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Technology to Transform Tomorrow

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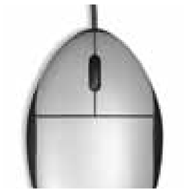
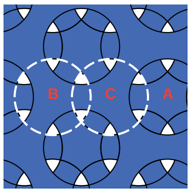
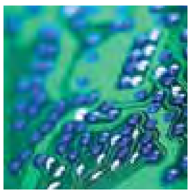
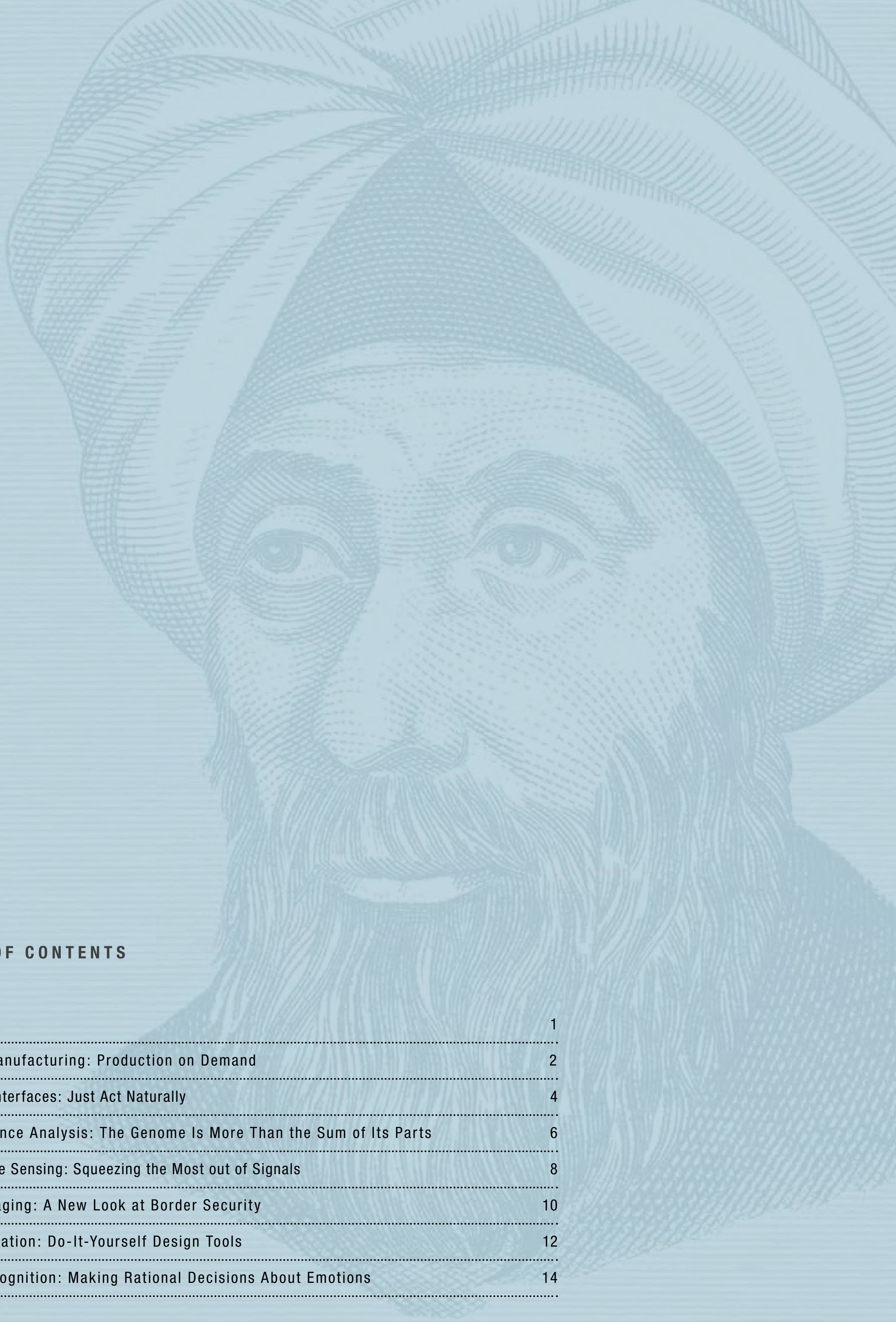






Additive Manufacturing
Affective Cognition
Compressive Sensing
Computer Interfaces
DNA Sequence Analysis
Flight Validation
Gravity Imaging

MITRE



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Ibn al-Haytham, Pioneer of the Scientific Method, 965–1040 C.E.

STEVE HUFFMAN, VP, CHIEF TECHNOLOGY OFFICER

Welcome to the third issue of *Envision*. Within these pages you will find insights into the emerging technologies coalescing in the laboratories of MITRE and other research centers. In the next five to 10 years or beyond, the technologies featured here could lay a new foundation for the way government agencies pursue the challenges they face.

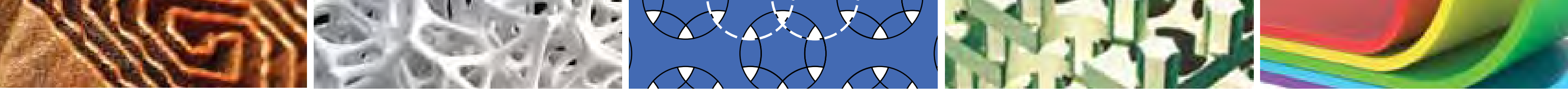
The key to this new foundation will be connections; research into emerging technology is not a solitary pursuit. So MITRE helps sponsors build strong, flexible networks of connections that foster innovation, spark creativity, and bring together talented people and challenging ideas.

The technologies featured in this issue are all in some way the result of those connections. MITRE proposals to redesign computer interfaces, to improve the effectiveness of DNA sequencing, and to enable the construction of vital spare parts for military equipment right on the front line all build off a framework of research by other organizations.

Connections within an organization are just as necessary as connections between organizations in the development of emerging technologies. MITRE's research into scanning sealed containers with gravity waves, into maximizing the capabilities of signal processing, and into improving airport efficiency all rely on a culture of collaboration and communication to fully focus our collective expertise.

Networks and the connections they engender are the engines that drive budding ideas into emerging technologies. And, as we hope this issue of *Envision* will attest, MITRE serves as a vital hub in that network of research, helping to expand and strengthen the connections among researchers, their ideas, their organizations, and their customers.

Envision's authors have included their email addresses if you have comments or questions. In addition, if you visit our website (www.mitre.org/envision), the authors have posted links to other related articles you might find of interest. We invite you to share your thoughts and feedback and to stay connected with us as we continue to research and explore technology to transform tomorrow.



ADDITIVE MANUFACTURING: PRODUCTION ON DEMAND

With additive manufacturing supplying a temporary part, equipment can remain operational until the actual replacement arrives.

James Barkley

SUMMARY: Additive manufacturing is a technique for building parts on demand out of layers of raw material such as plastic or metal. This technology possesses the potential to revolutionize manufacturing and acquisition.

3-D Printing

Beside a sun-baked road, members of a military bomb disposal unit cool their heels. A hundred yards behind them, a convoy of armored vehicles idles. A hundred yards ahead of them squats the burned out hull of an automobile, the perfect place to hide a roadside bomb. At their feet sits the robot employed by the unit to remotely investigate suspected bomb sites. One of its treads is detached, the victim of a broken fastener.

It's been a chronic problem for the unit, so they have no more replacement parts on hand. The next shipment of parts isn't scheduled for four days. Just as the convoy commander walks up to discuss choosing a new route, a Humvee races around the stalled convoy. On the passenger seat is the tread fastener, built from scratch on demand—courtesy of additive manufacturing.

Additive manufacturing, sometimes called 3-D printing, is a technique where a product is built up layer by layer from raw material, such as a liquid plastic or powder metal, following a computer-aided design blueprint. The technique was created in the late 1980s to cheaply produce custom parts for prototypes.

Rapid and Flexible Resupplying

With our enemies forced to innovate rapidly to survive, it's become increasingly important for the U.S. military to improve its own agility and flexibility. That means looking for ways to overcome a burdensome acquisition cycle requiring a great amount of cost, time, security, and storage space. With additive manufacturing, parts could be produced where they're needed, when they're needed.

Using additive manufacturing would allow for rapid replacement of parts in the field and allow deployed units to remain mission-ready. The technology could be installed and operated at or near deployment locations. Through the use of secure satellite data links or a local parts database, warfighters could access CAD designs for replacement parts, allowing them to repair equipment without the need to establish supply chains or wait for shipments. It could even allow operators to modify a part's design based on its performance in the field.

MITRE is pursuing a research project, called MakeOne, which investigates how to bring additive manufacturing capabilities to the field. MITRE is also designing a data model that helps designers understand all the relationships and attributes of additive manufacturing equipment and materials.

Layer by Layer

A common form of additive manufacturing uses a machine similar to an ink jet printer. The printer deposits a layer of resin on a support table according to a computer-directed design. An ultraviolet light cures the resin into a thin solid layer about as thick as copy paper. Successive layers are added by lowering the support table and printing a new cross-section layer until the part is complete in three dimensions.

Other types of additive manufacturing include:

- Sintering—heating powdered metal below its melting point until it forms a solid mass
- Melting—fusing particles together with heat
- Spray deposition—building solid objects with layers of finely sprayed molten metal
- Stereolithography—three-dimensional printing process that makes a solid object from a computer image by using a computer-controlled laser to draw the shape of the object onto the surface of liquid plastic
- Lamination—bonding solid layers together, as with plywood

Spare Tires

The safety of using parts produced with additive manufacturing techniques is the government's biggest concern in adopting the technology. But industry already uses additive manufacturing in high-performance environments such as airplane manufacturing and race car engine construction. Materials research has led to durable and flame-retardant plastics and high-grade titanium alloys that work well in the process.

When dealing with safety concerns, it's also important to consider additive manufacturing as a supplier of temporary parts rather than final replacement parts. If a part breaks in the field, vital equipment may be down until the replacement part can be secured. This can sometimes require great time, great money, or both.

But with additive manufacturing supplying a temporary part, equipment can remain operational until the actual replacement arrives. Because the temporary part is not intended to be the final replacement part, it doesn't need to meet the same stringent operating requirements. The additive manufactured part can bridge the gap, much like a spare tire on a car miles from an auto shop.

The Expensive and the Complicated

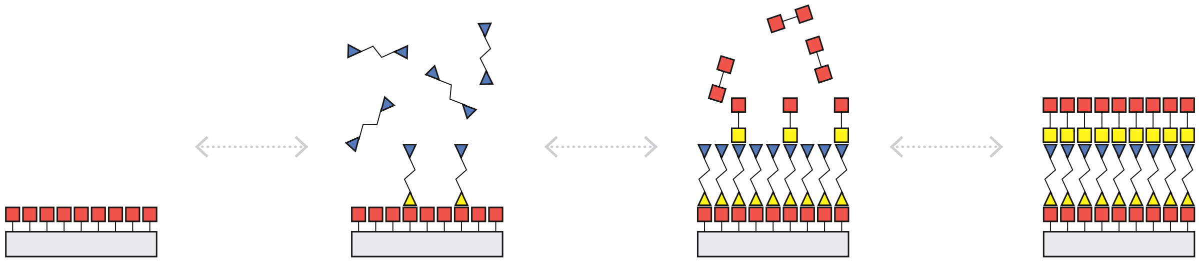
Additive manufacturing is particularly well suited to certain needs. For instance, sensor components often require specialized manufacturing techniques, making new units costly and repairs impossible. But researchers have successfully produced such components using inexpensive additive manufacturing techniques.

It's also handy at building structures traditional manufacturing processes struggle with, such as those with complex internal geometries or fine mesh structures across curved surfaces.

Single parts with functional subassemblies also fit the capabilities of additive manufacturing well. A classic example is the adjustable wrench. In traditional manufacturing, the knurled worm screw, adjustable jaw, and handle are produced separately and then assembled. An additive manufacturing machine can make the same part in a single build by using a support material in the gaps between the operating parts, which can later be washed away.

Although part production using multiple materials is still a new development, several companies and academic institutions have demonstrated the capability. For example, an aerosol jetting technology can produce fully functional embedded passive circuitry overlaid onto other material surfaces. The same technology can also produce specific patterns of solar cells.

Applications such as these could eventually revolutionize the manufacturing industry. But currently it is the military benefits, not civilian, that could prove most profound. When one missing part in the field can put our warfighters at great risk, additive manufacturing is a technology we cannot afford not to build.



INSIDE VIEW

Like many software systems engineers, James Barkley caught the computer bug at an early age. "In seventh grade, while the rest of the class was learning Algebra II, I was writing software to solve sets of equations for augmented matrices." Throughout his career, Barkley continued to focus on computing software. So to find himself starting up a hardware project like MakeOne surprised him. "I had been studying supply-chain problems for a Department of Defense project in 2008 when I ran across a 3-D printer at an open source conference. And that birthed the very common-sense idea of putting flexible manufacturing methods closer to the need."

>> **Additive Manufacturing**

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The humble "single-pointer" model using mouse, track pad, or touchscreen has given rise to multi-touch.

COMPUTER INTERFACES: JUST ACT NATURALLY

Jeff Colombe

SUMMARY: As computers have become more integral parts of our lives, computer designers have struggled to make them easier to use. Computer interfaces have evolved from banks of lights and switches, to keyboards and monitors, to the current era of advanced touchscreens. Future interfaces will allow us to control computers using gestures or even intentions.

Evolution, but Not Revolution

In the Steven Spielberg sci-fi film *Minority Report,* Tom Cruise's character, a law enforcement agent, steps in front of a computer screen to track down a man who is minutes away from killing his wife. Cruise doesn't start pecking away at a keyboard or rolling his thumb over a trackball. Instead, he moves his hands through the air with the grand gestures of a symphony conductor, and each twist of a wrist, slash of a finger, or grip of a fist causes images and data to blossom and retreat across the computer screen. His search quickly completed, he and his team rush to the rescue.

It is disappointing that, for most of us, such a simple and efficient computer interface system can only be found in a sci-fi film. Since the 19th century, automatic computing hardware in one form or another has dramatically reduced time, cost, and errors in our daily tasks. But although computers have long made our lives easier, working with them has never been easy.

During the early years, the use of computers was restricted to expert technicians with special training. Early electronic computers featured panels of lights and switches and hard-copy printouts dominated by text. In the 1950s, these gave way to electronic keyboards and cathode ray tube monitors that displayed text and (less often) graphics—a model that lasted about 30 years.

In the late 1970s, the mouse and the graphic user interface (GUI) were developed at Xerox PARC and soon after popularized by Apple and Microsoft. This ushered in an era of computers usable enough to become a feature in nearly every office and many homes. The pointer-and-GUI model has improved over time, especially in terms of support for rich audiovisual media, connectivity, and mobility, but has remained unchanged in its essential character for about 30 years.

The Incredible Disappearing Pointing Device

Today, we are in the midst of another massive shake-up in how people use computers. The humble "single-pointer" model using mouse, track pad, or touchscreen has given rise to multi-touch, a simple technological innovation that pushes the usability of computers far beyond what traditional pointing devices would allow. Multi-touch allows people to rapidly and intuitively pan, zoom, rotate in two and three dimensions, do simple drawing, and manipulate multiple data objects at the same time. And they do it directly on the display rather than having a device off to the side somewhere. The dramatic success of the first major commercial multi-touch devices, the iPhone and iPad, has been driving competitors to play catch-up for the last four years.

Multi-touch devices are so intuitive that a volunteer two-year-old "test subject" grabbed a MITRE-owned iPad out of an adult's hand and went to work, knowing what to do after just a few seconds of watching others. When the child was later shown a desktop computer, she tried to use her fingers on the screen. Upon being told that she needed to use the mouse, she picked up the mouse, placed it directly on the screen, and moved it as she had used her finger earlier.

The Touchless Touchscreen

Multi-touch interfaces have their drawbacks, however: the user must remain close to the screen, fingers and hands can block portions of the display, and accurate operations like drawing are difficult. The next step in usable and intuitive interfaces will free us from having to touch anything at all.

Oblong Industries has introduced a system based on the ideas shown in *Minority Report.* The system requires the user to operate in a special room with motion-capture gloves and to learn a special "hand-jive" of motor commands. Microsoft recently released its Kinect gaming system, which uses an infrared camera-based technology that senses gamers' complete range of motions, allowing them to control an interface with their whole body.

These "stand-off" interfaces are being developed mostly for the entertainment sector, in an effort to leapfrog the massive appeal of the Nintendo Wii gaming console. MITRE is partnering with Microsoft Research to go beyond entertainment to develop stand-off interfaces for business and productivity applications, ranging from control of a computer's functions to media-augmented communication and collaboration.

Eye-to-Eye Looking

Window Pane View

Extreme Ghosting

Mirror-Mirror

Finger as a Pointer

Today, we are in the midst of another massive shake-up in how people use computers.

"Mind Control"

Brain-computer interfaces could, in theory, eliminate the need to move one's body at all to control a computer. Non-invasive methods for brain-computer interfaces have shown promise for allowing locked-in quadriplegic patients to regain some control of their surroundings. An application of special interest to the government is in combat casualty care, restoring function to wounded combat veterans. Methods like functional near-infrared spectroscopy and electroencephalography are compact enough to be deployable for such purposes, unlike their unwieldy counterparts functional magnetic resonance imaging and magnetoencephalography, which require patients to place their heads inside large, heavy machinery in special laboratory facilities.

Another way brain-computer interfaces can be useful to the government is by measuring the mental activity and physiological state of users. MITRE is using brain-computer interfaces to measure user stress responses during controlled simulations of air traffic control operations. This knowledge can help in designing air traffic control systems that can anticipate and avoid situations in which controllers are overworked.

However, the ability to measure brain activity is not yet finely tuned enough to design a truly effective human-computer interface. The "telepathy headband" and the "mind control headset" will have to remain within the realm of science fiction, at least for now. But as a toddler fiddling with an iPad demonstrates, yesterday's sci-fi has a way of becoming tomorrow's reality.

INSIDE VIEW

Growing up with a father who was an arts educator and a mother who taught science gave Jeff Colombe a rare perspective on the two fields. "People tend to think of science as being on one end of a spectrum and the arts at the opposite end, but I've often focused on where they come together." This focus led him to pursue studies in biomedical engineering as a college student. "There was a similar appeal in terms of opposites—nature and technology—coming together." Research into how we develop visual perception and motor coordination led to his current investigation of human-computer interaction. "Once interfaces tap into the almost unconscious skill sets that we have developed over our lives, devices will seem to disappear, and we will interact directly with the media they deliver."

>> **Computer Interfaces**

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DNA sequencing figures heavily into DNA fingerprinting, pathogen detection, gene finding, genealogy study, and evolutionary tree reconstruction.

DNA SEQUENCE ANALYSIS: THE GENOME IS MORE THAN THE SUM OF ITS PARTS

Andrzej Brodzik

Is a boat whose planks have all been replaced one by one over time still the same boat?

SUMMARY: DNA sequencing technology has made rapid strides in recent years, generating a deluge of data. However, the design of robust tools that can extract useful and useable information in the face of random variations and inevitable errors has been lagging. MITRE researchers are developing new mathematical techniques to address this challenge.

Planks vs. Boat

One of the pioneers of microbial genomics, Antoine Danchin, recalls in his book *Delphic Boat* an ancient question originally posed to the oracle of Delphi. The question asked whether a boat whose planks have all been replaced one by one over time is still the same boat. Danchin echoes this question by asking whether it is the individual components of a gene or the relationships among them that define a gene. Should we attempt to deduce the biological function and the genetic family tree of an organism simply by comparing individual parts, or rather, should we set a more ambitious goal and try to guess the overall blueprint for the genomic construction?

This question seems to be of both fundamental and timely importance now that DNA sequencing figures so heavily into such important endeavors as DNA fingerprinting, pathogen detection, gene finding, genealogy study, and evolutionary tree reconstruction. These tasks all rely, in large part, on comparing an unfamiliar DNA sequence to one that is already known, establishing islands of similarity, and then forming a hypothesis about the function or meaning of the new sequence.

Graduating from Spelling

A DNA sequence is analogous to a sentence in English in which the letters correspond to four types of organic molecules, called bases. These bases are adenine (A), guanine (G), cytosine (C), and thymine (T). In DNA fingerprinting, for example, an unknown collection of DNA fragments, typically a few tens to thousands of bases long, is compared with one of several known collections of DNA fragments contained in a library. Either or both of these collections might be incomplete or unordered, or might contain errors, including symbol insertions and symbol deletions. Finding a match between collections establishes genome identity.

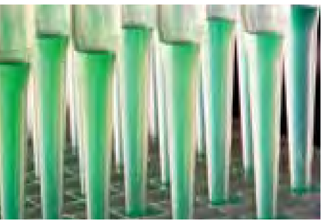
The analogy with the English language can be taken further. To determine the message contained in a text or the author of the text, we concentrate on the words in the text, what they mean, and how they fit together, rather than on the individual letters of the text. And even when we can't accurately read certain letters or sentence fragments, we can still decipher much of the meaning of the text.

It is therefore appropriate that in processing DNA sequence data, even data that is plagued with missing or corrupted information, we should similarly identify the key constituent components of genomes and investigate how they fit into the overall genomic design. Instead of comparing the letters of DNA sequences, we should compare the words and the sentences they are forming.

Speed Reading

The first step toward decoding a genome is to identify the atomic components of the genomic sequence.

MITRE researchers began this journey by marking the genomic atoms with short random strings associated with algebraic constructs. Then the team explored the utility of these strings in a DNA sequence homology evaluation, which means a sequence comparison performed by matching versions of the original sequences. Such evaluation permits us, at a reduced computational cost, to identify, from a large pool of data, those sequences that are in some way close to the query sequence and





to perform a rough sequence alignment that provides an indication of the overall sequence similarity.

This procedure consists of two essentially algebraic computations: the construction of sequences and the alignment of these sequences by a fast implementation of the cross-correlation method. Replacing the analysis of DNA sequences with an analysis of homology marker sequences significantly reduces the number of computations required. This reduction is proportional to the ratio of lengths of these sequences. MITRE designed this method motivated by its low computational complexity and its lack of limitations on the DNA sequence size it can analyze.

MITRE's research into the mathematics of DNA sequence analysis is far from a mere academic exercise. Future progress in molecular biology will bear directly on the development of effective strategies for mitigating such threats as bio-terrorism and bio-warfare. And the rate of that progress will ultimately depend on an effective merger of mathematical and life sciences.

INSIDE VIEW

Andrzej Brodzik has been a scientist for 25 years, and in that time, he has seen the focus of institutional research shift from curiosity-driven to problem-driven. "This is unfortunate because it puts blinders on the eyes of scientists. Today's problems are highly complex and require fittingly complex solutions. These solutions cannot be obtained simply by tinkering, without the laborious and difficult but necessary process of a theoretical model development. That does not mean, of course, that consideration of utility is not important. Both components are truly indispensible, and, indeed, choosing one over the other almost always leads to lowering of quality." The work on the structure of the DNA sequence provides a perfect illustration of the synergy of basic and applied research. "I found this work immensely satisfying because I took a highly theoretical approach and, in effect, obtained very broadly applicable results."

>> **DNA Sequence Analysis**

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COMPRESSIVE SENSING: SQUEEZING THE MOST OUT OF SIGNALS

David Colella

SUMMARY: Transmitting, processing, and storing signal data requires a lot of bandwidth. Compressive sensing seeks to increase the amount of information that can be accurately processed by lowering the amount of signal data a processor needs to sample to obtain that information.

Signal Solution

The military is always searching for signals: a radar signal that might warn of enemy movements, a radio signal that might betray enemy secrets, an acoustic signal that may reveal enemy locations. Once intercepted, signals must be processed to determine what information they contain. That data is then often broadcast to intelligence centers for further analysis. Receiving and broadcasting large amounts of signal data can tax communication systems, so researchers are investigating methods for compressive sensing to squeeze the needed amount of information from or into smaller amounts of signals.

A New Revolution

Every so often, a new signal processing technique promises to revolutionize our processing capabilities. Unfortunately, many of these techniques fail to live up to the hype. But occasionally, researchers are lucky enough to discover a technique with lasting impact. (One recent example is wavelets, the basis for the JPEG 2000 image compression standard, an improvement on the well-known JPEG standard.)

Compressive sensing has a real potential to be one of the techniques that has lasting impact in the processing field. It is a technique that alters the way in which we capture, process, and store information. Although the theoretical foundations for compressive sensing have been around for some time, it has been only recently that researchers have been able to exploit some of these ideas for practical applications.

Not Your Standard Signal Processing

Digital signal processors do not need to listen to an entire signal to identify it. They can sample the signal at regular intervals to gain the necessary information about it. Of course, the more a signal changes along its wavelength, the more samples a processor must take of the signal to accurately measure it. This sampling requirement is known as the Nyquist criterion. If the Nyquist criterion is not adhered to, accurate and unambiguous signal recognition is simply not possible.

Compressive sensing does not negate the Nyquist criterion. It does, however, create the opportunity to sample a signal at only a fraction of the intervals mandated by Nyquist when the right ingredients are available. Compressive sensing is effective because it measures information rather than simply sampling signals.

Compressive Sensing in a Nutshell

Compressive sensing has three components: sparsity, measurement, and reconstruction. Sparsity indicates that the signal of interest can be represented by relatively few basic elements. Measurement requires that the signal contain a significant amount of information for each of its basic elements. Reconstruction is the process of using optimization algorithms to refit the noisy information from the measurement into a clear signal. All three of these ingredients must work together for effective compressive sensing.

There are several challenges to bringing compressive sensing out of the lab and into the field. For reconstruction, where the bulk of the compressive sensing work is done, the research challenge lies in separating the target signal from the clutter of additional signals in the measured data. For sparsity and measurement, we need a greater understanding of how to match the right sensors to the right signals. One approach is to more effectively characterize the sparsity data to enable a better match for the sensors used in the measurement.

But an alternative for which there is more promise is choosing the proper sensors for the application. For example, researchers at Rice University have developed a single-pixel camera that can effectively capture an image by using a well-orchestrated series of lenses. Additionally, MITRE is exploring several opportunities for imaging applications as well as modified chip architectures for improving the back-end processing for signal recovery in compressive sensing applications.

From Theory to Practice

Although expectations based on theoretical calculations are impressive, the implementation of compressive sensing is not without its hurdles. In many cases, we are just beginning to understand how to effectively apply this technique to

Receiving and broadcasting large amounts of signal data can tax communication systems.

various application domains. And there is still much research to be conducted into the ABCs of compressive sensing itself without regard to any application. For example, researchers are investigating the benefits of incorporating a compressive sensing construct for machine-learning algorithms.

Ultimately, compressive sensing's ability to improve on sensing, transmitting, and storing large amounts of information lends it to applications in data compression, communications, and beam forming. Imaging applications—such as image compression, medical imaging, synthetic aperture radar, and hyperspectral imaging—can benefit from compressive sensing's abilities to take advantage of information sparsity. All evidence suggests that a compressive sensing approach will be able to improve performance for signal detection algorithms and uphold its potential for having a lasting impact on information processing.

Compressive sensing is effective because it measures information rather than simply sampling signals.

INSIDE VIEW

David Colella has worked as a signal processing engineer in MITRE's Electronic Systems & Technologies Technical Center for 20 years, but every day still brings something different. "There are always new ideas in the signal processing field or old ideas that are being reinvented or modified or adapted in new ways." And MITRE's culture of cross-team collaboration has provided him with the opportunity to explore technologies outside his field. "Sometimes you get deeply involved in another project and sometimes you just learn about it from the sidelines. But here at MITRE there's the opportunity to become engaged in a really diverse set of problems and a chance to look at a number of different technologies and applications."

>> **Compressive Sensing**

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GRAVITY IMAGING:
A NEW LOOK AT BORDER SECURITY

Lang Withers and Lynn Cooper

SUMMARY: A terrorist attack involving radioactive materials would result in mass casualties, cause widespread property destruction, and poison large areas. The current methods used to detect radioactive materials being smuggled across our borders in sealed containers are sometimes ineffective or can be thwarted. Gravity imaging, by which sensors detect the dense mass of radioactive materials, may provide a quick and reliable method for securing our ports.

Guarding Our Shipping Ports

Every year about 20 million large shipping containers enter the United States by sea or land. One container could deliver the uranium for an atomic bomb to a terrorist inside our borders. How do we screen all shipping containers, both reliably and efficiently? The U.S. Department of Homeland Security has established the goal of 100 percent container screening by 2012, a Herculean task.

Radiation detectors have been installed in our shipping ports, but they still produce too many false alarms to be dependable. The government needs alternative methods to detect fissile materials smuggled inside sealed containers—methods that can guard our nation's safety without harming our prosperity. Since radioactive materials are unusually dense, examining containers with gravity imaging is an intriguing solution.

Nano-gravity: An Untapped Natural Resource

Gravity is the most obvious force of nature, evidenced every time an apple drops from a branch. But gravity is also a very weak force; it requires the huge mass of Earth to pull that small apple down to the ground. The gravitational attraction between two apples on a branch is too small for us to notice.

But not small enough to escape our measurement. New instruments called gravity gradiometers, which measure the rate of change in the gravitation field, are sensitive enough to measure the nano-tugs of gravity between everyday objects. MITRE and collaborating researchers are developing methods to use gravity gradiometers to determine the contents of shipping containers.

Gravitational forces cannot be shielded or canceled out as electric forces can be. This means that even if a uranium bomb lies inside a steel shipping container, the gravity of the dense uranium can still be sensed outside the container. The steel adds to the total gravity sensed, but does not cancel or mask the uranium's gravity. So if we scan the gravity field outside of the container, we can detect the presence of materials of extraordinary density among its contents. The force generated by gravitons (particles that carry the gravitational force) can be used to form images.

Experimental Proof of Concept

Researchers Barry Kirkendall, Yaoguo Li, and D. W. Oldenburg demonstrated the theoretical possibility of 3-D gravity imaging in 2007. Their concept was to send shipping containers through a gravity gate, similar to airport passengers passing through a metal detector. The gravity gate would collect gravitational data as the container passes through. The data would then be translated into an image of the three-dimensional mass density distribution inside the container.

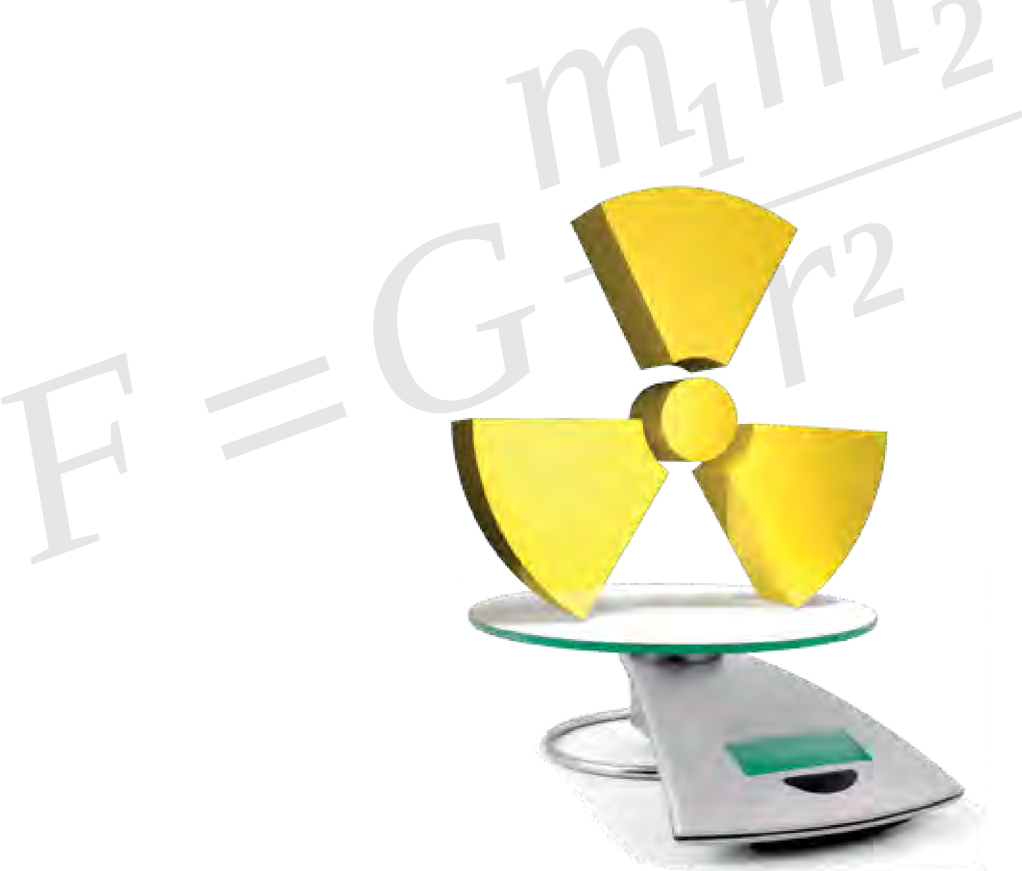
But such imaging has yet to be performed in the real world with real gravity data. MITRE is conducting experiments to prove the gravity gate concept. Our first experiment involves running a perimeter scan around an 8-foot-by-10-foot tabletop with test masses representing a rectangular slice of a cargo container's contents. One test mass is a tungsten brick with about the same density as uranium and plutonium.

This experiment is designed to recover a two-dimensional picture or mass density distribution of the slice contents. We have verified that the 2-D design is viable using simulated sensor data. The resolution is not perfect, but adequate to detect and locate tungsten, lead, and fissile materials.

The Right Tools

The experiment is a collaborative effort. We will use a state-of-the-art gravity-sensing instrument, invented at the University of Maryland and being refined for commercial applications by Gedex, Inc., located near Toronto, Canada. The Gedex instrument uses the motions of two small torsion bars, cryogenically cooled to take advantage of superconducting effects.

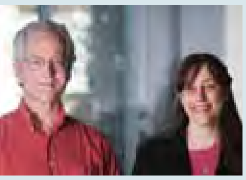
We hope to repeat the experiment later, this time using a laser-cooled, cold-atom fountain interferometer being developed at the Jet Propulsion Laboratory in Pasadena, Calif., by a team led by Nan Yu.



The gravity of the dense uranium can still be sensed outside the container. The steel adds to the total gravity sensed, but does not cancel or mask the uranium's gravity.

David Warme of Group W, who specializes in solving complex optimization problems, developed the image-recovery method. MITRE designed the experiment, and developed the forward model of the gravity sensing instrument.

By demonstrating that gravity imaging of containers is feasible using available instruments, we hope to spur the development of compact, inexpensive, lightweight gravity sensors with the exquisite sensitivity required, and the image recovery methods to interpret the data that these sensors provide. Both areas are nascent, wide open for research, and may prove crucial to maintaining the safety of our ports.

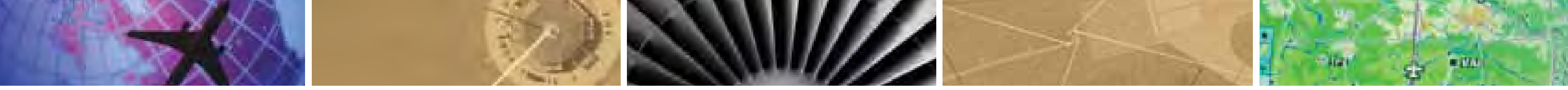


INSIDE VIEW

To get ready for their gravity imaging experiments, Lynn Cooper and Lang Withers needed a test sample as dense as the fissile materials to be imaged. Gold, platinum, or tungsten make good substitutes. "But clearly, we couldn't work with uranium or plutonium," says Cooper, "and we couldn't afford gold." Cooper discovered that NASCAR drivers use machined blocks of tungsten as counterweights in their cars. One slightly out-of-the-ordinary purchase order later, Cooper had a 36-lb. brick of tungsten. Looking ahead, Withers believes that MITRE is participating in the birth of a new non-invasive technology with many uses. "By sensing nano-gravity, we will be able to visualize things that might otherwise be inaccessible—from hidden bombs or tunnels to electrical conduits buried in concrete."

>> **Gravity Imaging**

If you have questions or comments about this article, email us at **lpwithers@mitre.org** or **lynncooper@mitre.org**. For links to related articles and resources, please see the online version of this article at www.mitre.org/envision.



FLIGHT VALIDATION: DO-IT-YOURSELF DESIGN TOOLS

Jeremy Irish

SUMMARY: As the demand for more efficient arrival and departure routes at airports continues to grow, the Federal Aviation Administration is seeking ways to allow airlines and private companies to meet the comprehensive safety testing requirements for designing flight procedures. MITRE has prototyped tools using inexpensive commercial technology that makes designing new procedures feasible.

Securing Safe Approaches

Despite the economy's current difficulties, travel experts expect air traffic to continue to increase at a steady pace. Some estimates show the number of planes in the sky at any given time doubling in the next few decades. To prepare the air traffic management system to accommodate this increased traffic while still maintaining our national airspace's exemplary safety record, the FAA is developing new concepts, standards, and solutions known collectively as the Next Generation Air Transportation System, or NextGen.

One of the goals of NextGen is to improve the rate at which aircraft can safely land, especially in low-visibility weather conditions. As a result, the demand for more advanced routes that allow the aircraft to self-navigate is on the rise.

Inspecting Approaches

Shortly before landing, an aircraft enters the approach phase of flight: the aircraft has achieved an appropriate speed for landing, it is descending at a fixed rate, the landing gear is deployed, the aircraft is lined up with the runway, and its wings are level. During an approach for a landing in poor visibility, a properly trained pilot in an appropriately equipped aircraft can fly the approach phase using just the navigation aid signals displayed on the instrument panel. This is called an instrument approach.

Traditionally, the FAA tests each instrument approach prior to allowing its use. This safety check, called a flight inspection, involves flying the procedure during good visibility to ensure adequate signal reception from the navigation aids and appropriate clearance from prominent obstacles.

Developing new instrument procedures is an expensive and time-intensive process, as each procedure requires a flight inspection to ensure a high level of safety. The FAA must dispatch a crew along with an aircraft to conduct these tests. During an inspection, it is not uncommon for the FAA to encounter issues that require sending crews back a second time to complete the tests. This can pose significant scheduling challenges.

For the subset of instrument flight procedures that rely only on the use of Global Positioning System satellites, the FAA saw a need to augment some of the safety tests by flying the entire approach and capturing the flight data. This requirement puts more demand on limited resources than can be met by authorized airlines and procedure design companies. In response, MITRE is working closely with the FAA to develop the Flight Validation Capability, which MITRE will provide to aviation organizations so that they can conduct these additional safety activities in a cost-effective manner.

The Right Tools for the Job

Flight validation consists of two distinct phases: a flight phase in which the procedure is assessed in an aircraft and a ground phase where the procedure may be assessed in a flight simulator and in which ground obstacles can be surveyed. For the flight phase, MITRE evaluated a variety of hand-held GPS units to record flight data. The best results were achieved using a $40 GPS receiver attached to the inside of the aircraft and connected to a laptop running the Flight Validation Capability.

The Flight Validation Capability generates a moving map that displays the real-time progress of the validation flight while recording the required data. The moving map greatly increases situational awareness and makes completing the required validation tasks much easier. The Flight Validation Capability can also alert the operator if the satellite signals fall below desired levels and can merge multiple GPS readings into a single integrated flight track.

Pinpointing Obstacles

Probably the most critical capability of flight procedure validation is accurate obstacle assessment. Ensuring obstacles are in the correct location, traditionally done by the FAA, can now be accomplished by an approved testing organization. The FAA allows certified companies to complete the obstacle assessment from the air during the flight phase or from the ground during the ground phase.

MITRE has prototyped a process to quickly and accurately conduct a ground-based obstacle assessment using inexpensive off-the-shelf equipment. The process consists of establishing a series of survey points around the given obstacle using a laser range finder and a hand-held GPS

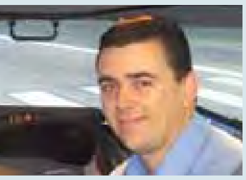
Travel experts expect air travel to continue to increase, perhaps doubling the number of planes in the sky.

receiver connected to the Flight Validation Capability software.

For the best accuracy, three or more survey points need to be recorded per obstacle. Once all measurements are complete, the software performs a "trilateration" calculation to determine the location of the obstacle with regard to the established survey points. Trilateration is a method in which a set of distance measurements from different locations is used to estimate an optimized location. Additionally, this solution provides the user with estimations of the survey accuracy, taking into account the instruments and geometry used in the survey.

Flight procedure developers can now survey obstacles to the required accuracy without the cost of hiring a surveyor. Furthermore, the increased accuracy of obstacle surveys enables developers to safely use a larger region of airspace. Having more room to work with means the efficiency of new procedures can be improved.

The Flight Validation Capability has been adopted by the FAA and several authorized domestic flight procedure validation organizations. The technology has also received attention from international airlines and foreign regulators interested in meeting similar validation requirements. MITRE recently filed an application with the U.S. Patent & Trademark Office to patent the Flight Validation Capability. As the program evolves, MITRE will continue to work alongside the FAA and other flight procedure validation organizations to make any needed changes and enhancements to the technology.



INSIDE VIEW

Both of Jeremy Irish's grandfathers flew in World War II. Fueled by their stories, Irish has pursued a love of flying and aircraft throughout his life. On some days in grade school, he would boot up a computer flight simulator in the morning, pilot a 747 through takeoff from Los Angeles, set the autopilot, and head off to class. By the time he returned home from school, he would be ready to land the plane on a runway in Tahiti. In college he earned his private flying license as well as a degree in aviation management. Even in his spare time, he can't stay away from the runway. He began taking photos of airplanes. That hobby has since grown enough that you can now see his photos featured in magazines and documentaries.

>> **Flight Validation**

If you have questions or comments about this article, email me at **jirish@mitre.org.** For links to related articles and resources, please see the online version of this article at www.mitre.org/envision.

The result: sadness if the surprise is small, fear if the surprise is large.

AFFECTIVE COGNITION: MAKING RATIONAL DECISIONS ABOUT EMOTIONS

Julia High

SUMMARY: In high-stakes and time-pressed situations, emotions often drive decisions. Researchers are developing formal models to explain and predict how fear, anger, and other feelings influence the choices that people make.

Bias in Decisions

Following the 9/11 attacks, Americans found themselves reevaluating their feelings about travel. Was air travel really as safe as they thought? Was it worth risking exposure to a terrorist act if it meant shorter travel times? Or did it make more sense to travel by car? The result of this outwardly rational analysis revealed a surprisingly large influence of emotion on decision making. Americans began flying less and driving more, although statistics show that flying would still be 10 times safer than driving even if terrorists were hijacking and crashing one passenger jet per week. In fact, a study showed that an additional 1,595 Americans died in car crashes as a direct result of the switch from flying to driving. This is six times higher than the total number of people on board the doomed flights of 9/11.

While we like to think that we conduct the bulk of our decision making through rational analysis, research has shown that when we're making decisions, our emotions often overrule our logic, particularly when evaluating and responding to perceived risk. This means that when the goal is to influence behavior—as is the case with many governmental communication efforts—the best strategy is to engage both the emotional and rational parts of the decision-making process. Understanding the interaction between our emotional and analytical processes is the goal of the emerging science of affective cognition.

The Decisive Brain

Research suggests that there may be physiological underpinnings for this interaction between emotion- and logic-driven decision making. When confronted with a need to make a decision, two systems are engaged. The first, referred to by psychologists as "S1," rapidly evaluates a large amount of sensory data to produce an intuition or "gut feeling" about the situation. The second, called "S2," carries out a slower, evaluative analysis over a subset of the data.

These systems are supported by different parts of the brain. S1 is associated with activity in parts of the brain linked with emotional processing, like the insula (which seems to be involved in monitoring overall feelings and emotions) and the anterior cingulate cortex (which is specifically sensitive to social emotions). S2 is associated with activity in frontoparietal regions of the brain that deal with reasoning processes and with processes that require the action of working memory—the short-term memory system that allows you to briefly remember and compare important concepts.

Although there is physiological evidence that emotions strongly influence decision making and psychological evidence—like the behavior of travelers after 9/11—that rational analysis is not the sole driver for decisions, many communication tools still emphasize an appeal to the rational part of the decision-making process. In order to improve these tools, it is important to understand the nature of the emotional contribution to decisions.

The Trajectory of Emotion

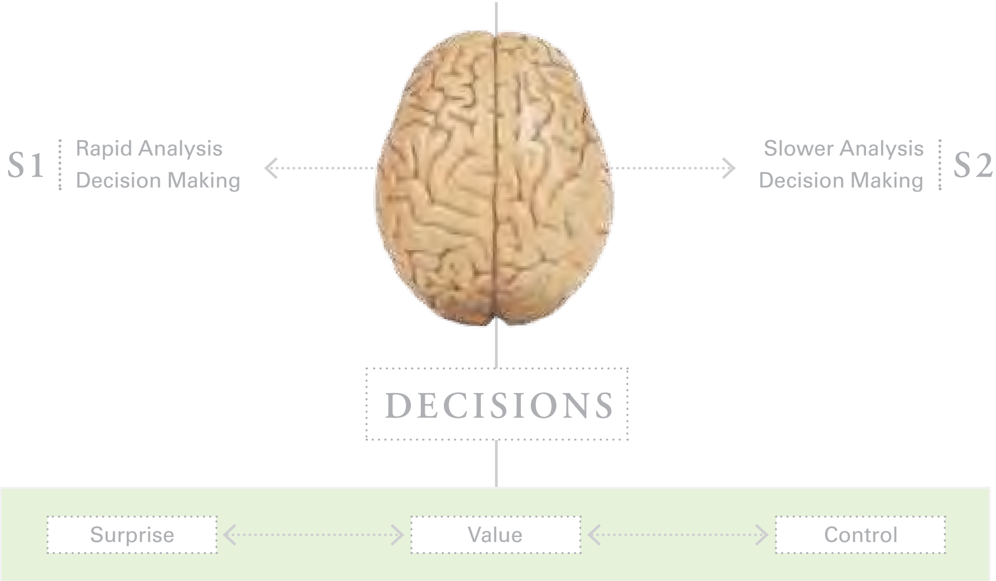
Researchers frame emotional experience in three dimensions: salience (surprise), valence (value), and dominance (control). Preliminary studies suggest that emotional experiences are not simply states but rather trajectories through the space defined by these dimensions.

For example, a surprising event is arousing (salience) and at first feels negative (valence). This is because you failed to predict the event, and failure to predict is generally bad for survival. This emotional response by S1 will brighten if further cognitive appraisal by S2 concludes the surprise is a welcome one. But if analysis reveals an unwelcome surprise, a negative emotion will result: sadness if the surprise is small, fear if the surprise is large. Cognitive appraisal then continues as you assess your ability to deal with the situation that produced the negative surprise.

Attractive Solutions

Based on this framework of salience, valence, and dominance, MITRE researcher Kevin Burns is developing formal models of affective cognition. These models would be useful in designing tools or techniques that present information for human consumption. For instance, accurate models of the relationship

Trajectory of Emotions



When confronted with a need to make a decision, two systems are engaged.

between emotions and deliberative analyses might allow MITRE sponsors to craft messages that appeal to both decision processes.

As an example, engineers are developing "sentiment analysis" systems. These systems can compute statistics on word occurrence frequencies in surveys, letters, emails, and other documents, in order to classify their valence. But such systems will be of limited use unless they also address salience and dominance; a negative sentiment could imply fear or anger, which, as we've seen, can produce opposite behaviors depending on the appraisal of dominance.

Further research with formal models is needed so that future systems can usefully detect sentiment and accurately predict behavior. Advanced systems might then adapt the substance of messages, like medical test results and government policies, to the styles of consumers—achieving desired effects by addressing affective desires.

INSIDE VIEW

"I first became interested in the neural basis of human cognition in middle school, when I read Terry Bisson's short story, 'They're Made Out of Meat,'" says Julia High. "In that story, members of a sentient alien race have a protracted discussion of how odd it is that humans can think and dream and even sing in spite of their strange biology." This humble inspiration has led to a multifaceted career at MITRE, where High's neurophysiology expertise has found a variety of outlets. "From designing cognitive neuroscience experiments to implementing social media campaigns, my projects are influenced by my understanding of how physiology influences behavior."

>> **Affective Cognition**

If you have questions or comments about this article, email me at **jhigh@mitre.org**. For links to related articles and resources, please see the online version of this article at www.mitre.org/envision.

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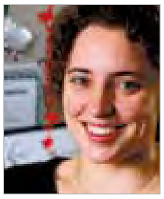

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Julia High is a member of the Human Systems Integration, Visualization, and Decision Support group, which is part of MITRE's Information and Computing Technology division. Her background in psychology and cognitive neuroscience and her personal interest in social networking tools have allowed her to support a diverse set of projects at MITRE, including MITRE's internal Agile Capability Mashup Environment and the Office of Force Transformation's speculations into the future of emerging technologies.

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