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IOT, DATA, AND THE NEW LAST MILE HIGHLIGHTS

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prepared by Nancy Kleinrock nk33@cornell.edu

An OS for Autos—Mr. George Hotz, Comma.ai

- Although some people love the act of driving, others prefer not to have to engage with the process of getting from here to there.
  - Those in the latter camp will either need to wait until self-driving technology matures or, alternatively, leave the driving to others by taking public transit, rideshare (if situated in a locale where such options perform efficiently), or hire a chauffeur.
  - Hotz, after offering a pessimistic overview of existing autonomous (level-four, no-driver) vehicles and his opinion that Tesla's driver-assist (level-two, attentive-driver) capability is overpriced and overhyped, describes comma.ai's alternative: a low-cost, open-source level-two addon to an array of conventional vehicles.
- Much ado has been swirling around the concept of driverless cars, but will they usher in Nirvana or are they a scam? Hotz believes the latter.
  - Alphabet's Waymo has covered some millions of real-world level-four (no-driver) road miles, but only in restricted locations and conditions, due to reliance on centimeter-scale-precision terrain mapping and use of 300-m LIDAR scoping.
    - Even where the $300K–$500K Waymo retrofitted vehicles roam, they do so more slowly than conventional car–driver combos: "Waymos travel the speed limit, they come to full stops at stop signs, and they slow down at the slightest hint of hesitation"—good for safety, but not for getting to your destination in a timely manner at a reasonable cost.
      - If Waymo estimates 18 minutes for a trip Uber suggests its driver will make in 12, the carless commuter will choose Uber and enjoy a little chat with the human behind the wheel en route.
  - Or consider Drive.ai, and its $77M "retirement home shuttle bus"—a sham market in Hotz's opinion.
  - And, speaking of shams, Hotz lumps in ethics consultants, who ponder the morality of autonomous-vehicle software.
    - Given that upwards of 90% of vehicular accidents are caused by drivers who are drunk, distracted, or overtired, why should undo attention be given to pondering whether a driverless car should swerve to avoid a toddler in the road at the expense of a crosswalk full of adult pedestrians.
  - "The autonomous-vehicle vision wouldn't even be a revolution; at best, it's cheaper ride sharing"; the *cheaper* part should eventually arrive, but is not here yet.
- Some autonomy has been coming into focus over the past few years, not in the form of level four, but rather level two.
  - Tesla has been quite effective in marketing its level-two driver assistance system as *Autopilot*, but like all other similarly classified systems, it requires an attentive driver behind the wheel (not to mention a significant monetary barrier to entry).
- It is not Holz's vision to require every driver who seeks an assist to have to purchase a new, expensive vehicle, especially in a time when the car they already own remains fully functional.
  - He recognizes that personal car ownership is a strong and, in important parts of the world like China, growing market.
    - "Car ownership will continue for a long time. We are not going to rethink and revolutionize the way we own cars. People like owning cars for the same reason people like owning houses."
  - Autonomous-driving capabilities have been infiltrating the driving experience in the form of advanced driver-assistance systems (ADAS) over the past several years, even if not packaged with the same level of hype as Tesla has deployed.
    - What is cruise control, if not automatic gas? This form of driver assistance has been around for decades, whether as a built-in capability or as an aftermarket addon.
    - A more recent phenomenon is adaptive cruise control (automatic gas and brake).

- Lane centering is a case of automatic steering.
- "All of these combined—gas, brake, and steering—that's all of driving!"
- "Don't view autonomous vehicles as a binary, where there is a human driver or no human driver; don't think about it as a cliff, but as a gradual increase to full autonomy."

- Comma.ai's product, openpilot, is, in effect, Autopilot for the recent-model cars that people already have in their garages (specifically, select models of Honda, Toyota, Acura, Lexus, Hyundai, and Chevy).
  - The all-important comma.ai software layer—which is programmed in Python and variously assesses real-time driving situations, uses a fraction as a machine-learning training set, performs level-two assist functions (steering, acceleration, braking), controls the car-to-driver handoff, alerts the driver of hazards, etc.—is the guts of comma's system; this is what is under continual improvement by the company and members of its open-source community (as is Autopilot, by Tesla).
    - The three-part safety model dictates that (1) the car can never react in more quickly/jerkily than a human could (faster than one second); (2) the driver is always attentive to the driving situation; and (3) the driver can resume active control by touching either the gas or the brake.
    - The safety model is one thing; what defines safe driving is another.
      - Instead of strictly codifying the rules of the road—e.g., under no circumstances cross a double yellow line, which in practical circumstances would put a halt to forward progress for a car in a congested city like downtown San Francisco—comma's software relies on large-scale machine learning rooted in how people actually drive.
        - In effect, comma's software makes driving decisions as a committee of 100 drivers would: Some will make bad suggestions, but correct choices will rule the day.
        - "The way to do this is with big data and statistics."
      - Note that comma's dashcam-enriched hardware (described below) is continually improving and expanding the dataset, with 8.6M miles driven over the three years of openpilot's existence; the system has caused zero accidents when engaged.
        - Moreover, the omnipresence of dashcam footage greatly improves the ability to suss out the cause of any accident and appropriately assign blame (which legally remains with the driver for any level-two system).
        - By using its system, every comma.ai customer agrees that the firm has full access to all data the system generates; "I am not wishy-washy. You are giving us all the data, and we will use it for whatever we want; if you aren't good with that, don't use the system."
- For comma, the software is a giveaway; the firm makes money by selling its hardware—but to whom?
  - With capabilities on par with Autopilot, Hotz initially intended to sell openpilot to the behemoths of the car industry, but their operations were so huge that he found no viable entry point for openpilot to get a foothold.
  - Instead of pursuing manufacturer buy-in, comma has gone the route of ensuring manufacturer compatibility instead.
    - Today's business model is to sell directly to consumers; future expansion is expected by partnering with car dealerships for mass distribution.
  - By purchasing and installing three pieces of hardware from comma.ai (total purchase price, roughly $750), the car's existing adaptive cruise control and lane-keeping assist systems experience notable improvements and, as per comma's slogan, deliver "ghostriding for the masses."
    - Put otherwise, if Tesla's Autopilot is the iOS for cars, openpilot is the Android.
  - Hardware components:
    - panda—comma's OBD-II interface;
    - giraffe—module that connects to the panda and collects data from the car's radar;
    - EON dashcam devkit—running comma's open-source software, this forward-looking camera improves existing adaptive cruise control and lane keeping, while the driver-facing camera performs attention monitoring for added safety.
  - "You can put openpilot in any of [the supported] cars, and it will take over the steering, the gas, and the brakes, and it will do a significantly better job than the manufacturer's system."
    - Currently, openpilot users engage their systems for roughly 50% of daily miles driven, far in excess of Tesla's 30% engagement rate.
      - "Our goal is to get that number up to 100%."

        - As MIT-licensed open-source software, any interested party is welcome to rebrand and modify the software for their own purposes.
- To advance from level-two assistance to greater levels of autonomy will require 360° vision capabilities as well as whole-system redundancy and a safety model that does not assume an attentive person in the driver's seat.
    - Hotz does not anticipate significant modification of the basic infrastructure of the driving landscape as levels of autonomy increase; stop signs will remain important features, as will lane lines.
        - The "horrific" alternative would be to rely on components of independent vehicles to reliably—always—communicate and make consensus-based decisions.
            - "The beauty of stop signs is that it decentralizes logic."
    - "When will we get [to full autonomy]? When the statistics say we have."
        - The current openpilot system is trained on 100K miles of data, whereas the standard for a level-four system is 1B miles of training data.
        - Geographic regions with different driving rules/styles require independent training of the system (e.g., driving on the left vs right side of the road; Buenos Aires vs Washington, D.C.).
            - Geography also plays into road conditions; Hotz does not recommend use of his system when roads are snow-covered.
    - Hotz is sanguine regarding the digital security of cars, saying, "Car hacking is not really a thing. Just use industry-standard security and don't do stupid things. We have given up on the China market; our stuff gets in through GitHub."

Games That Autonomous Vehicles Play—Dr. Adam Millard-Ball, University of California-Santa Cruz

- Once fully autonomous vehicles (AVs) become the norm, unless explicitly programmed or regulated otherwise, their intrinsic incentives will conflict with what is best for society at large.
    - As an economist, Millard-Ball considers future safety and traffic considerations from the stance of game theory and presents two examples: the dynamic interplay between pedestrians and cars, and the looming traffic jams as driverless cars cruise—very slowly—to avoid the cost of urban parking while their owners catch lunch, attend to business, shop, or otherwise pass the time in the city.
    - As Millard-Ball explains, the undesirable outcomes of these scenarios can be overcome with a combination of road pricing and street redesign.
        - "We have to put policies in place to push AVs toward a socially beneficial future."
- First, consider the game of crosswalk chicken, a game that pedestrians and drivers play whenever they face off: Neither cares to yield to the other, but both ultimately fear a collision even more.
    - Despite pedestrians having the legal upper hand, physical vulnerability induces them to give way to armored objects outweighing them by at least an order of magnitude.
        - A pedestrian can never know whether a human driver might be drunk, inattentive, or sociopathic and will therefore not risk stepping out in front of an unyielding car.
    - What changes when an algorithm, not a human, is in control of the vehicle?
        - An AV would not engage with a pedestrian to the bitter end: its programming requires it to be inherently attentive and not sociopathic.
        - Recognizing this, pedestrians will take liberties with AVs, crossing impulsively with little fear of bodily harm.
        - "I can force it to stop by starting to cross the street."
        - A corollary of pedestrian supremacy is that urban car rides will become interminably slow as the progress of not only the AVs, but all vehicles on the road, inch along at the mercy of walkers.
- Next, consider the coordination game of strategic parking, a game that jointly optimizes on proximity to the occupant's destination and cost to park.
    - But when the vehicle is autonomous, it can drop the human arbitrarily close to the destination before heading off to park—or to not park.
        - Parking options: park in a nearby lot/garage, park on the street after cruising for a spot, cruise indefinitely until called for a pickup, or go home and park there until recalled.
        - Even if peripheral parking lots were purposefully constructed for the use of AVs, there is little expectation AVs would park there, since other alternatives would be less costly.
        - The incidence of cruising, in particular, is expected to rise dramatically as autonomous vehicles contribute to transportation in a large way.

        - Most notably electric cars, which suffer no cost when idling, will optimize on moving the minimal distance until the owner returns; as such, they will seek out streets with the slowest moving traffic: Standstill traffic mimics desirable parking.
        - AVs will therefore seek out congested streets, thereby congesting them more, and making them increasingly attractive to other cruisers.
            - "You can park practically for free by getting into a traffic jam. Autonomous vehicles want to be on the same streets where they can get into each other's way."
        - In simulation, Millard-Ball sees each car choosing the more congested street at each intersection, leading to urban cruising speeds of 2 km/hr—a standstill that saves several dollars in parking fees per hour per cruising car, but creates further urban havoc for other uses of city streets who actually want to move efficiently through the cityscape.
- The societal implications are plain: If parking costs effectively plummet, people will no longer be incentivized to take public transit in lieu of their personal vehicle; these additional cars will further exacerbate the problem.
    - Something must give, but a simple rule prohibiting "mobile parking" is unlikely to work.
        - Excuses for cruising might include looking for another rider or running an errand for the car's owner.
            - "Regulations are notoriously difficult to design if you are trying to get at somebody's intent."
    - Millard-Ball's solution is congestion pricing: charging a fee for cars to use the public right of way.
        - London, Singapore, and Stockholm have all adopted this strategy to positive effect, reducing the number of cars entering the urban core.
        - A flat fee might not adequately address the AV-cruising problem; a flat fee plus time-based metering—analogous to a parking meter—could be paired to nip cruising in the bud, as would differential pricing according to time of day and instantaneous roadway congestion.
            - "Charge a price that is equal to the cost you are imposing on other people; at busy times, that cost is going to be more. This pricing can help to even out the peaks and troughs, and be a partial solution to sizing the infrastructure to needs of the peak hour."
                - "Pricing before concrete: It is a lot cheaper and quicker to implement."
        - Still, as evidenced by the scant handful of cities that have adopted congestion pricing in any form, this strategy is politically risky, but Millard-Ball suggests that the games autonomous vehicles will play might provide the necessary incentive to move forward.
- An obvious positive outcome of both charging for AVs' cruising time and discouraging individual-car use in central cities—in favor of public transit, walking, and/or cycling—is to free up the land currently given over to parking lots.
    - This valuable real estate resource could then be redeveloped into dense transit-rich communities, with parking on the outskirts, and sidewalks, protected bike lanes, sidewalk cafes, and recreational areas incorporated into the infill redesign.
        - Reporting on a real-world case study, Millard-Ball relates that the combination of revenue generated from congestion pricing and the freed resource due to a 25% decrease in private-car trips in central London has enabled the synergistic construction of wider sidewalks and mass transit lanes.
    - Cities would again become walkable, and the default outcome of the game of crosswalk chicken would be for pedestrians to win.
        - "The improved safety primarily benefits pedestrians in an urban center, both from the you-don't-get-hit-by-a-car point of view, but also from a public health and urban livability point of view."
        - True, this model would degrade the ability for people in cars to move quickly through dense city streets, but suburbs and exurbs would still hold that appeal.
    - "The fact that we don't price streets—the fact that we give away cities' most valuable assets pretty much for free; that is, cars in motion—is perhaps one of the most regressive policies in the United States."
        - This is particularly true in cities undergoing widespread gentrification, where people with low-to-moderate incomes are being pushed out of the urban neighborhoods that have historically been their homes.
            - "How to provide access to cities for low-income people is a challenge with or without autonomous vehicles, as they are being flung out to places that have traditionally not been well-served by transit. Thoughtful use of congestion-pricing revenues could be used to address some of those inequities."

- What Millard-Ball has just laid out is the utopian view of the urban future, but a different set of policies could paint a very different picture.
  - Were AV liability rules written such that there were a liability cap associated with hitting a pedestrian, cars would come to rule the streets and pedestrians would be relegated to fenced-in areas or other artificial modes of separation from the resources of the city.
  - Policy choices shape cities in a literal sense; careful consideration is essential.
- Underpinning Millard-Ball's discussion has been an implicit assumption of private car ownership, but a rise in the shared-use model should not be ruled out.
  - In actuality, he anticipates a mix of private and fleet ownership, with suburban dwellers owning personal AVs and autonomous transit dominating urban centers, along with a smattering of personal-scale car sharing (autonomous taxis) as part of the mix.
  - Whether shared or private, an AV will play its optimization games according to the same rules, and shared-use AVs will experience natural peaks and lulls in demand, leading still to the mobile-parking conundrum.
    - "We see this now with taxis and Ubers and Lyfts, which are hanging out in a 7-Eleven parking lot or at a meter [during lulls]."

IoT, Attention, and the Emerging Information Ecology—Mr. Mickey McManus, Boston Consulting Group

- Exponentials have a way of taking those who live in a linear world by surprise; this, of course, includes all of us.
  - Even as the number of connected computational devices has expanded into the billions, the number of devices is—order-of-magnitude-wise—akin to the number of people currently alive.
    - It makes sense to speak of "information [being] in the computer."
  - With the impending buildout of the Internet of Things to the scale of trillions, no longer will this paradigm persist; instead, we—"you, me, our house, our products, our community"—will be "in the information."
  - Unless this information environment can be tamed, existence will be chaotic, with a trillion things sending *you* a billion messages (overwhelming, if even a tiny percent are spam); they will require updates, lie to you, and demand your attention.
  - As if things weren't already sufficiently complicated and attention-grabbing, we will then be living in an era of "unbounded malignant complexity."
  - Progressing in tandem with the Internet of Things are robotic automation and machine learning, together coalescing into something as fertile as the primordial soup from which life sprung, but this sea of networked matter will be much larger, faster, and more sudden—a "primordial tsunami," describes McManus.
  - So what happens when "things wake up?" he poses—when silicon minds and organic minds operate synergistically, and machine learning urges decision making to be based not on specs but on the generative outcomes of goals and constraints, and when robotics and the IoT's real-time sensing and actuation capabilities combine with computation to make predictions, solve problems, and learn in context.
  - This new paradigm sets the stage for a "growth mindset" and an array of positive outcomes that McManus envisions.
  - He dives into these abstractions using three examples—Astro Teller's 2000-era BodyMedia armband health monitors, a car that actively supports its own design, and generative building design to which a host of architectural interns simultaneously contribute—with a stated goal of "replacing mass with math."
  - Despite these rosy case studies, McManus also recognizes the dangers when bias creeps into any problem-solving exercise, whether it is a human or machine that expresses that bias; after all, the guardrails of any algorithm are initially coded by humans with all their frailties.
    - As such, McManus also explores the influence of bias on cognition—whether human or machine cognition.
- Examples:
  - Teller came to TTI/Vanguard in 2000 and 2003 to speak about his devices and Gordon Bell spoke of personal-health tracking beginning in, long before the FitBit tracker launched in 2008, long before Marco Della Torre shared the story of the Basis watch (2013), and long before so-called first adopters glommed onto the Apple Watch in 2015.

        - In a comfortably wearable package, BodyMedia successfully collected 90% of the bodily data that otherwise entailed a clinic visit and hookup to a variety of large medical apparatuses.
        - Teller's innovation was to use miniaturization and computation to replace dedicated instrumentation: math, not mass.
    - Autodesk's generative automobile design, in which "the service centers, factories, and your customers' garages all join your design team."
        - As a summer-long exercise, McManus analyzed the most advanced automobiles created by designers of the cars known for winning extreme races.
        - "I said, 'Give me your best car, and I want to rip it so that I have all the structural stuff, and I also want to put sensors all over it and rip the act of you driving it in the Mojave Desert.'"
            - McManus used laser-scanning and photogrammetry systems to analyze the car's structure at rest; instruments to measure metal deformation of the car at speed, during straightaways, curves, and jumps; in-helmet EEG and myriad other sensors to assess the stresses on the driver; and so forth—billions of data points in all.
        - Instead of performing conventional design based on the collected data, McManus and the Hackrod team fed all the data to a computational system, applied some constraints—"do not grow into this region, because that is where the human sits, and do not grow into that region because that is where a wheel is"—and let Autodesk's Dreamcatcher generative design software churn.
            - The humans evaluated Dreamcatcher's myriad outputs, iterating until the team of organic and silicon minds settled on a design that could be produced in conventional chrome moly tubing or, alternatively, 3-D printed in titanium or aluminum.
                - "By defining goals and constraints, every time a new manufacturing method came along, you could just hit a button and recompute; instead of encoding your design in a CAD file, you just encode your goals, and the system looks for it."
                - The result, once constructed in metal and plastic and rubber, was 25% lighter than the previously optimized model.
                    - "The car, itself, actually found places where it could improve. There is spare GPU power in the car; could it be shaped by itself—by its life?"
        - Generative-design principles hardly need be confined to high-value projects; why not have a wrench that redesigns itself when its human, tinkering with the bespoke car, whack knuckles once too often?
        - Or consider a sensor-laden workspace that understands the context of those who work within it and adjusts focus to the next logical step of a project? The space, then, becomes "part of the team," enhancing learning and accelerating the pace of progress through a task.
            - "We think about this differently when we start enabling the machine players to do formative assessment and [assist] the human players."
            - An ecology of ever-improving designs emerges as sensor-laden objects strive for perfection.
    - Architectural redesign in the Mars neighborhood of Toronto where, as with the automotive project, the focus was to be solely on goals and constraints, this time with a large team of interns collecting ground-truth data fed into a computational process to optimize the goals within the bounds of the constraints.
        - Constraints spanned physical (overall building footprint, number of floors, location of pillars), practical (adjacencies of workgroups, workspace preferences), and business (budget) considerations.
        - Some agents were tasked with tracking interior natural lighting through the course of a day; others, exterior views; still others, the soundscape, etc.
        - This process provided the architect with pairwise considerations such as productivity relative to views of the world outside.
        - The resulting choices yielded a redone interior space that was soon populated with employees.
        - "But we didn't turn the system off. The system is still aspiring toward those goals, and every so often it will flag the facility manager to move a bunch of cubicles" to accomplish some goal.
            - In the spirit of iterative improvement, that manager—in coordination with team members and the software—continually reevaluates the goals themselves to continue to improve the experience of working within the building.
- For machines and humans—silicon and organic minds—to work together synergistically is a true wonder; McManus explores the contributions of mindfulness that each brings to the table by focusing on creativity, common sense, and passion:

- Arguably, both types of thinkers express creativity (e.g., generative adversarial networks, as presented by Kenneth Stanley and Irmak Sirer to TTI/Vanguard), and some versions of artificial intelligence strive toward common sense (notably Doug Lenat's Cyc), but it is clear that humans uniquely own passion.
  - "Passion is really a weak word for what humans have; they actually can't help themselves."
- Yet, even without passion, silicon cognition is similar to organic cognition regarding bias.
  - "A bias is a lower friction way of getting somewhere—a shortcut."
- The danger of bias is that it is so often insidious; the entity engaging in a bias-supported action is often unaware of its presence or influence.
  - Both Lenat (2013, 2018) and Julie Ancis (2017) have raised this problem in TTI/Vanguard forums, pointing out that the list of cognitive shortcuts is both long and broad.
  - McManus deepens the concern by reporting how little it can take to reduce otherwise effective cognitive capacity and thereby let bias creep in unawares.
  - For instance, research has revealed that the distraction of having one's smartphone nearby—even if switched off—is enough to significantly reduce cognitive capacity; even worse, firms like Facebook have explicitly crafted business models around addictive distraction and reinforcement of biases.
    - "We have a whole campus at Facebook dedicated to an n = 1 destruction of cognition."
  - The potential to erode ethical decision making is alarming, with research showing that being asked to perform a simple cognitive task (e.g., basic addition) before being faced with an ethical dilemma (e.g., the runaway trolley scenario) will lead to an erosion of logical-cognitive capacity.
  - "I'm really worried about strip-mining cognition."
  - Might it be better if firms were required to reveal "cognition facts labels", analogous to nutrition facts labels, to lay plain the benefits and hazards to rational thought that could come from engaging with their products?
  - "I think we are facing *Silent Spring* 2.0. It will be largely brought on by the rise of IoT, machine learning, and automation, and I want to raise the alarm."
- But just as design can purposefully push people toward poor decisions, funneling the decision-making process toward a narrow and poorly considered outcome, the use of generative design can broaden horizons, push aside biases, and enable better cognition.
- Moreover, akin to anomaly detection, machine learning can be deployed to recognize when digital tools reinforce biases, and to provide alerts and refocus thinking in more cognitively sound directions.

Skateboarding, Ontologies, Chemistry, and AI—Mr. Rodney Mullen, Skateboarder and Entrepreneur

- To those within the fold, skateboarding is means of expression, a physical and creative outlet, a connective thread among community members, a sport, and a way of life.
  - Skating has been at the center of Mullen's life since his youth, having won his first world championship at age 14.
    - It has brought him fame and joy, provided him with a livelihood and lifelong friends, and, upon occasion, broken his body; it has also sparked in him insight and inventiveness.
  - Mullen speaks about all of these, as well as a project with IBM's Watson to semantically underpin the skating nomenclature, characterize the physical components of urban landscapes, and suggest trick combinations and where best to attempt them.
- The typical skater is a bit of an outsider, but seeks a sense of belonging—and finds it within the community.
  - People meet at skateparks and around urban features that inspire them to new heights, new tricks, and—too often—new injuries.
  - What draws them are the challenge of the terrain and the challenge and camaraderie of one another.
    - Across all echelons of the sport, skaters encourage and teach one another, sharing an ethos familiar to those in the hacking community.
    - "The whole community shares a common language of tricks that each of us try—and to distinguish ourselves through our individual expression of them. We're very much an open-source community, in the sense that we contribute through the tricks we create."
      - Wikipedia attributes the invention of 35 tricks to Mullen.

        - Individual tricks form the words of skateboarding's language; combinations form its phrases, sentences, and thoughts. Examples:
            - nollie outward halflip many 360 flip; nose many nollie half heelflip dark lip transfer fakie.
            - "We change the tricks to adapt, and we project them onto the environment around us."
        - "Two kids can be texting the names [of tricks] back and forth, and—regardless of their native tongues—completely understand the nuance of motion being expressed, even if the trick [combination] has never been done before."
            - Other physical disciplines have dedicated notation schemes—Labanotation (dance), path shapes (rock climbing), play diagrams (football)—but skating's is notably concise, even as it couples tricks with the terrain over which they are performed.
                - Example: *crooked grind* implies launching from—and therefore presence of—a ledge, rail, or flat bar.
    - At each level of advancement in the art of skateboarding, skaters put themselves on the line and practice, practice, practice.
        - Some trick combinations require hours of repetition; some require months.
        - Making progress is often analogous to the algorithmic approaches of backpropagation and gradient descent.
            - A skater might perfect the first half of a trick combo and then the second, but struggle to put the full sequence of moves together, working from the inside out to achieve mastery.
        - Analogizing from a different sport, Mullen notes that, just as the four-minute mile was once considered a hard barrier, when one runner hit the mark, others quickly followed.
            - So too with skating: A skill perfected by one skater will soon be replicated by others, who now deem it possible.
        - Skaters either cut their teeth in the vertical or free-skate versions of the sport.
            - One's initial entry point colors the style of skating and, in effect, generates a skater imbued with a dialect of skating that will forever be reflected in that individual's expression; early habits are arduous to break.
    - As a young teen, Mullen broke into the top echelons of professional skating as a free skater, seemingly out of nowhere, having grown up on a farm and practicing in isolation.
        - It took the community of skaters to truly draw out his talents and accelerate his pace of learning.
- At the conclusion of a 2018 speaking engagement about Mullen's creative process, a member of VMWare's leadership team approached him expressing a commonality of approach and an interest in collaborating.
    - The outcome is a project with IBM's Watson team to develop a structured language of skating.
        - Each trick has not only a name, but is also categorized according to its element type.
            - A few examples: *fakie*, *nollie*, and *switch* are all tricks that designate *direction*; *halfcab*, *360*, and *540* designate *rotation*; *heelflip*, *shuvit*, and *impossible*, designate the *base* of the trick; and *crooked grind*, *tailslide*, and *manual* designate the *landing*.
        - Assembling tricks into combinations requires adherence to logical rules about combining element types (e.g., one landing type per rotation type).
    - Trained from a video database of skaters doing their thing across Barcelona, a Watson-based chatbot can now guide skaters to the best location to attempt whatever trick combo they fancy.
        - Pro tip for skaters in northeast Spain: The skatepark at Molins de Rei is a great place to work on your fakie-heelflip-shuvit to switch-backside-bluntslide combo, but go to the Sants skatepark if your goal is to perfect your heelflip to frontside-nosebluntslide.
    - Mullen deems the suggestion generator imperfect: As Watson pieced together skating tricks using its flavor of cognitive computing, which combines machine learning with semantic knowledgebases, some trick sequences were anatomically incongruent.
        - This AI is not unique in this regard, as Mullen relates in stories of, for instance, an energy-saving AI opting for a blackout, or each member of an ensemble of (virtual) autonomous vehicles programmed for noncollision opting to remain well separated and perform individual 360s.
    - But Mullen also found Watson suggesting some novel trick combos that he was excited to hop on a board and try to perfect.
        - "It took nothing for granted in this beautifully unexpected way."
        - This reflected the essence of Mullen's approach to skating: "You can look at skating as a form of hacking the environment, in that we use it—[the environment]—in ways never intended and create something new in the process, although most [ways] are certainly unauthorized and some

are illegal, but today there is a whole community, and in fact an economy, based around it with a common language and a common ethos."
- Any professional skater can see a trick—or trick combo—and replicate it, but the true masters are those who create new tricks.
  - "Those who can create have to have a capacity to start movements, take it in the wrong direction—which you certainly will, at least a dozen times—for hours, backtrack to the fork where you think you went wrong, and take it another direction, undoing what you did. Undoing what you did, at that intensity after about 1000 tries, is not easy."
    - A body can easily get stuck in a habit after just a day or two of solid practice, not the 10K hours that is canonically considered necessary to solidify expert-level learning.
      - "That 10K-hour rule is an oversimplification."
  - Muller has little doubt that robots, given skateboarding's nomenclature and time—years—to experiment within its semantic boundaries, would also creatively devise new trick combinations.
- Were he granted a physical superpower to enhance his ability to skate, it would be to jump high, although having a tail (for balance) would revolutionize skating, as well.

Physical and Digital: Finding the Balance—Mr. Adrian Westaway and Ms. Clara Westaway, Special Projects

- Unite a product designer and design-oriented electronic engineer who is also a magician, and anything becomes possible.
  - The couple—in work and in life—bring an ethos of delight to all that they and their six-person team invents, with the decidedly nongimmicky goal of bridging gaps in the user experience by dreaming up four-to-six-year-ahead technologies and interfaces to solve real problems that exist today.
  - Depending on the need, each human-centered solution they craft is as likely to be physical as digital—or a combination of the two.
  - The Westaways present three case studies that illustrate both their method and their sense of form-plus-function design.
    - Each project involves a clear end goal; the design, which generally entails a mix of the physical and the digital, is always a servant of that goal.
- Solving a digital problem in a physical way—mobile phone for seniors:
  - While it is true that older folks are not digital natives, and that a larger share of them have physical or cognitive challenges compared with the general population, it is also true that they desire many of the benefits that digital technologies have to offer.
  - With Samsung, the Westaways were set out to create a seniors' phone that would do more than initiate a call to 9-1-1 or a handful of predesignated personal contacts; people's lives are richer than that.
  - The first challenge for a designer is to clarify what functions and form a device should have to meet the needs, desires, and ongoing satisfaction of its intended consumers.
    - To free focus group members from the confines of society's understanding of the concept of *phone*, the Westaways took a physical approach to addressing a digital problem: They presented each group member with a banana—appropriate, in light of decades of comedic phone call sketches—along with markers, stickers, pompoms, popsicle sticks, and other adornments.
    - The task was for each participant to design an ideal phone and to explain the purpose of each component.
    - The whimsical materials of the exercise knocked down barriers to expression and permitted people to unabashedly lay out their desires.
    - In this 2010 exercise, people variously included buttons for voice control, to find coffee, and to delight her child; notably, one participant drew a country map on her banana, suggesting a desire for GPS-based mapping, although he did not know that just that functionality was available on the phone he carried with him daily.
      - The exercise proved an eye-opener to not only the designers, but to focus group members, as well, some of whom had failed to explore the capabilities of the devices they owned and used.
        - To some, hidden features are Easter eggs waiting to be discovered; to most, however, they are opportunities lost.
      - To meet this need, the Westaways created a box of NFC-enabled instructional cards—a combination of the physical and the digital.

        - One side of each colorful card names a task (*make a call*; *make phone silent*, *calculator*, *check voicemail*, *send a message*), the other side lists the sequence of steps to achieve the goal, and tapping the phone with the card opens the app in question.
    - Of course, even before interacting with a phone's apps, becoming comfortable with a new device entails its unboxing and initial setup, which for some is a hurdle in itself.
        - Some older folks dive into the exploration of a new device with the comfort and eagerness of a young techy, but most are at least somewhat reticent.
        - In the research phase of the design process, Special Projects team members discovered all manner of approaches to learning to use a new device: one person planned to wait weeks for her daughter to visit from overseas before unboxing her new phone; a couple dug into the experience together, providing mutual support; and a club for senior women made exploration of new technology a team effort.
        - To help older people surmount the barrier of getting started with a new phone, Special Projects designed phone packaging that behaved as a book: The new owner would open the cover to reveal the first page and the SIM card; another page turn revealed the phone with an arrow and simple instructions for inserting the SIM. The next page would house the battery, again with unambiguous clarity on how and where to place it in the phone—and so the unboxing would continue, with an arrow pointing toward the power button and so forth, all using the familiar metaphor of a context-specific book.
            - Unfortunately, Samsung never released the unboxing book with any device; it is, however, the first user manual to earn a spot in the New York Museum of Modern Art.
- Making multitasking feel natural on a small screen—Magic UX:
    - App design has risen to the level of professionalism such that most everyday tasks can be tackled within a well-constructed app, yet a chasm exists when coordinating related tasks that live within different apps (e.g., calendar, messaging, and maps when arranging a meetup).
    - Magic UX is a system-level utility that uses the phone's accelerometer to enable the user to pin distinct apps to individual spatial locations.
        - When users move the phone relative their body, the location-designated app appears.
        - In-app content can be dragged to another app/location with ease.
    - Example use cases:
        - Virtual desktop: Link workflow components to a physical space and have the associated apps appear in a stable 3-D configuration creating a location-specific virtual desktop when arriving at that locale (e.g., the office, home, colleague's office).
        - Associated apps: Whenever the user opens one app, several others open simultaneously, each appropriately pinned relative to the orientation of the central app (e.g., when opening WhatsApp, an emoji chooser also opens nearby and to its right).
        - Photo sorting: Organize a library of personal photos by dragging to folders that are jointly defined by category and relative location around the user.
        - Short-term memory aid, such as when deciding among a collection of Airbnb apartments.
    - Future user testing should reveal the cognitive load—if any—that users might experience in remembering the location associated with each app.
- Balancing the digital and the physical—Lego calendar for collaborative planning:
    - Successful projects entail the coordination of team members and tasks; the Special Projects team keeps this coordination real, visible, and fun with their Lego calendar:
        - Three 8'-wide swaths of Lego platform material are stacked on a hallway wall, each divided vertically into columns, one for each day of the month, further atomized into am/pm.
        - Every worker has a dedicated row in each month's array, and each of the company's projects is represented by a different color of Lego square.
        - For those clued in to the code, all they need do is walk along the hallway to know what's up and who will be involved.
    - The digital connection is under the hood of the app that converts a photo of the Lego calendar into assignments on each worker's digital calendar.
    - Changes to Lego calendar become confirmed by taking a photo of the wall; changes initiated within any team member's digital calendar become transferred to the wall by the hand of the next person who photographs the Legos: a digital alert instructs the individual to rearrange the toy squares accordingly.

- Substantial Lego calendar changes are a hassle to implement in physical space, which can be a reminder of the disruption to people's schedules represented by large-scale rearrangement of plastic squares.

Facing Up to the By-Products of Digitization—Ms. Judith Estrin, JLabs

- Estrin unabashedly loves technology, as evidenced by the eight technology firms she has cofounded, the board seats she has occupied (including at Sun, FedEx, Walt Disney, Rockwell, and Medium), and her stint as CTO of Cisco.
  - On this visit to TTI/Vanguard, she comes not to expound on the marvels of digitization, but rather the perils to society of its intemperate implementation.
  - She believes that if technologists fail to become aware of and overtly acknowledge the negative consequences of their collective creation, the positive potential will slip away.
  - It is not technology per se that creates problems, but rather the ways of applying technology; Estrin therefore speaks not of the evils of technology, but of digitization.
- Digitization is as profound and fundamental a societal shift as industrialization.
  - At the enterprise scale, digitization enhances decision making by improving the products a firm offers, the satisfaction of its customers, and the productivity of its employees.
    - The result: increasing profits.
    - Firms are evaluated not only by the growth of their stock, but also by its momentum.
  - Add to this the power to connect through the Internet's various popular platforms, and consumer outreach soars and content distribution accelerates.
    - There is resulting potential for unconstrained growth.
  - As digitization infiltrates content, processes, and behavior, the outlook of the enterprise transforms, with consumers recast as users, employees recast as assets, and convenience recast as a value.
    - Firms that venture down the rabbit hole of digitization without checking signposts along the way build up momentum and soon cannot stop their slippery slide.
  - But, wait! This generalized scenario sounds too good to be true—how could there be a downside?
- Estrin cautions that unbridled frictionlessness presents a danger, perhaps not initially for an individual business in the midst of giddy growth and popularity, but to society and to democracy.
  - Technology is used to alleviate friction from the gears of society to enable industry to grow.
    - Automation, maximizing engagement, users' easy access to content, firms' easy access to users—each of these accelerates the growth of firms in the digital economy.
    - It is not only the business sector that seeks frictionlessness: People want convenience and have little patience for delayed gratification.
  - But without some friction, societies collapse.
    - Rules, norms, moral values, and laws serve as societal guardrails.
    - Cognitive function and impulse control rein in bad behavior on the individual scale.
    - The ability to tolerate boredom, effort, and pain generate empathy for others.
    - Relationships, collaboration, and democracy pave the way for diverse people to form a functioning society.
  - Frictionlessness might seem attractive, but its logical endpoint is freefall, not freedom nor techno-induced utopia.
- Frictionless capitalism—where Morgan Stanley cons own customers out of their money, where VW cheats its customers and co-citizens of planet Earth to promised air quality, and where Facebook moves fast and breaks things without suffering consequences—is not an unalloyed good.
  - When a small number of firms grow unchecked, scale itself becomes a metric of technological and business success.
    - This has consequences: "Technology enables scale, and scale drives tech advantage"; the result is a cycle of scale begetting scale.
    - Replacing the ethos of the open Internet, innovative firms accrue benefit to themselves, not to the ecosystem.
    - The walled garden is again on the upswing as large firms acquire competitors; maybe the goal is to incorporate their innovations, but as likely as not the aim is simply to kill off the smaller player.
  - Tech giants nominally give away services, roping consumers into their fold, only to then mine their data and use/sell it with abandon.
    - "Open source is not the same as open systems."

- Disruptive innovation has given way to narcissistic disruption, in which disruption is done "for the sake of the disruptor, not for the sake of the economy."
  - Such attitudes and behaviors are only possible within the current environment of unconscious intentionality, where the incentives and the ambient lexicon induce an entire cadre of technology leaders to blind themselves to the negative consequences of their activities; beyond this are those suffering from conscious intentionality by seeking out predatory and otherwise pernicious opportunities for themselves or their firms.
    - It might be "better to ask for forgiveness than get permission," but some harms cannot be undone.
    - "It doesn't help to say after the fact, 'Oops, I broke democracy.'"
      - This unhappy outcome is the result of maximizing speed and scale by applying pattern recognition and formulaic algorithms to stratify users into homogeneous environments—echo chambers—where their own opinions become amplified and they lose sight of alternative views (except, perhaps, to mock them).
      - Social polarization might have begun before the rise of social media, but today's technologies amplify it.
  - Although much of the public conversation centers around the problem of loss of data privacy, Estrin is more concerned that digitization, as it has evolved, engenders personal harm: high levels of fear, anxiety, isolation, fear of losing economic or social status, actual loss of dignity, addiction to digital acknowledgement, and so much more.
    - Not everyone suffers, and indeed some people can effectively inoculate themselves from the harms of social media, whether by not engaging at all or not engaging emotionally.
      - It is similarly true, that some people can take opioid painkillers for short-term pain relief and not become addicted; the danger, both with social media and addictive drugs, is that many get sucked in unintentionally and irrevocably.
    - As an individual's cognitive and emotional energy is sapped by the consequences of digitization, less remains for other purposes.
      - Personal agency, critical thinking, and personal authority all flag as people lose trust in themselves and instead permit outside influences to dominate decision making.
      - Young people—digital natives—grow up assigning blind trust to technologies; after all, Amazon and Netflix always have lists of recommendations at the ready, and Facebook suggests people and brands you are sure to "like," whether you know them or not.
    - Societal harms also propagate like wildfire through digital landscapes, with prejudice being amplified by biased—or outright false—data.
    - Combine degraded critical thinking with biased input, and intentional self-control and adherence to sincerely held values lose their footing.
      - "Without intentional control over trust, we slip into acceptance of authoritarianism."
- The characteristics of digitization differ from those of a democratic society that can identify its strengths and weakness, and engage in collaborative critical thinking and problem solving, to develop viable outcomes for a better tomorrow.
  - Yelling louder than the next person makes waves on social media or in the comments section of a web forum, but this is not how problems get solved nor how democracy works.
  - Instead, access to information, a collection of common facts, and the ability to deliberate are crucial precursors to informed discussion.
  - Society is messy—democracy is messy—and to make our way through the mess requires presence of mind, patience, trust, openness, some willingness for risk, and the ability and inclination to question both ourselves and others.
    - Real collaboration entails vulnerability, which is difficult in an age when firms are hypercompetitive, tripping over themselves to outpace one another in the hope of landing on top.
- Although the dire situation Estrin has laid out derives from the technology sector, she also has a reason for hope: "If we pay attention to this stuff, we can start providing technology that doesn't have the same amount of cost."
  - To stem the rising level of rampant digital pollution, Estrin believes it is possible for responsible members of the technology sector to demand incremental change from the industry, even if a wholesale turnaround is impractical to expect.
    - Checks and balances are as important in business as they are in government.
  - Even as such an effort commences, the effects of digital pollution can be stemmed by enforcing existing rules/laws and also empowering people by arming them with information and tools,

        - Regulations rein in the activities of all manner of industries (energy, tobacco, pharma, food); isn't it time that the same level of oversight pertains to the tech sector?
    - Increasing the number of people with tech expertise in the halls of government is a noble long-term aim, but should not be relied on since progress is sure to be slow.
        - "Tech needs to be at the table, but not dominating the table," says Estrin, in a time when many in the top echelons of the tech sector are "more data-ists than humanists."
            - The assumptions and norms that have shaped the technology sector—e.g., frictionlessness—have created the current conundrum; it is time to rethink their implications and to choose to scale down (not up) to improve the potential for collaboration and deep trust.
- Friction, trust, reciprocity, dignity, balance—and, yes, even an element of stasis—deserve a place in the business of technology.
    - Estrin welcomes partners in her effort.

Health and Well-Being in the Workplace—Dr. Casey Lindberg, HKS

- The human body has evolved for movement, yet 90% of Americans spend their workdays indoors, with most as office workers.
    - Since a sedentary lifestyle has been unequivocally linked to poor health outcomes, it should be a public-health priority to design office buildings to maximize the physical movement of employees.
    - Stress presents a similar challenge: Some degree of stress promotes peak performance, but raise it too high and allostatic load will cause a person to reach a breaking point.
    - With a background in both psychology and architecture, Lindberg is uniquely situated to study the impacts of the physical workplace on workers' wellbeing.
        - Considering that physical activity, sleep quality, and stress are intertwined, he evaluates how different office setups—open bench arrangements, cubicles, and private offices—affect wellbeing, taking into account the objective qualities of the interior air, noise, lighting, and viewscape, as well as workers' perceived preferences.
        - Lindberg reports on a study that instrumented workers and office buildings with a variety of workspaces, as well as idealized lab settings for studying human interaction and performance.
- Case study: Lindberg's Wellbuilt for Wellbeing study, conducted in collaboration with the General Services Administration, assessed physiological status and associated it with components of the office environment of the Denver Federal Center, which underwent renovation in 2010, transitioning from a cubicle-heavy environment dominated by artificial lighting to an open bench workspace, where workers were suffused with natural light and views of the exterior landscape while sharing a common environment, except during occasional periods spent in conference rooms or other private spaces.
    - Metrics collected: heart rate variability (via chest strap; high HRV = low stress); indoor environmental quality (via necklace-based sensor as well as static nodes (wallnodes) distributed throughout the office environment); survey apps (questions posed to workers hourly); and static spatial attributes of the building.
    - Noise—Workers in the shared, open space experienced a steady level of background noise, which was lower than the bursts of loud conversation that took place in conference rooms.
        - Vocal interruptions by coworkers are generally perceived as major distractions, but the type of noise, and one's activity when hearing that noise, greatly influence the perceived impact.
            - Workers say they prefer private offices, more for noise exclusion than for visual privacy.
                - With a cubicle arrangement, loud individuals tend to be oblivious to their effect on coworkers because they cannot see the discomfort they cause.
                - Noise types distract differently: instrumental music or sounds of nature or city life might not distract at all, but a vocal soundtrack or chatting in the next cubicle might prove a significant distraction; spoken word in a foreign language might not mentally intrude, whereas it is hard to tune out speech that one understands.
            - Workers engaged in a collaborative act are less distracted by crosstalk among people working together on a distinct task than when working individually.
            - People suffer negative levels of stress when they believe their private conversations might be overheard by coworkers.
    - Air quality—Temperature is an important facet of comfort, but so too are humidity and percentage carbon dioxide.
        - Lindberg defines comfortable temperature ranges by season: summer, 75–81ºF; fall/spring, 70–81ºF; winter, 70–77ºF.

- The generally recommended range for relative humidity is 30–60%; 50% is ideal.
  - Stray too far afield, particularly in combination with a temperature too warm or too cool for comfort, and cognitive performance can flag.
  - Moreover, spending at least half of one's working day in a comfortable relative-humidity environment significantly enhances sleep quality when not on the job.
- Less publicly considered, but certainly impactful, is the concentration of interior CO_2.
  - Entirely distinct from its role as a greenhouse gas, when CO_2 rises, cognition falls.
    - Distinct from the Wellbuilt for Wellbeing study, a within-subjects study revealed that people function at full cognitive capacity in a room with 550 ppm CO_2, perform at only 85% in a 945-ppm CO_2 environment, and can only muster 50% when the CO_2 level hits 1400 ppm.
      - As a real-world benchmark, Lindberg measured CO_2 in the TTI/Vanguard conference room over the course of the morning: 560 ppm at 8 am when the room had yet to fill, 1100 ppm at 11 am, 1330 before breaking for lunch around 12:30 pm, and 600 ppm upon returning from lunch at 2 pm—a decrease in mental acuity before eating might have been due not to hunger but to re-inhaling CO_2.
  - The Wellbuilt study revealed that, when sitting at a desk in front of a computer monitor, exhalations hang stagnantly in the air ready to be gulped back in.
    - Fortunately, a small, simple, USB-powered desk fan can clear the air—and the office worker' head—by bursting the bubble of the CO_2 plume, thereby decreasing ambient CO_2 by 300 ppm.
  - Conference rooms were seen to have particularly high CO_2 levels, suggesting the need to improve ventilation—or, better yet, open a window if weather permits.
- Physical activity—The more shared the office type, the more workers engaged in physical activity: Open bench workers moved 32% more, on average, than private-office workers, and 20% more than cubicle dwellers.
  - That is, office workstation type was seen to have a net influence on physical activity at the office, which in turn influences physiological stress response outside the office environment.
- Visuals—After renovation, with natural light and an exposure to outdoor views, workers enjoyed lower stress levels at work and, again, carried over those gains at home.
  - Windows, and the views they offer, are generally positive design elements, but at times of day the sun shines too brightly for comfort.
    - Blinds provide workers with a satisfying sense of agency when glare intrudes, although they also benefit from a reminder to reopen blinds when the situation abates.
- In real-time, self-reported app-based surveys, workers report a nearly equivalent ability to remain focused and on task, regardless of workstation type (despite one-time survey responses in which workers anticipated better performance with a private office).

- HKS is building dedicated facilities to study how differing characteristics of the built environment influence people's interactions.
  - The Sensory Wellbeing Hub is a physical space designed to encourage focus and calm in people with autism spectrum disorder.
  - HKS's own offices—one in Chicago, one in London—are "living labs" with a culture of testing and innovation.
    - For instance, a heatmap of room occupancy indicated ongoing lack of activity in a room that was intended to be bustling; the ethos of iteration and tinkering led to redesign and improved usage.
  - The buildings' dashboards also continually report building status, including ventilation and infiltration rates, permitting optimization of air quality.
  - That is, instead of the conventional, linear process of architectural design—in which funds are allocated, a design is crafted, construction ensues, and the building is occupied—HKS adopts a dynamic-design approach with an eye toward continual improvement, both of the building and of the design process itself.
- IARPA is commencing the Multimodal Objective Sensing to Assess Individuals with Context (MOSAIC) program to further the understanding of human–workplace interaction.

The Future of Spacecraft and the Commercialization of Space—Mr. Jim Cantrell, Vector Space Systems

- During the 20th century, only nation states had access to outer space; private entities need not apply.

- The 1999 specification of CubeSats began to change that equation with small, lightweight satellites that could piggyback on the launch of a more substantial satellite.
- Shortly thereafter, with Cantrell as employee number three, SpaceX (and its billionaire-backed competitors) further transformed the landscape by moving the space race into the private sector.
- From the get-go, Elon Musk had his sights set on Mars, but Cantrell's entrepreneurial journey since leaving SpaceX within a year of its founding has led him on a different path—still a path upward, just not as far.
- Venture Space Systems is in the business of building the infrastructure to push the space economy toward its trillion-dollar potential over the coming two decades: "An Uber-like capability will come to space, but we need to build an infrastructure for it first."
  - Cantrell's goal: to build the logical equivalent of the elevator, which transformed Manhattan from a two-dimensional city into one that, uniquely for its time, reached skyward.
    - "Launch systems are the future's elevators."
- Cantrell describes the economic potential of large-scale microlaunch capability and how Vector is realizing it by building the Model T of rockets.

- Traditional satellites are behemoths—whether considered in terms of launch mass (1650 kg, on average), cost (over $100M), or development time (four years)—and therefore require considerable resources, planning, and dedicated infrastructure; in contrast, microsatellites are nimble, weighing orders-of-magnitude less in terms of mass—and cost—and requiring mere months of lead time.
  - Hundreds of microsatellites go up annually, with more waiting impatiently for a launch slot.
  - To meet this need, Cantrell's assembly line model intends to build a large volume of small launch vehicles that can escape into low-Earth orbit from anywhere, towed into place on mobile launch vehicles.
    - He anticipates that his business model should become cost-competitive with roughly 100 units, with a long-term goal of launching 100–1000 flights annually.
      - Vector's two rocket models:
        - the lower capacity Vector-R can accommodate 65-kg payloads ($1.5M/flight);
        - the larger Vector-H can accommodate 300 kgs ($4.5M/flight);
        - the two share design interchangeability (~ 250 parts per rocket), lowering the development cost of the modular-construction, two-stage rocket.
      - Each mobile launcher should accommodate two-to-three launches per day.
    - With suborbital testing now underway, Cantrell plans to launch orbital test flights this year, culminating a lightning-fast development phase: 2.5 years from company formation to first orbit.
- Note that, as a launch modality, Vector should be complementary to SpaceX, which addresses the annual need for 10–20 heavy-payload launches at $60M–120M each.
  - Although dozens of other firms are coalescing around the same goals as Vector, Cantrell's firm enjoys both a head start and substantial backing (roughly $100M), which positions it well, albeit with substantial pressure for commercial success.
- The relatively low price point per launch proves a game changer, not only bringing satellite capability into the realm of possibility for all manner of enterprises, but also upending the existing spacecraft insurance model, which itself has been a barrier to entry for commercial space endeavors.
  - In addition to any financial loss being only moderate for potential Vector-scale launch failures, the risk associated with collisions due to air traffic congestion is also downsized; smaller rockets require a commensurately smaller excluded air space for takeoff.
    - To further lower risk of air-based collisions, Cantrell is also pursuing the attractive alternative of launching offshore, where air lanes can be easily avoided.
    - He intends to fly back and recover—if not reuse—rockets' first stage to avoid contributing to what would otherwise eventually amount to nonincidental debris descending into the oceans.
  - A related risk factor is the growing volume of space debris, which Cantrell believes to be both a real concern and overhyped.
    - The greater the number of objects in orbit, the greater the chance for unwanted collisions aloft, but gravity naturally degrades the orbit of low-altitude satellites, which burn up upon reentry and are thus removed from the collision equation.
      - Vector will thrust its payloads into this altitude regime, not into the higher geosynchronous orbits that are popular with expensive satellites, further moderating risk and liability.
      - Space insurance is largely based on a no-fault model.

Using Satellites to Better Mine the Earth—Mr. Jeremiah Pate, LunaSonde

- A significant fraction of satellites orbiting Earth look down upon its surface for imaging purposes; LunaSonde instead peers beneath to image subsurface water, oil and gas, minerals, and natural or humanmade cavities.
  - Historically, gravity signatures have been the go-to method for detecting subsurface material distinctions, but despite billions of dollars devoted annually to exploration, resolution has not improved from the current norm of over 50 m, largely reducing mining to unproductive guesswork.
  - Pate is using machine learning and satellite-based imaging to reimagine the potential of the very-low-frequency (VLF) spectrum (3–30 kHz), which penetrates hundreds of meters through seawater and kilometers through solid ground.
    - Of course, such frequencies correspond to wavelengths of dozens of kilometers, which would seem pointless as an imaging platform.
    - The key is the deployment of an array of VLF antennas aloft; with triangulation, meter-scale resolution becomes possible.
    - Machine learning enters the mix when training the array on known subterranean features, making it subsequently possible to identify comparable features in newly imaged regions with considerable confidence.
  - Pate describes the technology and business of LunaSonde.
    - Incidentally, he is currently a freshman at Arizona State University.
      - His youth did not figure into his presentation to TTI/Vanguard nor into the discussion surrounding his enterprise; the professionalism of his comportment and apparent depth of knowledge in his chosen domain dominated instead.
- Although the theoretical potential of VLF in the mining industry was recognized well over 50 years ago, practical considerations have kept it from taking hold.
  - Terrestrial VLF antennas require acres of land and megawatts of power—obviously impractical as the basis of a satellite installation.
  - But Pate is unwilling to be tied down by VLF's wavelength constraints.
  - His innovation is to create a sparse-aperture array of low-power coordinator resonators; each element measures a few cubic inches, with the collection of dozens of picosatellites—connected by optical fiber microfilaments—expanding into the so-called Gossamer satellite after reaching orbit.
- It is one thing to have an idea; it is another to engineer it into existence.
  - The first hurdle was to improve the kilohertz-range resonator's efficiency by three orders of magnitude; the LunaSonde team achieved the necessary metallurgical advances.
  - Next was the recognition that only from space could an array of resonators achieve the desired spatial imaging resolution: VLF wavelengths dictate that the antenna array would need to be at least 20 km aloft; resonator performance dictates the need for a cryogenic environment—fortuitously, space is cold.
  - "Space isn't the best solution for this picosatellite technology; space is the *only* solution for this technology."
    - Pate has scheduled the launch of an initial prototype with 36 6U picosatellites for late 2019, with the full deployment of an array of 60–100 12U picosatellites in early 2021 and an eventual goal of global coverage with a constellation of ten satellite clusters by 2025.
- LunaSonde will store the collected data in its internal database to create a library of radar features to train its AI and serve as a basis for the resource discovery service it intends to introduce commercially.
  - That is, the company's "on-orbit infrastructure" is a means to an end: subterranean resource identification.
  - The 36-CubeSat prototype will visualize subsurface aquifers in sub-Saharan Africa, with some of the collected data serving as a training set for subsequent discovery of other instances of this crucial resource.
    - Pate is conferring with a dozen water development companies and will charge for voxel-scale data on the basis of gigabytes delivered.
    - Success with the initial mapping efforts should make possible the long-term goal of predictive analytics to inform governments and regions of impending water scarcity, as well as the location of newly discovered resources.
    - Although initially lower precision, voxels will eventually achieve 10x10x10-m resolution.
- Pate likens his exercise to "taking an MRI of planet Earth" and wishes to become the "Google Earth of underground resources of many types."

- Not naïve regarding the potential to exploit the natural resources that LunaSonde's technology promises to digitally unearth, Pate is in discussion with governments and NGOs to assure the responsible use of the firm's data.
- Moreover, Pate has taken a long-term view of the business he leads.
  - Having recently turned away an offer of venture funding, he believes it is important for the people who conceptualize a technology to maintain control over guiding its direction.
  - As the "idea person" and CEO of LunaSonde, Pate cleaves to much of this control, but also recognizes the value of each member of his team, notably his experienced CTO Don Doerres.

Thinking about 6G—Dr. Dipankar Raychaudhuri, Rutgers University

- Every decade or so, a new generation of wireless supplants its predecessor, bringing with it support for new apps: First-gen wireless enabled analog mobile telephony, 2G technologies introduced digital voice and introduced texting, 3G supported the mobile web, 4G brought IP telephony and all manner of video to the mobile platform, and 5G promises the ubiquity, gigabit-per-second speeds, and true-millisecond latencies needed to support mobile augmented/virtual reality, the mutual awareness of connected vehicles, and the Internet of Things.
  - Even as the specifications for 5G wireless continue to be hashed out and finalized, work is commencing on the goals for the follow-on generation and the technologies that will enable them.
  - The extent to which 5G delivers on its promise remains to be seen, but the capabilities of 6G a decade out will minimally satisfy the requirements of applications desired today.
  - To kickstart 6G, the National Science Foundation has launched the Platforms for Advanced Wireless Research (PAWR) program, a public–private initiative that aims to develop flexible, city-scalable R&D testbeds.
    - In its initial stage, PAWR has designated $20M to each of two testbeds: POWDER-RENEW, run by the University of Utah and Rice University, and COSMOS, run by Rutgers, Columbia, and NYU.
  - Raychaudhuri discusses the New York City-based testbed with the somewhat tortured name-to-acronym association—Cloud-Enhanced Open Software Mobile-Wireless Testbed for City-Scale Deployment (COSMOS)—which intends to transform Columbia University and the surrounding West Harlem neighborhood into a hub for technology innovation as it deploys a multilayered blend of software-defined radios, software-defined networking, optical networking, and edge computing, with deployment extending its tendrils throughout the buildings, streets, and vehicles of the bustling metropolis.
    - "With $20M, you cannot build out a whole city, but we are trying to build something that can approximate the experience in an urban area and try to gain experience about the various technologies that will be available as we go beyond 5G."
    - COSMOS will provide a vibrant platform for 6G research and development and a valuable new resource for those who live and work within the boundaries of its deployment.
    - A core goal of COSMOS is to transform network innovation from a top-down, walled-garden, enterprise-driven process to one in which solutions bubble up from open, city-scale experimentation.
- Today's mobile technology primarily connects smartphones to the services of the broader Internet and thereby to one another; 6G will connect among all manner of enabled digital devices and will rely significantly on edge computing to deliver real-time services.
  - 5G is edging down the latency scale toward 10 ms (from 4G's 60 ms) and up the bandwidth scale toward 500 Mb/s (from peak 4G in the USA of 50 Mb/s); not only should 6G surpass these 5G metrics by a factor of two, but is also expected to simultaneously deliver fast compute (10–100 GIPS) through the power of tightly coupled edge computing.
    - The combination of these capabilities will prove game-changing once deployed widely and will give NYC an early leg up as experimental projects roll out throughout the coming decade.
  - "Everyone agrees that the future mobile network is going to have to migrate from today's smartphones to many other things—IoT and, beyond that, sensing and a little bit of actuation. We can move to a world with a very tight loop between human beings and the environment around them."
  - 6G will be a significant step along the path to a future in which computing permeates the environment without calling explicit attention to itself by, as has been the long-standing practice, summoning each end user to a screen for every interaction.

        - "The paradigm shift is going from communications to computing that is integrated with your daily life. Maybe there won't be visible devices in the future, and we need to enable that through architectural change and fundamental technology change."
- Building on Rutgers' earlier network—Open-Access Research Testbed for Next Generation Wireless Networks (ORBIT is the purported acronym)—COSMOS is an open and fully programmable platform intended to ease the path for researchers experimenting at each layer, from COSMOS's radio hardware and front-haul network resources to the radio cloud (encompassing the compute and front-haul network) to the general-purpose cloud consisting of compute and a back-haul network, all of which rides atop the end-user device layer.
    - Software-defined radios and networks make the testbed unreservedly flexible; researchers need only load a new code configuration to experiment with the architecture or applications, rather than having to make structural alterations to the testbed.
    - Still, the physical components of the testbed matter; these include computational elements (core computing at NYU, local control and computing at Columbia, and the network operations center at Rutgers with host servers for network control, user portal, and experiment management.
        - Connecting these and the backhaul network is dark fiber with optical WDM switches; small (personal-scale), medium (pole-mounted), and large (building-top, sector-scale) radio nodes complete the upper layers of the testbed.
            - The software-defined radios are designed to accommodate gigabit-per-second data rates with frequencies within the 400MHz–6 GHz range and the 28 and 60 GHz bands.
            - Radio nodes and the edge cloud share signal-processing responsibilities, and the rich resources and experience of the open-source software-defined radio community make the code base robust from the get-go.
            - Similarly, the Linux Foundation's Open Source Operating System will serve as the underpinning standard for the software-defined networking work.
            - "The open platform allows people to download their code and run different kinds of experiments on it."
        - Not only will researchers at the host universities have access to the testbed, but external access will be available to authorized-and-authenticated users through a gateway at an AT&T building at 32 Avenue of the Americas.
- A four-site pilot has already been deployed, seven more sites will come online before the end of the calendar year, and a phased deployment will continue until most of West Harlem has been served.
    - The local community is being primed to not only accept, but embrace, the experimental deployment.
        - Network-level experimental research is being cordoned off from applications that will directly benefit members of the local community in the short run.
        - Members of the thriving NYC tech community are engaging through public events, university partnerships, local-government initiatives, and a collaboration between COSMOS and social venture Silicon Harlem.
        - Educational outreach extends to all levels of student—graduate, undergraduate, and K–12—plus COSMOS is providing community members with courseware, tutorials, and suchlike.
            - For example, neighborhood teachers have access to lessons/experiments and are being trained to engage students through COSMOS-based experiments (e.g., an experiment package to learn about static routing).
        - Community members are clamoring for faster Wi-Fi, but they are also opening their eyes to wider reaching aspects of wireless's potential.
- Initial experiments to be run on the COSMOS testbed:
    - Smart intersection at 120th Street and Amsterdam Avenue, with sensors (360º cameras, LIDAR) for object detection and 3-D object localization.
        - Edge-computing capabilities (e.g., image analytics) would be made available to mobile nodes (pedestrians and vehicles of various sorts) passing through the intersection.
            - Testbed experiments include full-duplex radio, MIMO, dynamic spectrum access, mobile core network, and AR/VR, in addition to applications dedicated to autonomous vehicles.
    - Dynamic spectrum access, deployed as a large number of access points without tight coordination in a dense urban environment.
        - Multiple simultaneous wireless technologies would share spectrum, with experiments to evaluate both distributed and centralized protocols and algorithms.
    - 5G mobile core network, developed as a clean-slate, flat-architecture deployment with the goal of plugging in any device with seamless functionality.

    - The purpose is to evaluate the success/challenges of 5G architecture under the stresses of real-world use.
  - Edge cloud evaluation for city-scale applications that require the touted combination of low latency, high throughput, and edge computation; example: Google Glass, which relies on edge cloud analysis of real-time imagery when resource use is high.
  - Cloud-assisted autonomous vehicles, in which the view experienced by one vehicle is augmented by the coordinated integration of point cloud imagery collected from another vehicle and processed in the cloud.

Converting Carbon Dioxide to Solar Fuels: Opportunities and Challenges—Mr. Xiangkun (Elvis) Cao, Cornell University

- Despite fluctuations in weather, the global climate is unequivocally heating up, with carbon dioxide as a principal greenhouse gas that must be reined via a multipronged approach to avoid a climate catastrophe; indeed, atmospheric CO_2 concentration is currently at an 800K-year high (405 ppm), even as billions of tons of the gas pour into the atmosphere annually—and as the United States withdraws from the Paris climate agreement.
  - Still, modern-day life depends on easy access to electricity, not only for people living in the developed world, but also for the billions who aspire to the opportunities that intrinsically rely on what we take for granted, such as light, heat, refrigeration, and telecommunications.
    - While some might argue that politics is the biggest problem facing those intent on jointly alleviating the impending threat and providing technological resources to the world's population, Cao agrees with Bill Gates, that technology itself can provide the bulk of the solution by devising low-cost, low-impact sources of electricity and fuel.
  - Meanwhile, the rest of the world, and researchers within the United States, are taking aim at CO_2.
    - One thrust is to cut down anthropogenic CO_2 production; another is to sequester atmospheric carbon—both are necessary.
    - Cao is developing a means to use the inexhaustible resource of sunlight to productively convert sequestered CO_2 into valuable, energy-dense liquid alcohol fuels (methanol and ethanol).
      - That is, Cao is engineering a business case for doing what is right for the planet.
      - He is again on the same page as Gates, who has identified large-scale carbon sequestration—1T tons of CO_2 this century, as per the IPCC—as a top-ten challenge for our age.
      - "This is a critical challenge and, as engineers, our collective obligation to future generations is to do something about this."
  - Having laid out the need, Cao shares the specifics of his photo-thermo catalytic approach to converting direct-from-air-captured CO_2 into fuel.
- While some firms are forming around alternative monetization strategies for captured CO_2—such as selling the gas to soft drink manufacturers or to industrial plants to feed into existing processes, or converting it into synfuels through electrocatalysis, Cao has his sights on alcohols, which are orders-of-magnitude more energy dense than Li-ion batteries or compressed hydrogen, without the toxicity of the former or leakage potential of the latter.
- Photo-thermo catalysis takes advantage a range of electromagnetic frequencies: ultraviolet/visible to excite catalysts' electrons for reactivity, and lower energy photons (infrared) to induce the heat necessary to accelerate reactions at the surface of the reactor's photocatalytic nanoparticles.
  - A concentrator accepts incoming sunlight into a shell-and-tube reactor that is infused with captured CO_2.
  - Optimizing photonic availability, glass rod waveguides coated with catalyst material direct the incoming light directly to reactive surface.
  - The result: fast reaction rates and high conversion efficiency.
- Until recently, the planet was self-regulating when it came to carbon, but industrialization has set the carbon cycle out of whack, photosynthesis falls short of converting the overabundance of CO_2 modern society emits.
  - When scaled up for production, Cao's so-called HI-Light reactor should augment nature by serving as an artificial photosynthetic factory, converting CO_2 into a "solar fuel."
    - Just as natural photosynthesis converts CO_2 and light into an energetically useful output, the HI-Light reactor performs similarly, albeit with an inorganic catalyst at its core.
    - "We belong to the carbon cycle."

- To date, however, the HI-Light reactor is a research project that relies on an LED lighting source and has demonstrated success for two reactions: the reverse water–gas shift reaction and CO_2 hydrogenation (both begin with CO_2 and hydrogen; the first generating CO and the second, methanol, as desirable products).
- Near-term goals include:
  - catalytic optimization for other reactions, variously dry reforming undesirable gases into synfuels, while also sequestering CO_2. Examples:
    - ethane, when sourced as an underutilized component of shale gas (products: CO and H_2);
    - greenhouse gas methane (products: CO and H_2);
    - nitrogen oxides (producing NH_3 for fertilizers), neutralizing the need for the Haber-Bosch reaction, which is responsible for 2% of global CO_2 emissions when generating H_2 from methane, itself a potent petrochemical greenhouse gas;
  - scale up from the initial 0.1-L and 1.0-L setups to 20–30-L reactors and beyond;
  - and fluidization of the catalyst for even greater reactant–catalyst contact.
- This research effort has partnered with commercial partner Dimensional Energy, which is building an industrial-scale operational pilot plant as a finalist in the $20M NRG Cosia Carbon X-Prize competition.

- Cao's preferred source of CO_2—direct-from-air sequestration—is only one of several possible methods, but it holds particular promise for removing the deleterious greenhouse gas from the atmosphere.
  - Scaled-up installation of reactors would require only a minimal physical footprint and reliance on freshwater, compared to large-scale forestation, bioenergy in combination with carbon capture and storage, or geoengineering in the form of enhanced weathering; the cost of direct-from-air sequestration is competitive with these alternatives, with no anticipated negative impact on the environment.
  - Significant progress is afoot to make such sequestration economically viable; Harvard's David Keith anticipates the cost of direct-air capture to fall to below $100/ton CO_2.
  - Taken together, direct-air capture is the most benign of approaches, whether from ambient air or at sources of large-scale CO_2 production (i.e., industrial flues).
- Arresting global warming will only happen through a broad set of initiatives, of which Cao's is one promising component.
  - Twenty high-profile investors (including Bill Gates, Jeff Bezos, and Jack Ma) have formed the $1B investment fund Breakthrough Energy Ventures, which is dedicated to funding cleantech companies with the lofty goal of "provid[ing] everyone in the world with access to reliable, affordable power, food, goods, transportation, and services without contributing to greenhouse gas emissions."

Redesigning City Streets and Mass Transit with AVs in Mind—and Vice Versa—Mr. Peter Calthorpe, Calthorpe Associates

- Global society is in the midst of three undeniable trends: climate change, population growth, and migration from rural regions to increasingly large cities.
  - Good management of urban form has the potential to mitigate the joint challenges these trends suggest; vice versa for poor management.
    - "Urban form defines our lifestyle."
  - Without focused planning, sprawl will only continue to overtake the landscape—whether the high-income, low-density sprawl of U.S. suburbia, the low-income sprawl of the global south (e.g., Mexico City, Delhi, Karachi, where the poor suffer severe inequities and are locked out of center-city opportunities), or the high-density sprawl that is infesting China.
  - But, well-planned, urban form can create mixed-use, mixed-income neighborhoods; encourage walking, cycling, mass transit, and auto-free streets; and preserve what is desirable, including natural ecologies, agrarian landscapes, established neighborhoods, and cultural heritage sites.
  - "We are going to double the quantity of urban fabric in the next 30 years. We're going to build cities for another 3B people, and we won't get that right if we continue to build in forms that damage the environment and overtax our resource consumption, make us unhealthy, and isolate the poor in ways that make them less productive."
  - Calthorpe, who sees the fact of impending urban growth as an opportunity, lays out a path for the future of cities that will combat climate change and "yield vibrant, healthier societies"; he also introduces the Urban Footprint tool for scenario planning, smart growth, and redevelopment analysis.

- The tragedy of American development is the lack of robust mass transit—a network that would lessen the car culture.
  - Urban design should center around transit corridors that create connections among places people wish to go—importantly within each city, but also between them.
  - Autonomous cars will change cities, but not in a good way, encouraging more miles driven, whether privately or fleet owned, and whether designed for single or shared occupancy.
  - In contrast, an increase in human-guided or autonomous mass transit will decrease road congestion and encourage walking and biking in newly safer streetscapes.
  - Residents of Los Angeles—that most car-centric of cities—passed a $120B sales tax initiative with revenues devoted to expanding rail, bus, and bike infrastructure, but not new roads.
    - The elimination of curb parking frees up lanes for alternative uses.
    - In protected lanes, buses/trains move along the roadways more quickly than neighboring cars.
      - "People will still have cars, but will use them for fewer trips."
  - The Bay Area is plagued not only by congested streets, but also by a housing crisis: the region has gained 437K new jobs, but only 137K new housing units, over the past decade.
    - The poor suffer most as they are pushed out of neighborhoods by gentrification.
    - The need is for denser housing close to jobs.
    - Calthorpe suggests significant redevelopment (notably of existing open parking lots) and transit conversion for the El Camino Real corridor, which stretches from the heart of Silicon Valley to Daly City, north of SFO.
      - He imagines the addition of 250K housing units, with associated commercial redevelopment to bring jobs and services close to where people live.
        - The plan would also support wide sidewalks, separated bike lanes, and autonomous buses/pods to limit car traffic and make commutes safer and more pleasant.
        - Low-cost, fast-moving, autonomous rapid transit (ART) would be game-changing.
          - Minimal at-grade improvements would be required to implement ART.
      - Calthorpe's scenario initially would pertain to the 43 linear miles of El Camino Real, but could be extended to encompass fully a 534 linear-mile network throughout the Bay Area.
- To facilitate urban planners seeking to improve the livability of their communities, Calthorpe has rolled out the comprehensive Urban Footprint planning tool.
  - With a tagline of "location intelligence software for smart cities," Urban Footprint provides a platform to empower designers and planning professionals as they explore location-specific data, build scenarios, run multimetric analyses, and build consensus around redevelopment plans.
    - Impacts to balance include land consumption, energy use, transportation, water use, conservation, household costs, walk accessibility, emissions, transit accessibility, and risk/resiliency.
      - Whole-system urban planning can simultaneously optimize across these domains.
- China's flavor of sprawl has resulted from cities exploding in size and scope over a short period, leading to dense sprawl instigated by the perceived need to build quickly with little foresight regarding livability.
  - Their national perspective is now changing, with human-focused, transit-oriented development taking hold, and open space and car-free streets receiving priority.
- Calthorpe does not pretend achieving a carbon emissions goals will be easy, but he does deem it doable.
  - To avoid climate catastrophe, per capita emission of CO_2 equivalents must fall to roughly 3 metric tons per year for those in the global upper income ranks (which includes essentially corners of the United States), whereas the level now sits at 18 metric tons.
  - An impossible task, one might think, but wealthy nations like Sweden are currently at 4.8 metric tons.
    - The difference, despite Sweden's months-long deep chill and darkness, is that its people walk, bike, and take transit, while living and working in energy-efficient buildings in well-planned cities.
      - "How do you get from 5 to 3.5 [metric tons]? It's not rocket science."
    - At the policy level, California is taking climate change seriously, as evidenced by its per capita emission that is roughly half of the national average.
      - Yes, it has been aided by a favorable climate and a relatively low level of industrial buildout, but smart-growth initiatives, vehicle efficiency regulations, energy-efficient building codes, and renewable power have all contributed significantly.
      - "Smart growth is the single largest step in terms of reducing carbon emissions in the state of California; we have a law around it called the Sustainable Communities strategy," which

optimizes on concentrating people in affordable live–work neighborhoods to reduce long daily commutes.
    - To achieve the necessary progress, Calthorpe believes the state of California must introduce umbrella regulations to supersede lesser policies at the local level.
        - Infrastructure is necessary, he believes, but the "right kind of infrastructure": not more freeways, but more transit—and autonomous transit.
        - Regarding intercity and interstate transportation, "High-speed rail is a must, and it is absurd that we don't have it."
            - The per-trip cost of building a high-speed rail infrastructure trumps that of building out the highway infrastructure.
    - The key to progress is multistakeholder buy-in, which is achievable when making the effort to "connect the dots" across special interests and helping all involved recognize that urban form is not a zero-sum game, but all can benefit by pulling together for a livable future.
        - Travel, land use, infrastructure, building performance—all interact in urban form.
- "Politicians don't want to talk about climate change because they don't want to talk about people changing the way they live, but the reality is that it doesn't take that much to get to [favorable] numbers."
    - "What is an affordable lifestyle is also a healthy lifestyle. They coincide; that's the good news."
- The principles of smart planning—preservation, mixed use, connection among street-level urban resources (including green space), walking, cycling, transit, and focused high-density corridors—are not only easily enumerated, but, in fact, not as hard to implement as one might imagine.
    - One German TTI/Vanguard participant views this whole discussion with incredulity, noting that Calthorpe's ideal simply "looks like home."
        - His firm pays for his bike, which he uses year-round, or alternatively he uses his city's fine mass transit; he has a car, but only uses it on weekends to visit the countryside or other cities.

Building Buildings with Reusability in Mind—Dr. George Berghorn, Michigan State University

- When traveling for pleasure, a common pastime is to visit venerable structures—a medieval church, a Mayan temple, a 2000-year-old dam—but as a young country, and one enamored of change, the United States is particularly bereft of such edifices.
    - "In the United States, we don't build for longevity."
    - The median age of the 77M owner-occupied homes in the United States is 37 years, which is in the same ballpark as the age of the nation's 50M vacant structures.
        - Contrast this with Berghorn's ancestral family's home in Italy: 350 years old, and, by local standards, fairly new.
    - Over these four decades, the mean square footage of homes has nearly doubled from 1500 to 2700.
    - What happens when changing consumer preferences, de-urbanization, or disaster (e.g., natural, military) renders a home—or an entire neighborhood—no longer desirable? Demolition, with no attempt to recover components for reuse, is the easiest and least expensive option; it is also the most wasteful.
    - Home abandonment has hit Michigan particularly hard; Detroit alone has lost two-thirds of its population since its 1950s heyday.
        - Of the nation's vacant structures, more than 10% (5.8M) are considered abandoned and slated for demolition; of these, 1.4M are in the Midwest and nearly a quarter-million are in the state of Michigan.
            - Urban centers are most afflicted, but no county in the state escapes the scourge.
            - Initially, abandoned properties are a source of blight; in the long run, they are a source of unwanted landfill (the volume of lumber disposed annually exceeds that harvested from all national forests)—but might unwanted housing stock instead become an opportunity?
    - The local need has spurred Berghorn to develop an alternative to the demolition of abandoned buildings; as such he has coined the term *domicology* to highlight the potential for a circular approach to construction that takes into account the entire lifecycle of a structure, from erection to deconstruction, with an eye toward reuse of materials and components.
        - Domicology is more than blight elimination, it is more than a means to address a public policy challenge, it is more than deconstruction, and it is more than an alternative to conventional engineering/architecture—it is, rather, the combination of all of these.

- The cost of reactive domicology—deconstructing conventionally built homes—is high, with appreciable effort devoted to the tedious task of removing nails from lumber; Berghorn's principal focus is instead on proactive domicology, where thought is put into eventual disassembly during a building's planning phase.
  - A range of design principles contribute to the goals of domicology: prefab/preassembly/modularity, simple/standardized connections, simple/separate building systems, minimization of components and materials, effective yet easily removed fasteners/fittings/sealants, reusable materials, flexible/adaptable/simple building design, and worker safety considerations (both during construction and deconstruction).
    - Each of these principles requires consideration and buy-in from a range from stakeholders in the building process: the owner, architects, engineers, general contractor, subcontractors/artisans, fabricators/manufacturers, and suppliers.
    - Berghorn considers a hybrid approach to building as the most effective solution, incorporating a mix of stick-built, panelized, and modular components to maximize eventual deconstruction but also provide for an affordable and appealing home.
  - To illustrate the potential of the domicological approach, Berghorn focuses on the pervasive high-volume, low-value material of the home construction field: lumber.
    - Lumber, if fully recovered from all the currently abandoned homes in Michigan, would amount to more than 1B board feet of wood—1.6M trees saved.
      - "Is anyone here a woodworker? We'd need a few friends, but we could make 219M end tables!"
      - Alternatively, this number of board feet could be repurposed as 644 18-story Brock Commons apartment buildings, a panelized-construction project that maximizes the potential of cross-laminated reclaimed wood.
        - Cross-laminated timber and glued laminated timber (glulam) have expected lifetimes of 85 years or longer, if well maintained, extending the life of virgin timber.
        - Delignified, thermal-and-pressure-treated wood would similarly provide a viable, strong and lightweight timber-sourced building material.
      - Low-quality deconstruction wood products can enjoy a second life as sound walls, chipped - wood pressboard, biomass fuels, etc.
- Tony Shaw raises the concern that the last thing excited new homeowners wish to consider is the end game for the project into which they are pouring their hearts, souls, and life savings, but Berghorn believes the concept of recycling/reuse has pervaded the public consciousness sufficiently to enable engagement with the new structural paradigm of domicology.
  - After all, 85% of North American steel is recycled/repurposed, but only about 5% of dimensional lumber sees a second life; its time has come.
  - Reclamation of one home's worth of lumber relieves global warming by more than 6 metric tons of CO_2-equivalents, akin to taking one car off the road; every bit helps.
- But the process of deconstruction is slow and therefore expensive.
  - Two homes of similar size in Lansing, Michigan, both met their ends: one was demolished in 40 worker hours; the other was deconstructed in 260 worker hours, with insufficient payback from resale of salvaged lumber to make the process economically viable.
  - Moreover, any stud used in construction must be certified, but no current standards exist for certifying reclaimed lumber, making reuse a nonstarter without regulatory reform.
  - Rustic wood has a high—but highly inconsistent—aesthetic value; retail prices for reclaimed barn wood vary widely, making salvage estimations difficult.
- As with so many things these days, large-scale image capture and machine learning have the potential to standardize the economics of deconstruction, especially during the transition period until domicological standards underpin commonplace building practices.
  - Microsoft has unveiled a national map of all U.S. buildings, with one-foot-per-pixel resolution; combine this with data from tax records and continual input from deconstruction activities to improve the on-the-ground assessment of building resources.
    - Berghorn proposes using the resultant database to train a model to associate likely interior features of buildings based on the array of their external features, thereby establishing a semantically rooted, geographical record of high-value components that might be salvaged when a building reaches the end of its useful life.
  - Once a house has been identified for deconstruction, as components (boards) are removed, they could theoretically undergo scanning to assess them for nails, visually grade them (e.g., according to

wood type and structural integrity), measure their dimensions, identify damage or surface contaminants, and so forth.
  - Berghorn has performed MRI scans of lumber to successfully assess for these characteristics, but concedes that there is no economic basis for doing so routinely.
  - Still some degree of scanning—if only visual—would precede sorting, processing, and shipping lumber to its next stage of constructive life.

Diamonds Are a Satellite's Best Friend—Ms. Jeanette Quinlan, Akash Systems

- Long gone is the time when satellites were solely conceptual wonders; today they are workhorses on which the planet's earthbound population relies for tracking the weather, the status of crops, the activities of adversaries, or a myriad of other purposes.
  - For a satellite to be useful, it must communicate the data it collects; doing so relies on a radiofrequency power amplifier, with gallium nitride-based high-electron-mobility transistor (GaN HEMT) devices leading the way.
  - These are plagued, however, by high heat production, limiting how dense their transistors can be without an efficient way to offload that heat.
    - True, space is mighty cold, but it has no air or other medium to carry away the heat.
  - To pave the way for universal—well, global—high-speed Internet access, Akash Systems is proposing to integrate a heat sink into GaN amplifiers by directly growing diamond, the most thermally conductive material (1600 W/mK), on GaN HEMTs via carbon vapor deposition.
  - Quinlan describes the need, the potential, the technology, and the business case behind this early-stage, venture capital-based, Silicon Valley startup.
- Today satellite communications fall short of the promise of ubiquitous connectivity, because RF power amplifiers render satellites too expensive and too large (if they have a bulky heating system), or their comms are too slow (if they sacrifice power because of heat).
  - We experience this on airplanes, forking over $30 to Gogo inflight service for paltry kilobit-per-second connectivity; Planet Labs suffers when only able to offload 2 GB of imagery daily.
- Akash's founder and CEO, Felix Ejeckam, devised a fabrication strategy to bind a polycrystalline diamond layer to a GaN HEMT wafer, thereby providing an integrated heat sink to dramatically lower the temperature of an operational amplifier and triple the power density, compared to conventional GaN-on-silicon carbide technology.
  - Akash's five-step process:
    - begin with conventional GaN-on-Si;
    - to it, wafer-bond a temporary carrier;
    - etch away the silicon;
    - in its place, vapor-deposit a layer of polycrystalline diamond, bonded with a thermally transparent, 10-nm, SiN interface at the GaN surface;
    - remove the temporary carrier, and the heat-sink-ready wafer is complete.
  - Whereas a 4W HEMT raises the temperature of GaN-on-Si by 189°C and a GaN-on-SiC by 78°C, it only raises GaN-on-diamond by 41°C.
  - A device that runs cooler is more reliable over the long term:
    - No failure was observed during a two-year-long test at a channel temperature of 200°C.
    - Admirable performance was also observed at elevated temperatures: no failure at 290°C over the course of one year, and gentle degradation beginning only at 350C°; compare with catastrophic degradation for GaN-on-Si HEMTs.
  - Efficiency gains, data rate, and amplifier linearity are commensurate with improvements in cooling, reliability, and performance.
    - For instance, a single satellite pass can accommodate an order-of-magnitude increase in data transfer (relative to GaN-on-Si or GaN-on-SiC).
    - The cooler, denser, more efficient GaN-on-diamond-based amplifier is key to unlocking the potential of the satellite revolution now underway: "Better materials means better products."
  - Currently Akash is working with partner foundries, but eventually plans to establish its own foundry.
- Satellites are not the only platform that would benefit from the GaN-on-diamond technology, but that market is enough to keep Akash busy; the firm has no plans to diversify, but will build and sell its power amplifiers at price points ranging from $50 to $2000.

Merging the Physical and Data Worlds without the Need for Keyboards, Buttons, or Touch Screens—Dr. Bruno Zamborlin, Hypersurfaces

- People interface naturally with one another and with the physical world, but accessing the digital world entails fiddling with a keyboard, mouse, dedicated touchscreen, or other technological artifact.
  - Zamborlin asks—and his firm, HyperSurfaces, answers—what would happen if the (almost-unadorned) physical world served as a gateway to the control of digital resources?
  - He defines a HyperSurface as an everyday object that—upgraded with simple sensors, an inexpensive system on a chip, and machine learning—becomes able to discern among actions taken on or around the object, actions that can be interpreted as instructions.
    - That is, a HyperSurface is a regular object that "becomes part of the data world," with no inherent need for Internet connectivity.
  - Zamborlin describes the underpinning strategy and presents a variety of HyperSurface examples.
- In Zamborlin's prototypes, a HyperSurface is established by placing one or several off-the-shelf piezoelectric transducers (vibration sensors) in, on, or around the object he wishes to transform into a HyperSurface; the object could be a common wooden cutting board (as he demoed live), a car door, a wall, etc., and a variety of sensors could serve as input devices (e.g., MEMS sensors, accelerometers, skin conductance electrodes (for galvanic skin response)), depending on the desired modality, sensitivity, and AI training resources.
  - Actions are taken on the object—taps and swipes in different locations, hanging items from a hook affixed to the object, dropping items onto its surface, scratching it with a fingernail, and so forth.
  - Sufficient repetition permits a neural network to be trained to differentiate and identify each action.
    - In his demos, Zamborlin's system verbalizes each action as it occurs, but it could just as well assign actions on the object to events in the digital domain; for instance, tapping the corner of a HyperSurface-ized coffee table could turn up the digital thermostat one degree, or swiping the rim of a HyperSurface-ized steering wheel could adjust the volume of the car's sound system.
  - By using off-the-shelf hardware components, HyperSurface is free to focus on software development.
    - The firm's patented algorithms train the AI model, reduce its essence to a few kilobytes, and flash it to the microchip associated with the newly digitized, standalone HyperSurface.
  - Per application, Zamborlin acquires more data than necessary, permits the training process to identify the most relevant signals for input disambiguation, and optimizes the hardware setup accordingly.
  - Aside from initial training, all computation takes place on-chip, ensuring users' privacy and eliminating the need for an Internet connection.
  - The bill of materials for the sensors and chip is minimal (~$3 per implementation); the firm's value is in its software and its growing database of physical-interaction data.
    - The business model of HyperSurfaces is to provide a software development kit and dashboard for collecting relevant data and selling the training of a machine-learning model as a service.
- Since receiving initial press coverage November 2018, Zamborlin has been approached by industry players of all stripes, each wanting to apply the HyperSurfaces modality to their own domain—everything from tech manufacturers seeking to gain insight on how customers interact with their products to industrial representatives seeking an in-the-field response to anomaly detection.
  - Fully-fledged HyperSurface prototypes:
    - HyperWall: A prototype has been trained to detect about a dozen distinct actions, including bounce a ball on the wall, bounce a ball on the floor, hang keys (on a hook on the wall), hang headphones (on a hook on the wall), tap a coin on the wall, collide a toy truck with the wall.
    - HyperCarDoor: Three vibration sensors embedded in the door can distinguish among finger taps at 16 distinct locations on the door, as well as recognize opening/closing the inside/outside door handles, tapping on the window glass, and more.
  - Examples of additional HyperSurface applications:
    - Hyper-electronics, hyper-cars, hyper-structures (sensor-enabled buildings), hyper-reality (sensor-enabled VR), hyper-toys (low-tech toys with HyperSurface inputs), and hyper-stores (with in-store analytics at a granular level).
  - Examples put forth by members of the TTI/Vanguard community:
    - Hyper-musical instruments (e.g., fretboards), merchandise that alerts a store clerk when a customer physically examines it, and underwater applications supported by water's superior sound conductivity.