

## Adding Art to the Rigor Of Statistical Science

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About a decade ago, in the mountainous Grampian region of Scotland, a team of medical researchers began studying a drug meant to help people survive a heart attack. Doctors would give the drug, called a clot-buster, to some patients before they had even reached the emergency room and then compare their survival rate with that of patients who had not taken the drug.

The results were astonishing. In a paper published in *The British Medical Journal* in 1992, the researchers reported that the drug had reduced the death rate of heart attack victims by about 50 percent. The sample size was small -- about 300 patients -- and the Grampian region was remote, meaning that it often took patients more than an hour to get to a hospital. Still, the results suggested that the clot-buster might be more effective than almost any similar drug to come before it.

A pair of British statisticians were skeptical, however. "The amount of data wasn't that overwhelming," said Stuart Pocock, one of the pair and a professor at the London School of Hygiene and Tropical Medicine. "So there was a residual doubt: was it too good to be true?"

To test their doubt, Mr. Pocock and his colleague, David Spiegelhalter, reached back two and a half centuries to a mathematical technique devised by a Nonconformist minister named Thomas Bayes who died before his seminal paper was ever published. Bayes's formula allows scientists to combine new data with their prior beliefs about how the world works. It is an idea that amounts to heresy in much of the statistical world. After all, the method requires individuals to make subjective decisions about how strongly to weigh prior beliefs. As a result, many scientists say it sullies pure data with bias and outside information.

But its adherents, who call themselves Bayesians, argue that the formula is an extraordinarily powerful tool that permits scientists to keep new information in the proper perspective. If a study, even a statistically significant one, suggests that pigs can fly, Bayes's theorem allows researchers to combine the study's results mathematically with hundreds of years of knowledge about the travel habits of swine.

Sure enough, when Mr. Pocock and Mr. Spiegelhalter analyzed the Grampian results in the context of other work on clot-busters, they found that the drug was likely to reduce mortality by about 27 percent, not 50 percent. They sent a letter with their findings to *The British Medical Journal*, and, as is the case in many academic debates, the matter seemed to end there.

Then, in May of last year, *The Journal of the American Medical Association* published a review of many studies on the clot-buster. It concluded that the drug seemed to reduce death by about 17 percent -- far closer to the professors' results than to the Grampian study's.

Bayesians around the world rejoiced. "It's a real-life example," said Robert A. J. Matthews, a physicist at Aston University in Birmingham, England, who gave a lecture on the Grampian case this month in Vienna. "People couldn't say, 'Well, you just altered your prior beliefs until they matched what we now know is the truth.' "

The victory may have been a small one in the struggle of Bayesian academics, but it came when Bayes was gaining a devoted following, particularly among many of the world's largest companies. With computers far more powerful than they were even a decade ago, the intricate calculations required for many Bayesian problems no longer seem so daunting.

As a result, Pfizercoei, the pharmaceutical company, is melding existing knowledge about broad drug categories with results from early animal tests to design optimal drug trials for human beings. Microsoftcoei has created a Bayesian computer program that can analyze incoming e-mail and phone calls to determine which are urgent and which can be temporarily ignored.

And a small British company called Autonomy, whose founder wrote his doctoral thesis on Bayesian methods, sells software that helps computers intelligently sort through the vast amounts of information that large organizations now produce on any given day. Autonomy's clients include the United States Departments of Defense and Energy, General Motors, Procter & Gamble and the Knight-Ridder newspaper chain.

Even in academia -- where the method remains the exception to the classical, or "frequentist," statistical approach -- it has gained some footholds. Astronomers have used it to estimate what faraway stars look like. Some philosophy classes include units on Bayesian theories. And last year Boise State University opened a center for the study of Bayesian methods.

At the core of Bayes's long-delayed popularity is an admission that the world is rife with uncertainty and often not suited to clean statistical tests. When repeated experiments are not feasible, Bayesians believe, sweeping generalization should not rest on a small amount of new data. Instead, they want to bring to bear knowledge that people have accumulated over many years, assign a weight to each part of that knowledge and then consider the new data.

When the new information is both strong and widespread, it overwhelms the old consensus. But when a relatively small amount of data contradicts a wealth of prior knowledge, the old consensus changes only slightly. "What Bayes says is, 'You're making outrageous claims here -- you're going to need outrageous evidence to back that up,'" said Mr. Matthews.

Think of how you might estimate the average weight of a potato. A Bayesian would combine a sample taken from a local vegetable stand with the expert opinions of food researchers. A frequentist statistician, on the other hand, would want to look only at the sample data -- and reserve judgment unless the sample was large enough.

"The Bayesian will say, 'I essentially have a larger sample,' and the non-Bayesian will say, 'You have a biased result,'" said Judea Pearl, a computer scientist at the University of California at Los Angeles.

A Bayesian might also be willing to stretch the limits of statistics and estimate the odds that Al Gore will run for president again in 2004, said Michael I. Jordan, a professor at the University of California at Berkeley. The Bayesian would study the behavior of past nominees who have lost close elections and would analyze Mr. Gore's recent fund-raising behavior.

The result of a Bayesian calculation is usually not a single number but a series of probabilities. "Part of the Bayesian spirit is that you always have uncertainty about everything," Mr. Jordan said, "and you always want to report your uncertainty."

In many ways, the approach is similar to a thought process that people use every day. When walking in a city, they decide when it is safe to cross a street based on the cars they see (the new data) and what they know about traffic flow (their prior beliefs). When fixing a broken refrigerator, they combine information about a leak they can see with their accumulated knowledge about what tends to malfunction in the appliance.

"Subconsciously, the human brain does a lot of this Bayesian processing without us realizing it," said Dr. Mike R. Lynch, the chief executive and founder of Autonomy.

To many scientists, however, the intuitive nature of Bayesian methods adds little to their appeal. In fact, the scientists say, by assigning mathematical weights to somebody's subjective beliefs, Bayesians corrupt the data they are working with. "The frequentist would say it's better to have no answer at all than one you can't have confidence in," said Richard Lowry, a psychologist at Vassar who is skeptical of Bayesian methods.

In this way, Bayes's theory is both conservative and radical: conservative because it tends to cast doubt on unexpected findings and radical because it questions the orthodoxy that each experiment should stand on its own. And in its duality, the idea is a fitting testament to its inventor.

Born in London in 1702, Thomas Bayes followed his father, Joshua, into the ministry. Both were Nonconformists, and one of the few works Thomas published during his lifetime was a defense of Issac Newton against a bishop who had attacked the logic of his calculus, according to the Encyclopaedia Britannica.

Thomas Bayes was successful enough as a mathematician to win election to the Royal Society of London, but he would be long forgotten today had it not been for a friend and fellow minister named Richard Price, who inherited Bayes's papers when he died in 1761. Mr. Price, himself famous for devising one of the first actuarial tables, came across the "Essay Towards Solving a Problem in the Doctrine of Chances," and in 1763 the Royal Society published it.

Statisticians have long recognized the rule's importance, and some high school classes use it to solve straightforward probability problems. But once both data and beliefs enter the picture, the math can become stupefyingly complex. Over the last 10 or 15 years, however, computers have become powerful enough to handle Bayesian calculations with relative ease, and the method has won a following. "We now have the tools," said Dr. Andy P. Grieve, a senior statistical consultant at Pfizer. "We are able to use Bayesian methods."

Indeed, some of Bayes's biggest fans can, like Dr. Grieve, be found in the corporate sector. For example, the NCR Corporation, which makes A.T.M.'s and bar-code scanners, and a consortium of big banks run a research center in London that is trying to use Bayesian methods to figure out which loans or investments different types of people are most likely to want.

Few companies are making a bigger push than Microsoft, which is trying to design software that would become a virtual secretary. The software, now being tested, combines facts about who has sent an e-mail message and the words it contains with information about a user's habits. The program then decides whether the user can wait a few minutes, or even hours, to see the message.

"We want to understand how to work with people in the way an insightful colleague would," said Dr. Eric Horvitz, who oversees a team of 20 researchers at Microsoft. "We're still a ways off from that, but that's the goal."

All this effort springs from an essay that is older not only than Microsoft or the computer itself but the United States or the harnessing of electricity as well. As Dr. Lynch said, "It's taken 250 years for the rest of us to realize just how intelligent Thomas Bayes was."