Murphy's Lab

By IVARS PETERSON

Perils and potholes on the road to true data

"... when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."
— William Thomson, Lord Kelvin

"If anything can go wrong, it will."
— Murphy's Law

The minute you think everything is under control, beware. Murphy lurks nearby, ready to meddle.

That's the moment when a sensor that has performed reliably through innumerable experiments will suddenly malfunction. When spurious electrical signals will surreptitiously creep into a stream of hard-won data. When a long-overlooked hardware quirk or software glitch will triumphantly proclaim its presence.

Such are the perils of experimental and observational science. Each measurement, dutifully recorded and elegantly displayed by a diligent computer, serves not only as a probe of the unknown but also as a testament to Murphy's ubiquity.

"I and my colleagues have been implacable foes of Mr. Murphy," says physicist Lawrence G. Rubin of the National Magnet Laboratory at the Massachusetts Institute of Technology.

But decades of experience suggest that no matter how much care someone may take to avoid Murphy's meddling, Murphy will find a way. "He's always going to win in some cases," Rubin insists. "All you can do is hope it doesn't happen too often."

And, as instruments become more sophisticated and technology more complicated, Murphy finds new playgrounds in which to show off his ingenuity and exercise his unique skills. "It gives him the chance to dream up things that we never knew about before," Rubin says.

Alas, too many researchers — both novice and experienced — no longer appreciate well enough the numerous ways in which data can be corrupted as signals pass from sensor to meter to computer. The crisp displays of digital electronic instruments and the breathtaking number-crunching, data-manipulating capabilities of computers distract them from questions about the quality of the original signals.

Many researchers no longer have first-hand knowledge of when to be skeptical of their measurements and when to trust them. Not so long ago, a scientist or technician would sit in front of a meter, patiently recording sequences of numbers in a notebook (or on the indispensable scrap of paper towel). It was possible to see directly when the meter had settled down, whether the signals made sense, whether any glitches or unexpected events occurred. Nowadays, inscrutable electronic boxes automatically convert analog signals into sequences of digits and send them to computers — with nary a researcher in sight.

And it is at the frontiers of research — at millikelvin temperatures, nanometer dimensions, kilogauss magnetic fields and giga-electron-volt energies — that it's easiest to fall into Murphy's traps. In these situations, experience gained at less extreme conditions may no longer apply.

Concerns that physics students and others no longer take Murphy seriously enough prompted Rubin, Scott T. Hannahs of MIT and Bruce L. Brandt, now at Florida State University in Tallahassee, to develop a tutorial on measurement technology in the laboratory. Presented last month at an American Physical Society meeting in Indianapolis, their tutorial carried the subtitle, "How to Give Murphy a Run for His Money."

Rubin and his colleagues belong to a group within the American Physical Society dedicated to promoting the cause of careful measurement in physics.

Switch on a power supply, and the momentary electrical surge that results can show up in a nearby data-conveying cable. Operate a television camera, and its characteristic frequencies can leak into electrical leads. The inevitable result of a highly electrified world, electromagnetic interference caused by alternating or fluctuating currents creates one woe after another.

Such problems are nothing new to experienced experimenters. Over the years, they have developed sophisticated means of filtering out unwanted signals, or they have learned to avoid making measurements when and where certain types of interference are likely to occur.

"It's always there, and we're always trying to beat it," Rubin says. "Murphy comes in by producing interfering signals that happen to arrive at the same time or at the same frequency as what you're looking for."

A classic example of what can go wrong occurred in early 1989, when astronomers thought they had detected the precisely timed flashes of light coming from a rapidly rotating neutron star in the remnant of supernova 1987A. To identify the pulsar's minute fluctuations in brightness, the astronomers used a sensitive, telescope-mounted detector to collect visible and infrared light from the supernova. The brightness data, recorded on magnetic tape, were then analyzed with a supercomputer at the Los Alamos (N.M.) National Laboratory.

The researchers focused their attention on extracting any faint signals that occurred at a fixed frequency — the output expected from a pulsar. In this way, they could eliminate any interfering sources of electrical noise, generally characterized by erratic or varying signals. Among the more notorious culprits were television cameras used to monitor telescope operations.

"[Electromagnetic interference] is a common problem and always a considerable worry," says team member Jerome Kristian of The Observatories of the Carnegie Institution of Washington, based in Pasadena, Calif.

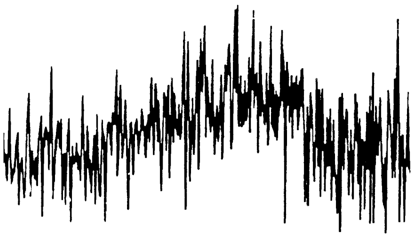
The first indication that there was something unusual about an observing run conducted on Jan. 18, 1989, at the Cerro Tololo Inter-American Observatory in Chile came about three weeks later while the astronomers were analyzing the collected data. The team found evidence of a faint signal that they could plausibly attribute to a pulsar — a signal at a frequency of 1968.627 hertz, which remained remarkably stable for nearly seven hours.

"What caught our attention was that it was so unusual," Kristian says. "We hadn't seen anything like it before."

It was also suspicious, and the astronomers spent several weeks checking for contaminating signals and making new observations. But the mysterious signal failed to reappear. "Nobody was ever really comfortable with the data, but finally it seemed irresponsible not to publish," Kristian says.

A year later, the astronomers at last saw a similar signal — in data from supernova 1987A *and* in data from a different pulsar in the Crab nebula. The signal couldn't have originated in the supernova.

A number of clues pointed to a particular television camera as the culprit. The observed frequency was very close to a



subharmonic of the camera's scanning frequency — a signal supplied via a high-voltage cable running from the power supply to the camera itself. Moreover, a detailed analysis of the original signal had already revealed puzzling shifts in intensity that couldn't be explained satisfactorily in terms of pulsar dynamics.

Normally, the television cameras used interchangeably at Cerro Tololo generate a broad spectrum of contaminating signals that tend to fluctuate and wander — quite unlike the steady signal expected from a pulsar. One particular type of camera, however, had a surprisingly accurate internal clock. It was one of these cameras that was operating during the fateful run.

This camera produced extraneous signals that were somehow picked up by wires connected to the detector. "When you dangle a thick cable carrying 30,000 volts ... nearby, no matter how well shielded, you'll eventually pick up a signal," says John Middleditch of Los Alamos.

Ironically, to protect this camera from exposure to light with the approach of dawn, Middleditch switched it off. "I didn't have to do that, but I was being careful," he says. Later that night, observations of a globular cluster revealed no special signal, seemingly confirming the pulsar's discovery.

The astronomers lost any chance of pinpointing the problem quickly when the suspect camera apparently went into temporary storage soon thereafter. No one ever bothered to keep track of which particular cameras were in use at any given time.

Repeated searches turned up no further signals until January 1990, when the astronomers detected an extraneous 7,874-hertz signal — at precisely four times the frequency detected a year earlier — in supernova data collected at the Las Campanas observatory, which had similar television cameras. The signal had to be spurious because no conceivable pulsar could ever spin this fast. A month later, a signal at the originally detected frequency showed up in all observations at Cerro Tololo. The errant television camera was back.

"All this was undoubtedly a combination of bad luck (or divine malice), misplaced pattern-finding skills, and the common human tendency to overinterpret a limited amount of data," Kristian and his collaborators wrote in a letter published in the Feb. 28, 1991 NATURE withdrawing their original finding.

Intermittent faults can be particularly frustrating. "Whether you're trying to fix a TV set or do an experiment, an intermittent [signal] drives everybody up the wall," Rubin says. "It doesn't happen frequently enough for you to track down its source, but when it comes up, Murphy's Law makes sure that it always happens at the worst possible time during an experiment."

In addition, nature often conveniently supplies a variety of contaminating signals or noise — at no extra charge. In condensed-matter physics, for example, experimenters fret over electrical signals generated by the unceasing movement of atoms and ions or by voltages induced whenever dissimilar metals touch.

"You have to worry about any connection between two pieces of wire," Rubin notes. "When you're looking at a sample, you don't want the contact itself producing unwanted signals."

The inevitable tangle of wires linking sensors, amplifiers, signal processors and computers supplies additional opportunities for Murphy's shenanigans. Rubin and his colleagues, for example, routinely twist complementary pairs of wires into tight coils to reduce the chances of picking up stray electromagnetic signals.

Although researchers generally know better than to create a rat's nest of wiring, they sometimes forget that instruments neatly connected by ribbon cables, which consist of separate wires permanently bundled together, may still be vulnerable. Unless the appropriate pairs of adjacent wires are somehow twisted together, these cables can also readily pick up spurious signals.

Even the smallest extraneous influences can affect an experiment. "When you're working at a microkelvin, it doesn't take much to disturb the experiment," Rubin comments.

The tortuous path from sample to computer is strewn with obstacles to true data. Each piece of electronic equipment along the way imprints its own idiosyncrasies on the signals that pass through.

One step often fraught with problems involves the conversion of a continuous analog signal coming from a sensor into a sequence of digits that a computer can manipulate. How well the digital data capture the analog waveforms depends on the quality and speed of the electronic equipment used to make the conversion.

But many researchers remain unaware of the limitations of the electronic equipment they use. "You need to do a certain amount of detective work to find out how [an instrument] works," Brandt says.

Yet Murphy makes sure you can't always trust the manuals either.

And you shouldn't rely on the computer to smooth away problems, Hannahs says. "You can't make up in software what you've already blown in hardware."

"It's always easy to collect garbage, and you can do it even faster with a computer," he adds. "Devote your resources to acquiring good data to start with."

Not every experiment requires such extreme care. "Lots of experiments are fairly easy to do, which means Murphy doesn't get in as often," Rubin says. "But sooner or later, you're going to run into a problem. Worse, you may not even know it happened, and as you continue taking data, it never occurs to you that all the digits in the computer don't mean a thing."

Fiendishly erudite, Murphy can also call upon unfamiliar or previously unknown physical effects to do his bidding.

Normally, researchers can assume that immersing a sample in a boiling liquid means that both sample and liquid will stay at the same temperature. So long as it remains in the liquid, there's no way the sample can be at a higher temperature.

But that's exactly what MIT researchers were astonished to find several years ago when they placed a sample in a liquid-helium bath. Surrounded by a hefty magnetic field, the sample's temperature rose as high as 6 kelvins above helium's boiling point of 4.2 kelvins.

"It took a lot of effort to figure out what was going on," Rubin says.

Bubbles form naturally within liquid helium and generally rise to the surface. However, the applied magnetic field exerted a greater force on gaseous helium than on the liquid. As a result, bubbles tended to collect at the magnetic field's center, where the sample was placed. Because a gas conducts heat less readily than a liquid, the gas layer trapped around the sample acted as an insulator and the sample's temperature rose.

"Conditions had to be special to create this particular problem. It took a very high magnetic field," Rubin says.

"Murphy found the loophole," he notes with grudging admiration. "Now *there's* a genius."

Researchers are constantly battling Murphy. Whether measured in megamurphies for colossal blunders or mere nanomurphies for everyday annoyances, such glitches remain a fact of life in experimental science.

"It amazes me that science copes with it as well as it does," Kristian says. "I'm surprised people don't get stung more often, particularly in difficult experiments. That speaks very well for the way people really do science."

Indeed, Murphy serves as a persistent prod, constantly pushing scientific research and technological development to new levels in efforts to overcome the obstacles he tosses in their way. □