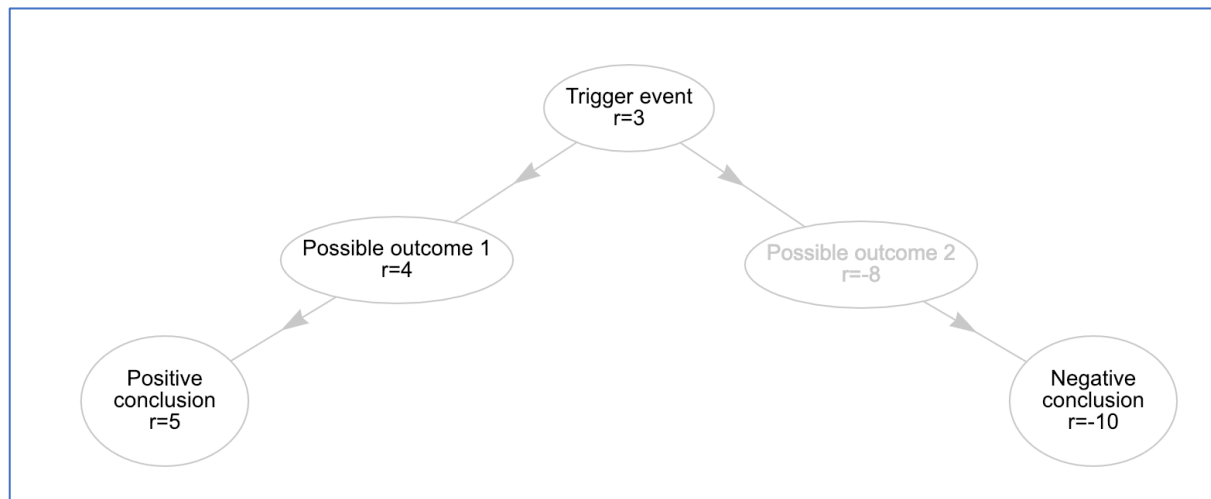


Figure 9a: before learning about possible outcome 2, the agent's overall valuation is positive

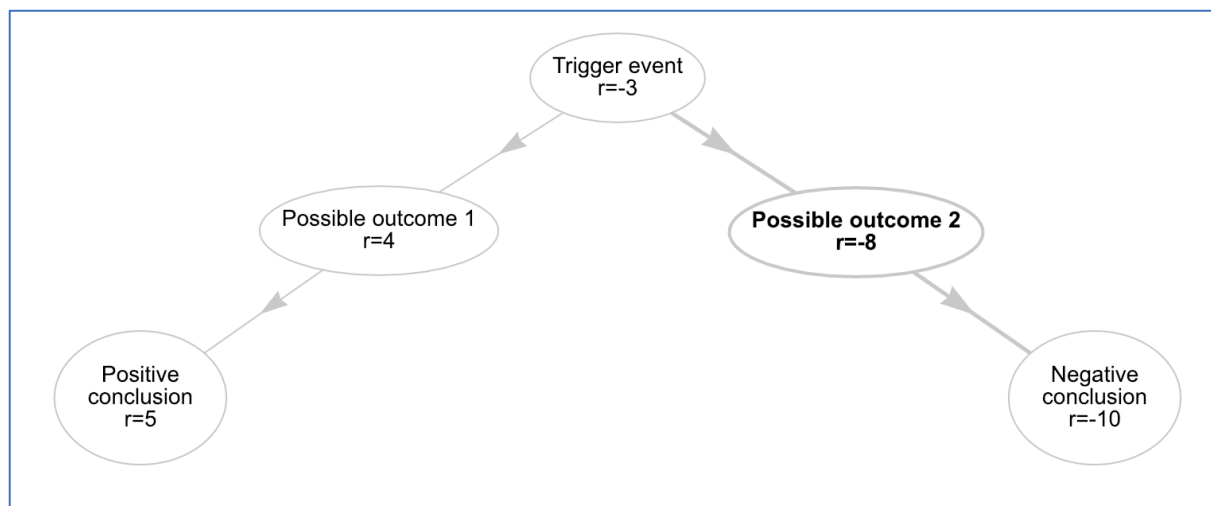


Figure 9b: after learning about possible outcome 2, the agent's overall valuation is negative

The way information is absorbed and communicated also creates supply constraints in the market for knowledge. Information is typically seen as a non-rival good, with no cost to copying or providing it once it has been created. However, if the meaningful component of information is not the external expression of it but the impact it makes on the agent's mental state, the cost of interpreting that expression must be considered part of the information's production function.

Conclusions from this argument include:

- Information markets are likely to be more partitioned and fragmented than we typically expect: with individuals gaining very different amounts (and even signs) of utility from the same external expression of a belief
- Information is non-satiable, with repetition of the same information still providing value
- Information can be priced, because the processes required to acquire and absorb it are still scarce
- Information is non-evaluable

The market for culture

Culture is usually consumed because the agent enjoys doing so – it produces rewarding cognitive goods. Agents may, in effect, choose to care about arbitrary nodes in their graph because doing so generates reward. A cultural object requires its viewer to willingly absorb its claims into their causal graph – knowing consciously that it may be fictional, but using *cognitive decoupling* to build the graph, hold it at arm's length and mentally navigate it for the duration of the consumption.

Other than the consumption of fiction (e.g. Lassie) a prime example of this is outcomes in sport. Although sport also has a social function, it seems likely that people attach significance to outcomes beyond just the utility of the social bonds involved. One mechanism by which this could occur is through an optimistic navigation of the causal graph to seek out potential positive outcomes. If agents have a bias (within this domain) towards imagining positive rather than negative outcomes, *or* if positive outcomes are simpler and less complex to imagine than negative ones, the model predicts that they will engage in thinking and speculation about sporting events.

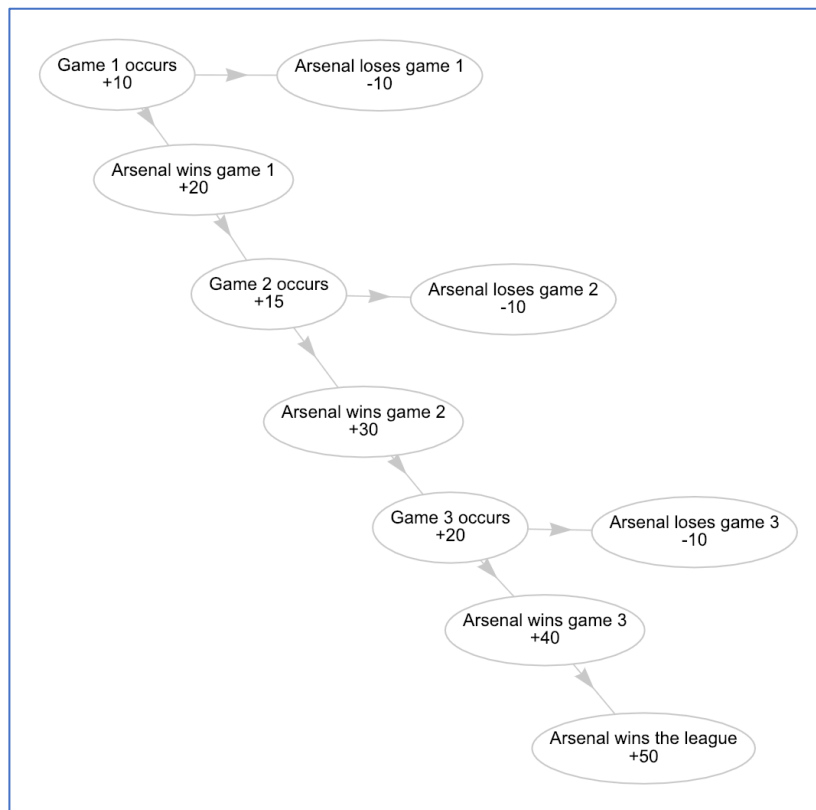


Figure 10: In this example, Arsenal needs to win three games in a row to win the league. If the agent truncates navigation of the graph at any point where this becomes impossible, they will focus only on the ultimately positive outcome and the overall experience of imagining the outcomes becomes rewarding – even though the probability of a positive outcome is low.

As well as providing subjective enjoyment to the consumer, the reward generated by these cognitive goods can also change their causal graph.

However, decoupling is never perfect. Our minds inevitably mistake some fictional claims for truth – not least because there is usually some truth in there. We willingly connect our reward centres to the decoupled version of the world – where is the fun in watching Lassie if we do not allow ourselves to care?

While my overt beliefs about Lassie’s world may be clearly marked as fictional, my mind is wandering autonomously over those beliefs and my established model of the world, making hidden maintenance updates. Those updates can transfer parts of the Lassie model into my “real”, permanent model.

If this does occur, cultural products can influence beliefs about the real world.

Valuation of normal goods

In a cognitive world, normal goods are no longer normal.

An agent's preferences over bundles of normal goods are no longer independent of the agent's mental state. All preferences are constructed based on the agent's causal graph. A bundle of goods activates nodes in the causal graph; the degree of reward generated by this activation guides the agent's choices.

The structure of the causal graph, and its state of activation prior to encountering the goods, both affect the degree of reward that the encounter generates. Therefore, preferences and choices over goods can in principle change as the agent's mental state varies.

Even more obviously, the agent's choices over normal goods are not only a function of the actual rewards those goods generate, but of the rewards the agent *predicts* they will generate prior to choice and consumption. Such predictions are firmly embedded in the agent's subjective model of the world.

The existence of a cognitive good in the agent's mind therefore affects their choices over normal goods. Cognitive goods act as complements or substitutes for normal goods.

For example: Awareness of dangers to the environment, a cognitive good, is a complement to recycled paper, a normal good. An increase in the total supply of that cognitive good will change the market price of recycled paper.

Marketing and advertising both directly create cognitive goods; this is the channel through which they change the market value of normal goods.

Money, as a normal good, is valued through the causal graph of agents throughout the economy. Agents' beliefs about both prices and availability of other goods affect their valuation of money. The caching of value through model-free learning then limits agents' ability to update this valuation.

Policy consequences

Policymakers may wish to affect the value that consumers put on money, as a monetary policy lever. The theory of cognitive goods suggests that they should:

- Encourage consumers to prospect over actual market prices, increasing the chance that they will update cached valuations
- Create new beliefs that directly influence the value of money: for example, increasing awareness of counterfeiting (to reduce valuation) or highlighting the highest potential returns available (to increase valuation). Being closer in the causal graph to the 'money' node, these beliefs will have an outsized influence on the valuation of that node.
- Encourage greater visibility of prices within transactions – for example discouraging the use of contactless payment or automatic direct debits from bank accounts.
- Focus these activities on agents whose valuation of money is most susceptible to change, or differs to the greatest extent to the policy-optimal valuation.
- Communicate directly about the value of money – possibly using pop-cultural tools.

Other potential policy implications include:

- Attempting to incorporate valuation of cognitive goods into overall consumer welfare functions. This model could provide support to the measurement of large-scale subjective welfare (BHKS) or the 'Gross National Happiness' concept (e.g. Diener 2000).
- Examining cognitive goods as a contributor to productivity. It is reasonable to expect that firms or individuals with a more accurate model of their customers' cognitive goods will be more efficient at producing wellbeing, whether or not this is reflected in priced market transactions.

Future research

Many of the themes mentioned above are developed only in outline form, and there is plenty of room for further theoretical exploration and empirical testing of the ideas proposed. If the process model gains further support from empirical neuroscientific or behavioural research, the implications for consumer microeconomic theory will be an interesting and rich area for working out.

Much work remains on the psychological foundations of the model. Although current directions in neuroscience research seem broadly supportive of the approach, it is too early to say with confidence that the mind definitely works on the basis proposed in this paper.

A number of the concepts discussed have previously been explored by both psychologists and economists qualitatively, but often without formal models. There has been a small body of cognitive economics literature (McCain 1992, Walliser 2008, Egidio and Rizzello 2003, Kimball 2015) some of which does propose more formal models, but it has rarely been connected explicitly to some of the empirically interesting problems that authors such as Loewenstein and Schelling have studied. Perhaps as a result, this field has never quite taken hold as a mainstream subfield in the economics literature. I hope that the model proposed in this paper will provide one possible source of momentum for future work.



Misty Robotics CEO Tim Enwall: Everyone will have a home robot in 10-20 years

BY KYLE WIGGERS

AUGUST 31, 2018

<https://venturebeat.com/2018/08/31/misty-robotics-ceo-tim-enwall-everyone-will-have-a-home-robot-in-10-20-years/>



The Misty II robot for developers. Image Credit: Courtesy Misty Robotics

In June 2017, when Misty Robotics spun out of Colorado-based startup Sphero— the folks behind the eponymous Sphero toy series, a motorized R2-D2, and a miniature replica of Lightning McQueen from Disney’s *Cars* franchise — it announced intentions to develop a “mainstream” home robot with the help of hobbyists, enthusiasts, and crowdfunding backers. With \$11.5 million in capital from Venrock and Foundry Group in the bank, the team wasted no time in getting to work. And the startup unveiled the first fruits of its 11-month labor — a robotic development platform called Misty I — at the 2018 Consumer Electronics Show.

In May, Misty Robotics took the wraps off the second iteration of its robot — Misty II — and made 1,500 units available for preorder, starting at \$1,499. (The first units are expected to ship by December 4.) The robot weighs in at six pounds, stands 14 inches tall, and packs electronics like a 4K Sony camera, a 4.3-inch LCD display, two hi-fi speakers, eight time-of-flight sensors, and three

far-field microphone arrays. It'll work with third-party services such as Amazon's Alexa, Microsoft's Cognitive Services, and the Google Assistant when it launches and will allow owners to create custom programs and routines — including ones that tap into machine learning frameworks like Google's TensorFlow and Facebook's Caffe2.

Misty Robotics isn't exactly rushing to market. It has a 10-year plan, and it's taking a hands-on approach to development. While a few preprogrammed skills (like autonomous driving and voice recognition) are available on GitHub, the idea is to let developers come up with use cases that the founding team might not have thought of.

I caught up with Misty Robotics CEO Tim Enwall ahead of IFA 2018 in Berlin to talk progress, the state of the home robotics industry, and what the future might hold.

Here's an edited transcript of our interview.

VentureBeat: So tell me what you've been up to lately.

Tim Enwall: We went out and raised money. Around July 4 of last year, we moved into our own offices and started building out a team. Then in May, we did a crowdfunding campaign, and we're super excited about how it went — we raised almost a million dollars. It proved to me that without a shadow of a doubt, we'd got a business worth tens of millions of dollars.

Now, we're driving toward shipping our product in December and doing all the hard work required to create the most advanced, affordable, useful, and easily programmable robots out there.

VentureBeat: Right. Maybe you can talk a bit more about Misty II. From where I'm standing, a lot seems to have changed since you announced it. Anki unveiled a home robot — Vector — and [Bosch-funded startup] Mayfield Robotics announced that it's shuttering its doors after years of iterating its robot, Kuri. So what do you think sets Misty apart from what's out there and what's come before? What will make it successful?

Enwall: The short answer to that question is the usefulness of the Misty platform.

When I speak to investors, journalists, and others about Misty, I like to ask them a couple of questions to set the stage. The first is, do you believe that in the relatively near future, there will be robots in every home and every office? Let's not debate the definition of "relative" for the moment. Yes or no?

VentureBeat: Possibly. I'm not convinced — I haven't come across or encountered a home robot I really thought was indispensable.

Enwall: But that's not the question. The question isn't, is there one that exists today? The question is, do you believe in the relatively near future, robots will exist in our offices in our homes in a widespread way? I'm talking the next 10 to 20 years.

The next question is, do you believe that in the future, we'll be buying 30 to 50 single-use robots like those that exist today? I'm referring to robot vacuum cleaners, lawnmowers, telepresence robots, security robots, et cetera ... Are we going to buy all of these, or are we going to buy one that does 30, 50, or even 100 things for us?

There is no company on the planet today — or in the future, for that matter — that can deliver a robot that'll perform all of the hundreds of things that robots will eventually do in the office or the home. To be clear: There's no company on the planet that has the resources and the talent to deliver a robot that does 50 things that are different for you in your home than the 50 things I want and the 50 things that somebody else wants. The only way to get there is through crowdsourcing.

So that's the concept behind Misty. Therefore, we have to deliver something that is powerful enough to create usefulness. And the only other product out there on the market that comes anywhere close to being able to provide a level of usefulness is ... [SoftBank's] Pepper, and that's a \$15,000 product.

VentureBeat: You've talked in the past about all the ways the Misty II platform will remain open and already, you're integrating with the many third-party services out there [like Alexa and the Google Assistant]. Was that a strategic decision? Do you think it'll help you gain traction?

Enwall: Yeah, definitely. Again, I'm a huge believer that the consumer who wants a robot in their house wants Rosie [from *The Jetsons*] ... and that class of robot does 100 things for the consumer.

Right now, every robot maker has decided to go the single-purpose route to serve the mass market. As a result, you've got this expectation gap between robots that can, say, vacuum the floor and Rosie. We believe that the only way to close it is by building a robot platform that can eventually do physically what Rosie can do, with the help of a software foundation that lets thousands of developers create the skills and the accessories.

VentureBeat: I'm guessing your open approach has guided Misty's hardware design. I mean, it can't be easy to figure out which components to include and which not to include. I'm sure price point is top of mind for you, and you probably can't fit everything you want and maintain affordability. Perhaps you could talk a bit about how the Misty II's design has evolved throughout the campaign and what your backers are telling you.

Enwall: From a hardware perspective, it's not going to change much from now to December — I mean, we're already piloting production runs in China. The decision-making process was guided by this question: How can we tack the most usefulness and stay within budget?

We wanted a robot that could do a lot of AI locally, and AI at all skill levels. Whether it's a college student or a professional who's experimenting with an independent robot can do for them, we wanted the robot to be very capable from an API perspective. We also wanted it to be autonomously mobile.

That's why we chose a pretty expensive but super capable 3D depth sensor so that it can not only navigate its way around, but produce a manipulable 3D map of the world for object detection and other features. We wanted Misty II to have high fidelity speakers so that when it *does* leverage natural language processing from Amazon or Google, it sounds great. We wanted the robot to have great microphones so that it's capable of working with voice.

Those are the sort of the basics we thought Misty II needed for it be useful. It had to be able to navigate by itself, and it had to have great eyes, great ears, and a great brain that's capable of capable of doing quite a bit of AI.

VentureBeat: So AI is a core part of the platform, I take it. That makes sense — artificial intelligence is what most people think of when they think of a robot. So was that a natural area of emphasis for you? Did you choose the Misty II's internals with that in mind, and are you going to supply developer tools that make it easy to get things like computer vision applications and natural language processing up and running?

Enwall: Yeah, absolutely. We put two powerful cell phone processors in there so that you can do some AI-related things, and we also opened up the pipeline for developers and gave them frameworks by which to access it.

We believe that with a mobile real-time platform, you've got all kinds of auditory and visual data that can feed learning systems. Most learning systems are off in the cloud somewhere, and they're fed data mainly in a non-real-time manner. When you're at the edge, you can feed a bunch of these learning systems and have them work collaboratively with the cloud to do additional processing.

VentureBeat: I'm glad you brought that up. There seems to be an ongoing debate about on-device processing versus cloud processing. It makes a difference whether you're talking about inference or model training, of course. But is it something you considered in the development of the Misty platform? Did you design it to ensure that it's not incomplete, so to speak, if there's not a reliable internet connection available?

Enwall: Oh yeah, we've done a lot to design it so that it's independent and autonomous of the internet. Most of our work, actually, concentrate on making this robot robust and effective and useful without being connected to the internet. Stuff like face detection, face recognition, autonomous mapping, and navigation — none of that requires any internet connectivity.

We think that's a pretty big distinction. When you're moving around in the real world and you're mobile, you have to respond in milliseconds. Regardless of what anybody would like to imagine about the latency of a round trip back to the cloud, it's just more latency than decisions that you can make locally.

I think there's a privacy component there, too. People will be even more aware of it with robots moving around offices and homes. It's certainly a vector that we believe in and spend time thinking about.

VentureBeat: With the remaining time we have, I'd like to ask about the future. When the Misty II launches and it starts to arrive in people's homes and places of work, where are do you go from there? Is there going to be some kind of marketplace where people can download creations from other users? Are there going to be frequent updates that enhance its capabilities?

Enwall: Absolutely. That's already part of the plan — there's a mechanism for developers to share their skills and accessories with each.

You can expect to see some skills emerging that might make your robot more valuable and useful to you, even in the earliest days, and it will continue to get better and smarter.

On our website, we've made our product roadmap publicly available. We only want to work on the things that our customer base finds valuable. We hope to every month be issuing a new feature, a new capability, so that the robot gets more powerful.

Who Owns the Robots ... Redux

Richard B. Freeman

Consider the newly born human, mid 2020s. Newbie will go to elementary school, high school, college and eventually graduate from formal education to enter the world of work around 2050. Who do you think will be newbie's main competitor for jobs in the middle of the 21st century? Other newbies? Immigrants? Or robots with artificial intelligence governing their behavior?

If you believe the media, it's AI robots, by a long shot.¹ Every week the newspapers, TV, Internet, etc. report advances in what algorithms or machines can do in the world of work. There are computer programs that out-do humans in repetitive white-collar jobs; programs that use machine learning to defeat champion chess and go players; programs that outfox professionals in incomplete information games such as poker, where bluffing adds uncertain complexity to play; and programs that write poems and create art. Absent AI, machines informed by sensors and directed by smart software are doing skilled work that humans once dominated, from welding in an automobile factory to accounting in an office. Some AI robots/software complement human workers but most substitute for human labor.

Driverless cars? Goodbye truck drivers, bus drivers, cabbies, Uber, and Lyft drivers!

Chatbots? It's Death of the Salesman!

Medical diagnosis? Machine learning gives fewer errors at lower cost than your family doctor!²

Finance and banking? Biggest investors in the US in work related software!

Advances in AI robotics technology have spawned a small industry of projections of the future of work³. Frey and Osborne's (2013; 2017) claim that 47% of US jobs were at risk of computerization made headlines around the world. Consistent with the media hype, and presumably influenced by it, 72% of Americans in a 2017 Pew Survey reported that they were worried about “a future where robots and computers can do many human jobs”.⁴ Surveying 352 machine learning experts⁵ about when they expected “unaided machines [to] accomplish every task better and more cheaply than human workers”, Grace et al (2016) report a median expectation that many occupations or work type tasks will “go robot” by the middle of the 2000s – just when 2020s newbies will be trying to establish their careers!—with full automation of all human jobs coming around 2140.

How much weight should we put on media reports, futurist projections, and expert technologists' views about the future of work? Noting the absence of *any* evidence of a job-threatening technological revolution in aggregate productivity or employment data, many labor experts and macro-economists believe that threat of a job-threatening “robolution” is largely

¹For examples, see “Robots will destroy our jobs – and we're not ready for it” Guardian, Jan 11, 2017; “Robots Threaten Bigger Slice of Jobs in US, Other Rich Nations” (Wired, Nov 28, 2017); “Automation could impact 375 million jobs by 2030” (Morningstar Dec 4, 2017); “Will Robots take our Children's Jobs?” New York Times, Dec 11, 2017.

² For <https://www.techemergence.com/machine-learning-medical-diagnostics-4-current-applications/>

³Winick, (2018) reviews over a dozen projections of the impact of technology on employment, nearly all which foresee a “robolution” in job markets.

⁴This is from a Pew Research study, <http://www.pewinternet.org/2017/10/04/americans-attitudes-toward-a-future-in-which-robots-and-computers-can-do-many-human-jobs/>. A Northeastern University-Gallup Study (“Optimism and Anxiety: Views on the Impact of Artificial Intelligence and Higher Education’s Response” January 2018, <https://www.northeastern.edu/gallup/pdf/OptimismAnxietyNortheasternGallup.pdf>) focused on artificial intelligence found similar results with 73% saying they “expect the introduction of AI will results in a net loss of jobs” though they also said that they think that jobs other than their own are more likely to be threatened.

⁵Defined as those who had 2015 published articles in either of two premier venues for peer-reviewed research in the field.

hype. If we faced a job-disrupting technological revolution, productivity would be rising rapidly, employment falling, and unemployment increasing; whereas in fact, productivity growth has been modest, the ratio of employment to working age population has recovered from its Great Recession low to near historic peak levels in 2017, and the unemployment rate has fallen to levels not seen since the late 1960s. The economic problems that show up in data – stagnating real wages for many workers, a falling share of labor in national income⁶, and the seemingly inexorable rise in inequality – preceded the development of AI robotization, leading some to conclude that the problems facing workers stem from labor's loss of bargaining power and political leverage rather than from technology (Mishel and Bivens (2017)).

Finally, critics of futurist projections note that past fears that machines would displace millions of workers – from the Luddites in the Industrial Revolution to the technocracy movement in the Great Depression to President Johnson's early 1960s National Commission on Technology, Automation and Economic Progress to Jeremy Rifkin's 1990s “End of Work” – all fizzled out. The technologies spurred economic growth that led to better jobs with higher pay for most workers. *Why should we believe that this times' fears of technology disrupting the labor market will turn out different than last times' fears?*

Different because ...

Lack of aggregate economic evidence of a technological revolution and the history of failed dystopia of machines taking jobs notwithstanding, I argue in this “redux” of “Who Owns the Robots Rules the World” (Freeman, 2015) that advances in AI robotics technology, new estimates of how industrial robots affect employment and wages, rapidly falling price of robots, and the exponential growth of industrial robots and software in business makes this times' technology more likely to disrupt labor markets than past technologies.

To begin, by substituting machine learning and intelligence for human cognition, AI robotic technology will challenge humans in many high skill high paid jobs as well as in the less skilled low pay physical jobs impacted by past automation. The digitalization of work, which has moved many business activities from the physical world in which we live to the innards of computers where AI “lives” will allow AI and other software algorithms to replace humans in previously non-automatable white-collar jobs. The expansion of the 3d printing and additive manufacturing proportion of the production of goods places previously non-automatable blue-collar jobs under computer control.⁷

The economic logic that offers most insight into the long-term effects of AI robotics technologies on workers is the theory of *comparative advantage*. Comparative advantage holds that technological change or any other major economic development (such as trade between two countries with different factor endowments, which spawned the theory) will show up more in the type of work people do and the income they earn from work than in some apocalyptic end of work. In the case at hand, even if AI algorithms/machines dominate humans in every work task, firms will still hire humans. They will hire humans to do work tasks which we can do at lower cost than machines, and hire machines to do the work they can do at lower cost than humans. The key question for newbie circa 2020s is the extent to which the machines will gain advantage in the high skill and high paid work activities that provide desirable career jobs.

Machines gain comparative advantage in activities that require considerable cognition, flexibility, and judgment in two ways.

⁶The magnitude of these problems varies with measures of wages and benefits, prices, gross domestic product, and employment; and with the self-employed and public sector shares of employment. In the US, the Bureau of Labor Statistics estimates a larger drop in labor's share than the Department of Commerce, and both differ from OECD estimates.

⁷<https://www.engineering.com/AdvancedManufacturing/ArticleID/16873/3D-Printing-Is-Poised-to-Continue-Outpacing-Growth-of-Traditional-Manufacturing.aspx>; https://www.3dprintingmedia.network/wp-content/uploads/2018/04/DfAM_Q1-2018-Report.pdf

First, by increasing the *breadth* of specialized tasks that machines *as a group* can accomplish. A machine that does a single specialized task more cost effectively than a human cannot compete with the human on the many other activities that constitute most jobs. But an ensemble of many specialized machines that does most or all of the tasks can compete with human versatility in the job.

Second, by increasing the *depth* of the machine in performing the disparate tasks that humans do – what computer scientists call *strong AI or artificial general intelligence*. A machine with artificial general intelligence could pass a Turing test and appear to be a human.

Given the difficulty AI has had in attaining its early goal of developing artificial general intelligence,”⁸ I have been most struck by the increased breadth of AI robots/ algorithms in doing more and more special work tasks as the primary route for machines to gain comparative advantage in skilled work. The division of labor among the algorithms and robots in the ensemble allows the whole to be greater than its parts in competing with humans in occupational tasks throughout the labor market. Even though all the welding robot does is weld; and all the painting robot does is spray paint; while the roomba vacuums but does not dance nor wipe a counter clean; with enough specialized machines superior to humans in their specific domain, a firm could easily find it cost effective to rent/lease an ensemble of machines rather than hiring the more versatile human. Initially the human would presumably have an edge in jobs with great uncertainty in tasks, but with big data on those uncertain jobs, an algorithm could presumably use machine learning to compete with humans in dealing with uncertainty.

Mind-boggling breakthroughs in AI technology in 2016-2017 show that specialized algorithms can now learn enough to outperform humans in situations filled with complexity and uncertainty and that machine learning has advanced so rapidly that a single algorithm can learn enough about several different games to out-do humans in all of them.

Google's AlphaGo triumph over the world's top Go players in 2016 is my first mind-boggling breakthrough. Go is a complete information game with so many greater possibilities than chess that two years earlier experts confidently claimed it to be beyond any machine algorithm in the foreseeable future. Human Go champions studied the game for years to build up an intuitive feel for how moves in the beginning and middle of the game influence winning possibilities at the end. AlphaGo gained its expertise by *playing more games against itself* in its digital environment than any human expert could play in a lifetime and by using reinforcement learning⁹ to evolve stronger strategies from its experience.

Carnegie Mellon's Libratus and the University of Alberta's Deep Stack triumph over human experts in the incomplete information game of poker, also in 2016. is my second mind-boggling breakthrough. Analysts described Deep Stack's win to “combin(ing) recursive reasoning to handle information asymmetry, decomposition to focus computation on the relevant decision, and a form of intuition that is automatically learned from self-play using deep learning.” As with the Go algorithm, the poker programs learned what moves worked best not only from moves by humans but also by accruing more experience than their human opponents through self-play in the digital world.¹⁰

The biggest breakthrough in AI technology was announced on December 5, 2017 when Google's DeepMind Go-team reported that, “Starting from random play, and **given no domain knowledge** except the game rules, AlphaZero (its follow-up to AlphaGo) achieved within 24 hours a superhuman level of play”, beating algorithms that had defeated the best humans in Go,

⁸Indicative of the early optimism, Herbert Simon predicted at the 1956 Dartmouth Summer Research Project on AI that “Machines will be capable, within twenty years, of doing any work a man can do”.

<https://www.digitaltrends.com/features/top-10-bad-tech-predictions/5/>

⁹ <https://www.tastehit.com/blog/google-deepmind-alphago-how-it-works/>

¹⁰ <https://www.theguardian.com/technology/2017/jan/30/libratus-poker-artificial-intelligence-professional-human-players-competition>. Also see Brown and Sandholm (2018); Moravčík, et.al. (2017).

chess and shogi.¹¹ That AlphaZero learned in one day to dominate opponents in three *different* settings has profound implications for comparative advantage and the future of work. It raises the possibility of developing machines that, while falling short of general machine intelligence, will have enough “job market or occupational intelligence” to compete with human versatility in all the tasks that make a prized worker or job candidate.

If AlphaZero could dominate strategic board games in 2017, what do you think Alpha20 will be able to do in work tasks in 2050 when newbie circa 2020 is on the job market? If you were hiring someone for your business, would you choose newbie college graduate or Alpha20 with its direct line to massive Cloud data and quantum computer processing power? More realistically, would your hiring algorithm choose Alpha20 or newbie circa2020?

The laws of robo-economics

The link between technology and labor can be further illuminated through the lens of the three laws of robo-economics (named in honor of Isaac Asimov's three laws), where robot refers generically to mechanical robots, algorithms or other machines that can compete with us for jobs.

Law 1. Robots become better substitutes for humans in work activities over time. The combination of artificial intelligence based on improved machine learning algorithms, greater computer power, and sensors/mechanics that interface with the off-line (“real”) world will make it easier to substitute machine for human labor over time, increasing the elasticity of substitution between AI robots and humans.¹² It does not matter for substitution whether the robot/machine has a humanoid appearance or is simply computer code as long as it can perform human functions. As the elasticity approaches infinity where robots and humans are perfect substitutes for each other, the traditional dichotomy between robots as machines or capital (K) and labor (L) breaks down. Robot capital that is a better substitute for human labor than for machines should be treated as part of L instead of as part of K and thus should be viewed as reducing wages by adding to labor supply rather than as raising wages as a complementary input to labor.

Law 2. Technological change in AI robotics reduces the cost of robot substitutes for humans, which drives down wages in tasks/jobs where both compete. By definition, technological change means getting more output from a given set of inputs. In the case of robots, this will show up by increased effectiveness of robots relative to their price. The increase could occur through declining prices for robots with specified skills or through new robot models with better skills at the same or even a modestly increased price.

There is considerable evidence for law 2 for the US and other developed economies. Business consulting groups report that robot prices in the US fell by 6% to 9% per year in real terms from 2005 through the mid-2010s.¹³ For the period 1990 to 2005 Graetz and Michaels (2015) estimated that the price of robots in six major developed economies halved and that the prices fell to about one fifth the 1990 level after being adjusted for quality improvements. Since firms will choose the least expensive way to produce goods and services, the falling cost of robot

¹¹ Science Alert, <https://www.sciencealert.com/it-took-4-hours-google-s-ai-world-s-best-chess-player-deepmind-alphazero>. The article quotes one human expert declaring, “This algorithm could run cities, continents, universes.”

¹²In a production function F where labor (L) and robots R produce output, the elasticity of substitution is $d\ln(L/R)/d\ln FL/FR$, where $\ln$ is the natural log and F_i is the marginal product. A profit-maximizing firm will hire workers so that $FL/FR = W/CR$, where W is wage unit of time and CR is the cost of the robot per unit of time.

¹³ARKInvest estimates that the unit cost in 2015 dollars of industrial robots fell from \$131,000 in 1995 to \$68,000 in 2005 and to \$31,312 in 2014 – an annual drop of 6.5% in 1995-2005 and 8.6% in 2005-2014 (<https://ark-invest.com/research/industrial-robot-costs0>). Statistica shows robot prices falling from \$63,000 in 2009 to \$45,000 in 2018. The Boston Consulting Group estimated price of welding robots in the auto industry was \$55,000 in 2005 and \$33,000 in 2014 – an annual drop of 5.7%, or 7.9% in constant dollars; and that the price of a robotic system of production, including project management, systems engineering, and peripherals fell from \$182,000 (2005) to \$155,000 (2010) to \$133,000 (2104), for a - 3.5% per year in nominal terms and - 5.7% in real terms. (<https://www.slideshare.net/TheBostonConsultingGroup/robotics-in-manufacturing>)

substitutes for humans will pressure humans to take wage cuts if they are to compete with robots in overlapping jobs or work activities.

Taken together, laws 1 and 2 predict a Malthusian future for humans due not to Malthus' prediction that humans would produce an endless supply of babies at the subsistence wage but because humans will produce an endless supply of robot substitutes at a declining cost¹⁴.

Law 3. The effect of AI robotic technologies on income depends on who owns the technologies.

In a world where machines do much of the work and receive much of the earnings, the economic winners are the owners of the machines while the losers are workers who compete with the machines. If you own the robot that does your job/the jobs of others, you benefit from the new technology. But if I own the robot that does your job, tough luck suckah! Who owns the robots rules the world!

Beginning of Evidence on the Beginning

That aggregate economic statistics show no sign of a robolution in the job market should not be surprising. Even after two decades of rapid growth, the US deployed on the order of 360,000 industrial robots in 2016 – one robot for every 340 or so full-time workers in the country.¹⁵ The number of industrial robots sold in 2016 was 31,400 – far below the half million or so immigrants who entered the US job market (Borjas and Freeman, 2019) and even further below the average growth of the work force of about 1 million persons per year over the past two decades. For all the hullabaloo, the beginning of robotization is too small to impact the aggregate economy.

The place to look for effects of robots/technologies that are just beginning to impact the economy is in sectors where the robots/technology expand rapidly compared to sectors where they are largely absent. To be sure, rigorous analysis of the confounding effects of sectoral differences beyond deployment of the new technology, of the factors that led to more rapid deployment of the technology in some sectors, and of possible spillovers among sectors is necessary to pin down causal impacts. But, by itself, the presence or absence of differences among the sectors provides valuable clues as to how the technology might affect employment and wages.

Several studies have used data from the International Federation of Robotics (2017) on the number of robots sold each year to different industries in different countries to conduct such analyses. Graetz and Michaels (2015) compared growing robot intensity in industries across 17 countries and found that robotization was associated with higher growth of industry productivity and wages with some reduction in total hours worked for low-skilled labor.

Combining differences in robot intensity among industries and the location of industries across US *commuting zones*, Acemoglu and Restrepo (2017) estimated that one additional robot per thousand workers in an area lowered the employment to population ratio by 0.18-0.34 percentage points and lowered wages by 0.25-0.5 percentage points. Analyzing changes in robot intensity by industry and area in Germany Dauth et al. (2017) found that an additional robot reduced employment in manufacturing by about two workers but did not impact employment in a region because service sector employment increased by about the same number, while also reducing wages significantly. Treating the variation in robots by industry in the US from 1993 to 2016 as a supply shock, Borjas and Freeman (2018) find that growth of robots reduced

¹⁴This turns upside down Herbert Simon's 1965 *Shape of Automation* analysis in which workers were the ultimate beneficiaries of even the most labor-saving technical change Simon viewed robots as substitutes for capital supplied at a going interest rate and thus as a classic K/L complement to labor, raising wages. By contrast my analysis treats AI robots as increasingly better substitutes for humans with declining cost over time.

¹⁵The IFR uses its data on yearly robot sales to estimate the stock of robots assuming that a robot operates for 12 years and is then scrapped completely. Borjas and Freeman estimate the “effective stock” using other assumptions and get similar magnitudes

employment by about 2.4 workers and reduced ln of earnings by 1.2 points, with larger effects in occupations viewed as having been automated or likely to be computerized. In a Harvard undergraduate thesis, Nan Chen (2018) found that rising robot intensity was associated with falling wages in US *occupations* characterized as having considerable routine work,¹⁶ largely for those doing production and material moving work, where employment also fell modestly.

Because less than 9 percent of the non-farm work force works in manufacturing, however, estimates of the effects of industrial robots in that sector cannot be readily extrapolated to the effects of the new technology on the rest of the economy. Outside of manufacturing, the key robots are service robots and machines such as ATMs that do human work but do not fit the industrial robot definition, while the digitalization of white-collar work makes software arguably the most important conduit/indicator of where the new technology will impact workers. In the US software spending has increased massively since 1990, increasing nearly nine-fold through 2017. The Census's 2013 Information and Communication Technology Survey shows the US spending over 50% more on software than on ICT equipment.¹⁷ The missing technology elephant that will impact the jobs of most workers is the software they work with, which to my knowledge has not been adequately investigated to date, and has accordingly become a main focus of my on-going research.

The Ownership Solution

Assume that the analysis of this paper is at least roughly on target – that expansion of AI/robot technology will move comparative advantage in some high wage cognitive activities from humans to machines– and that development of better and cheaper AI robot substitutes for humans will pressure wages down and shift income from workers to the owners of robots. If society wants the vast majority of workers and citizens to prosper in such a world, what can we do?

Per the “Who Owns ...” title, one potential answer is that public and private sector decision-makers institute policies and practices that enhance the ownership stake of workers in their own firms and in outside businesses as well. Rather than treating employee ownership as a niche institution to bridge the labor-capital divide and viewing pension funds as the primary mode for workers to accumulate capital, the ownership solution focuses on ways for workers to gain additional income from capital during their working lives commensurate with the increased earnings that flows to robots and related new technologies.

Behind the employee ownership part of this solution lies a large body of research that finds that firms with some form of employee ownership, profit-sharing (ownership of part of a stream of revenues or profits), or gain-sharing (ownership of part of the gains in attaining some company goal) have higher productivity than comparable firms without such programs, and that the workers in employee owned/profit-sharing firms have higher income and lower turnover than comparable workers in other firms (Blasi, Kruse, Freeman, 2017; O'Boyle et al 2015; Doucouglias et al 2018). Studies of the effects of ownership also show considerable variation in effects among the firms, which researchers often attribute to differences in company culture, sector, type of work, ownership, and management attitudes.

The US has the world's most extensive employee ownership and profit-sharing arrangements. In 2014 44.7% of US workers received some of their pay through ownership, profit-sharing or gain-sharing. One in nine US workers worked in 2015 for firms with Employee Stock Ownership Plans (ESOPs) that gave firms tax breaks to set up ownership programs or with ESOP-like plans. Most ESOPs share ownership with outside investors, holding on average about one-fifth of the value of their firm (Freeman 2018).

¹⁶The measure of routine is from the Department of Labor's O*NET data base of occupational characteristics.

¹⁷ This sums capitalized (investment) spending and non-capitalized (purchase or leasing of software,) spending of software compared to ICT equipment from <https://www.census.gov/data/tables/2013/econ/icts/2013-icts.html>

The European Union's Promotion of Employee Participation in Profits and Enterprise Results program encourages EU states to expand ownership,¹⁸ but offers no financial incentives. The action in employee ownership is at the country level, with different EU countries favoring particular forms of ownership or participation. France mandates profit-sharing under a 1960s scheme set up by de Gaulle. Spain has the Mondragon conglomerate of 100% employee owned firms. The UK gives tax breaks to workers who buy shares in their firm under employee stock purchase plans. And so on. The experience of countries shows that tax and other incentives generally work to expand the number of firms with ownership plans and the share of their assets or profits going to workers.

Given the risk of workers' holding capital in their own employer and variation in the success of employee owned firms, there are limits on the extent to which ownership of one's employer can replace labor income lost to AI robots. To have some security in earnings and be on a rising income trajectory workers will need income flows from other sources. Some analysts favor a government funded Universal Basic Income to serve as a lower bound for earnings. Many countries encourage workers to save part of their income in pension funds that invest in the broad economy and earn higher return than government bonds. In the US private pension funds held 25 trillion dollars in assets in 2017, with half in equity¹⁹, which makes them a major owner of business capital, but workers have little influence over where they are invested and the funds are not readily available for spending during the working years. Some countries and states in the US have set up Sovereign Funds seeded by state ownership of natural resources whose funds are invested widely and whose returns fund public goods. Only Alaska's Permanent Fund provides capital income to citizens through its yearly dividend to each resident regardless of age that I envisage as necessary for giving workers' a reasonably steady flow of capital income. Jones and Marinescu (2018) find the Alaska Fund to be an efficient way to supplement labor income.

In sum, my redux of who owns the robots ...has increased my confidence that we are entering a world in which the robots will do more of the work and gain more of the income, and that policies and institutions that increase workers' ownership or dividends from ownership should be part of any effort to assure that the benefits of the new technologies benefits us all. Who owns the robots citizens rules the world? Yes. Then we better own the robots.

¹⁸ <http://www.efesonline.org/LIBRARY/2009/PEPPER%20IV%20Web%20Oct-09.pdf>

¹⁹ <https://www.willistowerswatson.com/-/media/WTW/Images/Press/2018/01/Global-Pension-Asset-Study-2018-Japan.pdf>

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The Dream Labs of Future Robotics

By Tanya M. Anandan, Contributing Editor

Robotic Industries Association

10/30/2018

https://www.robotics.org/content-detail.cfm/Industrial-Robotics-Industry-Insights/The-Dream-Labs-of-Future-Robotics/content_id/7533

Tomorrow's robotics are taking shape in today's labs. From package delivery robots and self-driving cars, to surgical snakes and search and rescue robots, the innovations have profound implications. A year, 3 years, or maybe 5 to 10 years down the road, they could be at our door, in our home, or at our side when we need them most.

We will take a peek into our future through the lens of a few of the nation's top academic institutions for robotics research. Each of these universities continues to attract and recruit renowned faculty to their robotics rosters. They have interdisciplinary master's and doctoral programs in robotics. They spawn successful spinoffs and notable alumni that shake up the industry. They embrace a comprehensive approach to robotics research and education.

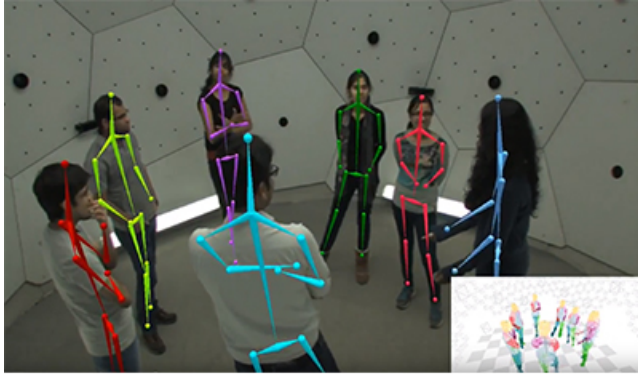
As we've said before, robotics is a multidisciplinary sport. The traditional areas of study, mechanical engineering, electrical engineering and computer science, have broadened into biological systems and cognitive science. Many of the top university robotics programs are attacking robotics challenges from all angles and making fascinating discoveries along the way.

Human-Robot Interaction

Established in 1979, the Robotics Institute at Carnegie Mellon University (CMU) is one of the oldest in the country and the first to offer graduate programs in robotics. The institute encompasses the main facility on CMU's campus in Pittsburgh, Pennsylvania, the National Robotics Engineering Center (NREC) in nearby Lawrenceville, and Robot City in Hazelwood with its 40 acres of robot testing fields at the site of a former steel mill. The university and the Greater Pittsburgh robotics scene have transformed the Steel City into Roboburgh, one of the well-established hubs we visited in a previous article on [Robotics Clusters the Epicenter for Startups](#).

The Robotics Institute is under the CMU School of Computer Science. Researchers take a comprehensive approach to robotics, studying robot design and control, perception, robot learning, autonomy, and human-robot interaction (HRI).

In fact, a central theme according to Martial Hebert, the institute's director, is HRI. "Much of the work in robotics has less to do with robots. It has to do with people," he says. "Understanding people, predicting people, and understanding their intentions. Everything from understanding pedestrians for self-driving cars, to understanding coworkers in collaborative robot manufacturing, any application that involves interaction with people at any level."



Researchers study and catalog people's body language to help robots better relate to humans. (Courtesy of Carnegie Mellon University)

One of the ways CMU is trying to better understand people is by studying our body language. Researchers built a life-sized geodesic dome equipped with VGA cameras, HD cameras, and depth sensors to capture images from tens of thousands of trajectories. The result is dynamic 3D reconstruction of people, their body poses, and motions.

As humans, we speak volumes through our body movements, posture, and facial expressions without needing to utter a word. The CMU Panoptic Studio was built to capture these subtle nonverbal cues and create a [database of our body language to help robots better relate to humans](#). The research is ongoing with datasets

now available for full-body motions, hand gestures, and 3D facial expressions.

Outside of academia, the work has not gone unnoticed. [Facebook was inspired to open a lab](#) in Pittsburgh and hired Yaser Sheikh, the CMU professor who developed the Panoptic Studio. It turns out nonverbal social interaction is just as important in the virtual world. Think Oculus Rift, the virtual reality technology now owned by Facebook.

Machine Learning and Robot Intelligence

Hebert says machine learning is another big area for CMU. The idea is to have a robot learn from its own actions and data, and learn to get better over time. Examples include manipulators that learn how to grasp, or drones that learn how to fly better. The recent collaboration between [CMU and Honeywell Integrated to develop advanced supply chain robotics and AI](#) will harness the power of machine learning to control and operate multiple robotic technologies in connected distribution centers.

“It’s a material handling application that includes sorting packages and moving packages around distribution centers at very high rates,” says Hebert, without divulging much about the robots they are using. A more recent [Honeywell partnership with Fetch Robotics](#) may provide a clue.

“We’re past the stage where robots only do repetitive operations,” he says. “They have to be able to make decisions, they have to be able to adapt to the environment. Things are not always in the same place or where they should be. That’s where machine learning and autonomy come into play. All of it comes together in this type of application.”

The project is underway at the university’s NREC facility, where for over 20 years CMU researchers have helped conceptualize and commercialize robotic technologies for industrial and government clients. From laser paint removal robots for F-16 fighter jets to unmanned bomb-clearing vehicle convoys, to autonomous crop harvesters, construction loaders and mining robots, the impact has been felt across numerous industries. [Watch this video](#) to see NREC technology in action, such as this Caterpillar self-driving mining truck.

Despite CMU’s audacious world of autonomous vehicles, Hebert says they focus less on the physical aspect of robotics research compared to robot intelligence. This is a recurring theme we hear inside and outside academia, the attention on algorithms, or the software side of robotics. He offers an example.

Kaarta makes a 3D mobile scanning and mapping generation system that puts advanced simultaneous localization and mapping (SLAM) technology in the palm of your hand – in real time. The 3D digital model is generated right in front of you on a handheld touchscreen interface, without the need for post-processing. At its heart is the patent-pending advanced 3D mapping and localization algorithms, a product of CMU’s robotics lab.

“Our contribution was to take massive amounts of data from the sensors and optimize it very quickly and efficiently,” says Hebert, crediting advanced mathematics and algorithms for the feat.

[Watch as Kaarta CEO Kevin Dowling demonstrates the system](#). He’s also a product of the doctoral program at CMU.

The system's compact size and customizable imaging hardware allow it to be mounted to ground or aerial vehicles, such as drones, for interior and exterior use. Right now, the company's products are directed toward infrastructure inspectors, surveyors, engineers, architects and facilities planners. But imagine the possibilities for first responders, hazmat teams, law enforcement, and down the road, for self-driving cars.

Search and Rescue Robots

Speaking of first responders, that brings us to a peculiar-looking robot developed in the labs at CMU. It goes where humans can't.

The Snakebot robot undulates its way into tight spaces and sticky situations, where the environment may be inhospitable and unpredictable for people, and even canines. Snakebot was on the ground for search and rescue efforts after a disastrous earthquake hit Mexico City last fall. Then this past spring, it was named [Ground Rescue Robot of the Year](#).

Howie Choset, a professor of computer science and Director of the CMU Biorobotics Lab where Snakebot was developed, says they are proud of the robot and its accomplishments to date. Still, challenges remain.

"The challenges are how to move (locomotion), where to move (navigation), creating a map of the environment, and providing the inspector with good remote situational awareness," says Choset.

A camera on the front of the robot helps an operator see the immediate area around the robot, but this has limitations in low-light conditions and highly cramped environments. In disaster scenarios, sensors for perceiving sound and smell may be more useful in detecting signs of life.



Snake-like robot helps first responders with search and rescue efforts by maneuvering into tight spaces and accessing difficult-to-reach areas. (Courtesy of Carnegie Mellon University)

[Watch CMU's snake robot](#) use its multi-joint body to climb poles, slither under fences, maneuver through pipes, roll into storm drains, and even swim.

Choset envisions snake robots destined for manufacturing applications such as inspecting tight spots inside aircraft wings, or installing fasteners inside airplane wings or boats, and painting inside car doors. He also hopes to see these [snake bots at work in the nuclear industry](#).

Medical Robotics

Another snake-like robot developed in the Biorobotics Lab has made significant headway in medical robotics, another noteworthy area of study for CMU. Unlike the snake robots used in search and rescue or industrial applications, the surgical snake is a cable-driven robot. Choset explains the difference.

"Imagine a marionette that has little wires that pull on different parts of the doll. A cable-driven robot is one where internal cables pull on the links to cause the joints to bend. The motors don't have to be on board, so you can get away with a lighter mechanism, or in my case, use bigger motors."

This is in contrast to the locomoting robot that crawls through pipes, where all of the motors are on board.

"I think minimally invasive surgery is a great area for robotics," says Choset. "The challenges are access, how to get to the right spots, and once you're there, developing tools, end effectors and other mechanisms to deliver therapies and perform diagnostics. Situational awareness, or being able to really understand your surrounding environment, is the next step after that."

The biorobotics team at CMU envisions minimally invasive no-scar surgery in the snake robot's future. But in the meantime, the technology has already found success in transoral robotic surgery and has been licensed to Medrobotics Corporation. Professor Choset is a cofounder of the Massachusetts-based company. RIA will dive deeper into this technology next month when we focus on surgical robotics.

When [a robot is attached to the body](#) or inside a human body, medical robotics takes human-robot interaction to new levels. But what about when humans are the robot's passengers? That's basically the scenario with self-driving cars. Let's take a ride to the Motor City.

Self-Driving Cars

The University of Michigan may be world renowned for its football program, but it is landmark self-driving vehicle research that put Michigan Robotics on the map – literally. Just 40 miles outside of Detroit, the Mcity Test Facility is a one-of-a-kind proving ground for testing connected, autonomous vehicle technologies in simulated urban environments.



A researcher goes hands-free as autonomous vehicle technology takes over the steering wheel during a high-performance driving run on a closed test track. (Courtesy University of Michigan)

The 32-acre site on U-M's campus in Ann Arbor has miles of roads with intersections, traffic signs and signals, sidewalks, simulated buildings, obstacles such as construction barriers, and even the occasional “dummy” to test pedestrian avoidance technology. It's the quintessential outdoor lab for researchers envisioning a local network of connected autonomous vehicles by 2021.

[Watch as researchers demonstrate the advantages of connected self-driving vehicles](#) and how augmented reality is helping them test these technologies more efficiently and safely.

“Self-driving is probably what we're known for the most,” says Dmitry Berenson, a professor of engineering at U-M. “That's a real strength here. We

have the U-M Transportation Research Institute (UMTRI) that has been conducting self-driving work for many years, even before it was popular. We're very close to the auto manufacturers, so we can very quickly set up meetings and integrate with them, and get feedback. Well-established relationships with Toyota and Ford are pushing self-driving technology forward.”

We first met Berenson when he was at Worcester Polytechnic Institute leading research in machine learning and manipulation planning. Back then, we were discussing his work with motion planning algorithms for a humanoid robot stacking boxes. Check out [Our Autonomous Future with Service Robots](#). Now, Berenson is Director of the Autonomous Robotic Manipulation (ARM) Lab, which he founded two years ago when he joined U-M. Algorithms are still his passion.

“Michigan is doing something really important, which is pushing the boundaries on algorithms to get robots into unstructured environments in the real world,” says Berenson. “We have people working on this in terms of aerospace applications, all the way to [legged locomotion](#), to manipulation like my group, to self-driving. There's a huge push in self-driving technology. Some of our faculty have startups in this area.”

U-M Professor Edwin Olson cofounded May Mobility in 2017. The startup's autonomous shuttle service is currently operating in downtown Detroit and [charting new territory in other Midwestern cities](#). As Director of the APRIL Robotics Lab, Olson is known for his work in perception algorithms, mapping, and planning. The licensed intellectual property behind these self-driving shuttles was developed in his lab.



Autonomous shuttle vehicle navigates city streets on specific routes, transporting self-driving technology and its passengers into the mainstream. (Courtesy of May Mobility, Inc.)

Replacing diesel buses in some cases, the [six-passenger electric shuttles navigate city streets on specific routes in business districts](#), or on corporate and college campuses. This follows last year's pilot in which May Mobility shuttled employees of Bedrock Detroit and parent company Quicken Loans between their offices and the city's parking garages.

A surge in funding from major investors such as BMW i Ventures, Toyota AI Ventures, and Y Combinator, plus a new partnership with tier-one auto supplier Magna International, could accelerate a nationwide rollout for Olson's autonomous shuttle startup.

Another U-M faculty member, Ryan Eustice, is Senior Vice President of Automated Driving at Toyota Research Institute. He's known for his work in SLAM technology.

"SLAM is crucial technology for self-driving cars," says

Berenson. "They don't know where they are without it."

Eustice is Director of the Perceptual Robotics Laboratory (PeRL), a mobile and marine robotics lab at U-M focused on algorithm development for robotic perception, navigation, and mapping. He worked on the Next Generation Vehicle (NGV) project with Ford Motor Company, the first automaker to test an autonomous vehicle at Mcity. [SLAM meets snow, check it out.](#)

Robotics Raises the Roof

Ford has a legacy stake in Michigan Robotics. A \$75 million facility currently under construction on the U-M Ann Arbor campus will be named the Ford Motor Company Robotics Building in recognition of the automaker's \$15 million gift to the engineering college. The 140,000-square-foot building will house a three-story fly zone for autonomous aerial vehicles, an outdoor obstacle course for legged robots, and a high-bay garage space for self-driving cars. Ford will also establish an on-campus research laboratory occupying the fourth floor, where the automaker's researchers will be able to easily collaborate with the university's faculty and provide hands-on experiences for students.

The new facility will also include classrooms, offices and lab spaces. Bringing students, faculty and researchers together under one roof in a space dedicated to robotics will encourage fluent interaction and the exchange of ideas. In effect, a culture designed to study the problems and solutions of robotics from all angles, including mechanics, electronics, perception, control and navigation, an approach university leadership refers to as "full spectrum autonomy." The building is slated for completion in early 2020.

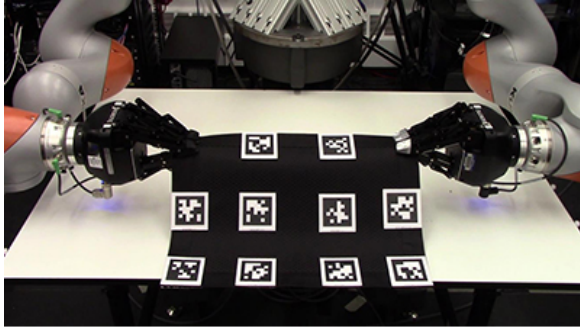
Toyota Research Institute has also dedicated funding to U-M research efforts. "They value our robotics and self-driving technology not because they think it will advance their interests tomorrow, but 5 or 10 years down the road," says Berenson. "My ARM Lab has one of these grants."

Robot Manipulation and Grasping

In his lab, Berenson is developing algorithms for robotic motion planning and manipulation. The research includes grasping in cluttered environments and manipulation of deformable objects, such as rope or cloth that are malleable and change shape when handled.

"We have deformable objects, we have piles of clutter, some of which we may have seen before, some we haven't. We have to manipulate them anyway," says Berenson. "We can't wait for someone to perfectly model the environment, and give us all the parameters and tell us where everything is, and provide a CAD model of every object. That's great in a factory, but it won't work in somebody's home."

"You will never have a perfect model of how this rope or cloth will behave. We have to be able to manipulate despite that uncertainty," he continues. "For example, we're able to put a placemat on a table in a particular position and avoid obstacles. We can do those types of tasks without knowing most of the parameters of the deformable object, like its stiffness or the friction values."



Researchers work with sophisticated robots in the lab to develop algorithms for autonomous motion planning and manipulation, envisioning robots that will someday collaborate more efficiently with humans in factories, hospitals and homes. (Courtesy University of Michigan)

Earlier this year, Berenson received a National Science Foundation CAREER award to improve the ability of autonomous robots to handle soft, deformable objects. Berenson believes the challenges involved in picking up deformable objects such as cables, clothing, or even muscle tissue can be overcome by representing the object and task in terms of distance constraints and formulating control and planning methods based on this representation. Enabling robots in this way could allow medical robots to perform tedious tasks in surgery or make hospital beds, and in home service, allow robots to handle clothes and prepare food.

“We’re really excited about this work because we believe it will push the frontier on what robots can do with very limited information, which is essential for getting robots to work in people’s homes or in natural environments.”

The ARM Lab is also working on algorithms for shape completion. This is particularly advantageous when you have a cluttered environment like a pile of clothing or other objects that need to be sorted.

“If you have a laser scanner and you scan something, you only see the front part of it. You have no idea what’s behind that or how far the object extends,” says Berenson. “We’ve been working on algorithms that allow us to basically fill in the part of the object that we don’t see.”

His team is taking advantage of a lot of the work already done by other researchers in deep neural networks for 3D reconstruction. Through machine learning, the algorithm has learned to look at a partial scan of an object and infer the parts of the shape it cannot see by looking at thousands of previously scanned objects. It turns out many household objects are very similar, so Berenson says they can get a pretty good prediction on household objects.

The research team is using some sophisticated robotic technology to test and verify their motion planning and manipulation algorithms. You will see a pair of KUKA LBR iiwa robot arms equipped with Robotiq 3-finger adaptive grippers manipulating everyday items of different shape, weight, and fragility. [Watch the ARM Lab robots in action.](#)

As robots begin to permeate our daily lives, disruption will come in many forms; not just technological. Social, ethical, legal and economic issues will raise concerns about privacy, liability, potential job loss, continued learning, and social conventions. One university is taking a closer look at the societal impact of robotics innovation.

Robot Ethics and Policy

At the heart of Corvallis, a city in central western Oregon about 50 miles from the Pacific Coast, we find a hidden gem. Part of the Willamette River Valley, the soil is very fertile here. Fertile ground for a rising star in the robotics field.

Oregon State University (OSU) is the city’s largest employer and home to the Collaborative Robotics and Intelligent Systems (CoRIS) Institute. Established in 2017 by OSU’s College of Engineering, CoRIS is mobilized to advance the design, development, and deployment of robots and intelligent systems able to interact seamlessly with people.

“We’re moving away from the idea that robots are over there behind the fence and people are on this side,” says Kagan Tumer, Director of CoRIS and a professor in the School of Mechanical, Industrial and Manufacturing Engineering at Oregon State. “We’re interacting with robots everywhere, from factories, to work, to even in homes now we’re starting to see AI and robots bought by consumers. Understanding how people interact with a robot, whether it’s a simple vacuum cleaning robot or a home-care-level talking robot, there are a lot of questions about what it means to interact with a robot.”

OSU researchers strive to address these questions through a strong collaborative research culture that is the hallmark of CoRIS. Multiple disciplines come together under one roof. There is also a [unique focus on ethics and policy.](#)

“That’s something we take very seriously,” says Tumer. “Usually institutions like this have a research director and an academic director. We specifically have a policy and ethics director for the deployment side because we think it’s critical. We are one of the only places I know that have graduate-level robot ethics courses. We want our graduates to not only be technologically savvy, but also understand the implications of the robotics technology they put out into the world.”

Oregon State’s CoRIS emphasizes the human element of robotics and AI. Researchers explore the ethical, political and legal implications of robotics to understand the scope and scale of the social and technological disruption, and its impact on the future of science, technology and society.

Robotic Legged Locomotion

Ethics and policy become more important as robots begin to share the same spaces as humans. Soon they will walk among us.

Cassie, a bipedal robot developed in the labs at Oregon State, garners a lot of attention as it strolls around campus. The robot may resemble a pair of ostrich legs, but biomimicry was not the mission. Cassie’s developers simply wanted to create the most stable legged platform for varied terrain and unpredictable environments.



Bipedal robot designed to walk on unpredictable, uneven terrain reshapes researchers’ expectations for dynamic robotic locomotion in the real world. (Courtesy of Oregon State University)

The way Cassie would end up at OSU was no accident. In an effort to recruit top robotics talent, Tumer sought out Jonathan Hurst, who has a doctorate in robotics from Carnegie Mellon. He became the first Oregon State faculty devoted to robotics.

Hurst’s passion is legged locomotion, specifically passive dynamics of mechanical systems. He established the Dynamic Robotics Laboratory and his group designed and built [ATRIAS](#), an early prototype to Cassie. ATRIAS gets its passive dynamics from series-elastic fiberglass springs, which act both as a suspension system and means of mechanical energy storage. The technology is based on the spring-mass model, a theory associated with the energy-efficient bouncing gait of animals. Imagine jumping on a pogo stick. Energy is stored in the spring when it’s compressed. When it expands, energy is released and you are thrust upwards.

“ATRIAS was a science experiment,” says Tumer. “It was never meant to be a robot in the real world. It was testing the idea of the models and the way that the passive dynamics of the robot works, and whether you can actually design a robot with very simple principles that would duplicate animal gait. Cassie is the outcome of that experiment.”

With control over two more joints in each of its legs compared to ATRIAS, Cassie is able to maintain its balance even when standing still or crouching. Full range of motion in the hips enables Cassie to steer. It’s also half the weight of its predecessor but twice as powerful and more energy efficient. A sealed system allows it to operate in rain and snow. Many of [Cassie’s components were custom-developed in OSU’s lab](#) when the team was unable to find off-the-shelf components that were small enough or had the required performance.

Oregon State spinoff Agility Robotics is marketing Cassie as a robust bipedal research platform for academic groups working on legged locomotion. The California Institute of Technology and University of Michigan are testing algorithms on Cassie to develop next-gen prosthetics and exoskeletons for persons with paraplegia. Beyond personal/assistive robotics, Tumer says the creators envision a career path for Cassie in package delivery and search and rescue applications.

“We’re not that far now from having driverless vehicles,” he says. “If you can imagine a delivery truck that drives itself to your neighborhood, how do you handle that last 100 to 300 feet? That’s when legged robots pop out of the truck, deliver the package to your door, go back to the truck and drive to the next stop.”

Cassie’s creators are working on arm-like appendages to carry those packages and to right itself in case of a fall. Because Cassie will eventually need “eyes” to see your front door, vision and other sensors are on the agenda.

“If you look at the area around any house, from the curb to the sidewalk, to the slight slope of the driveway, to one or two steps in front of the house, it’s a hazard course for any type of wheeled robot,” says Tumer. “When you can pair a legged robot with a self-driving truck, you’re done. Being able to walk in environments designed for humans is going to be a big thing.”

Investors like Andy Rubin’s Playground Global, Sony Innovation Fund, and Robotics Hub are banking on it. Albany, Oregon-based Agility Robotics raised \$8 million in a Series A round in early 2018. In June, they opened a second location in Pittsburgh, where the startup plans to take advantage of the area’s strong talent pool in robotics. Meanwhile, research on future iterations of Cassie continues at Oregon State.

Multi-Robot Coordination

Another significant research area for OSU is multi-robot coordination, Tumer’s main focus. He says many interesting real-world scenarios require multiple robots, or humans and robots, to work together. Search and rescue operations are one example.

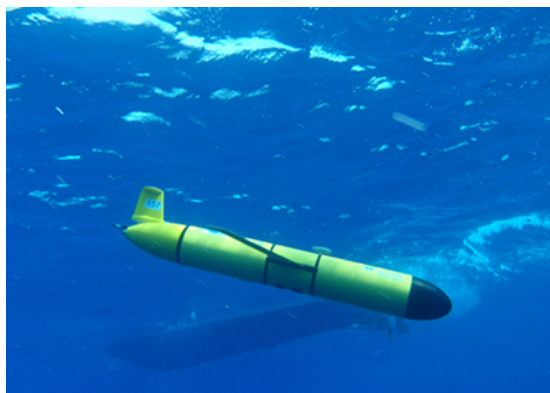
“You might have unmanned aerial vehicles (UAV) looking for debris. You might have unmanned ground vehicles (UGV) moving around. You may have legged robots. You will have a lot of components doing a lot of different operations,” explains Tumer. “The critical aspect is how we determine what each one of those robots should be doing so the team does what you want it to do. Determining the objectives that you need to provide to all of these different robots is a key part of our research.”

Tumer says the different robots in a multi-robot team would need to have some level of awareness of the task they are trying to achieve, so they can determine how to best contribute to the team. His group is trying to impart that high level of coordination capability to robots.

Underwater Robotics

Tumer’s research in multi-robot coordination may also apply to underwater robots. Oregon State has a strong oceanography department and they collaborate with CoRIS, particularly with OSU professor Dr. Geoff Hollinger who focuses on underwater autonomy.

“There’s a lot of underwater science that we do with robots,” says Tumer. “This is all about the health of the ocean, looking at how rivers bring the water and sediment, and how they propagate. There are a lot of research questions about how our environment is effected by everything we do, from runoff from rivers, to algae, to everything else. We have teams of intelligent gliders out there trying to collect information for our scientists.”



Autonomous underwater robots glide with the ocean currents, collecting and broadcasting vital data for weeks at a time. (Courtesy of Oregon State University)

These “intelligent gliders” or autonomous underwater vehicles (AUV) look like small torpedoes, but have no engine. They glide with the water currents rather than being self-propelled. On-board sensors collect data on water salinity, temperature, nutrients and oxygen concentrations at various depths. The gliders can autonomously change their buoyancy to submerge up to 1,000 meter depths and then surface hours later to broadcast their data and location via satellite. They repeat this process every six hours or so, collecting data 24 hours a day for weeks at a time. [Check out the video.](#)

Oregon State researchers working collaboratively from different disciplines in marine sciences and robotics are also equipping undersea gliders with bioacoustic sensors to identify different kinds of marine animals using their unique acoustical signatures. This helps scientists study the distribution of predators and prey, and their relationship to oceanic conditions.

[Advanced control algorithms](#) developed by Hollinger and the Robotic Decision Making Laboratory allow the gliders and other AUVs to more efficiently navigate strong currents and environmental disturbances, and respond to environmental cues. Enabling intelligent AUVs to gather information in environments outside the reach of human divers has long-term benefits for sustaining the fishing industry, protecting marine life, and understanding climate change.

As more robotic systems enter our waterways, streets and homes, researchers say we will need formal means of validation and testing to support deployment on a larger scale.

Robotics Validation and Testing

Carnegie Mellon's Herbert thinks the not-so-exciting but perhaps most critical research area for robotics over the next 5 to 10 years will be integration, validation and testing. This is especially critical as human-robot interaction becomes a part of our daily lives. To illustrate his point, Herbert draws an analogy to the aircraft industry.

"The flying public feels safe in a plane because we have 150 years of experience with a technology that has been validated and tested," he says. "We don't yet have those tools for AI and robotics. How do we do this for systems that learn over time, that adapt? Whose systems depend on the data they use to learn? How do we do this for a system that has complex interaction with people?"

"For this relatively new field of robotics, we don't yet have those engineering tools that allow us to guarantee performance, guarantee behavior of those systems," says Hebert. "It's what we need to be able to really use them in everyday applications. It's this collection of best practices and formal tools that we need to get to a system you can actually trust."

Trust will play a critical role in the acceptance of intelligent autonomous systems. Systems we can entrust to care for our loved ones and our most vulnerable populations, our children, our elderly; robots that will perhaps share our most intimate spaces; systems that will have access to our private data, details about our everyday activities, and privy to our conversations; robotic systems to which we will relinquish control. For that, they will need to earn our trust. Our bright future with robots depends on it. Researchers are helping us realize that future.

The Mysteries of Animal Movement

A scientist's unfettered curiosity leads him to investigate the physics at work in some very odd corners of the natural world.

By James Gorman

Nov. 5, 2018

<https://www.nytimes.com/2018/11/05/science/hu-robotics.html>

David Hu was changing his infant son's diaper when he got the idea for a study that eventually won him the Ig Nobel prize. No, not the Nobel Prize — the Ig Nobel prize, which bills itself as a reward for “achievements that make people laugh, then think.”

As male infants will do, his son urinated all over the front of Dr. Hu's shirt, for a full 21 seconds. Yes, he counted off the time, because for him curiosity trumps irritation.

That was a long time for a small baby, he thought. How long did it take an adult to empty his bladder? He timed himself. Twenty-three seconds. “Wow, I thought, my son urinates like a real man already.”

He recounts all of this without a trace of embarrassment, in person and in [“How to Walk on Water and Climb up Walls: Animal Movements and the Robotics of the Future,”](#) just published, in which he describes both the silliness and profundity of his brand of research.

No one who knows Dr. Hu, 39, would be surprised by this story. His family, friends, the animals around him — all inspire research questions.

His wife, Jia Fan, is a marketing researcher and senior data scientist at U.P.S. When they met, she had a dog, and he became intrigued by how it shook itself dry. So he set out to understand that process.

Now, he and his son and daughter sometimes bring home some sort of dead animal from a walk or a run. The roadkill goes into the freezer, where he used to keep frozen rats for his several snakes. (The legless lizard ate dog food). “My first reaction is not, oh, it's gross. It's ‘Do we have space in our freezer,’” Dr. Fan said.

He also saves earwax and teeth from his children, and lice and lice eggs from the inevitable schoolchild hair infestations. “We have separate vials for lice and lice eggs,” he pointed out.

“I would describe him as an iconoclast,” Dr. Fan said, laughing. “He doesn't follow the social norms.”

He does, however, follow in the footsteps of his father, a chemist who also loved collecting dead things. Once, on a family camping trip, his father brought home a road-killed deer that he sneaked into the garage under cover of night.

The butchering, a first time event for everyone in the family, he wrote once in a father's day essay for his dad, [“was an intense learning and sensory experience. There were a lot of organs in an animal, I learned.”](#)

His own curiosity has led him to investigations of eyelashes and fire ants, water striders and horse tails, frog tongues and snakes.

Dr. Hu is a mathematician in the Georgia Tech engineering department who studies animals. His seemingly oddball work has drawn both the ire of grandstanding senators and the full-throated support of at least one person in charge of awarding grants from that bastion of frivolity, the United States Army.

Long before his role in the Brett Kavanaugh confirmation hearing, Senator Jeff Flake, Republican of Arizona, put three of Dr. Hu's research projects on a [list of the 20 most wasteful](#) federally funded scientific studies. The television show, ["Fox and Friends,"](#) featured [Sen. Flake's critique](#).

Naturally, Dr. Hu [made the attack on his work the basis for a TEDx talk](#) at Emory University, in which he took a bow for being "the country's most wasteful scientist" and went on to argue that Sen. Flake completely misunderstood the nature of basic science.

Dr. Hu was tickled to think that one scientist could be responsible for such supposed squandering of the public's money. Neither he nor his supporters were deterred.

Among those supporters is Samuel C. Stanton, a program manager at the Army Research Office in Durham, N.C., which funded Dr. Hu's research on whether fire ants were a fluid or a solid. (More on that and the urination findings later.)

Dr. Stanton does not share Dr. Hu's flippant irreverence. He speaks earnestly of the areas of science to which he directs Army money, including "nonequilibrium information physics, embodied learning and control, and nonlinear waves and lattices."

So he is completely serious when he describes Dr. Hu as a scientist of "profound courage and integrity" who "goes where his curiosity leads him."

Dr. Hu has "an uncanny ability to identify and follow through on scientific questions that are hidden in plain sight," Dr. Stanton said.

When it comes to physics, the Army and Dr. Hu have a deep affinity. They both operate at human scale in the world outside the lab, where conditions are often wet, muddy or otherwise difficult.

In understanding how physics operates in such conditions, Dr. Stanton explained, "the vagaries of the real world really come to play in an interesting way."

Besides, Dr. Stanton said, the Army is not, as some people might imagine, always "looking for a widget or something to go on a tank." It is interested in fundamental insights and original thinkers. And the strictures of the hunt for grants and tenure in science can sometimes act against creativity.

Sometimes, Dr. Stanton said, part of his job is convincing academic scientists "to lower their inhibitions."

Needless to say, with Dr. Hu that's not really been an issue.



Dr. Hu has shown that the ideal eyelash length for mammals, like this sheep, is one-third the width of an eyeball. Credit Guillermo Amador



Another finding indicated that fire ants constantly make and break connections — essentially becoming a “self-healing” material. Credit Tim Nowack



Fire ants can even flow like a liquid, in Dr. Hu’s lab, although the beverage has a bite. Credit Tim Nowack

An aspiring doctor is led astray

“Applied mathematicians have always been kind of playful,” Dr. Hu said recently while talking about his academic background — although they are perhaps not quite as playful as he can be. A few years ago he did [gymnastic flips onto the stage of a Chinese game show](#) that sometimes showcases scientists.

He grew up in Bethesda, Md., and while he was still in high school, he did his first published work on the strength of metals that had been made porous. He was a semifinalist for the Westinghouse Science Prize (the forerunner of the Regeneron Science Search) and won several other awards.

That work helped him get into M.I.T., which he entered as a pre-med student planning to get an M.D./Ph.D.

He was soon led astray.

Dr. Hu's undergraduate adviser at M.I.T. was Lakshminarayanan Mahadevan, a mathematician who works to describe real life processes in rigorous mathematical terms.

Dr. Mahadevan, known to students and colleagues as Maha, [investigated wrinkling](#), for example. Naturally he won an Ig Nobel for that work.

"Maha lit the fire," Dr. Hu said. Before he encountered his adviser's research, he said, "It didn't really make sense that you could make a living just playing with things."

But he came to see the possibilities.

He stayed at M.I.T. for graduate work, in the lab of his adviser, John Bush, a geophysicist. Dr. Bush remembers him as very enthusiastic.

Asked by email about some of Dr. Hu's wilder forays into the physics of everyday life, he said, "A sense of playfulness is certainly a good thing in science, especially for reaching a broader audience." But, he said, "targeting silly problems is not a good strategy, and I know that David has taken considerable flack for it."

Dr. Hu may be the first third-generation (in terms of scientific pedigree) Ig Nobel winner, because Dr. Mahadevan studied under the late Joseph Keller, a mathematician at Stanford University. Dr. Keller won two Ig Nobels. One was for studying why ponytails swing from side-to-side, rather than up and down, when the ponytail owner is jogging. The other was an examination of why teapots dribble.

After M.I.T., Dr. Hu did research at the Courant Institute at New York University, another hotbed of real-world mathematics. He moved to Georgia Tech, after Jeannette Yen, a biologist there, told the university they ought to take a look at him.

From ants to self-assembling robots

Dr. Hu's research may seem like pure fun, but much of it is built on the idea that how animals move and function can provide inspiration for engineers designing human-made objects or systems.

The title of Dr. Hu's book refers to the "robots of the future," and he emphasizes the way animal motion offers insights that can be applied to engineering — Bio-inspired design.

When Brazil's Pantanal wetlands flood, for instance, fire ants form rafts so tightly interlaced that water doesn't penetrate their mass. When he picked up such a mass in the lab, Dr. Hu writes, it felt like a pile of salad greens.

"The raft was springy, and if I squeezed it down to a fraction of its height, it recoiled back to its original shape. If I pulled it apart, it stretched like cheese on a pizza."

He found out that the ants were constantly moving even though the shape of the mass stayed more or less the same. They were breaking and making connections all the time, and they became, in essence, a “self-healing” material.

The idea is appealing for many engineering applications, including concrete that mends itself and robots that self-assemble into large, complex structures. Depending on the force applied to them, a mass of a hundred thousand ants or so can form a ball or a tower, or flow like a liquid.

He and students in his lab also showed that the reason mosquitoes don’t get bombed out of the air by water droplets in a rainstorm is that they are so light that the air disturbed by a falling drop of water blows the mosquitoes aside. The finding could have applications for tiny drones.

They also showed that the ideal length for a row of mammalian eyelashes is one-third the width of an eyeball. That gives just the right windbreak to keep blowing air from drying out the surface of the eye. Artificial membranes could use some kind of artificial eyelashes.

And what about urination? It didn’t make sense to Dr. Hu that a grown man and an infant would have roughly the same urination time.

After he sent out undergraduates, under the guidance of Patricia Yang, a graduate student, to time urination in all the animals at the Atlanta Zoo, the situation became even more puzzling. Most mammals took between 10 and 30 seconds, with an average of 21 seconds. (Small animals do things differently.)

The key was the urethra, essentially a pipe out of the bladder, that enhanced the effect of gravity. Even a small amount of fluid in a narrow pipe can develop high pressure, with astonishing effects.

Water poured through a narrow pipe into a large wooden barrel can split the barrel. Dr. Hu said the experiment, known as Pascal’s barrel, can be replicated nowadays with Tupperware.

What is interesting about the urethra biologically is that its proportions, length to diameter, stay roughly the same no matter the size of the animal (as long as it weighs more than about six and a half pounds).

The 21-second average urination time must be evolutionarily important. Perhaps any longer would attract predators? But then predators are subject to the same rule. In any case, the principle of how to effectively drain a container of fluid could be useful, Dr. Hu wrote in the original studies, to designers of “water towers, water backpacks and storage containers.”

As usual, in his book Dr. Hu does not neglect the human side of his work, or treat it too seriously. He refers to the urethra as a pee-pee pipe. And he corrects his son when he brags that only he, not his sister, has a pee-pee pipe.

Not so, Dr. Hu insists. The urethra is present in males and females.

Once older, his children may never forgive him for this book. But middle school science teachers and nerds everywhere will thank him.



Evolving From Know-How to Know-What

Robert N. Charette, ITABHI Corporation

Computing is experiencing a “Cambrian explosion” of new technologies that promise great societal benefits but also create opportunities for misuse and societal harm. How to reduce this potential for harm is the objective of computing codes of ethics. Given the rash of ethical lapses related to computing, we ask whether codes of ethics are effective and, if not, why not?

Duke University civil engineering professor and well-known author Henry Petroski has written extensively on the subject of major bridge failures that have occurred once about every 30 years since 1847.¹ Petroski speculates that there are two intertwined reasons for this repeating pattern of failure: first, the failure happens because a novel bridge design is pushed beyond its safety limit. Second, and more interesting, the limit is exceeded because a new generation of designers and engineers forgot the critical lessons learned

about failure by the previous generation, who themselves had pushed the limits of an earlier novel bridge design too far. Philosopher George Santayana’s aphorism, “Those who cannot remember the past are condemned to repeat it,” seems a fitting description.

The IT community has an analogous repeating two-decade cycle, this one related to the community’s reawakening to the societal risks posed by ethical failures in the use of computing technologies. This cycle is reflected in the periodic updates in the community’s computing codes of ethics. For example, the Association for Computing Machinery (ACM)—the world’s largest scientific and educational computer society—last year updated, once again, its Code of Ethics and Professional Conduct.² This revision traces its origins to its 1992 Code of Ethics and Professional Conduct, which in turn revised the ACM’s 1972 Code of Professional Conduct.³

The latest ACM revision owes itself in large part to, again, two intertwined factors. The first is what researcher

Gil Pratt describes as the “Cambrian explosion” in emerging and novel computing capabilities, especially in the areas of artificial intelligence (AI), cloud computing, data analytics, facial recognition, quantum computing, and robotics that has taken place over the past decade.⁴ This eruption of new powerful technologies promises great societal benefits, but there are also un-

the prospect that IT will become even more pervasive and capable, has eroded the public’s trust that computing will be used in a manner where its benefits far outweigh the risks of its misuse.

Moved by the ongoing ethical lapses, including the unfair and discriminatory personnel practices often found in the IT industry and the future potential for harm that computing may create

stakeholders in computing. Furthermore, the ACM expects professionals to avoid harm, that is, unjustified negative consequences, caused by the use of the computing technology they develop, operate, or support.

Whether the new ACM Code of Ethics will be effective in changing the computing community’s behavior in any meaningful way remains to be seen. What seems conclusive, however, given the ever-growing list of computing-related ethical lapses, is that past codes of computing ethics have largely been ineffective in preventing the unethical use of computing. The question is whether updated codes of ethics, such as the ACM’s, end up being as ineffective and, if so, why?

Only when the technology becomes mainstream do the ethical issues identified earlier become real—not predicted—problems.

matched future opportunities for misuse that have created unease among the public and technologists alike.⁵

Second, the worries about the potential for future misuse are further amplified by the present ethically dubious applications or management of IT, as found in Facebook’s highly publicized Cambridge Analytica privacy fiasco and Volkswagen’s emissions cheating scandal, among a plethora of others that also helped spur the ACM ethics update. These incidents, coupled with

in a world where “computing technology is so interwoven into the fabric of daily life,” the ACM takes the position that computing ethics now needs to “become the personal responsibility of every professional in our industry.”²

The new code reiterates in its seven general ethical principles (see “ACM 2018 Code of Ethics: General Ethical Principles”) that the ACM expects computing professionals to contribute to society and human well-being and importantly recognize that all people are

DÉJÀ VU ALL OVER AGAIN

I contend that, like the bridge builders who pushed their designs past the limit, many of today’s computer professionals have either forgotten (or never bothered to learn about) the past ethical transgressions that drove the creation of earlier computing codes of ethics. As in the case of bridge failures, many of today’s ethical problems were identified when today’s mainstream computing technology was just emerging two decades ago. However, it can take a decade or more for a novel computing technology to reach the point where it is used routinely in an organization. Only when the technology becomes mainstream do the ethical issues identified earlier become real—not predicted—problems, and by then it is just too late to do much to reverse them.

Looking back at the world of computing four decades ago, this becomes evident. Although today’s emerging computing technologies have magnitudes more capability than their predecessors, their relative impacts on society likely will not. A comparable Cambrian-like explosion of computing technologies involving microprocessors, memory, networking, databases, and system architectures, to name but a few, took place during the

ACM 2018 CODE OF ETHICS: GENERAL ETHICAL PRINCIPLES

- » Contribute to society and to human well-being, acknowledging that all people are stakeholders in computing.
- » Avoid harm.
- » Be honest and trustworthy.
- » Be fair and take action not to discriminate.
- » Respect the work required to produce new ideas, inventions, creative works, and computing artifacts.
- » Respect privacy.
- » Honor confidentiality.

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late 1970s into the 1980s. Although the social benefits of these technologies were perceived as substantial, the potential for societal harm was also becoming more apparent. Incidents of computer-enabled criminal activity, costly government IT development failures, and IT operational failures, such as the infamous 1990 AT&T network failure, were being reported with growing regularity.⁶

Computing's increasing potential for harm in the late 1970s and early 1980s helped spur the development of computing ethics as a formal discipline in itself. Researchers Walter Maner and James Moor, among others, argued that the capabilities of IT over those of conventional technologies raised unique ethical questions.^{7,8} Computing's malleability, complexity, speed, low cost, and ability to reproduce and store information all combined to create technology-enabled ethical situations unlike those experienced before. This required new ways of thinking about the ethical consequences of computing on both society and individuals.

The increasing worries about the potential negative societal impacts of computing coincided with a growing lack of trust, not only in business—which experienced such a rash of ethical lapses in the 1980s that the period gained the moniker “Decade of Greed”—but in technology and technologists in general. Investigations into the 1979 Three Mile Island accident, the 1986 NASA space shuttle *Challenger* explosion, and the 1986 Chernobyl meltdown, among other high-profile incidents, raised questions in the public's mind about how much, or even whether, ethical considerations held much sway in professional technical decisions.⁹

In this context of a computing Cambrian explosion and a widespread questioning of the ethics of technologists, the 1972 ACM Code of Ethics was updated in 1992. One objective of the update was to increase the public's trust in computing professionals. A *Communications of the ACM* article in 1993, for instance, described how the new code

could help a computing professional's decision making when faced with a potentially unethical situation and made the point that a code of the ethics, such as the new ACM's, “holds the profession accountable to the public. This yields a major payoff in terms of public trust.”¹⁰

The 1992 ACM code was widely embraced by the IT community and helped spur the creation of numerous courses on computing ethics in university computer science and engineering programs. It also helped stimulate the publication of numerous technical articles and books on the social impacts of computing and the need for incorporating computer ethics in technology and engineering management decisions.

SUCCUMBING TO THE TECHNOLOGICAL IMPERATIVE

However, by the late 1990s, interest in the topic of computing ethics began to wane. One reason was the rapid expansion of the computing industry during the so-called dotcom-bubble period. Making enormous amounts of money from hyping a “disruptive” computing technology that promised to “change everything” became a major motivator across the industry. Concern over computer ethics was hardly a priority in this “get rich quick” environment, and in many circles, ethics was seen as an inhibitor to one's personal profit-maximization strategy.¹¹

The ethics of computing was also not at the forefront of thinking about computing in highest levels of the U.S. government, which had, early on, fully embraced the emergence of the so-called information superhighway, going so far as to exempt it from government regulatory oversight as a means to encourage technological innovation. Emerging computing technologies, such as the Internet, were viewed as being crucial societal transformative agents that would produce “an era of unparalleled [economic] promise,” in the words of President Bill Clinton.¹²

The technological imperative, the idea that technology-driven progress is

necessary, inevitable, and always beneficial to society in the final analysis of its risks and rewards, has always been strong in the U.S. psyche. In the 1990s, computing became synonymous with societal economic progress and productivity. It is little exaggeration to say that the prevalent attitude was that what was good for the IT industry was good for every country and that nothing was going to be allowed to inhibit the industry's growth. Worries over the potential misuse of computing fell into the dark shadows created by the bright spotlights trained on computing's potential benefits.

DROWNED IN DIGITAL CONVERGENCE

Another idea of the 1990s related to the technology imperative that helped undercut the concern for computing ethics was the concept of technological convergence, or synergy. This was the idea that the computing, communications, and entertainment technologies were on an unstoppable path of being integrated seamlessly together. In fact, convergence was seen by many scientists and engineers at the time as being indispensable for the U.S. computer and communications industries to remain competitive against the seemingly unstoppable Japanese industrial juggernaut.

Although there was some discussion about the possible societal impacts such a technological convergence might bring, debate centered more on what cultural practices needed to be changed in business, government, and education to fully benefit or profit from convergence. Opportunities for the ethical misuse of computing centered mostly on preventing intellectual property theft in such an integrated technical environment, with other possibilities for harm downplayed or not discussed at all.

At a 1995 National Research Council-sponsored international colloquium on technological convergence, futurist George Gilder summed up the prevalent feeling best when he stated, “I think the technology is enormously

beneficial . . . I don't think there is any significant downside."¹³ In other words, whatever ethical risks or negative social disruption convergence might pose, the tradeoff was worth it, given the enormously potential benefits to be had.

HOSTAGE TO CULTURAL CAPTURE

A third factor in undercutting the importance of computing ethics in the 1990s was a form of cultural capture, which occurs when regulators start thinking like those they are supposed to regulate. As discussed, governments placed a very light regulatory touch on computing so as not to inhibit innovation. This, in essence, gave a green light to the belief in the IT industry that if an activity isn't clearly illegal, it's not prohibited, and, therefore, it is ethical to pursue.

FROM KNOW-HOW TO KNOW-WHAT

Although the dotcom crash served to undermine computer ethics as a professional priority, the 9/11 terror attacks coupled with the rise of search engines and social media helped bury it. Over the past 20 years, there has been a steady defining-down of computing ethics.

What would have been held up as examples of unethical uses of computing in terms of the 1992 ACM Code of Ethics, especially with regard to personal privacy and confidentiality, has now been normalized. Governments argue that we must give up our privacy to ensure security and social order, and the computing industry argues that we must give up our privacy so that it can meet our needs and desires better.

Although there is no going back to 1992 and starting over again, perhaps

was distressingly missing was what he termed the much more important "know-what" element, "by which we determine not only how to accomplish our purposes, but what our purposes are to be."

In other words, what was the objective of automating specific work, and what were the unintended consequences of this automation? Should some work never be automated? Would anyone spend any time thinking about what these might be, Wiener wondered, or instead, would the effects of automating something that shouldn't have been automated be discovered only afterward, to everyone's regret?

Wiener argued that, with the automatic age at its very beginnings, it was the ideal time for scientists and engineers to take what he later labeled "an imaginative forward glance at history." This forward look, he said, was needed to avoid making preventable mistakes in applying computing in ways that might not only create direct harm but could also be exploited for unethical or inhumane purposes.

Laudably, the ACM Code of Ethics has emphasized the need to view computing from Wiener's know-what perspective and to acknowledge that all people are stakeholders in computing, not just IT professionals. This came through in the 2018 letter from the president of the ACM discussing the new code of ethics, who wrote that,

When the ACM Code of Ethics was last updated in 1992, many of us saw computing as purely technical. . . . Today, we find ourselves in situations where our work can affect the lives and livelihoods of people in ways that may not be intended, or even be predictable. This brings a host of complex ethical considerations into play.¹⁶

The ACM is currently working to develop methods to incorporate ethical considerations into computer science curricula from primary through

The computing industry argues that we must give up our privacy so that it can meet our needs and desires better.

This created a situation where those most able to act ethically with regard to computing use were also those who would profit from ignoring ethics. Computing codes of ethics are, at their core, about trying to define what computers should not be used for, an idea that was anathema to the computing industry. No one was ever going to get financially rewarded for not selling a computing technology that might be used legally but unethically by a customer.

Even after the dotcom bubble burst and when it became clear that computing ethics were collateral damage in the race for riches, there was little introspection on the part of the computing industry. A major reason was the mass layoffs in the industry that took place.¹⁴ Who has time to worry about computer ethics when you don't have a job?

it is time to go back even further, to cyberneticist Norbert Wiener's 1950 groundbreaking book, *Human Use of Human Beings*, which is seen by many as the first book warning about the ethical issues of computers.¹⁵ Wiener prophetically cautioned in his book that the "new industrial revolution" that computing would bring was a double-edged sword. Although computing "may be used for the benefit of humanity," he said, it could just as easily "be used to destroy humanity, and if not used intelligently, it can go very far in that direction."

What especially worried Wiener was that the main focus in the profession seemed to be concentrated on the "know-how" part of computing, that is, the technology needing development so that human tasks could be automated. Wiener held that what

graduate school, and it is helping IT professionals seeking advice on how to address ethical quandaries they may be encountering.

There have been multiple private efforts to implement Wiener's "imaginative forward glance" in an effort to better understand the ethical ramifications of emerging computing technologies. One is the nonprofit OpenAI, which was begun in 2015 by Silicon Valley entrepreneurs Reid Hoffman, Elon Musk, Peter Thiel, and others who were worried that AI might be misused. The organization seeks a "path to safe artificial general intelligence" and expects "to create formal processes for keeping [AI] technologies private when there are safety concerns."¹⁷

There has also been a resurgence of ethics courses at universities, along with novel ways to help students understand the ethical dilemmas they may face in their future careers. In addition, working computing professionals at Amazon, Google, and Microsoft have very publicly taken it on themselves to question whether it is ethical for their companies to be engaged in certain types of work.

All of these are encouraging signs that the ethical implications of computing are at the very least being discussed and, in some cases, acted on. The question is whether the interest will last any longer than it did back in the early 1990s. Furthermore, will these efforts have any real practical effects on IT professional decision making?

For instance, will there be concerted efforts on the part of IT professionals involved in the Internet of Things (IoT) to ensure that their company's devices are safe and secure and that the data gathered will be used ethically before the devices are sold, especially if their competitors do not take such steps? With the IoT marketplace projected to explode by an order of magnitude to a US\$6.5 trillion market by 2024, it seems doubtful.¹⁸

How will governments' increasing desire to control their populations

through the use of computing technology, such as in China, where this is seen as perfectly legitimate, further define what is considered ethical computing elsewhere? How will the world's militaries' fascination with AI-driven weaponry impact computing ethics?

The ACM Code of Ethics states that ethics is the personal responsibility of every IT professional. Perhaps it is time to say that it is the responsibility of every professional computing association and society as well. Instead of just publishing computing codes of ethics, the associations and societies as a group need to stand together and call out governments and commercial organizations for their unethical misuse of computing and recognize those organizations that use computing ethically. It is unfair to place all the responsibilities for ensuring that computing is used ethically on IT professionals alone if the associations and societies don't take public stands against misuse as well.

Toward the end of his book, Weiner wrote about the potential use of automation that "The hour is very late, and the choice of good and evil knocks at our door." He was reminding everyone that managing ethical risks is not about future technology decisions but the future of present decisions. The real question is, given the current Cambrian explosion of computing technology, which—good or evil—will be knocking at our door tomorrow?

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What the Lion Air Crash Teaches Us About Autonomous Cars

By David Mindell

<https://www.forbes.com/sites/davidmindell/2019/02/25/what-the-lion-air-crash-teaches-us-about-autonomous-cars/#4ba5f97f5e6c>

Feb 25, 2019



Take off from Chiangmai airport to Bangkok. GETTY

2019 opened with a reset of expectations for autonomous cars. Sensibly, OEMs and software companies backed off their claims for delivery of level-5 autonomous cars in 2020, saying it will take longer, perhaps much longer. As one engineering leader told me, “all of a sudden \$200 Million per year starts to feel like not that much money.” Another big company leader announced, in front of his management, “I’m confident we can make cars that will never hit anyone, I’m less confident we can make cars that will never ever get lost.” A major auto OEM strategy states that for the foreseeable future its cars will operate only in defined areas in good weather — even moderate rain challenges today’s sensors and algorithms. When asked about all-weather capability, another engineering leader candidly admitted, “we have no solutions for winter.” [Smaller players with immediate commercial demands are focusing on](#)

[minimum viable products](#) with limited autonomy on low-speed, fixed routes, with some early signs of success.

None of this is surprising. My 2015 book [Our Robots, Ourselves](#) explored decades of experience with robots and autonomy in extreme environments (undersea, aviation, spaceflight). Experience repeatedly shows that autonomy works best when it is deeply situated within human systems, and that “full autonomy,” (if it exists at all) rarely succeeds. (My company [Humatics](#) is building situated autonomy systems for a variety of industries).

John Krafcik, CEO of Waymo, now agrees. [He told the Wall Street Journal](#) late last year that in his view, “autonomy always will have some constraints,” and doesn’t see a day that any car could be “fully autonomous” under all weather and driving conditions. “It’s really, really hard ... you don’t know what you don’t know until you’re actually in there and trying to do things.”



Waymo CEO John Krafcik speaks at the Google I/O conference in Mountain View, Calif., Tuesday, May 8, 2018. (AP Photo/Jeff Chiu)

This is an enormous, and welcome, adjustment from a well-funded industry that until recently had pinned its hopes on naive views of a utopian autonomy — where somehow all human input is magically automated away and cars are alone in the world.

Rhetorical emphasis, at least, now shifts toward human-centered systems, driver assists based on various monitoring technologies that augment an attentive driver. It's a familiar pattern: unmanned aircraft took 70 years to find their niche, in part because technologies that improved their autonomy also improved the performance and safety of human operators (think automatic pilots). Autonomy plays catch up with its own augmentation of human ability.

New directions for autonomous cars also stem from events of 2018: fatal accidents involving an Uber test vehicle and an Autopilot-enabled Tesla, Waymo’s cancellation of an autonomous commercial service with no safety driver. Yet one other event in 2018, while much in the news, has not been linked to the autonomous cars industry, but should be: the October crash of a Lion Air 737 in Indonesia, killing all 189

passengers and crew. Final investigations are ongoing, but early evidence, as well as the preliminary accident report, point to a contention between pilots and their automation as a cause.



Instruments and controls sit in the cockpit of a Boeing Co. 737 Max 7 jetliner during preparations ahead of the Farnborough International Airshow (FIA) 2018 in Farnborough, U.K., on Sunday, July 15, 2018. The air show, a biannual showcase for the aviation industry, runs until July 22. Photographer: Simon Dawson/Bloomberg

Soon after takeoff, during climb out, the aircraft's computer system kept pitching the nose down. The pilots, "[confused and perhaps overwhelmed](#)," fought a back-and-forth battle as they struggled to keep the aircraft pointed up. This was the latest model 737 MAX from Boeing, and a new feature, called MCAS, intended to help prevent stalls, had problems due to a failed sensor input. Similar conditions had occurred on the ill-fated 737's earlier flights, but those pilots had successfully disconnected the system and continued the flight. When they reported the sensor failure to maintenance, the mechanics cleared the problem and declared the aircraft airworthy. The pilots on the fatal flight, early in the trip and close to the ground, did not execute the full checklist procedure to disable the MCAS, losing the battle that their immediate predecessors had won. The crew literally fought with the automation for several minutes, causing a series of oscillations in the aircraft's pitch and altitude. The humans finally lost and the aircraft plunged into the ocean at terrifying speed.

Debate has arisen between the airline, victims' families, and Boeing about whether the new MCAS behaviors should have been briefed to the pilots and included in training. The manufacturer and the airlines had economic incentives not to add training requirements, and the FAA signed off. Contention will likely continue for years in the courts and investigations, and may never be fully resolved. Regardless of blame and responsibility, the Lion Air crash highlights a tight coupling of autonomous systems and numerous dimensions of the human world in which they are embedded. A new feature was added by a manufacturer to improve safety. Training materials were not updated, as it was determined that existing procedures would suffice. Minor sensor failures were not handled as expected by the system.

Maintenance could not find the problem. Earlier pilots acted (mostly) correctly. Some pilots did not and tragedy ensued. These are all aspects of the human systems in which all autonomy is embedded. It is also why “full autonomy” doesn’t really exist — all technologies are embedded in the human world and the systems to create, operate, and maintain them.

Aviation is a more structured world than automobiles. Aircraft are regulated in design, manufacture, maintenance, and operations. Pilots are highly trained and medically screened. Repair is routinized. Software is extensively validated before deployment. Aircraft fly through uncertain environments, but airspace is incredibly “clean” compared to the roads: free of dust, mud, and, most important, people (except for a few piloting other aircraft). Operating manuals and checklists are also regulated — and people actually read them.

Autonomous cars will introduce to our daily activities of driving forms of automation that resemble those in the latest airliners. “Drive by wire” will emulate “fly by wire” — where the operator interacts not directly with the mechanisms but through the mediation of computers and software (your car likely already has “accelerator by wire” and “brake by wire”). In aviation, that software is highly “deterministic” — meaning it can be proven to do the same thing every time.

Yet in the Lion Air case, a seemingly small change in the automation, with some apparently minor missteps by the pilots, led to massive failure and fatality.

Automobiles too, are regulated, though considerably less so than aviation. Deployment and operation are widely distributed and largely uncontrolled. Rules of the road are less structured and uniform. Training is minimal to non-existent. Operators (drivers) cover a broad spectrum of human ability, experience, and health. Perhaps most important, autonomous car software will depend on AI algorithms that are emergent and non-deterministic, dependent on the history of their data with weak insight into what’s going on inside. And the system will be scaled to the hundreds of millions of vehicles and operators.

How will we manage the unruly complexity of autonomy at this scale?

Look at your windshield after the next time you drive on a dirty or wet road and imagine that film of muck coating a laser sensor. Then you’ll sense the leading edge of the degree of care, testing, and just downright innovation required to get this new technology right.



A driver lifts his hands away from the steering wheel of a Volvo Autonomous FMX self-driving truck, manufactured by Volvo Group, as it drives through underground tunnels, at Kristineberg mine in the Boliden area in Arvidsjaur, Sweden, on Friday, Sept. 2, 2016. The Autonomous FMX is equipped with LiDAR light radar sensors and GPS technology to create 3D maps of the vehicle's surroundings enabling it to navigate its way through tunnels. Photographer: Krister Soerboe/Bloomberg

Automated to Death

As software pilots more of our vehicles, humans can pay the ultimate price. Robert N. Charette investigates the causes and consequences of the automation paradox

By Robert N. Charette
15 Dec 2009

The passengers and crew of Malaysia Airlines Flight 124 were just settling into their five-hour flight from Perth to Kuala Lumpur that late on the afternoon of 1 August 2005. Approximately 18 minutes into the flight, as the Boeing 777-200 series aircraft was climbing through 36 000 feet altitude on autopilot, the aircraft—suddenly and without warning—pitched to 18 degrees, nose up, and started to climb rapidly. As the plane passed 39 000 feet, the stall and overspeed warning indicators came on simultaneously—something that’s supposed to be impossible, and a situation the crew is not trained to handle.

At 41 000 feet, the command pilot disconnected the autopilot and lowered the airplane’s nose. The auto throttle then commanded an increase in thrust, and the craft plunged 4000 feet. The pilot countered by manually moving the throttles back to the idle position. The nose pitched up again, and the aircraft climbed 2000 feet before the pilot regained control.

The flight crew notified air-traffic control that they could not maintain altitude and requested to return to Perth. The crew and the 177 shaken but uninjured passengers safely returned to the ground.

The Australian Transport Safety Bureau investigation discovered that the air data inertial reference unit (ADIRU)—which provides air data and inertial reference data to several systems on the Boeing 777, including the primary flight control and autopilot flight director systems—

had two faulty accelerometers. One had gone bad in 2001. The other failed as Flight 124 passed 36 571 feet.

The fault-tolerant ADIRU was designed to operate with a failed accelerometer (it has six). The redundant design of the ADIRU also meant that it wasn't mandatory to replace the unit when an accelerometer failed.

However, when the second accelerometer failed, a latent software anomaly allowed inputs from the first faulty accelerometer to be used, resulting in the erroneous feed of acceleration information into the flight control systems. The anomaly, which lay hidden for a decade, wasn't found in testing because the ADIRU's designers had never considered that such an event might occur.

The Flight 124 crew had fallen prey to what psychologist Lisanne Bainbridge in the early 1980s identified as the ironies and paradoxes of automation. The irony, she said, is that the more advanced the automated system, the more crucial the contribution of the human operator becomes to the successful operation of the system. Bainbridge also discusses the paradoxes of automation, the main one being that the more reliable the automation, the less the human operator may be able to contribute to that success. Consequently, operators are increasingly left out of the loop, at least until something unexpected happens. Then the operators need to get involved quickly and flawlessly, says Raja Parasuraman, professor of psychology at George Mason University in Fairfax, Va., who has been studying the issue of increasingly reliable automation and how that affects human performance, and therefore overall system performance.

"There will always be a set of circumstances that was not expected, that the automation either was not designed to handle or other things that just cannot be predicted," explains Parasuraman. So as system reliability approaches—but doesn't quite reach—100 percent, "the more difficult it is to detect the error and recover from it," he says.

And when the human operator can't detect the system's error, the consequences can be tragic.

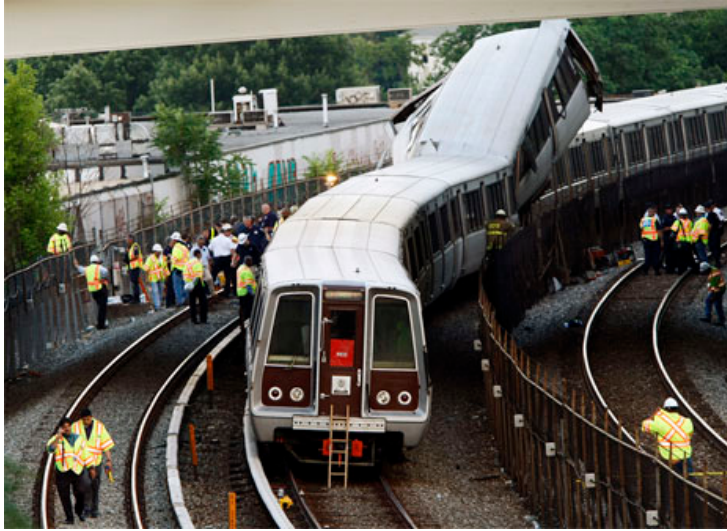


Photo: Win McNamee/Getty Images

In June of this year, a Washington Metropolitan Area Transit Authority (Metro) red line subway train operated by Jeanice McMillan rear-ended a stationary subway train outside Fort Totten station in

northeast Washington, killing McMillan and eight others and injuring 80. The cause is still under investigation by the U.S. National Transportation Safety Board (NTSB), but it appears that a safety-signal system design anomaly was at fault, in which a spurious signal generated by a track circuit module transmitter mimicked a valid signal and bypassed the rails via an unintended signal path. The spurious signal was sensed by the module receiver, which resulted in the train not being detected when it stopped in the track circuit where the accident occurred. So the safety system thought the track was clear when it was not. When she saw the other train in her path, a surprised McMillan hit the emergency brake in an attempt to slow her train, which may have been traveling nearly 95 kilometers per hour (59 miles per hour), but it was too late.

To put this accident in perspective, however, it was only the second fatal crash involving Washington, D.C.'s Metro in its 33 years of operation. In 2008, customers took 215 million trips on the system. Not counting train-vehicle accidents, a total of 27 people were killed and 324 people were injured in train accidents in the United States in 2008. This compares with statistics from 1910, when W.L. Park, general superintendent of the Union Pacific Railroad, asserted that "one human being is killed every hour, and one injured every 10 minutes."

Not only has automation improved train safety, but travel by plane, ship, and automobile is safer too. According to Boeing, in 2000 the world's commercial jet airlines carried approximately 1.09 billion people on 18 million flights and suffered only 20 fatal accidents. The NTSB estimates that traffic deaths in the United States may drop by 30 percent after electronic stability control becomes mandatory in 2012 for automobiles.

Charles Perrow, professor emeritus of sociology at Yale University and author of the landmark book *Normal Accidents: Living With High-Risk Technologies* (Princeton University Press, 1999), contends that “productivity, successful launches, successful targeting, and so on, increase sharply with automation,” with the result being that “system failures become more rare.”

One can see this in aviation. As automation has increased aircraft safety, the rarity of crashes has made it harder to find common causes for them, the NTSB says.

However, the underlying reason for this rarity, namely the ubiquity of increasingly reliable automation, is also becoming a concern for system designers and safety regulators alike, especially as systems become ever more complex. While designers are trying to automate as much as they can, complex interactions of hardware systems and their software end up causing surprising emergencies that the designers never considered—as on Flight 124—and which humans are often ill-equipped to deal with.

“The really hard things to automate or synthesize, we leave to the operator to do,” says Ericka Rovira, an assistant professor of engineering psychology at the U.S. Military Academy at West Point. That means people have to be alert and ready to act at the most crucial moments, even though the monotony of monitoring supposedly reliable systems can leave them figuratively or physically asleep at the wheel.



Photo: Steven Senne/AP Photo

That was the case in June 1995, when the 568-foot-long cruise ship *Royal Majesty* ran aground onto the sandy Rose and Crown Shoal about 10 miles east of Nantucket Island, off the coast of Massachusetts. Fifty-two minutes after leaving St. George’s, Bermuda, on its way to Boston, the Royal Majesty’s GPS antenna cable became detached from the GPS antenna. This placed the GPS in dead-reckoning mode, which does not take into consideration wind or sea changes. The degraded GPS continued to feed the ship’s autopilot. No one noticed the change in GPS status, even though the GPS position was supposed to be checked hourly against the Loran-C radio navigation system, which is accurate by roughly

one-half to 1 nautical mile at sea, and a quarter-mile as a ship approaches shore. The *Royal Majesty* proceeded on autopilot for the next 34 hours until it hit the Rose and Crown Shoal.

Why hadn't the watch officers noticed something was wrong? One major reason, the NTSB said, was that the ship's watch officers had become overreliant on the automated features of the integrated bridge system.

Watch officers, who in less-automated times actively monitored the current environment and used this information to control the ship, are now relegated to passively monitoring the status and performance of the ship's automated systems, the NTSB said. The previous flawless performance of the equipment also likely encouraged this overreliance. Checking the accuracy of the GPS system and autopilot perhaps seemed like a waste of time to the watch officers, like checking a watch against the Coordinated Universal Time clock every hour.

In many ways, operators are being asked to be omniscient systems administrators who are able to jump into the middle of a situation that a complex automated system can't or wasn't designed to handle, quickly diagnose the problem, and then find a satisfactory and safe solution. And if they don't, the operators, not the system's designers, often get the blame.

Adding another system to help detect the error and recover from it isn't a straightforward solution either. In Flight 124, the fault-tolerant, redundant system design helped to mask the problem. In fact, such redundancy often merely serves to act as yet another layer that abstracts the human operator from the system's operational control.

"In other words, the initial control loop is done by one system, and then you have a computer that is backing up that system, and another is backing up that one," according to Parasuraman. "Finally, you have to display some information to the operator, but the operator is now so far from the system and the complexity is so great that their developing a [mental] model of how to deal with something going wrong becomes very, very difficult."

Economics also figures into the equation. The ADIRU in Flight 124's Boeing 777 was designed to be fault-tolerant and redundant not only to increase safety but also to reduce operating costs by deferring maintenance.

"The assumption is that automation is not only going to make [what you are doing] safer but that it will make it more efficient," says Martyn Thomas, a Fellow of the UK's Royal Academy of Engineering. "This creates a rather nasty feedback loop, which means that when adverse events

become relatively rare, it is taken as an opportunity to deskill the people you're employing or to reduce their number in order to reduce a cost."

This erosion of skills in pilots was a major concern raised in the last decade as glass cockpits in aircraft became common [see *IEEE Spectrum's* article [The Glass Cockpit](#), September 1995].

Peter Ladkin, a professor of computer networks and distributed systems at Bielefeld University, in Germany, is heavily involved in aircraft accident investigations and is a pilot himself. "Line pilots are trained and told—and their procedures also say—to use the automation all the time. Many older pilots are really worried that when they get into difficulties, they aren't going to [know how to] get out of them," he says.



Photo: United Photos/Reuters

The crash in February of Turkish Airlines Flight 1951 just short of Amsterdam's Schiphol International Airport, which killed 9 people and injured 86 others, raised this concern anew. As the aircraft passed through 1950 feet, the left radio altimeter failed and indicated an altitude of -8 feet, which it passed on to the autopilot, which in turn reduced engine power because it assumed the aircraft was

in the final stages of approach. The pilots did not initially react to the warnings that something was wrong until it was too late to recover the aircraft.

"When we start removing active learning for the operator, the operator begins to overtrust the automation," Rovira says. "They're not going back and gathering those data pieces that they need" to make an effective decision.

Another issue associated with overtrusting the automation is that it can encourage "practical drift," a term coined by Scott Snook in his book *Friendly Fire: The Accidental Shootdown of*

U.S. Black Hawks over Northern Iraq (Princeton University Press, 2002). The phrase refers to the slow, steady uncoupling of practice from written procedures.

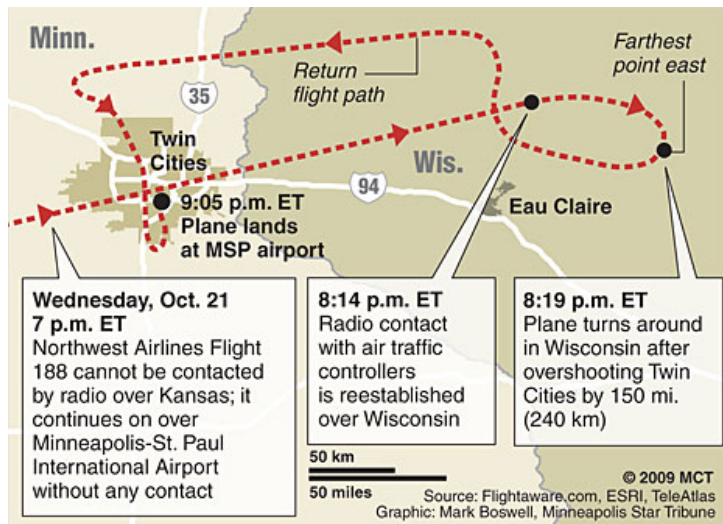


Illustration: Boswell/MCT/Landov

We see how that happened in the *Royal Majesty* incident, where the watch officers failed to follow established procedures. This was also the case in the October incident involving Northwest Airlines Flight

188 on its way to Minneapolis-St. Paul International Airport, which overshoot the airport by 150 miles. The pilots claimed they were working on their laptops and lost track of the time and their location. The aircraft was on autopilot, which in normal circumstances leaves the pilots with little left to do other than monitor the controls.

Again, when you are only a system's monitor, especially for an automated system that rarely, if ever, fails, it is hard not to get fatigued or bored and start taking shortcuts.

The situation isn't hopeless, however. For some time now, researchers have been working to address the ironies and paradoxes of automation. One new approach has been to address the issues from the human point of view instead of the point of view of the system.

"We draw a system's boundary in the wrong place," Thomas states. "There is an assumption that the system boundary that the engineer should be interested in [sits] at the boundary of the sensors and actuators of the box that is being designed by the engineers. The humans who are interrelating with these systems are outside it. Whether they are operators, pilots, controllers, or clinicians, they are not part of the system.

"That is just wrong," Thomas adds. "The system's designer, engineer, and overall architect all need to accept responsibility for the ways those people are going to act."

Victor Riley, associate technical fellow in Boeing Flight Deck, Crew Operations, argues that there needs to be a two-way dialogue between the operator and the automated system.

“The operator-to-the-system part of the dialogue is more important than the system-to-the-operator part,” Riley says. “People see what they expect to see, and what they expect to see is based on what they thought they told the system to do.”

Studies by Parasuraman, Rovira, and others have found that operators of highly reliable automated systems will often perform worse than if they were operating a lower-reliability system, which seems paradoxical.

Parasuraman explains that “if you deliberately engineer anomalies into the automation, people rely less on it and will perform a little bit better in monitoring the system. For example, if the system is 90 percent reliable, operators will be better at picking up the 10 percent of the errors than if the system is 99 percent reliable.”

Rovira also says that operators need to be able to see how well the automation is working in a given context.

“The goal for us as designers is to provide an interface that allows a drill-down if the operator needs to query the system, in the event they have a different perspective of the decision than the automation has given them,” Rovira says. “Or if not a drill-down, there should be some visibility or transparency right up front about what the underlying constraints or variables are that make this decision not totally reliable.”

Maybe one way to remind ourselves of the potential effects of the ironies and paradoxes of automation is to simply pull the plug.

“If we don’t want people to depend on automated systems, we need to turn them off sometimes,” Thomas observes. “People, after all, are the backup systems, and they aren’t being exercised.”

About the Author

Robert N. Charette, an *IEEE Spectrum* contributing editor, is a self-described “risk ecologist” who investigates the impact of the changing concept of risk on technology and societal development. Charette also writes *Spectrum*’s blog [The Risk Factor](#).

The Microbots Are on Their Way

Tiny sensors with tinier legs, stamped out of silicon wafers, could one day soon help fix your cellphone battery or study your brain.

By Kenneth Chang

April 30, 2019

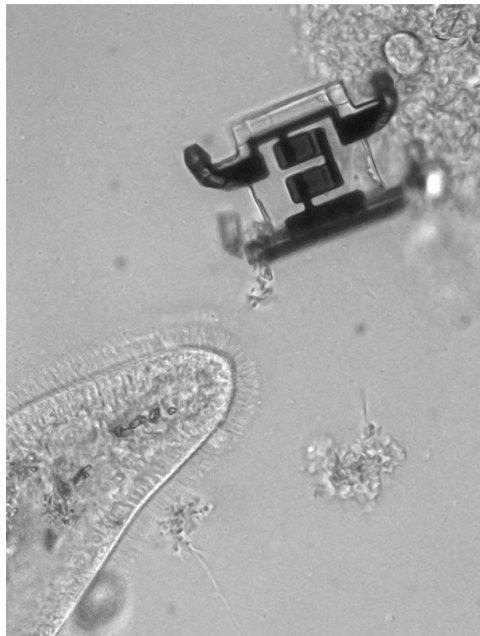
<https://www.nytimes.com/2019/04/30/science/microbots-robots-silicon-wafer.html>

Like Frankenstein, Marc Miskin's robots initially lie motionless. Then their limbs jerk to life.

But these robots are the size of a speck of dust. Thousands fit side-by-side on a single silicon wafer similar to those used for computer chips, and, like Frankenstein coming to life, they pull themselves free and start crawling.

"We can take your favorite piece of silicon electronics, put legs on it and then build a million of them," said Dr. Miskin, a professor of electrical and systems engineering at the University of Pennsylvania. "That's the vision."

He imagines a wealth of uses for these microbots, which are about the size of a cell. They could crawl into cellphone batteries and clean and rejuvenate them. They might be a boon to neural scientists, burrowing into the brain to measure nerve signals. Millions of them in a petri dish could be used to test ideas in networking and communications.



A microbot alongside a paramecium. Researchers envision using the tiny crawlers to measure signals in the brain. Credit Marc Miskin, University of Pennsylvania and Cornell University

The research, presented at a meeting of the American Physical Society in Boston in March, is the latest step in the vision that physicist Richard Feynman laid out in 1959 in a lecture, "There's Plenty of Room at the Bottom," about how information could be packed into atomic-scale structures and molecular machines could transform technology.

Over the past 50 years, Feynman's predictions about information storage have largely come to fruition. "But the second goal — the miniaturization of machines — we're really just getting started," Dr. Miskin said.

The new robots take advantage of the same basic technology as computer chips. "What we're doing is stealing from 60 years of silicon," said Paul McEuen, a physicist at Cornell University. "It's no big deal to make a silicon chip 100 microns on a side. What didn't exist is basically the exoskeleton for the robot arms, the actuators."

While working in the laboratories of Dr. McEuen and Itai Cohen, another Cornell physicist, Dr. Miskin developed a technique to put layers of platinum and titanium on a silicon wafer. When an electrical voltage is applied, the platinum contracts while the titanium remains rigid, and the flat surface bends. The bending became the motor that moves the limbs of the robots, each about a hundred atoms thick.

The idea is not new. Researchers like Kris Pister of the University of California, Berkeley, have for decades talked of "smart dust," minuscule sensors that could report on conditions in the environment. But in developing practical versions, the smart dust became larger, more like smart gravel, in order to fit in batteries.

Dr. Miskin worked around the power conundrum by leaving out the batteries. Instead, he powers the robots by shining lasers on tiny solar panels on their backs.

"I think it's really cool," Dr. Pister said of the work by Dr. Miskin, Dr. McEuen and their collaborators. "They made a super-small robot you can control by shining light on it and that could have all sorts of interesting applications."

Because the robots are made using conventional silicon technology, incorporating sensors to measure temperature or electrical pulses should be straightforward.

Dr. Miskin said his electrical engineering colleagues are often incredulous when they find out that the robots run on a fraction of a volt and consume only 10 billionths of a watt: "'You mean you can take my thing and put legs on it?' 'Yeah, absolutely.' 'And then you can have it piloted and compute and do all this other stuff?' People get really excited."

Challenges remain. For robots injected into the brain, lasers would not work as the power source. (Dr. Miskin said magnetic fields might be an alternative.) He wants to make other robots swim rather than crawl. (For tiny machines, swimming can be arduous as water becomes viscous, like honey.)

Still, Dr. Miskin expects that he can demonstrate practical microbots within a few years.

“It really boils down to how much innovation do you have to do?” he said. “And what I love about this project is for a lot of the functional things, the answer is none. You take the parts that exist and you put them together.”

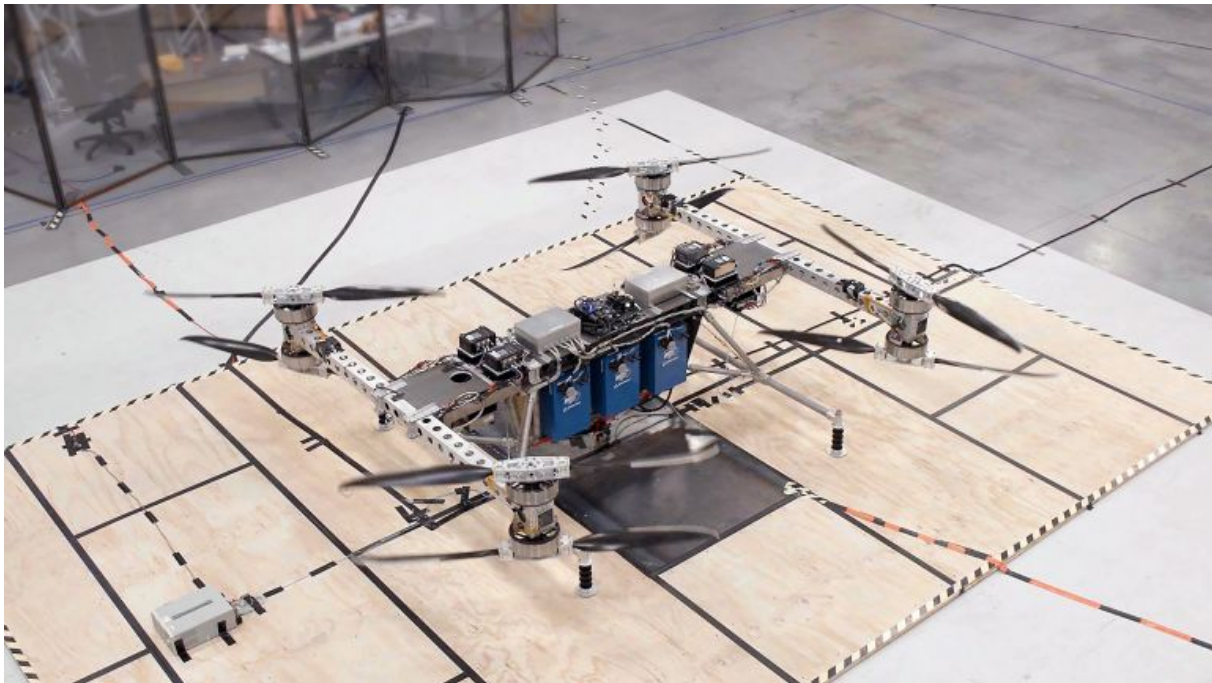


Boeing's New Prototype Cargo Drone Can Carry up to 500 Pounds

The VTOL prototype will help Boeing develop more future autonomous vehicles.

By Kyree Leary
January 11, 2018

<https://futurism.com/boeings-new-prototype-cargo-drone-carry-500-pounds>



Typically, when imagining a drone, one might picture something relatively small that can only carry a smartphone, camera, or another equally small object. Boeing, however, just revealed a new cargo drone that's capable of lifting 500 pounds.

The unmanned cargo aerial vehicle (CAV) prototype is much larger than anything you can find in a store. It's 15 feet long (4.57 meters), 18 feet wide (5.49 meters) and 4 feet tall. It also weighs 747 pounds.

A team of Boeing HorizonX engineers worked on the cargo drone for 3 months, equipping it with eight propeller blades and vertical-takeoff-and-landing (VTOL) capabilities. It recently completed its first series of test flights at Boeing's research lab in Missouri.

"This flying cargo air vehicle represents another major step in our Boeing eVTOL strategy," said Greg Hyslop, Boeing Chief Technology Officer, in a statement. "We have an opportunity to really change air travel and transport, and we'll look back on this day as a major step in that journey."

The Future of Autonomous Aircraft

Specifics related to the drone's top speed and range were not shared. However, that's not too unsurprising, given it's unlikely Boeing will mass produce this particular drone.

Instead, the cargo drone will be used as a test bed to facilitate the development and testing of better autonomous technology and vehicles, such as the electric VTOL being designed by Aurora Flight Sciences (bought by Boeing in October), and whatever "urban mobility" products it explores as part of its partnership with Near Earth Autonomy.

"Our new CAV prototype builds on Boeing's existing unmanned systems capabilities and presents new possibilities for autonomous cargo delivery, logistics and other transportation applications," added Steve Nordlund, vice president of Boeing HorizonX. "The safe integration of unmanned aerial systems is vital to unlocking their full potential. Boeing has an unmatched track record, regulatory know-how and systematic approach to deliver solutions that will shape the future of autonomous flight."



Disney Imagineering Has Created Autonomous Robot Stunt Doubles

The robot acrobats can flip through the air and stick a landing every time

By **Matthew Panzarino** / June 2018

<https://techcrunch.com/2018/06/28/disney-imagineering-has-created-autonomous-robot-stunt-doubles/>

For over 50 years, Disneyland and its sister parks have been a showcase for increasingly technically proficient versions of its “animatronic” characters. First pneumatic and hydraulic, and more recently fully electronic, these figures create a feeling of life and emotion inside rides and attractions, in shows and, increasingly, in interactive ways throughout the parks.

The machines they’re creating are becoming more active and mobile in order to better represent the wildly physical nature of the characters they portray within the expanding Disney universe. And a recent addition to the pantheon could change the way that characters move throughout the parks and influence how we think about mobile robots at large.

I wrote [recently about the new tack Disney was taking](#) with self-contained characters that felt more flexible, interactive and, well, alive than “static,” pre-programmed animatronics. That has done a lot to add to the convincing nature of what is essentially a very limited robot.

Traditionally, most animatronic figures cannot move from where they sit or stand and are pre-built to exacting show specifications. The design and programming phases of the show are closely related, so that the hero characters are efficient and durable enough to run hundreds of times a day, every day, for years.

The Na’vi Shaman from Pandora: The World of Avatar, at Walt Disney World, represents the state of the art of this kind of figure.

However, with the expanded universe of Disney properties including more and more dynamic and heroic figures by the year, it makes sense that they’d want to explore ways of making the robots that represent those properties in the parks more believable and active.

That’s where the Stuntronics project comes in. Built out of a [research experiment called Stickman](#), which we covered a few months ago, Stuntronics are autonomous, self-correcting aerial performers that make on-the-go corrections to nail high-flying stunts every time. Basically robotic stuntpeople, hence the name.

I spoke to Tony Dohi, Principal R&D Imagineer and Morgan Pope, Associate Research Scientist at Disney, about the project.

“So what this is about is the realization we came to after seeing where our characters are going on screen,” says Dohi, “whether they be Star Wars characters, or Pixar characters, or Marvel characters or our own animation characters, is that they’re doing all these things that are really, really active. And so that becomes

the expectation our park guests have that our characters are doing all these things on screen — but when it comes to our attractions, what are our animatronic figures doing? We realized we have kind of a disconnect here.”

So they came up with the concept of a stunt double for the ‘hero’ animatronic figures that could take their place within a show or scene to perform more aggressive maneuvering, much in the same way a double replaces a valuable and delicate actor in a dangerous scene.

The Stuntronics robot features on-board accelerometer and gyroscope arrays supported by laser range finding. In its current form, it’s humanoid, taking on the size and shape of a performer that could easily be imagined clothed in the costume of, say, one of The Incredibles, or someone on the Marvel roster. The bot is able to be slung from the end of a wire to fly through the air, controlling its pose, rotation and center of mass to not only land aerial tricks correctly but to do them on target while holding heroic poses in midair.

One use of this could be mid-show in an attraction. For relatively static shots, hero animatronics like the Shaman or new figures Imagineering is constantly working on could provide nuanced performances of face and figure. Then, a transition to a scene that requires dramatic, un-fettered action and boom, a Stuntronics double could fly across the space on its own, calculating trajectories and striking poses with its on-board hardware, hitting a target dead on every time. Queue re-set for the next audience.

This focus on creating scenarios where animatronics feel more ‘real’ and dynamic is at work in other areas of Imagineering as well, with autonomous rolling robots and — some day — the holy grail of bipedal walking robots. But Stuntronics fills one specific gap in the repertoire of a standard Animatronic figure — the ability to convince you it can be a being of action and dynamism.

“So often our robots are in the uncanny valley where you got a lot of function, but it still doesn’t look quite right. And I think here the opposite is true,” says Pope. “When you’re flying through the air, you can have a little bit of function and you can produce a lot of stuff that looks pretty good, because of this really neat physics opportunity — you’ve got these beautiful kinds of parabolas and sine waves that just kind of fall out of rotating and spinning through the air in ways that are hard for people to predict, but that look fantastic.”

Like many of the solutions Imagineering comes up with for its problems, Stuntronics started out as a research project without a real purpose. In this case, it was called BRICK (Binary Robotic Inertially Controlled brick). Basically, a metal brick with sensors and the ability to change its center of mass to control its spin to hit a precise orientation at a precise height — to ‘stick the landing’ every time.

From the initial BRICK, Disney moved on to Stickman, an articulated version of the device that could now more aggressively control the rotation and orientation of the device. Combined with some laser rangefinders you had the bones of something that, if you squint, could emulate a ‘human’ acrobat.

“Morgan and I got together and said, maybe there’s something here, we’re not really sure. But let’s poke at it in a bunch of different directions and see what comes out of it,” says Dohi.

But the Stickman didn’t stick for long.

“When we did the BRICK, I thought that was pretty cool,” says Pope. “And then by the time I was presenting the BRICK at a conference, Tony [Dohi] had helped us make Stickman. And I was like, well, this isn’t cool anymore. The Stickman is what’s really cool. And then I was down in Australia presenting Stickman and I knew we were doing the full Stuntronic back at R&D. And I was like, well, this isn’t cool anymore,” he jokes.

“But it has been so much fun. Every step of the way I think oh, this is blowing my mind. But, they just keep pushing...so it’s nice to have that challenge.”

This process has always been one of the fascinating things to me about the way that Imagineering works as a whole. You have people who are enabled by management and internal structure to spool out the threads of a problem, even though you’re not really sure what’s going to come out of it. The biggest companies on the planet have similar R&D departments in place — though the ones that make a habit of disconnecting them from a balance sheet, like **Apple**, are few and far between in my experience. Typically, so much of R&D is tied so tightly to a profit/loss spreadsheet that it’s really, really difficult to surmise something enough to see what comes of it.

The ability to kind of have vastly different specialities like math, physics, art and design to be able to put ideas on the table and sift through them and say hey, we have this storytelling problem on one hand and this research project on the other. If we drill down on this a bit more, would this serve the purpose? As long as the storytelling always remains the North Star then you end up having a guiding light to drag you through the pile and you come out the other end, holding a couple of things that could be coupled to solve a problem.

“We’re set up to do the really high-risk stuff that you don’t know is going to be successful or not, because you don’t know if there’s going to be a direct application of what you’re doing,” says Dohi. “But you just have a hunch that there might be something there, and they give us a long leash, and they let us explore the possibilities and the space around just an idea, which is really quite a privilege. It’s one of the reasons why I love this place.”

This process of play and iteration and pursuit of a goal of storytelling pops up again and again with Imagineering. It’s really a cluster of very smart people across a broad spectrum of disciplines that are governed by a central nervous system of leaders, such as Jon Snoddy, the head of Walt Disney Imagineering R&D, who help to connect the dots between the research side and the other areas of Imagineering that deal with the parks or interactive projects or the digital division.

There’s an economy and lack of ego to the organization that enables exploration without wastefulness and organically curtails the pursuit of things not in service to the story. In my time exploring the workings of Imagineering I’ve often found that there is a significant disconnect between how fascinating the process is and how well the organization communicates the cleverness of its solutions.

The Disney Research white papers are certainly infinitely fascinating to people interested in emerging tech, but the points of integration between the research and the practical applications in the parks often remain unexplored. Still, they’re getting better at understanding when they’ve really got something they feel is killer and thinking about better ways to communicate that to the world.

Indeed, near the end of our conversation, Dohi says he’s come up with a solid sound bite and I have him give me his best pitch.

“One of our goals of Stuntronic is to see if we can leap across the uncanny valley.”

Not bad.

Hyundai Is Building a Car That Can Walk on Four Legs

Elevate is a concept that has legs... literally

By Andrew J. Hawkins

Jan 9, 2019

<https://www.theverge.com/2019/1/9/18173742/hyundai-walking-car-concept-elevate-ces-2019>



CES typically attracts whacky ideas, especially from automakers that tend to use the electronics show to showcase their most outlandish and unbuildable products. Unfortunately, the 2019 show has been pretty tame by most measures, which is why it's so refreshing that Hyundai came to Las Vegas with a truly bonkers idea: a “walking car” with real, bendable legs. At last, something to haunt my dreams!

Like some mashup between a [Boston Dynamics robot](#) and something you might find [stomping across the frozen surface of the planet Hoth](#), Hyundai's Elevate vehicle is an automotive concept I can't recall having seen before. Hyundai says it designed it for first responders who need to access difficult terrain. (Think mountains, forests, or other rock-strewn landscapes that are inaccessible to

most terrestrial vehicles.) Electrically powered and modular so it can swap vehicle bodies for a variety of use cases, the South Korean automaker is calling it an “Ultimate Mobility Vehicle.”

Elevate has four “legs,” each with a series of joints, enabling the vehicle to mimic both mammalian and reptilian walking gaits. Here’s how the automaker describes this truly bizarre feature:

The legs also fold up into a stowed drive-mode, where power to the joints is cut, and the use of an integrated passive suspension system maximizes battery efficiency. This allows Elevate to drive at highway speeds just like any other vehicle. But no other can climb a five foot wall, step over a five foot gap, walk over diverse terrain, and achieve a 15 foot wide track width, all while keeping its body and passengers completely level. Further, the combination of wheeled motion with articulating legs provides a new paradigm of mobility by enabling faster walking speeds, unique dynamic driving postures and torsional control at the end of each leg.

If you’re getting a strong Mars Rover vibe off this thing, that’s on purpose: Hyundai thinks the technology underpinning this vehicle could make it ripe for an interplanetary mission. “By combining the power of robotics with Hyundai’s latest EV technology, Elevate has the ability to take people where no car has been before, and redefine our perception of vehicular freedom,” said David Byron, design manager at Sundberg Ferar.

Unfortunately, there’s no full-scale prototype to gawk at; instead, we get these videos of a not-to-scale model performing its featured leg stretches as well as some flashy computer graphics of how this thing will look in its final form.

In addition to emergency services, Hyundai says its concept could be ideal as a wheelchair-accessible vehicle. Imagine opening your front door to find this thing waiting right outside. Not at all creepy!

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