

# DUJS

Dartmouth Undergraduate  
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NO. 3

## PAST AND FUTURE OF SCIENCE

*Looking at science through the lens of time*

### Computer Graphics: Then and Now

Faculty interview with Jon  
Denning, Ph.D candidate

p. 5

### Cocaine for Toothaches

A look into the rich history of  
cocaine and amphetamines

p. 24

### Forecasting with Neural Networks

Training machine learning  
algorithms to predict the weather

p. 33

## About the cover

Photo by Joseph Mehling '69

Comments on the cover by Professor Emeritus Jay Lawrence

There can be nothing better, in one's present work, than bringing together the past and the future. Part of the writing on the blackboard (some equations and all diagrams) is about quantum effects in the buckling of tiny fabricated beams. My collaborators in this work were Professor Martin Wybourne and a postdoc, Stephen Carr. We made use of the seminal work in elasticity theory by Leonard Euler, known for his classical theory of the buckling of (large) beams, and we had the pleasure of citing the oldest work that any of us had ever cited (1). It was humbling to contemplate the range and power of Euler's accomplishments, particularly his facility with the nonlinear aspects.

The remaining scribbling is about a new subfield of science, quantum information, which includes studies of a quantum computer (which may lie in the future of science, but nobody knows for sure), and quantum cryptography (which exists in the present and has a promising future as well). People who work on quantum information, as well as on the foundations of quantum theory have gained a new appreciation of the writings of Einstein (2) and Schrödinger (3), not because they were among the discoverers of quantum physics, but because of their skepticism! - their belief that quantum theory could not be right too far from the atomic realm (that is, for things too big, or even for small objects too far apart). This skepticism was not shared by most of their colleagues, and their papers of 1935 which gave voice to the skepticism were largely ignored and unappreciated by the larger community (4).

But not any more! For about the last 30 years, people have been able to perform experiments that probe more deeply into the phenomena that quantum theory predicts, such as entanglement - the correlations between far-separated objects that appear to violate relativistic causality and require instantaneous action at a distance. (The term entanglement was actually coined by Schrödinger in 1935.) These experiments have shown that quantum theory indeed applies beyond the limits imagined by Einstein and Schrödinger, showing that their intuitions had been wrong. Quantum theory has proven correct far beyond their expectations. But their arguments of 1935 were so good, and laid out the issues so persuasively, that they helped us appreciate how truly remarkable such quantum phenomena are, and they helped inspire the last 30 years of efforts, not only to push the limits of observable quantum phenomena, but also to harness the nonclassical, counterintuitive aspects to useful purposes. Indeed, entanglement is a key feature of quantum cryptographic protocols, as it would likely be of a future quantum computer. One could say of the 1935 papers that the metaphysics of the past became the physics of the future.

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4. In the opinion of an Einstein biographer, [Abraham Pais, *Subtle is the Lord*, Oxford U. Press (1982)], Einstein made no important scientific contributions after 1925.

Jay Lawrence is currently a Professor Emeritus of Physics and Astronomy at Dartmouth College. He taught at Dartmouth College from 1971 to 2011 and his research interests include theoretical condensed matter and quantum information science.

# Note from the Editorial Board

Dear Reader,

This year marks the 15<sup>th</sup> anniversary of the *Dartmouth Undergraduate Journal of Science*. Since our founding in 1998, the *DUJS* has helped unify the undergraduate science community at Dartmouth. We provide an interdisciplinary forum to share research and to inspire students to pursue the sciences and science writing. To this end, the past year has been an especially busy time for the *DUJS*. We have focused on expanding our influence beyond Hanover. Last spring, we launched our International Science Essay Contest for high school students and received over 80 submissions from 20 countries. Additionally, the *DUJS* has expanded its readership over the past year. We now distributed our print journals to over 20 universities and several countries overseas including Tsinghua University in Beijing. Our new website, [dujs.dartmouth.edu](http://dujs.dartmouth.edu), has also begun receiving visits from viewers all over the world.

To match these expansions, our staff and editorial board membership has increased. This has allowed us to expand our content, beyond Dartmouth-related news, to include general science news, feature stories, and comics, all updated on a weekly basis online. New designs for our journal have also been implemented, with our expanded design staff. This 15<sup>th</sup> anniversary thus marks a high point for the *DUJS*. Looking back to our first issue, we are encouraged that the next 15 years of Dartmouth science will be as great as the past 15.

The theme of this commemorative issue is “The Past and the Future of Science.” The articles in this volume look at the past, present and future of a variety of topics in the sciences. Shawn (Yifei) Xie talks about the evolution of space programs. Yi (Annie) Sun describes the timeline of energy in the United States. Harrison Han dissects the history of epidemics. And Michael (Siyang) Li addresses advances in Moore’s Law. Olivia Dahl also analyzes the effect of psychostimulants on human physiology, and Mackenzie Foley reviews the development and future of genetics. Our interview of this issue features Jon Denning, a Ph.D candidate in the Dartmouth Computer Science Department. Denning’s research interests focus on studying 3D content creation and design workflows (primary focus), material visualization, and the perception of lighting and shadows.

This issue we also feature three external original research submissions. Dartmouth students Chris Hoder and Ben Southworth describe forecasting precipitation in Hanover, NH using neural networks. Benjamin Kessler, Milo Johnson and Wales Carter focus on the nature of interactions between *Nasutitermes ephratae* and *Eciton burchelli*. And Jonathan Guinther describes the process of mapping river flow with sensor swarms.

The growth of the *DUJS* over the years is a direct consequence of the hard work and dedication of countless writers, editors, staff members, and faculty advisors. We would like to take this opportunity to thank all of our contributors for helping make another excellent year.

Thank you for reading the *DUJS*, and we hope you enjoy this issue.

Sincerely,  
*The DUJS Editorial Board*

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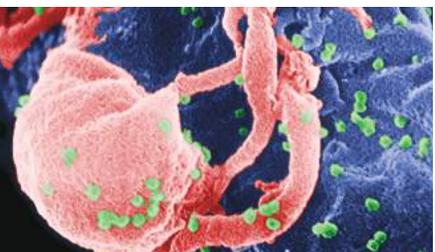
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# Table of Contents



**Science News** ..... 3

*Compiled by Scott Gladstone '15*

**Computer Graphics: Then and Now  
An Interview with Jon Denning, Ph.D candidate** ..... 5

*Alexandra Dalton '16*

**A Universal Look at Space Programs** ..... 8

*Shawn (Yifei) Xie '16*

**The Evolution of Energy in the United States** ..... 12

*Annie (Yi) Sun '16*

**A Review of Global Epidemics** ..... 16

*Harrison Han '16*

**Keeping Up with Moore's Law** ..... 20

*Michael (Siyang) Li '16*

**Psychostimulants: Cocaine for Toothaches and  
Amphetamines for All-nighters** ..... 24

*Olivia Dahl '14*

**Genetics: Past, Present, and Future** ..... 29

*Mackenzie Foley '16*

## SUBMISSIONS

**Forecasting Precipitation in Hanover, NH Using  
Neural Networks** ..... 33

*Chris Hoder '13 and Ben Southworth '13*

**On the Nature of the Interactions between  
*Nasutitermes ephratae* and *Eciton burchelli*** ..... 40

*Benjamin Kessler '13, Milo Johnson '13 and Wales Carter '13*

**GreenCube 5: Mapping River Flow with  
Sensor Swarms** ..... 43

*Jonathan Guinther '13*

# RECENT DISCOVERIES THROUGH SCIENCE

COMPILED BY SCOTT GLADSTONE



Retrieved from <http://en.wikipedia.org/wiki/File:Pakkanen.jpg> (accessed 30 April 2013)

**Figure 1:** A thermometer measures a cold temperature on a winter day. The measured temperature of negative 17 degrees Celsius, or 1.4 degrees Fahrenheit, is 256.15 degrees higher than absolute zero.

## SCIENTISTS ARE TRYING TO CREATE A TEMPERATURE BELOW ABSOLUTE ZERO (*Smithsonian*)

In the middle of winter, it is not uncommon to see the temperature dip below zero degrees on the Fahrenheit or Celsius thermometer, indicating the need to “bundle up” for the cold days ahead. However, the temperature can be driven even further down to a lower limit of “absolute zero,” a barrier enforced by the laws of physics.

Absolute zero occurs at zero Kelvin, which is equal to negative 458.67 degrees Fahrenheit or negative 273.15 degrees Celsius. At this point, all atomic and molecular motion stops; however, this absolute “coldest point” does not tell the full story. Temperature is also dependent on how particles are distributed within a system, which determines the level of entropy in the system. By definition, a system of high disorder, or high entropy, has a higher temperature (1).

A team of researchers at Ludwig-Maximilians University of Munich in Germany succeeded in manipulating a cloud of 100,000 potassium atoms into an arrangement that mathematically indicates a negative temperature on the absolute scale. In short, the team achieved this result by creating a system with high energy and low entropy, effectively “tricking” the equation for temperature into producing a negative value despite actually having a very “hot” gaseous cloud (2).

The researchers explained their methods by comparing their experiment to particles on a landscape where the height of a hill or valley represents the entropy of the system. At absolute zero, the particles have no energy and no motion, so they are at the bottom of the valley with minimum entropy. As the gas heats up, some particles gain more energy than others, so they begin to distribute themselves along a hill. According to the entropy-derived definition of temperature, “the highest positive temperature possible corresponds to the most disordered state of the system...[with] an equal number of particles at every point on the landscape. Increase the energy any further and you’d start to lower the entropy again, because the particles wouldn’t be evenly spread.” In principle, the researchers argued, it should be possible to achieve negative temperatures by increasing the energy of the particles while driving their entropy down (1).

The team tested this theory by cooling the atoms to very low temperatures and using lasers to place them along the curve of an energy valley with the atoms repelling one another. Then, the team did two things to turn this positive temperature system to dip below absolute zero: “they made the atoms attract [instead of repel] and adjusted the lasers to

change the atoms’ energy levels, making the majority of them high-energy, and so flipping the valley into an energy hill. The result was an inverse energy distribution, which is characteristic of negative temperatures.” Effectively, the team trapped all of the particles at the top of a hill by having them attract one another, yielding a low entropy and low kinetic energy system. According to the Ulrich Schneider, one of the team’s leaders, the atoms cannot lose energy and “roll down” this hill because doing so would require them to increase their kinetic energy, which is impossible in a system without an energy source. Schneider states, “We create a system with a lot of energy, but the particles cannot redistribute their energy, so they have to stay on top of the hill” (2).

This “trick” created a system that fell below absolute zero not because it was “colder” than the motionless absolute zero, but because it manipulated the entropy of the system to produce a negative mathematical temperature value (1). The result has tremendous implications in science, especially for fields like cosmology. For example, dark energy, thought to explain the acceleration of the expansion of the universe, exerts negative pressure, which suggests it might have negative temperatures that have never been measured before. “It is amazing experimental work,” says Allard Mosk of the University of Twente in the Netherlands, who originally outlined the theory behind the experiment in 2005.

## NEW VIEW OF PRIMORDIAL UNIVERSE CONFIRMS SUDDEN “INFLATION” AFTER BIG BANG (*Scientific American*)

New images of cosmic microwave background radiation from the European Space Agency’s (ESA) Planck telescope have shed light on the universe in the moments immediately following the Big Bang. Of the most interesting discoveries, scientists now peg the age of the Universe at 13.81 billion years, approximately 80 million years older than previously believed (3).

“For cosmologists, this map is a goldmine of information,” says George Efsthathiou, director of the Kavli Institute for Cosmology at the University of Cambridge, UK, one of Planck Observatory’s lead researchers. The microwave map strongly supports the theory of inflation, the process by which the universe expanded at an immense rate in the 10 to 32 seconds immediately following the Big Bang. According to the researchers, inflation would explain why the universe is so large and why we “cannot detect any curvature

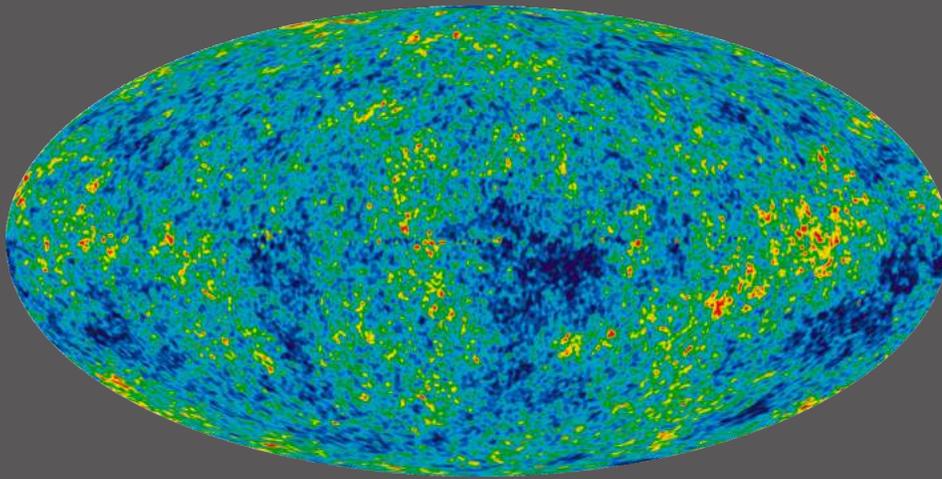


Image retrieved from [http://en.wikipedia.org/wiki/File:Ilc\\_Pyr\\_moll4096.png](http://en.wikipedia.org/wiki/File:Ilc_Pyr_moll4096.png) (30 April 2013)

**Figure 2:** A cosmic microwave background (CMB) image of the universe reveals 13.77 billion-year-old fluctuations in temperature (shown as color differences) that correspond to the seeds that grew to become galaxies. The microwave image of the infant universe was created from nine years of WMAP data.

in the fabric of space (other than the tiny indentations caused by massive objects like black holes)" (3).

The Cosmic Microwave Background, or CMB, measured in these new results was first detected in 1965 and has since been mapped by the Cosmic Background Explorer (COBE) and the Wilkinson Microwave Anisotropy Probe (WMAP). The new mapping of the CMB by the Planck Observatory is more than three times more sensitive than those of its predecessors, such as WMAP, and has allowed scientists to explore a multitude of cosmological theories, including dating the Big Bang, estimating the amount of dark matter in the Universe, and obtaining a rough measure of the "dark energy" that is accelerating the expansion of the Universe.

Other major results released by the Planck Observatory include that the universe is expanding slightly slower than previously estimated, meaning that the rate, known as the Hubble constant, is actually 67.3 kilometers per second per megaparsec. Additionally, the recent CMB analysis has revealed that dark energy comprises 68.3 percent of the energy density of the universe, with the contribution of dark matter increasing from 22.7 percent to 26.8 percent and the contribution of normal matter at less than 5%. The team expects to release their next tranche of data in early 2014, following current ongoing analyses (3).

## MUMMIES REVEAL THAT CLOGGED ARTERIES PLAGUED THE ANCIENT WORLD (*Nature*)

A clogged artery is a notable symptom of a modern, unhealthy diet. This fact, commonly noted by the media, has become a staple warning for conditions such as heart disease and is continually reinforced with analyses ranging from epidemiology research to documentaries such as "Supersize Me." However, a recent study suggests that

perhaps clogged arteries are not exclusively attributable to the international fast-food culture. A study of ancient mummies suggests "the condition was common across the ancient world, even among active hunter-gatherers with no access to junk food" (4). "There's a belief that if we go back in time, everything's going to be okay," says cardiologist Greg Thomas of the University of California Irvine, a senior member of the study team. "But these mummies still have coronary artery disease" (4).

Heart conditions such as heart attacks, stroke, and other cardiovascular diseases are the leading cause of death in the world today (4). These conditions occur as a result of excessive build-up of plaques comprised of cholesterol and macrophage immune cells in arterial walls. The clogging process is facilitated by an aggregation of "bad cholesterol," which accumulates faster in a lifestyle with a lack of exercise and a diet high in saturated fat. This belief has led to the suggestion that we should try to live "more like our hunter-gatherer ancestors, on a diet of unprocessed foods high in protein and unsaturated fats" (4).

To test that hypothesis, Thomas and his colleagues performed CT scans on 137 mummies from a variety of ancient populations. Their sample contained ancient Egyptian, Peruvian, Pueblo, and Unangan (Aleutian Islands, Alaska) individuals, all of whom had led very different lifestyles. For example, the Ancestral Puebloans were forager-farmers, according to the study, while the Unangan were hunter-gatherers with an "exclusively marine diet" (4). After the scans, the researchers looked for calcified plaques in artery walls and diagnosed "probable or definitely atherosclerosis," the condition of aggregating cholesterol that leads to major heart conditions.

What the researchers found was what Thomas simply referred to as "a shock." They diagnosed atherosclerosis in 47 of the 137 mummies (34 percent of the sample size), and found the condition in all four populations:

25 percent of the 51 ancient Peruvians were found with the condition, as well as 60 percent of the five Unangans. While the team had previously found indications of atherosclerosis in a population of ancient Egyptians, experts argued that these were elite individuals who lived on what was likely to be a rich and fat-heavy diet. In this new study, the team scanned individuals they believed to be "common men and women," and found that they had the same incidence of atherosclerosis as their elite counterparts.

Other scientists and field experiments have responded to this study with mixed reviews. Atherosclerosis pathologist Michael Rosenfeld of the University of Washington, Seattle points out that, in animal studies, atherosclerosis "does not develop without high levels of fat in the blood—whether as the result of bad diet or of bad genes," (4). He hypothesizes that perhaps the ancient mummies suffered from other conditions such as high levels of inflammation, kidney disease, or osteoporosis, which are also associated with build-up of plaque in arterial walls. "I still strongly believe that modern lifestyles have a lot to do with the development of atherosclerosis," Rosenfeld says. In response, Thomas and his colleagues state that cardiovascular disease is likely more than "simply a consequence" of an unhealthy lifestyle. "We've oversold the ability to stop heart disease," he says. "We can slow it down, but to think we can prevent it is unrealistic" (4).

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## Computer Graphics:

Then and Now

# An Interview with Jon Denning



Image courtesy of Jon Denning

BY ALEXANDRA DALTON

### Introduction

The field of digital graphics was founded with the principles of traditional 2D drawing and was vitalized by technology, epitomizing the harmonious union of art and science. Digital graphics drew upon pre-existing mathematical tools and principles, such as geometry, calculus, and matrices. The early developmental stages of computer graphics were marked by advances in early computing. These advancements included a key contribution by Dartmouth College, with the invention of the computer language BASIC in 1964 by John G. Kemeny, later president of the College, and Thomas E. Kurtz.

One of the first scientists to toy with the idea of an interactive computer graphics program was Ivan Sutherland, often called the “grandfather” of computer graphic generation (3). Using his programs, computer graphics could be more readily integrated into the areas of engineering and design. One such program published in 1963, called Sketchpad, represented a major breakthrough in the field of computer graphics. With this program came a pivotal demonstration of the potential for human interaction in the creation of computer graphics, as well as the potential for graphics to be used for both scientific and artistic purposes. This breakthrough set the tone and pace for future innovation (3).

Some of the most popular products currently being used in computer graphics at both the professional and amateur level include Maya and Cintiq. Maya is a commonly used modeling package that artists can use to create and manipulate meshes. The term “mesh” in computer science refers to visual representations of shapes through complex polygonal constructions. Cintiq, a product developed by

Wacom, is a tablet hybrid designed to allow the user to draw directly on the screen itself with a pressure-sensitive stylus. These products not only facilitate the creation and manipulation of graphics, but are also accessible to a variety of users. Customization is a key feature of Maya and Cintiq, so both provide a personalized platform for artistic expression. These two programs are examples of today’s basic tools in computer graphics.

Although computer-generated films and the incredibly complex artwork they showcase often leave audiences in wonderment, rarely is awe and praise directed toward the technology that brings this art form to life. One of the developers behind the technology that facilitates artistic expression in a digital medium is Dartmouth’s Jon Denning. The primary focus of Denning’s research is computer graphics. Through his studies, he seeks to support artistic expression by removing the obstacles created by the technology that digital artists use in order to generate computer graphics. The construction of polygonal meshes, for example, is incredibly complex and involves “tens of thousands of individual operations.” Denning’s research, especially through the project MeshFlow, focuses on the interactive visualization of mesh construction sequences (2). The researcher hope to streamline the artistic process through technological innovation, as Denning describes below in an interview with the *DUJS*.

### Q: When did you first get started in computer graphics?

A: Officially I started 4 years ago in 2009, but I’ve been writing computer graphics for years and years—probably 20 years at least.



**Art and Technology:** Jon Denning works on computer graphics. Denning's research, especially through the project MeshFlow, focuses on the interactive visualization of mesh construction sequences.

**Q: So when you started writing those graphics programs, were you creating them from scratch?**

**A:** Yes, computers have come a long way.

**Q: How would you compare these programs to the ones Pixar and other animation houses are using?**

**A:** Well, Renderman and its predecessors were your typical ray-tracing algorithms that cast a ray into the scene from the camera and bounce around to try to see what the camera is able to see. What I was typically writing was more like a gaming engine. We would use similar techniques in that we would cast rays out.

**Q: What kind of research are you doing right now?**

**A:** Currently I am working with artists to record what they are doing and develop tools to visualize what they do and then summarize it in a way that enable us to understand how an artist does what he or she does. What tools do they use and what patterns do they follow—do they work on this part of the model or that part of the model or do they hop around a lot? So I'm working on developing tools to be able to visualize and watch how an artist works.

**Q: So would it be translating the visual art into the visualized graphic?**

**A:** No, there are already tools there to do that, such as Blender, which is a free and open source program to do 3D stuff, sort of like Maya, the industry standard. What is nice about Blender is we are able to hook onto it and write code that will spit out what the artist was doing while they're working. These artists are used to working in Blender and nothing changes on their end, it's just saving snapshots of their data as they go. What my program does is that it takes those snapshot and compresses it and then plops it into a viewer that allows you to explore the construction sequence.

**Q: What would be an example of this?**

**A:** For instance, in one project we looked at digital sculpting with a digital block of clay, and we watched how the artist turned it into a face. We know where the virtual camera that allows the

artist to spin this virtual objects is located, and we know which brushes the artist was using. It's like the program Syntiques, which even tracks the pressure of strokes. We are just beginning to see how artists work from a scientific point of view.

**Q: What are you going to do with this information?**

**A:** Presently, we are just trying to tease out some patterns with it. Some future directions include being able to compare the workflow of two artists. If they both start at the same spot and each end up with a product that is supposed to be fairly similar to that of the other, how did the two artists get there and what techniques did one artist use compared to the other?

**Q: What would be an application of this?**

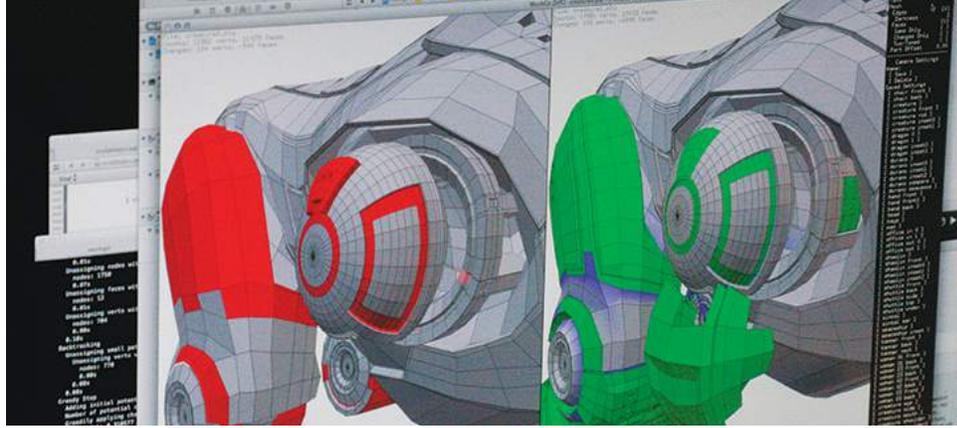
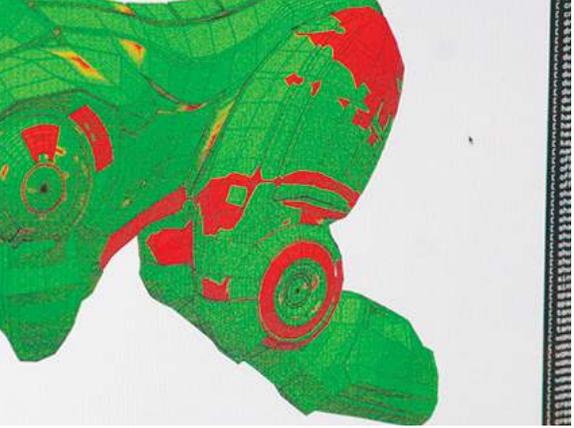
**A:** Well, if you have a teacher and a student, or a master and a novice, and the master produces a tutorial of how to do something for the student to follow, then the program would constantly be comparing the novice's work with the master's work. Feedback would be the immediate application.

**Q: What would you like to see done with this data?**

**A:** Because no one so far has really studied this data yet, it is hard to imagine the kinds of things you'd be able to pull out of it. One thing that I would like to be able to do is to find artists who are using a particular tool in a particular way but maybe don't use some other tool whose utility in the situation is not immediately obvious but obvious through the data. Maybe there is some other tool that is able to push these two tools together in a way that would allow the artists to do their job faster.

**Q: Where did these projects start?**

**A:** One of our first projects was called MeshFlow in which we recorded a bunch of artists. We took tutorials that were online and basically replicated them on a computer. Then we showed the tutorials to digital art students as an experiment for them to try to get some information from an online tutorial. We changed how summarized the information is. Rather than having to click this vertex repeatedly to move here, here, and here, the instruction was condensed to only show all these moves in one shot. So we did that experiment and many of the subjects going through that experiment considered it to be a good replacement for the static tutorial system. Compared to a document or a video medium, MeshFlow is a little more interactive, so if the artists need the extra level of detail to know exactly which vertices to push or they need just the top-level view, that's okay. In MeshFlow they can tailor the information to fit what they need. So that was kind of a starting point on this direction that we're heading toward.



Photos by Jinmyoung Young

**Q: When you're doing this research, do you feel that your ability to answer the question is limited by the technology that exists or are you constantly trying to make new technology to facilitate your project? Are there any limitations in the field right now?**

**A:** Well, one of the limitations that we're, in a sense, solving through these projects is that we want to know what the artists do, but there are very limited ways of getting to that information. So we ended up using Blender and writing instrumentation code for it to spit out snap shots as the artist is working. Once we had all of this data we had to figure out what to do with it, so we had to build a viewer on top of that. In comparing two different artists who are performing the same task, presently, there are a few ways to determine that one artist is working on a part of the mesh that roughly corresponds to the part of the mesh the other is working on, but we needed a lot more than this fuzzy correspondence solution. We needed more than "this part roughly matches to this other part," we needed something that was a lot more discrete like "this vertex matches to this one." And so we know how the movements differ when Subject A moves a vertex and when Subject B moves the same vertex.

I guess the limitation that we're running into is that no one has worked in this area yet, so we're having to develop a lot of infrastructure as we go. If it continues to go as well as it has, it will be very interesting in about five years, after all of this infrastructure has been established and people start to look at the data generated.

**Q: Are these more intuitive tools or control features for the artists?**

**A:** Pixar was one of the first companies to stick the animator into the technology to make the art come alive, but it was only able to do that by working closely with technology. The techs were able to give the animators the tools they needed to express themselves and to tell the story they imagined. So in my view, there could be a tool that could help them in a more intuitive, natural way, unhindered by the limitations of present technology.

There are some new hardware technologies that are coming out that could start working towards this idea, like Microsoft's Kinect, which is basically a sophisticated camera. There is a new Kinect-like device called Leap that doesn't scan the entire room, but scans a small area above your desk. You could have a 3D area or input to be able to manipulate the environment around you, much like the transition from the computer mouse or the trackpad to the full-touch or multi-touch screens. It's the same thing, but being up here in space being able to manipulate the data.

**Q: Like a hologram?**

**A:** Not necessarily, because it's not projecting, but it senses where your hands are—this allows the artist to manipulate the project.

**Q: What else are you working on?**

**A:** Syntique is basically a screen that allows you to use a stylus more like an actual pen. It detects which end of the pen you're using and measures the pressure of your stroke. With the pen, you have a more intuitive input device. It's like your paper-and-pen type of input, but it gives you much more control.

The future of computer graphics is accelerating due to the work of researchers like Denning. By analyzing the artistic process, Denning and his colleagues will facilitate artistic expression through his research, work that will undoubtedly impact the future of graphics. These efforts at Dartmouth are mirrored in the efforts of many attendees of the annual SIGGRAPH conference. The featured presentations showcased advancements that hold promises for the future of graphics. Of note in forthcoming feature films will be the increased realism of complex human hair using thermal imaging, a preview of which can be found in Pixar's "Brave." This is just one small example of the future of computer graphics, for the pace of technological advance is quickening with each new innovation. With the increased availability of graphics software such as Maya and the increased work of researchers such as Denning to make these programs more conducive to artistic expression, in all likelihood the common computer user may one day be as adept at graphics generation as word processing.

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# A Universal Look at Space Programs

BY SHAWN (YIFEI) XIE

*Friday September 21st, 2012 was an exciting day for many Californian aerospace enthusiasts. Camera-holding fans could be spotted atop buildings and bridges, trying to get a glimpse of the space shuttle Endeavour in mid-flight. The shuttle, perched on top of a Boeing 747, left Edwards Air Force Base early morning en route to its permanent resting place at the California Science Center (1). Endeavor's last ride heralded the end of the Space Shuttle Age, as well as NASA's shift toward a new direction in space exploration.*

## Introduction

Although space programs originated as part of the bitter Cold War technological rivalry between the Soviet Union and United States, the roles of these programs have expanded far beyond political demonstrations of military and technological prowess. Dozens of space agencies have sprung up across the globe since the conclusion of the Space Race, and each has come to pursue its own agenda in aerospace research and cosmic exploration (2). The proliferation of these space programs has shed light on many of the mysteries of the universe, but as more of these programs catch up to one another in terms of spacefaring capabilities, the United States again faces significant competition as it strives to reorient its goals and stay ahead of international competition. The recent retirement of its space shuttle fleet and President Obama's cancellation of the Bush-approved Constellation Program have forced NASA to direct the responsibility of low orbital launches to the private sector as it refocuses its attention toward developing a space transportation vehicle capable of sending astronauts deeper into space than man has ever gone before (3).

## Past

### *Origins of Space Programs*

The conclusion of World War II marked the beginning of a new era in global conflict: the Cold War. For decades, this enormous political and ideological rivalry remained the world's predominant source of tension and alarm. The United States and the Soviet Union each sought to prove the superiority of its own scientific achievements, athletic potential, military might, and, by extension, social-political system. Amidst this all-out competition, space exploration emerged as the new arena for both superpowers



**Figure 1:** The Space Shuttle Discovery and its seven-member STS-120 crew head toward Earth-orbit and a scheduled link-up with the International Space Station. The shuttle consists of a spaceplane for orbit and re-entry, fueled by an expendable liquid hydrogen/liquid oxygen tank, with reusable strap-on solid booster rockets.

to demonstrate their respective technological supremacy and guard themselves against rising nuclear threat (4).

### *The Space Age*

Though theories involving space travel had been proposed since the beginning of the twentieth century, the Space Age officially began when the Soviet Union successfully launched the first unmanned satellite Sputnik 1 into orbit on October 4, 1957 (5, 6). The Sputnik mission sparked a fierce “Space Race” that defined one of the focal points of the Cold War and served as the primary motivation for the creation of the United States’ own space agency NASA—the National Aeronautics and Space Administration (6).

After the Soviet Union and the United States successfully launched their first manned spacecrafts—Vostok 1 and Freedom 7, respectively—into space in 1961, the competing nations turned their attention toward landing the first man on the moon (6). NASA began a series of manned Apollo missions beginning in October 11, 1968, and the Soviets followed suit with development of the impressive, albeit flawed, N1 rocket (7). The competition culminated with Apollo 11’s successful touchdown on the lunar surface in July 1969 (4).

With the success of the U.S. lunar missions and the easing of U.S.-Soviet tensions during the 1970s, both of the nations’ space programs lost much of the support and motivation to carry out further ambitious projects (8). Nixon rejected

NASA’s visions for the development of lunar orbit stations and Mars landings by the 1980s, while the Soviets resigned themselves to their loss following four failed lunar launches between 1969 and 1972 (4,6).

### *After the Space Race*

While the two nations continued to use their respective space programs for military purposes, increasing emphasis was placed on less aggressive goals, such as research and mutual cooperation. The U.S. and Russia launched their first space stations in 1973 and 1971, respectively, with the stated purpose of conducting scientific experiments (6). Crews from the two nations met for the first time in orbit as part of the Apollo-Soyuz Test Project in 1975, paving the way for further international missions and the eventual creation of an International Space Station (6). Shortly afterwards, the U.S. also launched two research spacecrafts—Voyager 1 and Voyager 2—to explore the outer solar system, as well as the first Mars probes that marked the beginning of a series of unmanned rover missions to the red planet (6). NASA’s introduction of the space shuttle in 1981 revolutionized space travel, allowing astronauts to glide back to Earth on reusable space vehicles instead of enduring dramatic splash-downs upon reentry (9). Until its retirement in 2011, the shuttle fleet sent American astronauts on a wide range of research experiments and maintenance projects, including satellite repair, resupply missions to the International Space Station, and the orbital launch of the Hubble Space Telescope in 1990 (6,10).

By end of the Space Race, a number of nations around the world also initiated their own space-faring agencies and developed satellite-launching capabilities. While states in Europe collectively established a shared European Space Agency (ESA), countries in Asia were far less cooperative. China, Japan, and India each pursued independent goals and largely built their own programs, ushering in a new rivalry that many perceive as a regional analog to the U.S.-Soviet Space Race (11). For these nations, spaceflight capability served and continues to serve as an extension of their efforts to increase national influence and prestige while checking the powers of neighboring competitors (11).

“Spaceflight capability served and continues to serve as an extension of [a country’s] efforts to increase national influence and prestige while checking the powers of neighboring competitors.”

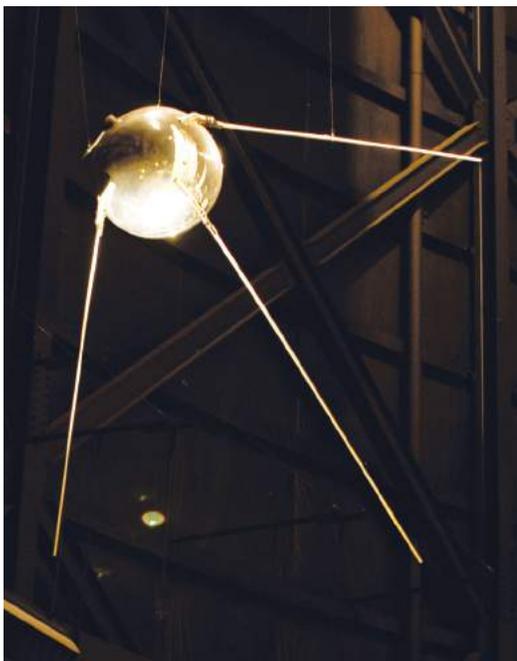


Image courtesy of U.S. Air Force

**Figure 2:** Sputnik I exhibit in the Missile & Space Gallery at the National Museum of the United States Air Force. Sputnik, which means “satellite” in Russian, was the Soviet entry in a scientific race to launch the first satellite ever.

## **Present**

### *A Second “Space Age”*

As more countries, mostly in Asia and the Americas, join the ranks of existing space powers, foreign rocket launch programs and space exploration missions have become more sophisticated and universal. Most notable of these developments occurred in 2003, when the Chinese succeeded in independently attaining manned



spaceflight capability, making it the third nation to do so besides Russia and the U.S. (11). Motivated by the strategic advantages of developing advanced space technology, newcomers such as South Korea, Taiwan, Singapore, Brazil and the Philippines have also introduced government-sponsored space agencies and set their own goals in space exploration. This recent growth in space activity within the international community is distinct from the rivalry of the 1960s between Russia and the United States. While the Cold War Space Race pitted the twentieth century's two greatest superpowers against one another in a relentless struggle to reach the moon, this modern Space Age is a multi-national marathon where each nation is free to set its own pace and strive toward individual goals (11).

### *End of the Shuttle Age and New Discoveries*

While the international community experiences renewed interest and accelerated progress in space exploration, NASA is also in the midst of a dramatic shift in its present missions. The esteemed U.S. shuttle fleet that sent American astronauts on dozens of low Earth orbital missions for the past thirty years finally retired following Atlantis's final touchdown at the Kennedy Space Center in July 2011 (10). The four orbiters now reside in museums of California, Florida, New York, and Virginia, serving as a testament to America's enormous achievements in aerospace technology over the last half century, as well as the challenges and tragedies it faced through the decades (1).

Meanwhile, NASA and the ESA's unmanned exploration programs have enjoyed tremendous success over the past decade. Two of the four Mars rovers launched since 2004 continue to transmit exciting data back to Earth. In particular, the rover Curiosity, which touched down on the Gale Crater in 2012, found clay-rich samples and oxidized carbon compounds in the mudrock of an ancient Martian lakebed, confirming the existence of a wet, life-supporting environment in the planet's distant past (12). On the other hand, the European space probe Huygens successfully landed on Saturn's largest natural satellite, Titan, revealing for the first time an exotic lunar surface once unobservable due to the moon's thick, brown atmosphere (13).

## **Future**

### *NASA: Future Plans*

In response to the Space Shuttle Columbia disaster in 2003, the Bush Administration introduced a new NASA program called the Constellation Project. Constellation oversaw the construction of a fresh lineup of space launch vehicles designed to be safer and have longer range than the agency's previous forms of space transportation. It focused on the development of two main pieces of space technology: the Ares rockets and the Orion crew capsule; these new spacecrafts would succeed the shuttles as the next generation of vehicles carrying astronauts to Earth orbits and eventually onto manned missions to extraterrestrial bodies (14). With the new designs, Bush expected NASA to resume lunar missions by 2020 (15).

**Figure 3:** The International Space Station (ISS) is a habitable artificial satellite in low Earth orbit. It follows the Salyut, Almaz, Skylab and Mir stations as the ninth space station to be inhabited. The ISS is a modular structure whose first component was launched in 1998. Now the largest artificial body in orbit, it can often be seen at the appropriate time with the naked eye from Earth.



Image courtesy of NASA

Seven years later, however, the Obama administration canceled the Constellation Project in light of an independent commission report headed by former aerospace executive Norman Augustine. The Augustine panel concluded that the project had fallen significantly behind schedule and, under present conditions, proved to be financially unrealistic (15). As a result, rather than focusing on a second lunar landing, the president encouraged NASA to transfer the responsibility of supply missions and manned low Earth orbit operations to private American spaceflight firms. However, until the private sector manages to develop the capacity to do so, America will rely on Russian Soyuz spacecrafts to help carry its crew and cargo (16).

Though Constellation is no longer an active program, NASA's plans to realize long-range interplanetary expeditions have remained intact. Under President Obama, the space agency shifted its focus to the development of low-cost, deep-space exploration vehicles, which would allow for a manned asteroid mission followed by an expedition to Mars (14). Funding has been redirected toward designing a modified version of the Orion project which, in conjunction with the agency's new proposal to create a universal launch vehicle called the Space Launch System (SLS), aims to send astronauts beyond low Earth orbit by 2021 (3).

Obama hopes these shifts in NASA's priorities will allow astronauts to travel beyond the range of the phased-out space shuttle sooner than would be permitted by Constellation's prior schedule (15).

### *International Potential*

American interest in once again attaining long-distance spaceflight ability faces significant international competition. China, India, Russia, and private spaceflight firms outside the United States have all set similar deadlines for the developing deep-space exploration technology and time frames for launching their respective extraterrestrial expeditions (16).

Aside from garnering national prestige and laying down the foundation for more advanced space missions, these nations and corporations are also captivated by the promise of extractable rare materials and the potential for economic profit. Researchers theorize that available precious minerals and Helium-3 isotopes on the lunar surface, for example, could lead to highly profitable gains and energy production (16).

### **Conclusion**

Despite their origins as an extension of the Cold War, space programs have grown to signify much more. Already, space-faring agencies around the world operate hundreds of satellites, spacecrafts, and scientific instruments that

have vastly improved human communications, demonstrated mankind's innovations in technology, and unveiled numerous mysteries of the cosmos. Their future missions and goals create boundless potential for scientific and societal achievements in the next several decades. As more nations set their sight on space as the final frontier, the capacity for international collaboration in scientific development remains high and, the future can, quite literally, be considered an exercise in looking toward infinity and beyond.

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# The Evolution of Energy in the United States

Image courtesy of Jean-Pol Grandmot. Retrieved from [http://upload.wikimedia.org/wikipedia/commons/0/02/Hotton\\_JPG08.jpg](http://upload.wikimedia.org/wikipedia/commons/0/02/Hotton_JPG08.jpg) [accessed 30 April 2013]

BY ANNIE (YI) SUN

**Figure 1:** Waterwheels were an early example of renewable energy.

## Introduction

The average American consumes the energy equivalent of seven metric tons of oil every year (1). The amount of energy consumed by Americans has increased over the years, and technology available to Americans has changed accordingly, raising the standard of living of those in the United States.

However, the problems associated with limited fossil fuel resources and the consequences of using them have also continued to grow. Energy will remain a focus of our national consciousness, with a growing emphasis on sustainability and energy independence.

## The Past

In the 1700s, most of the energy in the colonial United States was derived from renewable sources. Domesticated animals, such as horses and oxen, were used for transport, and waterwheels, along with wood combustion, were used for cooking and heating (2).

Gradually, technological advances spurred the young nation towards the use of coal, and later, oil. At the dawn of the Industrial Revolution, steam-powered machines used in industry and transport replaced wood as the dominant form of energy in the United States (2). A step up from steam-powered machines, electrical energy could be generated from coal and transported beyond the site of generation (2). Demand for coal consequently spiked.

By the early to mid-1900s, however, other efficient sources of energy began to supplant coal.

In many ways, oil and natural gas were easier to handle and to transport. In addition, compared to coal, oil and natural gas were cleaner sources of fuel (2). By the mid-1900s, the demand for oil and gas surpassed that of coal, ending its century-long dominance (2).

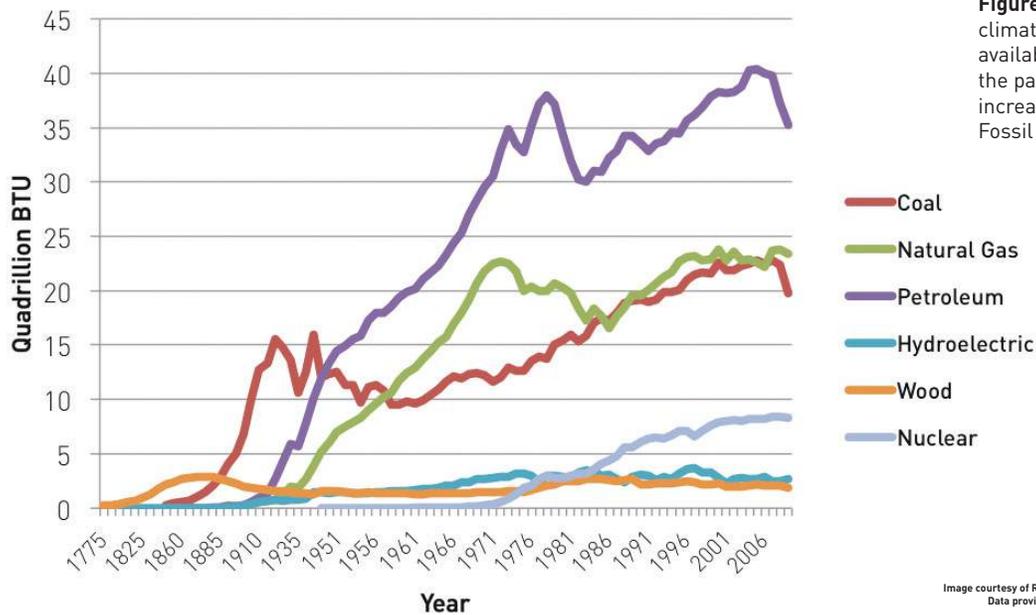
This demand continued to grow until the mid-1970s, when economic downturns and price manipulation contributed to shortages of oil and natural gas and caused spikes in fuel prices that have persisted even to this day. However, growth eventually resumed and continued until the financial crisis of 2008 (2).

In the midst of the United States' growing appetite for oil, nuclear power was first commercially produced in the 1950s. It found rapid increases in production by the 1970s as oil and natural gas began to look less like reliable resources (2).

The popularity of nuclear energy has grown, steadily, but disasters such as the Three Mile Island accident in 1979 and Chernobyl in 1986 have limited nuclear energy's progress through social pressures and safety concerns (2). In addition, nuclear waste is remarkably difficult to dispose of safely, as radiation persists through the decay of the radioactive isotope. Often, governments must store the waste in deep geological repositories to keep it isolated until it has decayed to a safe amount and is no longer radioactive (3).

As the concern relating to climate change, pollution, and the limited availability of fossil fuels has increased in the past several decades, there has been an increasing shift towards renewable energy. Since 1995, wind power has represented the

## HISTORY OF ENERGY CONSUMPTION IN THE U.S., 1775 TO 2009



**Figure 2:** As the concern relating to climate change, pollution, and the limited availability of fossil fuels has increased in the past several decades, there has been an increasing shift towards renewable energy. Fossil fuels still remain dominant.

Image courtesy of Rebecca Xu  
Data provided by EIA

most rapidly growing resource with an over 2000 percent increase (2). However, it still represents less than 0.75 percent of the nation's energy supply (2).

Since 1995, solar power has grown 55 percent due to the rapid fall of solar panel prices and advances in solar panel technology (2). Geothermal energy has grown nearly 27 percent in a similar time frame. The largest portion of renewable energy, however, still comes from biomass and hydroelectric sources (2).

### The Present

To a large degree, the United States still depends heavily on fossil fuels, much of it imported from overseas. The United States imports approximately 20 percent of its total energy needs (4). In March 2011, it imported \$420 billion dollars worth of oil; the United States has been the world's biggest importer of oil for decades (5,6).

A variety of factors indicate that available fossil fuels are insufficient for the world's needs. Governmental action against rampant drilling and probing for new sources of oil and natural gas, foreign wars and national instability, and terrorist activities have underscored the growing demand for energy (5). In addition, emerging economies such as China and India are developing an appetite that cannot be satiated by the current production levels of crude oil.

To mitigate the effects of these challenges on the United States' energy supply, the country is actively pushing for advances in renewable energy technology (7). As defined by the Energy Policy Act of 2005, renewable energy is "electric energy generated from solar, wind, biomass,

landfill gas, ocean [...] geothermal, municipal solid waste, or new hydroelectric generation capacity achieved from increased efficiency of additions of new capacity at an existing hydroelectric project" (7).

The solar capacity of the United States in 2012 was 2,000 megawatts, thanks in part to dramatic decrease in prices in solar energy technology; for instance, solar modules are 75 percent cheaper than they were four years ago (8). Solar power stems from four primary technologies, two of which involve creating electricity and two of which involve thermal energy (7).

In solar panels, photovoltaic (PV) cells involve the conversion of sunlight into electricity via photovoltaic modules--arrays composed of individual cells installed on or near a building. A power inverter converts the direct current (DC) electricity made by the PV cells to alternating current (AC), the form in which electric power is delivered to businesses and residences (7).

PV systems are found across the world and can convert 10 percent of surface-striking solar energy to usable electricity (7). In recent years, the development of thin-film PV cells has reduced the price of solar panels; unfortunately, the new technology has proven more difficult to mass-produce (9).

Solar power can also generate electricity without utilizing PV cells. Instead, solar panels can generate electricity by reflecting the sun's energy onto a receiver, creating high temperatures used to power a conventional electricity-producing turbine (9). This method creates large amounts of electricity but requires large areas of land to deploy (9).



## U.S. ENERGY CONSUMPTION BY SOURCE

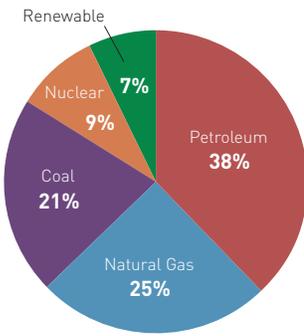


Image courtesy of Rebecca Xu  
Data from the U.S. Energy Information Association

**Figure 3:** The United States imports approximately 20% of its total energy needs. In March 2011, it imported \$420 billion dollars worth of oil; the United States has been the world's biggest importer of oil for decades.

## WHAT ARE SOURCES OF RENEWABLE ENERGY?

- Solar
- Wind
- Geothermal
- Biomass
- Biogas
- Hydroelectric
- Ocean

The two other forms of solar power involve the creation of thermal energy. In the first, a collector absorbs and transfers heat from the sun to water, which can be stored in a tank and used in domestic settings. A more complex form of this system involves active solar heating systems that use circulating pumps and controls. These allow for greater efficiency but are more expensive (9).

Finally, in solar ventilation preheat, solar power can be used to heat air before it enters a building. This decreases the energy burden of central heating systems. A transpired collector—a dark, perforated metal wall—is installed on a south-facing side of the building, creating about a six inch gap between the collector and the building's structural wall. Outside air is drawn through the perforations, the air is heated by the wall's warmth, and the air is drawn into the building's air duct system (9).

Beyond solar energy, another renewable source of energy is wind energy, which is harvested via turbines that spin an internal shaft connected to a generator. The generator creates electricity, the amount of which depends on the size and scale of the turbine (9). Last year, the combined investment in wind and solar power totaled \$280 billion dollars (8).

An interesting side effect of wind turbines has been termed the "Wind Turbine Syndrome," which involve reports of insomnia, headaches, and stress for residents living near wind turbines (10). These symptoms likely represent a "nocebo" effect: after wind turbines were reported to have negative physiological effects, more and more people began to report said symptoms. However, detailed public studies have demonstrated no correlation between wind turbines and the symptoms of this "syndrome" (10).

Geothermal energy is produced from heat and hot water found within the earth. Resources of heat come from near the surface or even miles deep underground; geothermal systems move heat from these locations to locations where they are used (9).

There are three primary types of geothermal systems. Geothermal heat pumps use the ground, groundwater, or surface water as both the heat source and the heat sink. The hot water from the geothermal resource are used directly for space conditioning or to process heat. Geothermal power can also be used for power plant electricity generation, as steam and binary geothermal power plants leverage heat from geothermal resources to drive turbines, thereby producing electricity (9).

Biomass involves fuel, heat, or electricity being produced from organic materials such as plants, residues, and waste. These organic materials come from sources such as agriculture, forestry, primary and secondary mill residues, urban waste, landfill gases, wastewater treatment plants, and crops specifically set aside for energy production (9).

Because biomass comes in various forms, it has many different applications. It may be burnt directly for electricity, combined with fossil fuels, or even converted into liquid fuels (9).

Landfill gas represent a viable energy resource created during waste decomposition. As organic waste decomposes, biogas composed of roughly half methane, half carbon dioxide, and small amounts of non-methane organic compounds is produced (9).

This methane can be collected and used as an energy source, instead of being treated merely as a byproduct of waste decomposition that is released into the environment. Collected methane may be burned to generate thermal energy or to create steam that would drive turbine generation of electricity (9).

Hydropower and ocean energy are also potential sources of renewable energy. Hydropower has been used for centuries to power machinery in the form of the simple waterwheel; today, the most widely known application involves the production of energy through dams (9).

Ocean energy includes two varieties of energy generation. Mechanical energy may be derived from the earth's rotation, which creates winds on the ocean surface that form waves. The gravitational pull of the moon creates coastal tides and currents as well. This energy could be captured and converted into electricity (9).

In addition, thermal energy from the sun heats the surface of the ocean while the depths retain a lower temperature. This temperature differential allows energy to be captured and converted to electricity (9).

In the realm of fossil fuels, new technology has opened up an enormous new resource: natural gas deposits sequestered within shale formations throughout the United States. This new procedure, called hydraulic fracturing, is combined with the existing technique of horizontal drilling to make organic-rich shales the largest and richest natural gas fields in the world (11).

Hydraulic fracturing frees up natural gas isolated in discrete pore spaces within the shale. By pumping liquids into a well at a high enough pressure, it fractures the rock. Through this method, an intricate network of interconnected fractures connect the pore spaces and facilitate the movement of oil and natural gas (11).

## The Future

From the vantage point of today's energy resources, it is very difficult to predict what lies in the future. For instance, it was predicted in the 1950s that nuclear power would quickly become an energy source that was too cheap to sell in economically traditional ways to the masses (6). In addition, in the 1970s, it was predicted that the world would run on solar power by the end of the

20th century (6).

However, certain trends in energy will persist in the near future. Renewable energy, for instance, will gradually claim a larger share in world energy consumption. After all, costs for renewable energy are falling, methods of integrating renewable energy into existing structures are improving, and new technologies are emerging (2, 12).

For example, compact fluorescent light bulbs use up to 75 percent less power than traditional incandescent bulbs (13). New refrigerators are three times as efficient as models from 1973 (13). If the rest of the world updated its appliances, more than 20 percent of world energy demand could be cut by 2020 (13).

The specter of climate change also has spurred governmental support of renewable energy projects. The benefits of renewable energy are widely recognized; greater use of renewable energy sources helps the U.S. move toward energy independence (since renewable energy projects are usually located close to where the energy is consumed), environmental impact is lessened, and costs are cut (2).

Traditional fossil fuels will not lose relevance in the near future, however. Hydraulic fracturing stands to become 70 percent of natural gas development in the future, spurred by private interest and its clean-burning nature (11, 14). In the last ten years, 50 percent of global energy consumption has been through coal, largely due to developing countries that prefer its cheapness and abundance (6).

North America also continues to expand its oil resources. The United States is on track to overtake Saudi Arabia as the world's largest oil producer by 2020; energy independence is plausible by 2030 (4). By 2035, the International Energy Association expects American oil imports to have sharply declined while European oil imports will continue to rise (6, 15).

## Conclusion

Many factors work against regaining old levels of comfort and confidence in energy abundance. The world is much more aware of the limits of its energy resources, particularly those of fossil fuels. The world's population continues to both grow and improve its standards of living and energy consumption. Despite strides made by developing nations such as China and India, two billion people still lack any access to energy (6).

However, many avenues remain to be explored. Renewable energy technology and economics are advancing; for example, solar microcells the size of glitter particles are in development (12). There are new sources of traditional fuels, such as hydraulic fracturing, set to become an increasingly important natural gas source in the coming years. Energy efficiency in existing technologies also is

an option with enormous potential.

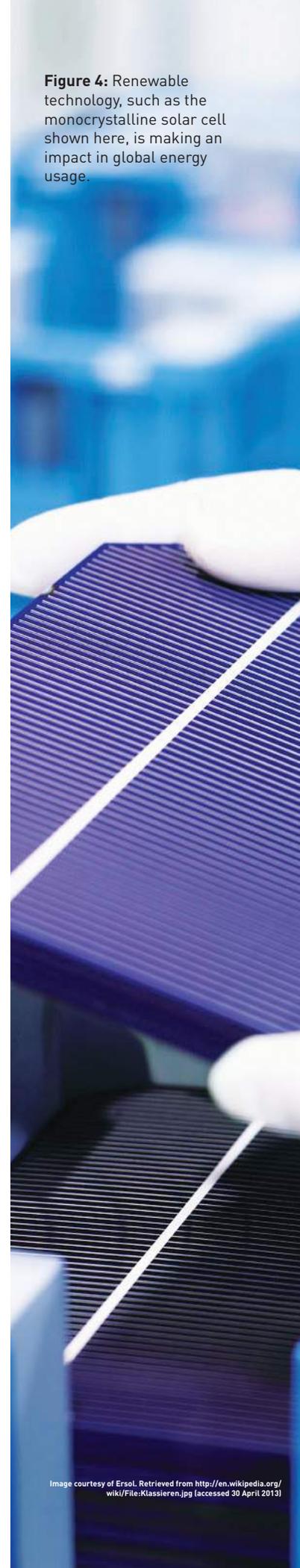
2012 was designated as the United Nations International Year of Sustainable Energy for All (6). Because of its very nature, energy is recognized as a tense issue: it is scarce, difficult to generate, and indispensable. Finding compromises between our energy demands and the planet's capabilities will be key to long-term solutions. With the right education, technology, and policies, the world has begun a campaign to move toward an increasingly optimistic energy future.

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**Figure 4:** Renewable technology, such as the monocrystalline solar cell shown here, is making an impact in global energy usage.



# A Review of Global Epidemics

Image courtesy of CDC

**Figure 1:** Transmission electron micrograph of the H1N1, or swine flu, virus that was rampant in 2009. Swine flu was one of the world's most recent epidemics.

BY HARRISON HAN

## Introduction

The word epidemic comes from the Greek words “epi” and “demos,” which translate to “upon people.” Epidemics are commonly referred to as outbreaks; however, the general public usually associates outbreaks with smaller, more contained cases. In contrast, “pandemic” describes a large and often devastating epidemic. The field of epidemiology is dedicated to the study of epidemics and their causes.

Epidemics have plagued mankind, killing millions of people over thousands of years. In the process, they have reformed society as we know it, playing a pivotal role in changing and developing the sciences, religion, and governments around the world.

## Past

Epidemics have left a significant mark on human history. Mankind has progressed from the nomadic hunter-gatherers to the vaccinated epidemiologist through lessons learned from past pandemics. The following endemic diseases are a few of the most significant in human history:

### *Bubonic Plague*

The most devastating recorded pandemic

was the bubonic plague, also known as the “Black Death.” The bubonic plague is a bacterial disease caused by *Yersinia pestis*. It typically affects wild rodents and is spread by fleas (1). If the bacteria enter the lungs, the affected individual will develop the pneumonic plague, a severe type of lung infection, which transmits through coughing. Symptoms do not arise for seven to 10 days after infection, but individuals can die within 24 hours of developing the plague.

Patients were nearly incurable during the Middle Ages. Fortunately, the bubonic plague can now be treated with antibiotics, but the mortality rate of patients who develop the plague remains high. The telltale sign of the plague were buboes, or swelling lymph nodes, in the groin, neck, and armpits that oozed pus and bled when irritated (1).

The plague is estimated to have killed between 75 to 200 million people in Europe over a five-year span from 1347 to 1352. Conservative estimates state that roughly one-third of the European population was decimated by the bubonic plague. More liberal estimates place that number around 60 percent. Given these statistics, it took another 150 years for Europe to replenish its population (1).

## Smallpox

The viruses *Variola major* and *Variola minor* cause smallpox. While the former has historically killed 30 percent of all the infected, the latter has killed less than one percent (2).

Smallpox is typically spread through the air or through contact with mucus or bodily fluids of a diseased person. The disease exhibits four different types: ordinary, modified, malignant, and hemorrhagic. Each type represents fluctuations in the presentation of the virus, with some more serious than others. Ordinary type smallpox represents approximately 90 percent of unvaccinated cases (2).

After an incubation period of approximately 12 days, initial common symptoms include high fever, muscle aches, nausea, and vomiting. The symbolic symptom of smallpox is the growth of a maculopapular rash, a thick red rash with small raised bumps, which soon developed into fluid-filled blisters. Modified type smallpox is characterized by markedly repressed symptoms, which rarely result in death. Malignant type smallpox is nearly always fatal and represents five to 10 percent of cases. Lastly, hemorrhagic smallpox is represented by hemorrhaging under the skin, giving it the name “black pox.” It is also often fatal (2).

Although smallpox was a reoccurring epidemic that struck several continents, the more significant outbreaks occurred in the Americas. From the 16th century until its eradication in the mid-20th century, smallpox ravaged the American native and colonial population. In particular, it played a significant role in destroying the native civilizations of South and Central America. During the late 16th century, explorers from Europe brought smallpox to the natives, killing an estimated 90 percent of the local population (2).

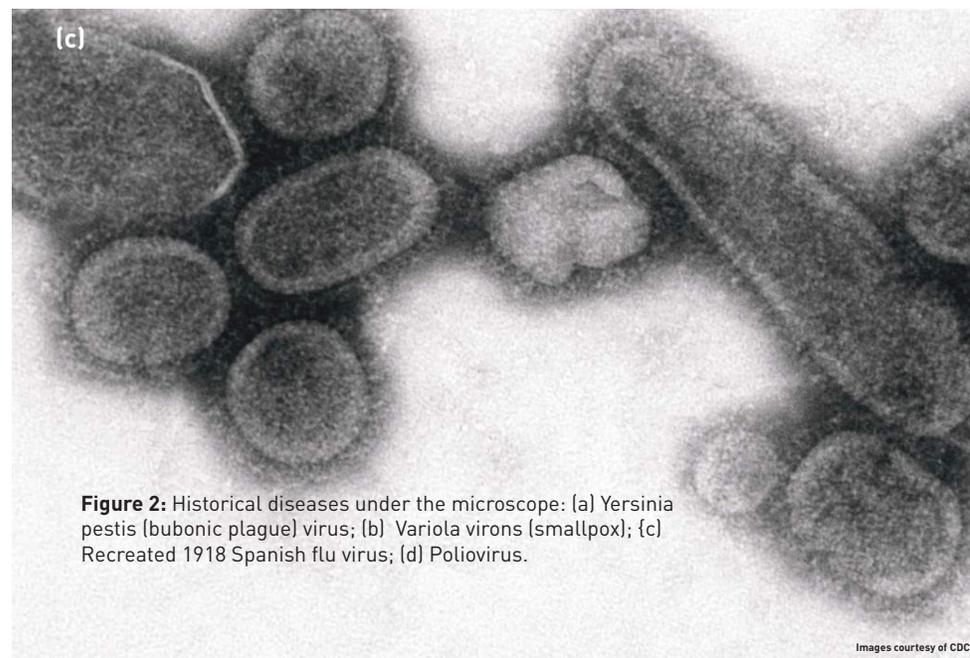
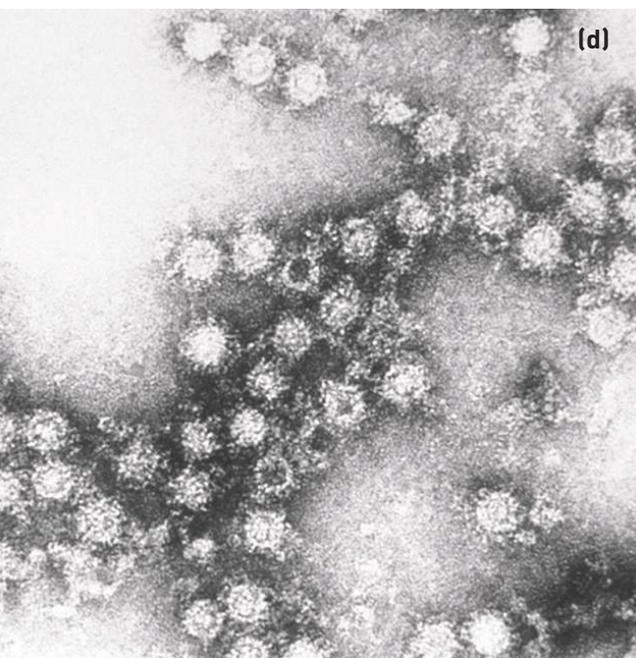
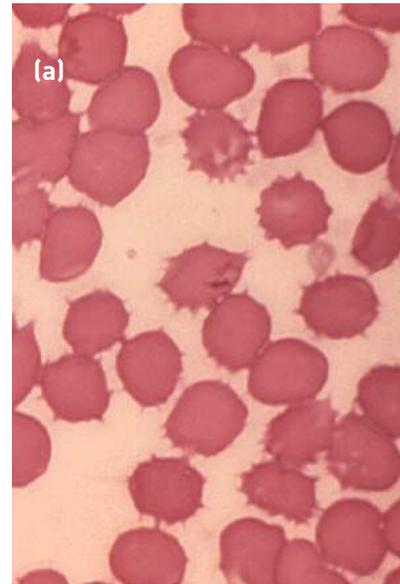
Over two centuries later, the first major breakthrough in epidemic containment occurred when Edward Jenner, an English physician, vaccinated a young boy with cowpox, a relative of smallpox, and then inoculated the boy with smallpox. The world’s first vaccination, derived from Latin *vacca* or cow, represented the first step of many to combat smallpox and epidemics in general. After a successful worldwide vaccination program, smallpox was completely eradicated in the United States in 1949 and worldwide in 1977, lending continued hope for the eradication of other epidemics and diseases (2).

## Spanish Influenza

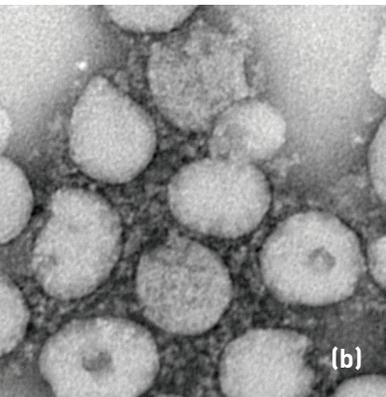
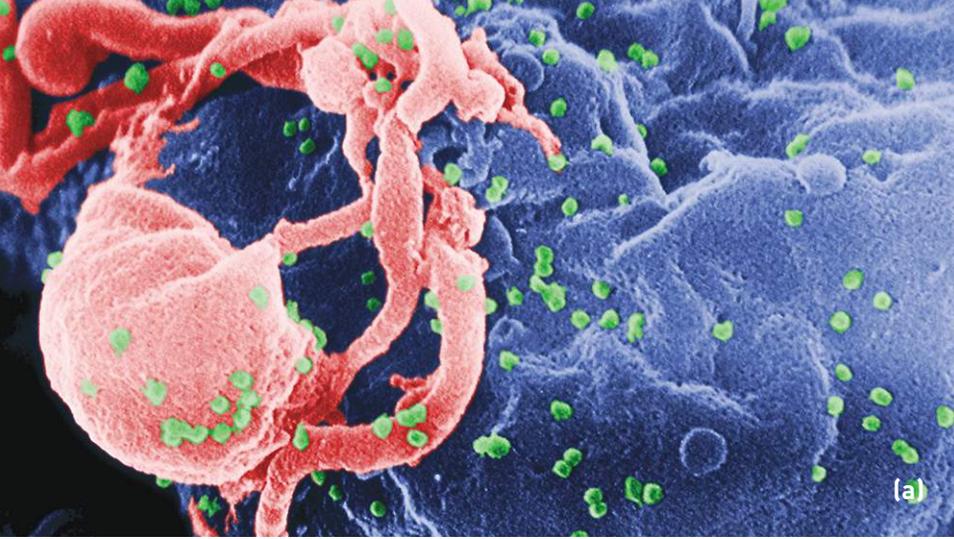
The Spanish Influenza epidemic of 1918 was a particularly devastating incidence of an influenza pandemic. Influenza, more commonly known as the flu, is caused by RNA viruses. Common symptoms include nausea, vomiting, fatigue, headache, chills, fever, and sore throat. Influenza is a seasonal disease typically transmitted via air pathways and through nasal secretions. It targets individuals without existing antibodies (3).

The flu is typically considered a relatively mild disease; however, extremely virulent forms can have devastating effects. In particular, the Spanish flu killed between 25 and 50 million people between 1918 and 1920, a range of three to five percent of the entire world population. The virus was particularly devastating in that it primarily affected healthy younger adults rather than children and the elderly, who are more often targeted by influenza (3).

The flu, named for its extensive media coverage in war-neutral Spain, coincided with World War I. The mortality rate of this disease was estimated to be between two and 20



**Figure 2:** Historical diseases under the microscope: (a) *Yersinia pestis* (bubonic plague) virus; (b) Variola virions (smallpox); (c) Recreated 1918 Spanish flu virus; (d) Poliovirus.



Images courtesy of CDC

**Figure 3:** Diseases of today: (a) HIV virus (AIDS); (b) SARS coronavirus.

percent, proving that even the flu could grow to be catastrophic.

### *Polio*

Poliomyelitis, also known as polio, is a viral disease known for causing acute paralysis of the legs. Polio is an infectious disease transferred through oral contact with fecal matter, either through polluted water or other methods. The virus does not exhibit symptoms in all who are infected, but, for the unfortunate few, it can enter the central nervous system and destroy motor neurons, which leads to paralysis and muscle weakness (3).

At the onset of the 20th century, polio began to surface in Europe and the United States, proving to be an epidemic that paralyzed thousands of adults and children. Consequently, a race to eliminate polio began, culminating in the invention of the polio vaccine in the 1950s (4).

The endemic disease eradication effort again showed promise; polio was declared eradicated in the United States in 1994. While polio has not completely disappeared, many organizations such as the World Health Organization (WHO), Rotary International, and UNICEF are confident that the virus will be vanquished in the near future, as it only exists in fewer than 20 countries today (4).

### **Present**

Over the past few decades, the field of epidemiology has expanded rapidly. An increased understanding of biological mechanisms for infectious diseases, coupled with a general surge in government and public interest in public health, has increased research on the causes and containment of epidemics. Surveillance of infectious disease epidemics has also increased (2).

Recent discoveries of vaccines and advancements in the field of epidemiology have rendered many of yesterday's dangerous diseases

harmless. Consider that AIDS, one of the largest pandemics of modern time, currently affects less than one percent of the world population, whereas the bubonic plague, uncontrollable at the time, was responsible for killing up to one third of the world's population.

Modern organizations and government agencies, such as the World Health Organization and the Centers for Disease Control and Prevention, limit the spread of epidemics, educate the public about current diseases, and continue to research new solutions to these endemic issues. Additionally, the World Health Organization has implemented guidelines, classifications, and preventative measures for pandemics such as the recent Avian Flu and Swine Flu. Although no catastrophic pandemics have cleaved through the human race today, recently several epidemics have made headlines.

### *AIDS*

Acquired immunodeficiency syndrome (AIDS) is a disease caused by infection with human immunodeficiency virus (HIV). HIV is a retrovirus that, when contracted, causes symptoms of fever, inflammation, and a maculopapular rash. Eventually, HIV will progress to AIDS when T-cells, an important type of white blood cell, count drops below a certain level. AIDS patients display symptoms of cachexia, or muscle wasting, pneumocystis pneumonia, and an increased risk of developing certain cancers.

HIV is spread by unprotected sexual intercourse, exposure to bodily fluids, or via mother to child during pregnancy, delivery, or breastfeeding. AIDS came to the United States in 1976 and was first discovered in 1981. Since then, it has killed around 30 million people worldwide. Currently, 34 million people live with either HIV or AIDS worldwide.

### *Swine Flu*

Swine flu, also known as Influenza A H1N1, is a strain of influenza that originates from pigs. The disease mirrored the behavior of the seasonal flu except that no vaccine for it existed. The major cause for concern lay in the virus's potential for mutation—it could become a disease as lethal and widespread as the Spanish Influenza. Mutations that increase transfer rate or severity could prove devastating, especially in undeveloped countries. By May of 2010, the World Health Organization declared the pandemic to be over. The estimated death total worldwide was between 151,700 and 575,400 people (4).

## SARS

Severe acute respiratory syndrome, or “SARS,” is a respiratory disease caused by the coronavirus. This virus induces symptoms of fever, muscle pain, coughing, and sore throat. Although the SARS virus ultimately was not a pandemic due to the size and scale of the disease, it had the potential to become one. SARS was responsible for 775 deaths worldwide, a paltry number at first glance but far more significant after factoring in the 9.6% fatality rate. No vaccine has been discovered, but research is underway (4).

## Future

Several factors play a role in determining whether humans will be able to overcome the next major pandemic.

### *Antibiotic and Antiviral Resistance*

The “plague” has resurfaced several times over the last millennium. There is always a possibility that it could develop drug resistance and once again become an extreme health risk. In fact, the Chief Medical Officer of the United Kingdom, Sally Davies, stated, “Antimicrobial resistance is a ticking time bomb not only for the UK but also for the world”, adding that “we need to work with everyone to ensure the apocalyptic scenario of widespread antimicrobial resistance does not become a reality” (5). Widespread antibiotic and antiviral resistance is an obstacle for eliminating many infectious diseases. Continued evolution would complicate development and further slow down scientists, who are already hindered by a declining budget and decreased urgency (5).

### *Biological Warfare*

Throughout history, biological warfare has been a significant threat to global prosperity. Professor Andrew Eaton, a researcher of infectious diseases at the University of Warwick, stated, “When people see the fatalities that can occur within a disease outbreak they understand the damage that can be caused to the enemy” (6). During the French and Indian War, smallpox was used as an agent of biological warfare in order to inoculate the natives (6).

Smallpox has since been eradicated, but two known frozen cultures have been preserved—one in the US and one in Russia. If they were to fall into the wrong hands, disaster could ensue. Furthermore, if other common diseases such as malaria or influenza were modified in a scientific setting, scientists could effectively mold the perfect pandemic and the ideal biological weapon (6).

Smallpox and other known diseases are not the only possibly terrifying biological weapons.

New diseases are continuously being discovered, and each could be utilized as a weapon of mass destruction (7).

### *Eradication of Additional Diseases*

Although many significant diseases have been safely shelved away in most parts of the world, a good number of other infectious diseases continue to cause chaos around the world. According to Marc Strassburg, in order to decide the next disease to be eradicated as a priority, the following factors must be discussed: “(1) the degree of understanding of the natural history of the disease; (2) types of appropriate control measures available; (3) mortality produced by the disease; (4) morbidity, including suffering and disability; (5) availability of adequate funding; (6) the cost-benefit of such an eradication effort; and (7) the probability of success within a given time period” (7).

He goes on to state that the reason malaria, one of the most morbid diseases of modern day, has not been eliminated is due to the potential budget. More than one billion dollars would be needed to establish the first year of a vaccination program. Other diseases also continue to exist because of limited funding (7).

## Conclusion

Scientific progress bodes well for the eradication of current pandemics as well as protection against those in the future. Nevertheless, continuous scientific advances and innovation will be required to combat a constantly evolving array of infectious diseases.

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“Widespread antibiotic and antiviral resistance is an obstacle for eliminating many infectious diseases.”

# Keeping Up with Moore's Law

BY MICHAEL (SIYANG) LI

Photo by Jinmyoung Lee

## Introduction

New lines of laptops, smartphones, tablets, and other computing gadgets roll out constantly. Each electronic is marketed as faster, smaller, and more efficient than its predecessor. Consumers flock to stores to keep up with the “latest and greatest” technology. Many ask why the computer industry is to maintain such growth for so long. The answer lies in Moore's Law, which is the observation that the number of transistors on an integrated circuit doubles approximately every 24 months (1). The distance between transistors on an integrated circuit is inversely proportional to the processing speed of a computer. Therefore, Moore's Law implies that the speed of processors due to transistor density doubles every 24 months. When improvements due to individual transistor speeds are factored in, the growth rate of net processor performance doubles every 18 months

**Figure 1:** Diagram depicting predicted growth rate of transistor density based on Moore's Law formulations and actual growth rate based on Intel's microprocessors. Moore's Law is very accurate in predicting the development of microprocessors.

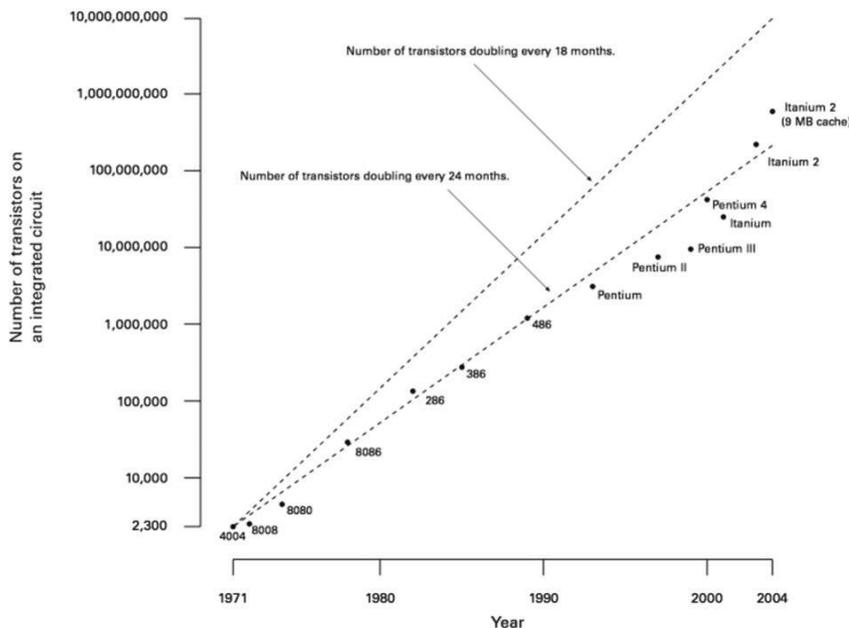


Image retrieved from [http://commons.wikimedia.org/wiki/File:Moore\\_Law\\_diagram\\_\(2004\).jpg](http://commons.wikimedia.org/wiki/File:Moore_Law_diagram_(2004).jpg) (Accessed 30 April 2013)

(1). The rate predicted by Moore's Law represents exponential growth—a rate which reflects large developments in the computing industry and is rivaled by the speed of developments in few other industries.

## Background

Moore's Law is named after Intel co-founder Gordon E. Moore. In a 1965 report in *Electronics Magazine*, Moore noted that the number of components in integrated circuits doubled every year from 1958 to 1965:

“The complexity for minimum component costs has increased at a rate of roughly a factor of two per year... Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000. I believe that such a large circuit can be built on a single wafer” (2).

At the time, Moore predicted that this growth rate could be maintained for at least ten years. Since then, his prediction has held true—transistor density has increased exponentially for the last half century (Fig. 1) (3). In fact, the law has become an industry standard and is often used to set long-term research and development targets. Companies that produce transistors use the rate predicted by the law as a benchmark for their progress, assuming that competitors will do the same. In this way, Moore's law is a self-fulfilling prophecy.

The specific formulation of Moore's Law has also changed over time to increase the accuracy of the law. Notably, in 1975, Moore changed his projection to a two-fold increase in transistor density every two years (4). David House, a colleague of Moore's at Intel, later factored in increased performance of individual transistors

to conclude that overall performance of circuits would double every 18 months (5). This is the rate that is commonly referred to today.

Although Moore wrote only of transistor density in his 1965 paper, other capabilities of digital electronic devices are strongly connected to Moore's law. Processing speed, pixel density, sensor strength, and memory capacity are all related to the number of components that can fit onto an integrated circuit (6). Improvements to these capabilities have also increased exponentially since their inception. The effects of Moore's Law have far-reaching implications on technological and social development, and affect many sectors of the global economy.

## Past

The history of computers is closely tied to the increase in computing power. As a result, the history of computers is shaped greatly by Moore's Law. As computing power grew exponentially, the capabilities and functionality of computing devices also increased. This led to more capable devices such as the cellphone or personal computer. This history of computing is often divided into four generations.

First generation computers, built from 1940 to 1956, were based on vacuum tubes, a precursor to the modern transistor (7). A vacuum tube is a device that controls electrical current in a sealed container. Early vacuum tubes were roughly the size of light bulbs and first generation computers built from multiple vacuum tubes often took up entire rooms. The size of the computers also meant they used a great amount of electricity and were expensive to operate. Computers built in this era were used primarily for low-level operations and could only solve simple problems one at a time. Input into the computer was in the form of punch cards and paper tape and output was in the form of paper printouts. An example of a first generation computer is UNIVAC (UNIVERSAL Automatic Computer), the first commercial computer, which was used by the U.S. Census Bureau for early census calculations (7). Although Moore referred to transistor-based computers in his 1965 assessment, first generation computers with vacuum tubes loosely followed the exponential growth rate estimated by Moore's law. As first generation computers advanced, vacuum tubes became smaller, faster, and more energy efficient.

By 1956, transistor technology had replaced vacuum tubes. This development represented the advent of the second generation of computers (7). Transistor technology proved to be far superior to the vacuum tube. Transistors were faster, smaller, cheaper, and more energy efficient. Early vacuum tubes generated a lot of heat, and although transistors also generated heat, it emitted significantly less than the vacuum tube. In addition, unlike vacuum tubes, transistors could

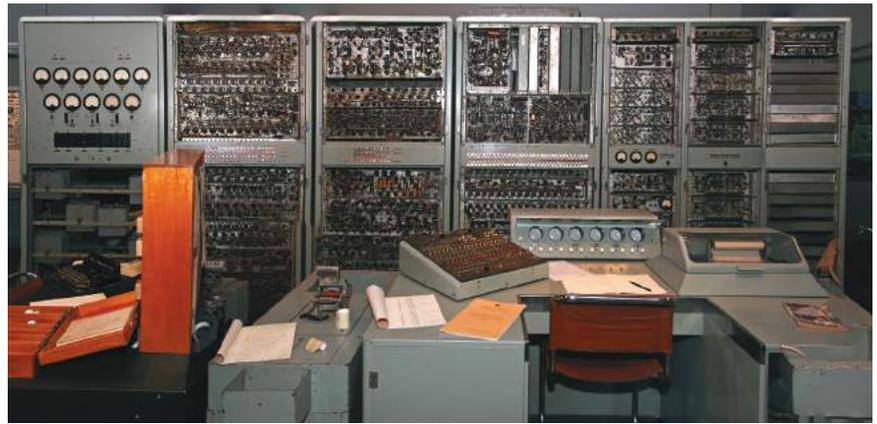


Image courtesy of Jiron. Retrieved from <http://commons.wikimedia.org/wiki/File:CSIRAC-Pano,-Melb.-Museum,-12.8.2008.jpg> (Accessed 30 April 2013)

begin to work without initially needing to reach a certain energy level. This meant that second generation computers required little to no start up time. Second generation computers still used punch card input and print output but could perform more complex operations at faster speeds. Second generation computers were relied on for heavier operations such as control of the first nuclear reactors (7). Despite these advances, most second generation computers were still too complicated and expensive for domestic use. Although modern computers have applied transistors in new ways, such as integrated circuits and microprocessors, the transistor technology of second generation computers is essentially the same technology that modern computers use. In accordance with Moore's Law, transistor technology has improved exponentially, with more transistors fitting into smaller spaces.

The development of integrated circuits is the major factor that distinguishes third generation and second generation computers from each other. Third generation computers became widespread around 1964 (7). Integrated circuits consisted of a large number of transistors fit onto silicon chips called semiconductors. These integrated circuits decreased the space between transistors and greatly increased the power and efficiency of computers. The transistors of third generation computers were packed densely enough that the size of most third generation computers is roughly equivalent to computers today. In addition, increased processing power enabled third generation computers to take input from a keyboard and produce output on a monitor. Third generation computers were also the first to use operating systems, which allowed devices to manage many applications at one time with a central interface to monitor computer memory. The IBM 360, introduced in the April of 1964, is commonly considered to be the first third generation computer (7). Because of decreased size and lower production costs, third generation computers were the first computers to become available to larger audiences.

As integrated circuits became smaller, more integrated circuits could fit into computing

**Figure 2:** CSIRAC, Australia's first digital computer, built in 1949. CSIRAC is the only intact first-generation computer in the world. Usage of vacuum tubes contributed to the large size of the computer.

**Figure 3:** Intel 4004 microprocessor, built in 1971. The Intel 4004 was the first fourth generation processor from Intel. With thousands of integrated circuit on a single microchip, the Intel 4004 could fit in the palm of a hand.

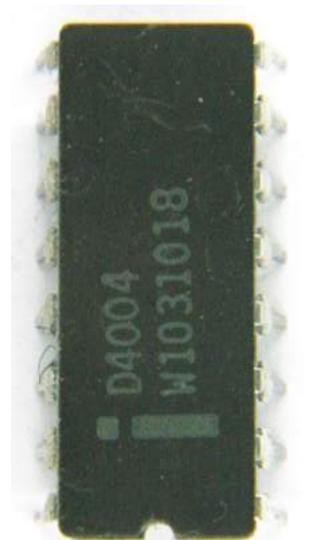


Image courtesy of ZyMOS. Retrieved from [http://commons.wikimedia.org/wiki/File:ic-photo-intel--D4004--\(4004-CPU\)-.JPG](http://commons.wikimedia.org/wiki/File:ic-photo-intel--D4004--(4004-CPU)-.JPG) (Accessed 30 April 2013)



devices. The fourth generation of computers is based on the development of the microprocessor, a single silicon chip with thousands of integrated circuits (7). The Intel 4004 chip developed in 1971 was one of the earliest fourth generation computer chips (Fig. 3) (7). It fit the central processing unit, memory, input and output controls on a single chip. The development of the microprocessor falls in line with predictions made by Moore's Law, as transistors became increasingly smaller and densely packed. The processors of early fourth generation computers could fit entirely in the palm of a hand. Although third generation computers were accessible to the general public, it was not until the development of early fourth generation computers that computer use by the home user became widespread. In 1981, IBM introduced its first home computer. In 1984, Apple introduced the Macintosh (7). As fourth generation computers developed, microprocessors continued to decrease in size and increase in speed and efficiency. As they became more developed, microprocessors began to be used for more than just desktop computers. Laptops, hand-held devices, gaming consoles, and other gadgets all began to make use of the rapidly developing technology. Fourth generation computers saw the development of networks, links between multiple computers and processors to perform certain common operations. This eventually led to the development of the internet.

## Present

Today, computers are considered to be at their fourth generation. However, since computing power continues to double every 18 months, modern computers are vastly more capable than the first generation computers developed in 1971. Intel's most recent Core i7-3770 microprocessor, released in April of 2012, has 1.4 billion transistors on a 160 cubic mm die. The processor has 4 processing cores which each run at 3.4 GHz at standard power (8). This is substantially more powerful than the Intel 4004, the first fourth generation processor from Intel, which ran at 740 kHz.

**Figure 4:** Watson, developed by IBM in 2010, won against reigning champions in game show *Jeopardy!*. Watson demonstrates capabilities of artificial intelligence and is an early prototype of a fifth generation computer.



Image courtesy of Clockready. Retrieved from [http://commons.wikimedia.org/wiki/File:IBM\\_Watson.PNG](http://commons.wikimedia.org/wiki/File:IBM_Watson.PNG) (Accessed 30 April 2013)

Modern day microprocessors can be found in a range of devices from Android smartphones to gaming consoles and household appliances.

Networks also play an increasingly important role in computing today. As of 2012, roughly 8.7 billion devices were connected to the internet (9). The internet is used to deliver information between computers and therefore increase the amount of information computers can access. In addition to increasing data access, the internet can also be used to increase computing power through the use of cloud computing. Cloud computing is the sharing of hardware and software resources over a network, which increases the capability of computers in the network over individual computers.

Today, many prototypes for fifth generation computers have been developed. The most well-known of these prototypes is Watson, an artificial computer system developed by IBM. Watson, as an artificially intelligent system, is capable of interpreting questions in natural language and producing a response. Watson's hardware consists of "a cluster of ninety IBM Power 750 servers... with a total of 2880 POWER7 processor cores and 16 Terabytes of RAM. Each Power 750 server uses 3.5 GHz POWER7 eight core processors" (10). In 2011, Watson competed on the TV show *Jeopardy* against former champions and won the first place prize.

## Future

The future of computer development depends on whether the growth rate estimated by Moore's Law can be maintained in the future. In 2005, Gordon Moore stated that the law "can't continue forever. The nature of exponentials is that you push them out and eventually disaster happens" (16). The computer industry will be faced with many challenges if it is to maintain the growth standard set by the Moore's Law.

One such challenge is overcoming Rock's Law, also known as Moore's Second Law. Rock's Law states that as computers become faster and more efficient, the cost for producers to fulfill Moore's Law becomes increasingly more expensive and difficult (11). Research and development, manufacturing, and test costs increase steadily with each new chip generation. The capital cost to produce at Moore's Law also increases exponentially over time. Although Rock's Law is not a direct limitation of Moore's Law, it does remove incentive for companies to continue keeping up with Moore's Law. Another challenge in maintaining Moore's Law is the fact that as transistor density increases, so does internal heat of the processor. This can lead to problems of overheating as well as excessive energy use. Michio Kaku estimates that silicon microchips can only withstand the heat of transistors down

to 5nm apart (12). In addition, as computers get more powerful, it becomes more difficult to justify increasing power when increased energy consumption is a direct result.

Moore's Law also faces many physical limitations. For example, the speed of light and the quantum size limit both limit the maximum possible speed for a processor of a certain size. When the speed of light, quantum scale, gravitational constant, and Boltzmann constant are considered, the maximum performance of a laptop of mass one kilogram and volume of one liter is  $5.4258e50$  logical operations per second on approximately  $10e31$  bits (13).

Although it is generally agreed upon that Moore's Law will eventually collapse, the exact time of collapse is not certain. In 2003, Intel predicted the collapse would be between 2013 and 2018 (14). However, it should be noted that within the last 30 years, the predicted collapse of the Moore's law has been pushed back decade by decade. Some academics see the limits of the Moore's law as being farther into the future. Professor Lawrence Krauss and Glenn D. Starkman predict an ultimate limit to the law about 600 years in the future (15).

Ultimately, the continuation of Moore's Law will depend on the ability of the computer industry to develop new technologies to overcome short-term limits, including the susceptibility of silicon to heat. Current research around computing has started to explore the development of a fifth generation of computers. Fifth generation computing will be primarily based on the development of quantum processors (7). A quantum processor is a processor that makes use of the interactions between particles on a quantum scale. Specifically, quantum processing takes advantage of the fact that photons and atoms can exist in multiple states which can then be used to store information and perform processes. Quantum processing increases the component density of processors greatly by bringing components to a quantum level. Therefore, quantum processing offers a significant increase in performance. In addition, quantum computers decrease heat output and energy consumption compared to their silicon-based counterparts.

As processors continue to increase in power, more advanced capabilities of computers will be possible. Most notably, computers with artificial intelligence will likely be developed. Artificial intelligence is an emerging technology that enables devices to act in a manner that simulates human intelligence (17). Artificially intelligent computers are able to interpret natural language input, learn, and organize information. IBM Watson, developed in 2010, is a current prototype of an artificial intelligent computer (Fig. 4). Although Watson has some of the capabilities of artificial intelligence, its capabilities are limited

by its hardware and computing power. However, as processors become more advanced, truly artificially intelligent devices that can simulate the power of the human brain may be possible.

## Conclusion

Moore's Law is a hallmark in the field of computer science. It is because of this law that technological and social change has been so rapid in recent decades and will continue at a rapid pace in the immediate future.

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# Psychostimulants: Cocaine for Toothaches and Amphetamines for All-nighters

Image courtesy of DEA. Retrieved from <http://www.justice.gov/dea/pr/multimedia-library/image-gallery/meth/meth-03.jpg>. [Accessed 30 April 2013]

BY OLIVIA DAHL

**Figure 1:** The “crystal meth” form of methamphetamine is a colorless crystalline solid and can be injected, snorted, or smoked.

“Some examples of evidence of the similarities between amphetamines and cocaine includes blind tests in which experienced drug users were unable to reliably distinguish between the two drugs, and that both drugs have similar patterns of modifications to neurotransmitter activity (9).”

## Introduction

Psychostimulants are psychotropic drugs that increase circulating levels of different neurotransmitters to generate arousal, counteract fatigue, and improve cognitive function (1-4). Amphetamines, cocaine, ecstasy, caffeine, and nicotine are among the most common psychostimulants, and each of these substances has been considered to have valid medical uses at some point in history (1-5). One of the main disorders for which doctors have prescribed psychostimulants is narcolepsy, a condition characterized by the inability to remain awake for extended periods of time (1,2,4-8). Other disorders that psychostimulants have historically been prescribed to treat include pain, depression, and even morphine addiction (1,5).

Of the psychostimulants, amphetamines and cocaine are particularly dangerous, alluring, and rich with history. Cocaine is illegal in the United States, although it is approved for medical use in some instances because of its anesthetic and vasoconstriction effects (8). Amphetamines also are medically approved in certain cases, and they are most commonly prescribed to people with Attention Deficit Disorder (ADD) and Attention Deficit Hyperactivity Disorder (ADHD) (4,6,8). It is useful to evaluate amphetamines and cocaine together because they have very similar actions in the brain, and the two drugs attract similar users (1,5,6). Some examples of evidence of the similarities between amphetamines and cocaine include blind tests in which experienced drug users were unable to reliably distinguish between the two drugs. Furthermore, both drugs have similar patterns of modifications to neurotransmitter activity (9).

While both amphetamines and cocaine have some approved uses in medicine, they are very commonly used illicitly (1,7,11-16). These two psychostimulants in particular attract many recreational drug users because they are known to induce euphoria and greatly improve self-confidence (1,5,6). Amphetamines and cocaine achieve these effects by increasing circulating

levels of dopamine (DA) and norepinephrine (NE), two neurotransmitters that are critically involved in the brain’s mesolimbic cortical DA pathway, also referred to as the reward pathway(1,5,9,10). The increased levels of DA in the reward pathway are most directly responsible for the euphoria that amphetamines and cocaine induce, while the increased levels of NE appear to be responsible for the drugs’ reinforcing effects (1,9,10).

Both cocaine and amphetamines come in a variety of forms, each of which has different properties (1). Pure cocaine looks like white powder and is associated with upper-class drug use (1,5). Free base cocaine is more commonly referred to as crack and is much less expensive (1). Crack comes in a crystalline form that varies in color from white to light brown, where whiteness is indicative of the purity of the substance (1). Crack is associated with lower-class drug use, and it is so named because of the cracking sound it makes when smoked (1).

Amphetamines have one methyl group, while methamphetamines have two methyl groups (1,5). However, this chemical distinction does not lead to significantly different behavioral effects among those who use these drugs (1,5). Methamphetamines metabolize into amphetamines, which accounts for the similar experiences elicited by the two drugs—both stimulate increased release of DA and NE. Methamphetamines induce similar feelings of euphoria and hypersexuality, but they are even more potent, addictive, and dangerous than amphetamines (14,17-19). The most common type of methamphetamine that is used recreationally is referred to as “crystal meth” and is incredibly stigmatized (1). Like amphetamines, it can be injected, snorted, or, most commonly, smoked (1). Methamphetamines do have some medically approved usage; Desoxyn is one methamphetamine that is approved to treat ADHD and is sometimes prescribed to help those struggling with obesity as a short-term solution (13,17). Methamphetamines are, however, extremely addictive and are prescribed only in extreme instances (13).

## Past

Cocaine is naturally derived from the *Erythroxylon coca*, a plant native to South America (1,5,11). Natives of the Andes have chewed leaves from this plant for centuries because of the plant's energizing effect, which counteracts altitude sickness and improves mood (1,5,11). In 1855, Gaedcke, a German chemist, was the first to purify the *Erythroxylon coca* plant into cocaine (5). Cocaine had the same therapeutic effects as chewing the leaves, only with much greater potency (1,5,11). It was not long before cocaine caught the attention of the medical world (1,5).

Freud, the father of psychotherapy, was among the most prominent men in medicine to realize the tremendous potential that this drug could have in improving medicine (1,5). He was eager to make a name for himself, so he experimented with cocaine, using himself as a medical guinea pig (1,5). Freud was immediately impressed with cocaine's miraculous ability to improve mood, alertness, and self-confidence, and he wrote a book to promote cocaine use: *Uber-Coca* (1,5). One of Freud's most egregious claims was that cocaine should be administered to morphine addicts, an advice which he later retracted (1,5).

Freud was not the only prominent medical practitioner who fell victim to cocaine's charm—soon after cocaine's discovery the entire medical community raced to unlock its potential (1,5,6). The 1800s were a time before effective anesthetics had been discovered, and this meant that surgery was extremely limited (5). It was possible to put patients under general anesthesia, but anesthetics could cause patients to vomit, which interfered with more delicate procedures, such as eye surgeries (5). In 1884, Karl Koller, an Austrian ophthalmologist, published a successful account of injecting cocaine into a patient's eye, thereby anesthetizing him sufficiently for eye surgery and bringing cocaine to the foreground of surgery and medical research as a promising local anesthetic (5,6).

Cocaine quickly gained approval from the medical community, but such a powerful and popular drug could not be contained solely within the medical world (1,5). Cocaine rapidly made its way out of surgery rooms and into soft drinks (1,5). Coca-Cola was so named for the plant from which cocaine is derived, and the beverage rose to economic success in large part because adding an addictive substance to a product brought customers back for more (1,5). In the early 1900s, children and adults alike were sipping on addictive Coca-Cola, lozenges were laced with cocaine that numbed sore throats, and advertisements boasted that bad moods need never happen again, since the golden age of cocaine had arrived (1,5).

Amphetamines were discovered three years following the first purification of cocaine (1,5,6). In 1887, another German chemist, Lazar Edelenau, was the first person to create an amphetamine

(1). The chemist stumbled upon amphetamines in his quest to create a substance like ephedrine, which is a bronchodilator used to treat asthma (1). Amphetamines were found to have very similar effects to ephedrine, but it was Gordon Alles, an American chemist, who re-discovered and popularized amphetamines nearly thirty years after their first discovery (5).

Amphetamines were first commercialized as a replacement for ephedrine in the 1930s, and they were initially marketed as the Benzadrine Inhaler (1). The Benzadrine Inhaler was an instant success, and it was not long before amphetamines were marketed as a cure for narcolepsy, depression, post-partum depression, and Parkinson's disease, along with a growing list of other conditions (1). During World War II, fighter pilots were administered amphetamines in order to stay awake for the entirety of their missions (1,5,6).

Amphetamines enjoyed a long period of medical approval, progressing from the treatment for asthma and depression to the cure for obesity (1,5,6). In the 1950s, amphetamines became a popular weight loss technique because they allowed people to lose weight effortlessly (1,5,6). Amphetamines came to be called "mother's little helper," both because they were handy appetite suppressants and because mothers could pop these pills in order to become peppier housewives (6). Housewives were not the only Americans under the influence—Andy Warhol was known to have enjoyed amphetamines, and even President Kennedy took amphetamine injections (6). In 1962, amphetamine use was so prevalent that there were eight billion amphetamine tablets circulating in America alone (6). Needless to say, addiction became a common problem in American households.

In 1957, Dr. P. H. Connell published a paper suggesting that amphetamine use likely led to psychosis (6). Up to that point, pharmaceutical companies had dismissed the accusations that amphetamines were causing psychosis, claiming that only those who had previously established symptoms of schizophrenia suffered

"Cocaine rapidly made its way out of surgery rooms and into soft drinks (1,5). Coca-Cola was so named for the plant from which cocaine is derived, and the beverage rose to economic success in large part because adding addictive cocaine to a product will bringbrings customers back for more (1,5)."



**Figure 2:** Once cocaine was discovered as a promising local anesthetic, it quickly entered the shopping baskets of everyday consumers through its use in the popular soft drink, Coca-Cola.

Image courtesy of roitberg. Retrieved <http://www.flickr.com/photos/roitberg/8482368312/sizes/l/in/pool-183833430N00/> (Accessed 30 April 2013)



psychosis (6). Connell's paper demonstrated that amphetamine use was the most common factor among psychotic individuals (6). The connection between amphetamines and schizophrenia was further corroborated by the fact that even naturally occurring schizophrenia was caused by an excess of dopamine (6).

Psychosis is one of amphetamine's most dramatic side effects, but cocaine and amphetamines both have many more downsides (1,5,6,17-24). High doses of either drug often lead to impaired judgment, impulsiveness, hypersexuality, and hypervigilance, as well as paranoia under the influence (1,2,5-7,24-26). These drugs also leave long lasting effects, including cognitive impairment, attention deficits, addiction, and diminishment of naturally occurring dopamine (DA) levels (22,26). In fact, amphetamine abuse has been shown to cause a 70% decrease in DA levels in some parts of the brain, and this decreased neurotransmitter production may be irreversible (2,22,26).

Cocaine and amphetamines fell from favor in the latter part of the twentieth century (27). In the 1960s, recreational drug use was so rampant that President Nixon based much of his domestic political platform on drug regulation (27). Some consider the 1970s to be a time of a "cocaine epidemic," because South America began producing and selling the drug more cheaply than ever before (6,27). The U.S. Department of Health and Human Services estimated that more than one million Americans began cocaine use each year between the late 1970s and 1980s, and parents across America were terrified that their children would end up on the streets or in mental hospitals as a result of drug experimentation (11,27).

While many spent the Summer of Love in 1967 experimenting with LSD in San Francisco, Nixon was already six years into his war on drugs (27). Nixon's campaign experienced its greatest success

in 1970, when Congress passed the Comprehensive Drug Abuse Prevention and Control Act (27). This law categorized drugs into one of five schedules according to their potential for abuse and their medical potential, and this method of categorization persists today (27,28). Schedule I drugs are those which have "no currently accepted medical use and a high potential for abuse," including heroin, LSD, and marijuana (28). Schedule II drugs are those which have a high danger of abuse, but also have some medical purpose (28). Both cocaine and amphetamines were put in this category in 1970, thereby marking the beginning of governmental regulation of the two psychostimulants (27).

## Present

While the Controlled Substances Act of 1970 dramatically reduced the availability of cocaine and amphetamines, there are still many Americans using the psychostimulants either illicitly or with prescriptions (11,27). There are very few instances in which doctors prescribe cocaine, such as sinus surgery and other procedures where cocaine might be necessary as a local anesthetic (8). There are safer anesthetics, and cocaine is considered as a last resort (8). Amphetamines, on the other hand, are still prescribed for a variety of conditions, including ADHD (for which Adderall is a commonly prescribed amphetamine), brain tumors, Parkinson's disease, autism, and for fatigue associated with HIV (4,12,13,20).

Abuse and addiction are the two greatest problems with cocaine and amphetamines in modern America (20,26,28). One study in 2008 showed that three million Americans have illicitly used amphetamines within the past year, and that number is on the rise. The percentage of Americans who have used meth within the past month has stayed pretty consistently between 0.3 and 0.4 since 1999 (11,14). There were roughly 800,000 drug-related emergency room visits in 2008, and of those, 500,000 were due to cocaine (14).

It is currently estimated that 1.5 million Americans are dependent on cocaine, and between 250,000 and 350,000 Americans are estimated to suffer from an amphetamine addiction (6). A 2007 study revealed that 4.1 percent of tenth graders in America have tried meth at least once in their lives (6). Crystal meth is particularly well known for its addictive properties, and for the intensity of the addiction (29). Rehabilitation programs for crystal meth addicts have the lowest success rates of any drug rehabilitation programs. Only seven percent of patients remain clean following treatment.

## Future

The future of neuroscience as it pertains to amphetamines and cocaine lies in addiction research to improve the odds for addicts who seek treatment.

**Figure 3:** During the Summer of Love in San Francisco in 1967, psychedelic drug usage was common.



Image courtesy of Robert Altman. Retrieved from <http://mms.businesswire.com/bwapps/mediaserver/ViewMedia?mgid=96771&vid=5>. (Accessed 10 May 2013)

Drug addiction, and illegal drug use in general, is intrinsically connected to violent crimes, both due to the illicit nature of drug smuggling, and because drug use itself can prompt people to rape, kill, and, in isolated but high profile instances, cannibalize (1,5,28). Drug use is an international problem; there are 24.7 million methamphetamine abusers internationally, and cocaine has an estimated 14-20 million users worldwide.

Addiction is defined as a craving for drugs so intense that it interferes with a person's ability to function in daily life due to lasting changes that drugs make to the reward pathway in the brain (10,24,26,33,30). This pathway, the mesocorticolimbic dopamine system, can be thought of as a tug-of-war between the prefrontal cortex (PFC), which commands higher-order thinking, and the lower brain regions, which include the ventral tegmental area, amygdala, and striatum (10,22,26). While the PFC is active when a person exercises self-restraint, or focuses on a challenging mental task, the lower brain regions are responsible for drug cravings, fear response, and are recruited in the stress response (10,22,26).

In a normally functioning brain, the lower brain sends signals to the PFC, alerting it to run from dangerous situations and attend to similar animalistic, impulsive concerns (9,23,26). The difference between a well-functioning brain and that of an addict can be observed in the differing connection between the PFC and the lower brain. While a normal PFC is able to strong-arm the lower brain into taking the backseat, the PFC of many addicts is less able to dominate the lower brain (9,22,26). There is also evidence that those with overactive lower brain regions and otherwise normal PFCs are still at risk for drug addiction, which can be caused by a problem anywhere along the mesocorticolimbic system(9).

The various and profound negative effects that prolonged psychostimulant abuse has on the brain make it very difficult to distinguish between brain anomalies that might lead to drug use and brain dysfunction that is caused by drug use (9,22). Nevertheless, there are creative ways of studying brain circuitry that might predispose some to addiction. For example, ADHD and post-traumatic stress disorder (PTSD) are just two of many mental illnesses that often exist simultaneously with drug addiction (9,22). Analyzing the neurological deviations associated with these disorders could provide clues about what activation patterns in the brain predispose certain people to addiction(22,23).

Both ADHD and PTSD can be considered disorders that predate addiction--ADHD because it is a developmental disorder and PTSD because it is caused by a traumatic event that often predates, and perhaps leads to, drug addiction (22). ADHD is characterized by attention deficits, impulsivity and lower performance on tests of inhibition (22). These characteristics of ADHD are attributed to



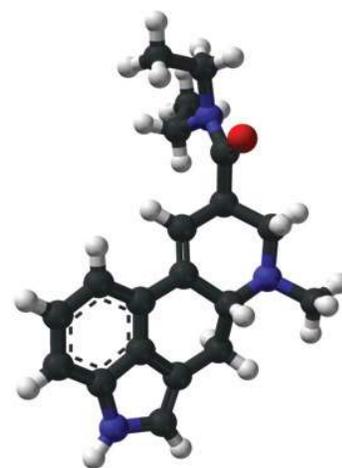
Image courtesy of DEA. Retrieved from [http://www.justice.gov/dea/pr/multimedia-library/image-gallery/cocaine/cocaine\\_hcl2.jpg](http://www.justice.gov/dea/pr/multimedia-library/image-gallery/cocaine/cocaine_hcl2.jpg). (Accessed 8 May 2013)

diminished activation of the anterior cingulate cortex (ACC), which is part of the PFC associated with attention (22).

PTSD, on the other hand, is a disorder characterized by hypervigilance, emotional disturbance, and compromised response inhibition (22). These symptoms are associated with hyperactivation of the amygdala, which is the region of the lower brain associated with fear, anger, and threat perception (22). PTSD is also associated with overactivation of the cingulate cortex, a brain region that is recruited to process and regulate emotional stimuli and responses (22). The hyperactivation of the amygdala and the cingulate cortex can explain the hypervigilance that is characteristic of PTSD, as well as the exaggerated perception of threat (22). The brain with PTSD is not merely over-stimulated—there is also hypoactivation seen in the disorder (22). The medial prefrontal cortex (MPFC) and the ACC are two regions of the brain that are underactive in patients with PTSD (22). Both of these regions are active in higher-level executive control, and it is likely that the hypoactivity of these regions is responsible for the difficulties with response inhibition (22,23).

While the neurological components of ADHD and PTSD are quite different, it is important to bear in mind that breaking any part of a circuit can lead to the same end result—in this case, addiction (22). The different neurological abnormalities seen in each disorder lead to behavioral similarities that might be more important as indications of a person's proclivity for developing an addiction (22). Some examples of behavioral defects seen in those with ADHD and PTSD include deficiencies in inhibitory control, information processing, executive function, working memory, and attention (22). All of these behavioral dysfunctions are also seen in drug addicts, regardless of comorbidity with any other mental illnesses, and it is easy to see how a person with dysfunctional inhibitory control would be more likely to fall into drug addiction; the inability to inhibit a desire to seek drugs is exactly

**Figure 4:** Cocaine has been used as an anesthetic in the past, but it has experienced increasing government regulation, including being classified as a Schedule II drug in 1970.



**Figure 5:** The ball and stick model of the lysergic acid diethylamide (LSD) molecule. LSD is classified as a Schedule I drug, meaning that it has a high potential for abuse.

Image courtesy of Wikipedia. Retrieved from <http://upload.wikimedia.org/wikipedia/commons/2/22/LSD-2D-skeletal-formula-and-3D-models.png>

“Modafinil is crucially different from cocaine in that it does not induce high levels of self-administration (1,22,23). In different trials with methamphetamine addicts, modafinil has improved verbal memory, attention, and even enhanced PFC and ACC activation (22).”

the problem that leads to addiction (22,23).

Science has made some progress in addiction research. Modafinil is one drug that has had some success in treating addicts. It has cognitive enhancing effects, and it promotes wakefulness (12,22,23). Modafinil neurologically mimics cocaine, increasing circulating levels of DAA, and it establishes this concentration through its similar binding patterns to cocaine (12,22,23). Modafinil is different from cocaine in that it does not induce high levels of self-administration (1,22,23). In different trials with methamphetamine addicts, modafinil has improved verbal memory, attention and even enhanced PFC and ACC activation (22). These successes do not directly lead to addiction recovery, but they do give addicts the advantage of enhanced cognitive abilities (22). Addiction is a disorder associated with a weak PFC relative to the reward pathway, and modafinil can help those in treatment to strengthen their PFCs (22). In fact, there is a strong movement to use cognitive enhancement medication in order to counteract addiction, including methylphenidate, better known as Ritalin (22). Modafinil has been approved as treatment for narcolepsy and other sleep disorders and its approval as treatment for psychostimulant addiction might not be far in the future (22).

Many medical treatments succeed in spite of scientists' ignorance of the way in which they work. Deep-brain stimulation (DBS) is just one such example. Placing electrodes in a specific part of the brain and then running a current through the electrodes has successfully treated depression and Parkinson's, although it is unclear exactly how it functions. DBS has been successfully performed in the nucleus accumbens of one patient suffering from alcohol addiction, and the procedure did alleviate his addiction. The surgery was intended to treat a severe anxiety disorder and depression, and it was only because he had such debilitating comorbid disorders that the surgery was performed. There have not been DBS surgeries on humans with psychostimulant addictions; such invasive techniques are generally considered only as a last resort, and they are still in animal clinical trials.

## Conclusion

It is easy to see how psychostimulants gained momentum so quickly in the 1900s, with endorsement from renowned figures like Freud, rampant publicity, and the desirable rush of energy, self-confidence, and euphoria that amphetamines and cocaine induce (1,5,11). While these drugs do have certain allure, it is important for the public to be aware of exactly how addictive they are, and just how little can be done to help those fighting with psychostimulant addiction. The days where amphetamines were called “mother's little helper” are gone, and the medical community has replaced flippant prescriptions with a healthy skepticism towards such addictive drugs (11,28).

Still, amphetamines are legally prescribed to many Americans, including children, and such remaining instances of psychostimulant prescription should be scrutinized (7).

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**Figure 6:** Deep brain stimulation (DBS) involves implanting electrodes in the brain of a patient, as shown here in this x-ray.



Image courtesy of NPR. Retrieved from [http://media.npr.org/assets/img/2013/03/07/deep-brain-stimulation\\_en-936a37f1865b9c51defbe05602c4091d78ea0af0-s51.jpg](http://media.npr.org/assets/img/2013/03/07/deep-brain-stimulation_en-936a37f1865b9c51defbe05602c4091d78ea0af0-s51.jpg)

# Genetics: Past, Present, and Future

BY MACKENZIE FOLEY

## Introduction

Genetics is the study of heredity and the variation of inherited elements known as genes. Although scientists have long known that an offspring's traits come from its parents, the findings of Darwin and Mendel have really allowed scientists to begin to understand how and why genetic variation occurs. With advances in scientific research and informatics, genetics has become increasingly significant in revealing the causes of diseases and the differences among individuals and species.

## Past

For centuries, western religion contributed to the widespread acceptance of the theory of "creationism," which refers to the literal interpretation of the Bible in which God created the Earth and all modern, immutable species around the year 4000 B.C.E. Advances in geology and observations of incremental changes of species in the fossil record over time led to skepticism that eventually brought forth the development of the theories that make up the foundation of selection theory.

The first major theory of genetics was hypothesized by Hippocrates in fifth century B.C.E. Hippocrates' theory is known as the "bricks and mortar" theory of genetics and states that taxonomical material consists of physical substances originating from each part of the body and is concentrated in the male semen, which develops into a human within the womb. Further, he believed that physical characteristics are "acquired." For example, a champion weight lifter who develops large biceps through training has "big bicep" parts, which would be passed to the lifter's offspring through his sperm and result in a big-bicepped child (1).

Decades after Hippocrates' proposition, Aristotle challenged his ideas by noting that handicapped individuals with missing limbs could go on to produce children with normal limbs. Additionally, he criticized the bricks and mortar theory by explaining that people can pass on traits that appear later with age. For example, a man with a full head of hair may conceive a child and then experience baldness years later. Thus, the "hair parts" were passed on while the "bald parts" occurred later with age, contradicting Hippocrates (1).

Before the era of modern genetic Carl von Linné, better known as Linnaeus, developed today's two-part scientific naming system (1). Later in the late 18th century, French naturalist Jean-Baptiste Lamarck proposed the first comprehensive theory of evolution. Although Linnaeus held the traditional opinion that species were created with certain traits that never changed, Lamarck contradicted the creationist belief that species were immutable; he claimed that species change in response to their environments by inheriting characteristics that their parents acquire over their lifetimes. For example, for a giraffe to reach leaves to eat off a tall tree, it would have to stretch its neck. Because giraffes need to eat leaves, the giraffes that acquired longer necks from stretching would be able to pass on their modified neck lengths to their offspring and eventually contribute to a new characteristic to the entire giraffe species (1). Following Lamarck, geologist Charles Lyell contradicted the biblical statement that the earth was about 5000 years old by proposing that contemporary geographical formations such as mountains and deserts were formed by natural physical processes that occurred over millions of years. These discoveries bolstered the argument that changes over time are the result of natural rather than divine intervention.

While a student, Charles Darwin was

**Figure 1:** An section of the first printout of the human genome to be presented as a series of books, displayed in the 'Medicine Now' room at the Wellcome Collection, London. The 3.4 billion units of DNA code are transcribed into more than one hundred volumes, each a thousand pages long and in type so small as to be barely legible.

"The first major theory of genetics was hypothesized by Hippocrates in fifth century B.C.E. "



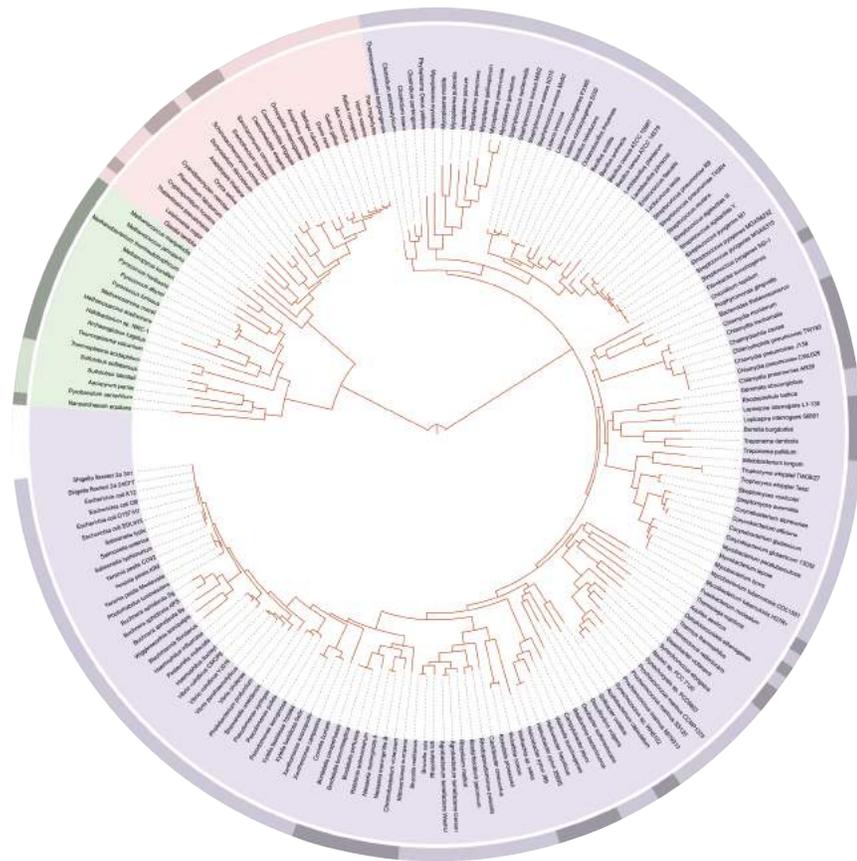


Image courtesy of Wikipedia. Retrieved from [http://en.wikipedia.org/wiki/File:Wellcome\\_genome\\_bookcase.png](http://en.wikipedia.org/wiki/File:Wellcome_genome_bookcase.png)

**Figure 2:** A phylogenetic tree of life showing the evolutionary relationship between species whose genomes had been sequenced as of 2006. The very center represents the last universal ancestor of all life on earth. The different colors represent the three domains of life: pink represents eukaryotes (animals, plants and fungi), blue represents bacteria, and green represents archaea.

selected to serve as the “naturalist” on board the ship HMS Beagle on a voyage to map the waters along South America’s coast (1). By recording extensive observations, Darwin developed his theory of natural selection, the major mechanism of evolution. Natural selection states that genetic differences can make individuals more or less suited for their environment. Those who are better suited survive go on to produce offspring, making the favorable traits characteristic of the population over time; those species with less favorable traits face extinction. Upon returning from his expedition, Darwin spent over twenty years collecting data and writing to publish his theories in his book *On the Origin of Species* in 1859. The reaction to *Origin* at publication was “immediate, international, and intense but also mixed” across both scientific and religious communities, as evolution contradicted the widely accepted principles of creationism (1). Continuing with his studies, Darwin attempted to explain the mechanism for natural selection in 1868 by proposing his theory of “pangenesis”—an updated version of Hippocrates’ brick and mortar approach. Pangenesis dictates that both mother and father secrete “gemmules” which aggregate in reproductive organs and combine to form the embryo. However, the setback to pangenesis was that after generations of blending within a population, members would be genetically identical, lacking variation and inhibiting natural selection. For instance, if a young child has a

watercolor set with multiple distinct colors and blends the colors together repeatedly with use, eventually each section of the palette would have a uniform brownish hue (1).

The mechanism of natural selection was illustrated by the research of Austrian monk Gregor Mendel in 1864. By studying pea plants, he proposed that inheritance came about by transmission of discrete units, known as “alleles”, rather than through blending. He said that in reproduction both the mother and father contribute a unit of their own traits, and the offspring inherits one of them perfectly intact and is free from influence of the other. Although Mendel published in 1864, the scientific community largely ignored his research, and the significance of his work was not realized until 1900 when several scientists discovered that their own findings lined up perfectly with those of Mendel (2).

The rediscovery of Mendel’s work led to the progress in genetics studies of the twentieth century. In the early twentieth century, Walter Sutton and Theodor Boveri extended Mendelian principles with their “Chromosomal Theory of Inheritance,” which states that an organism’s hereditary material resides in its chromosomes (3). By the mid-twentieth century, it was proved that DNA is the genetic material that made up chromosomes, and Watson and Crick discovered DNA’s “double helix” structure, laying the groundwork for modern molecular genetics advances (3). In 1953 the Modern Synthesis of Genetics was formulated, linking Mendelian genetics to Darwin’s theory of evolution by confirming that Mendel’s theory of discrete unit inheritance is the basis of natural selection (3). Later in the twentieth and early 21st century, genetics advances were geared toward the molecular level, and the dawn of the information age brought about modern genomics science as it is known today. The field of genetic engineering, or modifying the DNA of organisms, emerged in 1972 when the first altered molecule of DNA was constructed as “recombinant DNA.” In the following year, a functioning E.coli bacteriophage cell was produced using such recombinant DNA (3). In 1977, the Sanger group developed techniques to sequence, or decode, DNA and successfully used their methods to publish the entire genetic code of a particular strand of E. coli. In conjunction with technological advances of the era, the biomedical technique of polymerase chain reaction (PCR) was developed, significantly expediting the process of DNA sequencing and leading to the development of automated DNA sequencers in 1986.

The progression of DNA sequencing technology led to the launch of the Human Genome Project in 1990. This effort, funded by the US government, was a collaboration of the National Institute of Health (NIH), the Department of Energy, and international partners aiming to sequence all three billion letters of the human

genome, or genetic code. According to the NIH, “The Human Genome Project’s goal was to provide researchers with powerful tools to understand the genetic factors in human disease, paving the way for new strategies for their diagnosis, treatment and prevention” (4). Leading up to their publication in 2001, the first bacterial, yeast, and flowering plant genomes were sequenced (3). The Human Genome Project accomplished the mapping and sequencing of five prototype organisms meant to serve as a basis for interpretation of the human code, much like the Rosetta Stone allowed for interpretation of multiple languages (5).

Once completed, all generated data from the Human Genome Project were made accessible on the Internet to accelerate global medical discovery. The availability of this “human instruction book” was said by Doctor Francis Collins, Director of the NIH and head of HGP, to “mark the starting point of the genomic era in biology and medicine” (5).

## Present

Due to the extent of genetic knowledge acquired over time, it is now recognized that the adaptation of genetic code to the environment is the force behind evolution. However, these alterations occur gradually over the course of many generations. Consequently each individual carries around several potentially deleterious genes, related to their ethnic background and ancestral environment (6). According to Queen’s Medical Center, “Every disease has, in addition to environmental influences, genetic components that collectively determine the likelihood of a specific disease, age of onset, and severity,” (6). With advances in genetics and technology, scientists now have the capacity to identify some of these alterations and are learning more about how genes interact with other genes and the environment to cause disease or other health effects. For example, the Human Genome Project has already fueled the discovery of more than 1,800 disease genes. Additionally, researchers can find a gene suspected to cause a disease in a matter of days—a process that took years prior to HGP—and there are currently over 2000 genetic tests available for human conditions (4). These tools empower physicians to assess patients’ risks for acquisition of diseases and diagnose genetic conditions.

Because genetics enables professionals to identify differences in genes and their additive effects on patients’ health, medical treatments can now be tailored to more effectively complement an individual’s unique genetic code. Combining genetic knowledge with computational technology, the modern field of bioinformatics enables professionals to handle large amounts of data, which makes such analysis of individual patients’ genomes possible. Consider the field of pharmacogenomics: a field that examines how genetic variation affects

an individual’s response to a drug. According to the NIH, pharmacogenomic tests can already identify whether or not a breast cancer patient will respond to the drug Herceptin, whether an AIDS patient should take the drug Abacavir, or what the correct dose of the blood-thinner Warfarin should be,” (4). Focused development of these technologies in bioinformatics is dramatically reducing the price of genome sequencing, from about \$100 million in 2001 to just over \$1,000 today (7).

As stated by the NIH, “Having the complete sequence of the human genome is similar to having all the pages of a manual needed to make the human body. The challenge now is to determine how to read the contents of these pages and understand how all of these many, complex parts work together in human health and disease” (4). One illustration of this attempt of comprehension is the 2005 launching of the HapMap project, an international collaboration aimed at documenting common genetic variation, or “haplotypes”, in the human genome. These haplotypes interest genetics researchers because they tend to be similar within various global populations. So comparing haplotypes, which are chunks of genetic information, instead of individual letters in DNA sequences accelerates the search for genes involved in common human diseases. In 2010, the third phase of this project was published with information from 11 of these populations, making it the largest survey of genetic variation performed. The HapMap project has already yielded results in finding genetic factors in conditions ranging from age-related blindness to obesity (4).

Modern knowledge of genetics allows for new types of health care involving genetic engineering, or the alteration of genetic material. Because genetic engineers can insert and remove portions of DNA in organisms using enzymes and advanced technologies, new types of more efficient plants and animals are being created, and chemicals such as insulin, human growth hormone, and interferon are currently being produced for human genes in bacteria for health care benefits. Substances produced from genetically engineered organisms in this way have lowered costs and side effects associated with replacing missing human body chemicals (8). Methods in gene therapy, the replacement or removal of defective genes to correct errors that cause genetic diseases, are also under development in hopes of providing a more targeted, efficient, and effective approach to genetic disease treatment (9).

## Future

As stated by geneticists Wolf, Lindell, and Backstrom, “Only recently have we entered an era where deciphering the molecular basis of speciation is within reach,” (10). The advances in bioinformatics have made comparison of genomes across species efficient, bringing the possibility of a



**Figure 3:** The Maxam-Gilbert DNA sequencing procedure involves carefully fragmenting radioactively-labeled strands of DNA by a series of chemical treatments, each targeting a specific nucleotide base (A, T, G, or C). The original sequence is then inferred by identifying the specific chemical modifications that individual fragments have undergone by means of electrophoresis (the separation of molecules by size and charge in an electrical field) and autoradiography (the use of x-ray film to detect levels of radioactivity).

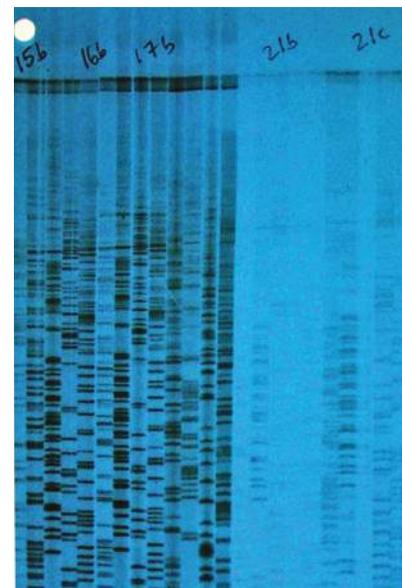


Image courtesy of Life Sciences Foundation. Retrieved from <http://www.lifesciencesfoundation.org/events-item-288.html>

comprehensive model of the evolutionary history of life closer to reality.

In addition to speciation insights, future decades bring promise of enhanced understanding the genetic bases underlying diseases. Despite many important genetic discoveries, the genetics of complex diseases such as heart disease remain “far from clear” (4). With a progressive understanding of the molecular and genomic factors at play in diseases, scientists anticipate more effective medical treatments with fewer side effects in the future. Several new initiatives have been launched in effort to achieve this deeper understanding:

1. The Cancer Genome Atlas aims to identify all the genetic abnormalities seen in 50 major types of cancer (11).

2. National Human Genome Research Institute’s (NHGRI) public small molecule library provides academic researchers with a database to chart biological pathways, which can subsequently be used to model the genome in experiments and serve as starting points for drug development. (11).

3. The Department of Energy’s Genomes to Life focuses on the genomic studies of single-cell organisms in hopes that once researchers understand how life functions on a microbial level, they can “use the capabilities of these organisms to help meet many of our national challenges in energy and the environment,” (11).

4. The Structural Genomics Consortium is an international effort studying the structure of the proteins encoded by the genomes of organisms put forth by the United Kingdom’s Wellcome Trust and pharmaceutical companies. These three-dimensional structures are critical in drug design, diagnosis and treatment of disease, and biological understanding. The information will be published in a public database (11).

Furthermore, the NIH is concentrating efforts in making genome sequencing more affordable and thus more widely available to the public, enabling easier diagnosis, management, and treatment of diseases (4). Leaders in the field forecast individualized analysis of individual genomes will result in a new form of preventative and personalized medicine in healthcare in the decades to come. A healthcare professional’s interpretation of a patient’s DNA sequence will allow for planning preventative lifestyle choices and crafting disease treatment to target the problem areas in the patient’s specific genome. Bioinformatics will enable genetically literate healthcare professionals to determine whether a drug will have adverse effects on a patient, optimize the therapies that will likely be most successful for a patient with a specific disease, and to identify the high-risk and low-risk diseases for the patient (6). Further, scientists claim, “by the year 2020, gene-based designer drugs are likely to be available for conditions like diabetes, Alzheimer’s disease, hypertension, and many

other disorders. Cancer treatment will precisely target the molecular fingerprints of particular tumors, genetic information will be used routinely to give patients more appropriate drug therapy, and the diagnosis and treatment of mental illness will be transformed” (5).

The Human Genome Project has also raised discussions on the ethical, legal, and social implications of the future of genetics. Policymakers are currently considering how to regulate the use of genomic information inside and outside of medical settings to ensure safety and privacy of individuals, as well as addressing health disparities across populations (12). Along with understanding medical conditions, genetics researchers are becoming increasingly able to connect DNA variation with conditions such as intelligence and personality traits—making the ethical, legal, and social implications of genetics research more significant (4). The impact of genomics on concepts such as race, ethnicity, kinship, individual and group identity, health, disease, and “normality” for traits and behaviors will need to be discussed (5). Controversial practices including human cloning, eugenics, and medical discrimination are some of the possibilities that come with the anticipated routes of genetic advancement (8).

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# Forecasting Precipitation in Hanover, NH Using Neural Networks

CHRIS HODER AND BEN SOUTHWORTH

## Abstract

*Even professional precipitation forecasts have a remarkably low level of accuracy. Most of these forecasts are done using numerical modeling, but an alternative method is to train machine learning algorithms on historical weather and precipitation data, and use these results to make predictions based on the current weather data. In this paper we implement a feed-forward back propagation neural network to predict precipitation in Hanover, NH. We then compared these results with other algorithms including a radial basis function neural network, a random forest,  $k$  Nearest-Neighbors and Logistic Regression. This work aims to improve on previous research in precipitation prediction by considering a more generalized neural network structure.*

## 1. Background

Meteorologists still lack the ability to produce truly accurate weather forecasts, especially with respect to precipitation. Nature's complex phenomena and the scope of the problem in both time and space lead to predictions that sometimes vary greatly from the actual weather experienced (Santhanam et al, 2011). Figure 1.1 (HPC, 2012) is provided by the National Oceanic and Atmospheric Administration (NOAA) and demonstrates the accuracy of quantitative precipitation forecasts from three different professional prediction models: the North American Mesoscale (NAM), the Global Forecast System (GFS), and the Hydrometeorological Prediction Center (HPC). A threat score is a function that ranges from 0 to 1 and provides a measure of how accurate a prediction was, with 1 being a perfect prediction. The inaccuracy of these predictions provides motivation for developing a better algorithm for predicting precipitation.

## 2. State of the Art

Traditionally, weather forecasting is done via two different methods. The first and foremost is based on numerically

modeling physical simulations with computers (Santhanam et al 2011). Although there has been much work and progress in this field, precipitation forecasts are still far from perfect.

Neural Networks have been used by meteorologists to accurately model many different weather phenomena such as humidity and temperature (Maqsood, et al 2004). Santhanam et al, worked to predict rain as a classification problem using a 2 layer back propagation feed-forward neural network as well as radial basis function networks. They produced a classification error rate of 18% and 11.51% for their feed-forward network and radial basis function network respectively (Santhanam et al 2011). Other work has been done using neural networks to predict precipitation but they have limited themselves to simple network architectures and short prediction times (French et al, 1991), (Kuligowski et al, 1998), (Hall et al, 1998).

## 3. Data

All of our data was obtained from the Physical Sciences Division of the National Oceanic and Atmospheric Administration. Which weather variables are most relevant to precipitation and the physical distance of measurements from Hanover necessary to predict precipitation was determined through an interview with a meteorology Ph.D. candidate at the University of Utah. We concluded that on the earth's surface we should consider wind direction, relative humidity, and mean sea level pressure. At elevations (measured in pressure) 500mb, 700mb, and 850mb we should use wind direction, relative humidity, specific humidity and geopotential height. For these variables, predicting precipitation one day in advance can depend on variables up to and over 1,000 miles away. Thus we selected the location of measurements for our data to approximate a box surrounding Hanover of approximately 2,000 miles in width and height. Figure 3.1 shows this box, with the blue marker indicating the location of Hanover and red markers representing the location of variable measurements.

This provided us with a total of 23 years of training data separated over 6-hour intervals, corresponding to 33,600 individual samples. Using a 13x10 grid of measurements shown in Figure 3.1 for our 19 variables of choice (four on the surface, five at three different pressure levels) gave us 2,470 input

Figure 1.1

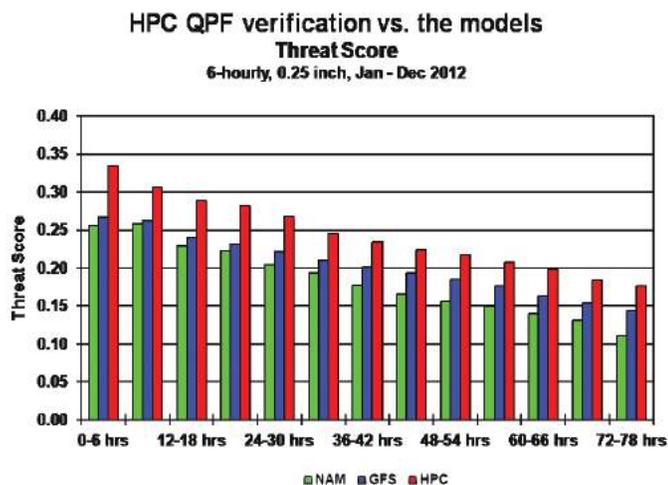
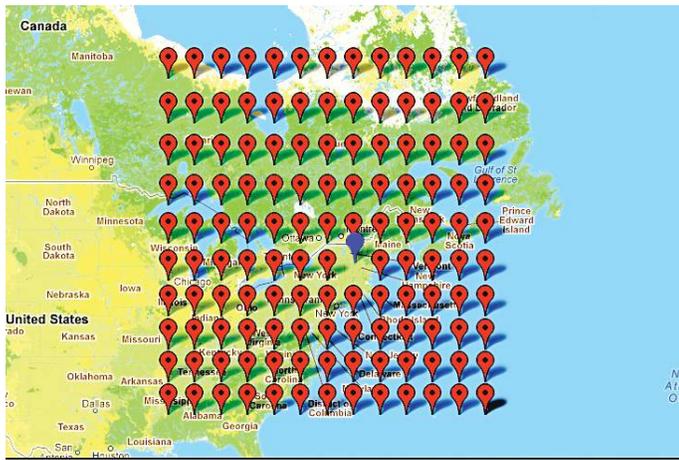


Figure 3.1



features. The data was preprocessed to normalize each input with a mean of zero and a standard deviation of one.

## 4. Algorithms

### 4.1 Neural Network

We have implemented a feed-forward back propagation neural network. The structure of the network has been generalized to allow for any number of hidden layers with any number of nodes in each layer. This means we have several hyper parameters that need to be tuned, such as the number of hidden layers and the number of nodes in each layer. The structure of the network can be seen in Figure 4.1. Networks with only two hidden layers have been shown to be able to model any continuous function with arbitrary precision. With three or more hidden layers these networks can generate arbitrary decision boundaries (Bishop, 1995). Furthermore, the output of a neural network for a classification problem has been shown to provide a direct estimate of the posterior probabilities (Zhang, 2000). The ability to model arbitrary decision boundaries is of particular interest for us since weather phenomena has been shown to be highly non-linear and dependent on a large number of variables.

The training of the neural network is done by the generalized back propagation algorithm to optimize the sum-squared error as a function of the weights of each node output and the bias values. An exact value for the gradient can be computed through application of the chain rule. Our implementation is a variation of the one outlined by K. Ming Leung in his lecture on back-propagation in multilayer perceptrons (Leung, 2008). The weights are initialized by sampling from a Gaussian distribution with a mean of zero and a variance of the square root of the number of input variables as suggested by Bishop (Bishop, 1995). Below we will discuss the generalized learning rule and methodology for our gradient decent method.

#### 4.1.1 Neural Network Notation

Consider a general Neural Network with  $L$  layers, excluding the input layer but including the output layer as shown in Figure 4.1 to the right.

In Figure 4.1 layer  $l$  has  $N_l$  nodes denoted  $X_i^{(l)} \in \{X_1^{(l)}, \dots, X_{N_l}^{(l)}\}$ . We will consider each node to have the same activation function denoted,  $f$ . However, one could easily extend this

algorithm to have a different activation function for each node or layer.  $w_{ij}^{(l)}$  is the weight factor from  $X_i^{(l-1)}$  to node  $X_j^{(l)}$ . We can also define an  $N_{(l-1)} \times N_l$  weight matrix,  $W^{(l)}$ , for each layer whose elements are  $w_{ij}^{(l)}$ . In addition, every node will have a bias term defined as  $b_j^{(l)}$ .

For a given set of labeled training vectors,  $T = \{(Z_1, Y_1), \dots, (Z_M, Y_M)\}$ , the goal of training is to minimize the sum squared error,

$$E = \sum_{i=1}^M ||Y_i - t_i||^2$$

where  $t_i$  is the output of the neural network for the input vector  $Z_i$ . For our algorithm we will only be considering one training example at a time, so  $E$  becomes just a single element. We then need to compute the gradient of  $E$  with respect to all of the weights.

Via back propagation we can derive the following update rules:

$$\frac{\partial E}{\partial w_{ij}^{(L)}} = a_i^{L-1} s_j^{(L)}$$

where  $s_n^{(L)}$  is defined as:

$$s_n^{(L)} = 2(a_n^{(L)} - t_n) * f'(n_n^{(L)}), \forall n \in \{1, \dots, N_L\}$$

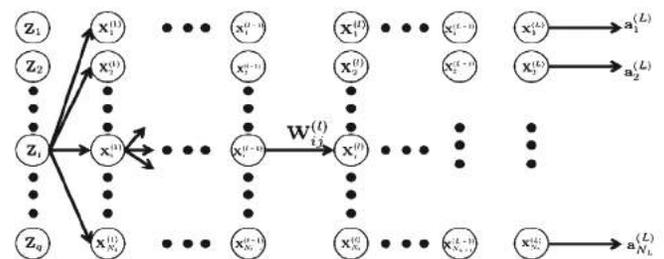
and  $f'$  is the derivative of the activation function. For the remaining internal hidden layers we get the following:

$$\frac{\partial E}{\partial w_{ij}^{(l)}} = a_i^{(l-1)} s_j^{(l)}$$

$$\frac{\partial E}{\partial b_j^{(l)}} = s_j^{(l)},$$

where  $s_j^{(l)}$  can be found recursively through the following equation:

$$s_j^{(l-1)} = f'(n_j^{(l-1)}) \sum_{i=1}^{N_l} w_{ji}^{(l)} s_i^{(l)}$$



Inputs ← Hidden Layers → outputs

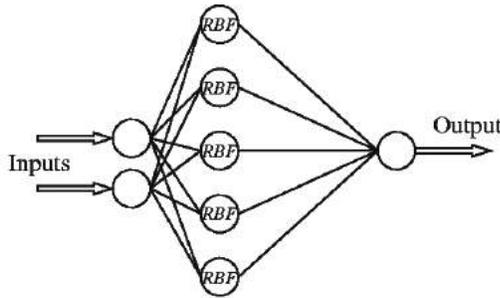
Figure 4.1: A general multilayer Neural Network consisting of  $L$  hidden layers and  $N_l$  nodes in each layer. The  $j$ th node in the  $l$ th layer is expressed as  $X_j^{(l)}$ . The weight from node  $i$  in layer  $(l-1)$  to node  $j$  in layer  $l$  is defined as the  $[i, j]$  element of the  $W^{(l)}$  matrix. The output of the activation function at node  $X_j^{(l)}$  is given by  $a_j^{(l)}$ . There is an implied bias input to each node that is not drawn in the image above.

Due to a heavy majority of examples with no precipitation, our initial results provided low classification error rates but classified everything as a non-precipitation event. After experimenting with different solutions to this problem, we settled on modifying our training algorithm to probabilistically sample precipitation examples evenly with non-precipitation examples during the stochastic training. Training also used a line-search method to dynamically adjust the learning parameter during training.

#### 4.2 Radial Basis Function Neural Network

We also implemented a specific kind of neural network called a radial basis function (RBF) network, the structure of which can be seen in Figure 4.2.

Figure 4.2



An RBF network has only one hidden layer composed of an arbitrary number of radial basis functions, functions that are only dependent on the distance of the input from some point. In this case we call these points the centers, and pick  $k$  centers in our sample space to correspond with  $k$  unique radial basis functions. Two general forms of radial basis functions that we chose to use are the Gaussian and thin-plate spline, shown below, respectively.

$$\phi_j(x) = e^{-\frac{\|x - c_j\|^2}{2\sigma_j^2}}$$

$$\phi_j(x) = \|x - c_j\|^2 \ln(\|x - c_j\|)$$

For each of these equations,  $x$  is the input sample vector being trained on or tested, and  $c_j$  the  $j$ th center vector. There are various ways to define the scaling parameter  $\sigma_j$  in the Gaussian function for an RBF network (Schwenker, et al). Two definitions that we tested are  $\sigma_j = d_{max} / \sqrt{2m}$  and  $\sigma = 2d_{mean}$ , where  $d_{mean}$  is the mean distance between all samples and centers,  $d_{max}$  the maximum distance of all samples from center  $j$ , and  $m$  the number of samples. After preliminary testing showing very similar results for each definition, we chose to use  $\sigma = 2d_{mean}$  for computational efficiency

For selection of our centers, we focused on random selection from our sample space in two ways, first selecting random samples from our training set and second selecting a random  $k \times n$  matrix of feature values from our training matrix  $X$ . Other ways to pick center vectors include using a  $k$ -means clustering algorithm and using orthogonal least squares to pick  $k$  vectors in the sample space. Centers were chosen using a Euclidean distance metric.

After designing our algorithm, we chose to use  $k = 100$ ,

500, and 1000 for the Gaussian as well as the thin-plate spline RBF to get a set of predictions for a wide spread of hidden layer sizes and two different RBFs.

The advantage of RBF networks is that the optimization can be done in two parts, closed form, thus making the computational aspect easier, and allowing for us to consider hidden layers of much larger magnitudes. For a given a weight function  $W$ , and a matrix of values calculated by our basis function,  $\phi$ , the general of form of our network is

$$y(x) = W\phi,$$

where  $x$  is some sample. Using a sum-of-squares error, we can then reformulate this as

$$\phi^T \phi W^T = \phi^T Y,$$

where  $Y$  is a matrix of outputs for the training set  $X$ . We then have that the weight matrix  $W$  can be solved for as

$$W^T = \phi^\dagger,$$

where  $\phi^\dagger$  is the pseudo-inverse of  $\phi$  (Bishop). Thus our training process is to first select centers  $c_j$ , for  $i = 1, \dots, k$  and calculate each row of our matrix  $\phi_j$  by plugging each training sample  $x_j$  into our radial basis function with centers  $C$ . We can then use this matrix and our output training set  $Y$  to solve for the weight matrix. To test data, we then plug a test sample  $x$  into  $y(x) = W\phi$ .

## 5. Results

### 5.1 Training and Testing standards

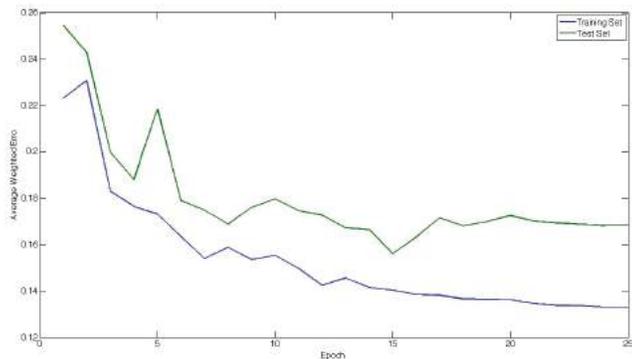
For all of our training and testing we used the following standards. We used data sets from the first 20 years as our training set. The data has been randomly reordered and pre-processed as discussed above. For testing we used the last 3 years of data.

As classification is our initial concern, we needed to convert our output values to boolean values. To do this we considered precipitation greater than .1 inches to be significant, and thus classified outputs greater than 0.1 in as precipitation. Predictions of less than 0.1 in were set to zero as non-precipitation.

There is no easy way to rank our classifiers as the “best” since we could tune our model to predict arbitrarily accurate for either of the two classifications. We therefore present the classification errors on both classes as well as the overall classification error to provide more information as to the success of our model.

### 5.2 Neural Network Classifier

In our final version of the neural network we were able to get informative results training our network. We ran 10-Fold cross validation across 21 different network complexities attempting to train our network to predict pitation 6 hours in the future. These cases trained different network structures ranging from two to four hidden layers with 5, 10 or 20 hidden nodes per layer. The best average validation error for the classification data was 0.1509 with a network structure of 3

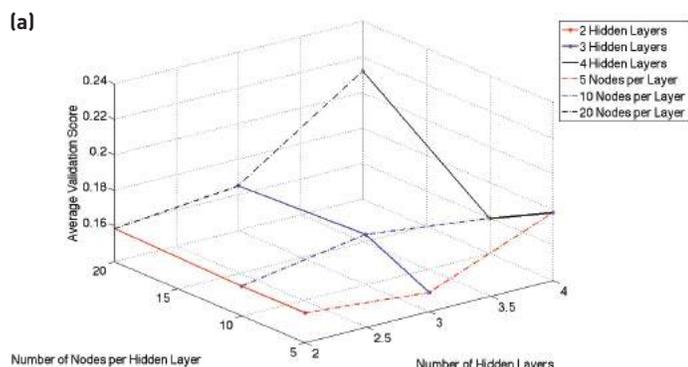


**Figure 5.1:** This figure shows an example of the error on the training and validation set during the training of a neural network. Each epoch trained over  $\frac{1}{4}$  of the examples in the training set.

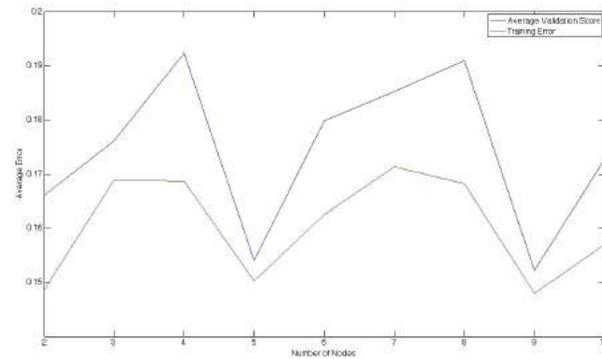
hidden layers with five nodes in each of the two non-output layers. Figure 5.1 shows an example of the error on the test and validation set as a function of the epoch during training. The network had two hidden layers with three nodes and one node in layers one and two, respectively. For visualization purposes Figure 5.2 below shows both our classification and regression results for nine of these cases where the number of hidden nodes were the same at each layer.

Having observed that, in general, the simpler neural network structures produce the most extensible results to unseen data, we re-ran our 10-Fold cross validation considering only two layer networks. In this experiment we varied the number of hidden nodes in the first layer from one to ten. Figure 5.3 to the above right shows the average validation error and average training error for these 10 cases. However we can see that there was little trend from simple to complex structure.

Having achieved fairly good success classifying precipitation 6 hours in advance, we then moved on to predict further into the future, running our training algorithm on prediction data sets of 12, 18 and 24 hours. Due to excessive training times we were unable run 10-Fold cross validation but instead simply train each case one time. Unfortunately, due to the stochastic nature of our training method this provides a rather inaccurate and noisy look into the prediction potential



**Figure 5.2:** Results for both classification and regression data predicting precipitation 6 hours in the future. 10-Fold cross validation was run across varied network structures with different number of hidden layers and a varied number of nodes in each layer. (a): Average Validation Error Rate for each case when training our classification network. (b): Average Sum Squared Error of the Validation set when training our regression network



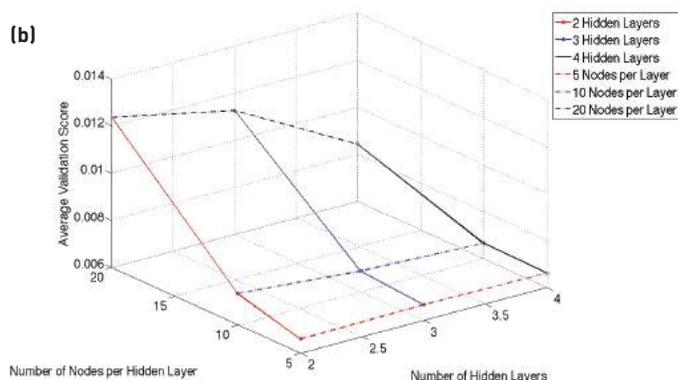
**Figure 5.3:** This shows the average validation scores of networks trained during 10-fold cross validation as we varied the number of nodes in the layer.

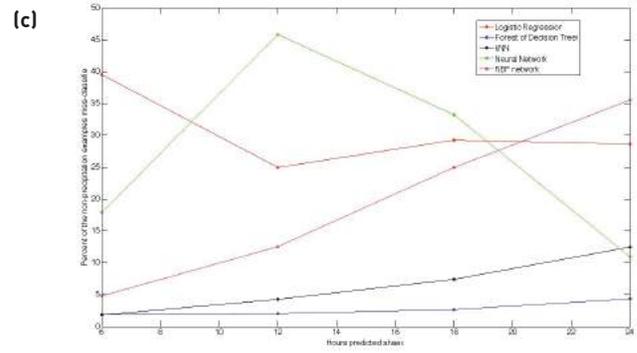
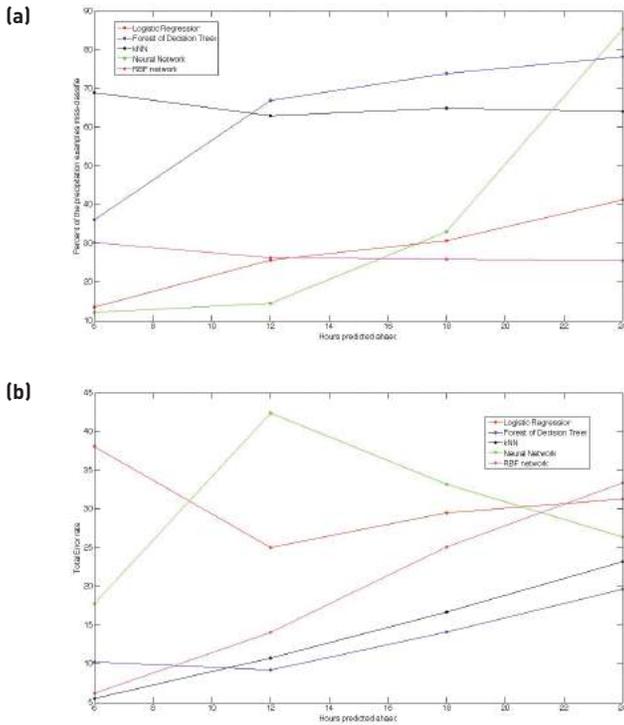
of our model for the different network structure cases. The best results for these larger prediction times are contained in Table 6.1.

Figure 5.4 (next page) illustrates the best results as we increased prediction time. We can see that in general our predictions get worse as time increases. The decision trees were able to maintain a fairly low overall error, but were one of the worst with classifying precipitation.

After training our RBF algorithm on the training data for both the Gaussian and thin-plate spline over time periods of 6, 12, 18 and 24 hours, and for hidden layer sizes of  $k = 100, 500,$  and  $1000,$  we ran our test data through the resulting classifier. Table 5.1 on the next page shows the error for precipitation events, error for non-precipitation events and overall error for each of the resulting classifiers.

As can be seen in Table 5.1, the RBF algorithm performed admirably well, especially when extending our forecasts to longer time intervals. Both the Gaussian and thin-plate spline produced good results, with the Gaussian proving to be marginally more accurate. Although the RBF classification of precipitation events six hours in advance could not compete with the standard neural network results, as we increased the prediction timeframe all the way to 24 hours, the RBF network demonstrated a robustness that we saw in no other algorithms. A part of this robustness however did





**Figure 5.4:** Figure (a) shows the percent of the precipitation examples misclassified in our models as a function of the prediction time. Figure (b) shows the percent of the non-precipitation examples misclassified in our models as a function of the prediction time. Figure (c) shows the total error rate as a function of prediction time.

lead to some over-classification of precipitation events, leading to a higher overall error. The RBF error in classifying precipitation events in the training set can be seen in Figure 5.5, the error for non-precipitation events can be seen in Figure 5.6, and the overall error can be seen in Figure 5.7 (next page). Note these figures contain results from both the Gaussian and thin-plate spline basis functions, for  $k$ -values of 100, 500 and 1000, and time intervals of 6, 12, 18 and 24 hours.

It is interesting to notice that the plots for the classification error of non-precipitation events and overall classification error are very similar, but in fact it makes sense. There are so many more samples of non-precipitation than precipitation events that the total error rate and non-precipitation error rate should be similar, as non-precipitation events make up a very large proportion of the entire test set. A similar correlation can be seen in other algorithms that produced very low total error rates, which were initially

convincing, until it was determined that the algorithm had simply classified everything as non-precipitation.

The over-classification done by the RBF network can be seen in the opposite trends of error in precipitation events and non-precipitation events as the time frame increased. To maintain a robust accuracy in predicting precipitation events, the algorithm began classifying more precipitation events over longer timeframes, clearly not all of which were accurate. Thus the accuracy of precipitation classification actually increased slightly as the timeframe increased, but the overall accuracy and accuracy of non-precipitation simultaneously declined linearly.

### 5.3 Comparison

To compare the results of our networks to a baseline, we also ran our data through a few simpler models for comparison. We chose to run a forest of 20 randomly generated decision trees,

**Table 5.1**

RBF	Gaussian			Thin-Plate Spline		
	Precip.	Non-Precip.	Total	Precip.	Non-Precip.	Total
hr,k = 6,100	0.473	0.035	0.059	0.482	0.026	0.051
hr,k = 6,500	0.314	0.043	0.058	0.343	0.043	0.06
hr,k = 6,1000	0.302	0.048	0.062	0.294	0.043	0.057
hr,k = 12,100	0.319	0.144	0.164	0.346	0.138	0.161
hr,k = 12,500	0.288	0.132	0.149	0.302	0.15	0.167
hr,k = 12,1000	0.263	0.126	0.141	0.327	0.144	0.164
hr,k = 18,100	0.291	0.272	0.275	0.281	0.285	0.284
hr,k = 18,500	0.264	0.259	0.259	0.303	0.277	0.281
hr,k = 18,1000	0.259	0.25	0.251	0.303	0.291	0.293
hr,k = 24,100	0.278	0.368	0.349	0.28	0.407	0.381
hr,k = 24,500	0.234	0.36	0.334	0.239	0.418	0.381
hr,k = 24,1000	0.255	0.355	0.334	0.26	0.404	0.374

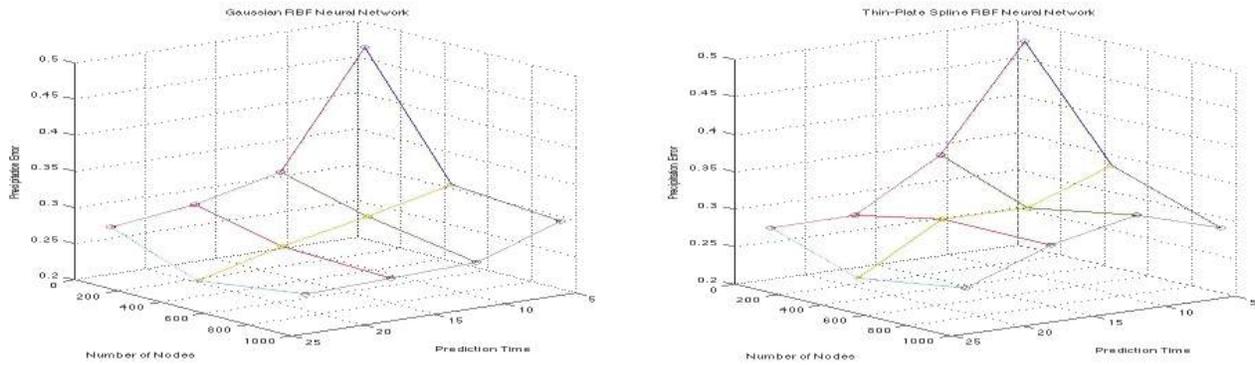


Figure 5.5: Error of the RBF classifying precipitation events for both the Gaussian and thin-plate spline basis functions.

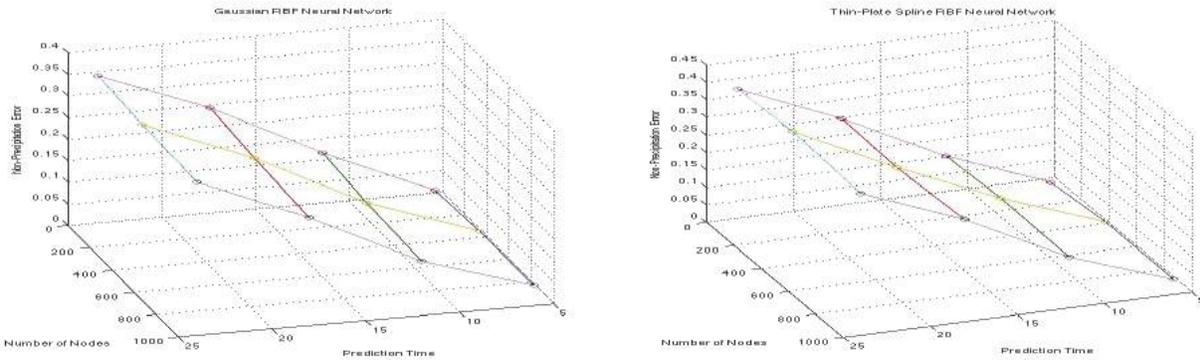


Figure 5.6: Error of the RBF classifying non-precipitation events for both the Gaussian and thin-plate spline basis functions.

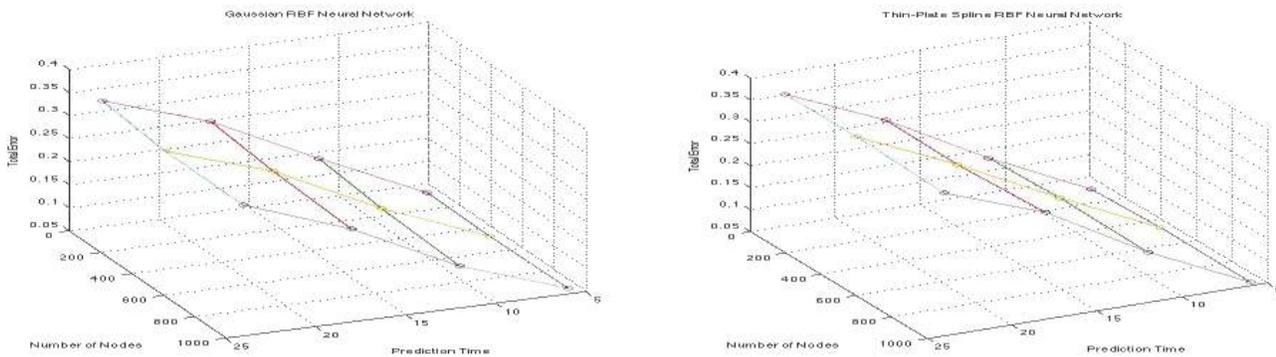


Figure 5.7: Total classification error of the RBF for both the Gaussian and thin-plate spline basis functions

k-nearest neighbors (kNN) and logistic regression.

## 6. Conclusion

A comparison between our best classification results for each model can be seen on the next page in Table 6.1. We can see that both our neural networks as well as the radial basis functions performed very well against the simpler algorithms. The radial basis function also performed better than other algorithms as we moved out to longer prediction times.

The RBF network could be enhanced by running cross-validation, something computationally intensive but favorable to improved results. It is also worth looking into alternative basis functions, as we only considered two of many possible options. The Gaussian performed better of the two, probably due to its inclusion of a scaling factor gauging the general distance between samples and centers, and there are other basis functions with similar scaling parameters. Last, the

choice of centers is a critical part of the RBF network, and implementing either clustering algorithms or an orthogonal least squares method could offer significant improvement on results.

Overall, our classification networks performed favorably with those published by Santhanam et al. Furthermore we were able to achieve moderate success looking further into the future with 12, 18 and 24-hour predictions. Our best classification results at predicting precipitation in six hours was a neural network structure, which produced error rates of 12.1% and 17.9% on the precipitation and non-precipitation examples respectively. This presents an improvement over the Santhanam group, which achieved only 19.7% and 16.3% error rates classifying rain and no rain respectively. Furthermore, we were able to achieve relative success taking our algorithms and training them for longer prediction times.

Future work could look into more network structures, especially for regression. Most of our work focused on

Model	Prediction timeframe	Percent wrong precip.	Percent wrong non-precip.	Total error rate
Logistic Regression	6	13.469	39.536	38.079
Forest of Decision Trees	6	36.031	1.850	10.228
kNN (n=5)	6	68.980	1.788	5.544
Neural Network (best)	6	12.121	17.869	17.742
RBF Network (best)	6	30.204	4.785	6.206
Logistic Regression	12	25.673	24.942	25.023
Forest of Decision Trees	12	66.874	2.053	9.201
kNN (n=5)	12	62.940	4.260	10.731
Neural Network (best)	12	14.493	45.856	42.397
RBF Network (best)	12	26.294	12.574	14.077
Logistic Regression	18	30.682	29.260	29.488
Forest of Decision Trees	18	73.864	2.640	14.093
kNN (n=5)	18	64.915	7.431	16.674
Neural Network (best)	18	32.955	33.234	33.189
RBF Network (best)	18	25.852	24.986	25.100
Logistic Regression	24	41.209	28.650	31.261
Forest of Decision Trees	24	78.132	4.299	19.653
kNN (n=5)	24	64.066	12.435	23.172
Neural Network (best)	24	85.385	10.906	26.394
RBF Network (best)	24	25.494	35.520	33.380

**Table 6.1:** This table outlines the best results for the various models tested over the four different prediction time frames.

classification of precipitation versus non-precipitation and not optimizing the regression networks. Very large and complex networks with large numbers of nodes were not considered due to overwhelming training time but these could provide better modeling for the larger test frames. Additionally, further work could look to vary the activation function or the connectivity of a neural network.

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# On the Nature of the Interactions between *Nasutitermes ephratae* and *Eciton burchelli*

BENJAMIN KESSLER, MILO JOHNSON AND WALES CARTER

## Abstract

The fierce struggle between predator and prey, so commonly witnessed in nature, has existed for hundreds of millions of years. Prey species have persisted when they have evolved defending against or avoiding predators. In the Osa Peninsula in Costa Rica, the army ant *Eciton burchelli* is an abundant generalist predator that is broadly devastating to other invertebrates and even small predators. The termite *Nasutitermes ephratae*, another abundant social insect species in the region, appears to be a potential prey item for *E. burchelli*. We examined the current and evolutionary relationship between these two species using a series of tests designed to understand the interactions between *N. ephratae* and *E. burchelli* as compared to their interactions with other species. Our results suggest that *N. ephratae* has a species-specific defense against *E. burchelli* and that *E. burchelli* has a species-specific avoidance behavior towards *N. ephratae*. We believe these species have coevolved in an arms race and that currently *N. ephratae* has the upper hand, in accordance with the life-dinner principle.

## Introduction

Sometime after life first arose from the primordial soup, but before the explosion of modern animal life in the Cambrian, organisms began to subdue and consume other organisms to gain the energy necessary for life (1). Since then, the phenomenon of predator-prey interactions has become one of the most ubiquitous and important relationships in the natural world (2). Rigorous mathematical models have described how these predator-prey associations can be stable over geological time via negative feedbacks governing their abundances (3). However, our best understanding is of specialist predators that rely on one or a few sources of prey (4). The dynamics become more complicated with generalist predators (4), and the stable coexistence of prey amidst predators is more challenging to explain. For example, the history of invasive predators shows us that generalists can continue to flourish after they have caused a severe reduction, or even extinction, of one of their prey items (5, 6).

On the floor of the lowland forest of the Osa Peninsula in Costa Rica, there is no generalist predator more devastating and awe-inspiring than the army ant, *Eciton burchelli*. As dawn passes and light filters through the canopy, colonies of up to 700,000 *E. burchelli* march forth from their bivouacs beneath dead logs or within the buttresses of trees (7). By midmorning, orderly lines lead outward from the queen's abode and eventually branch into a swarm of conspicuous foragers that scour the forest floor and the trees above. The swarm, accompanied always by the shrieking cries of opportunistic antbirds, leaves a path of mortality in its wake that few invertebrates escape (8). These deadly colonies, which have been compared to packs of miniature wolves on the hunt (9), prompted us to ask: how do other abundant insect species in the lowland jungle survive amidst this scourge of predation? Since most antipredator strategies against army ants rely heavily upon escape as a strategy (10), this question is especially pertinent for other colonial eusocial insects that live in large stationary nests, most notably other ants and termites.

Ants and termites, the "superpowers of the insect world," have been locked in a coevolutionary arms race for millions of years

(7, 11). The aggressive attacks of ants have exerted tremendous evolutionary pressures on termite species, resulting in a myriad of defensive strategies, from the enlarged snapping mandibles of *Capritermes* to the cylindrical heads that *Cryptotermes* use to plug openings in their nest (7). The soldiers of *Nasutitermes* use a specialized "spray gun," or rostrum, on the front of their heads to spray sticky and odorous chemicals at their attackers, with surprising accuracy for creatures that are blind (12, 7). The nature and specificity of such defenses provide clues to the history of the coevolutionary arms races between ant and termite species.

Based on initial observations that *E. burchelli* avoids the termite *Nasutitermes ephratae*, we narrowed our initial question to concern how *N. ephratae* has persisted in the presence of *E. burchelli*. To better understand the current and evolutionary nature of their relationship, we investigated; 1) if the avoidance behavior observed in *E. burchelli* is specific to *N. ephratae*; 2) if other ant species, one sister species and one distantly related species, show the same avoidance behavior, and; 3) if the termites have a species-specific defense against *E. burchelli*.

## Methods

We initially observed a column of *E. burchelli* passing over a *N. ephratae* nest without attacking on 4 February 2012 in Corcovado National Park, Costa Rica. Surprised by the lack of attack by *E. burchelli*, we explored this perceived avoidance further over the next 3 days. We placed pieces of *N. ephratae* nest (with *N. ephratae* present) approximately 10 cm<sup>3</sup> in size in an intermediate foraging column of *E. burchelli* and then observed and filmed the response of that column. We repeated this three times on columns of varying size and distance from the bivouac. We conducted this same set of three trials, filming when possible, on foraging columns of both *E. hamatum*, a congeneric army ant species characterized by column foraging and specialization in insect larvae, and *Atta colombica*, a dominant leafcutter ant species in this region (Hölldobler and Wilson 1990). These tests were designed to compare the responses of a closely related species (*E. hamatum*) and those of a distantly related ant species

(*A. colombica*) to *E. burchelli*.

We also dragged a cotton swab, onto which we had previously applied the fluids of crushed termites, across the substrate of three *E. burchelli* columns to test for the possibility of a chemical signal of termite presence. With the same logic as, we repeated this termite swab test on both *E. hamatum* and *A. colombica*, and we ran control tests using swabs from other non-ant arthropods and clean swabs. Finally, we brought individuals of our four focal species back to the lab and examined the interactions between each ant species and *N. ephratae* by placing a single ant in a Petri dish with ten termites, with three replicates for each species.

## Results

Each time we exposed *E. burchelli* to termites, we observed either a complete relocation or abandonment of the foraging column; smaller columns were abandoned, while larger columns were redirected. We saw this behavior both when the foraging column was on a termite nest and when it was at a location that was originally termite-free. To control for the physical disturbance of adding termite nest pieces, we placed leaves in an *E. burchelli* column. The ants were wholly undeterred and went over or through the debris in every case. When we placed several *A. colombica* individuals in the foraging column, *E. burchelli* continued without any sign of perturbation, and the leafcutters avoided the column. When we placed nonsocial arthropods, including an arachnid and an orthopteran, in the army ant column, they were immediately attacked, subdued, and dismembered by the instantly forming aggregations of *E. burchelli*. We saw a variable response to the addition of *N. ephratae* to *E. hamatum*, but responses were never greater than minor relocations and more often were nonexistent. *A. colombica* did not react or relocate its foraging column in response to the addition of termites.

We observed an immediate and dramatic avoidance reaction in *E. burchelli* when exposed to swabs of crushed termites. This was similar to their responses to termite nest pieces, but contrasted strongly with our observations during control tests. We observed no response to a clean swab, stereotypical hunting behavior and continuation of the column to an arthropod swab, and briefly increased general activity to a swab of crushed *E. burchelli*.

*Atta colombica* individuals did not respond to any of the swabs except for the swab infused with members of their own species, which made the ants scatter and then resume their path. *Eciton hammatum* responded to the three *N. ephratae* swab tests variably, once ignoring the swab and twice slightly changing course at the site of the swab as if briefly following the scent. *Eciton hammatum* responded to a spider swab with slight aggregation and apparent interest, and an *E. hammatum* swab caused them to scatter but then return to their original path.

Throughout these trials, we observed a curious phenomenon when *E. burchelli* was exposed to *N. ephratae*. Occasionally an *N. ephratae* individual, in response to an approaching *E. burchelli* individual, would point its nostrum up toward the ant and, by some unknown mechanism, promote a complete and sudden paralysis in the ant, often with the stereotypical characteristic of one raised and one lowered antenna. This type of interaction was consistently present in a small number of ant individuals in each trial. We also observed this in one instance where we only presented *E. burchelli* with a cotton swab of crushed *N. ephratae*.

When we touched a single ant and termite to one another in the laboratory, each held by forceps, this paralytic response seemed to be most common when the termite's rostrum came into contact with the antennae of the army ant. We witnessed no such response in either *E. hamatum* or *A. colombica* in any trial either in the field or in the lab.

The results of our ant-termite pairings in the lab were consistent across replicates within each species. *Eciton burchelli* consistently appeared to become incapacitated with reasonable rapidity, by both a combination of glued limbs and the paralysis we had previously observed. On the other hand, *E. hamatum* was incapacitated slowly by *N. ephratae* soldiers, who glued themselves to one another and to the ant, causing it to writhe and struggle. *Atta colombica* and *N. ephratae* mostly ignored each other in this test, but we occasionally witnessed *N. ephratae* attacking *A. colombica*, presumably with glue, and *A. colombica* grooming itself in response and then continuing unhindered. (See supplementary materials for videos of our experiments).

## Discussion

Though termites are generally considered one of the most important food sources for army ants (10), *E. burchelli* clearly avoided introduced *N. ephratae*, a behavior that was not observed when *E. burchelli* was confronted by other arthropods (*A. colombica*, an arachnid, and an orthopteran). We believe that this avoidance represents an adaptive behavior in *E. burchelli* because there would otherwise be a considerable cost to the army ant colony each time they encountered the ubiquitous *N. ephratae*. We observed this distinct avoidance behavior in response to both live termites and a swab with crushed termites, indicating that *E. burchelli* uses a chemical signal to determine the presence of termites and trigger this response. A closely related army ant species, *E. hamatum*, responded to *N. ephratae* much less consistently and stereotypically than *E. burchelli*, while *A. colombica*, a distantly related species, exhibited little or no response. Considering these results, we believe that the observed avoidance represents a newly derived synapomorphy in *E. burchelli*.

Termite soldiers have been called "a cast of nightmarish monsters," and though *Nasutitermes ephratae* soldiers can seem innocuous enough to a casual observer, they by all means fit this description (13). The use of monoterpene and diterpene glues by *Nasutitermis* species is well documented (14); we interpret the response of *N. ephratae* to *E. hamatum* that we observed in the lab as an example of their generalized response to nest invaders. In contrast, when *N. ephratae* encountered *E. burchelli*, they attacked and always elicited a temporary state of stereotyped "paralysis" in at least several ants, in which the ants stood perfectly still instead of struggling against the physical effects of glue. Termite defensive glues have been observed to contain chemicals with irritant or toxic properties (7), so the paralysis reaction in *E. burchelli* could be the pathological effect of a selective toxin specific to them in *N. ephratae* glue. Such a toxin could have evolved as part of the defensive repertoire of *N. ephratae* against predation by *E. burchelli*. Another possibility is that paralysis is an adaptation of *E. burchelli* to specifically avoid costly contact with *N. ephratae*. The former mechanism is more parsimonious, but we do not reject the latter possibility. Further studies are necessary to distinguish between these possibilities.

In any case, our studies indicate species specificity on both

of sides of the interaction between *E. burchelli* and *N. ephratae*, which implies a highly derived form of predator-prey interaction. The paralyzing attack of *N. ephratae* appears to be specifically oriented towards *E. burchelli*, and the marked avoidance behavior of *N. ephratae* seems to have only evolved in *E. burchelli*. Based on these characteristics, we believe that this interaction may be the result of coevolution. The lack of such a paralytic effect on the congeneric *E. hamatum* supports the notion that this defense has evolved to specifically target *E. burchelli*. However, it remains possible that this is a more generalized defense against attackers and that *E. hamatum*, a specialist predator on social insects, has acquired an additional adaptation to overcome the effects of the toxin.

A particularly fascinating implication of our findings is that the adaptive response by *E. burchelli* to *N. ephratae* is one of avoidance rather than a mechanism to overcome the termite's defenses. Though these two species may not today be predator and prey, our studies apparently reveal the ghost of predation past. The termites have managed to reach a ceasefire with *E. burchelli*. While the best understood predator-prey systems involve specialist predators, which must outdo their prey or face certain death (3), this dichotomy does not hold for *E. burchelli*. *Eciton burchelli*, a generalist, has evolved to avoid *N. ephratae* rather than to escalate the evolutionary arms race. This appears to conform to the life-dinner principle (15), which argues that strong selection to survive, in this case on *N. ephratae* exposed to *E. burchelli*, will trump the relatively weak selection on a generalist predator, here *E. burchelli* to gain a meal. An army ant attack is a matter of life and death for an *N. ephratae* colony, and the species has clearly evolved defenses in response to this strong selection pressure. Consequently, the termites are costly and dangerous prey, and now *E. burchelli* has apparently evolved to change its diet rather than trying to subdue this dangerous quarry. This principle may serve to explain how potential prey species around the world have persisted amidst powerful generalist predators over evolutionary time. It reminds us that though nature be red in tooth and claw and species locked in battles that wage for millions of years, occasionally a prey species may escape the yoke of predation, leaving only whispered clues to their violent past.

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# GreenCube 5: Mapping River Flow with Sensor Swarms

JONATHAN GUINTHER

## Abstract

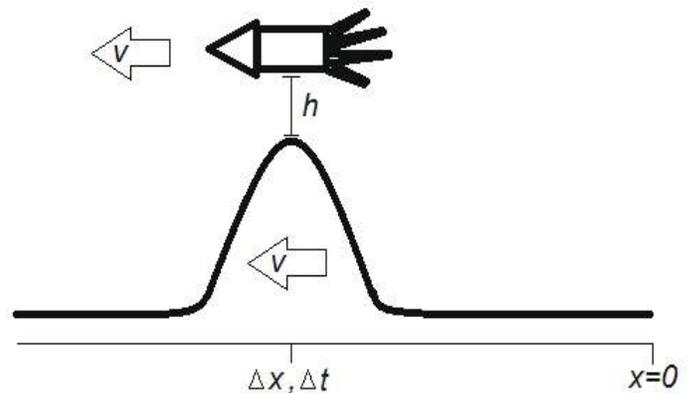
*If you happened to be around the Ledyard dock or canoeing down the Connecticut on the right day last spring, you would have seen a bizarre scene: twenty or so Rubbermaid containers bobbing down the river and four or five canoes full of eager undergrads paddling in circles around them. Far from some weird Dartmouth ritual, this was actually a test-run of an undergraduate scientific experiment, overseen by Professor Kristina Lynch in the Physics Department. The experiment was implemented and run by students in the GreenCube lab, which has previously run balloon-borne science experiments.*

## Introduction and Motivation

Professor Lynch is a rocket scientist, which might come as a surprise, considering the opening story. But she does not design or improve the rockets themselves; she uses rockets as a tool to study her real research interest: the Aurora Borealis, commonly known as the Northern Lights. The aurora is beautiful object of study, its many colors and constantly shifting form can be a truly breathtaking display but only if you are at the right latitude to see it. The aurora only appears at certain high (and low) latitudes as a result of how the energy from the Sun interacts with Earth's magnetic field. Energized particles run along the magnetic field lines near the poles—causing the fine, changing structure of the aurora, a field of particular interest to Professor Lynch.

Nearly every year, Professor Lynch, a few graduate students, a handful of Dartmouth employees, and other researchers from NASA travel to Norway or Alaska to study the Northern Lights. When the conditions are just right and the aurora is putting on a magnificent show, they launch a sounding rocket, an instrument-carrying rocket designed to take measurements, to try to glean some information about the aurora's curtains of light. In fact, thinking of the aurora as a curtain helps to understand what brought the GreenCube lab canoeing after an armada of floating Rubbermaid containers and the motivation behind the physics research project known as the GreenCube 5.

Imagine that you and a friend are holding a piece of curtain at each end. You quickly flap the curtain to create a little wave of fabric which travels to your friend. Now imagine that a sounding rocket is riding the curtain like a surfboard and wants to measure the height of the curtain to create a "movie" of the wave. The rocket can only measure the exact position that it is traveling over. Let's say that the rocket is launched at the exact moment that you create the wave and that the rocket and the wave travel at the same speed such that the rocket rides on the crest of the wave. In this particular instance, the movie made by the rocket would be pretty boring since the rocket would measure the same height (the height of the crest) the entire time. This scenario is diagrammed in Figure 1 on the next page. This is not an accurate description of the real wave. Even if the rocket travels faster or slower than the



**Figure 1:** A rocket wants to measure the height of a traveling wave. In this scenario, both travel at speed  $v$ . Notice how for all times  $t$  and positions  $x$ , the rocket will measure the same height  $h$ . In fact, no matter what speed the rocket travels at, it will be unable to uniquely construct the original behavior of the traveling wave. This phenomenon can be mitigated by using multiple rockets.

wave, the rocket will be unable to uniquely reconstruct the original motion of the wave. This is because both the wave of the curtain and the rocket are changing in time and space. One solution to this problem is to launch a grid of rockets at different times and positions, as explained below.

For simplicity, suppose you launch three rockets in a line, one rocket ahead of your wave, one on the crest of your wave, and one after your wave. If the rockets and the wave are traveling at the same speed, the first and last rockets measure a height of zero and the middle one measures the height of the crest over the entire flight, just as before. However, for any given point along the curtain, the first and second rockets will have obtained a different value at a different time. This conveys information about the height and the speed of the wave they are trying to observe. With some clever analysis, a decent movie of the curtain-wave can be constructed.

This example above conveys the difficulty of using a single rocket to measure a structure like the aurora which is changing in time and three-dimensional space. It also motivates the use of a multi-point measurement system (e.g. multiple rockets). Such a system may seem like a good idea,

but the logistics of managing multiple sets of equipment and the process of assimilating the data were both big unknowns to Professor Lynch and the GreenCube lab. Therefore, it was necessary to find some interesting physical system to test the new process. As it turned out, rivers were an excellent testing ground.

## Goals and Design Requirements

The goal of this GreenCube mission was twofold: (1) to demonstrate proof of concept of a multi-point measurement system and (2) to measure something of scientific interest. The first goal can be broken down into two parts: the management of many payloads (equipment that makes measurements) and the assimilation of the resulting data. Measuring the fine-scale flow features of a river was a good medium with which to test these goals for the following reasons:

- Measuring river flow is logistically simpler than measuring something in the atmosphere.
- It allows for the use of many more payloads than would be possible in other mediums.
- It is a simplified data assimilation problem because river surface flows are stationary in time and two-dimensional.
- Fine-scale river flow is interesting because it controls where large woody debris (LWD) are deposited on the banks. These logs become havens for animal life.

Having established that a swarm of sensor payloads will be used to measure river flow, the next step was designing the payload and the swarm architecture. First of all, the payloads must be waterproof. Secondly, to mimic the conditions of flying an array of spacecraft through the aurora, they must communicate their data wirelessly in real-time. Finally, the payloads must be equipped with a sensor to measure river flow. The more payloads used to measure river flow, the more detailed the final description will be. It was thought that twenty payloads would be a good balance between managing a large fleet, the data produced by such a fleet, and obtaining an adequate description of river flow. Thus the high-level goal of GreenCube 5 became to launch a fleet of payloads into a river to create a detailed, accurate map of the river's flow.

## Implementing and Running the Experiment

The first step was to build all of the payloads. Each payload contains an electronics stack, a 9-volt battery, a weight, and a foam cutout to keep the other parts in place. These components are housed within a waterproof Rubbermaid 1.2 Liter food storage container. The electronics stack consists of an Arduino UNO control board, a compass board for magnetic field and acceleration measurements, a GPS, and a radio for real-time data transmission. The electronics were designed to be similar to ones which could fly aboard rockets to measure features of the aurora. Because the GPS transmits position (from which we derive velocity) of the payloads, it was used to map the surface river flow. A total of twenty payloads were constructed, each containing the exact same parts, but with a unique name to keep track of them. In addition, two radio-receiving stations were built. These stations consist of

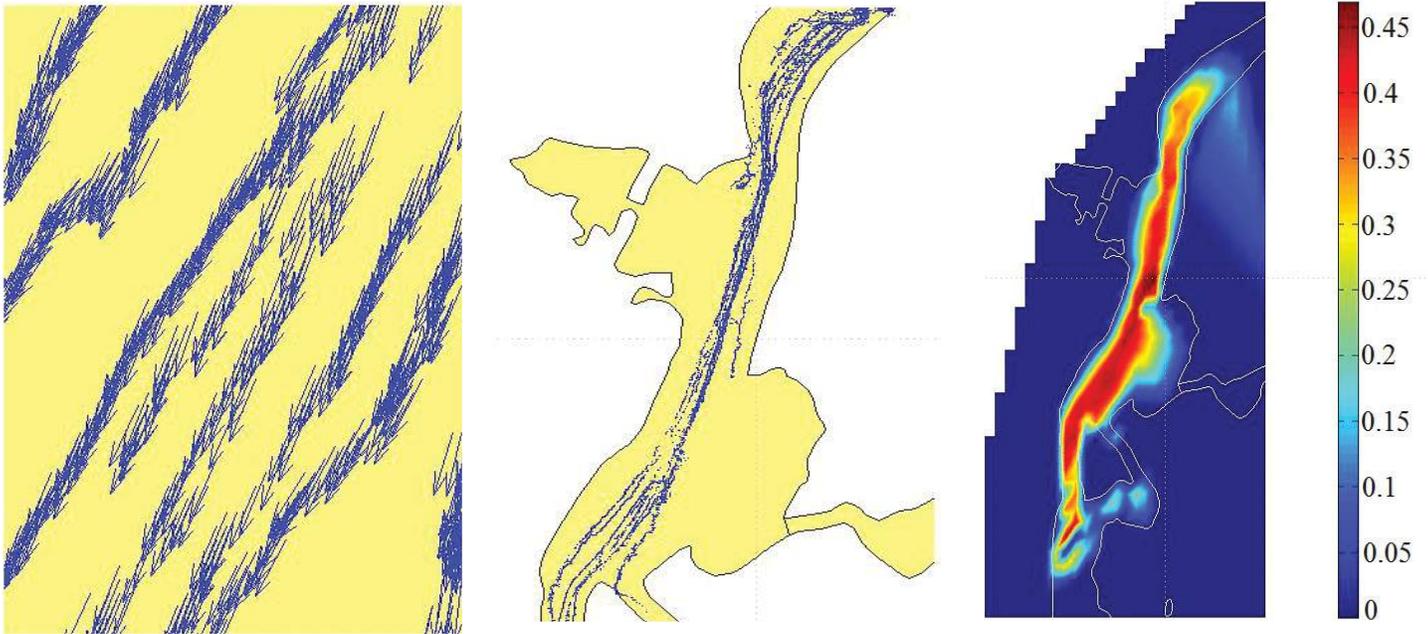
a radio and a laptop that receive data from all of the payloads. Because the radios operated on a relatively short range, it was necessary for the receiving stations to remain close to all the payloads. The best way to do this was for the receiving stations to be aboard two different canoes, which followed the group of payloads as they travelled down the river. Two stations were built to add robustness to the system, in case one became separated or dysfunctional for any reason.

After the payloads and group stations were tested in the lab, the next step was to test them in a slow-moving body of water. This type of river is less interesting in comparison to a winding, narrow river because the surface flow patterns are less complicated and LWD deposits on the river bank are less common. Fortunately, the Connecticut River is both relatively slow and calm and was chosen for the initial experiment. In addition to the two receiving stations aboard canoes, three students in canoes followed the payloads down the river, watching for ones which tipped over or stopped transmitting. To get the payloads started down the river, the two receiving station canoes took staggered positions on the river by the Ledyard dock and slowly paddled across, dropping payloads as they went. This created an initial grid of ten by two. However this grid quickly disintegrated. Some of the payloads became trapped in slow moving water and were manually extracted by the students in canoe. Also some of them were not completely waterproof and thus stopped transmitting data to the ground stations. The payloads were allowed to float past Gilman Island, a trip of around one and a half hours, after which they were collected and brought back to the lab. Other than the few payloads that were not completely waterproof, this trial run was a success.

After the experiment in the Connecticut and a few modifications to the payloads, the next test was to be run in a more scientifically interesting river. The Ompompanoosuc River was an excellent choice because it is conveniently close to campus, an order of magnitude smaller than the Connecticut (200 meters versus 15-35 meters), and contains more bends and turns. The launch at this river was trickier because it flowed so quickly. Students positioned themselves along both sides of the river by the Union Dam and launched the payloads one after another. The variation in paths taken by each payload created almost no sense of a "swarm". Also the LWD of interest to hydrologists often entangled the payloads which required manual intervention. In this qualitative respect, the payloads seemed to be a good model for LWD. Due to rapids and overturning, some of the payloads stopped transmitting. However, enough data were obtained from the fleet to be useful over the entire course from Union Dam to close to the edge of the Connecticut, where the rivers join.

## Analysis and Results

The first step in assimilating the data was the removal of the irregular portions of data, such as the manual interventions to free the payloads from slow water or entanglement. Because the data were plotted on maps from the US Census Bureau, points which were outside the boundaries of the river due to incorrect mapping or GPS error were included by manually changing the boundaries. When the data were ready for analysis, the velocity of the payloads was plotted on the maps of each river using the position data from the GPS. The



**Figure 2:** Left: a close-up plot of payload velocities on the Connecticut River, before interpolation. Center: a wider view of the same. Right: a map showing magnitude of velocity in m/s over the same stretch of river, interpolated from data shown on the left.

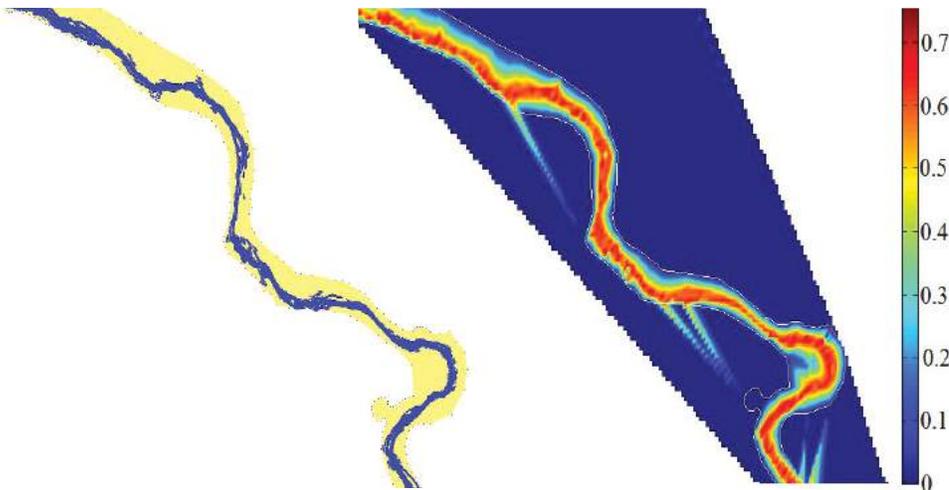
boundaries of the river were assumed to have a surface velocity of zero. The flow of the rivers was assumed to be stationary in time. This means that if you launch two payloads from the same spot in the river ten minutes apart, they should follow similar paths down the river. Thus, the time when a payload measured a certain surface velocity was irrelevant to the analysis.

A two-dimensional interpolation of velocity was performed between the boundaries of the river. The interpolation works by fitting a surface of the form  $f(x, y) = V$  to the observed data points, where  $V$  is velocity at that point. This interpolation can then be queried for individual points for which there was no data previously. Interpolated plots were created by selecting points in a fine, regular-spaced grid and making a colormap from those points. The spacing of this grid was chosen to reflect the average spacing between the payloads in the river. If the grid spacing is too fine, then aliasing may occur; if it is too

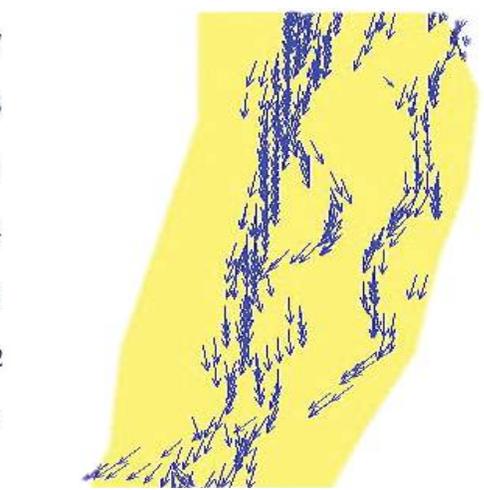
coarse, then some data are being lost. Finally, the divergence and curl of the surface flow was calculated. These are properties of vector fields which denote an origin or sink of a vector field and the vorticity of a vector field, respectively. This analysis was performed in Matlab.

Figure 2 above shows velocity data for a section of the Connecticut before and after interpolation. The “before” velocities show little spatial variation in magnitude, which is reflected in the lack of prominent features in the interpolated map. Figure 3 (below left) shows a similar set of plots for the Ompompanoosuc River. The interpolated maps appear to provide a reasonably accurate representation of the river velocities as measured by the payloads.

On the Ompompanoosuc River, the flow was observed to follow a roughly sinusoidal pattern within the river channel in several places, as shown in Figure 4 (below right). This



**Figure 3:** As with above, a vector plot of velocities and an interpolated velocity map with units of m/s.



**Figure 4:** Sinusoidal variation in flow observed on the Ompompanoosuc

observation fits with the known tendency of river water to meander in sine-derived curves.

Next the divergence and curl of the interpolated velocity functions were taken. A river is an incompressible fluid, so its surface flow should have no divergence unless there is an upwelling. Curl should be nonzero in places with eddies or places where the river curves. Predictably, the divergence and curl plots for the Connecticut River were very uninteresting. As shown in Figure 5 to the right, neither plot deviates much from zero.

Divergence and curl were calculated for the Ompompanoosuc River velocity function as well. The divergence should be close to zero, as it was for the Connecticut. However, artificial divergences may appear in areas where the river boundaries were extended. There should be a positive curl on one side and a negative curl on the other, a manifestation of the river velocity approaching zero at the boundaries. Figure 6 shows the divergence and curl in one section of the river. Note that the expected pattern is seen in these plots.

## Conclusion

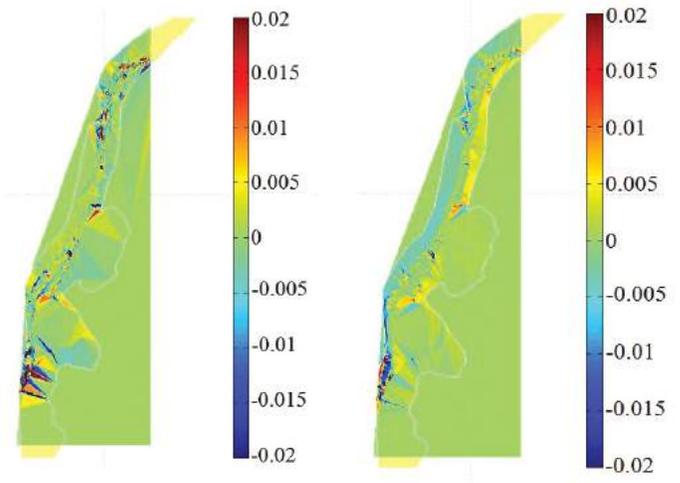
In conclusion, both goals of Greencube 5 were successful. A fleet of twenty, low-cost measurement systems was created and maintained over the course of two separate missions to map the surface velocity of two different rivers. These payloads were designed, built, and tested within a few months, a process greatly aided by the Arduino board's usability. It was also shown that interpolated velocity maps of these rivers generally matched the real system and more complicated analyses--including the curl and divergence of these velocity maps--matched the expectations for each river. Additionally, measuring the surface velocity was an interesting experiment in terms of modeling how LWD are deposited on banks to create a protected environment for animal life.

Currently the lab is working on a new data assimilation procedure which incorporates state-of-the-art signal reconstruction techniques. There is much work to do before these payloads can be flown through the upper atmosphere to create maps of the aurora, but this project has laid both the logistical and analytical foundations to make such a venture possible.

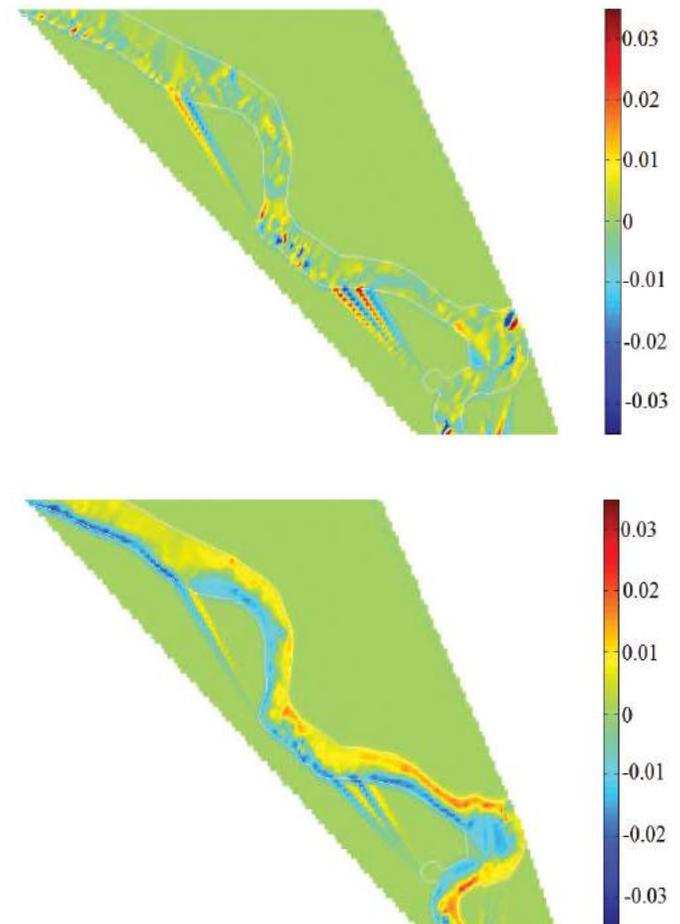
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**Figure 5:** The divergence [Hz] (left) and curl [Hz] (right) of the velocity function for the Connecticut River. Overall, deviations from zero are small in both plots.



**Figure 6:** Divergence and curl [Hz] in a curvy section of the Ompompanoosuc. The spikes in that lie outside the river are artifacts of the interpolation procedure.

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$$\frac{2}{3l} \left( \cos \frac{2\pi x}{l} + 1 \right)$$

$$\frac{1}{2}, \frac{1}{2} \left( \frac{\pi}{l} \right)^2, \frac{1}{2} \left( \frac{\pi}{l} \right)^4$$

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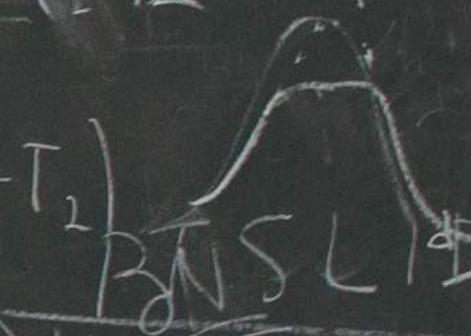


$$16 \left( \frac{\pi}{l} \right)^2 = \frac{1}{3} \left( \frac{2\pi}{l} \right)^4$$

$$y(x) = \frac{1}{2} (1 + \cos \frac{2\pi x}{l})$$

$$\beta = \frac{1}{2}$$

$+Q_2^{-1}$   
 $Q_2^{-1} T_2$



$Q = 550 \text{ cm}^{-1}$   
 $g(E) = \frac{1}{\sqrt{E}} e^{-\beta E}$   
 $\frac{d}{dE} \left( \frac{1}{\sqrt{E}} e^{-\beta E} \right) = 0$

Critical

$$E_{oc} = \left( \frac{1}{2\beta} \right)^2$$

$$\frac{d}{dx} \left( \frac{1}{\sqrt{x}} e^{-\beta x} \right) = 0$$