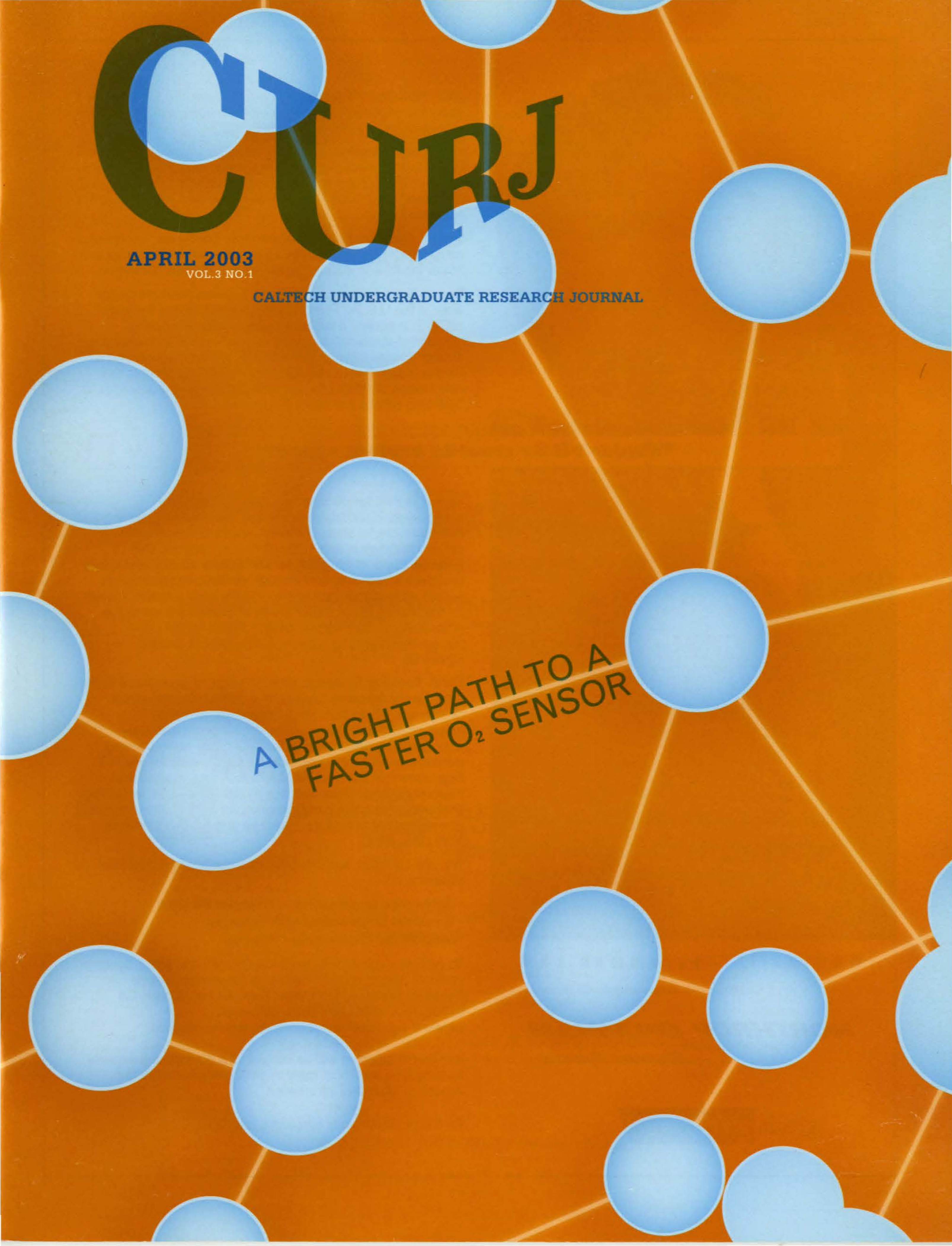
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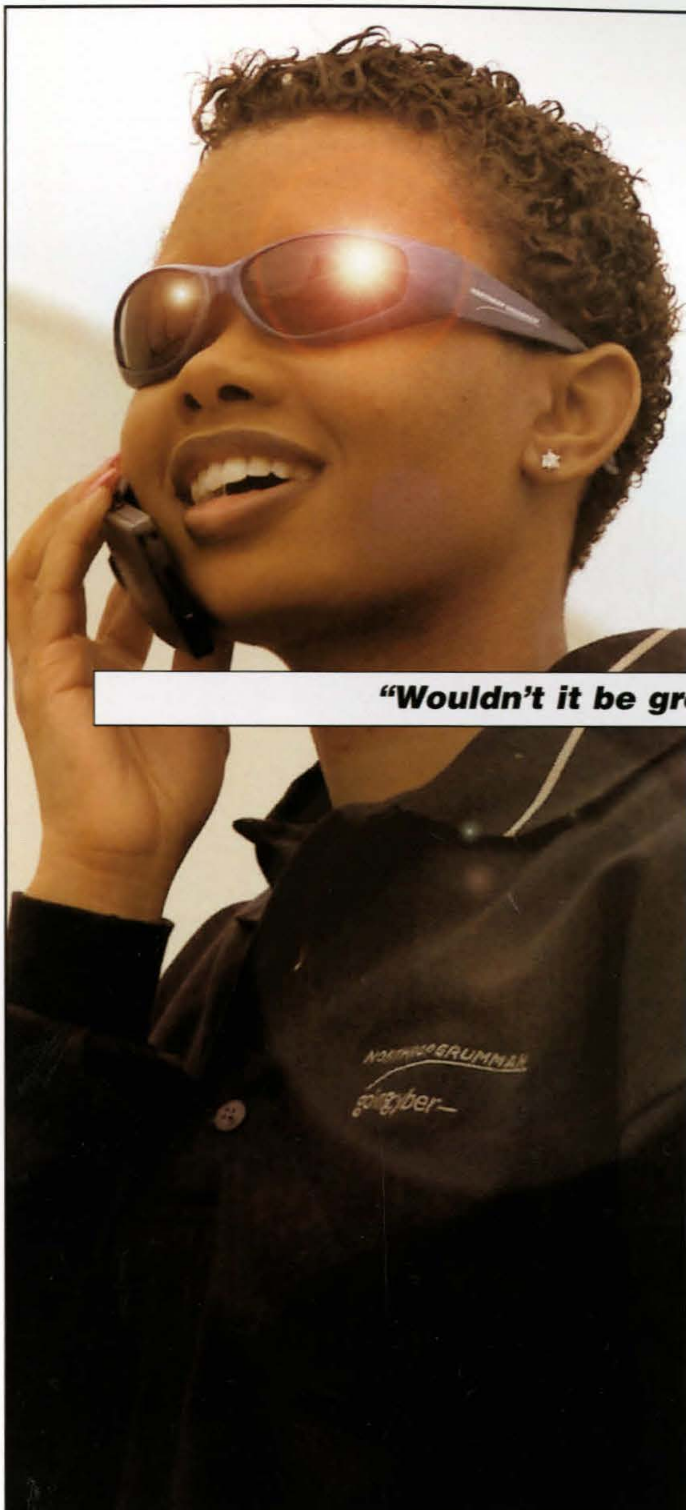
A BRIGHT PATH TO A FASTER O_2 SENSOR



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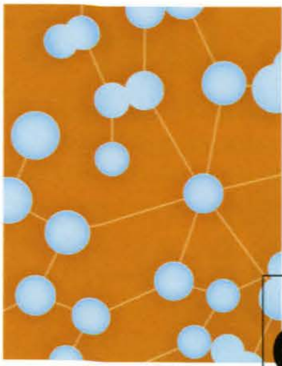

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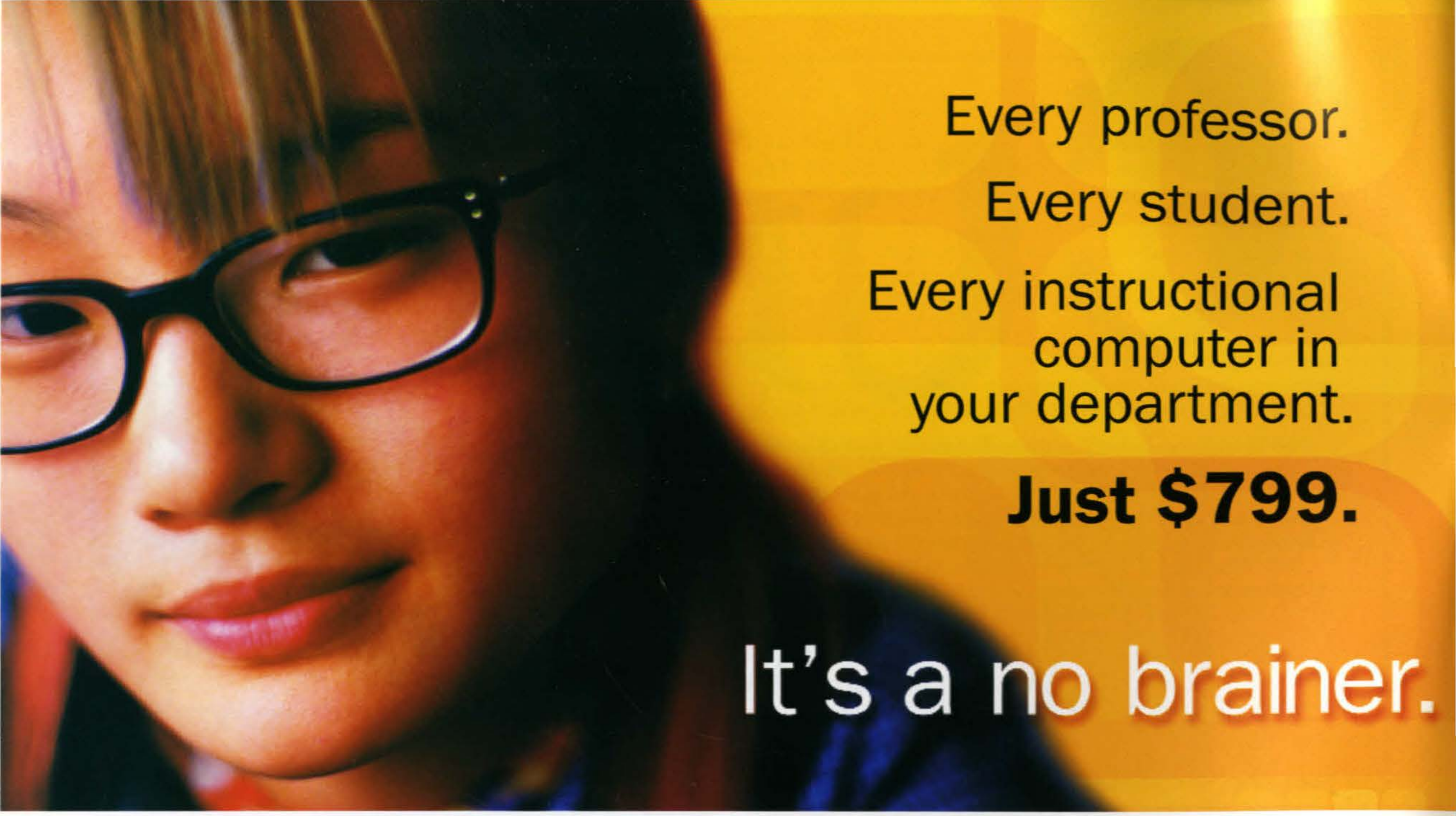

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FROM THE EDITOR

With the rapid development of research requiring interdisciplinary expertise, scientific collaboration is becoming increasingly important. New fields of study are blending the talents and expertise of biologists, electrical engineers, physicists, anthropologists, programmers, and linguists to create exciting new areas of research.

The steady improvement of communications techniques and infrastructure, particularly in the realm of electronic communications, has aided interdisciplinary collaboration; it provides a flexible way for researchers to share data and ideas. This same flexibility has eased the crossing of international lines as cutting-edge research conducted in one hemisphere is quickly incorporated into budding projects on the other side of the globe.

In addition to increased interaction between academic disciplines, close relationships between academia and the venture capital industry have led to the formation of a number of startup companies. Other types of strategic alliances have widened the range and accelerated the pace of research at academic institutions. The result is a more frequent infusion of academic research into industry.

Equally important is the role collaboration plays in allowing both undergraduate and graduate students to master techniques essential for conducting research. In addition, under the guidance of a mentor, young scientists learn to ask key questions and develop essential methods of thinking through collaborative observation and hands-on research that no formal classroom can offer.

The growing trend of introducing undergraduates to academic research environments allows student researchers to contribute to their intellectual curiosity in multiple scientific disciplines before choosing a specialization. Early exposure to these research settings will allow budding scientists to meet the growing need for interdisciplinary and global collaboration while gaining valuable research experience necessary to assure the development of the next generation of scientists.

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REFORMING SPECTRUM REGULATION TO ACCOMODATE NEW WIRELESS TECHNOLOGY

BY HOWARD SHELANSKI

In November 2002, the Federal Communications Commission released its Spectrum Policy Task Force Report. The report recognized that the FCC's "command-and-control" approach to licensing radio spectrum to particular users for particular purposes should give way to a more flexible, market-oriented approach that allows spectrum to move to more valuable uses. This policy letter briefly outlines the problem to which the Spectrum Policy Task Force attempts to respond, and discusses further technological and regulatory questions that need to be addressed going forward.

Many innovative, wireless communications devices rely on access to unlicensed radio spectrum: frequencies open to users for a variety of purposes on a non-exclusive basis. Yet there are limits to the capacity of such unlicensed spectrum and most usable radio frequencies are not so freely available to new wireless uses. Instead, vast amounts of the most valuable frequencies are licensed exclusively to particular users and for particular purposes. No one else can use the frequencies that the FCC has allocated to, for instance, NBC in a particular geographic area and not even NBC can freely convert its frequencies from television broadcasting to some other use. These limitations are regulatory, not technological. Similarly, wireless phone carriers have exclusive licenses to certain blocks of spectrum in the geographical areas in which they operate. People using WiFi and other such devices may not operate over those licensed frequencies or even over adjacent frequencies that might interfere. The fact that so much valuable spectrum is tied up with incumbent users, some of them providing services that might be less valuable than some new innovations coming to market, raises an important question: what can be done as matters of technology and public policy to ensure that wireless innovations will not be blocked from the airwaves?

Technological research can productively approach spectrum management through the "3 R's" of resource use: "Reduce, Recycle, and Reuse." The engineering community has long focused on reduction and continues to succeed in decreasing the amount of spectrum necessary to provide various wireless services. Recycling and reuse of spectrum, however, have received less attention, and research into these two methods of increasing spectrum efficiency is at a comparably undeveloped stage. What are "recycling" and "reuse" of spectrum? Spectrum recycling refers to allowing use of new technologies to provide a given service while ensuring compatibility with remaining users of legacy systems deploying older technology. For example, instead of having to find new spectrum for digital cell phone service, the spectrum already used for analog service could be "recycled" and used by digital transmitters and receivers while still allowing remaining analog users to make and receive calls over the network. Spectrum reuse, in contrast, refers to the simultaneous coexistence of multiple wireless systems that share the spectrum to provide various different services. Both recycling and reuse would make it possible to increase non-exclusive use of radio spectrum by different services and thus undermine the interference rationale for exclusive spectrum licenses.

From the standpoint of public policy, the 3 R's of "reducing, re-using, and recycling" spectrum raise several questions. Regulators already encourage deployment of technology that reduces the spectrum needed for a particular service. The FCC's task force report thus tries to reduce the spectrum tied up by particular licensees and proposes mechanisms to get licensees to give up spectrum that can be used more productively by others. Some questions for further research are how well those mechanisms will work and whether they provide adequate incentives over time to move spectrum to more efficient uses.

Regulation faces a harder challenge in accommodating "recycling" and "re-use" of spectrum. If we think of recycling as the overlay of one service on top of another on a particular frequency, such that the underlying, incumbent service does not even know the new service is operating, then recycling limits the need for exclusive rights to that frequency for the provider of the underlying service. Recycling thus either expands the number of licenses that can be granted for transmission over a given frequency or reduces the need for service restrictions on a single licensee's use of the spectrum. Regulation has made some efforts to respond to recycling. For example, the FCC long ago recognized that some broadcast spectrum could be recycled by transmitting data over the "vertical blanking interval"– the almost imperceptible break between frames of a television transmission–thus allowing a data service to operate simultaneously with the television broadcast. The FCC approved such data transmissions and has since implemented other regulations more generally conducive to recycling, such as rules increasing flexibility of use of any given spectrum allocation and granting a licensee the right to "sublet" spectrum to other users. Important questions are whether current policies do enough to encourage spectrum recycling and how spectrum regulation might have to change as new recycling mechanisms are developed.

Reuse of spectrum, i.e. the simultaneous use of given frequencies by multiple users to provide heterogeneous services, also raises important policy challenges, for such simultaneous use is fundamentally at odds with exclusive licensing of frequencies. The FCC has recognized that, in light of reuse possibilities, some radio spectrum should be available on an unlicensed basis or as a "commons." To what extent might re-use technologies counsel a further shift from licensing to a spectrum commons? What kind of regulation should apply to the commons? Indeed, the fact that technology undermines the logic for exclusive spectrum licensing does not mean that such technology eliminates the need for all oversight and management of spectrum use. What ground rules are needed for use of common spectrum and how should they be structured and implemented? How do the answers differ across the alternative re-use technologies that might be developed?

The discussion above outlines how regulation both informs and is informed by the potential viability of new radio technologies currently under development. The FCC's Spectrum Policy Task Force Report is a first step in making spectrum regulation more responsive to technological change. At this point, however, the FCC's report is only that: a report. Neither the Commission nor Congress has decided on what specific changes to exclusive licensing should be made or on how to govern or organize use of spectrum when users do not have exclusive property rights. The purpose of this letter has been to discuss the technological and regulatory issues that bear on those decisions and to raise some questions the answers to which will be critical to the future of wireless technology and services in the United States.

Howard Shelanski is a Professor of Law at the University of California at Berkeley and a co-director of the Berkeley Center for Law and Technology. He specializes in the areas of regulation and antitrust. In 1998-1999 he served as a Senior Economist to the President's Council of Economic Advisers and in 1999-2000 he was Chief Economist of the Federal Communications Commission. Professor Shelanski received his B.A. from Haverford College and his J.D. as well as his Ph.D. in Economics from the University of California at Berkeley.

EVADING THE OBVIOUS: RICH NATIONS IN A MOSTLY POOR WORLD

BY DAVID DAPICE

The last two decades in the 20th century will be noted by future historians for many particular trends. Computers and communication got a lot cheaper and faster. The Soviet Empire collapsed. China and to a lesser extent India began a period of rapid growth. Biotechnology and genomic sciences gave hints of their future potential. Perhaps the rise of terrorism will be seen as an episodic blip or as a fundamental trend. Maybe the rise of international financial crises will be noted for their future importance. Among all of these trends, there is one that is indisputable. Growth for most nations, India and China aside, was slower in the 1980–2000 period than it was from 1960 to 1980. Not only that, most poor nations had per capita growth slower than the per capita growth of the rich nations. During a period of growing international capital and trade flows, there was an astonishing rate of economic failure.

It is true that India and China collectively account for nearly 40% of humanity. Excluding them from the developing countries is closer to dividing a pie in half than taking out a small slice or two. But even India is uncertain about the pace of its overall poverty reduction. Its rising middle class is heartening and undeniable, but many of its citizens appear to be benefiting but little from its 6% annual growth. Meanwhile, most of Latin America, Africa, the Middle East, and the transition economies have had a difficult decade or two, and even "successes" like Argentina, Thailand, and Indonesia flounder.

At one level, it is reasonable to ask how important these economic trends are. It is too bad if two or three billion people–perhaps half of humanity–fail to enjoy much or any economic growth, but does it really matter? This note is about why it should matter to realists, not just those who mean well.

First, start with the rise of the computer and communications. Due to the falling costs and increasing availability of everything from televisions to computers on the Internet to cell phones, it is easier than ever to find out about what is happening to others. Some of this is "news" and some of it is more fundamental. Advertising, television shows, and movies show how wealthy most rich nations are. Very poor people have become aware that they and their children will live in indescribably wretched conditions while others live in what seems like incredible security and luxury. A very human response would be anger and envy, especially if reasonable efforts to improve one's own lot seemed fruitless.

Second, consider the nature of technology. Many weapons are knowledge intensive rather than highly specialized. As knowledge is becoming widely spread, then weapons involving dirty bombs or biological agents or various chemical mixtures will be relatively easy to assemble. Of course, it will not be the poorest that plan or assemble such weapons, much less deliver them. With increased security, there are likely to be many aborted attempts. But as even Israel has found, it is hard to stop angry people who are willing to die. Can a model based on global flows of goods and capital and information thrive when there are likely to be so many dangers? Think of the war on drugs as a hint of how difficult it would be to deal with these dangers. (Hint: The price of heroin and cocaine fell sharply in the last decade.)

Third, consider the effective policies of the rich nations. Immigration, a major source of income equalization prior to World War I, has been severely curtailed except for the well-educated. Total aid, often given for commercial or strategic reasons, equals $1 billion a week. Subsidies to rich country farmers (including higher prices paid by consumers) are close to $1 billion a day. These subsidies destroy export markets for poor country farmers and subsidize rich nation exports. Major items such as textiles and steel, among the few goods which could be exported by poor nations, are often restricted to protect rich nation producers. Taken in total, these policies prevent many nations from being able to participate and benefit much from international trade. The lack of exports leads to domestic problems, making it also difficult to attract private capital. The aid that is given is often ineffective, as massive debt relief for many poor nations implies. (Much of that aid was loaned at interest rates of about 1% a year, but the burden of debt is excessive! How well could the aid have been used?) A realist in a poor country that does not happen to be one of the educated few would have to conclude that prospects for most were poor.

We are probably entering a long, difficult period in which the major threat to security and prosperity comes from terrorist or criminal elements utilizing technology to wreak havoc. The best way to undermine them would be to find ways to spread prosperity, giving everyone a stake in curbing their activities. But, as argued above, special interests (and even wider public opinion) are resistant to policies that would allow people and unsubsidized goods to flow more freely. Repeated terrorist acts will most likely create even more reluctance to allow these flows. Thus, the promise of creating effective and widespread benefits from global economic integration may fall victim to the combined forces of narrow self-interest and a very human reaction to insecurity and violence. Indeed, there is the possibility of a loss of both freedom and economic dynamism as the quest for safety results in increased controls and a decreased willingness to take risks. In such an environment, the rate of scientific advance would also slow.

If there is a way out of this dilemma, it will have to come from several quarters. An effective energy policy that devalued oil might create pressures for democratic change in the Middle East and Central Asia. Progress in trade talks might create a quid pro quo in which the poor reduce agricultural subsidies in return for less service protection. Enlightened diplomacy could create coalitions that eliminate havens for the terrorist elements, giving them no place to rest and train. Improved sensors could detect germs or chemicals quickly, allowing fast responses to limit damage. Failing this, the future will be difficult, less prosperous and more violent than the recent past.

David Dapice is an Associate Professor of Economics at Tufts University and also the chief economist of the Vietnam Program at Harvard University's Kennedy School of Government.

EVOLUTION
WITH A COMMERCIAL TWIST

"But what if we could **engineer an evolution**, bringing about the same magnitude of change **in just a few weeks?**"

BY HELEN F. CHUANG

HAVE YOU EVER DREAMT OF SPONTANEOUSLY growing wings? Have you ever wished you could gain powers like immunity to the elements or to disease? Peter Parker may have accidentally gotten his genes crossed with those of a spider, but most of us will have to wait and hope for a little luck while nature slowly evolves our genes before we receive superhuman powers. It may seem unlikely for the human race to attain any such combination of traits, but scientists have been harnessing the power of evolution on a smaller scale to force similarly unlikely traits on proteins.

Evolution operates through random mutations, but the chance that any single mutation might be beneficial is slim. When a beneficial mutation does occur, the effect on the organism is usually minute. Consequently, natural evolution takes millions of years to effect a noticeable change in a species. For example, it took approximately thirty-three million years for apes to evolve into the early human species. Although deliberate breeding of animals can bring about major alterations in physical traits within a few generations, such breeding is not a form of evolution. One of the few exceptions is the short time required for bacteria to acquire antibiotic resistance, which can occur in just a few years. However, in most cases, we can neither readily observe nor utilize natural evolution.

But what if we could engineer an evolution, bringing about the same magnitude of change in just a few weeks? This is exactly the function of directed molecular evolution (DME), a technology developed to meet the increasing commercial demands for modified proteins, specifically enzymes, for use in industrial applications.

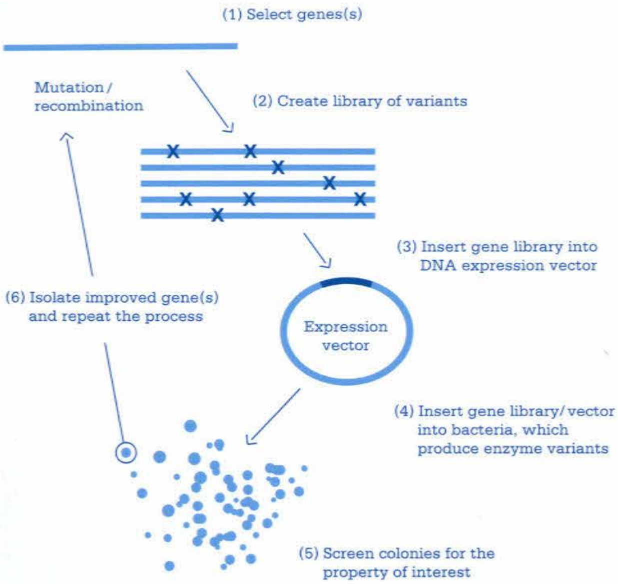

FIGURE 1 Outline of DME experiment. A DME experiment starts with the original (wild-type) DNA and creates many mutants using error-prone PCR. The mutants are then screened for desired traits, and the superior mutants undergo further rounds of mutation and selection. *Source: The Royal Society of Chemistry.*

SYNTHESIZING NEW ENZYMES

Directed molecular evolution (DME) is an accelerated evolution of proteins carried out in a laboratory by protein engineers. In nature, the environment provides the selective pressure; for example, a hot environment pressures the organism to evolve more thermostable proteins. In the laboratory, the engineer provides the selective pressure by choosing between desirable and undesirable mutants. The engineer, however, does not have to follow the rules of nature when providing selective pressure. He can evolve an enzyme with characteristics not encountered in nature, such as tolerance for unusual conditions, by screening for those mutants that perform the best under the specific constraints.

The engineer speeds up evolution in the lab by increasing the error rate of the DNA polymerase, the enzyme responsible for replicating DNA. Such error-prone replication raises the probability of producing desirable and undesirable mutants. A convenient technique is to add metal ions, such as magnesium, to the polymerase, thereby increasing the error rate to approximately one to two mutations per gene per cycle. After each round of replication, the engineer screens the mutants and puts the most desirable ones through subsequent rounds of error-prone replication and screening (see Figure 1). This cycle is repeated until he finds a DNA strand that produces a protein with the desired characteristics.

"The engineer can evolve an enzyme with characteristics not encountered in nature."

DME requires little understanding of how a protein's sequence and structure affect its functions. Before it was fully developed, protein engineering efforts focused on a technique called rational design, a technique that attempts to engineer proteins by altering them directly. A protein's three-dimensional conformation is determined by its sequence of amino acids, and this conformation governs the protein's function. In principle, a protein engineer could study sequences of various proteins and determine which segments account for which function. Then, using this knowledge, the protein engineer could simply add, delete, or modify specific segments in a protein to create new functions, a technique called site-directed mutagenesis. In theory, a rational design engineer could also create a protein from scratch by designing the suitable sequence of amino acids without knowing the sequence of any existing protein that performs a similar function.

While the theory behind rational design is sound, the implementation is sometimes impractical. Studying protein sequences to identify segments responsible for specific functions is more difficult and time consuming than expected. András Szilágyi and Péter Závodszky, researchers at the Hungarian Academy of Sciences, conducted a comprehensive survey of thermophilic, or heat-tolerating, protein structures. They compared various properties of thermophilic and non-thermophilic enzymes but could draw no definite conclusion.

Because proteins are very complex molecules, small changes in a sequence can result in dramatic alterations in function.

In contrast, DME circumvents any need to understand a protein's complexity. When DME evolves a desired enzyme, the protein engineer may have no knowledge of the specific changes that took place or how these changes modified the enzyme. "Our knowledge is puny compared to what would be required to design enzymes from first principles. But if we settle back and admit our ignorance, it really frees us up to take this very different approach," remarked Frances Arnold, Professor of Chemical Engineering and Biochemistry.

DME could also prove invaluable in fundamental studies of proteins, including rational design. The rational design of proteins is often complicated when neutral mutations appear and obscure essential mutations. Neutral mutations are changes in a protein sequence that do not affect the protein's properties, while essential mutations are those that alter function. A rational design engineer comparing the sequences of two different proteins may find it difficult to distinguish between neutral and essential mutations. However, by using DME technologies, the engineer can create mutant sequences that contain only essential mutations. Since DME incrementally introduces mutations into a protein, every change that is selected counts toward the final outcome. Thus, rational design engineers can limit their study to those sequences generated by DME. In addition to aiding rational design, DME can also emulate the natural evolution of a protein and provide clues to a protein's history.

"Research institutes such as Scripps and Rockefeller are employing DME to develop an HIV vaccine."

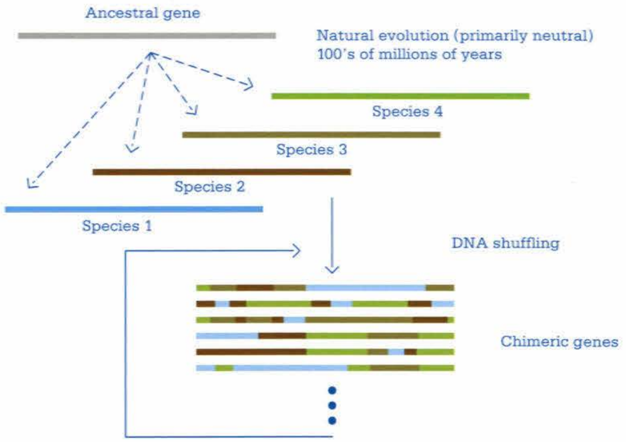

FIGURE 2 Flowchart for gene shuffling. Genes from different species coding for the same protein are chopped up into segments and re-sewn to generate new sequences of the gene. These new sequences can undergo more rounds of shuffling until a sequence with desired properties is found. *Source: The Royal Society of Chemistry.*

SEX IN A TEST TUBE

In 1994, Willem P.C. Stemmer at the Affymax Research Institute added a new twist to DME: molecular breeding, or gene shuffling. DME that only explores mutations of a single gene is called asexual. Asexual DME takes baby steps of one or two mutations per cycle, whereas gene shuffling allows the engineers to explore a much wider range of sequence possibilities. Instead of improving a gene through stepwise mutations, Stemmer proposed generating novel sequences by taking genes that code for the same protein from various organisms, chopping the genes up, and then re-sewing them at corresponding sites to generate new combinations (see Figure 2). This process, called gene shuffling, is similar to the sexual reproduction process in nature in which genes from the parents are shuffled to generate the child's genes.

The offspring of sexual evolution can inherit advantageous traits from both parents; for example, if a protein engineer wants to create a digestive enzyme that functions at both high and low temperatures, the engineer can take digestive-enzyme genes from both thermophilic and psychrophilic (cold-loving) organisms and shuffle them. In this sense, gene shuffling is similar to the breeding of animals, which is why some protein engineers also call this procedure molecular breeding. Some shuffled daughter genes may be nonfunctional, but the few that exhibit superiority over the parent genes can then be selected to undergo further shuffling.

Unlike sexual reproduction in the real world, gene shuffling allows engineers to combine genes from more than two parents, using fifty or more parents simultaneously. Also, gene shuffling is not restricted to genes

"DME cannot alter the protein's function completely or produce enzymes that are too distant from existing ones."

within a species, as it is in nature. In the laboratory, an engineer can theoretically cross a horse and a fly if their DNA sequences are sufficiently well-matched. Gene shuffling has proved to be more powerful than asexual DME on several occasions. In one experiment, Andreas Crameri and his collaborators compared how well asexual DME and gene shuffling each improved a certain enzyme's activity. Genes from four different microbes each underwent asexual evolution, and the four genes were also recombined in a gene shuffle. After just one cycle of shuffling, mutants appeared that showed a 270- to 540-fold increase in enzymatic activity over the parents, whereas asexual evolution of the individual genes had produced mutants with at most an 8-fold increase in activity. Due to this demonstrated added power of gene shuffling, many laboratories now routinely combine gene shuffling with asexual evolution to improve enzymes even more quickly.

ENGINEERED PROTEINS IN THE MARKETPLACE

A chemical or pharmaceutical plant carries out thousands of chemical reactions each day. Catalysts are frequently employed, but many current industrial applications use chemical catalysts that are often inefficient, hard to recycle, and toxic to the environment. Consequently, recent research has focused on enzymes, or biological catalysts. Because they react specifically with the target compound, generate relatively few side products, and are biodegradable, enzymes are very desirable candidates for industrial applications. However, natural enzymes, which are easy to obtain, are typically unsuitable. Whereas natural enzymes have evolved to function in mild temperatures and mild aqueous environments (typical physiological conditions), industrial applications often require high temperatures, acidic solutions, or organic solvents. Therefore, protein engineers are putting more effort into developing unnatural enzymes, and DME is an effective means for accomplishing this goal.

Through directed evolution, protein engineers have succeeded in making thermostable enzymes from non-thermostable ones and improving the catalytic activity of thermophilic enzymes at lower temperatures. Although many protein engineers worried that increased thermostability of an enzyme would result in decreased activity at lower temperatures, Arnold's group discovered that when DME is used to improve an enzyme's thermostability, its activity is often retained (sometimes even increased) at all physiological temperatures. Thus, its ability to tolerate industrial conditions does not come at the cost of decreased catalytic function.

The current markets for DME include protein-based pharmaceuticals, protective and therapeutic vaccines, chemicals, and agriculture. Pharmaceutical products under development include treatments for allergy, inflammation, and cardiovascular disease. Organizations such as the Scripps Research Institute and Rockefeller University are employing DME to develop an HIV vaccine. Vaccines for cancer, malaria, and other infectious diseases are also on the agenda. The National Cancer Institute is currently using this technology to develop cancer treatments. In agricultural studies, DME is helping to increase the crop yield and nutritional content of corn and soybeans. It is also being used to clean up our environment: Rio Tinto, a mining and mineral-processing company, is working on carbon dioxide abatement, while Chevron is better utilizing methanol in fuel cells to power pollution-free electric vehicles. While most of these products have yet to enter the market, many commercial DME products are already available. For instance, Novo Nordisk of Denmark has introduced a DME-improved laundry detergent enzyme.

YOU GET WHAT YOU SCREEN FOR

Even with all this potential, DME is not a magic wand. When Arnold's group attempted to develop an enzyme as an ingredient for cold-water detergents, they produced an enzyme that could not lift stains very well. Additionally, evolving a protein with a certain property requires technology to screen for that property. Although the food-processing industry might be interested in mutated nut proteins that are less allergenic, screening for allergenicity of a protein is hard at high throughput because such screening requires live cells. Many screening technologies exist, but some are tedious or imprecise. This mutant-screening step is often the bottleneck in each round of DME. Most industrial applications require that an enzyme have multiple features, and it is challenging to screen for multiple properties simultaneously. Finally, although DME can improve the performance, robustness, and durability of a protein, it cannot alter the protein's function completely or produce enzymes that are too distant from existing ones. DME is a procedure of modification; making a protein from scratch requires rational design.

In addition to these limitations, a universal problem of biotech merchandise is affordability. Glenn E. Nedwin, a research resident at Novo Nordisk, pointed out that although DME makes fantastic enzymes for all kinds of industrial applications, it fails to address a bigger problem–the high price tag. Chemical catalysts may be less efficient, but they are still more popular due to cost. "I have plenty of interesting enzymes that no one wants to buy because [these enzymes] can't compete, for example, with the price of chlorine," he said.

TOWARD A COLLABORATIVE FUTURE

DME is a powerful and practical technique to create a multitude of synthetic enzymes without having to fully understand the perplexing nature of protein structures. However, it is only one part of protein design technology, and it suffers from such limitations as complicated screening technology and the inability to make enzymes from scratch. A successful future for protein design will require the collaborative efforts of DME and rational-design engineers. DME is a multi-step approach that generates and searches through a large collection of random mutants. Rational design, on the other hand, is a computational approach that relies on mathematical formulas and sophisticated computer programs. While DME can easily improve an existing enzyme, rational design can provide the starting template. With the collaborative efforts of protein engineers of all disciplines, we, as consumers, can benefit from stronger vaccines, more effective disease treatments, cheaper and more nutritious food, and a cleaner, more energy-efficient industry powered by non-toxic enzymes. C

Helen Chuang is a fourth year undergraduate in Chemical Engineering at the California Institute of Technology. *The author wishes to thank Dian De Sha and Professor Frances Arnold, Dickinson Professor of Chemical Engineering and Biochemistry at Caltech.*

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> "Although DME makes **fantastic enzymes** for all kinds of industrial applications, it fails to address a bigger problem– the **high price tag**."

ARROW'S THEOREM THWARTS THE PERFECT ELECTION

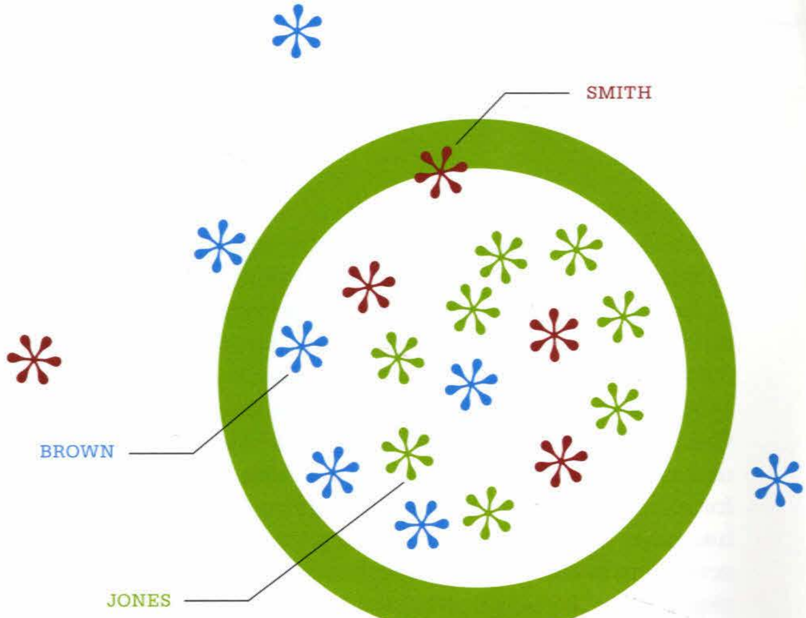


FIGURE 1 A plurality system is used in many political elections in the United States today. Only each individual's top-ranked candidates are considered in the balloting, and the candidate who receives the greatest number of first place votes is the winner in this system. Under this system, the group would elect Mr. Jones, since 8 people have him as their top choice.

BY KEVIN COSTELLO

THE LOSER OF AN ELECTION IS NEVER HAPPY WITH THE OUTCOME, BUT SOMETIMES – AS WE SAW two years ago in Florida – it seems that even the winners can be upset at how an election is run. Is there a "correct" way to run an election so that the outcome is fair to everyone, or is there truth to the cliché that you can't please everybody all the time?

These questions were tackled by Kenneth J. Arrow's study of elections. While working towards his doctorate at Columbia University, he made a list of axioms, a group of properties, that he felt reasonable elections should satisfy. Although mathematicians and social scientists had tried for hundreds of years to find an election system that satisfied all of them, no such system had ever been found. In his 1951 Ph.D. thesis, Arrow proved a most surprising result: that such an election system would never be found, because no such perfect system existed!

EXACTLY WHAT IS AN ELECTION?

The term election, as Arrow used it, is a bit more general than the way it is used in today's common political parlance. In Arrow's loose sense, an election is any method of combining a group of individual preferences, or votes, into one final result. Many political elections combine the votes from a large number of ballots into a single societal ranking, which is then used to choose a winning candidate for the election. Olympic figure skating uses another type of election, in which the goal is to combine the rankings of a set of judges into a complete ranking of all the competitors, which can then be used to determine the top three competitors for the purpose of awarding medals. Another sample election occurs every time a group of people tries to pick a place to eat. Starting only with the individual preferences of its members, the group somehow needs to decide on a single ranking of the restaurants

"Population, as an aggregate, can have **preferences** between pairs of candidates that would seem **contradictory** if given as the preferences of any **single individual.**"

that combines these preferences, or at least on a single restaurant that can be considered the group's top pick.

Arrow thought of an election as a function, a process that takes all the rankings given by the voters as its input and outputs a single ranking of the candidates. He assumed that the preferences of the voters are transitive. That is, if a voter prefers candidate A to candidate B, and candidate B to candidate C, then she also prefers candidate A to candidate C. The process should also be able to handle any possible ordering of the candidates by the voters so that no matter how the voters cast their ballots, the election reaches some sort of result. Furthermore, the process must determine the winning candidate based only on the votes that are received, and not on any other factor. Since we want consistency in elections, an ideal election shouldn't be randomly decided.

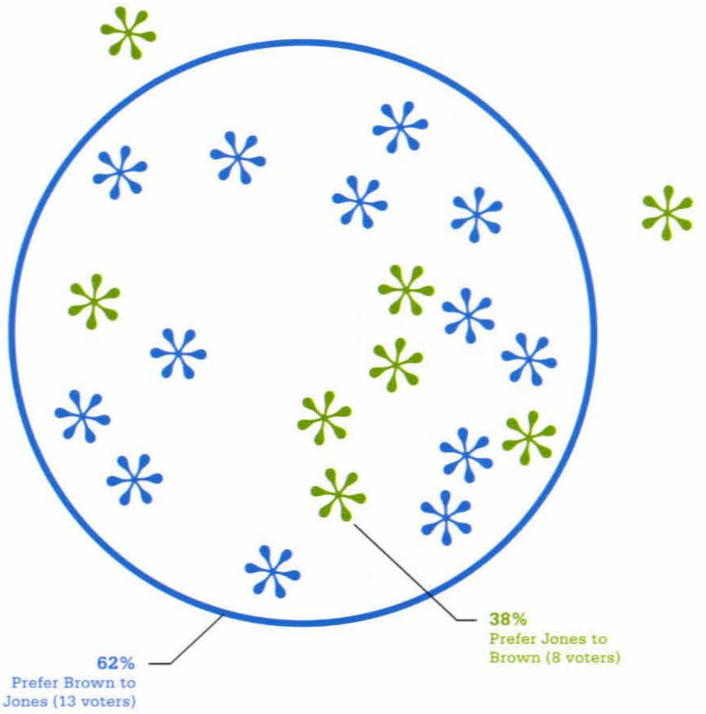


FIGURE 2 Preferences of the 21 voters, once Smith is removed. Since Mr. Brown now has a majority, he would be elected.

ONE ELECTION: THREE WINNERS

By choosing a very general definition of elections, Arrow was able to include a wide variety of systems under his theorem. Consider a group of 21 people trying to choose between 3 possible candidates: Mr. Jones, Mr. Smith, and Mr. Brown (see Figure 1).

While a plurality system has some merits, it also has flaws. The final choice may (as demonstrated in Figure 1) actually be the least favorite choice of a clear majority of the voters. As a possible solution to this problem, in 1870 MIT professor W.R. Ware suggested a system known as Instant Runoff Voting. In this system, voters rank all the candidates. Again, initially only the first place votes for each candidate are considered. If no candidate has a majority of the votes at this point, one or more of the candidates are eliminated (usually either the candidate with the fewest votes or all candidates but the two with the most votes), and the eliminated candidates are removed from all voters' preference lists. The process is repeated until one candidate receives a majority of the votes, and the candidate who thus receives a majority is declared the winner. This system allows the results of a runoff election between a smaller group of candidates to be calculated immediately without having to actually have the voters vote again (hence the "instant" runoff). For the election in Figure 1, Mr. Smith would be eliminated, since he received only 6 first place votes, and his votes redistributed according to voter's second choice, as in Figure 2.

Another alternative allowing preferences beyond a voter's first choice was suggested by the French mathematician Jean-Charles de Borda in 1770. In Borda Voting, voters first rank all the candidates; then, each candidate is given one point for each first place vote, two for each second place vote, and so on. The candidates are finally ranked from the lowest score to the highest. This method is used, for example, when the Associated Press ranks college football and basketball teams. Sportswriters rank their top 25 teams, and a team receives 25 points for being a first place team on a ballot, 24 for being a second place team, and so on, down to only receiving a single point for being ranked

Candidate	1st place votes	2nd place votes	3rd place votes	Total Score
Mr. Jones	8	0	13	$8\times1+0\times2+13\times3 = 47$
Mr. Smith	6	15	0	$6\times1+15\times2+0\times3 = 36$
Mr. Brown	7	6	8	$7\times1+6\times2+8\times3 = 43$

TABLE 1 An example of voting under the Borda System.

25th. The teams with more points are ranked higher, which then decides who can play for the national championship. For the 3-candidate election in Table 1, Mr. Jones would receive 47 points (1 point for each of 8 first place votes, 3 points for each of 13 third place votes). Similarly, Mr. Brown would receive 43 points (8 third place votes at 3 points each, 6 second place votes at 2 points each, 7 first place votes at 1 point each), and Mr. Smith would receive 36 points (15 second place votes at 2 points each and 6 first place votes at one point each). Since Mr. Smith would have the lowest total, he would be elected under the Borda system.

A final option for an election system is absolutism. In an absolutist system, one voter has absolute control. Society's rankings are deemed to be the same as his personal rankings, and whatever choice he makes is taken to be the choice of the entire society. Arrow actually used the term dictatorship to refer to this type of election, but that word has grown to have other connotations. In actuality, the pivotal voter in an election run under this system has more power than Stalin ever had, since nothing can possibly overrule him.

At first glance, plurality, Instant Runoff Balloting, Borda Voting, and absolutism seem to be quite varied. Yet all are present under Arrow's definition of an election, and his theorem therefore applies to all of them.

BUILDING A BETTER ELECTION

Before Arrow began his work, most election theorists–both academics considering an ideal election and reformers attempting to fix perceived problems in the current system–started by noticing a flaw with the current system of elections, i.e. an undesirable property of the current system. In response, they would propose a new election method to overcome this difficulty. Sooner or later someone else would find a flaw in the newly suggested election method, and the process would repeat itself.

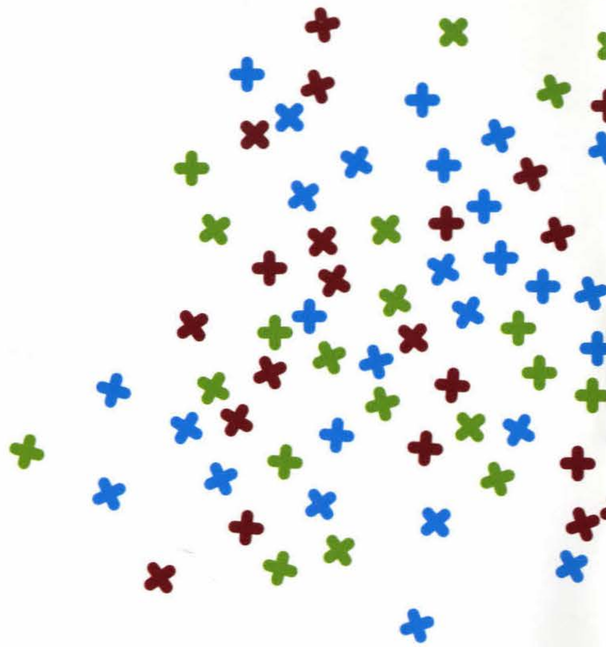
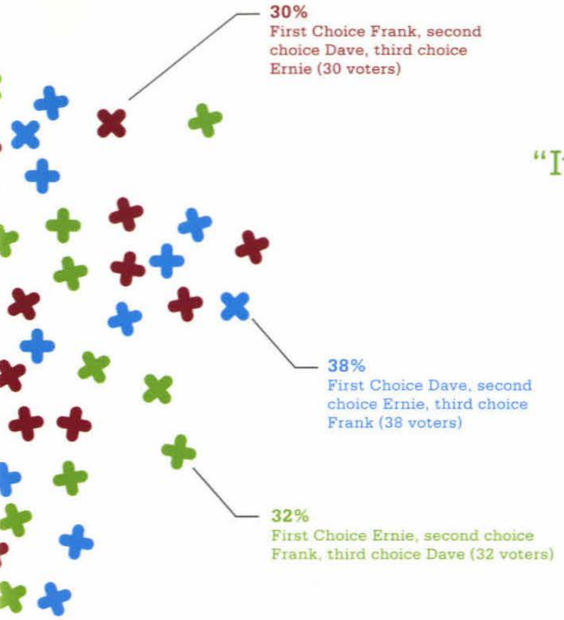


FIGURE 3 Initial preferences of the 100 voters. Frank is eliminated for receiving the fewest first place votes, and, since 68 voters prefer Dave to Ernie, Dave wins the election.

After proposing his axioms, Arrow then proceeded to show that his own axioms were cumulatively inconsistent, meaning that it was impossible to design a system of election that fulfilled all of them at once.

One of Arrow's election properties was that it be able to produce some result no matter what preferences the voters give on their ballots (this property is known as completeness). Because the purpose of an election is to arrive at a decision, it seems reasonable to require an election to always end decisively. This property places no constraints on the final result other than that one exits.

Another one of Arrow's requirements, citizen sovereignty, is an expression of the people's right to use an election system to choose the candidate they want. Thus, every possible ranking of the candidates should be able to occur after some election. Arrow also believed that a system where only one voter had any power would not accurately depict the voter's wishes, so he imposed a condition of non-absolutism. Finally, Arrow imposed two conditions on how the society's choice (the outcome of the election) responded to changes in individual preferences. The first of these conditions, monotonicity, stated that a candidate should never be penalized in the election for becoming a more popular choice among the voters. If one or more voters decide to change their ballots so that only one candidate is ranked higher, the monotonicity requirement states that that candidate should not do any worse in the



"It will turn out that a single person's preferences were used to break the voting cycle each time so that individual has absolute power."

election as a result of voter's ranking higher. As Arrow put it when he stated his theorem, "we are trying to describe social welfare, not some sort of illfare."

It may seem hard to imagine an election system that penalizes a candidate for doing well, but the "reform" system of instant runoff balloting actually does this. An example of such a violation involves an election, in which the candidate with the fewest votes is eliminated after one round of balloting (see Figure 3).

Next, suppose three voters in the second group (the ones who preferred Ernie) have a change of heart and move Dave to the top of their rankings (see Figure 4).

Arrow's final condition had to do with the effect of third party candidates on an election, or rather the lack of an effect. Arrow believed that the choice between two strong candidates should only depend on the voters' preferences amongst those two candidates, and not on

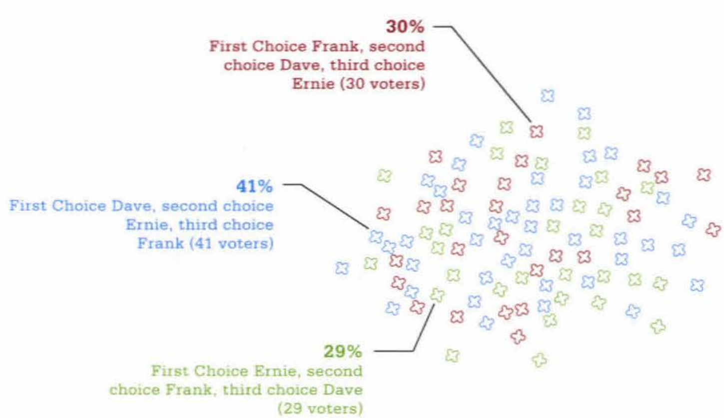


FIGURE 4 Preferences of the 100 voters (after 3 voters change their minds) Ernie is now eliminated after the first round. Between Dave and Frank, 59 voters prefer Frank to Dave, so Frank now wins the election. By giving him their votes, the 3 voters who changed their minds cost Dave the election by expressing their preference for him!

the voter's preferences for a third candidate (an irrelevant alternative, as he termed it) who was not going to win anyway. Again, this is a statement of Arrow's belief that an election should be decided by the wishes of the voters; without this condition, a candidate who stands no chance of winning can change the course of an election merely by deciding to appear on the ballot.

As it turns out, this property is violated by the plurality system commonly in use today. For example, if a small village of 21 voters tries to elect a mayor by plurality vote (see Figures 5 and 6), the presence of the irrelevant alternative Chris would decide the election between Alice and Bob!

ABSOLUTE FAILURE AND VOTING CYCLES

On the surface, each of Arrow's restrictions seems reasonable. In fact, it is quite possible to design a system that satisfies any one of the conditions by itself. What Arrow showed, however, was that these conditions were mutually exclusive; no matter how convoluted an election system involving at least three candidates, it was bound to either violate citizen sovereignty, penalize a candidate for receiving votes, be dependent on the performance of irrelevant candidates, or be an absolutist system.

Arrow proved this by starting from the assumption that he had an election system that satisfied all of his initial requirements except for non-absolutism. Arrow then showed that such a system had to contain, for each candidate, a pivotal voter who personally could decide that candidate's ranking relative to any other candidate. This pivotal voter was the same person for each candidate, since otherwise there would be an irreconcilable conflict when two different pivotal voters both chose their candidates to finish ahead of all the other candidates. Arrow now had (in his theoretical "perfect" election) a voter who could choose any candidate's ranking relative to any other candidate. That individual has the absolute power to decide the election, so Arrow's final condition (that no voter had absolute power) was violated. Since any system that satisfied the first three conditions violated the fourth, it had to

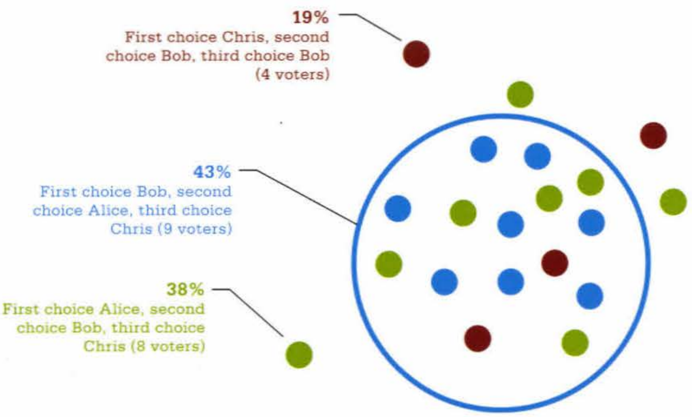


FIGURE 5 Preferences of the 21 voters (with Chris included). Bob wins with 9 first place votes.

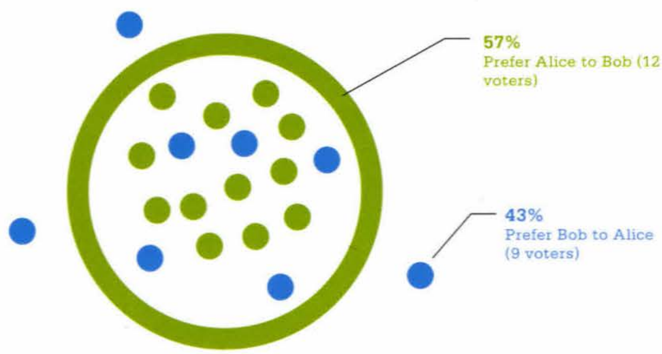


FIGURE 6 Preferences of the 21 voters (with Chris no longer included). Alice wins with 12 first place votes.

be the case that no system could satisfy all four conditions at once.

Arrow showed the counterintuitive result that every single possible election suffers from one of a small set of flaws. One of the reasons this occurs is that the population, as an aggregate, can have preferences between pairs of candidates that would seem contradictory if given as the preferences of any single individual. For example, in the election between Dave, Ernie, and Frank (before the three voters changed their minds), 68% of the voters preferred Dave to Ernie, 70% preferred Ernie to Frank, and 52% preferred Frank to Dave (see Figure 7).

Although each individual's preference leads to a well defined ordering of the candidates, when the preferences are added up a cycle occurs where Dave is preferred to Ernie, Ernie is preferred to Frank, and Frank is preferred to Dave. If an election system is to be complete, it needs to be able to declare a victor, even if the votes occur in this sort of strange fashion. In fact, the system needs to be able to make a decision no matter how complicated a cycle amongst the candidates is created by the voters. Arrow's requirements, in particular his requirement that irrelevant third parties don't influence an election's result, cause all of these situations to be interlinked. If, in Arrow's "perfect" election, one method such as declaring the winner to the candidate with the most first place votes is used to break the cycle for some set of votes, the same method must be used for breaking cycles caused by other sets of votes. There are many possible ways that even as few as 100 voters can vote, and after all the interlinking between closely related sets of votes is accounted for, it will turn out that a single person's preferences were used to break the voting cycle each time–so that individual has absolute power–at least for the election in question. Despite all of Arrow's dodging, he still ended up with an absolutist election.

"Any voting system in which the voters have the ability to elect any slate of candidates they choose, must either have a single voter with absolute power or create situations where a voter has an incentive to lie."

"Election theorists can **improve elections** by making it **so unlikely** that one of these **catastrophes** occur that they **become** nearly **impossible in practice.**"

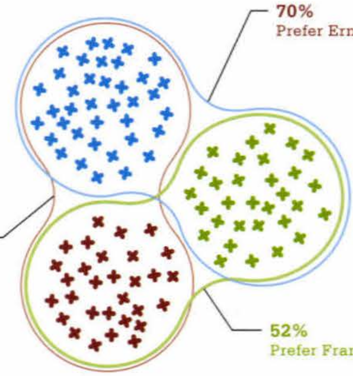


FIGURE 7 Preferences of the 100 voters in the election among Dave, Ernie, and Frank, using the same data from Figure 3.

LYING VOTERS, ABSOLUTE POWER, AND ELECTION REFORM

Although Arrow himself only initially suggested one group of axioms, later political science professors were able to adapt his method of attack to other groups of axioms and have discovered other sets of requirements which are in fact incompatible with each other. Just like with Arrow's requirements, it is futile to attempt to design an election system that satisfies all these requirements. At least one of them will be violated somewhere.

An example of such a theorem was independently proved by Allan Gibbard at the University of Michigan and Mark Satterthwaite at Northwestern in the 1970s. Their theorem states that any voting system in which the voters have the ability to elect any slate of candidates they choose must either have a single voter with absolute power or create situations where a voter has an incentive to lie by giving a preference on her ballot that is different from her actual preference. Any system that gives voters the freedom to elect any candidate they wish must in some situation penalize a voter for stating her true preference on the ballot. Though it may be desirable to have an election system which always rewards expressing your actual preference, Gibbard and Satterthwaite showed that such a system can never exist in practice, so an election theorist's time is better spent looking elsewhere for ways to improve the system.

Given Arrow's Theorem, is election reform then pointless? Not necessarily. Arrow only showed that certain compromises were inevitable, and that no reformer could design an election meeting all his criteria simultaneously. His theorem says absolutely nothing about conditions beyond those select few, and leaves open the possibility of reform in other directions.

Another thing to remember is that Arrow's theorem is merely a worst-case scenario. All Arrow showed is that at least one of his conditions had to be violated somewhere–that some conceivable set of preferences could lead to a problem. Election theorists can improve elections by making it so unlikely that one of these catastrophes will occur that they become nearly impossible in practice.

Perhaps more than anything, Arrow's theorem simply tells would-be reformers, "Don't spend your time trying to change these specific flaws. Look elsewhere." By applying rigorous analysis to the theory of elections, Arrow was able to elucidate exactly what reformers of elections can and cannot accomplish, and thus satisfy more of the people more of the time.

Kevin Costello is a fourth year undergraduate in Mathematics and Economics at the California Institute of Technology.

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A BRIGHT PATH TO A FASTER O_2 SENSOR

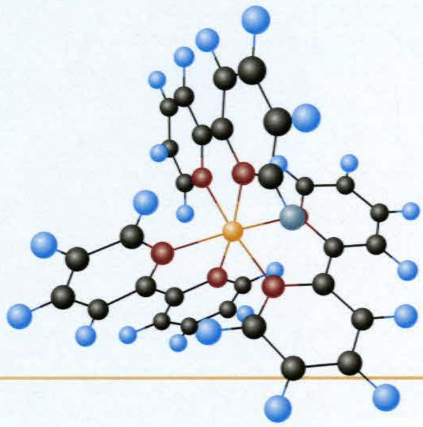
BY TYREL M. McQUEEN

MEDICAL RESEARCHERS ROUTINELY USE OXYGEN SENSORS IN breath analyzers to measure cardiac function of individuals. They compare oxygen uptake to other measures of cardiac activity to study changes within the body. Despite the high accuracy of current measurement techniques, demand in recent years has grown within the medical research community for a faster oxygen detection method to aid in sensitive studies in which critical events occur on a millisecond timescale.

In addition to medical research, a high-speed oxygen sensor has many other practical applications. Engineers have already utilized oxygen sensors in power plants and car engines to optimize fuel efficiency. A faster sensor in these applications would enhance performance and reduce emissions by allowing more precise control of the oxygen-to-fuel ratio.

Currently, we are developing an oxygen sensor based on fluorescence quenching that will be several times faster than competing technologies. However, the device needs further testing and fine tuning to ensure that it will function properly in practical working environments.

"Demand has grown within the medical research community for a faster oxygen detection method to aid in sensitive studies in which critical events occur on a millisecond timescale."



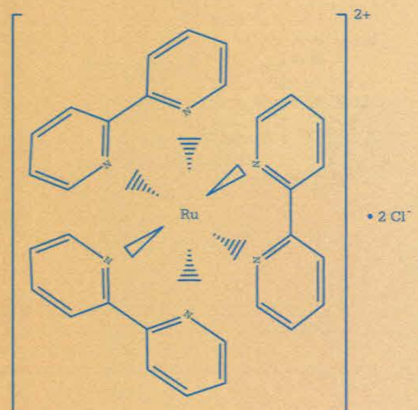


FIGURE 1 Tris-(2,2'-bipyridyl) ruthenium (II) chloride changes its fluorescence behavior in the presence of oxygen. When excited with blue light (455 nanometers), this dye emits a bright orange light (610 nanometers). The more oxygen present, the less intense the orange emission.

DETECTING OXYGEN

There are many techniques for measurement of oxygen concentration, including methods based on paramagnetism, tunable diode laser adsorption spectroscopy, and mass spectrometry. The most common sensor is a zirconia (ZrO_2) solid-state electrochemical cell, first developed in the 1960s by Kalevi Kiukkola and Carl Wagner.

Zirconia sensors are accurate for measuring trace amounts up to 100% oxygen and are easy to assemble; however, they also have drawbacks that severely limit their use. Carbon monoxide and other gases interfere with potentiometric measurements, and the response time is relatively slow (approximately one second). Additionally, the zirconia sensors require heating to at least 400 degrees Celsius (although they are rarely used below 650 degrees Celsius), leading to an explosion hazard in the presence of combustible gases.

A new technique, luminescence-based oxygen sensing, avoids most of these problems. The principle behind this new class of sensors is fluorescence quenching. There are particular compounds whose fluorescence is affected by the presence of certain gases such as oxygen. These molecules can be tailored to respond only to the gas of interest, with minimal interference from other gases. Tris-(2,2'-bipyridyl) ruthenium (II) chloride, a ruthenium dye (see Figure 1), is one such compound that is sensitive only to oxygen.

Detection of oxygen via luminescence follows several steps. The dye absorbs blue light to form a high-energy complex for a few nanoseconds that then decays back to its ground state, either with the emission of orange light, or without (see Figure 3). As the concentration of oxygen increases, the intensity of emitted orange light decreases because of the second pathway. It is therefore possible to measure the oxygen concentration of an unknown sample by measuring the intensity of light emitted by the dye.

This type of oxygen sensor does not require high temperatures to function, and few gases interfere with

"It is possible to measure the oxygen concentration of an unknown sample by measuring the intensity of light emitted by the dye."

FIGURE 2 A typical sol-gel with the bright orange ruthenium dye embedded in it after the solvent alcohol has evaporated.

detection, overcoming two of the major drawbacks of zirconia probes. However, luminescence-based sensors suffer from other drawbacks, primarily the susceptibility to dye bleaching. Over time, the fluorescent dye "wears out" and ceases to fluoresce. Thus, decreases in intensity are not only due to changes in oxygen concentration in the sample, but also due to natural degradation of the dye. Consequently, sensors based on luminescence intensity must be recalibrated often to maintain accuracy.

Measuring the lifetime of dye fluorescence overcomes this difficulty. The excited dye undergoes one of two relaxation processes. The longer the intermediate exists, the more likely it is to interact with an oxygen molecule (C) and the less likely it is to emit orange light (B). Increasing oxygen content changes the amount of light emitted and decreases the average time the dye exists in the excited state. By measuring this luminescence lifetime rather than raw intensity, the effect of dye bleaching is minimized. As long as there is enough dye present to obtain a significant signal, bleaching does not unduly impact sensor accuracy.

In these experiments, we performed all optimizations using intensity measurements because the electronics necessary for making lifetime measurements were not yet available. However, these optimizations should be equally applicable to the lifetime-based sensor.

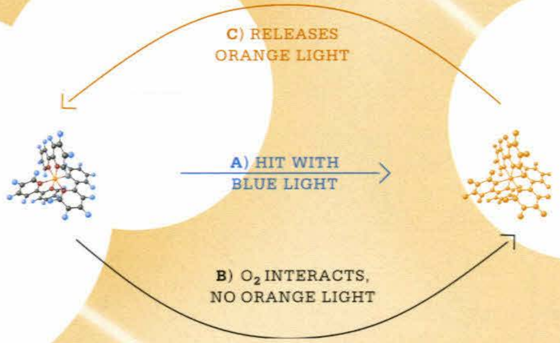


FIGURE 3 Steps in luminescence oxygen sensing. The dye is exposed to blue light, which causes an electron transfer from the ruthenium metal to the attached ligand groups, producing the high-energy intermediate (step A). In the absence of O_2 the intermediate relaxes back to its low-energy state, emitting orange light (B). In the presence of oxygen, some of the excited molecules interact with O_2, losing their energy in the collision and relaxing to the low energy state without emission of orange light (C).

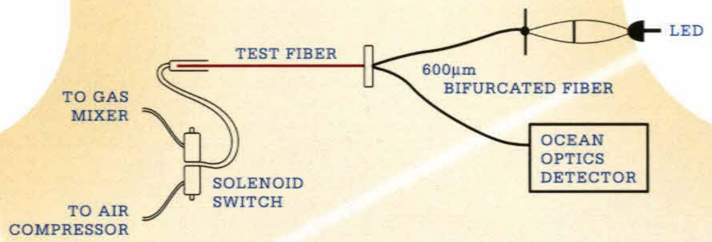


FIGURE 4 Apparatus used to test fiber tips. The only component that must be switched to test a new tip is the 7" fiber segment (shown in red) that is coupled to the bifurcated fiber and protrudes into the isolated gas chamber. A pair of solenoids acts as a high-speed gas switch, permitting rapid switching between gas flows.

FOUNDATIONS OF A WORKING SENSOR

To use a fluorescent dye to detect oxygen, the dye must both be in contact with the sample and be aligned with the necessary optics for measurement of fluorescent intensity or lifetime. For this reason, the dye is incorporated into a support matrix that holds it immobile and allows it to be exposed to an unknown sample.

A variety of materials can be used as a support matrix, but we considered two: polymers and sol-gels. The polymers consist of commercial polystyrene or polyvinylchloride (PVC). The dye is incorporated by dissolving both it and the polymer in an organic solvent, followed by evaporation of the solvent. The sol-gel, or porous glass, matrices (see Figure 2) are prepared in-house from silicon precursors. The dye is added by dissolving it in the alcohol solution in which the sol-gels are prepared. The sol-gel is then dried via evaporation of the solvent alcohol. In both cases, the dye is incorporated into the matrix and is held immobile in a porous structure.

Both polymer and sol-gel support structures provide adequate immobilization of the dyes, but they tend to limit sensor speed because oxygen takes time to diffuse throughout the support matrix. Therefore, matrices of large pore sizes are desired for a fast sensor. However, the pores should not be large enough to allow the dye to be washed out. Considerable effort went into finding a matrix whose pores are large enough for the desired speed while simultaneously small enough to prevent loss of the dye.

In this project, support matrices were dip-coated onto the tip of a fiber optic cable before the solvent completely evaporated. These coated tips were then dried to remove the solvent, so the matrix held the dye on the fiber. We constructed an apparatus (see Figure 4) with a short (7") fiber with coated tip that could be easily exchanged with others to facilitate testing of various support matrices and tips. All candidate tips were judged based on their response for a 100% oxygen to 100% nitrogen change in gas composition.

PUSHING THE LIMITS OF SENSOR SPEED

The first lab-prepared oxygen sensors based on these matrices were slower than competing technologies. Consequently, we studied three factors affecting matrix pore size: drying temperature, preparation solvent, and

SOL–GEL FIBER CALIBRATION CURVE

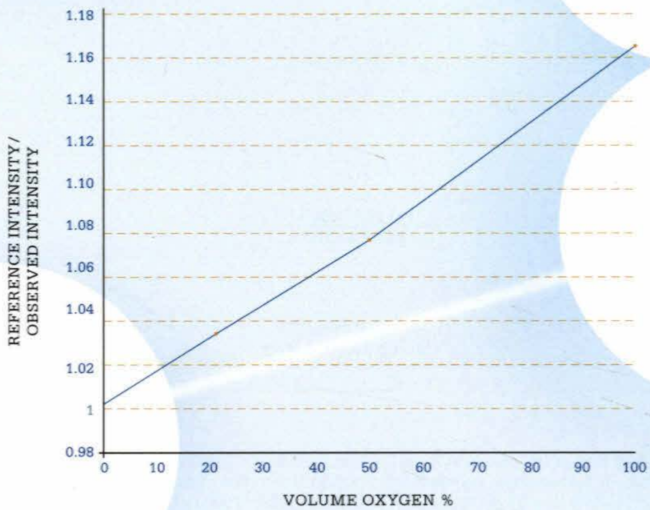


FIGURE 5 Stern-Volmer plot of a sol-gel fiber based on intensity measurements. Note that the linearity indicates that calibration curves for these sensors should be easy to construct. All probes tested showed this type of linearity.

doping of the matrix with a small quantity of a foreign chemical prior to drying. In addition, the geometry and cleaning of the fiber tip were varied to optimize sensor signal performance and increase precision.

Fiber tips were dried at temperatures ranging from 25 degrees Celsius to 140 degrees Celsius. Tests on these fibers showed that high drying temperatures corresponded to slower sensors. This is consistent with the fact that a sol-gel collapses into itself and forms a dense ceramic if it is heated before the solvent has completely evaporated.

A more important factor in final sensor speed was the solvent used during preparation. Bulkier alcohols, such as isopropyl alcohol, created faster sensors than similar probes prepared with small alcohols such as wood alcohol. Sensors prepared in isopropyl alcohol were approximately five times faster than ones prepared in smaller alcohols and were also faster than most competing measurement techniques.

Furthermore, speed improved when we added small quantities of a bulky foreign chemical to the support matrix before drying. These factors combined to produce a sensor that had a response time of 210 milliseconds for a sol-gel matrix, and 60 milliseconds for a polystyrene polymer matrix.

These sensors must also be precise to have any practical applications. The signal transmission properties of a variety of fiber optic tip geometries were tried and compared. The best tip geometry, a slanted configuration, was created by grinding the end down to approximately a 45 degree angle and cleaning it with an acid wash. In general, sensors with this tip were two to ten times more precise than sensors with other geometries, making them comparable in precision to a zirconia electrochemical cell.

OXYGEN SENSORS IN MEDICINE AND INDUSTRY

For this type of oxygen sensor to be a practical, low-cost analytical tool, the probe must behave in a reproducible and well-characterized manner. Simple fluorescence quenching should follow the well-known Stern-Volmer relation. By measuring fluorescence intensity (or luminescence lifetime) of a set of known samples, a calibration

“Fast sensors require matrices of large pore size.”

SOL-GEL FIBER RESPONSE

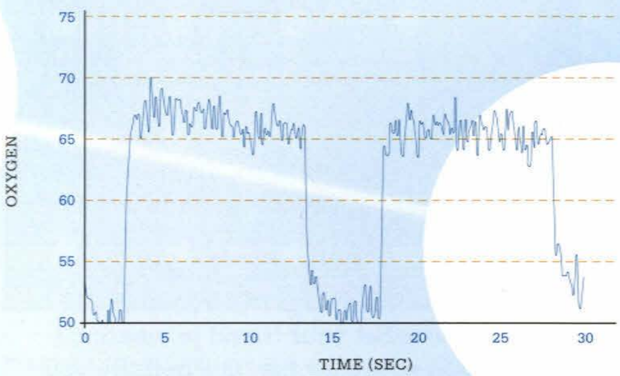


FIGURE 6 Sample response for an air/nitrogen breath simulation. The response time of this sensor was 210 ± 50 ms.

curve can be constructed for the sensor based on the Stern-Volmer model.

Based on the linear calibration curve (see Figure 5), it seems likely that a fluorescence-based sensor could have many practical applications. Although we successfully optimized the probe tip, the high-speed electronics for luminescence lifetime measurements still require considerable work. Additionally, these sensors must be thoroughly tested for durability and reliability in practical environments.

When complete, this new oxygen sensor will permit high-resolution measurement of oxygen that will aid society. The small size, high efficiency, and need for only occasional recalibration will make this technology the oxygen sensor of choice in operating rooms, power plants, remote field sites, and any other place where high speed is essential and frequent recalibration is difficult or impossible. C

Tyrel M. McQueen is a third year undergraduate at Harvey Mudd College majoring in Chemistry.
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"One of the most interesting features of the **scintillating grid** is that while the grid itself is static, the illusion it creates is dynamic."

THE SCINTILLATING GRID ILLUSION

BY TIMOTHY DONG

YOU'RE AT A DINNER PARTY TALKING TO THE INDIVIDUAL NEXT TO you about the newest issue of CURJ when your friend happens to walk by. You don't want to be rude, so you're reluctant to break eye contact with this fellow CURJ lover, but on the other hand, you're also terribly interested in what your friend has decided to wear to the party. Can you maintain eye contact while still paying attention to what your friend is wearing? The answer, which can easily be tested in everyday life, is a definite yes. Although we frequently think of fixation and attention as a single process, the above example demonstrates that the two are, in fact, distinct. The dynamic nature of attention–its ability to wander even in the absence of eye movement–provides a good starting point for explaining dynamic visual illusions such as the Scintillating Grid Illusion.

The Scintillating Grid Illusion (see Figure 1) is created by superimposing white disks onto the intersections of vertical and horizontal gray bars on a black background. When allowed to scan the grid freely, observers report seeing fictitious dark spots that seem to appear and disappear randomly at the intersections. One of the most interesting features of the scintillating grid is that while the grid itself is static, the illusion it creates is dynamic.

Visual attention and saccadic eye movements (short fixations through which the eyes selectively sample different regions of the visual field)–two intrinsically dynamic components of the visual system–are potential candidates for explaining the illusion. While it is known that the illusion is enhanced by saccadic eye movements, it is still unclear whether the illusion is attributed to the shifts in fixation, the shifts in attention that accompany the saccadic eye movements, or both. We found that attention does indeed play an independent role in the illusion.

We presented six men and six women with a scintillating grid on a computer screen in three separate experiments investigating eye fixation, visual cueing, and visual search. In each experiment, following exposure to the scintillating grid, subjects were asked to identify either the disks that had scintillated or the disks that had not scintillated by clicking on the intersections of a neutral grid that did not elicit the illusion. Due to the nature of the task, it was necessary to keep the size of the grid as small as possible. A pilot study indicated that a 3x3 grid still elicited a reasonably

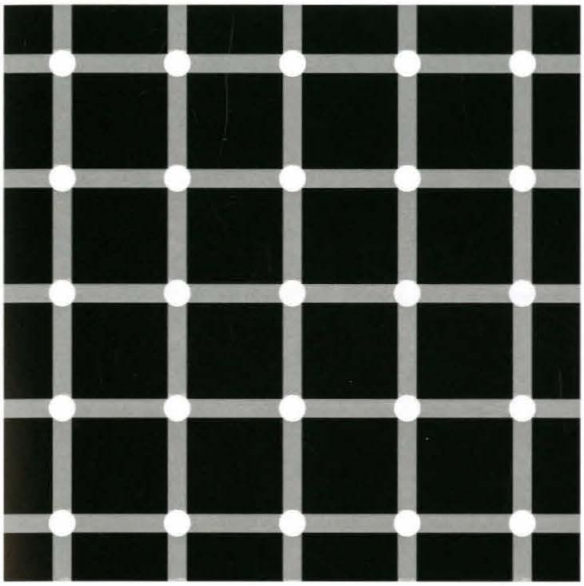

FIGURE 1 The Scintillating Grid Illusion. As subjects scan the grid freely, they typically report seeing dark spots that flash on and off at the intersections. The illusion is generally not observed at the intersection fixated upon.

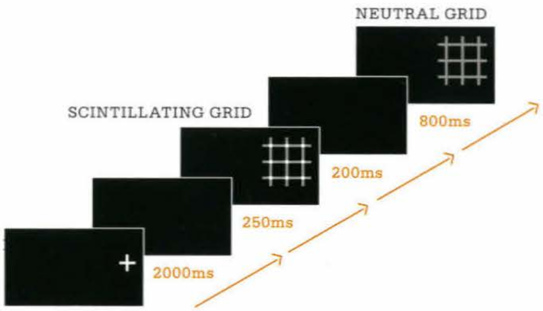

FIGURE 2 Procedure and results for the first experiment (fixation). Sequence of images presented to subject.

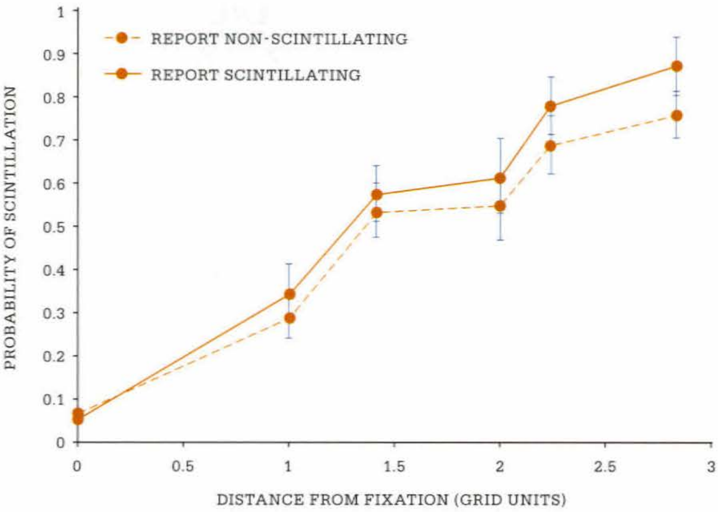

FIGURE 3 Probability of scintillation at an intersection as a function of the distance between the intersection and fixation cross. The two lines indicate different reporting methods that gave statistically comparable results. Disks farther away from the fixation point displayed greater scintillation than intersections closer to fixation.

strong illusion, so this grid size was used for all our experiments. The three experiments were repeated in two sets so that each subject would report alternately with both methods (clicking on scintillating or non-scintillating intersections). We analyzed the probability of any intersection "scintillating" as a function of the distance between that intersection and a particular "interest point" (either the fixation point, visual cue, or search target), depending on the type of experiment conducted.

To effectively separate attention from eye fixation, it was necessary to minimize the possibility of eye movements during each trial. Prior research on the scintillating grid showed that, with steady fixation, the illusion was maximized for presentation durations between 210 and 350 milliseconds, and that with saccadic eye movements (free viewing) the optimal fixation period was between 250 and 550 milliseconds. The grid was thus presented for 200 milliseconds, long enough for subjects to experience the illusion, but short enough to minimize the occurrence of eye movements. In addition, subjects were explicitly instructed to keep their eyes continuously focused on the fixation cross for the duration of each trial.

EYE FIXATION

In this experiment, subjects were asked to focus on a fixation cross which we positioned randomly on the screen for each trial. We then presented a scintillating grid for 200 milliseconds with one randomly chosen intersection superimposed on the location of the fixation cross. After an 800 millisecond intervening delay, subjects then reported the disks that either had or had not scintillated by clicking on the intersections of a neutral grid. The results from this experiment are shown in Figure 3. We found that the greater the distance from an intersection to the fixation point, the greater the occurrence of scintillation at that intersection. The large range of scintillation probability (7%-87%)

"Attention does indeed affect scintillation independently of fixation."

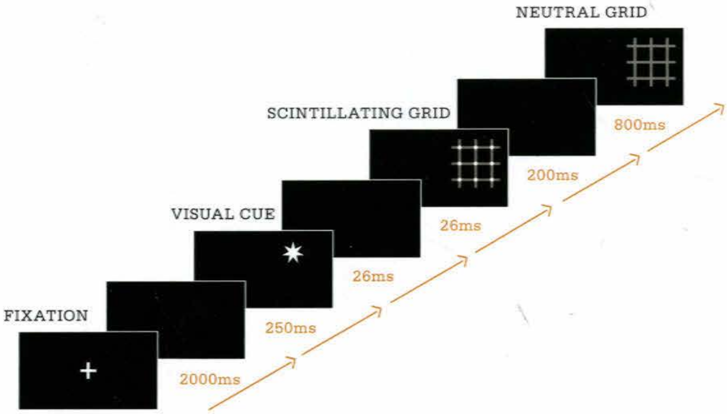

FIGURE 4 Procedure for second experiment (cueing). Sequence of images presented to subject. The sudden appearance of the cue is assumed to draw attention toward the cue (and away from the fixation cross).

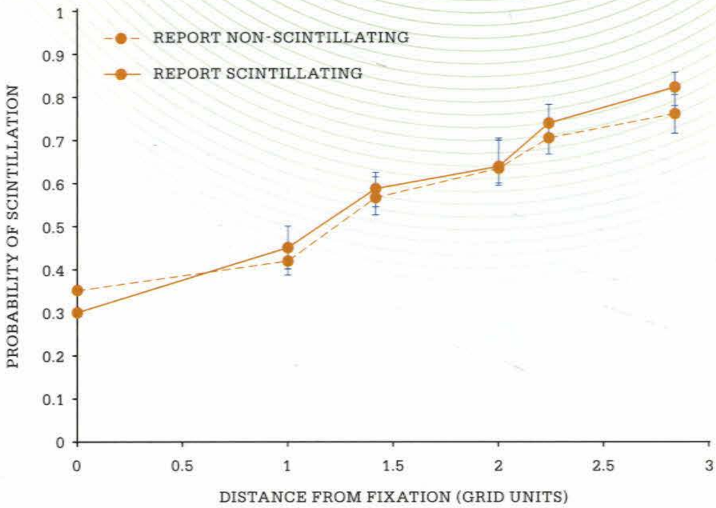

FIGURE 5 Intersections farther away from the attentional focus displayed greater scintillation than intersections closer to the attentional focus. Different reporting methods gave statistically comparable results.

demonstrates that the 3x3 grid used throughout all our experiments was capable of eliciting the illusion to an appreciable degree. The consistency between reporting methods indicates that subjects were indeed reporting the Scintillating Grid Illusion as opposed to merely demonstrating a natural bias for clicking on particular intersections. This was true for all experiments.

A DISTRACTING FLASH

For our second experiment, the fixation cross was always presented at the center of the screen, while the position of the visual cue was randomly assigned. It is known that the sudden appearance of a cue automatically draws visual attention to its location. We presented the grid with one randomly chosen intersection superimposed on the location of the cue (see Figure 4). While fixation was directed at the center of the screen, attention was instead covertly directed at an intersection of the grid.

Increasing the distance from the cue (assumed to reflect the focus of attention) led to increased scintillation (see Figure 5). While these results suggest that attention did play a role in the illusion, the first experiment

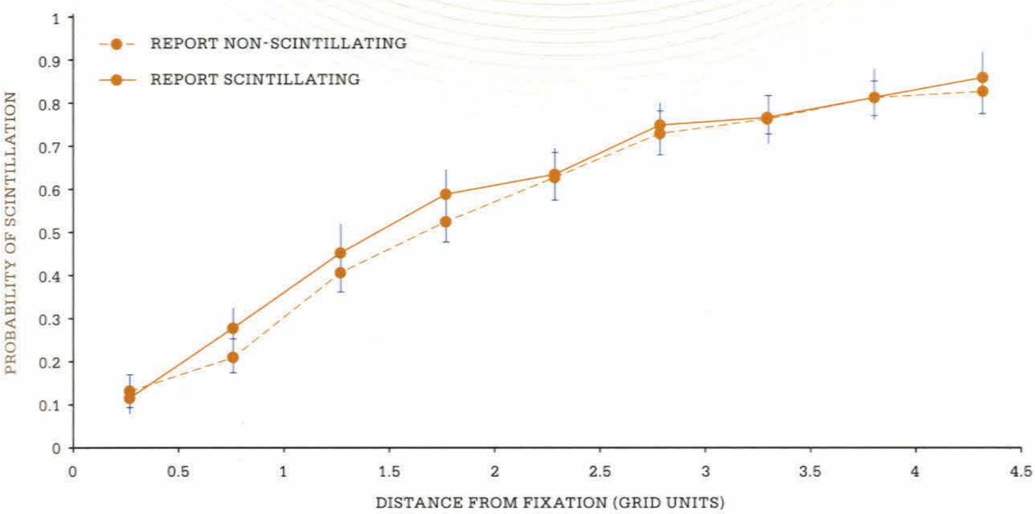

FIGURE 6 Intersections further away from fixation also displayed greater scintillation than the closer intersections. Again, differences in reporting methods are not significant.

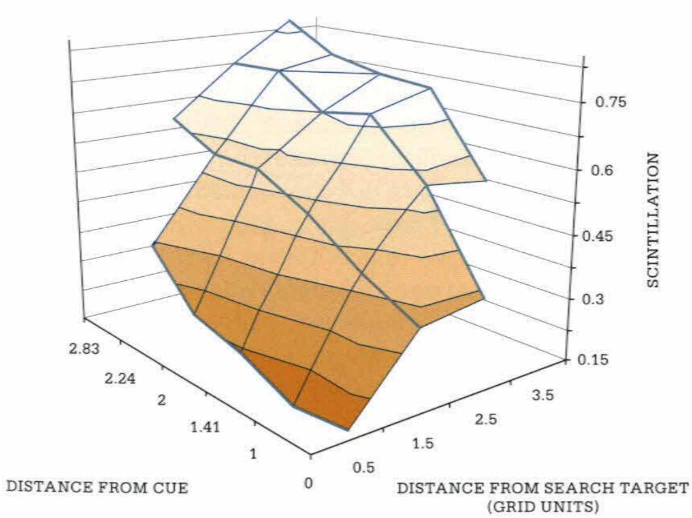

FIGURE 7 Joint influence of the placement of the cue and the fixation cross on scintillation. Regardless of the fixation point's location, increasing distance from cue caused scintillation to increase (shown in highlighted lines on graph).

suggests that fixation may be involved in the illusion in this experiment as well. When we changed the interest point from the location of the cue to the location of the fixation point, the resulting graph (see Figure 6) was very similar to that of the first experiment. Increasing distances from the fixation point again led to increased scintillation. Thus, both the distance from the fixation point and the distance from the cue affected the Scintillating Grid Illusion. To analyze the effects of these two factors and their interactions, we created a three-dimensional plot (see Figure 7). Scintillation always increased significantly with increasing distance from cue, regardless of the distance from fixation. This indicates that attention affects the Scintillating Grid Illusion independent of fixation. To further investigate this result, we performed another experiment incorporating a visual search.

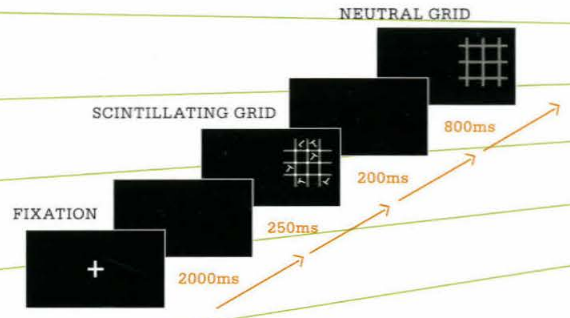

FIGURE 9 Procedure for the third experiment (visual search). Sequence of images presented to subject. Subjects looked for a target letter (an *L*) among several distracter letters (the *T*s), while still monitoring discs that had/had not scintillated.

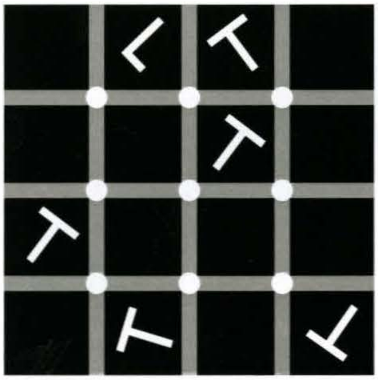

FIGURE 8 Typical example of a modified scintillating grid.

TARGET ACQUIRED

The visual search paradigm provides an alternative method of separating attention from the point of fixation. In this third experiment, we instructed subjects to keep their eyes focused on the fixation cross presented at the center of the screen. They were then presented a modified 3x3 scintillating grid containing letters interspersed randomly within the grid squares (see Figure 8). The letters included a single *L* (the search target) and five *T*s (the distracters). The grid and letters were displayed together at a random location on the screen. Following an 800 millisecond intervening delay, a neutral (non-scintillating) grid appeared, on which subjects were asked to identify the location of the *L* by clicking on one of the grid squares and then to report the disks that did or did not scintillate by clicking on the appropriate intersections (see Figure 9). Correct identification of the target's location in visual search tasks is known to require attention.

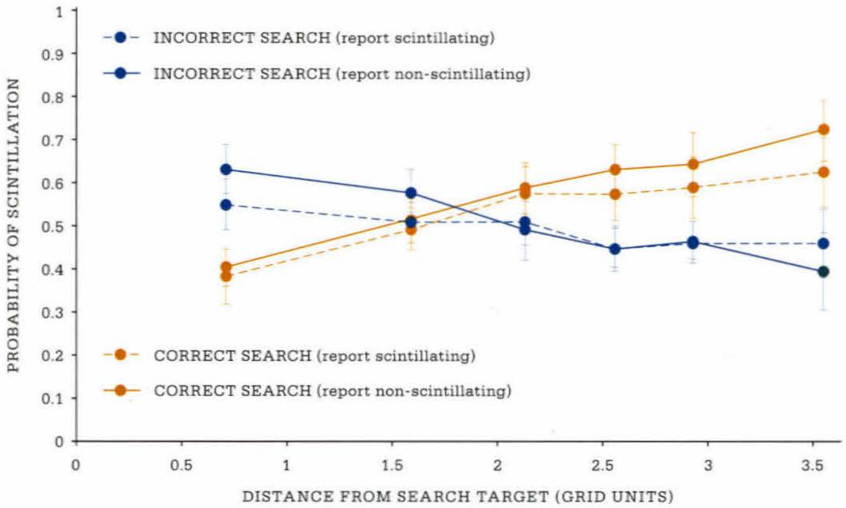

FIGURE 10 Effect of search performance and distance from search target on scintillation. Locations closer to the attentional focus display less scintillation than those farther from the attentional focus. The differences between the trends of correct and incorrect search are significant.

"Further study ... has the potential to help us better understand not only attention but also other processes in the visual system."

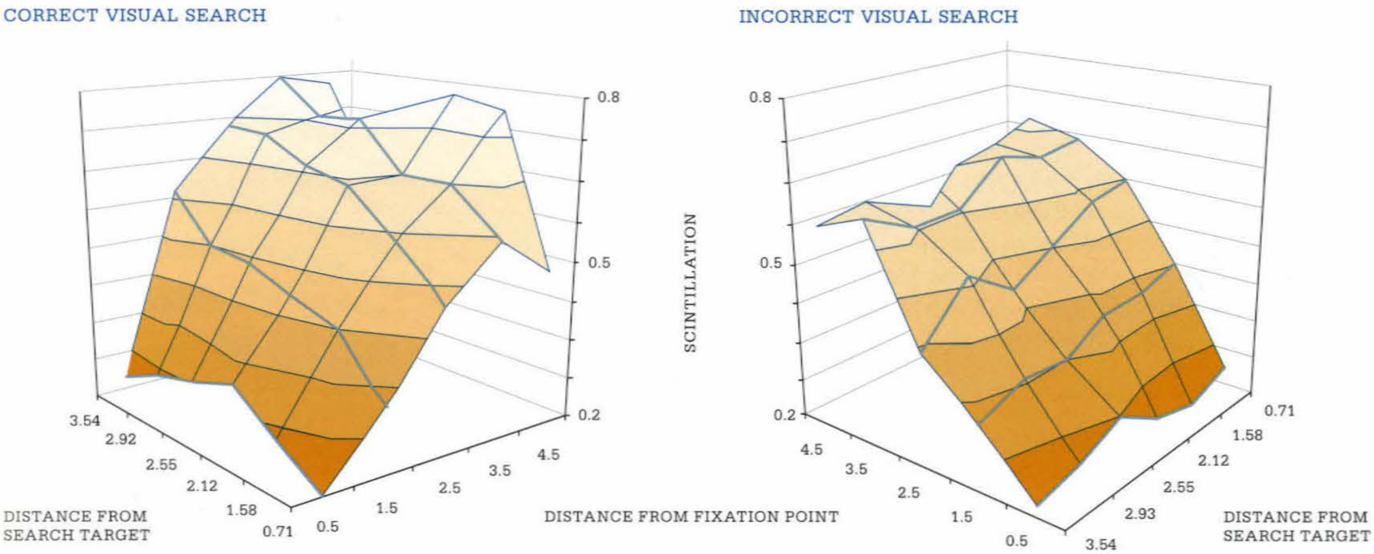

FIGURE 11 Joint influence of the location of the search target and the location of the fixation cross. For correct search, regardless of distance from fixation point the increase in scintillation with increasing distances from search target is significant; for incorrect search, regardless of the fixation point's location, the decrease in scintillation with increasing distances from search target is present, but not significant.

We separated the results from these experiments into two categories, depending on whether the subject had correctly or incorrectly identified the location of the search target. Subjects on average correctly located the search target 59% of the time (chance level was 6.25%). On correct search trials, we assumed that they had attended to the location of the target; likewise, on incorrect search trials, we assumed that they had not attended to the location of the target.

For correct trials, scintillation increased with increasing distances from the search target, while for incorrect trials, scintillation decreased with increasing distances from the search target (see Figure 10). There is a highly significant correlation between the effects of search performance (whether or not the subject correctly identified the search target's location) and distance from search target. This shows that there is a significant difference between the trends of correct and incorrect search. Thus, attention again plays a role in the Scintillating Grid Illusion. As in the case of visual cueing, this does not preclude the involvement of fixation in the illusion as well. Switching the interest point from the location of the search target to the fixation point, we obtained results similar to those from the first two experiments. Scintillation again increased with increasing distances from the fixation point, regardless of search performance, while the differences between correct and incorrect search were not significant. We created a three-dimensional plot to separate the effects of the attended location and the fixated location on scintillation (see Figure 11). In correct search, regardless of the distance from fixation point, scintillation showed a significant increase with increasing search target distance; for incorrect search, the corresponding decrease in scintillation was present but not significant.

The identical trends obtained from the attentional cueing and visual search paradigm indicate that attention does indeed affect scintillation independently of fixation. Scintillation is stronger in areas farther away from the focus of attention, and weaker in areas closer to the focus of attention, regardless of where one is fixating.

CONSEQUENCES OF THE ILLUSION

Analysis of the three-dimensional plots (see Figures 7 and 11) shows that the change in scintillation attributed to varying distances from the fixation point is generally larger than the change attributed to varying distances from the attended location–either the cue or the search target. One might then conclude that eye fixation plays a larger role in the scintillating grid illusion than attention. However, while fixation can be assumed to remain at the center of the screen for the entire grid presentation, one cannot assume that attention occupies only one location (i.e., the location of the search target in correct search trials) during that time. In particular, attention could have been temporarily present at the fixation point in a certain proportion of trials. Thus, while we can conclude that attention affects scintillation independently of fixation, we cannot assume the converse to be true.

In light of our results, one possible explanation for the Scintillating Grid Illusion is that without attention, the illusory dark spots would be seen at every intersection; it is only by attending to an intersection that we perceive that the intersection has remained white all along. Under normal viewing conditions, the constant shifts of attention across the grid might account for the "scintillating" effect. There is a way to test this hypothesis. Individuals with damaged superior colliculi have difficulty making shifts in attention. If these individuals were tested in our study, it is possible that they would report seeing darkened intersections present more uniformly throughout the grid than normal observers.

Despite the findings discussed here, the Scintillating Grid Illusion remains a mystery. Although we know that the lack of attention increases the probability of scintillation at a given intersection, we still do not know the cause of scintillation–namely, the process whose action induces the illusion to occur in the first place. Further study of the Scintillating Grid Illusion has the potential to help us better understand not only attention but also other processes in the visual system. C

Timothy Dong is a first year undergraduate at the California Institute of Technology. He wishes to thank his mentors Dr. Rufin VanRullen and Dr. Christof Koch for their support and guidance. This work was funded by the 2002 Axline Caltech Summer Undergraduate Research Fellowship.

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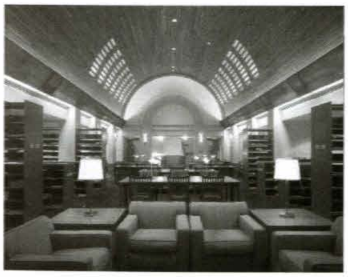

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sand dune music

BY STEVEN GAO

YOU'RE ALONE IN THE MIDDLE OF THE DESERT. THE NEAREST person is miles away. Suddenly, you hear a booming sound that resembles a siren or an airplane. New sounds join the first, producing an eerie chorus. After a few minutes, the music dies down, and silence returns.

This scene captures the mood and power of a booming (sound-producing) sand avalanche. As early as the 14th century, scientists and explorers have reported that certain dunes could produce sounds ranging from cannon fire to trumpets and thunder. Some assumed that demons or other apparitions made these musical sounds. Marco Polo claimed that evil spirits "at times fill[ed] the air with the sounds of all kinds of musical instruments, drums, and the clash of arms." Booming dunes have been reported in Middle Eastern literature for at least 1,500 years and have been found all over the world, from the Middle East, the Sahara Desert, and southern Africa to Chile, Hawaii, Nevada, and California. However, few researchers have explored the phenomenon in the past century, and the origin of these booming sounds remains unclear.

"Marco Polo claimed that evil spirits 'at times fill[ed] the air with the sounds of all kinds of musical instruments, drums, and the clash of arms.'"

"In certain dunes with the right type of sand and the proper environmental conditions, sand flow produces a booming sound."

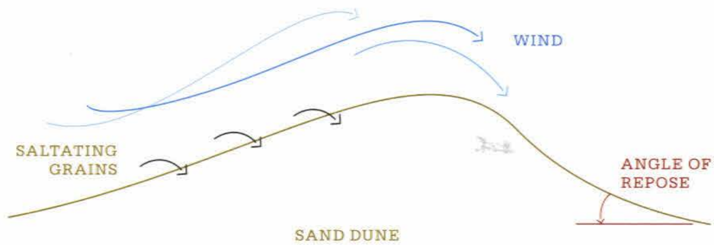

FIGURE 1 Dune formation. The wind forms dunes in this basic process.

This experiment refines a technique to quantify sounds created during human-triggered sand avalanches and presents a preliminary design of experiments to simulate sand avalanches in the laboratory. Analysis of natural sand avalanches and laboratory simulations reveals that several factors affect the sound frequencies of booming sands.

HOW BOOMING SAND DUNES FORM

The wind forms sand dunes by selectively moving grains of certain sizes. Large sand particles remain stationary, while tiny specks are easily carried great distances through the air. Mid-sized grains bounce repeatedly along the ground in a series of low hops called saltation. These particles slow down when the wind subsides or else rebound off soft patches of sand. Sand accumulates, trapping more sand and forming a dune (see Figure 1).

Sand grains are blown up the windward slope of the newly forming dune and dumped down the lee, or downwind, face. Because the denser grains of sand make shorter hops along the dune, they land on the upper part of the lee face, making it steeper. These trapped grains build a slope of increasing steepness until the angle (formed by the line of the sand and the horizontal) reaches the angle of repose, approximately 34 degrees for dry granular materials. When the slope slightly exceeds the angle of repose, the excess sand from the dune's crest flows to the base in so-called "avalanche tongues." This avalanche is usually a relatively quiet event, but in certain dunes with the right type of sand and the proper environmental conditions, sand flow produces a booming sound. This acoustic emission results from shearing and rubbing between sand particles during the avalanche. As the sand comes to rest near the base of the dune, the booming gradually wanes in intensity and eventually stops.

Booming sand is typically composed of grains that have similar sizes, round shapes, and fairly smooth surfaces. In addition, the sand is dry because any moisture would affect the friction between the grains and preclude the shearing that causes the booming sound. However, the exact combination of factors that gives sand its booming properties has not yet been discovered.

"Laboratory simulations show that all three parameters–orientation, type of lid, and volume of sand–slightly affect the frequency of the sound produced."

FIGURE 2 Caltech researchers record sounds produced by man-made sand avalanches at Kelso Dunes in the Mojave National Preserve.

In our experiment, we quantified sounds created during human-made avalanches and collected sand for laboratory testing from the Kelso Dunes in the Mojave National Preserve and the Eureka Dunes in Death Valley National Park. The Kelso Dunes, with an area of 115 square kilometers and a maximum depth of 215 meters, is one of the larger dune fields in California. These stationary dunes have been accumulating for thousands of years. In a 1979 trip to Kelso, Peter K. Haff reported that "the most spectacular and enduring vibrations were produced by the movement of large quantities of sand. This could be initiated by vigorous kicking at the sharp dune crest in order to dislodge a metastable surface layer on the lee slopes." Haff also investigated the Eureka Dunes, located northwest of Death Valley. Despite covering a relatively small area (measuring only 5.3 kilometers long and 2.4 kilometers wide), they reach an elevation of 207 meters, making them the tallest dunes in California. At Eureka, Haff reported that the dunes "demonstrated all the booming properties observed at Kelso Dunes, although the acoustic intensity did not appear to be as great."

RECORDING AND RECREATING THE BOOM

We first selected the proper equipment for sound data collection. After extensive testing and comparison of several microphones' abilities to pick up the range of frequencies (approximately 50-300 Hz) associated with booming sands, we chose an ear microphone built by Professor James Boyk at Caltech. An appropriate sound card was also selected for digital data processing in this frequency range. We gathered our data at the Eureka and Kelso Dunes (see Figure 2). Man-made sand avalanches were created by sliding down the dunes feet first, and were then recorded with the ear microphone, a video camera, and two geophones. Numerous samples of both booming and silent sand (i.e., sand that did not produce a booming sand when kicked) were collected from the crest and the base of the dune, respectively.

In the laboratory, we simulated sand avalanches to investigate the different factors that affect the booming phenomenon. Sand samples were dried and filtered to ensure the uniformity of size distribution found in natural dunes, and then poured into quart-sized jars. The sand-

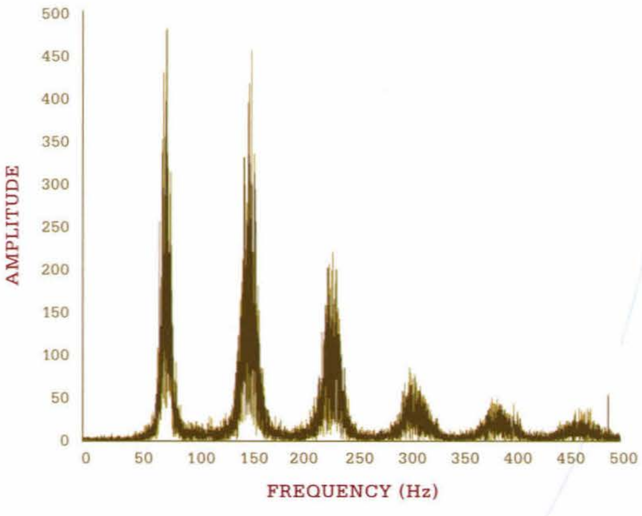

FIGURE 3 Amplitude vs. frequency graph of man-made avalanche recorded on-site at the Eureka Dunes.

filled jars were shaken for 20 seconds at a frequency of 150 Hz, and sounds were recorded with the microphone. We tested how three parameters–orientation, type of lid, and volume of sand–affected the amplitude and position of the fundamental frequency of the sound. In order to investigate the effect of orientation (i.e., direction of sand movement), each jar was first shaken horizontally and then vertically. The effect of the lid was examined by first covering the jar with a metal lid and then with a human hand to determine whether the impact of sand grains against the metal lid produced extraneous sound frequencies. Finally, the effect of the sand volume was evaluated by placing varying volumes of both booming and silent sand in the jars.

Recorded sounds from field and lab tests were analyzed using Fast Fourier Transforms. All periodic waves, which include sound waves, can be generated as a linear combination of sine and cosine waves of different frequencies and amplitudes. The Fourier Transform decomposes a particular wave into its component frequencies. Graphs showing amplitude vs. frequency are the "fingerprints" of each experiment.

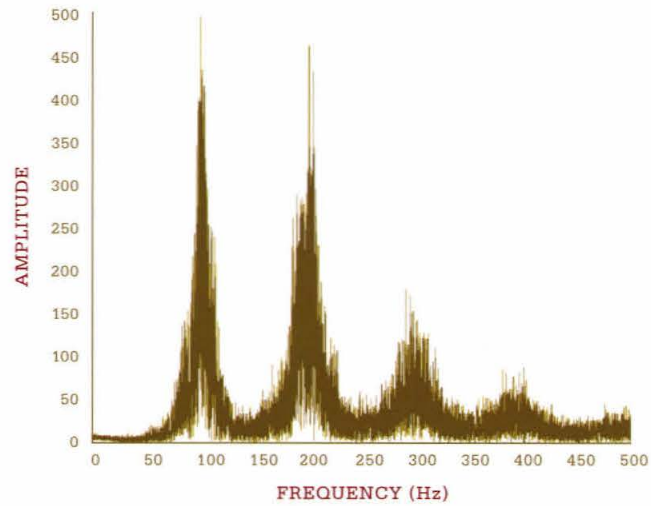

FIGURE 4 Amplitude vs. frequency graph of man-made avalanche recorded on-site at the Kelso Dunes.

SIFTING THROUGH THE SAND DATA

Amplitude vs. frequency graphs show small differences between the fundamental frequencies of man-made avalanches recorded on-site at the Eureka and at the Kelso Dunes. The amplitude vs. frequency graph of Eureka's booming sand (see Figure 3) shows a fundamental tone at approximately 80 Hz, accompanied by five harmonics at 160, 240, 310, 390, and 460 Hz. The graph of booming sand from the Kelso dunes (see Figure 4) shows a fundamental frequency at 100 Hz, with three harmonics at 200, 300, and 400 Hz. These data seem to disprove the 1997 finding that booming sounds have never been observed to contain more than one harmonic of the fundamental tone.

Laboratory simulations show that all three parameters–orientation, type of lid, and volume of sand – slightly affect the frequency of the sound produced. The direction of sand movement (and, consequently, the direction of wave propagation) shifts the fundamental frequency. Vertical shaking creates a slightly higher fundamental frequency (approximately 210 Hz) than horizontal shaking (170 Hz). Unlike the on-site avalanche recordings, these jar-shaking lab simulations do not contain any harmonics of the fundamental tone. In addition, silent grains do not exhibit the characteristic peak at approximately 200 Hz observed for booming sands. The lack of distinguishable frequency peaks for the silent samples makes the orientation of shaking irrelevant. Jar-shaking simulations also show that the metal lids muffle the booming sound and thus result in lower magnitudes of the frequency spikes in the metal lid trials. The fundamental tone shifts down by approximately 15 Hz when moving from trials with the metal lid to trials with the hand lid. Sand volume tests reveal that smaller volumes of sand produce broader spikes with smaller amplitudes than greater volumes of sand. Fundamental frequency, however, remains in the same range of approximately 200 Hz. Once again, no harmonics are seen in the laboratory simulations. Silent sand graphs simply show background noise, making sand volume an irrelevant parameter.

FROM DUNES TO VOLCANOES

This experiment showed a fundamental frequency in the 175–225 Hz range for nearly all on-site recordings of booming sands, which is not present in silent sand samples. Data analysis also suggests a broad-band increase in frequencies along the 50–400 Hz range for silent sand. The orientation, type of lid, and volume of sand in laboratory simulations appear to affect the amplitude and frequency of the resulting Fast Fourier Transform generated graphs.

We need to do additional work to confirm these results and to refine the experimental design of the laboratory simulations. One way is to mechanize the shaking process by building a device that shakes jars of various sizes over a wide range of frequencies, thereby standardizing the current procedure. Another direction of future research is to increase the scale of the laboratory testing–that is, to use bigger shaking

"This experiment showed a fundamental frequency in the 175 – 225 Hz range for nearly all on-site recordings of booming sands, which is not present in silent sand samples."

jars and greater volumes of sand in order to recreate more accurately the amount of sand that is moved during a natural dune avalanche. In addition, sorting samples of sand into different size ranges and then recording jar-shaking tests for each individual range may provide clues as to which sizes of grains are responsible for the phenomenon, thereby narrowing the search for the source of the booming sounds. An understanding of the booming sand phenomenon can ultimately extend to other important geologic and technologic processes involving granular material flows, such as snow avalanches, rockslides, and volcanic eruptions.

Steven Gao is a first year undergraduate at the California Institute of Technology. This work was completed with Christopher Brennen and Melany Hunt, Professors of Mechanical Engineering, and funded by the 2002 Axline Caltech Summer Undergraduate Research Fellowship. The author wishes to thank Kathy Scott, Steve Hostler, Gustavo Joseph, and Zac Dydek in the Thomas Mechanical Engineering Laboratory and, especially, Professors Brennen and Hunt for their help and guidance throughout this research endeavor.

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GASTRIC ULCERS IN THE

RAT RACE

BY MISTY RICHARDS

PEPTIC ULCERATION IS A SERIOUS ORGANIC GASTROINTESTINAL DISEASE THAT AFFECTS approximately ten percent of the adult male population in Western countries. Social, psychological, and physiological factors all contribute to these ulcers, but the specific causes are not well studied. Researchers have developed animal models to investigate the mechanisms behind ulceration. This study used one of these models to investigate the role of one particular neurotransmitter in gastric erosions of rats exposed to the activity-stress paradigm.

"The activity-stress model is particularly relevant because it can produce ulcers in the glandular portion of the rat's stomach that are similar to human peptic ulcers."

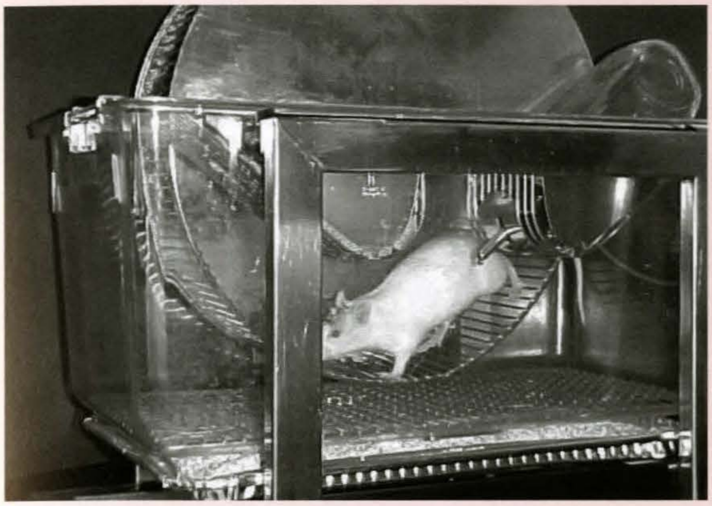

FIGURE 1 A rat in the A-S condition goes for a run.

The Activity-Stress (A-S) model is one paradigm used to investigate the effects of stress on behavior. The setup places rats in cages with running wheels and allows them access to food for one hour each day (see Figure 1). In 1997, D. M. Dwyer and R. A. Boakes discovered that rats in this situation increase their activity levels, decrease food consumption, and die within three to twelve days. They also found that these rats have elevated levels of corticosterone. Other research has shown that corticotropin releasing factor (CRF) plays a role in regulating corticosterone levels. Control rats which are only fed for an hour every day but do not have access to a running wheel remain relatively healthy.

We hypothesized that increased levels of CRF would stimulate increased running, decreased eating, and weight loss in addition to acting as a protective agent against gastric erosion formation. We then tested to see if daily infusions of astressin (a CRF antagonist) would block CRF and attenuate the effects typically associated with A-S while producing more gastric erosions.

INDUCING STRESS

The Activity-Stress model is particularly relevant because it can produce ulcers in the glandular portion of a rat's stomach that are similar to human peptic ulcers. The paradigm offers many advantages over other methodologies because animals exposed to it experience stress from realistic activities such as food restriction and increased activity to find food. Other means of creating a stressful environment, such as restraint, shock, and handling, are not typical in nature and are not as relevant to the human population. In addition, increased activity and neglected nutrition are common causes of stress in both humans and animals, making the results easier to generalize.

In our experiment, we randomly assigned forty-eight female albino Sprague-Dawley rats to eight conditions corresponding to each possible combination of drug, food restriction, and wheel access. The animals were surgically fitted with cannulae to allow the infusion of chemicals into the lateral ventricle of the brain, and then given a week to recover. After the recovery period, we put the rats into cages with or without running wheels, depending on the rat's group assignment, and allowed them five days to habituate to their new environments. Over the course of the next two weeks, we measured the rats' food intake, body weight, and activity while infusing them daily with astressin or water (as a control), appropriately. We sacrificed the animals after two weeks or after they showed a 25% decrease in body weight, then dissected the rats and measured the area of the gastric erosions.

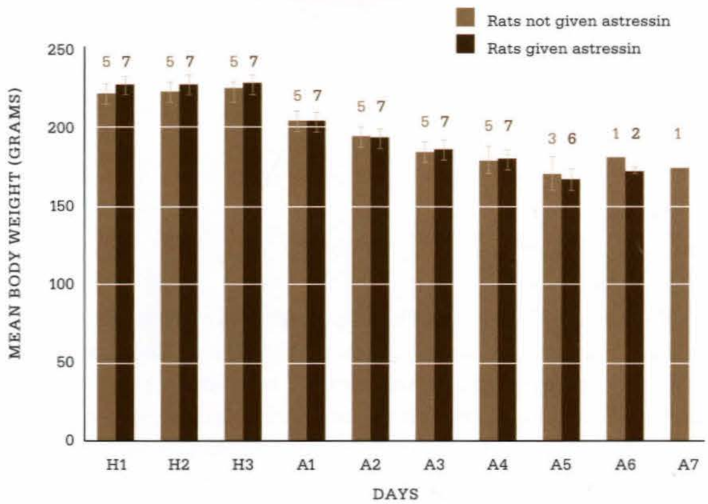

FIGURE 2 Mean body weights of rats in activity-stress. All rats in the activity-stress group continued to lose body weight during the restricted feeding period.

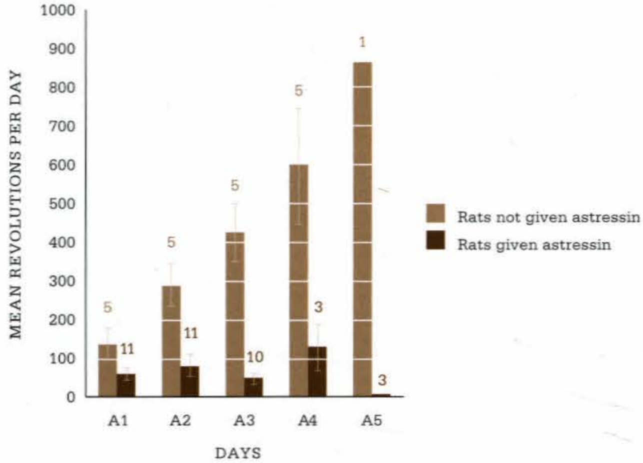

FIGURE 3 Wheel revolutions over time for rats in activity-stress. On average, rats that were given astressin ran the same distance each day throughout the experiment while rats without astressin ran further each day. The numbers indicate the number of rats that were still alive on a particular day.

STRESS INDUCED EROSIONS

We found that the data did not agree entirely with our expectations. While all of the animals in the A-S condition began to lose weight once the habituation period ended (see Figure 2) and activity levels for rats without astressin increased as expected (see Figure 3), food intake increased as the time progressed where we thought it would decrease.

We were also surprised to find that astressin did not significantly reduce all the effects of the A-S condition. Generally eating less (see Figure 4) and losing more weight when compared to rats not given the drug, the animals only showed a decrease in activity levels. Our control animals, which had free access to food and no running wheel, behaved as expected and showed no change in body weight or eating habits.

Although these results did not meet our expectations, the data on the areas of gastric erosion matched our original predictions. All animals with restricted feeding and access to a wheel had significantly larger regions with ulcers than those which were not stressed, which suggests that our experimental setup created the activity-stress ulcer. Free feeding, sedentary rats that were given astressin had stomach ulcers while those that were not given astressin did not. This suggests that astressin blocks CRF and causes the stomach to release more acid and less bicarbonate, producing more ulcers.

Examining the data on the gastric erosions of animals with and without astressin in the A-S condition, we reached the unexpected conclusion that animals given astressin had fewer ulcers than those with astressin. However, this result is misleading because the experiment dealt with a very small number of rats, and even one outlier can distort the data. In our study, there was one rat, which was not given astressin, that had five times the area of gastric erosions than the other animals in its condition. This rat may have needed more time to grow accustomed to her environment and therefore may have experienced additional stress. Performing the data analysis again without considering this rat, we found that animals not given astressin had a smaller area of gastric erosions than animals with astressin, which suggests that CRF protects against the formation of gastric ulcers.

"All animals with restricted feeding and access to a wheel had significantly larger regions with ulcers than those which were not stressed."

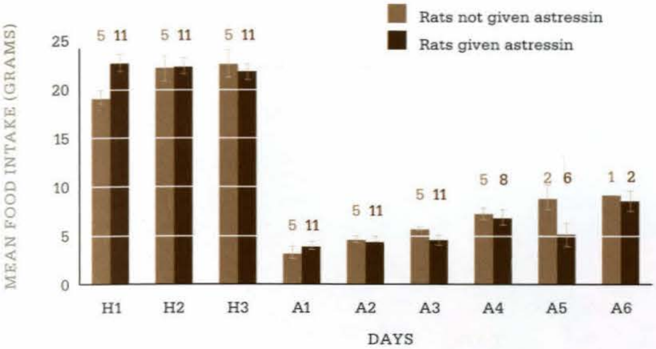

FIGURE 4 Food intake over time. As the days progressed, the rats continued to consume more food, but, on the whole, rats given astressin ate less.

A TRAIL TO THE CURE

The results of this experiment suggest that intracerebroventricular (ICV) astressin causes the formation of stress induced ulcers in rats. This agrees with previous research which showed that brain CRF inhibits gastric acid secretion under stress while intravenous (IV) administration of CRF does not have an effect on the erosions. However, there is much that we do not understand concerning the role of CRF in animals.

The significance of our results could be strengthened by repeating the experiment with larger numbers of rats. This would give us a more accurate picture of the way the average rat might respond to conditions because it would reduce the influence of outliers. In addition, some of our rats became sick with meningitis and encephalitis halfway through the experiment due to contaminated water, which could explain why our results don't completely replicate previous results. We can also explore CRF's effects under different conditions. Because peptic ulceration is a chronic illness, we would prefer to use an experimental setup which would have a less dramatic effect on the subjects. This experiment was only able to study the acute effects because almost all of the rats all died within a week of the start of the experiment. We would also like to determine whether CRF affects the secretion of gastric mucus, which protects against erosions.

Our results suggest that CRF could inhibit the formation of stress induced erosions, probably by reducing gastric acid secretions through the automatic nervous system. We may be far from a cure for stress induced gastric ulcers, but more help from rats may help solve our rat race problem. C

Misty Richards is a fourth year undergraduate at UCLA, majoring in Psychobiology with a minor in Applied Developmental Psychology. This research was completed in the form of an honors thesis under the supervision of Dr. Carlos Grijalva, Professor of Psychology in the division of Behavioral Neuroscience. *The author wishes to thank Dr. Grijalva and her co-workers Zita Konik and Vinuta Rao for their support and effort in the completion of this research project.*

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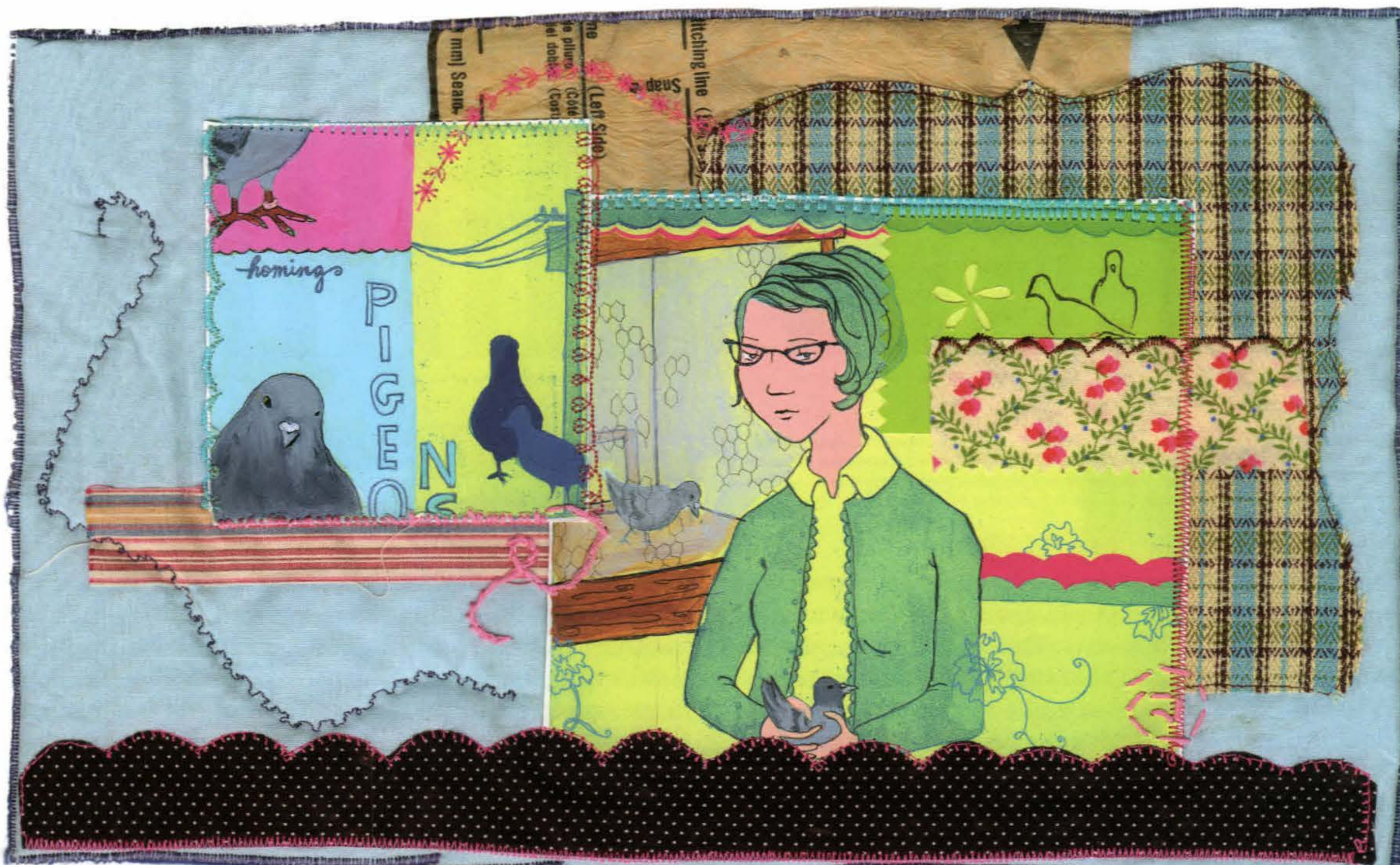
HOMING PIGEONS

BY CAROLINE HWANG



Homing Pigeons
mixed media, 9.5" x 15"
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Caroline Hwang
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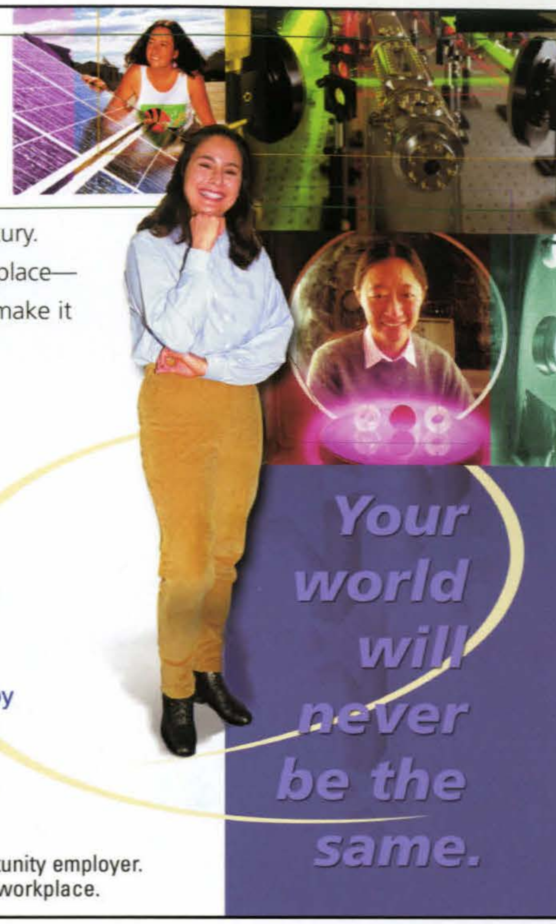

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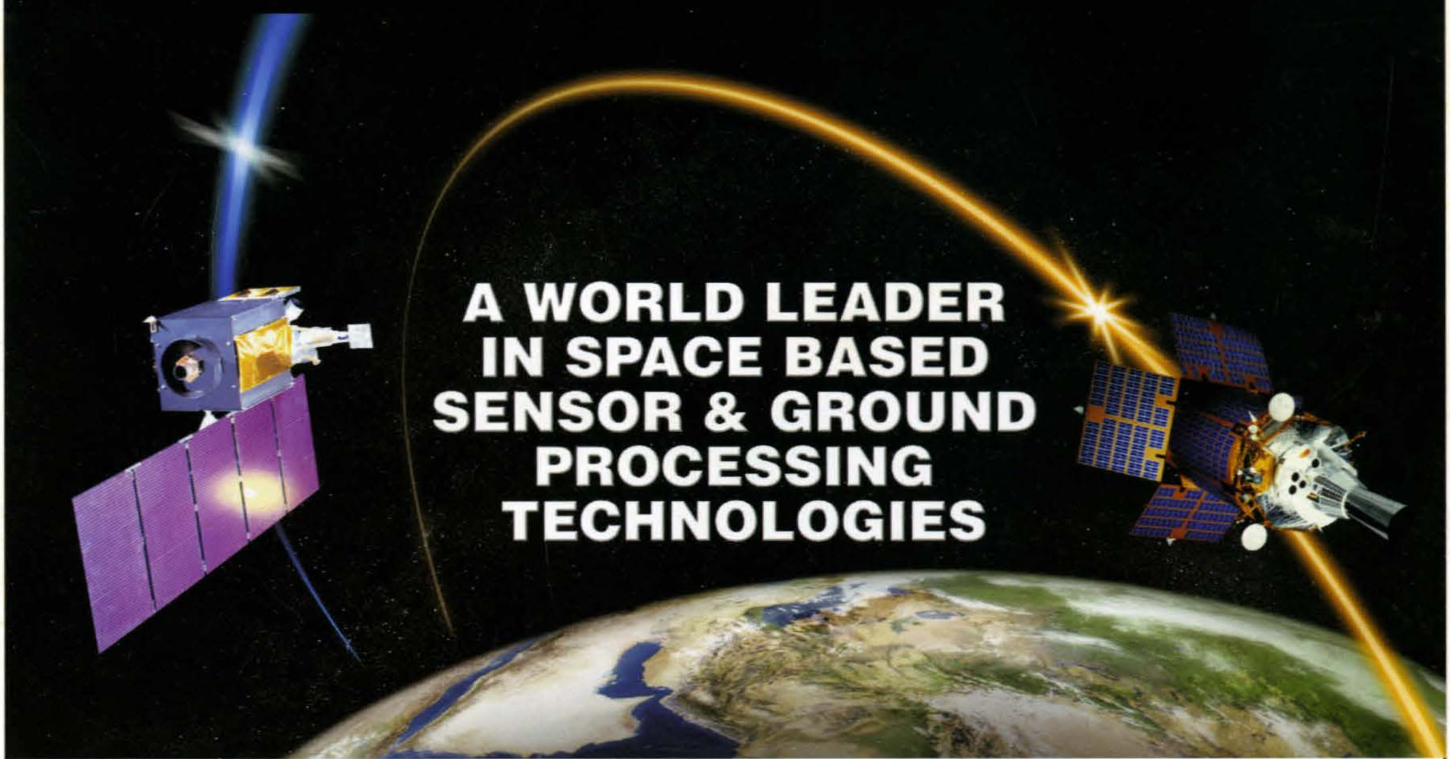

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