THE SCIENCES

Published by the New York Academy of Sciences • March/April 1993 • $3.50

THE FIVE SEXES

Why Male and Female Are Not Enough

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ON THE COVER: Jan Gossaert (Mabuse), *Hermaphrodite and Salmacis*, c. 1500

EXPOSED AT THE FRONT

Documenting the Forgotten Victims of the Cold War

photographs by Carole Gallagher

Saint George, Utah, lies in the heart of Mormon country; there, as in the many other quiet desert towns dotting the region, life and death are taken to be gifts from heaven. And so on January 27, 1951, when an atomic blast rocked the Nevada Test Site directly upwind—the first of more than a hundred atmospheric tests to blossom fiercely at the site during the next dozen years—the citizens of Saint George accepted it as yet another sign of the government's divine inspiration.

The nuclear-weapons testing program in the United States was never so benign, however, a fact made clear only in recent years with the release of formerly classified documents. Clouds of radiation, as toxic as the one released by the explosion of the Soviet nuclear reactor at Chernobyl, rained pink fallout as far east as New England, poisoning milk, killing livestock and injuring residents along the path. Thousands of soldiers, ordered to conduct combat exercises near ground zero, were exposed to debilitating doses of radiation, as were hundreds of electricians and pipe fitters employed at the test site. In the years since, veterans, test-site workers and downwind residents have fallen prey to cancer at an alarmingly high rate.

Unlike most civilian casualties of war, those victims of the cold war had no warnings about the hazards to their health; indeed, they were subjected to a cruel campaign of disinformation. Test-site infantrymen were falsely assured: "The sun, not the Bomb, is your worst enemy." Women suffering the effects of radiation poisoning—loss of hair, badly burned skin—were dismissed from local hospitals, diagnosed with "neurosis" or "housewife syndrome." When one downwind citizen wrote to the Atomic Energy Commission reporting that her young son and several neighbors had died from what appeared to be fallout-induced cancers, the agency director tersely rebuked her: "Let us keep our sense of proportion on the matter of radioactive fallout." Any dangers to which she and her neighbors "might" be exposed, he added, "involve a small sacrifice" in the name of deterrence.

Nowhere has the human toll of that "small sacrifice" been so eloquently documented as in the photographs of Carole Gallagher. From 1983 until 1990 Gallagher lived and traveled in several states of the West and the Southwest. In areas the AEC once designated "virtually uninhabited," Gallagher earned the trust of dozens of veterans, test-site workers and downwind residents unwittingly exposed to radiation. The portraits she gathered recall the humanitarian tradition of Walker Evans, Dorothea Lange and W. Eugene Smith: direct and understated, tragic yet never exploitive.

It would be easy to dismiss Gallagher's work as an unfortunate chapter in a closed history. The Radiation Exposure Compensation Act, passed in 1990, offers radiation victims an official apology and an opportunity for remuneration. Nuclear tests, conducted underground in Nevada since 1961, may soon halt altogether under a moratorium signed last August by President

Bush. Yet for Gallagher's subjects the wounds of the cold war remain fresh. Critics of the compensation act note that it offers meager recompense—$50,000 to $100,000—and that to only a narrow segment of the affected population. Eligible counties lie adjacent to ineligible ones, almost randomly; of the more than twenty cancers classified as radiogenic by the National Academy of Sciences, only thirteen are deemed worthy of remuneration under RECA. Nor does the act compensate the second generation of victims: children born with defects, cancer or other chromosomal damage resulting from their parents' exposure. Adjudications under separate laws designed solely for atomic veterans have granted fewer than 3 percent of the claims made so far—evidence, critics say, that both the laws and their administration are inadequate.

Meanwhile, even underground testing poses a risk to downwind residents. Of the more than 760 known underground tests, at least 126 have released radioactivity into the atmosphere. Although the releases since 1971 have been comparatively small in dosage, many nonetheless went unannounced. In May 1986 test-site managers attempted to disguise radiation vented from the test blast Mighty Oak by releasing it just as the cloud from Chernobyl drifted overhead. It is no coincidence that underground tests and controlled ventings are conducted only when the wind blows eastward, away from Los Angeles and Las Vegas. Asked by Gallagher to account for the practice, a spokesman for the Department of Energy casually replied, "Those people in Utah don't give a s--t about radiation."

The remark typifies the contempt the federal nuclear-weapons industry continues to express for the safety of its workers, the public and the environment. Last year a federal grand jury charged that for years DOE has helped the Rocky Flats weapons plant near Golden, Colorado, conceal environmental crimes from the Environmental Protection Agency. A major federal nuclear dump site in New Mexico is poised to open without having met a single federal environmental regulation. What Gallagher's camera captures, then, is no sad anomaly of yesteryear but the first casualties of a public trust betrayed. Given a face and a voice, her subjects express a dignity and a demand for truth as quiet and fierce as the radiation that haunts all our lives. •

—ALAN BURDICK

CAROLE GALLAGHER *is a writer and photographer living in New York City. These photographs, as well as extensive interviews conducted by her, appear in* AMERICAN GROUND ZERO: THE SECRET NUCLEAR WAR, *which will be published in April by MIT Press.* ***ALAN BURDICK*** *is a senior editor at* THE SCIENCES.

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THE FIVE SEXES

Why Male and Female Are Not Enough

by ANNE FAUSTO-STERLING

IN 1843 LEVI SUYDAM, a twenty-three-year-old resident of Salisbury, Connecticut, asked the town board of selectmen to validate his right to vote as a Whig in a hotly contested local election. The request raised a flurry of objections from the opposition party, for reasons that must be rare in the annals of American democracy: it was said that Suydam was more female than male and thus (some eighty years before suffrage was extended to women) could not be allowed to cast a ballot. To settle the dispute a physician, one William James Barry, was brought in to examine Suydam. And, presumably upon encountering a phallus, the good doctor declared the prospective voter male. With Suydam safely in their column the Whigs won the election by a majority of one.

Barry's diagnosis, however, turned out to be somewhat premature. Within a few days he discovered that, phallus notwithstanding, Suydam menstruated regularly and had a vaginal opening. Both his/her physique and his/her mental predispositions were more complex than was first suspected. S/he had narrow shoulders and broad hips and felt occasional sexual yearnings for women. Suydam's "feminine propensities, such as a fondness for gay colors, for pieces of calico, comparing and placing them together, and an aversion for bodily labor, and an inability to perform the same, were remarked by many," Barry later wrote. It is not clear whether Suydam lost or retained the vote, or whether the election results were reversed.

Western culture is deeply committed to the idea that there are only two sexes. Even language refuses other possibilities; thus to write about Levi Suydam I have had to invent conventions—*s/he* and *his/her*—to denote someone who is clearly neither male nor female or who is perhaps both sexes at once. Legally, too, every adult is either man or woman, and the difference, of course, is not trivial. For Suydam it meant the franchise; today it means being available for, or exempt from, draft registration, as well as being subject, in various ways, to a number of laws governing marriage, the family and human intimacy. In many parts of the United States, for instance, two people legally registered as men cannot have sexual relations without violating anti-sodomy statutes.

But if the state and the legal system have an interest in maintaining a two-party sexual system, they are in defiance of nature. For biologically speaking, there are many gradations running from female to male; and depending on how one calls the shots, one can argue that along that spectrum lie at least five sexes—and perhaps even more.

For some time medical investigators have recognized the concept of the intersexual body. But the standard medical literature uses the term *intersex* as a catch-all for three major subgroups with some mixture of male and female characteristics: the so-called true hermaphrodites, whom I call herms, who possess one testis and one ovary (the sperm- and egg-producing vessels, or gonads); the male pseudohermaphrodites (the "merms"), who have testes and some aspects of the female genitalia but no ovaries; and the female pseudohermaphrodites (the "ferms"), who have ovaries and some aspects of the male genitalia but lack testes. Each of those categories is in itself complex; the percentage of male and female characteristics, for instance, can vary enormously among members of the same subgroup. Moreover, the inner lives of the people in each subgroup—their special needs and their problems, attractions and repulsions—have gone unexplored by science. But on the basis of what is known about them I suggest that the three intersexes, herm, merm and ferm, deserve to be considered additional sexes each in its own right. Indeed, I would argue further that sex is a vast, infinitely malleable continuum that defies the constraints of even five categories.

NOT SURPRISINGLY, it is extremely difficult to estimate the frequency of intersexuality, much less the frequency of each of the three additional sexes: it is not the sort of information one volunteers on a job application. The psychologist John Money of Johns Hopkins University, a specialist in the study of congenital sexual-organ defects, suggests intersexuals may constitute as many as 4 percent of births. As I point out to my students at Brown University, in a student body of about 6,000 that fraction, if correct, implies there may be as many as 240 intersexuals on campus—surely enough to form a minority caucus of some kind.

In reality though, few such students would make it as far as Brown in sexually diverse form. Recent advances in physiology and surgical technology now enable physicians to catch most intersexuals at the moment of birth. Almost at once such infants are entered into a program of hormonal and surgical management so that they can slip quietly into society as "normal" heterosexual males or females. I emphasize that the motive is in no way conspiratorial. The aims of the policy are genuinely humanitarian, reflecting the wish that people be able to "fit in" both physically and psychologically. In the medical community, however, the assumptions behind that wish—that there be only two sexes, that heterosexuality alone is normal, that there is one true model of psychological health—have gone virtually unexamined.

THE WORD *hermaphrodite* comes from the Greek names Hermes, variously known as the messenger of the gods, the patron of music, the controller of dreams or the protector of livestock, and Aphrodite, the goddess of sexual love and beauty. According to Greek mythology, those two gods parented Hermaphroditus, who at age fifteen became half male and half female when his body fused with the body of a nymph he fell in love with. In some true hermaphrodites the testis and the ovary grow separately but bilaterally; in others they grow together within the same organ, forming an ovo-testis. Not infrequently, at least one of the gonads functions quite well, producing either sperm cells or eggs, as well as functional levels of the sex hormones—androgens or estrogens. Although in theory it might be possible for a true hermaphrodite to become both father and mother to a child, in practice the appropriate ducts and tubes are not configured so that egg and sperm can meet.

In contrast with the true hermaphrodites, the pseudohermaphrodites possess two gonads of the same kind along with the usual male (XY) or female (XX) chromosomal makeup. But their external genitalia and secondary sex characteristics do not match their chromosomes. Thus merms have testes and XY chromosomes, yet they also have a vagina and a clitoris, and at puberty they often develop breasts. They do not menstruate, however. Ferms have ovaries, two X chromosomes and sometimes a uterus, but they also have at least partly masculine external genitalia. Without medical intervention they can develop beards, deep voices and adult-size penises.

No classification scheme could more than suggest the variety of sexual anatomy encountered in clinical practice. In 1969, for example, two French investigators, Paul Guinet of the Endocrine Clinic in Lyons and Jacques Decourt of the Endocrine Clinic in Paris, described ninety-eight cases of true hermaphroditism—again, signifying people with both ovarian and testicular tissue—solely according to the appearance of the external genitalia and the accompanying ducts. In some cases the people exhibited strongly feminine development. They had separate openings for the vagina and the urethra, a cleft vulva defined by both the large and the small labia, or vaginal lips, and at puberty they developed breasts and usually began to menstruate. It was the oversize and sexually alert clitoris, which threatened sometimes at puberty to grow into a penis, that usually impelled them to seek medical attention. Members of another group also had breasts and a feminine body type, and they menstruated. But their labia were at least partly fused, forming an incomplete scrotum. The phallus (here an embryological term for a structure that during usual development goes on to form either a clitoris or a penis) was between 1.5 and 2.8 inches long; nevertheless, they urinated through a urethra that opened into or near the vagina.

By far the most frequent form of true hermaphrodite encountered by Guinet and Decourt—55 percent—appeared to have a more masculine physique. In such people the urethra runs either through or near the phallus, which looks more like a penis than a clitoris. Any menstrual blood exits periodically during urination. But in spite of the relatively male appearance of the genitalia, breasts appear at puberty. It is possible that a sample larger than ninety-eight so-called true hermaphrodites would yield even more contrasts and subtleties. Suffice it to say that the varieties are so diverse that it is possible to know which parts are present and what is attached to what only after exploratory surgery.

The embryological origins of human hermaphrodites clearly fit what is known about male and female sexual development. The embryonic gonad generally chooses early in development to follow either a male or a female sexual pathway; for the ovo-testis, however, that choice is fudged. Similarly, the embryonic phallus most often ends up as a clitoris or a penis, but the existence of intermediate states comes as no surprise to the embryologist. There are also uro-genital swellings in the embryo that usually either stay open and become the vaginal labia or fuse and become a scrotum. In some hermaphrodites, though, the choice of opening or closing is ambivalent. Finally, all mammalian embryos have structures that can become the female uterus and the fallopian tubes, as well as structures that can become part of the male sperm-transport system. Typically either the male or the female set of those primordial genital organs degenerates, and the remaining structures achieve their sex-appropriate future. In hermaphrodites both sets of organs develop to varying degrees.

INTERSEXUALITY ITSELF is old news. Hermaphrodites, for instance, are often featured in stories about human origins. Early biblical scholars believed Adam began life as a hermaphrodite and later divided into two people—a male and a female—after falling from grace. According to Plato there once were three sexes—male, female and hermaphrodite—but the third sex was lost with time.

Both the Talmud and the Tosefta, the Jewish books of law, list extensive regulations for people of mixed sex. The Tosefta expressly forbids hermaphrodites to inherit their fathers' estates (like daughters), to seclude themselves with women (like sons) or to shave (like men). When hermaphrodites menstruate they must be isolated from men (like women); they are disqualified from serving as witnesses or as priests (like women), but the laws of pederasty apply to them.

In Europe a pattern emerged by the end of the Middle Ages that, in a sense, has lasted to the present day: hermaphrodites were compelled to choose an established gender role and stick with it. The penalty for transgression was often death. Thus in the 1600s a Scottish hermaphrodite living as a woman was buried alive after impregnating his/her master's daughter.

For questions of inheritance, legitimacy, paternity, succession to title and eligibility for certain professions to be determined, modern Anglo-Saxon legal systems require that newborns be registered as either male or female. In the U.S. today sex determination is governed by state laws. Illinois permits adults to change the sex recorded on their birth certificates should a physician attest to having performed the appropriate surgery. The New York Academy of Medicine, on the other hand, has taken an opposite view. In spite of surgical alterations of the external genitalia, the academy argued in 1966, the chromosomal sex remains the same. By that measure, a person's wish to conceal his or her original sex cannot outweigh the public interest in protection against fraud.

During this century the medical community has completed what the legal world began—the complete erasure of any form of embodied sex that does not conform to a male–female, heterosexual pattern. Ironically, a more sophisticated knowledge of the complexity of sexual systems has led to the repression of such intricacy.

In 1937 the urologist Hugh H. Young of Johns Hopkins University published a volume titled *Genital Abnormalities, Hermaphroditism and Related Adrenal Diseases.* The book is remarkable for its erudition, scientific insight and open-mindedness. In it Young drew together a wealth of carefully documented case histories to demonstrate and study the medical treatment of such "accidents of birth." Young did not pass judgment on the people he studied, nor did he attempt to coerce into treatment those intersexuals who rejected that option. And he showed unusual even-handedness in referring to those people who had had sexual experiences as both men and women as "practicing hermaphrodites."

One of Young's more interesting cases was a hermaphrodite named Emma who had grown up as a female. Emma had both a penis-size clitoris and a vagina, which made it possible for him/her to have "normal" heterosexual sex with both men and women. As a teenager Emma had had sex with a number of girls to whom s/he was deeply attracted; but at the age of nineteen s/he had married a man. Unfortunately, he had given Emma little sexual pleasure (though *he* had had no complaints), and so throughout that marriage and subsequent ones Emma had kept girlfriends on the side. With some frequency s/he had pleasurable sex with them. Young describes his subject as appearing "to be quite content and even happy." In conversation Emma occasionally told him of his/her wish to be a man, a circumstance Young said would be relatively easy to bring about. But Emma's reply strikes a heroic blow for self-interest:

> Would you have to remove that vagina? I don't know about that because that's my meal ticket. If you did that, I would have to quit my husband and go to work, so I think I'll keep it and stay as I am. My husband supports me well, and even though I don't have any sexual pleasure with him, I do have lots with my girlfriends.

YET EVEN AS YOUNG was illuminating intersexuality with the light of scientific reason, he was beginning its suppression. For his book is also an extended treatise on the most modern surgical and hormonal methods of changing intersexuals into either males or females. Young may have differed from his successors in being less judgmental and controlling of the patients and their families, but he nonetheless supplied the foundation on which current intervention practices were built.

By 1969, when the English physicians Christopher J. Dewhurst and Ronald R. Gordon wrote *The Intersexual Disorders,* medical and surgical approaches to intersexuality had neared a state of rigid uniformity. It is hardly surprising that such a hardening of opinion took place in the era of the feminine mystique—of the post–Second World War flight to the suburbs and the strict division of family roles according to sex. That the medical consensus was not quite universal (or perhaps that it seemed poised to break apart again) can be gleaned from the near-hysterical tone of Dewhurst and Gordon's book, which contrasts markedly with the calm reason of Young's founding work. Consider their opening description of an intersexual newborn:

> One can only attempt to imagine the anguish of the parents. That a newborn should have a deformity . . . [affecting] so fundamental an issue as the very sex of the child . . . is a tragic event which immediately conjures up visions of a hopeless psychological misfit doomed to live always as a sexual freak in loneliness and frustration.

Dewhurst and Gordon warned that such a miserable fate would, indeed, be a baby's lot should the case be improperly managed; "but fortunately," they wrote, "with correct management the outlook is infinitely better than the poor parents—emotionally stunned by the event—or indeed anyone without special knowledge could ever imagine."

Scientific dogma has held fast to the assumption that without medical care hermaphrodites are doomed to a life of misery. Yet there are few empirical studies to back up that assumption, and some of the same research gathered to build a case for medical treatment contradicts it. Francies Benton, another of Young's practicing hermaphrodites, "had not worried over his condition, did not wish to be changed, and was enjoying life." The same could be said of Emma, the opportunistic hausfrau. Even Dewhurst and Gordon, adamant about the psychological importance of treating intersexuals at the infant stage, acknowledged great success in "changing the sex" of older patients. They reported on twenty cases of children reclassified into a different sex after the supposedly critical age of eighteen months. They asserted that all the reclassifications were "successful," and they wondered then whether reregistration could be "recommended more readily than [had] been suggested so far."

The treatment of intersexuality in this century provides a clear example of what the French historian Michel Foucault has called biopower. The knowledge developed in biochemistry, embryology, endocrinology, psychology and surgery has enabled physicians to control the very sex of the human body. The multiple contradictions in that kind of power call for some scrutiny. On the one hand, the medical "management" of intersexuality certainly developed as part of an attempt to free people from perceived psychological pain (though whether the pain was the patient's, the parents' or the physician's is unclear). And if one accepts the assumption that in a sex-divided culture people can realize their greatest potential for happiness and productivity only if they are sure they belong to one of only two acknowledged sexes, modern medicine has been extremely successful.

On the other hand, the same medical accomplishments can be read not as progress but as a mode of discipline. Hermaphrodites have unruly bodies. They do not fall naturally into a binary classification; only a surgical shoehorn can put them there. But why should we care if a "woman," defined as one who has breasts, a vagina, a uterus and ovaries and who menstruates, also has a clitoris large enough to penetrate the vagina of another woman? Why should we care if there are people whose biological equipment enables them to have sex "naturally" with both men and women? The answers seem to lie in a cultural need to maintain clear distinctions between the sexes. Society mandates the control of intersexual bodies because they blur and bridge the great divide. Inasmuch as hermaphrodites literally embody both sexes, they challenge traditional beliefs about sexual difference: they possess the irritating ability to live sometimes as one sex and sometimes the other, and they raise the specter of homosexuality.

But what if things were altogether different? Imagine a world in which the same knowledge that has enabled medicine to intervene in the management of intersexual patients has been placed at the service of multiple sexualities. Imagine that the sexes have multiplied beyond currently imaginable limits. It would have to be a world of shared powers. Patient and physician, parent and child, male and female, heterosexual and homosexual—all those oppositions and others would have to be dissolved as sources of division. A new ethic of medical treatment would arise, one that would permit ambiguity in a culture that had overcome sexual division. The central mission of medical treatment would be to preserve life. Thus hermaphrodites would be concerned primarily not about whether they can conform to society but about whether they might develop potentially life-threatening conditions—hernias, gonadal tumors, salt imbalance caused by adrenal malfunction—that sometimes accompany hermaphroditic development. In my ideal world medical intervention for intersexuals would take place only rarely before the age of reason; subsequent treatment would be a cooperative venture between physician, patient and other advisers trained in issues of gender multiplicity.

I do not pretend that the transition to my utopia would be smooth. Sex, even the supposedly "normal," heterosexual kind, continues to cause untold anxieties in Western society. And certainly a culture that has yet to come to grips—religiously and, in some states, legally—with the ancient and relatively uncomplicated reality of homosexual love will not readily embrace intersexuality. No doubt the most troublesome arena by far would be the rearing of children. Parents, at least since the Victorian era, have fretted, sometimes to the point of outright denial, over the fact that their children are sexual beings.

All that and more amply explains why intersexual children are generally squeezed into one of the two prevailing sexual categories. But what would be the psychological consequences of taking the alternative road—raising children as unabashed intersexuals? On the surface that tack seems fraught with peril. What, for example, would happen to the intersexual child amid the unrelenting cruelty of the school yard? When the time came to shower in gym class, what horrors and humiliations would await the intersexual as his/her anatomy was displayed in all its nontraditional glory? In whose gym class would s/he register to begin with? What bathroom would s/he use? And how on earth would Mom and Dad help shepherd him/her through the mine field of puberty?

In the past thirty years those questions have been ignored, as the scientific community has, with remarkable unanimity, avoided contemplating the alternative route of unimpeded intersexuality. But modern investigators tend to overlook a substantial body of case histories, most of them compiled between 1930 and 1960, before surgical intervention became rampant. Almost without exception, those reports describe children who grew up knowing they were intersexual (though they did not advertise it) and adjusted to their unusual status. Some of the studies are richly detailed—described at the level of gym-class showering (which most intersexuals avoided without incident); in any event, there is not a psychotic or a suicide in the lot.

Still, the nuances of socialization among intersexuals cry out for more sophisticated analysis. Clearly, before my vision of sexual multiplicity can be realized, the first openly intersexual children and their parents will have to be brave pioneers who will bear the brunt of society's growing pains. But in the long view—though it could take generations to achieve—the prize might be a society in which sexuality is something to be celebrated for its subtleties and not something to be feared or ridiculed. •

Anne Fausto-Sterling *is a developmental geneticist and professor of medical science at Brown University in Providence. The second edition of her book* Myths of Gender: Biological Theories about Women and Men, *published by Basic Books, appeared last fall. She is working on a book titled* The Sex Which Prevails: Biology and the Social / Scientific Construction of Sexuality.

MOOD INDIGO

Exploring the Spectrum Beyond the Blue

by SIDNEY PERKOWITZ

On travels through Bavaria some time ago, I had the good fortune to visit the University of Würzburg, nestled amid the rolling wine country along the River Main. I am a physicist, and so, though I travel primarily to enjoy the simple pleasures, I was thrilled when my hosts recognized my professional interests and put me up in the very room once occupied by Wilhelm Conrad Roentgen. If memory serves, I even slept in Professor Roentgen's own bed. Or perhaps I only dreamed that, after an evening spent sampling the local wine. But there is no doubt that in 1895 Roentgen was living in Würzburg when he made a contribution to science that changed the world: the discovery of X rays. That wonderful discovery helped spark twentieth-century revolutions in medicine and physics, and it strongly contributed to the puzzling quantum theory of electromagnetic radiation. Roentgen's exploration focused attention on the invisible, powerful part of the spectrum extending from ultraviolet to X radiation and on to gamma and cosmic rays. The importance of the research was quickly recognized: in 1901 he was awarded the first Nobel Prize in physics.

Roentgen was not the only explorer of the spectrum to begin his trek in Germany, where the wine or the air must stir some special creative element. How else can one explain that the discovery of ultraviolet radiation, which is spectrally adjacent to Roentgen's X rays, took place less than a hundred miles northeast of Würzburg? In 1801 Johann Wilhelm Ritter, then twenty-five years old, was a respected scientist at the University of Jena and a newly appointed member of the court of the Duke of Gotha. Ritter had strong ideas about unity and polarity as principles of nature, exemplified in the linked but opposing north and south poles of magnetism.

Inspired by William Herschel's discovery in 1800 that invisible infrared rays lie beyond the red in the spectrum of sunlight, Ritter sought a polar twin in the form of unseen radiation beyond the opposite, violet end of the spectrum. His probe was a piece of paper soaked in a solution of silver chloride. It was already known that the preparation, a kind of proto-photographic film, turns black under visible light. But as he exposed the paper to the rainbow of colors emerging from a prism, Ritter watched the paper darken even more rapidly just beyond the violet portion of the spectrum than it did in violet light. Unseen rays appeared to be changing the silver chloride to silver.

Ritter did not know what caused the fade to black. And Roentgen did not understand the fearsome effect that enabled him to thrill the world by displaying the bones of a living hand. But today physicists know that those pioneers had turned up two key pieces in a larger puzzle. Ultraviolet and X radiation both are part of a much broader, unified physical picture of electromagnetic waves; they both are forms of light. Moreover, with increased understanding of those forms of light have come increasingly powerful applications. Certainly both ultraviolet and X radiation, in excess, are damaging to the body. But in moderation they serve as powerful diagnostic tools, and they can even heal. X rays are also employed in the study of crystalline solids, which form the backbone of the electronics and computer industries. And in recent years it has become clear that faster, more powerful and more precisely focused beams of ultraviolet and X radiation can serve important scientific and technological needs. In many cases those wavelengths are the most useful means of delivering enormous bursts of energy to a small area in an extremely short time.

To understand better the unseen light in the ultraviolet and X-ray region of the electromagnetic spectrum, think again about the colors of the rainbow. Those colors change across the rainbow in an orderly sequence, which young students memorize with the aid of the fictitious name ROY G. BIV. The letters in the mnemonic correspond to the initials of the colors, in order of decreasing wavelength: red, orange, yellow, green, blue, indigo, violet.

The eye cannot see light whose wavelength is shorter than the deep violet, about 380 nanometers (billionths of a meter) between the crests of successive waves. But as the wavelength gets shorter, more wave crests pass a given point in space each second, or in other words its frequency gets higher. And the higher the frequency, the more energetic the light.

But what could it mean to say that light is more energetic? In quantum theory there are two complementary pictures of light, to be applied more or less as dictated by the needs of explanation. All light of a given wavelength is associated with a photon, or particle of light having a definite energy; the shorter the wavelength, the more energetic the photon—the "harder" and more penetrating it is. Radiation with wavelengths between 400 and four nanometers is said to lie in the ultraviolet region of the spectrum. That region is further divided into UVA (between 400 and 320 nanometers), UVB (between 320 and 280 nanometers) and UVC (below 280 nanometers, the most energetic ultraviolet radiation of all).

Still more energetic are the X-ray photons, whose longest wavelengths are defined to measure thirty nanometers; the X-ray region thus overlaps part of the ultraviolet. X rays whose wavelengths are longer than 0.1 nanometer are called soft, and those with wavelengths shorter than 0.1 nanometer are called hard—again, because of their increased penetrating power. Like a high-powered rifle bullet, an X-ray photon can scar even a solid crystal, and it can do terrible damage to biological tissue by breaking the bonds between the atoms that form its molecules and by tearing away electrons from the atoms themselves, or ionizing them. The less energetic ultraviolet photons are more like pistol bullets, but there is growing evidence that they cause even more harm to the soft tissues of life than do X rays.

TWO PRINCIPAL natural processes generate ultraviolet and X-ray photons. The first is the so-called thermal emission of electromagnetic energy, from any body whose temperature is above absolute zero. The atoms that make up the body vibrate back and forth at many different frequencies. Because they are electrically charged, each vibration sets up an electromagnetic wave at the frequency of the vibration. The result is a continuous spectrum of radiant energy that is broadcast outward across the virtually continuous set of frequencies represented by the enormous number of atoms in the body.

The energy broadcast at each frequency, however, depends on the temperature of the body. Only extremely hot bodies generate ultraviolet and X-ray photons as a substantial fraction of their output. Even the sun emits less than a tenth of its radiant energy at wavelengths shorter than 400 nanometers. Some of that short-wavelength radiation comes from the solar surface, whose temperature is roughly 6,000 degrees Celsius. Hotter internal parts of the sun contribute additional continuous short-wavelength energy, as well as emissions at specific wavelengths that show up as bright lines in the solar spectrum.

Such bright-line emissions come from the second process that generates ultraviolet and X-ray photons. Every atom is made up of a positive nucleus, to which negatively charged electrons are electrostatically bound. As quantum theory has it, the electrons are arrayed around the nucleus only in specific orbits or shells, each with a definite energy. The single electron in an undisturbed atom of hydrogen, for instance, resides in its innermost orbit, a fraction of a nanometer from the nucleus and therefore subject to a strong pull that holds it in a tight embrace. An electron in an outer shell is less compulsively held; it is more nearly a free body, with higher energy. If an inner electron gains energy from some outside source, it alights in one of those distant shells, but it soon returns to its initial site. As it does, it gives off a flash of light, a photon. The photon's energy, and therefore its wavelength, is determined by the difference between the higher and lower electronic energies.

The electronic energies are determined by the strength of the nuclear attraction, which is set by the count of protons in the nucleus. The electron in a hydrogen atom is held by only one central proton. As that electron returns to its innermost shell from any outer one, it emits ultraviolet light whose wavelength is at least one hundred nanometers. A heavier atom, however, includes more nuclear protons, the combined charge of which pulls an electron far more intensely. The twenty-nine protons in the copper nucleus, for instance, can give rise to energy differences from shell to shell nearly a thousand times greater than the ones in hydrogen. The photons emitted when electrons fall into the innermost orbit have wavelengths of less than a nanometer: they are X-ray photons. Any reasonably heavy element can produce X rays in that way. The wavelengths are sharply defined and are characteristic of the emitting element, since they come from electronic transitions between exact energy levels.

Because large energies are needed to generate X rays, X rays are not produced naturally on the earth except in some radioactive processes. In the sun, X-ray line emissions occur because the great thermal energy promotes electrons to higher shells. And other sources in the distant cosmos produce X rays at unthinkable powers. Since the first extrasolar X-ray emitter, Sco X-1, was discovered in 1962, hundreds of such astronomical sources have been observed. Many have been associated with visible stellar objects: Sco X-1 is identified with a star in the constellation Scorpius, and another source, Tau X-1, is located in the Crab nebula. Sco X-1 is so powerful that if its emissions could be gathered and stored for one second, they would meet all the energy needs of the United States for a billion years. People are safe from such terrible cauldrons of radiation because the emissions are greatly attenuated over the light-years they travel to reach the solar system.

IT IS THE FAR LESS POWERFUL ultraviolet light from the earth's own furnace, the sun, that is a harmful feature of daily life. Fortunately, the small fraction of the sun's energy emitted in the ultraviolet is further diluted by the atmosphere, especially by its layer of ozone. The ozone molecule, made up of three oxygen atoms, effectively absorbs ultraviolet radiation at wavelengths shorter than 295 nanometers. Unfortunately, the protection afforded by that airy armor is jeopardized by the current thinning of the ozone layer, attributed to chlorofluorocarbons released by human activity. But even with an undamaged ozone layer the ultraviolet light reaching the earth's surface is energetic enough to cause harm. Solar UVB light may well be an important cause of skin cancer, and the incidence of that form of the disease is rising as people are spending more time at the beach.

Ultraviolet photons can cause damage directly by breaking chemical bonds in DNA, the genetic material in cell nuclei that determines the growth and development of the cell. But the interaction of ultraviolet light with human biochemistry is a tangled skein of effects. Some threads in the tangle give rise to serious illness and death; others cure disease.

Statistical evidence inescapably links solar ultraviolet radiation to some skin cancers. An increase of 1 or 2 percent in UVB radiation increases the incidence of nonmelanoma forms of skin cancer by 2 to 4 percent. But the connection between the more serious melanoma cancers and the sun is not so well understood. One important factor seems to be whether or not a person has had exposures to ultraviolet rays strong enough to burn the skin; that may explain why indoor workers are more at risk for melanoma than those who spend their days outdoors.

Although the exact mechanism for damage in melanoma is unclear, the direct damage that turns ordinary cells cancerous seems to be only part of the story. The sites where melanomas erupt on the body are not always the most heavily exposed ones. The far-reaching implication is that the absorption of ultraviolet light may suppress the body's natural defenses against tumorous cells. It is as if the ultraviolet bullets were coated with a poison that inflicts a devastating second-stage effect; after damaging the DNA in cells, the radiation goes on to prevent the body from containing and healing early injuries.

AND YET, as if to compensate for its own most widespread evil, ultraviolet light can also be exploited to treat some kinds of cancer. In a procedure known as photophoresis a patient's blood is removed, irradiated with ultraviolet light and returned to the body. The procedure relieves symptoms of the skin cancer called mycosis fungoides, and it may also increase survival rates, with none of the side effects associated with chemotherapy. Photophoresis is promising as well for certain forms of leukemia.

Ultraviolet light is also employed to treat certain diseases by activating photosensitive drugs. One therapeutic application is for psoriasis, the chronic appearance of scaly dry patches on the skin; because the treatment relies on long-wavelength ultraviolet light, it is known as psoriasis-UVA (PUVA) therapy. The UVA works together with the drug psoralen to slow the process that causes psoriasis legions. Every year between 25,000 and 50,000 people receive PUVA therapy in the U.S.

Unfortunately, that bright thread in the tangle of human responses to ultraviolet light is interlaced with a worrisome dark strand. The same PUVA therapy that relieves psoriasis may activate full-blown AIDS in people infected with HIV. And ironically, many HIV-infected patients have skin conditions that make them candidates for PUVA therapy.

The human response to X rays is similarly tangled. In large doses they have terrifying effects on tissue, and even as recently as the 1950s the cumulative effects of repeated doses went largely unrecognized. It was not uncommon at that time to find X-ray machines in shoe stores, where customers could pay to wiggle their toes and watch the movement of the bones in their feet. X-ray exposures are now kept to a minimum for patient and operator, but they remain a staple of medical practice. They are also exploited for their destructive powers to treat some cancers. Abnormal cells are more sensitive to damaging radiation than are ordinary ones, and so they can be selectively destroyed.

THE MEDICAL ROLE OF X rays has been enhanced in recent years by computerized tomography (CT) scans, which instead of a flat picture give a three-dimensional view of the inside of the body. To generate the image a computer-controlled mechanism moves the X-ray source in defined orbits around the long axis of the patient's body, and an X-ray photograph is made at each of many positions. The real power of the process comes from another computer, which assembles the scans into a three-dimensional representation. The computed image enables the radiologist at a computer-graphics terminal to rotate a sculptural picture of a living skull or any other part of the bone structure, much as Hamlet mused over Yorick's remains.

X-ray analysis in nonmedical applications has also become an essential tool for understanding the modern world. Electronics, metallurgy and other materials-based technologies draw heavily on the science of crystalline solids, which aims to determine how the atoms in the solid are packed together in space. Some arrangements are as simple as regular stacks of cannonballs, such as the array of atoms in silicon, the material for electronic chips. Others challenge the visual imagination, such as the ornate placement of the constituent atoms in yttrium barium copper oxide, a new high-temperature superconductor. But simple or baroque, a common feature is that the atoms typically lie less than a nanometer apart. Even with unlimited magnification, ordinary visible light cannot discriminate the details of those structures. Only light with a wavelength comparable to the interatomic spacing—that is, X radiation—can discern the features.

Wavelength is a gauge of measurement because it defines how waves act when they encounter a solid structure. Picture a moored buoy bobbing up and down in a train of regular ocean waves. As each wave crest reaches the buoy, the obstacle disturbs the wave front. The disturbances fan out, and so some waves move off in a direction different from that of the incoming waves. The net effect of the buoy is the diffraction, or bending, of the waves, a property inherent in wave behavior.

Now add a second buoy near the first, and imagine that one of the marching waves reaches the two buoys simultaneously. Identical diffracted waves form at the buoys and crisscross in the region between them. If the distance from crest to crest—the wavelength—of the original marching waves is greater than the spacing between the buoys, the emerging diffracted waves are still much in step. An observer would be hard put to tell whether two buoys or only one buoy had disturbed the original wave front. If the wavelength is the same or less than the spacing between the buoys, however, crests as well as troughs appear near the obstacles. The result is a distinctive interference pattern, strengthened where crest matches crest and weakened where crest matches trough. An observer studying the disturbed wave front could clearly see that the marching waves had encountered two obstacles.

Stripped of the romantic imagery of ocean rollers and clanging buoys, the example simply shows that when light waves illuminate a structure, they cannot pick out, or resolve, geometric features smaller than the wavelength of the light itself. Infrared, visible or ultraviolet light cannot probe the nanometer-size details of a crystal. Only X rays can.

And so early in this century investigators began to apply X-ray diffraction to examine and catalogue crystalline solids. The geometries and dimensions determined by the new technique formed the basis for microscopic theories of solids, which take concrete form in today's technology. X-ray analysis remains a prime tool for examining the structure of materials such as high-temperature superconductors, "Bucky balls" (the new geodesic dome-like carbon-based molecules named after the architect Buckminster Fuller), and intricate compounds with biological significance. The technology has given rise to some of the most accurate experimental measurements ever made.

LAMPS AND LASERS provide the ultraviolet light, and high-voltage electron tubes provide the X rays needed for most ordinary work. But it is virtually axiomatic in science that exploring the limits of nature demands the most advanced technology available. Some investigations require X rays or ultraviolet light at extraordinary intensities; other efforts demand a source that can be flexibly tuned to different wavelengths; others still must have brief bursts of radiation.

To meet those needs the best answer to date has been to build sources that can push electrons to enormous accelerations. The accelerated charges generate X-ray and ultraviolet radiation at high fluxes. Even the standard X-ray tube depends on accelerated electrons: they are boiled off a wire filament and accelerated across the evacuated tube by a high voltage. When the electrons smash into a target on the other end of the tube, the collision releases X rays. But there are practical limits on the X radiation available from the linear design of the tube and its reliance on high voltage alone. More clever schemes are more productive, but the means are immense.

The most useful new source of ultraviolet and X radiation is the synchrotron, an enormous device that traces its origins to the accelerators originally designed to study elementary particles. In particle research itself that line of machinery has culminated in the astonishing Superconducting Super Collider, a racetrack for subatomic particles, fifty-four miles around, that is under construction in Texas. Machines designed as synchrotron light sources do not require such a gargantuan scale, but their size is still impressive. The National Synchrotron Light Source (NSLS) at the Brookhaven National Laboratory on Long Island, New York, the nearly completed Advanced Light Source at the Lawrence Berkeley Laboratory in California and the European Synchrotron Radiation Source (ESRF) being built at Grenoble near the French Alps each could comfortably house a couple of dirigibles or enclose most of a football field.

Synchrotrons rely on magnetic fields to accelerate energetic electrons, which then radiate light in vast quantities. The push or pull of a magnetic field on moving electrons is a fundamental property of electromagnetism. A current of electrons creates a magnetic field; conversely, an electron moving in a preexisting field is subject to a force at right angles to its direction of motion. In the synchrotron light source powerful magnetic fields force a cluster of electrons to circle an enormous evacuated track. The magnetic fields continuously push the stream of electrons inward, toward the center of the circle. According to Newton's laws of motion, where there is a push, there is an acceleration. And as the electrons accelerate toward the center, they radiate light. The same synchrotron mechanism, scaled up to stellar size, is thought to be responsible for the intense X radiation observed from cosmic sources such as Tau X-1.

The amount of light radiated by any synchrotron source depends on the speed of the accelerated charges. In the earthbound version of the synchrotron the electronic speed is increased by feeding bursts of carefully timed energy to the orbiting charges. The energy and speed of the particles grow with every burst, until each electron carries billions of volts of electrical potential and is moving at nearly the speed of light. The resultant electromagnetic radiation is typically millions of times stronger than the radiation from conventional sources, and it spans a wide range of wavelengths. The NSLS facility, for instance, generates radiation at wavelengths that vary across nine orders of magnitude, from 0.01 nanometer (hard X rays) to a centimeter (in the microwave region of the spectrum).

IN ADDITION TO the many wavelengths available from a synchrotron source, an extremely bright beam can be generated. Brightness is a measure of the density of photons in the beam, and high brightness implies an intense beam focused on a small cross-sectional area. In fact, the full power of the synchrotron can be brought to bear on a minute target; conventional X-ray sources cannot be so focused.

The focusing is important for several reasons. First, quantum theory suggests that solids take on valuable new properties when they come in small, so-called mesoscopic packages. Those properties will become increasingly important as new generations of electronic chips are formed on such small scales. Second, novel materials can be made initially only in minute quantities, and X-ray analysis must be able to observe the atomic arrangements across only a few micrometers. In a recent experiment X-ray analysis was carried out on a crystalline filament of bismuth only one-hundredth the thickness of a human hair. Finally, the tight focusing of the synchrotron is particularly important for the study of biological substances such as proteins, which are difficult to form into large crystals.

Another advantage of synchrotron radiation is that it is pulsed, like an enormous photographic strobe light. The light blinks on as each group of electrons circles the ring. Thus synchrotron light can make rapid X-ray snapshots that freeze the action in the microscopic world one frame at a time. That capability is critical for examining certain biological processes. To understand how an enzyme works, for instance, one must study the chemical action of the molecule in real time. Such a study is planned for the ESRF synchrotron. The electrons in that machine will circle the ring a million times every three seconds, which will make possible virtual home movies of enzyme reactions, with successive frames spaced as little as three-millionths of a second apart.

Perhaps the most advanced medical use of synchrotron light is transvenous coronary angiography, under development at the NSLS Medical Research Facility. The technique employs synchrotron X rays to examine the coronary arteries, which carry oxygen-rich blood to the heart. When the arteries are choked with fatty plaque, heart disease ensues. In the standard method of examination a dye containing iodine is injected directly into the coronary arteries to enhance the X-ray contrast. But the injection is dangerous, and physicians dare use the technique for only the most pressing cases. The risk is lower if the injection is made into a vein, but then the dye is diluted before it reaches the coronary arteries. Any blockage is hard to see under ordinary low-power X rays. The synchrotron light can be selected for the wavelengths most effective for enhancing contrast, and it can be shined at sufficient power to give excellent images. The X-ray dose to the patient is comparable to that with the conventional method.

A VISITOR TO a synchrotron light source—with its immense activity, suggesting that important science is under way—might feel that human control of ultraviolet and X-ray light is complete. The truth is more complicated and even paradoxical, for much is still unknown about this forbidding part of the spectrum. Those of us who study matter are proudly certain of our quantitative findings when X rays probe inert or dead material, yet we are puzzled and fearful when ultraviolet light pierces living cells. The deep emotional gulf reflects the differing grasps of the physical and the biological worlds.

I begin to experience the paradox in a personal way as I recall my travels in Germany, where Roentgen and Ritter found the intense X-ray and ultraviolet photons. After visiting Würzburg, I turned west and a little north to Mainz, where I boarded a side-wheel steamer to sail down the River Rhine. I remember taking the sun, being showered with radiation that physically bade nothing but ill for my exposed skin. But there I enjoyed a half-hour of complete happiness, one of those rare confluences of perfections whose true weight is felt only years later. Sitting relaxed aboard the ship, I sipped Rhine wine and watched castles and vineyards glide by. Perhaps enough German wine and air would have made me a spectral explorer like Roentgen and Ritter. But something else stays with me in crystalline vividness. I see yet the sparkling orderliness of the steamer, the fascinating variety of the passengers, the pale gold of the wine, all bathed in the pure, clean brightness of that sunlight. The joy I felt came from the magic of the moment, and from an innocence that marked a younger me. Few enough moments since have brought me such euphoria. For many of us few moments carry such pure pleasure as the ones lived dangerously in the sun's light. •

***SIDNEY PERKOWITZ** is Charles Howard Candler professor of physics at Emory University in Atlanta. He is at work on a book about light, from its cosmic origins to its role in the next generation of technology.*

STILL LIFE IN AMBER

Time Capsules of DNA from 40,000,000 B.C.

by GEORGE O. POINAR, JR.

THE LANDSCAPE IS SUBTROPICAL, lush with the fernlike trees that flourished in western Canada seventy-five million years ago. An adolescent *Tyrannosaurus rex* trails its mother as they ramble through trees and underbrush. A blood-sucking mosquito flying from a nearby tree lands on the young *T. rex* and begins to search for a thin-skinned part of the dinosaur's hide. Finally the mosquito settles in for its long dinner by digging its proboscis into the scaly underbelly of the beast. After gorging, the bloated insect flies off into the woods to search out an egg-laying spot in a hospitable tree. But the mosquito unwisely selects a kauri pine tree, which oozes sticky pitch from its bark; instead of putting down eggs, the insect suddenly finds itself in a fight for its life, engulfed by a golden-yellow goo. The battle is short but decisive. The mosquito struggles against asphyxiation, thrashes about for a few seconds, loses a foreleg and expires, frozen in its death throes.

There it remains until 1991. Then, like archaeologists entering the tomb of Tutankhamen, molecular biologists break into the mosquito's coffin, now fossilized into yellow amber, to resurrect what died so long ago. Not for the mosquito, however, is this a freakish chance for a second life. That prize belongs to its last meal. By extracting and cloning DNA from the dinosaur's blood cells, still vital and undigested in the belly of the prehistoric insect, the intrepid biologists bring *T. rex* back to life after millions of years of crystallized slumber.

Such is the wildly imaginative premise of Michael Crichton's 1990 novel, *Jurassic Park*. Of course as the novel unfolds that premise begins to seem relatively tame; the plot really gets off the ground when the available DNA gets cloned and expressed in a fantastic zoo stocked with prehistoric animals, and the animals prove to be more than their keepers have bargained for. But the thrill-a-second novel, which will be released in a film version early this summer, has at least one big toe in real biological research: ancient DNA is indeed being extracted and cloned from extinct organisms preserved in amber.

I discovered my first piece of amber in 1962, on the western coast of Denmark, and since then I have taken great pleasure in the hobby of collecting bits of the semiprecious stone, with their delicate specimens of bygone life inside. But early in 1982 that hobby transformed itself into a life's work. The turning point came when my wife, Roberta Hess-Poinar, an electron microscopist in the entomology department at the University of California at Berkeley, and I examined a forty-million-year-old fungus gnat encased in amber. We expected to see only the outline of the insect's cuticle when we looked at the specimen under a light microscope. Instead we observed dark areas within the outline, indicating that the body of the organism itself, not an impression or a fossil, was inside the amber. Excited by what we saw, we then examined the specimen under the much higher magnification of an electron microscope. We were astonished to behold the cells of the gnat's tissue: striated muscle cells, complete with nuclei containing what appeared to be chromatin, the part of the cell that carries the genes. Miraculously, even more delicate parts of the cell had also survived—ribosomes, mitochondria, the endoplasmic reticulum, lipid droplets of myofibrils. Suddenly amber was no longer a mere curiosity that enabled collectors to see shadows of animals from the ancient past; now it was a veritable time capsule, delivering real specimens, essentially intact, to the twentieth century.

The sight of the muscle cells gave me hope that DNA, too, might have survived. The late molecular biologist Alan C. Wilson and I set out to extract DNA from organisms in amber. We were widely thought to be wasting our time with such a futuristic project. Several granting agencies refused to fund us: the project was considered too avant-garde. But we could not set the idea aside just yet. Wilson, his graduate student Russell Higuchi and I continued with the research on our own time and money, working on weekends, during lunch hours and in spare hours between other projects. We made sporadic progress and discovered many samples that contained DNA. But we never did the definitive experiments that would determine whether that DNA was from the organism or was a contaminant.

Around 1987 the investigation ground to a halt, though both Wilson and Higuchi continued to experiment with DNA from Egyptian mummies and from dried-out ancient organisms. The story might have ended there but for the interest of my eldest son. In 1989 Hendrik Poinar, then a student at California Polytechnic Institute at San Luis Obispo, chose ancient DNA in amber as his senior project. He, working with his adviser, the molecular biologist Raul J. Cano, devised a method of cracking the amber and extracting and rehydrating the DNA. By 1991 they had obtained their DNA but had yet to determine whether it belonged to a more recent contaminant. Later that year our team—Cano, Hendrik and I—isolated, amplified and sequenced DNA from an extinct stingless bee suspended in amber that was between twenty-five million and forty million years old. After nearly a decade of unfunded research, the back-burner project had finally borne thrilling results. Ours is the oldest DNA reported so far, but future work will undoubtedly push the record much further back in time.

The discovery of DNA in amber and the finding that it can still be replicated raise in a novel and stimulating way one of the most venerable and fundamental questions in biology: What is life? I am willing to say, assuming that DNA from ancient amber will one day be expressed as a protein in a living cell, that ancient DNA is, in a sense, alive. I am aware that my position is a controversial one; after all, to most people the oldest living thing is the bristlecone pine tree, a mere few thousand years old. DNA from amber, if counted among the living, attests to an incredible longevity, now measured in tens of millions of years.

UNTIL THE ROMAN AUTHOR Pliny set the record straight, the origins of amber were shrouded in mythology and superstition. The ancient Greeks thought it was the solidified urine of a lynx or the tears of the Heliades, mythical sisters who were transformed into trees after the death of their brother and wept tears of amber. Pliny correctly traced its beginnings to tree resin, the familiar tacky pitch that exudes from pines and other conifers. The fossilization of amber takes place over millions of years. The resin solidifies on being exposed to the air, but it retains some pliability. With the passage of a few million years the many small molecules in the resin form a large polymer network, creating a kind of plastic substance called copal. In the form of copal the resin is no longer pliable, and it fractures if it is dropped. But copal is not amber, and geologists can only guess at the exact details of the process that transforms copal into amber over additional millions of years. It does seem likely that the copal fossilizes only if it is protected from the elements but exposed to seawater. The process goes on to this day, and new deposits of amber and copal continue to be unearthed.

Amber is found all over the world, sifted from the rocky beaches of the Baltic coasts or chiseled out of buried veins high in the mountains of Lebanon, Mexico and the Dominican Republic. It may have been the first stone ever valued as a semiprecious gem: amber has been worn as jewelry; carried as a talisman into battle; carved into dice, chandeliers and cups; and generally prized so highly it has led to bloodshed and intrigue throughout history. In the Middle Ages the Order of the Teutonic Knights wrested control of the Baltic amber trade from the Prussians and ordered all amber turned over to them—on pain of death. In the Second World War a room made entirely of amber, commissioned in 1701 by King Frederick I of Prussia, was stolen by the Nazis and remains lost to this day. The S.S. officer in charge of the room died in a Polish prison in 1986 at the age of ninety without having revealed its whereabouts. Since then art detectives, passionate amateur collectors and even the former East German secret police have searched for it in vain: notable in the fruitless quest was a German art dealer found stabbed to death in a forest near Munich in 1987.

Pine resin, similar to the substance that fossilizes into amber, is still used in Greece as it was in ancient days to stop wine from fermenting. Field doctors in the American Civil War kept wounds free of bacteria by dressing injuries with fresh pine resin. The Greek historian Herodotus documented the Egyptians' method of keeping their mummies so pristine: they poured myrrh, derived from the Middle Eastern tree *Commiphora molmol*, into the cranial, abdominal and pelvic cavities of the corpse, as well as over its linen wrappings. The method was so effective it kept out bacteria and fungi. In 1967 Peter Lewin, an electron microscopist at the University of Toronto, found cells with intact nuclei and cytoplasmic organelles in the hand of a mummy.

In amber the properties of resin that ward off infection and decay also work to preserve the integrity of DNA. Resin not only inhibits microorganisms from getting to the entrapped organism but also deactivates cellular enzymes that would otherwise dissolve components of the cell. Furthermore, resin rapidly displaces water from entrapped biological tissues, which would decompose them. But amber does not seal tissues in an oxygen-tight tomb. Recent work shows the amber matrix to be porous enough to slowly absorb and release gases. Only amber buried deep in the earth is in an oxygen-free environment and can adequately preserve an organism.

Once pitch envelops its victim, the organism is immobilized and sealed off. Most die within ten seconds of being trapped; we have found flies in the act of mating, insects whose parasitic worms were caught emerging from their bodies, organisms with blood-sucking mites still attached or with parasitic fungi sprouting spores on their cuticles. Often an organism is discovered with a gaping hole in place of the abdomen, the victim of a bird's attack. Some animals struggle so fiercely against the viscous resin that they leave their limbs in the sap or twist themselves into seemingly impossible positions.

Organisms in amber tell a story neglected by the fossil record. The protagonists are the delicate and the fragile, rare figures in the more usual kinds of fossilization. Amber inclusions are the only source of knowledge about extinct algae, soft-bodied protists and single-celled organisms. Through pieced-together fragments and sophisticated dating techniques paleontologists can recreate the ecosystem of extinct animals and plants, even to minuscule parasites and spores. Inclusions in amber span a wide range of organisms, from 220-million-year-old spores to a twenty-five-million-year-old pollen grain that was starting to germinate at the instant of its resinous immersion. Amber opens a gold-tinted window onto a world long vanished, inhabited by insects and beasts whose ways of life one can only guess at today.

FINDING A PIECE OF AMBER with an insect or a plant inside is an exciting, even singular event. But each amber inclusion is also part of an ancient mosaic of vanished ecosystems, making every such discovery part of a far richer story. Reconstructing the microcommunities of the resin itself, and the macrocommunity that extends beyond the tree into the greater environment, can be likened to weaving a vast tapestry, in which subtly connecting strands of life must be discerned among the thousands of plant and animal species.

Indeed, literally hundreds of thousands of individual inclusions confront the contemporary paleontologist. In Dominican amber alone more than 315 families of arthropod are represented. And aside from that range of animal biodiversity, hundreds of kinds of fungus and spore and many families of plant are found in amber. Among the vertebrates only frogs and lizards seem to have become trapped in amber, but feathers and fur attest to the presence of birds and mammals. Even without the direct evidence of the vertebrate fossils, the presence of those animals can be inferred from the remarkable number of their parasites, such as fleas, ticks, mosquitoes, biting midges, horse flies and blood-sucking flies.

Reconstructing the larger picture—the world beyond the resin-producing tree—demands more detective work from the paleontologist, with fewer clues to go on. A bamboo seed was recently discovered in Dominican amber. The top of the seed was hooked, and caught in one of the hooks was a strand of mammalian hair. An examination showed that the hair came from a carnivore; the only carnivore known to carry such bamboo seeds today is the jaguar. Thus perhaps an early cat once brushed against a bamboo stalk while prowling through the forest and picked up several stowaway seeds. The large cat likely then scratched itself against a tree to dislodge the seeds, and one of them fell into a deposit of fresh resin. Miraculously the seed and the hair remained embalmed there, in a drop of golden tree sap, waiting for millions of years to be discovered and deciphered.

The ability to clone and study the DNA of ancient or extinct organisms opens up a new chapter in the science of paleontology. DNA, of course, embodies the genetic code, which directs the growth and function of the cells of an organism. Comparing the genetic sequences of ancient organisms with the genes of contemporary life-forms should add immeasurably to the understanding of the evolutionary changes—and evolutionary stability—of certain traits.

DNA IN AMBER is only the most recent source of that coded record—preserved microscopically in machine-readable form—of the history of life on earth. In 1984, for instance, Russ Higuchi cloned a DNA fragment from the dried skin of the extinct quagga, a kind of zebra that was exterminated in the 1880s. The following year Svante Pääbo of the University of Munich cloned DNA from the skin of an Egyptian mummy. And last January Pääbo embarked on his latest attempt at molecular archaeology: analyzing the DNA of the Stone Age man buried 5,000 years ago and dug out of a glacier in the Otz valley eighteen months ago. Pääbo hopes to find remnants of viral DNA in order to decipher the path of viral evolution during the past 5,000 years.

Cloning DNA preserved in amber is complicated. The amber is submersed and chilled in liquid nitrogen, at a temperature of 196 Celsius degrees below zero, and then cracked open with the addition of a few drops of hot, sterile saltwater. The tissues thus exposed are removed with sterilized needles, and the DNA is extracted and placed into a soaplike solution. The container of DNA is then shaken, and the DNA fragments are shaken out. Because the DNA samples are the size of molecules, to study them investigators take advantage of one of their most important biological properties: their ability to replicate themselves. A single fragment of a DNA molecule can be placed in a solution that splits the double helix of the fragment in two. An enzyme in the solution then causes each half to reassemble a complementary mate out of the raw materials in the solution. After the process is repeated many times, the solution contains many identical copies of the original DNA, thereby enabling the investigator to study the sequence and determine the arrangement of its coded instructions.

But beyond cloning and study, a further application of ancient DNA seems irresistible: Could it not be put to use for the purpose it once served in the ancient world—to direct the making of proteins in a cell? In principle, the technology for doing so already exists. A piece of ancient DNA could be spliced into the DNA of a so-called retrovirus, which could in turn splice itself into the DNA of an ordinary cell nucleus. Because nuclear DNA encodes the instructions for the cell to make proteins, the cell might be induced to manufacture a protein encoded by the inserted ancient DNA. For example, investigators hope someday to place the DNA of extinct insects into drosophilid flies, so that the extinct DNA could give rise to traits thought to be lost millions of years ago. One problem with the scenario is that fragments of ancient DNA may not be complete enough to encode proteins. Even if they do encode proteins, incorporating those proteins into a host cell and getting them to replicate may not be possible; contemporary cells might suppress their manufacture. The fantasy envisioned in *Jurassic Park* may not be just around the corner, but it is certainly stimulating to contemplate the implications of more contemporary biological preservation. Could useful organisms such as medicinal plants, more recently extinct than the dinosaurs, still yield their healing alkaloids if their DNA were somehow preserved?

THE DISCOVERY OF viable DNA in amber raises important questions about accepted views of what constitutes life. Consider the various ingenious methods nature has devised to ward off death. Most higher animals become dormant for part of the year, and so they can stay alive in hard times. Bears go into a deep sleep and frogs burrow under the mud. Certain small invertebrates can survive in a dehydrated state for years or even decades. Some nematodes, roundworms that live in moist, hidden habitats such as the bulb of a flower or moss on a tree, fold up into a creased, inanimate form when the environment turns dry. The animal can survive nearly half a century in that state. A number of simple organisms such as fungi or bacteria metamorphose during lean times into even simpler, energy-conserving versions of themselves. Spores, for example, derive from countless unicellular and many multicellular forms of life. The oldest surviving spore on record was a bacterium discovered in canned meat after 120 years. In 1950 a seed of *Nelumbium rucifera*, a lotus flower native to southern Manchuria, bloomed after resting dormant in the mud of an ancient lake bed for more than 30,000 years.

None of the dormant states I have just listed poses any serious challenge to the standard scientific definition of life. One usually thinks of something as alive if it reproduces, mutates and is selected for; at least the dormant states can directly give rise to states that meet those criteria. The need to broaden the current understanding of what counts as living becomes most urgent when one examines the many levels of life. When an organism dies, for instance, organismic life stops; the organism ceases to function as a whole. But its parts can be removed and placed in a culture medium or in another living individual. Those parts can still be considered alive, not on an organismic level but on a cellular one. When the cells begin to die, sequences of their DNA that code for certain proteins can be cloned, or amplified, and inserted into a living cell. There they can continue to control the expression of the same proteins in the new cell.

I submit that any entity—organism, cell or molecule—capable of growth, reproduction or direct protein synthesis when placed in an optimum environment, is alive. For an adult woman's kidney the optimum environment might be the body of a child. For a 30,000-year-old lotus seed, it might be a warm, wet summer. For the DNA of an extinct insect, it could be the cell of its twentieth-century descendant. According to current estimates, at least 50 percent of well-preserved organisms entombed in Tertiary amber, organisms that date back to between twenty-five million and fifty million years ago, contain viable DNA. If all that DNA is alive, then life is a remarkably tenacious state of being. •

George O. Poinar, Jr., *is a professor of biology at the University of California at Berkeley. His most recent book,* Life in Amber, *was published in 1992 by Stanford University Press.*

ON THE MAKE

by GEORGE BASALLA

THE EVOLUTION OF USEFUL THINGS
How Everyday Artifacts—from Forks and Pins to Paper Clips and Zippers—Came to Be as They Are
by Henry Petroski
Alfred A. Knopf; 288 pages; $24.00

FORKS, PHONOGRAPHS, AND HOT AIR BALLOONS
A Field Guide to Inventive Thinking
by Robert J. Weber
Oxford University Press; 277 pages; $25.00

AMONG THE EXTENSIVE COLLECTIONS OF THE NEW-YORK Historical Society is a striking portrait, painted in 1796 by Frederick Bartoli, of the famed Seneca chief Cornplanter. A warrior of mixed lineage, Cornplanter fought against the early European settlers, later made peace with the United States, met with Presidents Washington and Jefferson and, in the last decade of his life, had mystical visions that led him to renounce Christianity and return to the worship of the Great Spirit of his Indian ancestors. A visitor to the museum can only pause and admire the leader's handsome visage.

A careful observer of the painting, however, will notice something curious: in his left hand Cornplanter holds a tomahawk, from the head of which emerges—incongruously—a clay pipe, tobacco smoke curling upward. The unusual implement, known as a pipe or "smoak" tomahawk, is not the kind portrayed in old Hollywood westerns. Nevertheless, it was the tomahawk most widely used among American Indians from the early eighteenth until the early twentieth century. The head of the tomahawk, with a cutting edge at one end and the pipe bowl at the other, usually was forged from iron and steel; it was fitted with a wooden handle, pierced longitudinally to serve as a pipe stem, yet it was sturdy enough to withstand rough treatment. Thus the device prepared the owner for both extremes of social engagement: in peace it could be filled with tobacco; in war it became a lethal weapon.

Given the ubiquity of the pipe tomahawk in American Indian life, it is surprising to learn that it was not in fact a native invention. For centuries native residents made do with stone axes but quickly abandoned them when European traders arrived and metal axes became available. In 1765 alone the English Northern Indian Department ordered 10,000 metal axes to trade for animal pelts and skins. At about that time an anonymous English blacksmith or ironware manufacturer hit upon the idea of the dual-purpose tomahawk, and it immediately captured the fancies of the American Indians. Native artisans later tried to copy the device in stone, but the task proved too arduous. Thus the pipe tomahawk, popular for more than two centuries in war and in peace, remained an imported item of Western technological ingenuity.

The pipe tomahawk is an apt entry into the bewildering world of artifice that human beings have created during the past three million years. Material culture has come a long way from the first stone ax. Karl Marx once noted with incredulity that craftsmen of nineteenth-century Birmingham, England, had access to more than 500 kinds of hammer, each one suited to a particular purpose. Today the typical office worker must contend with an equally dazzling array of seemingly indispensable gadgets, from paper clips, thumbtacks, staplers and staple removers to photocopiers, fax machines, push-button telephones and desktop computers with innumerable word-processing programs. The number of new products available to consumers is growing at an astounding pace: last year the U.S. Patent and Trademark Office awarded 109,728 patents, almost double the number ten years earlier. The modern world, to paraphrase William James, is a buzzing, blooming garden of artifacts.

Several recent books, the most notable by the Harvard biologist and ecologist Edward O. Wilson, have drawn attention to the astonishing diversity of the biological world. But what forces are responsible for the diversity of the human artifactual record? Where, for instance, did paper clips come from—and why? How did the fork get its tines? Do new species of invention spring forth—and die off—through some technological analogue to Darwinian natural selection? Into such heady territory enter two compelling new books on the subject, Henry Petroski's *Evolution of Useful Things* and Robert Weber's *Forks, Phonographs, and Hot Air Balloons*. As each author readily concedes, the human compulsion to invent is a subtle and murky one indeed.

OBSERVERS OF NATURE have long marveled at how the earth's creatures appear to be uniquely suited to their individual tasks in life: the woodpecker with its tree-battering bill, the aardvark with its snout seemingly tailor-made for slurping up ants. Naturalists before Darwin usually ascribed such neat confluences of form and function to the workings of some grand design, the consequences either of a deity or of some vague "final cause" of Aristotelian philosophy. If the fossil record offered evidence of past extinctions, such evidence only underscored the perfection of the current array of organisms.

Attempts to account for the diversity of the artifactual record have labored under a similarly progressivist notion, best expressed in the old saw "Necessity is the mother of invention." In the Aesopian fable a crow, parched with thirst, drops pebbles into a pitcher of water until the liquid rises to within sipping reach. Similarly (so the reasoning goes) people build wells and dams to acquire water; construct houses for shelter; domesticate plants and animals to ensure a steady food supply; and invent the wheel, ships and the rest of technology to meet their other pressing needs. On closer examination, however, the logic of this argument quickly dissipates. The automobile, such an inherent part of modern commuter society, was never "needed" in the proper sense. Nobody before 1895 was clamoring for the replacement of the horse as a means of transportation; indeed, for the first ten years of its existence, the automobile was all but dismissed as a novelty. Even the oldest known stone tools possess a degree of symmetry and finish that went beyond the need to produce an efficient cutting implement.

Petroski, a professor of engineering at Duke University, fully understands the difficulty of distinguishing between humanity's desires and its necessities. Early in *The Evolution of Useful Things*, an entertaining collection of case studies of silverware, tin cans, Scotch tape and other everyday items, he declares, "Invention begins not so much in need as in want." With that statement he rejects the modernist formula that form follows function. Certainly a can opener fulfills its function of opening cans, Petroski admits. But does that function require the modern opener to be shaped the way it is—hand-cranked, with a serrated wheel blade? Wouldn't a hammer and chisel serve as well? (They did until 1858, when Ezra Warner of Waterbury, Connecticut, received the first patent for a can opener, a device described by one commentator as "part bayonet, part sickle.")

But if artifactual form does not follow function, what does it follow? In a word, argues Petroski, failure. "The form of made things is always subject to change in response to their real or perceived shortcomings, their failures to function properly." In the past century Warner's invention has been superseded by several models of opener (not to mention several kinds of can), each touted as more convenient than the one before. The Bull's Head opener of 1907 featured an L-shaped blade and worked on the wedge-and-lever principle, but like others of its kind it left a dangerous jagged edge. In 1928 Sears, Roebuck and Co. advertised an "up to date can opener" with a serrated gripping wheel. Today the appliance store offers an array of openers, including electric ones, each with its faults: too hard for arthritic hands to operate, parts too inaccessible to clean, clutters up the countertop and so on. Clearly, Petroski notes, the success or failure of an artifact depends on a long list of factors. Function is one of them, but aesthetic, economic and moral factors also play a role. "Luxury, rather than necessity, is the mother of invention," he writes.

Petroski avoids succumbing to a progressivist view of the development of technology. Each artifact does *not* follow another in some rank order, with each successive version better suited to its task than the preceding one, and each improvement spurred by an objective analysis of the failures of the predecessor. The kind of failure described by Petroski cannot be anticipated in the laboratory. Hence, in his technological universe, there is no such thing as perfection. "New products are seldom even near perfect, but we buy them and adapt to their form because they do fulfill, however imperfectly, a function that we find useful." As the English inventor Henry Bessemer once proclaimed, in a statement quoted by Petroski, "The love of improvement knows no bounds or finality." But where Bessemer sees progress Petroski sees a series of artifacts whose forms are designed and redesigned, modified and remodified, to suit societal wants that are themselves in constant flux.

Petroski's theory of technological change has much more in common with Darwin's theory of evolution than with theories of technological progress. Like Darwin, Petroski hesitates to assign a final goal to the process of invention; like Darwin, Petroski emphasizes changes brought about by the pressures of existing circumstances. According to Petroski's reasoning, the world of artifacts is so diverse because the definition of failure is constantly shifting. If technological change were governed instead by a set of scientifically determined criteria for efficiency or function—say, some quantifiable essence of can-openerness—then made things would come in far fewer flavors.

Of course, there are limits to the Darwinian analogy. Within the organic world, species evolve by default: those creatures whose genes render them less fit for their surroundings do not survive long enough to pass on the information to the succeeding generation. If a species "fails" and becomes extinct, the failure is not the outcome of the machinations of some Great Intelligence; rather, it is caused, more humbly, by the subtle interplay of contingency and chance.

The world of artifice, in contrast, is intelligence incarnate, specifically intelligence of the human kind; failure, as Petroski notes, is largely in the mind of the perceiver. Yet the questions remain: Who are the perceivers of artifactual failure? Who decides that the latest model of can opener, car, pencil or paper clip is not up to snuff: the citizens whose daily lives depend on such items? or the engineers and inventors who create them? Mostly the latter, Petroski argues. Technologists, attuned to the advantages and disadvantages of various materials and to the minutest changes in design, are among the first to call attention to perceived failure—and the first to do something about it.

Consider the lowly paper clip. The earliest paper clips were simple straight pins that perforated the paper and—all too often—the fingers of those who handled the pinned sheets. Pins continued to be used as fasteners well into the twentieth century, though by the middle of the nineteenth century inventors had begun patenting paper clips that gripped sheets of paper without pricking them or their handlers. But the impetus for changing from pin to clip did not come from disgruntled office workers. Rather it was inventors who first perceived the "failure" of straight pins and then continued to find fault with every paper clip invented thereafter. The fact that some twenty billion perfectly adequate paper clips are made and used each year has not halted the inventor's quest for a better clip. At this very moment inventors are grappling with “the paper clip problem,” a conundrum whose existence owes more to the restless mind of the inventor than to the grave deficiencies of existing paper fasteners.

Finding fault with and improving an invention are only half the battle; consumers must then be convinced the device they already own is not as desirable—indeed, not as necessary—as the “new, improved” model. Consider the zipper, another of Petroski’s numerous case studies. The device originally was invented in the late nineteenth century as a shoe fastener that would eliminate the “chore” of buttoning one’s shoes. By 1915, when a working zipper was ready for manufacture, the Hookless Fastener Company was faced with the problem of “how to create a demand . . . for something which most people had never seen and few had ever dreamed of.” 3M, the manufacturer of the Post-It Notes that now litter the walls and desks of offices worldwide, solved a similar problem by distributing free samples of the product until would-be customers discovered that they could not live without little sticky squares of paper. Until the mid-1980s, when Post-It Notes hit the market, no office worker had ever expressed a need for the novelty. The pipe tomahawk was subject to similar forces. American Indians had never cried out for such an invention; the device did not become a necessity until after it had appeared on the scene.

PETROSKI DESCRIBES in engaging detail the incremental changes that led from straight pin to paper clip, meat knife to fork. Yet his purely gradualist theory of technological evolution founders when it meets a prime invention. Although every novel artifact is modeled to some degree after some antecedent, an invention is more than a gradual extension of an existing one. The automobile was not simply a minor improvement on the horse and buggy: the car required a motor, a feat of inventiveness and engineering unto itself. Similarly, the Wright brothers’ airplane was more than just a modified kite; the transistor was more than just a redesigned vacuum tube; and the pipe tomahawk was an ingenious conjunction of two disparate forms. Petroski’s analysis, though it emphasizes failure, is still an analysis of engineering failure. As such it cannot account for those flashes of insight that suddenly enable the inventor to modify or combine old forms and thereby create new ones.

Therein lies one of the critical differences between the evolution of organisms and of artifacts, a difference first pointed out by the twentieth-century American anthropologist Alfred Louis Kroeber. In the organic world, new complex forms emerge as they split off from the main branch of the tree of life. The process is relatively slow, because it depends on the sexual reproduction of organisms within a species; hybrids and mutants do appear, but most of them are unable to pass on their novel forms. In the made world, by contrast, there are no boundaries, no inherent prohibitions against the mating of different species of artifact. Bicycle and horse-drawn carriage were merged to create the motorcar. The tobacco pipe and metal ax—two objects typically considered unrelated—were joined to produce the pipe tomahawk.

In his book on inventive thinking Robert Weber, a psychologist at Oklahoma State University, extends Kroeber’s argument on the speed of technological evolution. Weber demonstrates that by simply joining pairs of artifacts to produce new artifacts a process is begun that quickly yields a large number of inventions. Several sharp blades can be combined to create a saw. Two blades can be joined in opposition to create scissors. The new artifacts lead to still more inventions: wood saws, hacksaws, rotary saws; scissors for paper, cloth or fingernails. Because made things are not constrained by the strict rules that govern the transmission of genetic material, it is theoretically possible for the artifactual world to display even greater variety than the organic world.

UNLIKE MOST COMMENTATORS on technological change, though, Weber focuses exclusively on the cognitive aspects of the subject. For him artifacts are more than a physical presence: they reveal the “hidden intelligence” of their inventors. By parsing inventions, breaking them down into their constituent units, Weber aims to disclose the strategies and procedures employed by that intelligence in creating new things. Armed with a long list of such heuristics, each one garnered from his study of the specific features of an invention—Leonardo’s helicopter, the Wright brothers’ airplane, such things as hammers, needles, soup ladles, doorknobs, Velcro fasteners, stone tools—Weber strives to explicate the flash of insight that lies at the heart of inventiveness.

Weber notes, for instance, four kinds of heuristic for joining. The first is the joining of inverses: an eraser joined to the end of a pencil removes what has been written; a claw joined to the end of a hammer takes out the nail driven in with the other end. In the second kind of joining, two complementary inventions can be combined to increase the utility of each: some cameras incorporate a light meter, and some hair cleaners combine shampoo and conditioner. Third, an invention can link individual devices having shared attributes: the various “blades” (real blades, plus openers, awls, saws and so forth) on a Swiss army knife share a handle and a storage case. The fourth item in Weber’s catalogue he calls an emergent-function heuristic, in which joined inventions yield new capabilities not inherent in the parent ones. The hand-cranked apple peeler, for instance, was built on the principle of the lathe; with a few minor changes to the form, new capabilities—coring and slicing—quickly emerged.

Weber devotes an entire chapter to joining as a way of generating new inventions, and he identifies seven kinds of combination, from a weak interaction among the constituent parts to a strong, synergistic one. His step-by-step investigation provides a number of insights into the act of invention. For example, he notes that the Wright brothers’ airplane was a design that aimed simultaneously to optimize three distinct variables: lift, control and power.Yet in the end Weber’s method of analysis proves less than satisfying. The major flaw is that his view of the heuristics of invention is derived only from a study of the inventions themselves. Far more insight might have been gained from the diaries and laboratory notes of the inventors or from the work of scholars who have studied inventions in their historical context. In effect, Weber focuses almost exclusively on the utility of artifacts, a trait that, as Petroski recognizes, is only a part of the story.

Accordingly, Weber’s analysis falters when it encounters an invention such as the pipe tomahawk. In Weber’s heuristics the device would rate as an example of an unrelated assemblage, "the weakest form of integration, a null or zero join." What functional advantage could possibly be gained by joining a pipe and a tomahawk? Yet the historical record testifies that the implement proved overwhelmingly popular, and Weber leaves the reader unequipped to discover why. By the same token, the automobile came into great demand after 1905, even though plenty of horses were still available to get people from point A to point B. Clearly more than utility spurred the rise of the industry. Indeed, the Model T lost favor when Henry Ford's competitor, General Motors, realized that consumers wanted more than mere functionality. GM offered its customers a hierarchy of five models, from the Chevrolet to the Cadillac, and annual model changes emphasizing stylistic and minor mechanical innovations.

IT IS UNFORTUNATE that Weber gives such short shrift to the cultural and social factors driving invention; those factors, it turns out, are the predominant forces of technological evolution. Even Petroski, who analyzes silverware for its ability or inability to pick up food, is unable to explain why, in the nineteenth century, a distinct kind of fork was required solely to spear asparagus, or why three kinds of spoon were needed, respectively, to stir coffee, tea and hot chocolate. If Post-It Notes or the latest model of paper clip catches on, the reason in part is that the inventor has tapped in to some general dissatisfaction with the array of consumer products already available, functional as they may be. Yet that explanation alone is inadequate. Consumerism is a fairly recent phenomenon, a produce of the nineteenth century.

Of course, any attempt to elucidate all the societal forces that drive invention would lead the scholar into deep water; it would hardly be fair to hold either Petroski or Weber to such an account. Their books are knowledgeable and engaging, sure to be enjoyed by the vast majority of readers not inclined to wade into an intricate social history of, say, Victorian table manners. As Petroski admits, the precise causes for the evolution of artifacts are likely to remain elusive because the criteria of success and failure "will always retain an aspect of subjectivity." But such warnings are unlikely to deter those people who imagine that the history of invention can somehow shed light on the shadowy origins of creativity—even though that urge to explain derives more from the wants of historians than from some biological need. •

GEORGE BASALLA *is professor of history at the University of Delaware. He is the author of* THE EVOLUTION OF TECHNOLOGY, *published in 1988 by Cambridge University Press.*

Laurence A. Marschall

The Outlandish Passions of the Pack Rat

FINDERS, KEEPERS: Eight Collectors, *by Rosamond Wolff Purcell and Stephen Jay Gould; W. W. Norton & Company; 155 pages; $50.00*

When Geoffrey Braithwaite, the protagonist of Julian Barnes's eccentric novel *Flaubert's Parrot*, visits an exhibit of Gustave Flaubert memorabilia, he is shown an item reserved for special visitors: a shoe box inherited by Flaubert from his physician father, containing the severed heads of two hanged criminals, the rope marks still evident around their necks. The incident is as unsettling as it is bizarre, for it hints at a voyeuristic side of human nature, a tabloid facet of the urge to know.

Rosamond Wolff Purcell's detailed color photographs of real items from real collections are no less bizarre than the inventions of Julian Barnes. In Leiden and Saint Petersburg she beholds the lifework of Frederik Ruysch, a seventeenth-century Dutch anatomist who collected limbs, organs and the bodies of fetuses and newborn babies. Ruysch transformed tissue preservation into an eccentric kind of art, injecting a fluid that highlighted the circulatory system as graphically as the red lines in a medical illustration. Three centuries later his anatomical specimens retain a ruddy glow that almost conceals their lifelessness. An infant's head, hemmed by a collar of fine lace, squints out from a glass cylinder; a disembodied arm arches upward in a jar, an eye socket suspended on a thread held in its fingertips.

Peter the Great, who visited Holland in 1697, was said to be so touched by one such preparation by Ruysch that he knelt and kissed the child's face. He later purchased the entire collection and took it home to Russia, adding it to an enormous "cabinet of curiosities" that already contained a two-headed sheep, a four-legged rooster, a stuffed and mounted elephant, the seven-foot giant who had served as Peter's footman, and a collection of human teeth extracted from various subjects by Peter himself, not necessarily for medicinal purposes. Were these scientific specimens, objects of art or merely the excesses of one of the idle rich? In Peter's time such collections were high fashion, and such distinctions were unclear.

Of the collections portrayed so vividly in *Finders, Keepers*, those of Ruysch and Peter the Great seem the most jarring to modern sensibilities. Less gruesome and more in keeping with scientific practice is the work of Eugen Dubois, a late–nineteenth-century Dutch curator who made plaster casts of the brains of fossil and living animals to chart the evolution of intelligence. Also more understandable is the driving curiosity of the nineteenth-century collectors Thomas Hawkins and Mary Anning, who chipped delicate fossils from the sediments of coastal Britain; the German physician Philip Franz von Siebold, who in the 1820s smuggled exotic specimens ranging from hermit crabs to stuffed monkeys out of Japan; and the late taxonomist Willem Cornelis van Heurn, who filled his collecting drawers with skins of dogs, pigs and moles [see the photograph above] to document the subtle variability within a species.

Purcell's camera, like the work of the collectors she admires, focuses on particulars. In the iridescent feathers of a bird of paradise, in the quizzical stare of a stuffed hedgehog, in the meticulously inked identification numbers on a skeletal claw, or even in the severed arm suspended in a jar with the care of the sculptor, she captures the obsession with beauty and order that drives the true collector. In the accompanying text Stephen Jay Gould, a paleontologist and curator at the Museum of Comparative Zoology in Cambridge, urges the viewer to appreciate the scientific insights that can be gained from the embalmed species. Folly and excess there may have been, but the grand generalizations of modern biology would be unsupportable without the work of the collectors of the past.

THE WHOLE INTERNET: User's Guide and Catalogue, *by Ed Krol; O'Reilly & Associates; 376 pages; $24.95*

On a recent morning, in search of an eyewitness account of a seventeenth-century solar eclipse, I browsed through library catalogues in Guadalajara, Strassburg and Munich. After lunch I viewed astronomical images beamed to Tokyo via a Japanese satellite, monitored sky conditions over Flagstaff, Arizona, put the finishing touches on a paper with a collaborator in Boston, and chatted about politics with a cousin in Tel Aviv. All this I did without leaving my study; a few lines typed into my personal computer summoned the desired information to my screen. Like many of my academic colleagues, I am connected to the Internet, a sprawling web of computers that brings the world to my desktop and enriches my life. Although I've been using the Internet for scarcely two years, I can't imagine staying home without it.

The global computer network has been spreading invisibly, like the underground root system of a blossoming rose, for almost twenty years. In the 1970s the Department of Defense funded an experimental network called ARPAnet, which linked mainframes engaged in military research. That experiment was so successful that the National Science Foundation soon followed suit with a network for its own members. Soon hackers developed ways of sending mail messages and pictures over that network in a flash, of holding group discussions and playing games.

No longer was a person limited by the manpower, software or hardware of a local site. If someone else had written a program, set up a data base or installed a high-speed processor, anyone on the network could use it. So many resources were available that everyone wanted to connect to everyone else, and by the late 1980s they could, on a loosely overlapping array of networks known as the Internet. Today literally millions of computers—at businesses, homes, libraries, government offices, even public schools—are connected directly or indirectly to one another on the Internet.

If all that is news to you, have no fear. Ed Krol, a computer systems manager at the University of Illinois, has written a genial guide to the Internet that assumes little more than the ability to turn on a PC. Krol starts with the basics, describing how to capture files from distant computers, how to log in to network bulletin boards, how to send mail messages and how to read them. Yet veteran users also will find the book invaluable for its technical details and for its listing of arcane sources of information. With *The Whole Internet* at your side you can read the latest Department of Agriculture commodity reports, find out what fish are biting in Georges Bank, locate a rare statistics program or download a recipe for Bavarian ale.

With its digital traffic growing exponentially, the Internet may soon join the telephone system and the interstate highway network as a fundamental utility for the twenty-first century. Commercial enterprises, some of them listed in the ample appendices, already are making the Internet available to users who do not have direct access at work or at school. Krol's book thus is as timely as it is readable: it opens gateways to a new electronic world.

PI IN THE SKY: Counting, Thinking, and Being, *by John D. Barrow; Oxford University Press; 317 pages; $25.00*

Galileo Galilei, writing at the dawn of the scientific era, likened the secrets of nature to a book lying open. "But we cannot understand it if we do not first learn the language and grasp the symbols in which it is written," he cautioned. That language, he added, is mathematics, "and the symbols are triangles, circles and other geometrical figures, without the help of which . . . one wanders in vain through a dark labyrinth." Almost four centuries later Galileo's wisdom seems well justified, yet why mathematics is so successful in describing the world remains an opaque mystery at the heart of the maze. How is it that mathematics so compactly describes the workings of the cosmos? What is it about nature that allows its rich variety to be confined by the rigid bonds of logic?

Such are the questions John Barrow, an astronomer at the University of Sussex, addresses in his ambitious and entertaining new book. Is it possible, he asks, that nature is inherently mathematical—that mathematical entities are at least as real as the objects of nature? If so, mathematics must exist a priori, to be discovered just as new particles, life-forms and galaxies are discovered. By such reasoning two plus two is four because twoness and fourness are real entities, as is the relation between them.

Or perhaps the opposite is true. It is possible to imagine a natural world with features different from the present one: people with two brains instead of one, galaxies shaped like pretzels instead of spirals, atoms the size of houses. But two plus two is always four. In that respect mathematical truth seems to differ fundamentally from physical truth. Perhaps mathematics is just an invention, a mental tool that enables the mind to fit sense impressions, procrustean fashion, into the molds dictated by some internal logic. Perhaps, as Immanuel Kant had it, mathematics says as much about the workings of the mind as it does about the natural world.

Examining such issues in a broad philosophical and historical context, Barrow lays out a number of views on the origin and nature of mathematics. He explains how people learned to count and how the meaning of numbers changed from culture to culture and from time to time. As mathematics grew in sophistication, so did the wonder and mystification of its practitioners. Even in the present century opinion has been divided. Some mathematicians, following Plato and Pythagoras, view each equation as a shadow of the real world of numbers and relations. Others see their subject as a mere elaboration of the formal rules of logic, whose aim is to derive theorems and avoid contradictions.

Who is right? The latter, purely formal approach to mathematics encounters many problems, notes Barrow. The brain is obviously part of nature: Does the structure of the world then determine the genesis of logic? And why is it that of so many mathematically possible worlds, only one seems to exist? Don't those facts lend credibility to the objective nature of mathematics?

Yet the view that mathematics is an entity "out there," to be discovered, is also problematic. What does it mean to say that numbers exist independent of the physical world? How could anyone ever verify their existence? Troubled by such questions, Barrow regards the claims for a Platonic reality as empty and ultimately unsatisfying.

There seems to be no way out of the philosophical labyrinths. Barrow remains exhilarated by the complexity of the challenge, however, and with him as the guide the reader need not despair at the situation. In the end, Barrow admits, we cannot separate our understanding of nature from the operations of nature itself. "We are," he concludes, "the children as well as the mothers of invention." •

***LAURENCE A. MARSCHALL,** author of* The Supernova Story, *is a professor of physics at Gettysburg College in Pennsylvania.*

Initial Conditions

Editor's Notebook

IS THERE NO END to the revisionist impulses of the age? As this magazine went to press, the armed services were being asked to face the reality of homosexuals in uniform and let gays and lesbians serve openly. Now Anne Fausto-Sterling has the temerity to suggest, in our cover story titled "The Five Sexes" (page 20), that physiological reality forces people to revise their thinking about an assumption even more fundamental: that all children are born either girls or boys.

But surely, Fausto-Sterling's provocative title notwithstanding, the number of sexes is one question that science—not to say every Jane and Jack among us—must have settled long ago. And it is true that the sexual physiology of our species has already been described, albeit only in surprisingly recent times: by the urologist Hugh H. Young in 1937. But by Young's account the variety of human sexual "equipment" is breathtaking, indeed shocking to those of us who are encountering it for the first time. It includes virtually every conceivable combination of external sexual characteristics, as well as various mixtures of genetic and hormonal potential.

As it happens, the physiological reality is almost unknown outside medicine—and that fact alone is symptomatic of a society unwilling to accept the truth about its members. As Fausto-Sterling tells it, the truth is that the "condition" almost all physicians lump into a category called intersexuality is not all that rare. She reports that one out of every twenty-five infants is born neither male nor female. Fausto-Sterling's real interest is in what can be made of the psychological aspects of five sexes. Nothing much is known, it turns out, primarily because, almost universally, intersexual infants are surgically altered so that they can fit into one of the two prevailing sexual categories. That intervention *may* safeguard the physical and psychological well-being of the child. But Fausto-Sterling argues that such measures are never even called into question.

Elsewhere in this issue we look at several worlds once thought to be lost forever, whose traces are now being recovered in the nooks and crannies of the contemporary world. From rural Bosnia, where horrific acts of tribal rape and murder are being carried out under the Orwellian banner of "ethnic cleansing," comes the story of an intrepid linguist, who discovered Homer's ancient tradition of oral epic song preserved in the chants of coffeehouse poets (see Mary Knight's "Homer in Bosnia," page 10). The mnemonic formulas of those Bosnian bards—stock phrases, metrical vamps, rhetorical flourishes—hold the key to the literary works that have defined our own concept of the adventure tale, Homer's *Iliad* and *Odyssey*. There is rich irony here, given the contemporary civil war in the region. Early in this century coffeehouse patrons were asked what they made of the tales of ancient ethnic rivalries told by the songs. The strife has passed, they replied. "At the time it was so, now one evokes it in memory."

Another lost world—this one reclaimed from forty million years ago—has been discovered inside the golden stone called amber (see "Still Life in Amber," by George O. Poinar, Jr., page 34). There, frozen in their death throes, are mosquitoes and other insects that might once have feasted on the dinosaurs. Poinar and his colleagues have learned how to crack open the amber (you immerse it in liquid nitrogen, then drip hot saline solution onto the chilled rock) and extract and clone the DNA from the insects. The next step is to find a strand of DNA long enough to include a gene, insert the gene into a fruit fly and resuscitate the proteins of long-extinct species. Now, if the resuscitated DNA were to come from the blood cells of the dinosaur that had unwittingly been the mosquito's last meal . . . but then, that is the premise of Michael Crichton's novel *Jurassic Park*, "soon to be a major motion picture."

—PETER G. BROWN

PEER REVIEW

Letters from Readers

PERSONALITY PLUS

Nowhere in Frank W. Putnam's article on multiple personality disorder (MPD) ["Altered States," November/December] does he mention the body of opinion in psychiatry and psychology that either rejects the concept of MPD or considers it vastly overdiagnosed. From 1816 until 1960 cases of MPD were reported at a rate of about one every two years. Recently that rate has increased enormously, and there are some therapists who say they have diagnosed MPD in as many as a hundred patients. Typically several of those patients are alleged to have more than ten distinct personalities.

The plausibility of that diagnosis is highly suspect. Martin T. Orne and Nancy K. Bauer-Manley, both of the University of Pennsylvania, reported in 1991 that therapists themselves seemed to be polarized into two groups: one "reporting large numbers of cases" of MPD, and the other believing "that if MPD occurs spontaneously at all, it does so extremely rarely." In a survey I conducted of thirty-eight physicians and others with a special interest in the subject, four indicated that MPD was a valid condition and quite common; fifteen thought it occurred occasionally but was overdiagnosed; and nineteen thought it was an artificial production, encouraged by physicians, patients, films, books or the media, or other factors. I cannot say that my sample was representative, but it did make clear that among a group of informed individuals, half did not believe the diagnosis was valid at all, and the great majority of the rest thought it should be diagnosed only occasionally.

It is regrettable that this possibility was ignored by Mr. Putnam.

HAROLD MERSKEY
London Psychiatric Hospital
London, Ontario

Frank Putnam replies: In my article I describe a new approach linking MPD to the discrete behavioral states of consciousness seen in early child development and in a number of psychiatric disorders. Thus the epidemiology and the validity of the disorder were not a focus of the article. Yet the diagnosis of MPD, like a number of other psychiatric diagnoses, has drawn criticism about its prevalence and validity. Mr. Merskey notes that since the early 1800s there has been a steady trickle of cases reported in the medical literature, and he then expresses concern that the number of reported cases has increased in the past two decades. But an increase in identified cases is not unique to MPD; in the same period Lyme disease, obsessive-compulsive disorder and the battered-child syndrome, among other conditions, all have been reported more often than before. In each instance the increase reflects a greater professional awareness of the clinical presentation of the disorder. An increase in the number of diagnosed cases is not grounds for declaring a medical or psychiatric diagnosis invalid. Rather it affirms the clinical utility of that diagnosis in delineating a group of patients who do not fit into other categories.

The assertion made by Mr. Merskey here, and by Orne and Bauer-Manley elsewhere, that the vast majority of MPD cases are diagnosed by a few clinicians is not supported by a review of the literature. In every area of medical research some specialists and researchers contribute larger samples and publish more articles; nonetheless, a review of the names of authors contributing to the hundreds of recent articles on MPD reveals a healthy diversity of authorship, similar in range to the experts who discuss medical or psychiatric conditions of comparable prevalence. Notwithstanding Mr. Merskey's unscientific opinion poll, MPD is not a diagnosis made by only a few clinicians. Critics who charge that MPD is induced in susceptible patients by films, books or the media have never explained why patients would develop that disorder and not eating disorders, obsessive-compulsive disorder or manic-depressive illness—all of which get substantial coverage in the popular media.

Certainly some clinicians agree with Mr. Merskey and disbelieve or suspect the validity of MPD. I even agree with him that MPD is being overdiagnosed in some instances, and I have published suggestions for more stringent diagnostic criteria. But concerns about the validity and true prevalence of a psychiatric diagnosis are not unique to MPD. For example, the validity of the diagnosis of schizophrenia has been vociferously challenged. Questions about the prevalence of MPD can be addressed by careful epidemiological research. And debates about its validity should focus on examining those "forms of validity" required of all psychiatric disorders: Does the disorder have a well replicated, highly specific clinical description? Can it be identified with specific tests? Can it be distinguished from other psychiatric conditions? By all those criteria the diagnosis of MPD stacks up very well, compared with most other psychiatric disorders.

In my article I attempt to demonstrate that the apparently bizarre symptoms of MPD can be understood as the result of overwhelming trauma, often child abuse, which act in early childhood on a normal developmental process, the discrete behavioral state. As I clearly state in the article, the alter personalities of MPD patients are not to be mistaken for whole people. Rather they are best conceptualized as discrete states of consciousness with limited functions and dimensions of personality. In aggregate, they make up the personality of the patient. If one understands that even a newborn child manifests at least five distinct behavioral states, it is not surprising that some adult patients exhibit far more than ten personalities. There is still much to learn about MPD, but research on the disorder is teaching us about the integration of the many aspects of our own selves that we juggle in our daily lives.

SALT SOLUTION

We applaud John Kolars's view, presented in "Trickle of Hope" [November/December], that there is promise for an eventual solution to the critical issues of water rights in the Middle East. For more than a decade there has been an international interest in using both saline waters and seawater for agricultural and industrial purposes. The basis of that interest is known as the biosaline concept, which envisions the harmonious interplay of biological systems with saline environments, to the ultimate benefit of man.

Certainly, research on the biosaline concept could be accelerated and its applications investigated with the aid of modern advances in biology. But the most important point is that the sensible application of modern knowledge to the use of saline water or seawater opens new opportunities that could reduce the potential for armed conflict.

JAMES C. ALLER
Great Falls, Virginia

OSKAR R. ZABORSKY
McLean, Virginia

PLAYING THE NUMBERS

In his essay on the history of telephone numbering conventions ["The Numbering Crisis in World Zone 1," November/December] Brian Hayes could have added that recent telephone-system changes have eliminated an important bit of information the consumer once received when dialing a number.

I live in area code 215 in Pennsylvania, just across the Delaware River from area code 609 in New Jersey. I can make calls toll-free to some telephone exchanges in each area code, but I must pay for calls to other exchanges within my own area code. The same would be true if I were making calls from the other side of the river. It used to be easy to tell whether a toll number was being dialed. All toll calls had to be dialed with the prefix 1.

That has changed. Now I must dial all 215 numbers without the 1 prefix and all 609 numbers with it (plus the area code itself, which previously was not needed). You have to look in the directories to see whether a toll is being charged on a call to either area code.

RICHARD A. CYLINDER
Yardley, Pennsylvania

PRIME TWINS

Enrico Bombieri is a great mathematician; his article "Prime Territory" [September/October] is entertaining; and he comes down solidly on the side of the believers in the Riemann hypothesis.

But he doesn't seem to have read the story of the twins very critically. They loved the calendar game, and they were good at it. They had exceptionally good memories. And then there was the "primes" game. Why is Oliver Sacks so sure that, as Mr. Bombieri puts it, "they were unable to make ordinary calculations"? Perhaps they secretly knew how to find out whether two numbers have a common prime divisor, but they could not (or did not) communicate their method.

Now my questions to Sacks: How many six-digit primes did they produce in about how many minutes? Describe what you call your "precious book of primes." It seems to contain all primes less than 1,000,000, as well as some primes with eight or ten digits. You say that one of the twins, John, mentioned a nine-digit number. Mr. Bombieri says it was a prime number, as if you had all forty-five million nine-digit prime numbers in your book! Did you save the twenty-digit "primes" for posterity? I would consider it a great victory for the twins if those numbers, even if not prime, had no prime factor less than 1,000.

There are many algorithms for checking primality. So why call the twins' talent "bizarre, . . . even otherworldly," when there may be no more to it than, for example, checking 2^n-2 for divisibility by n? Prodigious, I agree, and it's a pity their talent is gone.

Let's talk problems. Problem 1 (to prove): There is no odd perfect number. Problem 2 (to prove): There is no prime of the form 2^n+1 for n greater than 16. And so forth. When Mr. Bombieri says that problems of this kind are uninteresting, I think what he means is that one should not waste time looking for numerical examples. But note that if an example exists, the problem is decidable. Therefore any proof that the problem is undecidable is a proof that the problem as stated is true. What Mr. Bombieri should admit is that they are uninteresting to him because he is convinced they are too hard to prove.

A minor flaw: Someone failed to check the exposition of the RSA public encoding key system with a competent colleague and made a bit of a mess of it. Still, changing "such a multiplication" to "some arithmetic" and deleting the last line of the paragraph should avoid misleading the reader.

Finally, I can't resist adding that this is the first time I have ever seen a list of the small Mersenne primes (primes of the form 2^n-1) with the six-digit prime $2^{17}-1$ omitted. Any time in the past forty-four years that someone has mentioned 131,071 in my presence, I have been elated and ready to mention 524,287 in return.

JOHN L. SELFRIDGE
Northern Illinois University
De Kalb, Illinois

Enrico Bombieri replies: Oliver Sacks is a well-known and respected scientist and a good writer who knows how to tell an interesting story. I do not know which table of primes he used, but I find it credible that he had access to a table of primes up to 1,000,000, which included several other, larger primes up to ten digits as examples of large primes. Sacks does not say that his table contained all nine- or ten-digit primes. He did check the smaller numbers, and they were primes. It is not clear to me, after rereading Sacks's account of the twins, whether he checked the nine-digit number for primality, so the statement that that number was a prime is a misunderstanding on my part, not an embellishment by Sacks. Sacks says he had no way of checking the twelve-digit numbers, but he is silent about the nine-digit one. He does imply that his tables included some primes of ten digits, which indeed provoked the interested reaction of the twins.

As for any algorithms the twins might have applied, that is anybody's guess. A pedestrian suggestion would be that they could test small factors quickly, and so numbers passing the test had a high probability of being prime. Mr. Selfridge mentions the Fermat (or Chinese) pseudoprime test. Sacks also discusses the point, and he mentions a suggestion that the twins could have used some visual form of modular arithmetic.

Mr. Selfridge asks, "Why call the twins' talent 'bizarre, . . . even otherworldly,' when there may be no more to it than, for example, checking 2^n-2 for divisibility by n?"

That is idle speculation. The real question is another one. The twins had an IQ of sixty, and they could not do simple addition or subtraction with any accuracy; they had no understanding of what is meant by multiplication or division. I do not think those statements are inferences by Sacks; clinical cases much like the twins are constantly subjected to tests of all kinds that measure their mental and psychic abilities. It is mind-boggling, at least to me, that the twins could memorize large numbers and that they were interested in such abstract games as naming prime numbers. The average person, me included, has difficulties in memorizing more than a dozen objects at a time. What is bizarre, indeed even otherworldly, is that two people with IQs of sixty would choose to talk with each other about prime numbers. And about the divisibility test nonchalantly mentioned by Mr. Selfridge, I can say that many people with IQs well above average, including several of my nonmathematical friends, have difficulty comprehending it, let alone applying it.

Mr. Selfridge suggests my real motive for stating that certain problems are uninteresting is my belief that such problems are too hard to solve. He mentions the problem of proving there is no odd perfect number. He then says, referring, I believe, to my statement about undecidability, that "a proof that such a problem is undecidable is a proof that the problem as stated is true."

But Mr. Selfridge distorts my statements about undecidability, which I vaguely and purposely limited to "certain problems of that kind." If Mr. Selfridge had stated the problem as: "There are only finitely many perfect numbers," he would have an example of a problem similar to his problem 1, which could well be undecidable. Is the problem undecidable? I do not know. But I do know that certain problems easily formulated in arithmetical terms, such as the halting problem for Conway machines, are undecidable. That is the closest answer so far to my original question. So let us look at problem 1 again.

There are two sides to the problem about the existence of odd perfect numbers, namely its interest and its difficulty. As to interest, in my opinion, the problem is the typical candidate for the curio shop, the ultimate search for the perfect oddity. As such, it is of no interest to me except for its recreational side. As a mathematical problem I think it is uninteresting because it is an isolated question. And as to difficulty, there are so few examples of undecidable problems that I think it is an interesting enterprise to explore the boundaries between number theory and mathematical logic. My guess is that many "natural" questions are undecidable in arithmetic. If that is indeed the case, the conclusion is that what at first sight appears "simple" and "natural" need not be so in reality. So why is one question more interesting than the other? The answer is that my understanding of mathematics would change very little by finding an odd perfect number, but would certainly change a lot by knowing for sure that the undecidable is always around the corner!

I agree with Mr. Selfridge's criticism of the exposition of the RSA system and with his proposed change of the phrase "such a multiplication" to "some arithmetic." The multiplication that had to be carried out was to compute a certain power of a number (the message) modulo the product of the two primes, and the text got oversimplified. On the other hand, one should be cryptic and not overly clear while talking about cryptology.

Alas, n=17 is indeed missing from the list of exponents of Mersenne primes.

Rejoinder by John Selfridge: When Mr. Bombieri asserted that "mathematicians believe the perfect numbers go on forever," what he probably meant was all "right-thinking" mathematicians. Most of us would agree that there is always a Mersenne prime between p and 2^p, and we would find a readable proof of that claim to be extremely interesting. Have I "distorted" something by saying that this assertion is not "truly" undecidable? Being shown why there are infinitely many Mersenne primes or why there are no odd perfect numbers might illuminate techniques that apply to other problems in mathematics.

Some years ago I tended to agree with the eighteenth-century Swiss mathematician Leonhard Euler that one could never solve $w^4=x^4+y^4+z^4$ with integers alone. Solutions had been searched for w as high as 220,000 in 1967, and nothing had been found. If the search had gone on to 425,000, a solution would have turned up. But the real contribution to mathematics was the brilliant discovery by Noam Elkies of Harvard University of an infinite family of solutions, not including any that might have been found by earlier methods. Such a case surely illustrates that looking in vain for numerical examples contributes little, even if examples exist but are beyond one's reach.

Rejoinder by Enrico Bombieri: I like to include myself among the mathematicians who wish to see a proof of the existence of infinitely many Mersenne primes. Mersenne primes have earned their place in mathematics, for they occur in many contexts, including algebraic topology and the classification of the finite simple groups. On the other hand, one must keep an open mind to all possibilities, including that of unsolvability. Otherwise serious mathematicians might still be trying to square the circle, trisect the angle, solve the fifth-degree equation by radicals and so on—all problems that have been proved unsolvable. I agree with Mr. Selfridge when he says that "being shown why there are infinitely many Mersenne primes or why there are no odd perfect numbers might illuminate techniques that apply to other problems in mathematics." That is precisely my point: the "why" may be more important and interesting than the answer yes or no. A method of solution that opens new avenues may be more interesting than the solution itself.

I like the example of Euler's equation. Elkies's beautiful work teaches us that, before using brute force, it may pay off to use a little finesse first, and one should not be discouraged by the fact that a problem looks, or is, difficult to solve. •

Scribal Warfare

The discovery of the Dead Sea Scrolls in 1947, heralded as the greatest single event in biblical archaeology, has been overshadowed ever since by secrecy, controversy and animosity. And the race to publish the first definitive interpretation of the scrolls has taken its toll on academic protocol. At a recent conference in New York City, sponsored by the New York Academy of Sciences and the Oriental Institute of the University of Chicago, the language sometimes turned ugly: Cries of "Liar!" and "You stop laughing, Brownstein!" echoed throughout the meeting hall, as a simmering debate boiled over into a shouting match. A panel discussion, "Ethics of Publication of the Scrolls," turned the hall into a battleground as investigators took oral swings at one another's scholarship. It was more than professorial ego flexing—though there was plenty of that too. The scrolls arouse passion because they are thought to hold keys to the historical relation between Christianity and Judaism.

The fuss began forty-six years ago, when two bedouin shepherd boys stumbled on some leather and papyrus parchments in a cave at Khirbet Qumran, an ancient settlement, then part of Jordan, overlooking the Dead Sea. In the next decade eleven caves in the area were excavated, yielding a host of texts, many fragmentary, and most of them roughly 2,000 years old. Among them were religious writings, messianic prognostications, psalms and hymns, some of which anticipate ideas expressed in the New Testament. Scrolls from the first cave were released immediately, but a wealth of other material went unpublished. Those artifacts remained in the control of a small group of scholars that was awarded jurisdiction by Jordan's King Hussein. The group, made up primarily of French Jesuits, was headed by a Dominican priest and sociologist, Father Roland de Vaux. According to the group's theory, virtually accepted as gospel for some time, the scrolls were composed by members of the Essenes, an isolated, monastic Jewish sect obsessed with its own strict laws of devotion and purity.

Even after the 1967 Arab–Israeli war, when the scrolls came under the jurisdiction of the Jewish state, the material continued to be controlled by Hussein's designates. The group's leadership passed to John Strugnell, then of Harvard University, in 1987, but four years later he was forced to resign. In an interview with an Israeli newspaper he had declared that Judaism was a "horrible religion," and he had suggested "mass conversion" as the solution to what he saw as the Jewish problem.

As the leadership of the scroll group tottered, the rest of the scholarly field rallied its forces. Forty years had been too long to wait for the chance to study the texts. It was time to take action. The scroll monopoly had survived a Middle Eastern war and a leader gone mad; but in the months surrounding Strugnell's resignation in 1991, the floodgates opened, and previously unreleased material was made accessible to all scholars. That year Ben Zion Wacholder and Martin G. Abegg, Jr., both of Hebrew Union College in Cincinnati, published a bootleg version of twenty-four manuscripts by reconstructing the text from a concordance released in 1988 (see "Reassembly Required," by Brian Hayes, *The Sciences*, May/June 1992). A few months later the Huntington Library in San Marino, California, released facsimile photographic plates of all the scrolls, and the Israel Antiquities League in Jerusalem soon followed suit. After decades of silence and stagnant scholarship, the intellectual logjam was broken.

But the new openness has hardly brought peace to scroll studies. Instead the debates have intensified, as interpretations, restorations and translations have been publicly released. The organizers of the recent New York conference had hoped the event would induce scholars to be a bit more cooperative; according to one of them, Norman Golb of the University of Chicago, "It was a small miracle that these people were in the same room together." But the initial good will gave way to a raging debate over the book *The Dead Sea Scrolls Uncovered* by Michael O. Wise of the University of Chicago and Robert H. Eisenman of California State University at Long Beach.

Although the dispute centered around Wise and Eisenman's lack of documentation, Eisenman maintains that the real thrust of the criticism was against his interpretation. Many scholars now discount the theory of Essenic authorship, which it seems had little evidence to recommend it in the first place. Eisenman offers perhaps the most radical alternative. He contends the texts are "Jewish Christian" and originated with a community similar, if not identical, to a group of Messianic, orthodox Jews led by James, the brother of Jesus. James is a shadowy but possibly important figure, whom some scholars think was consigned to obscurity by Paul, Jesus' most zealous promoter.

In an interview Eisenman asserted that his theory may "rescue this James and his community from the oblivion official Christianity and Judaism have thrown them into." Furthermore, Eisenman cites the ideas espoused by the scroll community as evidence that Judaism and early Christianity were all but interchangeable. He essentially removes Christianity from its dependence on the unique, mytho-historical figure of Jesus Christ and establishes it as the Messianic, orthodox Judaism of the scroll community. Other theorists are not as quick to place the scroll community in a Jewish–Christian context, and many criticize Eisenman for looking at only those scrolls that support his theory.

In all likelihood neither Eisenman nor anyone else will ever learn the truth about the scrolls, which include some 800 texts in several thousand fragments. James Mueller, a professor of religion at the University of Florida, compares them to "dozens of jigsaw puzzles, all missing three-quarters of their pieces." But the release of the material has breathed new life into a once static field, and amid the hype and angry academic hysteria emerge provocative pictures of a pivotal era.

—WENDY MARSTON WITH DAVID SOLOFF

GOING ALL THE WAY

When the Belgian government proclaimed in 1988 that its AIDS-education efforts had proved successful, that most gay men practiced safe sex and knew how HIV is transmitted, Ralph Bolton was impressed—too impressed. Suspecting "a massive case of denial," Bolton, a medical anthropologist at Pomona College then working in Brussels, sought further evidence, though not in a conventional manner. Gay himself, Bolton conducted an informal study in which he met dozens of men in local bars, parks and bathhouses, had sex with them and later noted their predilections for either moderate or high-risk sexual activity.

Bolton's study exposed serious flaws in the government's data. Not only were most gay men still engaging in unprotected oral and anal sex and other high-risk behaviors; they also were lying about it to public-health interviewers. Bolton's unorthodox methodology, meanwhile, has raised questions of its own. Is it ethical for an anthropologist studying sexual behavior to have sex with his subjects? Has Bolton blurred the participant-observer distinction to the point of abandoning it?

Bolton contends that traditional methods of gathering information do not work when applied to the intimate realm of sex. Many Belgian respondents admitted that when they are asked about their sexual practices in interviews or on questionnaires, they give the answers they think are expected of them rather than confess to risky behavior. Firsthand observation is not a viable approach either. Who but the most uninhibited couple would submit to such scrutiny? And even if willing subjects were found, could an anthropologist be sure that they were not engaging in less hazardous sex than they might when not observed?

And so Bolton took the advice of the late sociologist Erving Goffman: "Go to where the action is." He quickly notes that he never actually engaged in high-risk sexual behavior. Rather, Bolton would proceed during an encounter to the point at which the next logical step was a high-risk activity—and then tactfully insist on prophylaxis. "People didn't object to using condoms," he says. "But almost invariably it was I who raised a precaution."

Not everyone embraces Bolton's participatory methodology. Renée C. Fox, a sociologist at the University of Pennsylvania, has expressed concern that none of Bolton's subjects provided explicit informed consent, a standard ethical safeguard among anthropologists. Bolton counters that doing so would have biased the study. "Obviously I didn't introduce myself saying, 'Hi, I'm Ralph Bolton. I'm doing sex research, and I'm going to observe you during our encounter.' But I never disguised that I was an anthropologist studying sexual behavior." Bolton concedes, however, that "that information pretty much went in one ear and out the other."

Even without participation, a professional interest in sexual behavior can tarnish one's reputation. But Bolton says that his own image does not concern him. "I'm just interested in doing what has to be done to stop this epidemic. Frankly, I'd just as soon be studying sports behavior in Scandinavia."

—ALAN BURDICK

RANDOM TREACHERY

14159265358979 . . . : the sequence goes on forever, a twisted tangle of digits in which no pattern has ever been discerned. Indeed, mathematicians have known for decades that you can't tell a random sequence of digits if one is staring you in the face. But what happens if you need a string of random numbers to solve a problem? You could toss a pair of dice, but the dice might be loaded. You could measure the precise times, in milliseconds after midnight, that the voltage fluctuations in the line current to your computer exceed some value, but how would you be sure the power station doesn't drop the voltage every day at noon? And if you were to use the sequence of digits above, your solution might be skewed because you picked the decimal expansion of pi.

Computer simulations thus must make do with *pseudo*random numbers—almost random sequences generated by a computational routine. Investigators who need to assume randomness to solve a problem must, in essence, just cross their fingers in the hope that pseudorandomness won't matter. Usually it doesn't, and the most reliable routines are known from the great collective experience in such matters. Until recently the possibility that the best routines might give wrong answers was only a theoretical one.

But no longer. Writing in a recent issue of *Physical Review Letters*, Alan M. Ferrenberg and David P. Landau, both of the University of Georgia, and Y. Joanna Wong of the IBM Corporation's Supercomputing Systems in Kingston, New York, reported they have discovered that a "high quality" generator gives "systematically incorrect results."

That demoralizing finding arose from the team's investigation of the Ising model, a standard method in theoretical physics for predicting how the bulk properties of matter—magnetism, for instance—can arise from the random distribution of certain physical properties on an atomic scale. To test the computer algorithm used in their investigation, Ferrenberg and his colleagues tried it out on a problem whose solution was already known. To their dismay, the answer given by the algorithm was not even close. They traced the difficulty to a subtle interaction of the algorithm with the random-number generator that fed the algorithm; other good random-number generators gave similarly wrong answers. Even more puzzling, when the investigators applied a generator known to be less sophisticated—and generally less reliable—than the first ones, the results on the test run were quite good.

The conclusion is a logical worst case. Like the mirror of the Hubble Space Telescope, the powerful lens of computational simulation may be systematically distorted. Without making extensive tests, no one should assume that any one combination of algorithm and random-number generator is giving accurate results.

—PETER G. BROWN

SPACEBALL

In baseball lore the term *Moon shots* refers to a flurry of home runs hit early in the 1959 season by a Los Angeles Dodger outfielder named Wally Moon. At that time the Dodgers occupied the Los Angeles Memorial Coliseum, where the forty-two-foot-high left field screen loomed only 252 feet from home plate, an absurdly short distance by big-league standards. Although he was a fine hitter, Moon amassed an unremarkable total of 142 homers in his twelve-year career. But he lofted several of them over the coliseum screen in the spring of 'fifty-nine, jump starting the Dodgers toward a world championship. And it is for those few, well-publicized pokes that he is best remembered.

David B. Slavsky, an astronomer and baseball junkie, has been thinking about moon shots of an altogether different kind. With the major leagues and the ozone hole both expanding out of control, Slavsky, the dean of natural sciences and mathematics at Loyola University, has been trying to imagine how the Old Ball Game might be played on lunar turf. Published in a recent issue of *Mercury*, his conclusions suggest that baseball, though by no means an exclusively American pastime, is a uniquely terrestrial one.

Much of what takes place on a baseball field depends on two physical forces: gravity and air friction. Gravity, of course, pulls any airborne object down, toward the surface. Air friction, caused by the cumulative resistance of air molecules, retards the progress of an object in flight. The faster the object moves, the more air friction it encounters along the way. But the moon, as Slavsky points out, has no atmosphere—which eliminates air friction from the bargain. Moreover, the pull of gravity on the moon is only a sixth as strong as it is on the earth. Both circumstances would profoundly affect hitting and pitching in lunar ball fields.

For one thing the outfield fences, generally no more than 420 feet from home, would have to be moved back some. "You can calculate how far an object will travel in a vacuum if you know the initial speed and angle at which the object leaves the ground—or for our purposes, the bat," Slavsky says. "An average big-league home run starts its journey at about a thirty-degree angle, with a speed of roughly 110 miles an hour." Those values vary with each hitter, but it is safe to say that under actual lunar conditions, even a Moon shot would travel about 3,000 feet; a genuine tape measure blast would literally go a mile. Slavsky acknowledges that his fanciful construct requires some suspension of disbelief. "It's doubtful that a hitter wearing a bulky space suit on the low-gravity moon could dig in and swing very well," he says. "Nor, for that matter, could a pitcher push off the rubber without floating several feet on his follow-through."

Those realities aside, it's clear the moon would be a positive graveyard for pitchers. Virtually every weapon in the hurler's arsenal is a direct consequence of air friction. Consider the curveball, which has been baffling hitters ever since Candy Cummings of the Brooklyn Excelsiors purportedly chucked the first one (underhand, incidentally), shortly after the American Civil War. "When a curve is thrown by a right-hander, for example, the ball rotates from the third-base side of the diamond toward the first-base side," Slavsky explains. As a result, he says, the third-base side of the ball travels at a greater speed than does the first-base side and thus encounters more air friction. And it is the force of that extra friction that makes the pitch hook toward the first-base side—sometimes by as much as two feet.

On the moon, in the absence of air friction, the thrown "curve" would be straight, fat and deliciously hittable. So would the screwball, which is essentially a reverse curve. Fastballs, it is true, would be a bit faster if no air molecules were blocking their path; but deceptive movement—which, more than pure speed, marks a great "heater"—would be impossible without air friction. The mischievous knuckleball owes its unpredictable flutter to atmospheric effects: the ball is thrown slowly, with minimal rotation, which makes it prey to asymmetric forces on all sides. To be sure, a good knuckler also requires considerable craft. But even Eddie Rommel, Hoyt Wilhelm, Phil Niekro and all the other masters of the form would be out of their league in a lunar loop.

Expansion-mad magnates take note: the outlook is no better on other nearby astronomical bodies. Mars, which has a negligible atmosphere and slightly more gravitational pull than the moon, would present many of the same problems, only scaled down somewhat. And on Venus, where the atmosphere is many times thicker and the air friction far greater than it is on the earth, it would be like playing baseball in bouillabaisse.

—RICHARD JEROME

Mary Knight

Homer in Bosnia

Salih Ugljanin lived long before the rails that now connect Vienna with the Aegean Sea had cut through the steep South Slav mountains, a simpler time than the present for Yugoslavs, perhaps, but hardly less volatile. A follower of Islam, Salih had emigrated from Albania to Serbia, where he readily picked up "Bosnian," or local Muslim habits. Until he was about sixty years old he lived by driving cattle and sheep; then, some time before the outbreak of the First World War, he opened a *kafana*, a coffeehouse, in the town of Novi Pazar. Men gathered for long hours in such establishments, partly to socialize and share the news of the day, but mostly to listen to the entertainment—heroic narrative poetry recited to the accompaniment of a one- or two-stringed unfretted instrument called the *gusle*

As a child Salih had heard similar songs, and his father had encouraged him to play the gusle and recite the poems. From the time he arrived in Novi Pazar, Salih frequented all the kafane to hear the songs of Bosnian singers. One of those *guslars*, Cor ("Blind") Huso Husein, acknowledged as the most talented bard in the region, taught Salih the ten-syllable-per-line verses of ten long poems in his own repertoire. Curiously, neither man knew about lines of poetry or even about words: the two poets were illiterate and thought in terms of utterances that expressed complete ideas. Yet they each readily developed a secure feel for the trochaic pentameter of their songs: each line made up of five metrical feet and each foot the combination of one heavy and then one light syllable.

With his repertoire of Cor Huso's ten poems, Salih made a start as a guslar, singing for many years at kafane before opening his own. Even after financial constraints forced him to close his business, he continued to perform in public. He often sang at weddings, which in Bosnia could last a week, and in other coffeehouses during the long nights of the Muslim high holiday Ramadan, when village men broke their daily fast with food, strong coffee, tobacco—and poetry. Salih would not take a fee for his services ("It isn't the custom," he would protest), but he would happily take food or drink or even donations collected from the patrons by the coffeehouse proprietor.

From all over the district men would come to hear Salih's tales of Muslim heroes fighting the battles of 200 years earlier. In the light of the violent Muslim–Christian relations those stories recount—not to mention recent ethnic bloodshed in the region—it may come as a surprise that Christian bards would also perform in the coffeehouses, though they would adapt their poems to suit the religious taste of the audience. (The reason for such versatility is that the Christian and Muslim epics are intimately bound.) When asked once, early in this century, about the apparent paradox, some coffeehouse patrons replied that the days of strife had passed; they, Muslim and Christian alike, now lived in harmony. Of the old hatreds described in the epics they said, borrowing a stock line from the poems themselves—"At that time it was so, now one evokes it in memory." Today their comments take on excruciating irony.

In some coffeehouses even women might be allowed to listen, though curtains modestly screened them from the eyes of unrelated males. As a turbaned Salih sat cross-legged with the sound box of his gusle resting near his ankles, he would intone the verses of his poem and stroke the bow across the horsehair fibers to sound a melody whose range was small and whose phrasing was frankly repetitious. If he dawdled in his recitation, some in the audience might cry out "*Goni! Goni!*" ("Get going! Get going!"). But most times people sat with rapt attention.

In 1934, when Salih was quite elderly, he was approached by a listener who had been especially enthralled with the day's performance. Milman Parry was a dashing young Harvard professor with a flair for romance and an uncommon passion for languages. His interest in Salih arose from more than a fascination for local color. He was in Novi Pazar on a mission to advance the understanding of two masterpieces of the human spirit: the *Iliad* and the *Odyssey*, the ancient Greek epics attributed to Homer, the allegedly blind bard about whom virtually nothing is known. Parry was convinced that through the living epic tradition embodied by Salih he could solve one of the great conundrums of classical scholarship: Who was this Homer? And if, as Parry believed, Homer composed before the advent of a written Greek literature, how was it possible for the poet to give extemporaneous recitations of the 15,000 lines of verse ascribed to him? The answers to those questions have led to a lively study of other extemporaneous traditions that, to this day, sheds light on creative works from classic epics such as *Beowulf* to the sermons of old-time country preachers to the improvisations of modern jazz.

Parry had journeyed into the hinterlands of the South Slav region (the name *Yugoslavia* means land of the South Slavs) because the tradition of singing *junackepjesme* (*yoo-nahch-kuh-pyes-muh*) had begun to die out, especially in the more traveled areas. The trend had begun around the time of the First World War, when literacy began to take its toll: once people could read, they seemed to lose interest in the oral tradition. And so Parry went to Novi Pazar to find people who, like Salih Ugljanin, were illiterate. The zealous American set out to record as many of the local heroic songs as he could, with one condition: the performed work could not be reproduced as if it had been memorized from a book. Instead, Parry insisted, it had to be recreated in the true style of the guslars: spontaneously, with general adherence to the basic story line, but with improvisations that suited the skills of the performer.

Travel to Novi Pazar, even in 1934, was hard going. The roads were rugged and bandits were common. And Parry was not traveling light. Three large cases held the recording equipment specially built for his venture: one carried an amplifier and playback apparatus; the other two held turntables for recording the music onto twelve-inch aluminum disks. (Two turntables were needed to get uninterrupted recordings of a singer's performance; as one disk was coming to the end, a switch activated by Parry or an assistant would transfer the sound to a fresh disk on the second turntable.) Furthermore, the recording equipment of the time did not run on its own power, and so at first Parry had to lug along his own generator. Later he persuaded a technician in the Zagreb branch of Bell Laboratories to devise a battery-powered system, but the two 110-volt batteries proved almost as bulky and heavy as the generator. Parry also had to cart along boxes of aluminum disks as well as tins full of grease that he smeared on the surface of each disk before dubbing. All the baggage made it impossible for Parry to slip inconspicuously into a small Yugoslav town. And so, not surprisingly, his project attracted many bards and many pseudo-bards from the surrounding countryside.

Parry interviewed many of the more accomplished bards in the region, including Salih Ugljanin. The interviews gave Parry invaluable insight into how the poets created their epics, along with important leads for future research. Often a bard would direct the young American to other good singers, some of whom would then compete to recite the best version of a poem.

Parry's relentless investigation of Serbo-Croatian epic was no shot in the dark. On the contrary, he was certain his studies would eventually answer the Homeric riddle: Had a single poet composed the *Iliad* and the *Odyssey* in their entireties? Or had many poems by several poets been stitched together into a nearly seamless whole? The word *nearly* is a key factor in the question, for it happens that the poet—or poets—can occasionally be self-contradictory. For example, the text of the poem might report the death of a minor hero—and then include him among the living several verses later. Coupled with the repetitions that all readers have noticed, there is an apparent sloppiness—a continuity problem, in Hollywood jargon—for which critics must account. Parry had a bold, new idea: the author of the *Iliad* and the *Odyssey* was indeed one person, as tradition had it, but he had composed his poems orally, just as Salih and his ilk created theirs.

Parry suggested other parallels between Homer and the Yugoslav bards: both the ancient and the modern poets performed their works before audiences who had heard many similar performers and poems before. And, like his guslar descendants, Homer need not have known how to read or write to create his poems: each poet operated in a long-established tradition. Most startling of all, Parry contended that if the Homeric poet was trained in a tradition of oral poetry, he probably relied on some kind of metrical or linguistic device that enabled him to create the works anew each time he recited them.

Parry called the device a formula, which he defined as "a group of words . . . regularly employed under the same metrical conditions to express a given essential idea." The formula would serve both as an aide-mémoire and as a kind of pit stop: as the poet recited his formulaic phrase, he could use the time to prepare his thoughts on upcoming verses. Most likely the formulaic phrases were epithets regularly attached to proper names—Ox-eyed Hera, for example, or Odysseus, the Man of Many Ways. Parry hypothesized that such combinations were "fixed" and could be used without reference to the immediate action. Likewise, they could be applied to other nouns, as long as the meter was not violated. The oral poet, composing as he recited, probably deployed such combinations as they were metrically convenient.

To support his contentions Parry compiled statistics on noun–epithet combinations as well as on other stock phrases repeated throughout the *Iliad* and the *Odyssey*. He discovered that formulaic phrases tend to appear at the ends of lines and that there is only one formula for each metrical circumstance. Parry discovered not only formulaic expressions that were attached to persons, horses, ships and the like but also that the narrative itself unfolds in a formulaic manner: the time and place of an action were often cast in formulaic terms, such as "when the lovely dawn shows forth with rose fingers" and "in the wide Troad." Common actions, such as sitting down to eat, were repeated with the same expressions. Parry underscored no fewer than twenty-nine formulas in the first twenty-five lines of the *Iliad* and thirty-five formulas in the first twenty-five lines of the *Odyssey*.

Next Parry compared his Homeric results with the Serbo-Croatian epics. For example, when Salih recited a version of *Marko and Musa the Highwayman*, Parry readily recognized its formulaic language. The main character, Marko, is given a standard description, and both the epithet and the character's name tend to fall at the end of a line: *Poranijo Kraljevicu Marko* (literally, "Arose the son of the king, Marko"). The line preceding that one is reminiscent of Homer: "One day dawn came." Places, too, have formulaic attributes: "Bitolj, that wide city." Repetitions abound—repetitions fixed by tradition, repetitions that recur in poem after poem; all of Salih's poems, in fact, use the same expressions.

In his two trips to Yugoslavia, Parry amassed nearly 13,000 texts on more than 3,500 phonograph disks. His collection, now housed at the Widener Library of Harvard University, is proof that a singer would not repeat a song word for word. Rather, the bard would recite it as faithfully as he could, claiming his version to be the "truth . . . exactly as he heard it," or as Salih concludes his *Song of Baghdad*: "I say! In this way I have heard it, in this way to you I have told it." Indeed, he would even say he had repeated it "word for word"—though given his imprecise understanding of *word*, the expression was merely his way of saying "true."

Some guslars did dare to invent new poems with modern ideas and heroes, albeit using traditional formulas. Salih improvised a song on the Greek war that had taken place around the turn of the century. In that song a new player, the Queen of England, fit the metrical formula for queens, so her inclusion was not a problem. But an incident in which a message is sent by telegraph caused the poet to stumble. All the formulas for missives have two or four syllables, and so Salih's new-age *telegraph*, containing three syllables, could not fit the traditional metrical context. The solution was not to change the meter but to alter the new phrase to fit the formula. Wherever Salih wanted to use the word *telegraph*, he could introduce the line with the old formulaic "letter was sent" and add a new phrase, "by telegraph," which would not violate the meter. Applied to Homer, such a conservative tendency enforced by meter could account, Parry suggested, for the archaic diction in the Greek epics. Phrases were frozen into formulas that were never updated; where new words could not fit in place of the old, the old wording remained.

If Homer's poems were composed orally, as Parry maintained, how could one account for their superhuman length? The *Iliad*, for instance, runs to 15,690 lines. Reciting the poem without pausing takes roughly twenty-seven hours. How could a poet improvise a work of such magnitude? But it seems that the guslars of the early twentieth century were well up to the task. Over several days one singer Parry studied, Avdo Mededovic, sang an epic of 13,331 lines and dictated one that was 12,323 lines long; moreover, he had several others of similar length in his repertoire.

Just when it appeared that Milman Parry might enjoy some acclaim, fate intervened. In December 1935, a few months after he had returned from his second field trip and shortly before he was to report his findings at the annual meeting of the American Philological Association, he killed himself accidentally with a gun he had long carried to defend himself against bandits. His work had been well known among classicists in his lifetime, but it was only after his death that his reputation gained more general acclaim.

Albert B. Lord, Parry's most gifted collaborator, carried on with the study and completed the bulk of the grunt work Parry never had the chance to tackle. Lord catalogued, transcribed, translated and analyzed the texts of collected Serbo-Croatian epics. He also made three field trips of his own to Yugoslavia, often tracking down singers Parry had interviewed as many as seventeen years before. Singers who "repeated" the songs Parry had recorded proved they had not merely memorized the poems; each version was distinct, though the two versions were remarkably similar because of the all-pervasive formulas used to construct them.

After conscientiously questioning the singers, Lord outlined the development and apprenticeship of a bard in the oral tradition. Every guslar had heard thousands of songs composed in the formulaic idiom before attempting to sing one himself. As an apprentice a singer would then learn from experienced performers, as Salih had learned from Blind Huso, while also trying a hand at recitation. Veteran singers, who had perfected their techniques through years of practice, could draw from a commensurately large storehouse of formulas and could improvise confidently.

Most important, however, Lord cogently synthesized the results of the fieldwork in his 1949 dissertation (revised and published in 1960 as *The Singer of Tales*), effectively creating a new field of study. No longer would classicists speak of the Homeric Question as much as the Oral Traditional Question; no longer was it assumed that literature was confined to written matter.

The responses to the work of Parry and Lord were not entirely enthusiastic. A number of scholars were uncomfortable with the idea that Homer was illiterate and that he composed his great epics by stringing together standard formulas. If that was so, how creative could the poet have been? And if he was not creative, how great could his poetry be? Much of the resistance to the oral-formulaic answer to the Homeric Question was emotional; some guslars frankly shout their epics, and any lover of Homer who had listened to the recordings of such guslars was particularly disinclined to favor the Parry–Lord hypothesis.

The central problem for the dissenters is this: Are the formulas themselves properly regarded as nothing more than building blocks, albeit blocks that, when fitted together, make up something impressive? And is the end product rightly called art? John Miles Foley of the University of Missouri in Columbia, in many respects a successor to Lord, has argued persuasively that the aesthetic criteria by which scholars have long judged written literary works are simply not valid for interpreting works composed orally. The poems of Homer and Salih must be seen in their own context, in the tradition itself—in all that contributes to the artistic creation. In that regard, one must take into account both the listeners' deep familiarity with the oral genre and the expectations they have developed through years of encounters with what Foley calls immanent art, art created with a host of traditional meanings and associations implicit in its very expression. The participation of the audience is made possible, in fact, because the formulas convey greater meaning than meets the ear. In other words, the singer addresses the audience in a dedicated idiom; at the same time the audience tunes in to the same frequency, so to speak, having enjoyed a long association with the connotations and traditions of the vocabulary.

Foley maintains there is a separate idiom for each genre and subgenre of oral art. Thus the idiom for Serbo-Croatian epic narrative cannot be applied in composing charms or recipes or funeral laments, all of which have their own dedicated idioms. The idioms can be demonstrated experimentally by placing the genre-dependent sample alongside the unmarked, everyday language. The formulas appear and the specialized vocabulary rises to the surface: Turkishisms long since dead or tenses no longer used, for instance, in the Serbo-Croatian epic genre.

Foley has been pivotal in broadening and deepening the public concept of oral art. The Center for Studies in Oral Tradition, which he directs, coordinates the activities of the new discipline, communicating with some 2,500 scholars studying more than 120 traditional literatures around the world; the center's chief publication, *Oral Traditions*, is now in its seventh year. A primary activity of oral specialists has been to reexamine old texts such as *Beowulf* and *La Chanson de Roland* for evidence of oral elements in their composition. Linguistic analysis of numerous other traditional texts supports an oral-formulaic origin: ancient Chinese, medieval Greek, Old Irish, medieval Spanish, Sumerian.

But because the ancient and medieval texts provide readers with only part of a tradition (usually a representation of only one performance of a work survives), living models continue to inform the understanding of works whose traditions are now long dead. A major ongoing project at the University of the Western Cape in South Africa is to collect the history of the indigenous peoples, whose stories were largely ignored by the Afrikaaners and are nearly lost. All of Africa, in fact, affords fieldworkers significant opportunities for study in a variety of genres—epic, praise poetry, laments. In Central America, Jane F. Morrissey and Cristina Canales of Elms College in Chicopee, Massachusetts, are tracking current legends of a Christian cleric whose tale has been handed down concurrently in Spanish and the local Mayan language. Scholars from Finland and Germany, too, are recording and analyzing oral material from the former Soviet Union, especially in the Turkic-speaking republics of central Asia. And there remains a dwindling population of guslars in the South Slav region, though they are dying out, primarily because of the lack of an audience. In every case Parry's hypothesis has borne fruit; formulas operate in all kinds of oral compositions, whether created for a typical Palestinian wedding or used in ritualistic insult chants among New Guinea highlanders.

The oral-formulaic theory has also been successfully applied to traditions in North America. The historian Bruce A. Rosenberg of Brown University has studied what are known as spiritual sermons gathered from folk evangelists throughout the U.S. Those old-time country preachers compose their sermons orally and deliver them by alternating between prose and rhythmic chants. The prose serves to build up the enthusiasm of the congregation, and the rhythmic sections rise and fall around a tonal center, building to a climax before the preacher again returns to the prose. During the most heated moments of the chanting, members of the congregation respond in any way they please.

Rosenberg noted that the chanted portions of the sermons were remarkably formulaic in just the way Parry had used the term. A metrical pattern was evident; when an accomplished preacher has a line that is too short for the meter, he compensates by lengthening the syllables. When he doesn't know what he'll say next, he repeats a line or draws on one of his stock formulas. Even though the action is not moving ahead, the pause and repetition rouse the audience. When queried directly about that tactic, every preacher claimed that "God was feeding him so fast he needed to sort out the proper thoughts." On the other hand, when a preacher heard a tape of a rival using the same tactic, he might say, as one did, "Oh, he's just stallin' for time."

The oral-formulaic theory bears on music as well, from the modern blues and jazz traditions forward to rap and back to medieval chants. For instance, Leo Treitler, a member of the music faculty at the City University of New York, has studied the transmission of Gregorian plainchants, liturgical songs developed from the living tradition of hymns, psalms and spiritual songs of early Christian worship. What Treitler found musically was comparable to what Parry and Lord found in South Slavic songs. Certain formulas could be identified in the older versions of the chants—composed before the development of a precise musical notation—suggesting the chants were learned orally, beginning when the singer was still a choir boy. The chants were finally written down in the Carolingian era, during the eighth and ninth centuries. There were different melodic traditions from various European traditions, which conflicted with the ambitions of the Carolingian leaders to impose uniformity throughout the church. The story that circulated through European ecclesiastical and historical traditions since the Carolingian era was that Pope Gregory the Great composed the chants under divine inspiration and that his was the only true version. That myth lent authority to the Carolingian campaign to impose a single chant tradition throughout the empire.

Modern critics commit the same error as the Carolingians when they suppose that all the extant manuscripts of a poem or other ancient work come from a single source and that the "original" can be derived through a comparison of the manuscripts for "errors." As Parry wrote, "the odds are overwhelming against the possibility that any poem could be the best version. One can only say of the best version of a given poem that it was the best that could be collected."

The drive for the single "original" text of a Gregorian chant or of any composition produced orally arises from a kind of knee-jerk reaction by scholars much more accustomed to writing. A similar reaction took place among early critics of jazz and blues, some of whom dismissed the musicianship as mere "noodling," because the players were not reading notes. Recent work by a number of scholars, including Jeff Todd Titon of Brown University, has shown that formulas are the key to those genres as well. But the remarkable flexibility and widespread applicability of Parry and Lord's work has altered scholarly thinking not only about oral literature but also about written work. A reexamination of old texts and comparative fieldwork indicates that creative work ranges across a broad spectrum from the purely oral, as in Homer, to the securely textual, as in Virgil's *Aeneid*.And identifying the context that gives meaning to oral works is equally informative for understanding written texts and for works that fall somewhere in between. •

***MARY KNIGHT** teaches classical civilization at New York University, where she is a doctoral candidate in the classics department.*