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COLUMBIA SCIENCE REVIEW
In 1990, Marilyn vos Savant, renowned for her IQ of 228, published the solution to what’s called the Monty Hall problem as a response to a reader’s question in Parade magazine.

“Suppose you’re on a game show, and you’re given the choice of three doors: Behind one door is a car; behind the others, goats. You pick the first door, and the host, who knows what’s behind the other doors, opens the third door, which has a goat. He then says to you, ‘Do you want to change your pick?’”

Common sense indicates that it would make no difference to stick with door No. 1. But in fact, as vos Savant explained, it is more advantageous to switch! This is because the only way you would lose by switching is if you initially picked the door with the car, which occurs with a probability of 1/3. This leaves a 2 in 3 chance that switching will help you win.
We encounter them for the first time in elementary school, yet a complete understanding of their properties still eludes mathematicians today. Primes, or integers that are only divisible by 1 and themselves, lie at the center of modern research in the field of number theory. The ancient Greek mathematician Euclid (c. 300 BC) was the first to prove that there are infinitely many primes and that any integer can be factorized into a product of primes. But we have yet to learn a great deal about the behavior of primes, especially in their arrangement along the number line. When we list positive integers in consecutive order — 1, 2, 3, 4, 5… — the size of the gaps between the primes is seemingly random. However, in May 2013, Yitang Zhang from the University of New Hampshire shocked the mathematical world with a paper describing the first finite bound between prime numbers. According to Zhang, for at least one even integer $n$ less than 70 million, there are infinitely many pairs of primes, not necessarily consecutive, that differ by $n$. Since Zhang’s revolutionary findings were first published in the Annals of Mathematics, there has been a race to lower that bound of 70 million. As of now, claims of bounds as low as around 600 have been made but not confirmed by leading experts in analytic number theory.

What makes up all this stuff around us? Forty years ago, many scientists would have replied that everything consists of protons, neutrons, and electrons. However, recent discoveries by theoretical physicists have suggested a new idea entirely. Many now believe that everything that makes up you, the words written on this page, and indeed the entire universe is composed of unfathomably small, vibrating strings. The idea has been dubbed “string theory,” and is driven by complex laws of physics and mathematics comprehensible to a select few. The theory states that all matter in the universe is comprised of strings and that how each string “vibrates” dictates what type of particle it will be. As if that weren’t strange enough, the theory also calls for at least six extra squashed spatial dimensions that are too small for us three-dimensional beings to perceive. The scales at which scientists expect the laws of string theory to operate are much too small to be experimented with today’s technology. But the mere possibility of arriving at a conclusion to the age-old question of “What makes up the universe?” represents a significant milestone for physicists and mankind as a whole.

Think you’re a good liar? Here’s a quick way to find out. In five seconds, take the index finger of your dominant hand and trace a capital Q on your forehead. …Have you done it? Now, some of you will have traced the Q with the tail pointing to your left, in a way that would make sense to an external observer. Others will trace the Q with the tail pointing to your right. According to psychologist Richard Wiseman, if you were part of the former group, you are a good liar. Not only that, but you also tend to be extroverted and love being at the center of attention. If you were part of the latter group, you are not the best liar and tend to be more introverted. The viral YouTube video that popularized this rule of thumb was based off of an actual study by Glen Hass on self-awareness theory. The theory states that the more self-focused you are, the more you adopt the perspective of an external observer looking at yourself. The less self-focused you are, the more you divert attention away from yourself. Hass applied this theory to a similar series of “E” tests on 175 undergraduate females, and found that the above phenomenon was what resulted. So in a way, you’re a self-focused, talented liar if you tend to draw a backwards Q on your forehead!
Transhumanism: A Function of Hybrid Nanomaterials?

Joanna Diane Caytas
Illustration by Allison Scott

When science fiction speaks of cyborgs, it brings attention to the fact that technology is already beginning to transcend the human scale. Within the fields of artificial intelligence and robotics exists the concept of a technological ‘singularity,’ a robot surpassing human mental and emotional capabilities. This notion is also closely related to intellectual movements such as ‘transhumanism’ or ‘Humanity+,’ dedicated to improving the human condition through technological advances by perfecting human intellectual, physical, and psychological capacities, exceeding even ‘human enhancement’ that already uses technological advances for non-therapeutic purposes. Not least because of our computational ability to make and pursue a massively increased number of connections, natural and quantitative science has embarked on a dramatic trajectory from linear to exponential growth across all areas of human knowledge. Never before have knowledge exploded at a pace even remotely comparable to the last two decades, although even shorter periods come to mind. This phenomenon will increase further. Leaps of innovation, both in substance and relative celerity, increased to such an extent that all future technology will invariably be governed by some variant of Moore’s Law. Intel co-founder Gordon Moore observed in 1965 that the number of transistors on integrated circuits (later: chip performance) doubles roughly every two years (later: every 18 months). Similar observations hold true not only of IT efficiency but also of the resulting use of processed information in other knowledge areas. It is axiomatic that any variant of Moore’s Law will outpace the capacities of biological evolution as we know it. Therefore, emerging and converging technologies such as nanotechnology and biotechnology are scoured for ways to overcome limitations of the human condition in its physical, intellectual, and psychological dimensions. Such transcendental ideas have their roots in the earliest dawns of mankind, with the epic of Gilgamesh’s search for eternal life likely far from its first manifestation, not to mention Mary Shelley’s 1818 novel Frankenstein. Cross-disciplinary visionaries such as physicist-philosopher-neuroscientist Nick Bostrom, head of Oxford’s Future of Humanity Institute, or Peter Diamandis, co-founder of Singularity University and founder of the X PRIZE Foundation, are predicting a future determined more than ever by technology despite existential risks. It is also noteworthy that ethical and philosophical dimensions of their research received a high level of attention and focus from the outset of human enhancement.

One of the critical transcendental border crossings into these visions is in material sciences. Specifically notable is the creation of hybrid nanomaterials, both in a sense of hybrid organic-inorganic materials as well as functional hybrids (nanomaterials made of discrete inorganic nanoparticles). If a merger of man and artifice were to materialize, compatibility needs to start at the molecular level at the scale of nanotechnology. Of course, prosthetic implants did not require nanotechnology in the past, but more sophisticated future applications likely will. When organic-inorganic interfaces of suitable qualities are created, mankind will have a future not limited by evolutionary biology. Instead, limitations will be sidestepped through physical, intellectual, psychological and spiritual union with our own creations.

Nanotechnology is but one tool of leverage in the process of transcending the “natural” human condition although, for its many implications and applications for life and information sciences, it is a particularly important one. And given the central role of cross-disciplinary pursuits in this process of transcendence via transformation, hybrid nanomaterials represent a category of particular importance in their context. These hybrids are about constructing the building blocks, creating new possibilities to tailor and optimize material properties for various applications in a category of particular importance. This process can result in new hybrid nanomaterials with the advantages of its components, but without their individual disadvantages. Because components of hybrid nanomaterials are themselves nanoparticles, their properties are already dif-
ferent from chemically identical materials that do not exist in nanoparticles form, the way the properties of solid gold differ from those of its colloidal forms. These differences may be reflected in changed physical, optical, or electromagnetic properties. In particular, transparency or resilience may improve compared to non-hybrid nanomaterials. This offers new potential for hybrid applications in areas for which their original components may not have been previously considered.

Based on their component parts, hybrid nanomaterials may be classified into two distinct groups: hybrid organic-inorganic materials and functional hybrid materials. Additional classifications are offered that distinguish between their purposes, such as new materials versus catalyst applications, with additional subdivisions under each of those categories.

Hybrid organic-inorganic nanomaterials represent today’s most popular type of hybrids. They are conjugates of organic (containing carbon compounds) and inorganic structures, usually taking the form of a metallic lattice filled with organic or biological particles on a nanoscale. Synthetic hybrid organic-inorganic nanomaterials are the subject of extensive exploration in biomedical research and development of biomimetic materials, such as artificial bone structures. Examples of synthetic hybrid organic-inorganic nanomaterials also include biosensors, biocatalysts, as well as uses in drug delivery and in nanomedicine.

Some organic-inorganic hybrid nanomaterials exist in nature, for example in the form of bone structure or in the abalone shell. In the case of bone, mineral hydroxyapatite sheets with a thickness of 2 nm are embedded in tropocollagen, a basic form of collagen in its triple helix form, sized 5 nm. Nanoscale bundles of tropocollagen form a matrix for hydroxyapatite nanocrystals but are also recognized by bone marrow stem cells as signals to turn into bone-forming cells, osteoblasts. Research into biomimetic substances that emulate bone structure aspires to produce a fully self-assembling synthetic substitute for collagen as a template for hydroxyapatite crystallization.

Polymer nanocomposites, on the other hand, are systems in which the major component is a polymer and the minor component has nanoparticle form, sized below 100 nm. An application of polymer nanocomposites in solar cells is especially promising commercially due to the material’s flexibility and light weight which reduces the cost of manufacture and installation of photovoltaic panels. Most variants of efficient organic/inorganic hybrid cells use titanium dioxide nanostructures 300-500 nm thick as an especially transparent material that allows maximum absorption of light. Another auspicious avenue for the exploration of hybrid organic-inorganic nanomaterials is seen in chitosan-based applications that exhibit biomedical potential due to the antibacterial, and antiproliferative activities of this generally biocompatible and non-toxic material derived from crustacean shells. The superior physical and chemical properties of chitosan-based nanomaterials include high surface area, photoluminescence and conductivity, suggesting revolutionary promise in drug delivery as well as in biodetection.

Functional hybrid nanomaterials consist of a combination of discrete inorganic units such as nanoparticles, nanorods, fullerenes (spherical carbon molecules), and carbon nanotubes (cylindrical carbon nanostructures).

The properties of chitosan-based nanomaterials include high surface area, photoluminescence, and conductivity, suggesting promise in drug delivery biodetection.

Carbon nanohorn is a variation of the nanotube that consists of a structure that forms a cone consisting of a graphene sheet (a two-dimensional layer of graphite) rolled at an angle, which is closed at one end with a semi-fullerene cap. The resulting film has properties fundamentally different from nanotubes: while nanotubes arrange themselves into paralleled bundles forming ropes, nanohorns form clusters. The resulting spike-shaped carbon nanoparticles with diameters of tens of nanometers form a highly porous membrane with a very large surface area, which has promises in applications for the storage of gases, for example in fuel cells.

Certain less common carbon nanostructures called carbon nanobuds are formed by fullerenes covalently bonded to the sides of carbon nanotubes, resembling buds emerging from a twig. Similarly to carbon nanobuds, carbon nanostructures called carbon peapods are formed from carbon nanotubes and fullerenes, with the exception that, here, fullerenes are located inside the nanotubes. For this application, endohedral fullerenes can be used that contain in themselves an atom or a molecule. These structures create an especially flexible material.

Multi-walled endohedral fullerenes, known as nano-onions, are another variant of carbon nanostructure. The concept of nano-onions is already being implemented in a new generation of drugs against cancers that are difficult to treat, such as triple-negative breast cancer: a standard chemotherapy drug molecule is enveloped in multiple layers of active, protective substances to deliver a nano-bomb directly into cancer cells.

For the specific purpose of the application of technologies to marked improvement of the human body at the individual level, hybrid nanomaterials are likely to play a role in the elimination of congenital mental and physical barriers and the improvement of the quality of life, simply because, nearly for the first time in history, they give us access to the very building blocks of life, and of organic-inorganic materials under conditions of radical acceleration of the pace of all technological innovation.
Double Invasion and Double Defense
Our Battle with Malaria

Amy Xia
Illustration by Kimberly Shen
Nausea, headache, chills, and sweating
Coughing, vomit, pain, and fever

No, this is not the cute jingle from the Pepto Bismol advertisement. Instead, these are symptoms of malaria, a deadly disease that puts half the world’s population at risk and results in more than 200 million new cases annually. Malaria causes more than 627,000 deaths every year, especially in sub-Saharan Africa, where it accounts for about 90% of total deaths. The heavy death toll of malaria contrasts sharply with the near weightlessness of the disease’s vector—a mosquito that weighs merely 0.000088 ounces. Although malaria has affected human populations for more than 4,000 years, it was only until the late 19th century that scientists determined the pivotal role of the mosquito. In 1897, Dr. Ronald Ross discovered that the female Anopheles mosquito transmitted the malarial parasite, winning him the Nobel Prize in Medicine in 1902. Since then, researchers have been working to combat the mosquito’s deadly sting.

However, the mosquito is in fact only the carrier for the true cause of disease: Plasmodium falciparum. This protist is the deadliest of four parasitic species that infect humans. It must strike a double invasion of both human and mosquito in order to complete its life cycle.

In humans, malaria begins with something as small as a bug bite. Mosquitoes with Plasmodium parasites in their salivary glands infect humans by feeding on their blood. The probing process injects the mobile parasites, in the form of sporozoites, into the human bloodstream. After the initial bite, the sporozoites proliferate in liver cells, multiplying and dividing into tens of thousands of merozoites within cyst-like structures called “liver schizonts.” Unfortunately, during the parasite’s incubation period of nine to fourteen days, humans remain symptomless and unaware that inside them, merozoites are pillaging their liver cells and duplicating at astounding rates. Like a secret army preparing troops and supplies for invasion, the parasite increases its fleet of foot soldiers—merozoites—until the dawn of attack.

The invasion is bloody. As swarms of merozoites vacate the liver cells and pour into the bloodstream, they have their eyes on the prize: hemoglobin. While the merozoites invade red blood cells for their oxygen-rich hemoglobin protein, white blood cells of the human immune system serve to defend against the plundering trespassers. However, even if just a few merozoites attach to red blood cells, the parasites are still able to multiply by the thousands. This proliferation is fueled by hemoglobin and ultimately causes serious illness and symptoms. While most merozoites replicate through this type of asexual reproduction, some will also develop into non-pathogenic sexual forms known as gametocytes. If an Anopheles mosquito feeds again, ingesting these male and female gametocytes, the life cycle of Plasmodium continues menacingly.

Once inside the mosquito, the gametocytes develop into male and female gametes, which are haploids that then fuse into zygotes, or diploids. The zygotes attach to the walls of the mosquito’s midgut, forming oocysts. Just as the previously mentioned liver schizonts are sites for merozoite proliferation within the human liver cell, the cysts are wombs for sporozoite replication in the mosquito body.

This is preparation for another Plasmodium invasion, this time on different enemy territory. The mosquito’s line of defense, an inundation of toxic chemicals, is no match to the progeny of Plasmodium. The sporozoites burst from the oocysts and invade the mosquito’s salivary glands. We know the rest of the story from here: the conquered mosquito feeds on another human victim, injects the sporozoites, and thus completes the Plasmodium’s life cycle.

Humans have worked hundreds of years to stop malaria. Just as there are two spheres of Plasmodium infection, human and mosquito, there are two lines of defense against malaria: targeting pathogenic asexual Plasmodium in humans and targeting the mosquito vector. For example, quinine from the bark of the cinchona tree has been used in its unextracted form as a general therapy tool for fever and a treatment for disease for 400 years. By 1820, scientists isolated quinine, and it became the default malaria treatment. More effective anti-malarial drugs like chloroquine became the standard beginning in the 1940s, although, after two decades, overuse of the drug led to the development of resistance, a pertinent problem in the medical world today. While there is no viable vaccine currently available, the World Health Organization (WHO) has identified more than two dozen malaria vaccine candidates that are currently in clinical development stage, with many others in preclinical development. RTS,S is a vaccine developed by GlaxoSmithKline; currently, it is in Phase 3 clinical development, the furthest that any malaria vaccine has advanced to date. With additional funding from the Gates Foundation through the nonprofit organization PATH Malaria Vaccine Initiative, pediatric trials in seven African countries have been conducted. However, researchers continue to face enormous challenges in vaccine development. Since there are no known correlates of immunity for malaria vaccines, their effectiveness can only be determined through clinical trials, which are expensive and time-consuming. The development pathway also requires adequate financing and mechanisms to ensure the availability of the vaccine. In addition to using drugs to target the parasite, weapons like insecticides and bednets are useful for attacking the mosquito vector, thus preventing it from infecting humans. Nonprofits such as Nothing But Nets strive to raise awareness and funds to fight malaria by giving free mosquito nets to people in areas of Sub-Saharan Africa. However, malaria epidemics in Cameroon during November of 2013 demonstrate how these are holes in strategies involving the use of mosquito nets. Cameroon’s systemic problems like declining standards of living that worsen the existing medical crisis and reduce the efficacy of bednets. Because of Cameroon’s unstable economy and the scarcity of food, many families are forced to use the nets for other purposes, such as fishing. Alleviating the many underlying issues that characterize Cameroon and other areas affected by malaria poses an additional challenge for effective disease prevention efforts. The fight is difficult, but with hope, scientists will.
Anyone who’s been to a busy hospital has likely experienced the pitfalls of “drive-by medicine.” You fill out a bunch of paperwork, the nurse does an initial assessment, directs you to have a seat on the bed, and says the words: “the doctor will be right with you.” You wait, each anxious movement making a loud crinkling sound from the paper sheets in an otherwise silent room. When the doctor finally arrives, he or she runs rapid-fire through a checklist of questions, gives you a brief diagnosis, prescribes treatment, and disappears. All of this occurs in around eight minutes on average, according to a study of Internal Medicine interns at John Hopkins University. The rest of your recovery, it seems, is up to you.

Actual appointments may vary, but no matter the nature of an ongoing treatment plan, studies show doctor-patient communication to be a critical factor. A meta-analysis of research on the subject, published in Medical Care, showed a 19 percent higher risk of nonadherence to prescribed treatments among patients whose physician communicates poorly than among those whose physician communicates well. Hospitals are also finding that a crucial element in improving doctor-patient communication is regular follow-up outside the office. In fact, an article in the Wall Street Journal in April reported research from Patient Safety & Quality Healthcare showing that 80 percent of what doctors tell patients is forgotten as soon as they leave the office, and 50 percent of what patients recall from talking with their doctors is incorrect.

With 70 percent of American adults ages 18 and older having a high-speed broadband connection at home, patients seeking to understand their diagnosis better might turn to the Internet. Yet, a 2011 survey by CompTIA, an IT trade association, stated that only 15 percent of practices in the U.S. have web portals that allow patients to view their own medical records, preventing most patients from directly accessing treatment information as needed.

Placing those records online, however, wouldn’t necessarily benefit those most in need of better healthcare. For patients in low-income households and across the developing world, mobile phones are significantly more accessible than the Internet. Data from the International Telecommunications Union, a UN agency, shows more than 6.8 billion mobile phone subscriptions worldwide, equal to 96.2 percent of the global population. Even in the developing world, mobile phone subscriptions equal 89 percent of the population, and when compared to only 31 percent with access to the Internet, it appears mobile phones are the most ubiquitous means of direct communication with patients regardless of nationality or income.

The use of mobile phones in medicine, known as mHealth, is growing, and developers are creating applications to text message directly with patients regarding ongoing treatment. Healthcrowd is a recent start-up in mHealth founded in June 2011 by Neng Bing Doh and Dr. Bern Shen – one example of current efforts to expand the use of text messages in healthcare. The company is one that has chosen the accessibility of text messaging over more elaborate apps available for smart phones. “We made a very early decision,” Dr. Shen said in our interview, “to go the other route with something very low-tech... which was text-messaging. We figured that the last thing we wanted to do was to propagate and make worse the digital divide.” The first pilot to evaluate Healthcrowd at the University of Iowa Hospitals and Clinics Emergency Department found that 87 percent of patients with incomes less than 20,000 dollars a year had unlimited texting, suggesting the advantages of using texts over more high-tech options to reach low-income households.

One of the earliest text-messaging health services is Text4baby, launched in February of 2010 by the National Healthy Mothers, Healthy Babies Coalition. Text4baby is a free service where new and expectant mothers can receive text messages with evidence-based health information about pregnancy and newborns less than one year of age. A study by the National Latino Research Center and the University of California San Diego showed that 74 percent of participants reported that Text4baby messages informed them of medical warning signs that they did not know about, and 67 percent...
of participants reported talking to their doctor about a topic that they read in a Text4baby message. Other free public health efforts include SmokeFreeTXT from the National Cancer Institute and HealthTpixts, which offers subscription to a range of programs from dental hygiene to anger management. Unlike HealthCrowd, these programs all use only one-way communication.

While there are numerous offerings in secure two-way text-messaging services, including those offered by major mobile service providers such as Verizon’s Secure Universal Message System, TigeText from Sprint, or AT&T’s Global Smart Messaging Suite, Healthcrowd hopes to distinguish itself with the development of what it calls “dynamic messaging,” where Healthcrowd considers patient demographic information and previous texts between patients and a healthcare provider to tailor future text messages to each patient.

Like Netflix or Pandora, says Dr. Shen, “we use similar tools based on your pattern or content of your response, and use that over time to get to know you better.” The text messages can then be tailored to a patient’s needs. During an early study, for example, the University of Iowa Hospitals and Clinics used Healthcrowd to help kids manage type 1 diabetes. Texts would prompt the kids to reply with their pre-breakfast, lunch, dinner, and bedtime glucose levels.

This effort to personalize the text messages for greater results is the company’s core strategy. Because many chronic diseases can be partially managed through modifiable risk factors such as diet, medication, and exercise, Healthcrowd seeks to use techniques in the ad industry to influence these behaviors. Most secure two-way texting services are focused solely on providing a safe way to send information to patients via text. The larger goal of companies like Healthcrowd, however, is to automate some of these messages, freeing up time for doctors and nurses to focus on specific needs rather than general reminders.

A current study being conducted at the University of Iowa Hospitals and Clinics Emergency Department by Dr. Andrew Nugent is designed to test whether using Healthcrowd to follow up with emergency room patients can improve compliance with treatment, increase patient satisfaction, and reduce readmission rates within 30 days. The study offers emergency patients the opportunity to sign up, and patients are randomly assigned to a texting group or no-call group. The texting group is then sent an automated follow-up text 24 hours after their visit, as well as one and two weeks later. The text is a simple prompt asking the patient to text back “OK” if they are doing well, or “help” if they have any questions or problems. From there, any patient texting “help” is contacted by a nurse navigator who receives the text and does the follow-up, first via text and then by phone if necessary.

With emergency room visits, Dr. Nugent said in an interview, “The generic way to follow up with the patients is not follow up at all.” Doctors may request follow-ups with patients for whom they have a specific concern based on the reason for their visit, but dedicated phone follow-up services that have been implemented at some hospitals take a lot of manpower to get the patient on the line. Ironically, emergency medical follow-up seems to be best served by having a less immediate system. “The problem with phone calls is you never know when you’re going to get a hold of somebody. The texting is always available so they can look at their phone even if they miss the text,” says Dr. Nugent. Likewise, while a nurse navigator at the hospital originally receives the texts, that nurse can respond at the first opportunity or pass the patient’s text on to his or her doctor if the nurse cannot answer the questions.

Text messages have the advantage over calls of being easy to send en masse and having a more permanent record of the exchange. An automated message can be sent to every single patient, while texts for help from patients in reply filter further response down to those in need. The texts then stay on their phones, so patients can always reference them if they have forgotten the initial conversation with their doctor.

Some limits of text messaging are clear, however. “We don’t make any bones about ‘this isn’t an immediate response, this is an ‘at your leisure’ response,” says Dr. Nugent. Patients are advised before they join the program that for anything urgent, they should call 911 immediately, and for more serious concerns they will still be advised to schedule another appointment with their doctor in person.

“Text messaging will never replace the richness and nuance of an interpersonal interaction,” says Dr. Shen. “It’ll never be as good as a one-on-one conversation with your doctor or nurse or health coach or case manager, but for routine, basic, repetitive tasks, it’s great, because it scales very neatly, very efficiently, and for certain tasks that are very simple, it’s perfectly adequate.”

A common concern of mass texting, of course, is information sent to the wrong people. The UIHC’s Emergency Department study takes every precaution with Healthcrowd to avoid this, and no identifiable patient or illness-specific information is sent by text. One time during the study, however, a message intended for one patient was sent to everyone enrolled in the project. These potential errors will have to be seriously addressed as mHealth companies seek to personalize text messages going forward.

“With mobile health and digital health in general, there’s always concern with data breaches,” says Dr. Shen. He’s convinced, however, that these concerns are outweighed by the potential benefits of a carefully executed system. “As with many other aspects of our lives, we’re willing to trade a little bit of potential privacy risks against convenience. Almost anybody would be willing to use an ATM or do online purchases.”

SPRING 2014
Five decades ago, Dr. Robert Wilson, a British-born Brooklyn gynecologist, published a book in 1968. It was 20 years after the Food and Drug Administration approved hormone replacement therapy for mitigating menopause symptoms in the 1940s. This book became a bestseller in the United States. Through the book “Feminine Forever,” Dr. Wilson became the first person to publicly advocate estrogen therapy. Dr. Wilson’s book introduced menopause as an estrogen-deficiency disease, and proposed estrogen therapy as a necessary treatment. “Every woman alive today has the option of remaining feminine forever,” Dr. Wilson wrote. Millions of physicians and female patients were persuaded by his ideas. The sales of estrogen quadrupled after the book release and aging women embraced the blessing of estrogen treatment. The evidence for its positive effects on the symptoms of menopause started to appear in the literature.

In 1990s, two influential studies unexpectedly emerged. The first was the Heart and Estrogen/progestin Replacement Study (HERS) conducted on women with a history of cardiovascular disease. The second study was conducted by the Women’s Health Initiative (WHI). Both studies indicated that the long-term use of a combination of estrogen and progestin carries greater risks such as heart disease, stroke, or hip fracture. HERS and WHI shattered almost four decades of conventional wisdom regarding hormone treatment. With clinical and observational evidence produced by both sides, debate continued regarding its efficacy on treating menopausal symptoms such as memory impairment. Consequently, women reaching menopause were faced with a dilemma: take the hormone, and risk a higher chance of cancer and cardiovascular disease, or not, and possibly expose themselves to cognitive impairment.

According to a review by Whitney Wharton at Alzheimer’s Disease Research Center at the University of Wisconsin written in 2013, as female life expectancy increases, women have a higher chance of living longer post-menopause. Further research is needed in many respects. However, a growing body of evidence strongly demonstrates hormone treatment improving human brain function. Observational, longitudinal, and randomized controlled trials confirmed estrogen as essential to brain functioning in postmenopausal women worldwide. Current evidence seems to support estrogen’s effects on mood, social behavior and executive function. Evidence indicates that the presence of estrogen enhances functions across the cognitive spectrum, allowing estrogen therapy to become a fascinating research topic for bettering women’s health and society as a whole. Estrogen therapy is being prescribed to millions of premenopausal women each year.

On September 12, 2013, a study published in the New England Journal of Medicine revealed the effects of estrogen on middle-aged men. Investigators found the complex effects of testosterone in men depend on a type of estrogen. The study claimed that estrogen is needed for libido and fat regulation in both sexes. In a separate study, Dr. Peter Snyder, a professor of medicine at the University of Pennsylvania, led a groundbreaking research study to investigate the hormone therapy effects for male seniors with low testosterone. According to Dr. Snyder, testosterone deficiency is caused by estrogen deficiency. It is astonishing to think that estrogen might play a much bigger role in men. Thus estrogen is the culprit behind middle-aged men’s ballooning waistlines. Female hormones also play a major role in preventing testosterone decline symptoms. “male menopause,” in men.

Unlike estrogen, testosterone’s mechanisms of action have never been clearly established. The long-term risks and benefits of testosterone therapy are unclear. In the scientific literature, estrogen is described to modulate various circuits in the brain. On the other hand, it is unclear if testosterone modulates the brain, leads to prostate cancer, or prevents heart disease.

Men gradually make less sex hormone as they age. Until recently, it was believed that muscle weakening in middle-aged men resulted from testosterone decline. However, according to Dr. Snyder’s study, it is estrogen deficiency that induces many aging-related symptoms in men. Dr. Finkelstein, an endocrinologist at Harvard Medical School, corroborates Dr. Snyder’s findings and demonstrates testosterone decline is caused by a decline in male estrogen levels. Doctors say it is too abrupt to make specific recommendations, but those who complain of muscle strength should not blame testosterone deficiency alone.

Currently Dr. Snyder is leading another study of 800 men aged over 65 to investigate “Masculine Forever” by use of both hormone treatments. These follow-up clinical trials will address whether testosterone treatment is linked to men’s youthfulness. Research will be completed next year, which may bring answers to important clinical questions.
such as the long-term effects of testosterone therapy.

According to Victor W. Henderson’s 2010 review published in Current Psychiatry Reviews, since “Feminine Forever” many studies have fervently advocated the protective role of estrogen in relation to aging symptoms. The evolving knowledge on hormone therapy took over four decades. Both sexes make estrogen out of testosterone but during the last four decades the pharmaceutical industry exclusively focused on estrogen.

It is unclear how long it will take to have to certain knowledge on testosterone therapy. However, the pharmaceutical industry has started to focus on testosterone. Every year testosterone therapy is prescribed for millions of men. Every year, Americans spend nearly two billion dollars on testosterone gels, patches, and injections to alleviate male menopause symptoms. This number is expected to more than double by 2017. Sales of testosterone may double, triple or even quadruple in the next decades. As long as the demand exists, the pharmaceutical industry is sure to be not too far behind with a “Masculine Forever” drug.
Close to 80% of the mass in the universe is unaccounted for. The only hints of the missing mass’s existence are from the breadcrumbs of gravitational influence it leaves behind on the normal matter that makes up you, my dog, and every far-off galaxy. Physicists have labeled this mysterious, unknown quantity of mass “dark matter,” and it is currently one of the biggest open problems on the frontier of theoretical and experimental physics. The effort to detect dark matter draws over $100 million each year alone, and thousands of professors and graduate students from all over the world have dedicated their careers to understanding it.

The first bits of evidence indicating dark matter’s existence came from astronomical data of distant rotating galaxies. To the naked eye, or more precisely, to a telescope capable of detecting light across the entire electromagnetic spectrum, far-off galaxies are rotating faster than they “should.” For a spiral galaxy, the rotational speed at any point on the spiral is related to both the point’s distance from the center of the galaxy and the amount of mass present in the galaxy. Given both the speed of a point on the galaxy and the radius to that point, astronomers can deduce the total amount of mass present. However, astronomers can also estimate the amount of mass simply by observing the total amount of light given off by the stars that constitute the galaxy. As it turns out, there’s a large discrepancy between the two calculated masses. For a given galaxy to rotate as fast as it does, it would
need roughly ten to twenty times more mass than physicists and astronomers observe from the amount of light it radiates.

And yet, that mass is nowhere to be found. There simply is no luminous matter, or matter that interacts with light, to contribute gravitational influence and make galaxies spin as fast as they do. But the extra gravitational force must come from somewhere. There must be some unaccounted quantity of mass that appears to be five to ten times more plentiful than ordinary protons, neutrons, and electrons. This unseen quantity of mass that isn’t interacting with or producing any light is “dark matter.”

Indeed, this mysterious bulk of matter could be nothing. It’s possible that the general theory of relativity, the prevailing theory of gravity, breaks down at the cosmic distances the telescopes are measuring. It could be that the masses necessary to produce such rotational speeds are in fact exactly what physicists are observing, and the discrepancy exists only due to the inadequacy of their equations. But this seems unlikely. General relativity has been rigorously tested and experimentally corroborated since its creation a century ago. Further, there exists greater evidence for dark matter in what physicists call, the Cosmic Microwave Background, which is the afterglow of radiation from the Big Bang.

So if the existence of dark matter is logically sound, what, then, does it consist of? Physicists have ruled out all usual suspects; that is, all the particles that constitute the Standard Model of particle physics. The Standard Model, completely describes the interactions of all known particles like quarks, electrons, neutrinos, and the various bosons. Dark matter can’t consist of normal atoms, since atoms’ constituents interact with light and dark matter patently does not; nor can it consist of neutrinos or any force-mediating particle. Thus, dark matter must constitute a new class of particles heretofore undiscovered, and given that normal matter consists of a variety of particles like protons and electrons, it wouldn’t be unreasonable to think that dark matter itself includes a variety of elementary particles. For all we know, dark matter could consist of a whole new class of particles interacting via a whole new class of fundamental forces, thereby forming a whole new class of cosmic structures.

However, despite the exotic possible features dark matter may have, physicists can only hope to find it through the “ordinary,” conventional properties they already understand. Since dark matter doesn’t interact with light, it’s not unreasonable to assume it doesn’t interact at all via the electromagnetic force. Therefore, if it is to interact with normal matter at all, it needs to be through the three other known fundamental forces: gravity, the weak nuclear force responsible for radioactive decay, and the strong nuclear force responsible for holding together the atomic nucleus. Based on this restriction, theoretical physicists have postulated that dark matter could be a WIMP, or Weakly-Interacting Massive Particle. WIMPs are hypothetical, particles predicted by Supersymmetry, a speculative extension of the Standard Model, which only interact via gravity and the weak nuclear force.

Many of the experiments aiming to detect dark matter make use of the predicted properties of WIMPs. Since WIMPs are hypothesized to interact via the weak nuclear force, their interaction with ordinary matter would take place at small length scales on the order of an atomic nucleus. As such, many of the experiments designed to detect dark matter directly are centered around the collisions of WIMPs with other nuclei. One such experiment is the Cryogenic Dark Matter Search, which measures the vibrations of germanium nuclei after a germanium-WIMP recoil. Since the vibration is subtle, the germanium atoms are cooled close to absolute zero, and the heat produced by the vibration is taken as the signature of an event. Another class of direct detection experiments involves using highly pure, liquid noble gases, like argon or xenon. In these experiments, WIMP-xenon recoils excite the xenon nuclei to higher energies. When the nuclei then drop from this excited state to the ground state, a photon is emitted. This photon is either detected directly or through a cascade of electrons ionized from other xenon atoms as the photon moves through the liquid volume. Depending on the number of events recorded and the size of the liquid xenon volume, physicists can determine the approximate mass of the WIMP, which would be the particle’s unique signature. As of yet, the two main liquid xenon experiments, the xenon Dark Matter Project and the Large Underground Xenon Detector (LUX), have turned up null results for low-mass WIMPs. That is, if the WIMP exists, its mass is greater than the energy scales that have been explored so far.

There also exist experiments dedicated to indirectly detecting dark matter based on even more speculative properties of WIMPs. If the WIMP responsible for dark matter is its own antiparticle, then Supersymmetry predicts that its self-annihilation would produce an excess of high-energy gamma rays, positrons, and antiprotons. Detecting this excess is the purpose of the International Space Station’s Alpha Magnetic Spectrometer, an instrument designed to record the cosmic rays flying through space. As of May 2013, AMS has produced the most promising data hinting at dark matter’s detection. However, the instrument has yet to discriminate between the different possible sources of high-energy particles. Pulsars, which are highly magnetized, fast-spinning neutron stars, are also capable of creating the cosmic rays that AMS measures as a positive WIMP annihilation event.

Thus far, dark matter has remained elusive, but physicists see little cause for concern. Experimental data has only just begun to carve out the range of masses where WIMPs can exist. Extremely sensitive detectors are only a few years away, as both the LUX and XENON teams are currently designing devices that would make use of over a ton of liquid xenon. Further, the inability of AMS to distinguish between WIMP annihilation events and pulsars is only temporary. More data of high-energy events would give physicists the capacity to pinpoint the source of cosmic rays. Indeed, within the physics community, there seems to be general optimism that the true nature of dark matter will soon come to light. As Samuel Ting, the Nobel Laureate who designed the AMS, says, “It is only a matter of time, perhaps months or a few years.”
Global warming is no secret, and neither is the ever-increasing amount of carbon dioxide in our atmosphere. We’ve all heard about efforts to lower man’s carbon footprint and find alternatives to fossil fuels. But I’m guessing relatively few people know about one particularly fascinating way to decrease atmospheric carbon dioxide concentration, a process whose future might lie within a curious rock in the mountains of northern Oman, a country on the eastern corner of the Arabian Peninsula.

This rock, called peridotite, naturally soaks up carbon dioxide, storing the carbon in solid form. The rock is usually buried deep within the earth’s interior, inaccessible to scientists, but the shifting of tectonic plates at the edge of the Arabian Peninsula has exposed it at the surface where it reacts with atmospheric carbon dioxide.

So why does this rock matter? For decades, the US has been capturing carbon dioxide gas and permanently storing it underground in a process commonly referred to as Carbon Capture and Sequestration (CCS). Scientists now believe that CCS is crucial in solving our greenhouse gas crisis. Furthermore, current research suggests that storing carbon dioxide in peridotite might just be the most efficient and sustainable model of CCS out there.

Geologists have found that minerals in peridotite, most notably olivine, react with carbon dioxide to form solid carbonates, which fill up cracks and pores in peridotite to form prominent white veins within the rock. Columbia’s own Peter Kelemen, Arthur D. Stroke Memorial Professor of Geochemistry in the Department of Earth and Environmental Sciences, has shown that these reactions occur at surprisingly high rates. By speeding up these natural processes even further, it may be possible for peridotite to capture and store billions of tons of carbon dioxide each year. Considering that the total human output of carbon dioxide is about thirty billion tons per year, this could make a significant difference in the overall carbon dioxide budget until alternative energy sources can ultimately replace fossil fuels.

In the earliest proposals for CCS via mineral carbonation, scientists proposed a method of mineral carbonation “at the smokestack,” in which rocks would be quarried and sent to power plants to be ground into fine powder and mixed with carbon dioxide-enriched water. However, this method is likely to be too expensive. On top of the high costs of quarrying and transportation, these “off-site” reactions are very slow and must be accelerated with costly and energy-consuming processes like elevating pressure and temperature. Fortunately, the cutting-edge research of Peter Kelemen and his colleagues at the Lamont-Doherty Earth Observatory may lead to a promising alternative that is low-cost, safe, and long-lasting.

Kelemen has spearheaded a global effort to research mineral carbonation of peridotite for carbon dioxide storage “in situ,” meaning in the rock itself. “This rock from the earth’s interior is out of equilibrium with our atmosphere and hungry for carbon dioxide. We want to take advantage of that,” Kelemen said. In a personal interview, he added, “This is chemical potential energy, as a geochemist would say. It’s there to be harnessed on a massive scale, if we can learn how to do it.” In other words, the goal of his research is to “understand the processes of natural
olivine carbonation, and then do as little as possible to accelerate these processes in order to consume globally significant amounts of atmospheric carbon dioxide."

Kelemen’s research is focused in the mountains of northern Oman, where he can study the exposed chunks of peridotite-rich mantle. Here, he and his colleagues have been studying the chemical processes of peridotite carbonation and have discovered, using radioactive carbon dating, that the reactions are far more rapid and prevalent than previously thought. They have also discovered that the carbonation process can become "self-heating," meaning that if the carbonation reactions occur fast enough, the amount of heat released by the reaction can offset the cooling that occurs when cold fluids interact with rocks in the subsurface. Also, the researchers have found that when carbonates form in the pores of peridotite, it presses out against the surrounding rock, forming small fissures that provide access to more fluid. This allows fresh olivine to react with more atmospheric carbon dioxide, kick-starting a positive feedback loop of more carbonation and splintering. Ultimately, Kelemen’s research has revealed that these rocks are made to handle large inputs of carbon dioxide, and maybe all scientists have to do is speed up the process.

Kelemen and his team proposed one method for speeding up the carbonation by drilling boreholes into the rock, heating it up, and then pumping carbon dioxide-infused water into the rock. This "on-site" method may be less expensive than "off-site" methods because it avoids the cost of quarrying, transporting, and grinding the rocks. Furthermore, once a rock is heated, the energy to sustain the high temperature is provided by the carbonation reaction itself, and the high pressure necessary for the reaction is provided by the presence of overlying rocks.

However, a major economic problem still remains: the energy-gobbling process of capturing carbon dioxide at power plants and transporting it into the rock formations. Consequently, Kelemen and his colleagues have proposed an alternative process using seawater rather than carbon dioxide enriched water. Shallow seawater naturally exchanges carbon dioxide with the atmosphere, so using seawater would avoid the costs of industrial carbon dioxide capture and transport. Deeper in the earth, rocks are hotter and under higher pressure, so one could drill into them without the need for pre-heating the rocks or pumping fluid at high pressure. Due to convection, cold seawater might circulate down the hole as hot seawater emerges. This process would be thousands of times less efficient than using purified carbon dioxide, in terms of kilograms of carbon dioxide stored captured within a single borehole each year. But if drilling holes and fracturing rocks is thousands of times less expensive than carbon dioxide capture and transport, then this method could be the golden ticket.

Kelemen said, “It would be great if we could do a pilot study where we had a couple of boreholes on the shoreline somewhere—Oman or California—and we were able to test some of these techniques at scale. But right now, because there’s no carbon tax or cap-and-trade system, people don’t feel like they can make money from it, so it’s fairly hard to get a commercial operation interested in a $10 million pilot experiment.” In fact, a recent study by the Global CCS Institute, reported in The New York Times, has shown that despite the scientific community’s consensus that CCS is essential to meeting our international goals for slowing the buildup of greenhouse gases, the number of large-scale CCS projects has dropped from 75 to 65 in the past year. The report states, “While CCS projects are progressing, the pace is well below the level required for CCS to make a substantial contribution to climate change mitigation.” Furthermore, the report claims that despite the growth in renewable energy, about 60% of energy in 2060 will still come from fossil fuels, so “CCS is not an optional technology if we’re to address climate change.”

Kelemen is patient and hopes that eventually there will be a societal desire to take on the cost of carbon management. He analogized the elimination of greenhouse gases to the building of the sewer system in nineteenth century London. Although it became the world’s largest city in about 1820, London had no central sewers, so Londoners just threw the contents of their chamber pots out of their windows. It was free, so no one cared, until a series of costly cholera epidemics persuaded Parliament to pay for the construction of a new sewer system. Similarly, Kelemen thinks we just need the right kind of persuasive, intrinsic motivation: “Right now it doesn’t seem to cost anything to throw your garbage into the atmosphere,” Kelemen explained in an interview. “When and if people get the idea that it’s actually costly for them to do so, then they’ll be willing to spend money to fix it, but that moment hasn’t arrived.” He predicts that if we continue on our course of increasing fossil fuel consumption by three percent each year, the amount of carbon dioxide in our atmosphere will double in 50 years. With this in mind, he is hopeful that people will take on the costs of carbon management within the Columbia Class of 2017’s lifetime.

In the meantime, Kelemen and his colleagues will continue on their pursuit to better understand the natural processes of mineral carbonation in peridotite, to better understand how a veiny rock in the mountains of northern Oman could soak up billions of tons of carbon dioxide a year.
It’s the year 1871, May 15th Charleville, France: A wildly frustrated, rebellious, coy, and brilliant teenager by the name of Arthur Rimbaud writes one of his school teachers and a fellow poet each a letter before departing from the Hell he perceived his small village to be. In the process of addressing his desire, he would consequently initiate what many consider to be modern poetry, “I say that one must be a seer, make oneself a seer. The Poet makes himself a seer by a long, immense, and rational dissoluteness of all the senses. All the forms of love, of suffering, of madness; he searches himself, he consumes all the poisons in him, to only keep their quintessence. Inexpressible torture where he needs all the faith, all the superhuman strength, where he becomes, above all others, the great patient, the great criminal, the great accursed, - and the supreme Savant!”

“I wonder…”

The virtual era, could it be that beyond love, social justice, nature, and technology, science wholly reveals itself to be the great muse of the next generation of poets, concerning themselves primarily with the last universal language, and could it be that poetry, embracing science with warm arms, is capable of creating a landscape for this leap in expression?

The anxiety and critique of industrial progress of the past two hundred and fifty years have produced remarkable works of literature and art. Those unsettling masterpieces of science fiction such as Frankenstein are often discussed as the residue of a prophetic imagination mingling with the tensions of a rapidly evolving scientific moral.

In eras of extraordinary growth, there comes an equal sense of apocalypse!

It’s not uncommon to run into conversations regarding the decay, decadence, and the potential desolation of human ethics as a result of twenty first century devices. Certainly, there is truth to arguments which claim that by and large we as a global community are paradoxically growing ever more disconnected, perhaps despondent in the same moment revolutions are being hosted via Twitter, as the realities of wealth separation on, poverty growth, and environmental deterioration further ripen the earth for increases in chaos.

If one is to take a broad look at history, it should be mentioned that there is an adjusting phase - a period of time which people bend and begin to hypothesize precisely how the developing technology around them is impacting their lives.

Perhaps, we are in the phase of discovery.

And if we assume this to be a possibility, are we not alive during one of the most utterly beautiful and heart rending turning points in human evolution? Take a moment. What if we all undergo Rimbaud’s experiment and heave our intuitions into the smoggy twenty-first century air; what if we all become seers? What does next week hold? Next year? How will New York City appear in the year 2027?

Here is how young Arthur Rimbaud concluded his sentiment, “…For he arrives at the unknown! Because he has cultivated his soul, already rich, more than anyone else! He reaches the unknown, and when, terrified, he ends up by losing the meaning of his visions, at least he has seen them! Let him die of his bound through the unheard-of and countless things: other horrible workers will come; they will begin from the horizons where the other has succumbed!”

As for the so-called twenty-first century poet, one in particular remains trapped in the void commonly referred to as reddit. He scans the virtual slum for weird, mad, and cute technology articles potentially impressive details to include in a certain article on the relationship between science and poetry. For better and worse, the future has arrived.
The New Frontier

Kyle Misquitta
Illustration by Kimberly Shen

While looking up at the night sky with the naked eye alone, we are sometimes privileged enough to behold a vast array of stars scattered throughout our galaxy, select planets within our solar system, and even the occasional meteor burning brightly as it streaks across Earth’s mesosphere. There are some phenomena, however, that occur in space at such high energies that our eyes simply cannot perceive them, and therefore, we cannot fully appreciate them. Many of these occurrences take place in the gamma-ray band of the electromagnetic spectrum. Gamma rays are the most energetic form of light, and, as such, they are characterized by very high energies (VHE). VHE gamma-ray astrophysics arguably rests at the heart of our generation’s dogged fixation to learn more about the universe in which we live. In an attempt to accomplish just that, there are a number of ground-based telescope observatories that have been dedicated to this quest.

Together, the VERITAS, MAGIC, and H.E.S.S. telescope arrays make up the three currently operating Imaging Atmospheric Cherenkov Telescopes (IACTs). Collectively, the IACTs have the ability to detect energy from roughly 50 gigaelectron volts (GeV) to 50 teraelectron volts (TeV). The electron volt (eV) is simply a unit of energy. The prefixes giga- and tera- denote the order of magnitude of the energy at hand. For instance, the gigaelectron volt is one billion electron volts and the teraelectron volt is one trillion electron volts. To put these numbers in perspective, visible light photons, which are “particles” of light, have energies anywhere between 1.63 and 3.26eV, numbers that pale in comparison to the quantities of energy these telescopes are setting out to detect. In considering such enormous levels of energy, it immediately becomes evident why the causes of such emission are of great interest to scientists: the events that emit gamma rays are on the scale of supernovae and extremely energetic phenomena, some examples of which we will address soon. Studying such occurrences not only deepens our understanding of the cosmos but also motivates us to learn more. Having said this, the role that the IACTs play in this endeavor cannot be overestimated.

But, how exactly do they work? Very Energetic Radiation Imaging Telescope Array System (VERITAS), located at the Fred Lawrence Whipple Observatory in Arizona, operates by detecting what is known as Cherenkov radiation in the atmosphere. Imagine a single gamma-ray photon entering Earth’s atmosphere. As the gamma ray interacts with the electromagnetic field of an adjacent atom, it decays and produces an electron and a positron (can be thought of as a positively-charged electron). As these pairs interact, they lose some of their energy to create more photons. These photons in turn create more electrons and the cycle continues into a cascade that travels down the atmosphere until the energy to continue this process is insufficient. As these highly energetic particles travel through the atmosphere, they do so faster than the speed of light would in the same medium. The result is a faint blue light known in the scientific circle as Cherenkov radiation. The brief flashes of this bluish light last for only a few billions of a second and are extremely faint. How, then, can the IACTs detect them? They make use of what is known as a photomultiplier tube (PMT). PMTs are extremely sensitive light-detecting devices. Once they are struck by an incoming photon with high enough energy, a cascade of electrons is produced with the help of a series of metal plates (called dynodes) resulting in an electric signal. The electric signal can then be interpreted and used to gain information about the radiation itself. On the ground, the IACTs do an incredible job of furthering our knowledge of VHE gamma-ray activity, but if they alone were our only resource, then our understanding of such phenomena would be rather incomplete. Orbiting Earth are several observatories that aim to give us the big picture by complementing the data that the ground-based observatories provide.

In regard to gamma-ray astronomy specifically, perhaps the most prominent space telescope is Fermi. The Fermi gamma ray observatory’s most important instrument is undoubtedly the Large Area Telescope (LAT). How does the LAT work? Imagine once again a single gamma-ray photon. Upon entering the LAT, that photon interacts with several layers of thin tungsten sheets. In the process, the photon decays and produces an electron-positron pair, much like the atmospheric interaction described earlier. The paths these two particles take are closely monitored by the LAT so that the direction of the gamma ray can be determined. Another instrument aboard Fermi is the gamma-ray burst monitor (GBM). The GBM consists of twelve sodium iodide and two bismuth germanate scintillators. A scintillator is any material which, when struck by an incident particle, emits absorbed energy in the form of light. Different materials will have different energy sensitivities. In such a way, Fermi is able to detect the location of the gamma-ray source.

Knowing how gamma rays are detected is a huge step in the direction of understanding VHE astronomy, but equally important is an awareness of what phenomena in space occur at a high enough energy to actually emit gamma rays. One such source of gamma rays is gamma-ray bursts (GRBs). GRBs are intensely bright sources of electromagnetic radiation lasting
from fractions of a second to several minutes. Many of the GRBs observed by astronomers are thought to have originated from the explosions of stars, either supernovae or hypernovae (which are more energetic explosions). Another source of GRBs can be found in a binary star system. Simply put, a binary star system consists of two stars orbiting each other around a common center of mass. As the stars move closer toward each other, they eventually collide and, provided this occurs at a high enough energy, emit gamma rays.

Cosmic rays, which are high-energy particles traveling at speeds close to that of light, are another source of gamma rays. They are believed to primarily come from the supernova remnants (SNRs) of stars. When stars explode, massive amounts of matter are expelled and travel outward from where the explosion occurred. As the cloud of matter expands, the particles about its periphery continually cross back and forth over the border of the cloud. This continual back-and-forth motion accelerates the particles until they acquire enough energy to escape from the matter cloud. When, for example, a proton or electron accelerated in this manner interacts with other particles, gamma rays can be produced. In the case of an electron, a gamma ray results from the reflection of the electron by an atomic nucleus. When accelerated protons collide with other protons, a pion particle can be produced. When pions decay, pairs of gamma rays are produced. In this way, SNRs are yet another source of gamma rays.

Massive explosions, however, are not the only sources of observable gamma rays. In fact, the sun also emits gamma rays during events called solar flares. Solar flares occur when the magnetic fields in the sun undergo a process called “reconnection,” which takes place when the magnetic fields overlap and release pent-up energy. The result is a bright flash in which charged particles are heated and accelerated either toward the sun’s surface or outward, away from it. When accelerated protons (positively-charged particles) interact with gas in the sun’s atmosphere, pions are produced. Pions, as mentioned, decay into gamma rays, which is where Fermi comes in. Although the sun is rarely one of the brightest observable sources of gamma rays, on March 7, 2012, the intensity of a solar flare briefly made the sun the brightest gamma ray source, brighter than even the Vela Pulsar, which usually holds that title.

Having mentioned the Vela Pulsar, it is important to gain some familiarity with what exactly pulsars are. First and foremost, a pulsar is a spinning neutron star. Neutron stars are extremely compact stars with a radius of roughly 10 km and a mass 1.5 times that of the sun. As these neutron stars spin, they eject beams of particles and radiation at opposite poles (that is, 180 degrees from each other). The radiation emitted is frequently within the gamma-ray or X-ray band. As mentioned, the Vela Pulsar is amongst the most studied and well-known pulsar. The Crab pulsar is another well-known pulsar that is also spectacularly inspiring to view. Because it emits radiation in the radio, optical, X-ray, and gamma-ray bands, it is brilliantly colorful.

Perhaps one of the most interesting and promising applications of gamma ray astronomy, however, can be found in the search for dark matter. For several decades now, astronomers observing the motion of galaxies (both on an individual basis and in clusters) have noticed that the observable mass of such systems is insufficient to account for their motion. Arguably the most concrete backup for this observation comes from Kepler’s third law. Kepler’s Law relates the period of an orbit to the semi-major axis of the orbital ellipse and the mass of the orbiting object. In theory, if instead we know the semi-major axis and the period of the orbit, then we can solve for mass. If we take into account only the visible mass, then we observe a deficit: galaxies should be spinning apart because there would be insufficient mass to hold everything together. Since, obviously, this does not happen, there must be some mass present that we cannot see. This theorized mass is referred to as “dark matter.” One of the theories to explain dark matter utilizes what are called weakly interacting massive particles (WIMPs). WIMPs are believed to neither absorb nor emit light and hardly interact with other charged particles. However, when two WIMPs collide they annihilate and release gamma rays. If careful observation of gamma ray emission can be narrowed down to those potentially produced by some form of dark matter, then the implications of such a discovery would be monumental.

Very clearly, there are a myriad of sources of gamma rays in the universe. In studying each of these phenomena, our understanding of the events that occur within each will continue to grow. For this reason, scientists have already undertaken a project to build the next generation of ground-based telescopes: the Cherenkov Telescope Array (CTA). The goal of the CTA is to improve the current energy range detectable by the IACTs, for example, by an order of magnitude.

In doing so, the completion of the CTA would mark a new milestone in our quest to understand the workings of the universe. Indeed, both VERITAS and the CTA represent the opening of “a new window into high energy astronomy” says Reshmi Mukherjee, a professor of physics at Barnard College. Her work focuses on exploring the nature of particle acceleration in extragalactic blazar jets and on understanding the acceleration and emission mechanisms of very high energy sources. She and her group are currently collaborating with Brian Humensky, a professor of physics at Columbia University, and his group which is currently working on analyzing galactic and extragalactic sources detected by Fermi and the VERITAS array. Jointly, they are busy designing a prototype of the “Schwarzschild Couder Telescope” with the goal of improving upon the CTA. “The future of VERITAS looks great,” she goes on to say, “VERITAS will continue to operate as a premier telescope in the northern hemisphere and provide us with clues to understanding the physical phenomena in the astrophysical sources.”
Alternative energy is at the forefront of our social consciousness, as evidenced by changes in legislation and governmental grants. Efforts against global warming, spearheaded by Al Gore in the late 1990’s, have set the tone for scientific innovation in the new century. The overarching goal is to maintain our fast-paced, energy-demanding lifestyle, while also reducing carbon emissions and preserving the health of our planet. On this front, fuel cells present themselves as important avenues of possibility, as they emit less greenhouse gases and air pollutants.

Fuel cells use the concept of oxidation-reduction reactions to convert chemical energy into electricity. In most types of fuel cells, hydrogen enters at the anode with one proton and one electron. A platinum catalyst, which speeds up the rate of reaction without being consumed in the process, splits apart these charged particles, and the positively charged ions pass directly to the cathode while the electrons are forced to travel through an external circuit to the cathode, which generates electricity. Oxygen is pumped in at the cathode, and it combines with the hydrogen ions to create water. Although there is a wide variety of fuel cells, the Department of Energy has chosen to focus on Proton Exchange Membrane (PEM) fuel cells, as they are able to function in lower temperature and pressure conditions. As a result, we can build clean electricity perpetually out of only hydrogen and oxygen.

So the question arises: why have these cells not become the staple of energy production? The answer comes down to financing. While platinum is one of the best catalysts and is used in a variety of significant reactions, including vehicle emission control, petroleum purification, vegetable oil hydrogenation, and most importantly, oxidation-reduction reactions, it is exorbitantly expensive. In addition, platinum catalysts degrade quickly in the harsh conditions of these reactions and, as a result, must be replaced often.

There are several means through which we can attempt to rectify the problem. On one hand, we can try to completely eliminate platinum from these oxidation-reduction reactions and look for a newer catalyst that is equally effective but much cheaper. Researchers in South Korea and the United States have been exploring the potential of graphene nanoplatelets with a halogen attached to the edge of each layer as a replacement catalyst, and so far, the results have been resoundingly positive. Iodine-edged nanoplatelets managed to generate 33% more electricity than regular, unadulterated platinum and maintained 24.9% more of its activity after 10,000 cycles. Additionally, as recently reported in Nature Nanotechnology, large and intricate structures involving nitrogen along with graphene can increase activity and stability as well. Clearly, there is high potential for graphene as a catalytic replacement for platinum.

On the other hand, we can try to cut down on the amount of platinum needed in oxidation reduction reactions. This is usually done by changing the geometrical shape of the catalyst, or by creating alloys that supplement platinum activity while reducing the amount of necessary platinum. These structures are usually synthesized through galvanic replacement, a process in which one of the metal species the “sacrificial template” is oxidized by the ions of another metal that has a higher reduction potential. The template is oxidized and dissolves into the solution while the second metal is reduced and plated onto the surface of the template. Literature suggests that hollow or porous platinum-based catalysts and platinum-based alloys result in an increased catalytically active surface area. The next step in the development of geometrical structures is to find a way to synthesize these structures economically and efficiently.

As we have seen, the amount of platinum necessary for oxygen reduction reactions in fuel cells can be greatly limited by either searching for new but equally efficient catalysts or by changing the geometrical structure/chemical composition of the catalyst. If we manage to find a way to reduce or eliminate platinum efficiently, fuel cells can move from fantasy into the realm of possibility.
The Neuroscience of Drug Addiction

AUDREY SHI
ILLUSTRATION BY GEMMA GENE

We’ve all seen drug addiction when it comes to shows like Breaking Bad or The Wire. Drug addiction is such a visible and controversial topic that it permeates almost all forms of our media. It begs the question: Why does drug addiction occur? What does it scientifically entail? And why is it that some people become dependent on drugs, while others are able to lead normal lives? In fact, the answer is a lot more complex than you might imagine. Dr. Carl Hart, an associate professor at the Columbia University Psychology Department who researches the behavioral, and neuropharmacological effects of drugs on humans, believes that drug addiction is more dependent on environmental factors, like poverty and a lack of resources, than on neurological changes. “If you’re living in a poor neighborhood deprived of options, there’s a certain rationality to keep taking a drug that will give you some temporary pleasure,” explained Dr. Hart in an interview with The New York Times. At the same time, there is a plethora of literature on drug addiction that underscores its debilitating effect on the brain, with evidence indicating that drugs can physically and chemically alter the architecture of the brain. It is likely that future developments in drug addiction research will implicate both environmental, pressures and drug-induced neurological changes as causes of substance dependence.

Everyone recognizes dopamine, a chemical involved in movement, memory, pleasure, and reward, as the neurotransmitter that mediates drug abuse. All addictive drugs trigger dopamine-signaling, albeit in different ways: cocaine blocks the reuptake of dopamine, while alcohol and narcotics suppress cells that would otherwise inhibit dopamine-secretion, and nicotine induces neurons to release dopamine. For a while now, it’s been known that repeated drug use is associated with a decrease in the level of dopamine (DA) D2 receptors. In 2001, a group of neuroscientists led by Dr. Panayotis Thanos of the Brookhaven National Laboratory investigated the relationship between DA D2 receptor levels and alcohol abuse by observing the effects of DA D2 receptor overexpression in mice. By treating the mice with a viral vector, a virus engineered to deliver the DA D2 receptor gene to the cells of the mice, the researchers were able to increase the amount of DA D2 receptors in the brains of the mice. They found that the increase in receptors reduced alcohol self-administration in the mice by as much as 64%, suggesting that high DA D2 levels may protect against alcohol abuse. Importantly, this means that the opposite, or having genetically low levels of DA D2 receptors, could predispose people to substance abuse. Under this model, called the “reward deficiency syndrome,” it is hypothesized that people with low DA D2 levels abuse drugs because more dopamine is needed to compensate for a resulting decreased activation of the brain’s reward system.

However, research on DA D2 receptors has indicated that the symptoms of drug addiction may involve much more than simply the pleasure system of the brain. Addicts, for instance, will continue to self-administer drugs even with the development of tolerance or adverse side effects. In other words, substance abuse is not only associated with areas of the brain connected to pleasure, like the nucleus accumbens and the amygdala, but also with areas of the brain associated with decision-making and emotion, like the orbitofrontal cortex (OFC), which is responsible for driving and for the signaling of the expected value of rewards. Disorders associated with the OFC include Obsessive-compulsive Disorder (OCD) and Attention-deficit Hyperactivity Disorder (ADHD), and damage to the OFC typically causes disinhibited and impulsive behavior, as well as difficulty in altering behavior in response to changes in environment. In a 2000 study, researchers found that reduced levels of DA D2 receptors are associated with impaired brain function (glucose metabolism) in the OFC, implying that drug abuse may involve an inability to flexibly change behavior, comparable to the symptoms observed in patients with damage to the OFC. Furthermore, research has shown that the OFC plays a role in guiding behavior by signaling the perceived relative value of rewards. In an interesting 2007 study, a group of researchers investigated the effect of drug addiction on the ability to process monetary rewards. They found that 9 out of 16 cocaine users ranked the monetary amount of $10 to be equally valuable as $1000, while only two of the 13 control subjects displayed this decreased sensitivity to reward gradients, a statistically significant difference. They also found positive OFC activity in the control subjects, but little to none in the subjects with cocaine-use disorders. Thus, scientists have conceptualized drug addiction in terms of what is called I-RISA, or Impaired Response Inhibition and Salience Attribution, where drug addicts attribute more importance and relevance to drug-related cues than to non-drug-related stimuli. This newer, more modern view of drug addiction takes into account the impairment of higher-order cognition regions like the OFC, making the issue of drug abuse even more complex and multifaceted than it already is. It is becoming more and
more evident that the circuits involved in drug addiction encompass variety of processes, including those as diverse as inhibitory control, motivation, drive, memory, and learning.

In addition to biological factors, there is also a significant environmental role in drug addiction, which explains why some people who are genetically predisposed to drug addiction never end up developing its symptoms. Monkeys, one of our closest biological relatives, have highly hierarchical social systems in which members of a group are divided into dominant or subordinate categories, often depending on their levels of aggression. Armed with this knowledge, scientists in a 2002 study at the Wake Forest University School of Medicine investigated the effects of social stressors on DA D2 receptors and drug usage in monkeys. First, levels of DA D2 receptors and cocaine self-administration were examined in rhesus monkeys that were placed in isolated housing, where isolated housing is considered a source of stress. After a year and a half, the monkeys were moved into group housing, where they were able to establish a stable social hierarchy. The researchers found that while the subordinate monkeys continued to self-administer levels of cocaine similar to the amounts they administered when they were individually housed, the dominant monkeys reduced their cocaine intake, and even displayed an increase in their level of DA D2 receptors. It is hypothesized that the dominant monkeys, through their ability to control environmental resources like social contact, food, and sex, were able to return to a “normal” neurological state, decreasing their susceptibility to cocaine abuse. In fact, the changes in amount of cocaine intake in the dominant monkeys occurred over a period of merely three months of social housing. This is strong evidence that vulnerability to the abuse of drugs is mediated by factors like social context and environmental stress, which may be as important, if not more important, than genetic predispositions. An additional study has confirmed that social factors have an effect on D2 receptor levels in humans, showing that the presence of social status and support is correlated with increased D2 receptor binding, which is analogous to the higher level of D2 receptors in dominant over subordinate monkeys.

In a noteworthy study, Bruce Alexander, a Canadian psychologist, found that rats trained to self-administer morphine continued to self-administer morphine in isolation, but decreased their consumption when they were moved to an enriched, social environment, which the researchers called “Rat Park.” Rat Park consisted of running wheels, nesting areas, and even colorful walls. Since rats are naturally gregarious and social animals, Alexander hypothesized that the isolated rats would display increased susceptibility to morphine addiction in comparison to the socially enriched rats. In fact, he and his colleagues found that the rats living in cages consumed 20 times more morphine than the rats living in Rat Park. While the inhabitants of Rat Park could be induced to consume more morphine when it was mixed with sugar, an additional experiment found that the rats consumed even more of the mix when naloxone, a morphine inhibitor, was added, suggesting that the rats were only increasing consumption of the morphine-sugar mix in order to obtain sugar, not because sugar concealed the bitter taste of morphine. Although Alexander’s 1978 study garnered little initial response from the scientific community, it nevertheless showed that drug addiction comprises more than simply an addictive effect from drugs. Social and physical environment play important, key roles as well.

Clearly, it is difficult to determine whether neurological changes or environmental factors play a larger role in determining drug addiction. One large risk factor, however, is the age at which drug use begins. Adolescents are particularly vulnerable to drug addiction because their brains are still reorganizing and pruning synapses so as to improve communication among cells. Research has also shown that OFC activity is decreased in teenagers who have experimented with drugs, which indicates that some teens may already be predisposed to drug addiction.

With this added complexity in mind, it is evident that many more years of study will be needed before we can understand how to resolve the multifaceted problem of drug addiction.
Imagine a disease that could strike a person at anytime from the age of 20 until his or her death. Even more frightening, the person’s risk of contracting this disease increases over time. Symptoms start small and insignificant, such as trembling hands and sluggish movements. Over time, symptoms worsen until the individual’s hands are shaking so violently that he or she can no longer decipher his own handwriting. Soon, he begins to find difficulty in forming new memories; eventually, he develops dementia and falls into a deep state of depression. Such a disorder is real, and it goes by the name of Parkinson’s disease (PD).

PD affects approximately seven to ten million people every day, and it costs the United States almost twenty-five billion dollars per year for treatment and social security payments. Experts have discovered that this illness is caused by the loss of 80% of a person’s dopaminergic neurons, brain cells that release the neurotransmitter dopamine, in the substantia nigra, a part of the brain that produces smooth, controlled movements.

Furthermore, it is unknown exactly why these brain cells die, but there are several genetic and environmental factors that may cause PD. Several gene mutations have been discovered that can directly cause PD, but most cases have no genetic explanation. Rather, scientists believe that PD can arise due to a person’s overexposure to environmental toxins, including herbicides and pesticides. Thus, no one is immune to this unforgiving disease.

Unfortunately, there are currently no permanent treatments for PD. The drug levodopa has proven effective in temporarily relieving the symptoms of PD by supplying dopamine to vital brain areas through the conversion of levodopa to dopamine, but over time, resistance to the drug develops until it becomes ineffective. Some researchers have proposed using transcranial magnetic stimulation (TMS) as a means of easing the symptoms of PD. TMS works by continually stimulating and reducing brain activity in the regions most affected by PD. Studies have shown TMS to relieve symptoms for up to three months. However, there is no available method to permanently heal the source of the disease, to repair or to replace the destroyed neurons in the brain. Or is there?

Within the past 20 years, researchers have identified a promising procedure that may cure PD and restore the patient’s brain. This technique requires the differentiation of stem cells into dopaminergic neurons. These neurons are then transplanted into animal models in order to replace those that were damaged by the effects of PD.

This method initially involved embryonic stem cells because of their ability to become any type of cell in the human body, including dopaminergic neurons. However, this practice was questioned and discontinued due to the ethical controversy of using embryonic stem cells in research. Fortunately, induced pluripotent stem (iPS) cells were developed. iPS cells are adult somatic stem cells that have been genetically modified to express the characteristics of embryonic stem cells. They have the capabilities of embryonic stem cells but without any of the controversy. As a result, research using differentiated stem cells was allowed to continue.

This new procedure for defeating PD occurs in three steps. First, the researchers create a plasmid, which is a single-stranded, circular string of DNA. They then insert the genetic sequence for transcription factors that are needed for cell differentiation into the plasmid. These transcription factors are a special type of protein that activates and regulates the genes in a cell. The researchers usually place a marker, such as green fluorescent protein (GFP), inside the plasmid to help them track which cells have undergone differentiation. Therefore, phase one is the creation stage: a vector is created by which the code for transcription factors can be inserted into the stem cells.

Next, the researchers must insert the plasmids into the iPS cells. Scientists have a variety of methods to accomplish this, including transfection. Transfection is the process by which foreign genetic material (in our case, the vector) is implanted into the host cell. This is accomplished by
creating tiny pores or holes in the cell’s surface through which the vector can enter. Transfection is commonly used because it is efficient and does not harm the host cell. Once inside, the vector enters the nucleus, and its transcription factors are transcribed, which leads to the activation of genes needed for differentiation into dopaminergic neurons. The markers, such as GFP, are also activated and allow the researchers to observe which cells have been transfected because those cells will appear bright green when examined under a black light. Thus, phase two of the procedure is the insertion stage: the vector is implanted into the cell’s nucleus, and its transcription factors activate the genes required for differentiation into dopaminergic neurons.

Over time, the differentiated cells undergo numerous morphological changes: they begin to secrete dopamine, to exhibit electrical activity, and to resemble neurons in appearance. Ultimately, the researchers reach the final stage in the experiment. The scientists select animals with PD and inject the developed neurons into their substantia nigras. The animals are assessed regularly to discern whether their motor functioning is returning to normal. After the animals die, researchers slice their brains and investigate how well the implanted neurons integrated with the rest of the brain. Experiments have shown that after undergoing this procedure, diseased animals perform similarly to normal animals in numerous behavioral tests that test motor function and coordination. In addition, fluorescent microscopy shows the injected neurons, which exhibit a bright green color due to the GFP, connect very effectively with the surrounding neurons. As a result, phase three, the testing stage, is complete: the induced dopaminergic neurons are able to improve motor skills in animals by seamlessly integrating themselves with the original neurons.

Thus, this process of cell differentiation and neuron implantation is very promising for further research and for clinical treatment of PD. But why stop there? This method may eventually be able to treat any neurological disease that is caused by cell loss. Alzheimer’s disease, Huntington’s disease, and Lou Gehrig’s disease could soon also be disorders of the past. However, before we jump too far ahead of ourselves, research still needs to be conducted to determine the long-term safety and efficacy of these cells. Are more transplanted neurons better? Will they lead to overpopulation and give rise to further complications? Could this process of differentiation be conducted inside the animals’ brains to save money and resources? Nevertheless, this technique is a huge leap forward in the battle against neurological disorders.
The folk tale of John Henry’s contest with the steam engine—a dramatic pitting of man against machine—still captivates the imaginations of American innovators today. According to popular legend, the invention of a steam-powered hammer in the mid-nineteenth century threatened to supplant the laborers involved in the expansion of the railroad lines across the continental United States. John Henry, a worker renowned for his strength and skill in steel-driving, challenged this threatening new device to a test of speed. Though he emerged victorious from the race, the struggle left him utterly spent: he is said to have died with his hammer in his hand. Nonetheless, Henry’s tragic conquest of his mechanical adversary symbolizes an overarching conflict: the irreplaceability of human persistence, determination, and ingenuity in the face of society’s scientific forward march.

Over a century since John Henry’s legendary struggle, today’s healthcare professionals are en-
countering an evolving contest in the medical field—that of the trained human physician against the computerized diagnostic database. Popular perspectives have arguably shifted in favor of unbridled technological advancement. The notion that computers may contribute substantially to improvements in the efficacy of healthcare delivery invariably meets with little resistance in our age of digital devices, smart handheld electronics, and wireless nanotechnologies. In the past several decades, the medical implementation of intelligent support systems has virtually exploded, driven by a virtually unprecedented avalanche of health data. As the healthcare sector itself has grown in size, scope, and complexity, the modern medical professional has had to manage more information than ever before, a trend that has also coincided with the increasing availability and appeal of computerized applications in the hospital. However, with the introduction of digital decision support systems and artificial intelligence (AI) programs into the clinical setting, new quandaries have emerged: How will advances in information technology affect medical practice? Will physicians, nurses, and healthcare providers be replaced by sophisticated computers or intelligent machinery?

Answers to these questions may be rooted in technological history. It wasn’t long after the invention of the personal computer that the first biomedical informaticians began to seek potential implementations of smart technology in hospital wards. The earliest applications of electronic computation in clinical decision support (CDS) devices were laid out in a groundbreaking project at the University of Pittsburgh School of Medicine in 1973. The INTERNIST-I system, a program designed and described by Dr. Randolph A. Miller and his fellow researchers in a 1986 status report, aimed to provide “high-powered diagnostic assistance” to physicians by means of “functionally mimicking the reasoning of an expert clinician.” As a primitive artificial intelligence, the program was fed a veritable encyclopedia of diagnostic data both in the lab and in the clinic; thus, INTERNIST-I was capable of adapting through the assimilation of new inputs into its evaluative framework—that is, learning. Nevertheless, like any early prototype, the program was not without its flaws. INTERNIST-I was soon abandoned as a clinical tool because of its poorly designed interface and excessive reliance on lengthy periods of data entry. Many physicians also viewed the program as defective because it could only work on a single possible diagnosis at any one time.

A subsequent attempt made by University of Pittsburgh researchers to draw upon the automated and algorithmic efficiency of computerized gadgetry took the form of the Quick Medical Reference (QMR) project in the mid-1980s. Designed as a “logical extension” of the INTERNIST-I initiative, the QMR database gave physicians easy access to a user-friendly diagnostic resource, one which contained vital information on upwards of 550 of the most common conditions (“bread-and-butter cases” in medical jargon) observed in day-to-day medical practice. According to Miller’s research team, it “attempt[ed] to overcome many of INTERNIST-I’s deficiencies” by providing a more accessible expert knowledge base, one which catalogued frequently encountered symptoms and diseases rather than merely the most challenging cases. In practice, the QMR project far surpassed its predecessor. By focusing only on the evidence-based findings relevant to each specific clinical problem, it effectively aided physicians in differential diagnostics and subsequent therapeutic decision-making. Though obsoletely and generally out of commission—since the widespread implementation of handheld applications in the new millennium, the QMR project was declared a critical victory for intelligent systems, paving the way for a host of similar CDS programs still in use today.

These early trials, developed at the dawn of the digital age, constituted some of the first organized attempts at integrating novel information technologies into the medical workplace to benefit both patients and practicing providers. Still, an important question remains: what advantages do these innovative knowledge sources confer at present? A ready answer can be found by examining the typical causes of medical error. Diagnostic mistakes may occur frequently in even the most pedestrian of clinical cases. Small oversights, minute failures to properly weigh and assimilate the symptomatic features of an illness, and even seemingly insignificant miscommunications or management problems between hospital staff account for a large number of procedural complications and incorrect prescriptions.

As esteemed surgeon and author Dr. Atul Gawande of Massachusetts General Hospital points out, “It is a central truth in medicine...that all doctors make terrible mistakes.” In an Institute of Medicine report on the incidence of clinical error in 1999, biostatisticians confirmed that “at least 44,000 people, and perhaps as many as 98,000 people, die in hospitals each year as a result of medical errors that could have been prevented.” Iatrogenic harm, the personal damage resulting from the actions of the medical professional, is rarely the consequence of actively malicious intent on the part of the physician. Dr. Gawande underscores this point with an old adage: “To err is human.” However, the fact remains that impulsive or uninformed decision-making in the clinical realm is a perilous endeavor; even the smallest accident can quickly snowball into a full-blown catastrophe. Accordingly, the inherent limitations of human judgment must be taken into account when aiming to remedy the issues posed by misdiagnosis and any resulting malpractice. With such a large number of errors,
informaticians are able to build a weighty case in favor of more widely available, in-depth electronic support for doctors. By introducing digitized databases into common practice, thousands of costly deaths, illnesses, and complications might be successfully averted.

The most important benefits of intelligent CDS technology lie in the computer’s unique capabilities for the analysis, management, and assimilation of large quantities of data via algorithmic control. Indeed, had the fabled John Henry been a modern physician challenging an AI system to a battle of applied clinical knowledge and pure medical information output, he would have been facing a much more formidable foe. Massachusetts Institute of Technology professor Peter Szolovits, in his 2010 lecture on the future role of artificial intelligence in the medical field, outlines three main tasks carried out by physicians—"diagnosis, prognosis, and therapy"—which computerized systems may assist in or, in time, assume altogether. In recent years, innovators have attempted to incorporate a variety of different ideas into the ongoing development of more complex technologies, including modalities for high-throughput analysis of electronic health records and programs which make use of decision trees to supplement physicians’ treatment plans. These systems would extend human abilities by providing a means of screening massive amounts of data at once, allowing for convenient and efficient means of accessing a wealth of detailed health information; additionally, they promise to accelerate the bench-to-bedside transfer of current biomedical research findings by facilitating immediate interaction between medical experts. As a result, physicians—if given the proper training—would be able to harness novel electronic resources to cast a wider net in the detection of disease and the elimination of excess error.

To the modern medical establishment, a lingering concern is one of future coexistence: will man and machine continue to work side by side for the betterment of modern medicine, or will one ultimately come to supersed the other? In the ever-evolving realm of health technology, rumblings of radical change are already being heard on the horizon. As Michael Miliard of Healthcare IT News observed, “Robots are increasingly prevalent in surgical suites...[and] machines can be better at noticing abnormalities on radiology reports than the human eye.” According to the informatics principle of distributed cognition, however, humanity’s creative intellect achieves its fullest potential, when coupled effectively with computerized backup. This leads most informaticians to reflexively dismiss the notion that an artificial intelligence-based CDS system could ever completely replace its human counterparts in the diagnosis and treatment of disease. At the bare minimum, Miliard and most healthcare technology experts agree that computers will foreseeably always require “flesh-and-blood supervision” to function effectively when interacting with patients.

Meanwhile, a smaller—though equally vocal—contingent of forward-looking CDS proponents contend that intelligent programs such as IBM’s Watson database, a highly sophisticated supercomputer armed with natural language processing modalities and the capacity to learn nuanced information for future application, will eventually develop heuristic abilities through sheer exposure to new inputs. In other words, advanced devices will soon come to truly contextualize and “comprehend” the problems which they so easily solve. In a widely publicized 2011 Jeopardy! contest, Watson handily defeated two reigning champions at their own game; this subsequently inspired a host of futurists and AI enthusiasts to ponder what sort of applications could be found for computer technologies in the coming years. In medicine, it has been postulated that a system like Watson could have a powerful impact on the efficiency and accuracy with which differential diagnoses and treatment options are evaluated. Dr. Kent Bottles, a public health expert at the Thomas Jefferson School of Population Health, puts the contrast between basic human cognitive capacities and Watson’s formidable processing power into stark perspective: "Neuroscience teaches us that the most brilliant human can only keep seven items straight in his head at once. Watson can take a question about a patient’s symptoms, analyze it, generate a differential diagnosis, collect and evaluate the entire medical literature on the subject and come up with a diagnosis with a measurable level of confidence.”

Others speculate that artificial intelligence will eventually become developed enough to allow patients to form trusting relationships with sociable humanoid robots. Emotive machines—those capable of detecting, registering, and responding to visual and auditory emotional cues—have already been developed by visionary engineers and independent corporations in the United States, Japan, and elsewhere. If the sensitivities of these robots were complemented with Watson’s sheer problem-solving genius, eager futurists opine, a new generation of computerized doctors could eventually come to dominate the medical landscape entirely.

For the moment, however, clinical decision support systems serve humbly as technological assistants in diagnostic error analysis and information management, quietly being implemented behind the scenes as we proceed into the twenty-first century—and hardly resembling the menacing steam-driver John Henry’s tale. On the contrary, with steady advancements in digital health technology, benevolent electronic entities like Watson may become increasingly commonplace in clinical medicine, lend a wider array of capabilities to the medical professionals who work alongside them, and significantly improve clinical outcomes in the process.
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