Forensic scientists are equipping police investigators with powerful tools for collecting and analyzing evidence. Whether some techniques infringe on civil liberties is a matter for public debate

A New Breed of High-Tech Detectives

HIGH-TECH DETECTIVES

This special focus peers over the horizon at the technologies that promise to transform crime solving.

▶NEW TOOLS

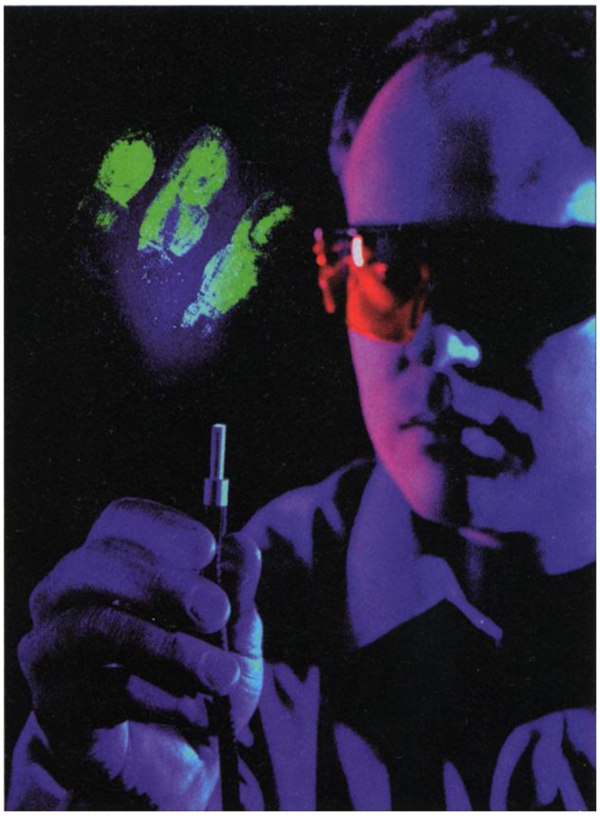
BODY CHEMISTRY

On an early spring day in April 1999, police in Albuquerque, New Mexico, found Stephanie Murphy's body wrapped in a sheet on the back seat of her car. Catherine Dickey, a forensic scientist on the force, suspected that the murdered 37-year-old had been sexually assaulted. Finding evidence for such a crime would be difficult, however. Murphy's body had been shut in the car in the hot desert sun for a few days, so any semen left on or around the body would have started to break down. "They knew that in that advanced state of decomposition they'd have a hard time finding any kind of evidence of a sexual assault," says Colin Smithpeter.

Smithpeter thought he might just be able to help. He and his colleagues at Albuquerque's Sandia National Laboratories are developing a unique camera designed to uncover just the sort of hidden evidence that the police were hunting for. Smithpeter met Dickey at the morgue, where she went to work examining the body with a blue light and tinted goggles, searching for traces of semen that would fluoresce in response to the lamp. She found nothing. Then Smithpeter unveiled his camera, which detects and processes faint glows that are elicited by an intense beam of blue light. The camera picked up three tiny stains on Murphy's skin. One turned out to be dried semen, a later lab test showed. The residue was shipped to the New Mexico state crime lab for DNA analysis, in anticipation that the killer had left behind a biological calling card.

Murphy's killer remains at large, but at least investigators now have something to go on. "No criminal is so clever that he or she never leaves a trace," says Edward Crew, chief of police in Birmingham, U.K. That's the guiding principle of forensic scientists, who are developing a cornucopia of techniques for detecting and analyzing elusive shards of crimes. Most of the new tools have grown straight out of basic research. Confocal microscopes, for example, can reveal idiosyncrasies in handwriting, while chemistry labs can sniff out molecules of naphthalene and other combustion products in a spent shotgun cartridge, offering a means of determining when a gun was fired even days later. Computer software can now calculate the exact position of a victim's body by reconstructing the trajectory of a spray of blood on a wall. And sophisticated databases can store vast amounts of information and search for unforeseen clues and connections between cases.

No area of forensics, however, can boast more progress than DNA profiling, itself a product of the revolution in genetics research over the past couple of decades. Single hairs and specks of bodily fluids can provide enough DNA to help pin a crime on—or clear—a suspect. And handheld DNA devices, laser scanners, and digital cameras could soon bring the forensics lab to the crime scene, beaming back evidence to databases that could become Orwellian in scope, containing information on every one of us.



Incriminating smudges. A Sandia National Laboratories researcher examines fingerprints under blue light as part of a project, run by the lab's Colin Smithpeter, to find vital evidence without the use of powders and other more intrusive forensics tools.

CREDIT: C. SMITHPETER/SANDIA NATIONAL LABORATORIES

Leading the way to a technology profusion that would surely astound even Dick Tracy are a handful of outfits throughout the world, including the FBI, the U.S. National Institute of Justice (NIJ), the U.K.'s Forensic Science Service (FSS), and the U.S. national laboratories. Their influence on crime solving will only grow, insiders say. "There is still a huge amount of untapped potential in the use of forensic science to fight crime," argues FSS research director Trevor Howitt.

But as the O. J. Simpson case and recent pretrial hearings on the admissibility of expert testimony warn, these fancy new techniques can be vulnerable to challenge in court. Some developments are also raising civil liberties concerns. And as detection techniques become increasingly sensitive, the problem of sifting the wheat from the chaff at a crime scene mushrooms, guaranteeing a role for the human investigator despite all the gadgetry.

The DNA revolution

When Ronald Keith Williamson found himself a free man in early 1999, he had his genes and molecular biology to thank. Eleven years earlier, Williamson had been convicted of the 1982 rape and murder of Debra Sue Carter in Ada, Oklahoma. Recent DNA testing of hair and semen found at the crime scene failed to link

Williamson (or a second man charged) to the crime. But the DNA did implicate a former suspect in the case. Williamson is one of eight people to be freed from death row so far in the United States on the strength of DNA evidence.

DNA profiling is a powerful technique for gauging the likelihood that a biological sample, such as blood or semen, came from a specific individual. In Williamson's case, the analysis belatedly ruled him out. The technique is the jewel in the crown of modern forensics. "That's the main area where we have really advanced in the past several years," says Joe DiZinno, scientific analysis section chief of the FBI Laboratory in Washington, D.C. The use of profiling to identify suspects was pioneered by geneticist Alec Jeffreys of the University of Leicester, U.K. His approach, called multilocus profiling, used restriction enzymes to cleave the DNA at specific sites. The resulting fragments differ in size from person to person, as revealed by gel electrophoresis, in which fragments of different masses migrate at different speeds when subjected to the pull of an electric field. That was 1985, when a single, relatively large specimen took weeks to process and yielded a barcodelike output that was difficult to compare to other DNA samples.

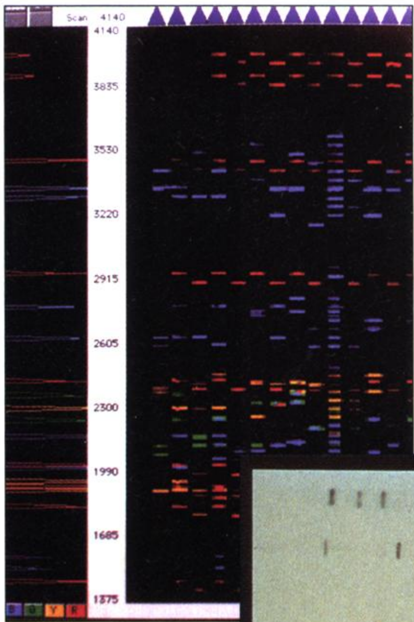
Modern profiling relies on short tandem repeat (STR) analysis, which debuted in the forensics world in 1994. This technique looks at specific areas of DNA molecules containing simple blocks of base pairs; the blocks are repeated end to end. The number of occurrences of each block, or repeat unit, varies by individual. Examining several DNA regions, or loci, and counting the number of repeated units in each area generates numbers that form a molecular label of the DNA's owner. STR analysis as it's used for DNA profiling relies on the polymerase chain reaction (PCR)—"the cornerstone of the whole process," says Bruce Budowle of the FBI in Quantico, Virginia —to make millions of copies of the selected STR regions. The resulting DNA fragments are then sized up by gel electrophoresis, which yields the number of times each repeat unit appears in the fragment. This gives the DNA profile as a numerical tag for easy database comparison.

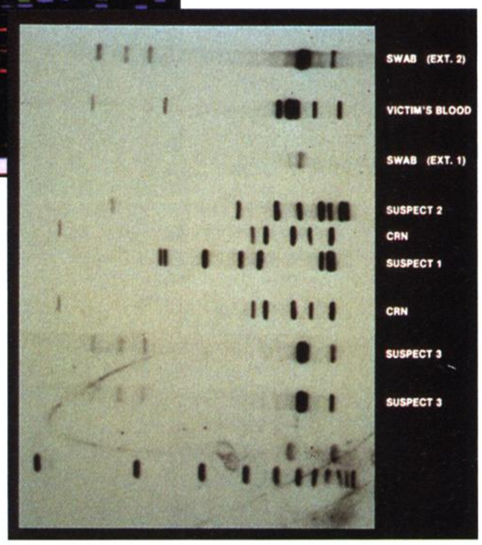
The latest variation on the technique, introduced in Britain in mid-1999, targets 10 DNA loci—enough to guarantee that the odds of someone else sharing the same result are slimmer than one in a billion. Chance matches are even less likely in the United States, where the FBI routinely examines 13 STR sites. "The chance of two [unrelated] individuals on average having the same DNA profile is about one in a million billion," claims Budowle.

Thanks to PCR, today's routine work needs genetic material from a mere 600 cells containing about a nanogram of DNA; a speck of blood just 2 square millimeters in size will do nicely. Such sensitivity permits scientists to type DNA from, say, the mouth area of a mask tossed away after a bank heist, cigarette butts, or licked postage stamps on envelopes. The FSS "had a case where a guy picked up a brick and threw it through the window of a liquor store, and off the brick they picked up his DNA profile," says geneticist Keith McKenney of George Mason University in Fairfax, Virginia. In another case, a discarded match supplied enough damning DNA. In these instances, saliva or dried blood didn't provide the smoking gun. Every 24 hours the cornea is replenished, and the dead cells are sloughed off into tears. By rubbing their eyes, the brick throwers and match users could have transferred these or other cells to their fingers, regularly reloading the DNA pen that left their telltale signatures.

As powerful as DNA evidence is in court, forensic scientists are hoping to make it even more useful to crime investigators by providing them with the tools to infer suspects' physical characteristics. Geneticists can assess the likelihood that a person is a redhead simply by testing for mutations in the gene for the receptor for a hormone that spurs production of the pigment melanin. Ethnicity can be inferred from the frequencies of alternative forms, or alleles, of genes; allele patterns differ by racial origin. And the FSS is backing research at University College London's Galton Laboratory on the genetics of facial shape. A noble Romanesque profile or deeply cleft chin could be a villain's downfall. "All facial characteristics are on the agenda," says FSS molecular biologist Gillian Tully, who acknowledges the huge challenge of deciphering the genetics of such traits, many of which are the products of several genes. Nevertheless, she says, "within 10 years we might be looking at genetic tests for the basis of the main facial characteristics like, for example, nose, chin, and forehead shape."

The FSS is also exploring the use of genetic markers called single-nucleotide polymorphisms, or SNPs, for DNA analysis. SNPs—individual base pairs of the DNA molecule that are known to vary between individuals—are hot items for tracking down disease genes and determining a patient's potential reaction to experimental drugs (*Science*, 17 March, p. 1898). Although it would require about 50 SNP sites to achieve the same level of confidence as with STR analysis, SNP analysis holds a trump card: easy miniaturization, which means faster processing. Indeed, researchers and biotech





Evidence of progress. Today's DNA profiling using short tandem repeats *(top)* owes its existence to the pioneering multilocus profiling approach.

CREDITS: (TOP TO BOTTOM) BRITISH FORENSIC SCIENCE SERVICE; COURTESY OF CELLMARK DIAGNOSTICS INC., GERMANTOWN, MARYLAND

companies are already developing rapid SNP identification techniques. "The potential exists to analyze several hundreds or even thousands of samples on a single microscope slide–sized device," says Tully. Complementing such a SNP lab on a chip would be miniaturized setups for extracting and amplifying DNA.

FSS chief executive Janet Thompson and others envisage technology, including handheld forensics devices, that can be brought to a crime scene and transmit data to a central facility for onsite analyses. Experts are debating how far down this track investigators should go. "I'm not so sure how desirable that is," says DiZinno. He argues that evidence is better analyzed in a lab environment to avoid contamination of samples with extraneous DNA. Population geneticist

Lisa Forman of the NIJ in Washington, D.C., agrees: "Although there may be a place for some onsite analysis at the crime scene, nothing will replace the laboratory bench," she says, "because the kind of care and control that can occur at a laboratory bench is crucial for forensic evidence." Budowle has another concern: "You don't want the police taking over that analytical process, because, remember, there's the whole interpretation of the results. Then when it goes to court, suppose there's a challenge on the evidence. Is the police officer going to go in and defend that challenge?"

All in the family

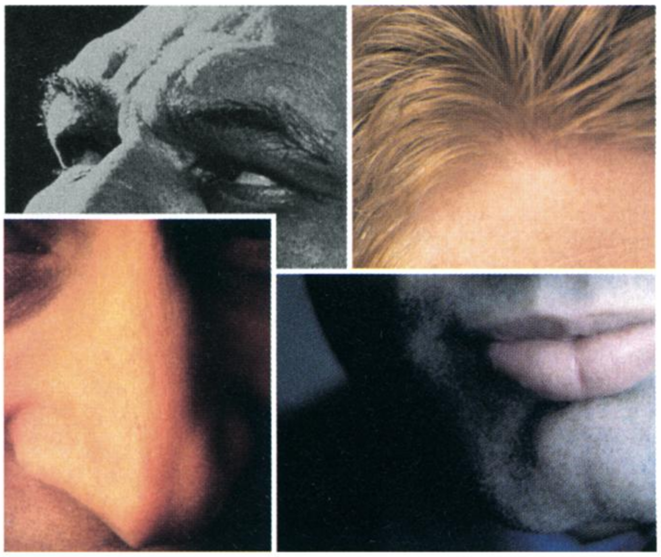
The DNA profiling that links dresses to presidents and Coke cans to cokeheads relies on DNA from the cell nucleus. A new star in the firmament for U.S. forensics efforts is the DNA present in mitochondria, the cell's powerhouse.

At first glance mitochondrial DNA (whose forensic potential was pioneered in the United Kingdom) may seem like an odd tool. It offers less variety than nuclear DNA and is less discriminating, because the same sequences are passed from one generation to the next from mother to child, via the egg. Brothers and sisters, for example, share identical mitochondrial DNA. More than compensating for these shortcomings is that "there's probably 10,000 times as much mitochondrial DNA as there is nuclear DNA," says McKenney. "In a sample that's aged or degraded, it's quite common that the nuclear DNA has been degraded beyond the point of recovery, and yet there is mitochondrial DNA that can be recovered."

For this reason mitochondrial DNA is associated with some of the glitzier results in DNA analysis. It has been extracted from 100,000-year-old Neandertal remains, has linked the 9000-year-old remains of "Cheddar Man" to a relative living today just down the road in Cheddar, England, and has identified the remains of Tsar Nicholas II based on similarities in the mitochondrial DNA of a close relative, Britain's Prince Philip.

"The forensic application of mitochondrial DNA comes from the hair and fiber folks," says McKenney. Hairs are often found at crime scenes. Although the fleshy root of a plucked hair contains nuclear DNA suitable for STR analysis, the shaft does not. It's possible, however, to grind up the hair shaft, copy the mitochondrial DNA using PCR, and sequence it. The FSS used mitochondrial DNA analyses to identify remains recovered from the Paddington rail disaster in London last year, by matching samples with DNA profiles of the victims' relatives.

Although mitochondrial DNA can't conclusively link an individual to a crime, it can point a finger at a family, explains McKenney, who has employed similar analyses to study the familial links of 500-year-old Inca mummies. And that, he says, beats the more traditional and "somewhat subjective" microscopic comparison of the physical characteristics of crime-scene hair.



Telltale features? Sifting DNA samples for genes linked to prominent facial features could trip up a fugitive with a memorable look.

CREDITS: (HAIR AND CHIN) DIGITAL IMAGERY PHOTODISC INC.; (NOSE) S. MCALISTER/IMAGE BANK; (EYES) RIPLEY ENTERT/IMAGE BANK

The value of establishing family ties is not lost on missing-persons investigators. "Many people who have disappeared, or died, or whatever, didn't bother to leave a nice, clean sample of their DNA," says McKenney. "So what you can do is, you can go to any one of their maternal relatives and get the same mitochondrial DNA." The new FBI missing children's initiative, planned to come online at the start of 2001, will focus on gathering relatives' mitochondrial DNA. Samples from missing children (or their remains) recovered later would be compared to the relatives' DNA. "That's an example of how mitochondrial DNA is now, I think, ready for prime time," says McKenney.

Also making mitochondrial DNA more attractive to forensics investigators are new methods for quicker and cheaper sequencing. Tully helped develop a technique called minisequencing. "When you're sequencing, you look at something like 780 bases of the mitochondrial DNA," she says. "When you're minisequencing, you're looking at 12, but you're looking at 12 of the bases that are most likely to differ between individuals." This approach can slash the time it takes to get results from a batch of mitochondrial DNA samples from 3 months to 3 weeks. That's still ages compared to an STR analysis, which requires about 24 hours, but it provides a quick and dirty means of eliminating scores of potential suspects from an inquiry involving, say, a single hair at a crime scene. Or following a rape, it saves time being able to identify which hair needs to be sent for a more thorough analysis. Minisequencing "opens up many more cases for mitochondrial analysis," says McKenney.

Chemical clues to killers

For all its power, DNA profiling can't nail all criminals: Not every crime scene throws up biological evidence. But forensic scientists are tapping into many other scientific disciplines. "The operative words are faster, better, cheaper," says DiZinno, borrowing a phrase from NASA.

The subjects of all this high-tech identification range from pen ink to automotive paints and explosives residues. Even duct tape, which is often used to bind victims or tape explosive devices in place, can help link a suspect to a crime. Researchers have developed a way to compare evidential duct tape to samples from known sources. The tape's adhesive has a characteristic chemical signature that allows a comparison between the questioned tape and known samples, as revealed by x-ray scattering or by a scanning electron microscope.

Non-DNA chemical analyses could be destined for the field as well. The Forensic Science Center at Lawrence Livermore National Laboratory in California is developing a portable combined gas chromatograph and mass spectrometer that can churn through 200 high-quality analyses in the field each day. A prototype weighing just 20 kilograms is already in the hands of the FBI. Livermore researchers are also pushing portable mass spectroscopy to new limits. In a system under development, a sample is placed on the tip of a probe and inserted into a chamber. A laser blasts the sample into ion shards that are penned in by the electrical fields of an ion trap. The ions are then kicked out of the trap by electric pulses into a time-of-flight mass spectrometer tube, which identifies them by mass. The device is well suited to detecting minute traces of airborne chemicals such as nerve gas, for example, or to analyzing the composition of a hair for the chemical residues of drug use.

Even the lowest of low-tech crimes are

getting high-tech attention. Forcing open doors and windows with a wrecking bar, for example, leaves gouges that can be matched with the tool that caused them. At the FSS's behest, Isomark, a company based in Nuneaton, England, developed a fine-grain silicon putty for taking casts of tool mark impressions. The impressions have a resolution of a tenth of a micrometer and can be scanned to create a digital image.

Which family's mummy? Mitochondrial DNA analyses, used to trace family ties of 500-year-old Inca mummies, will soon figure prominently in the FBI's hunt for missing children.

Standing in the dirt while levering open a window leaves a footprint—and telltale wear marks can point to the shoe's owner. Over the past year, Simon Bramble and his FSS colleagues have developed and patented a laser scanner for footwear marks, essentially an upturned flatbed document scanner with modified optics, held a centimeter above the footprint on three stubby legs. The scanner, which is making its debut at real crime scenes this summer, offers a number of advantages over old wet-film photography. "We can immediately see the result, so we are confident we have captured the mark," says Bramble. And besides sometimes being sharper, digital images can be transmitted immediately for comparison with a library of footwear marks, fingerprints, or tool marks.

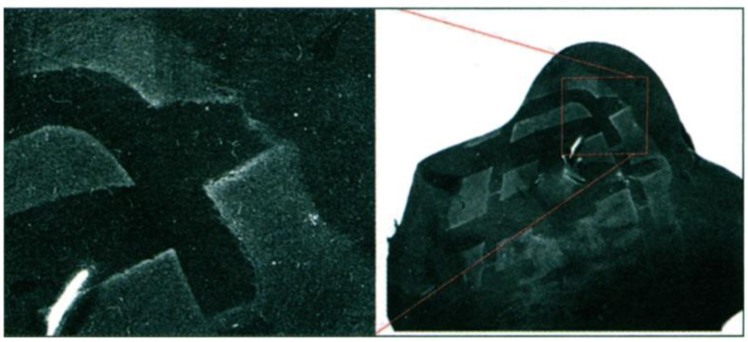
The analysis of rotting bodies is also yielding to modern science. A one-of-a-kind facility in Tennessee is developing biochemical profiles of human corpses as they decompose to help investigators determine how long a body has been lying around (see p. 855). Other teams are applying DNA analysis to a time-honored method for making such a determination: analyzing maggots from corpses. Because the life cycles of maggot species vary by season and time of day, the type of larvae gives clues to when, exactly, a victim died. But because the larvae of many maggot species look alike, forensic entomologists are forced to keep the larvae in jars until they metamorphose into adults and can be told apart (see NetWatch, p. 827). Now, DNA technology is poised to make maggot-filled jars redundant. "DNA profiles of the larval forms can be used to identify what those maggots are," says the NIJ's Forman, who says this approach has yet to be offered up in court.

CREDITS: (TOP) J. REINHARD; (BOTTOM) S. BRAMBLE

Fingering the criminals

Long before DNA profiling burst on the crime scene, police investigators nailed hundreds of thousands of suspects with a familiar forensic technique: fingerprinting. Now, this time-tested technique is itself coming under scrutiny. The renewed interest is coming in part from court challenges to fingerprinting evidence in the United States that, says Vivian Baylor of the national security program office at Oak Ridge National Laboratory in Tennessee, "have really got the fingerprint community in an uproar."

Renowned fingerprint expert David Stoney of the McCrone Research Institute in Chicago and others have argued that the technique for comparing fingerprints—homing in on variations in only a few of the whorls that make up a print—is arbitrary and therefore unreliable. In pretrial hearings held in separate cases in September 1999 and April 2000, defense lawyers used those arguments to try to prevent fingerprinting evidence from being introduced in trials. Both challenges failed, but attacks on fingerprinting evidence are expected to continue. "The bottom line with fingerprints is that they have been accepted forever," says Forman, but that "there is rather more limited scientific validation." A startled NIJ is currently inviting submissions for research efforts aimed at providing additional scientific support for fingerprint identification.



A single misstep. The FSS's new laser scanner allows for quicker comparison of physical evidence such as footwear marks.

As some experts try to shore up the identification of fingerprints, others are working to wring more information out of the oily deposits themselves. A 1993 case in Tennessee indicated just how much researchers had to learn. A 3-year-old girl had been abducted, raped, and murdered by a friend of the family. The killer confessed to the crime while under the influence of drugs and alcohol, but when he dried out he denied it all. That forced Knoxville, Tennessee, police to turn to the physical evidence. They were certain the child had been in the suspect's car, but dusting revealed no sign of her fingerprints. Puzzled, police forensic scientist Arthur Bohanan made a surprising discovery: Children's fingerprints evaporate quickly. To help figure out why, he approached colleagues at the nearby Oak Ridge National Laboratory. There, Michelle Buchanan and her team discovered that the sebum exuded from the skin of children younger than about eight is laden with more volatile components than adult sebum. Thus a child's fingerprint vanishes quickly, sometimes in hours.

The Oak Ridge team's studies have also suggested that fingerprints could provide more information than simply patterns of whorls. Their gas chromatography and mass spectrometry analyses revealed traces of estrogen in prints left by women and testosterone in those left by men, suggesting the ability to distinguish fingerprints by sex. And prints left by a smoker revealed traces of nicotine metabolites, raising the prospect of fingerprint analysis for metabolites of drugs such as cocaine, Baylor says.

Finding fingerprints can be a problem, however: Dusting works well only for fresh prints on smooth surfaces. Thus one challenge is to extend the repertoire of surfaces from which a fingerprint can be extracted—getting a print off toilet tissue, for example, is very difficult. Another is to unravel old, overlapping prints and ascribe dates to each, something that remains a pipe dream. A common trick for making prints visible is to fix them with superglue vapor (cyanoacrylate) before using high-energy blue lighting to view them. Apart from the fact that the trick fails in the dry heat of places like New Mexico, there are other problems. "First of all, you have to superglue the whole world, which isn't all that helpful for the people doing it, but second of all you also have to black out all of the ambient light," says Forman.

This is where Sandia's Smithpeter comes into the frame. His "multispectral" camera creates images of light emissions stimulated by a powerful blue light used to sweep a crime scene for fingerprints and other stains. The blue light triggers molecules in semen, saliva, or urine stains to fluoresce and emit light at a lower frequency, typically in the green-yellow range. The camera is fitted with filters designed to block out reflected blue light, but pass the fluorescent light through to a charge-coupled device (CCD) detector. The trick is to make the illuminating lamp flash on and off at a fixed frequency and to record at a slightly different frequency. Because the blue light is filtered out, most of the time the camera simply sees the ambient light. But every so often the camera is "on" at exactly the right moment to catch a glowing stain, which shows as a bright flash against the string of ambient light signals before and after.

An alternative to blue lighting would be to induce fluorescence with an ultraviolet or visible laser. A group led by John DiBenedetto at the Special Technologies Laboratory, a Department of Energy facility near Santa Barbara, California, is developing such lasers to pinpoint and image fingerprints and stains in ambient light. The team's approach is to exploit the spectral signature in the fluorescence coaxed from the sample by the laser light to identify it, then use a CCD camera to create a digital map of the stain.

Database indictments

On Good Friday of this year, a 23-year-old university student, Sara Cameron, was murdered in the Newcastle area of Britain. Her killer left behind just enough DNA at the crime scene for forensic scientists to build a profile of the unidentified male suspect. (Police are withholding other details on the nature of the evidence.) When their investigation stalled, they decided to do something drastic: take DNA samples from up to 10,000 men living in the area. British police cannot force the public at large to provide cell samples, but this has not inhibited people from cooperating during inquiries. The DNA testing has eliminated several potential suspects from the investigation, but so far has not led them to Cameron's killer.

Mass DNA screenings raise an obvious point: DNA evidence by itself can't identify an unknown criminal. But the chances of finding the owner of DNA left at a crime scene will grow as more and more DNA profiles are included in searchable databases. For example, a police investigation into the rapes of two teenage British girls in 1989 sputtered until a fellow named Colin Jacklin gave a false name at a routine traffic stop in March 1998. Jacklin was arrested and enrolled in the U.K.'s DNA database; it turned out that his profile matched DNA samples collected at the rape scenes. Jacklin was found guilty of committing two rapes and an indecent assault; he's now serving two life sentences.

In 1995, the United Kingdom became the first country to create a national DNA database. Based on the 10-loci STR approach, it now holds about 800,000 profiles of people suspected or convicted of an imprisonable offense. It is a major force in police intelligence, with about 600 "hits" every week from samples collected at crime scenes. British lawmakers have been generous to crime fighters, allowing them broad latitude in the acquisition of samples for DNA profiling. Other countries with DNA databases—including Austria, Germany, the Netherlands, and New Zealand—are typically more restrictive about the circumstances under which DNA samples can be drawn from individuals.

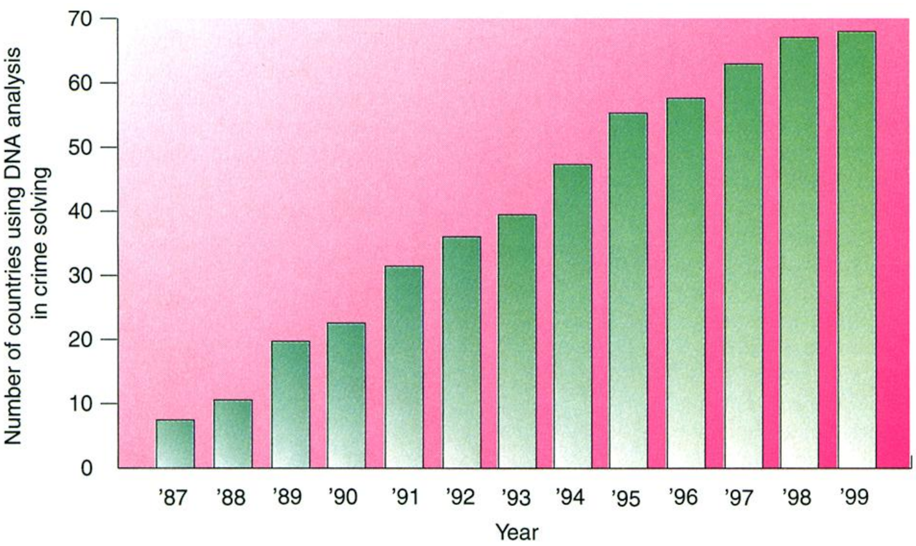
In the United States, each state has passed laws that allow a DNA sample to be collected from individuals convicted of rape or other sex crimes, and many also permit sampling from people convicted of murder, burglary, or even certain misdemeanors. "It varies from state to state as to which crimes will qualify an individual after conviction for DNA analysis," says the FBI's DiZinno. The U.S. national DNA database system, called CODIS, or combined DNA index system, started up in October 1998. It collates data from all the state databases. There are maybe 100,000 profiles in CODIS now, but according to DiZinno a whopping 750,000 blood samples from convicted felons have yet to be profiled and those profiles incorporated into CODIS.

At some point, society will be faced with a difficult question: Should everybody be included in a DNA database as a matter of course? As costs plummet—currently a single STR-type DNA profile costs about $100—a populationwide database will soon be financially feasible. "I think it's going to come," says George Mason's McKenney, who is building a mitochondrial database with Department of Justice backing. "Once we understand the value of DNA profiling, and we put in sufficient assurances that it won't be abused or misused, then we will pass laws that say everybody will be profiled on birth," he says. "It will be just like a Social Security number."

That prospect unnerves civil liberties lawyers and some forensic scientists. "At least in the United States that would never happen," predicts DiZinno. "There are too many privacy issues involved." And Budowle would rather it didn't happen: "You have to have a balance between the privacy of the citizen and the needs of the state," he says. As forensic science grows more sophisticated, that balancing act will be ever harder to maintain.

—ANDREW WATSON

Andrew Watson writes from Norwich, U.K.



The long molecule of the law. A 1999 survey of Interpol countries revealed a growing use of DNA analysis in police work. Although only 16 nations reported having DNA databases in place, another 45 are planning to launch their own repositories soon .

CREDIT: FBI/INTERPOL