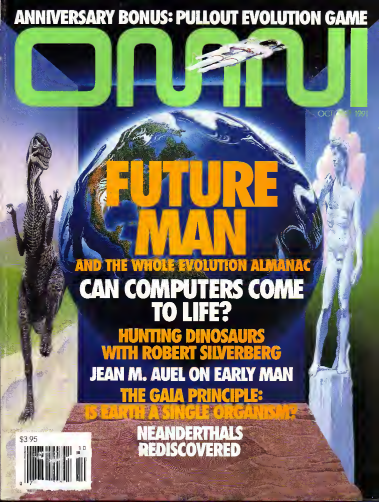

ANNIVERSARY BONUS: PULLOUT EVOLUTION GAME
OMNI
1991
FUTURE MAN
AND THE WHOLE EVOLUTION ALMANAC
CAN COMPUTERS COME TO LIFE?
HUNTING DINOSAURS WITH ROBERT SILVERBERG
JEAN M. AUEL ON EARLY MAN
THE GAIA PRINCIPLE: IS EARTH A SINGLE ORGANISM?
NEANDERTHALS REDISCOVERED
$3.95

OMNI

VOL 14 NO 1 OCTOBER 1991

EDITOR IN CHIEF & DESIGN DIRECTOR: BOB GUCCIONE

PRESIDENT KATHY KEETON
EDITOR KEITH FERRELL
GRAPHICS DIRECTOR FRANK DEVINO
MANAGING EDITOR PHIL SCOTT
ART DIRECTOR DWAYNE FLINCHUM

Nature carved in stone distinct records of time's vast changes Modern man however has left more ambiguous traces suggests the illustration by Randy Nelsen (Earthbooks) He found his own uses for stone, first for tools and shelter then for art Man still evolves slowly and subtly (Additional art and photo credits page 55)

OMNI (ISSN 0149-8711) is published monthly in the United States and Canada by Omni Publications International Ltd 1965 Broadway New York NY 10023 5965 Second-class postage paid at New York NY and at additional mailing offices POSTMASTER Send address changes to Omni Magazine Post Office Box 3041 Harlan IA 51537-3041 Volume 14 Number 1 Tel (212) 496-6100 OMNI is a registered trademark of Omni Publications International Ltd Printed in the USA by Meredith/Burda Corp and distributed in the USA Canada, United States territorial possessions and the world (except the UK) by Curtis Circulation Company 433 Hackensack Avenue Hackensack NJ 07601 Distributed in the UK by COMAG Tavistock Road West Drayton London UB7 7QE England Subscriptions U S APO—$24 one year Canada and elsewhere—$28 one year Single copies $3 50 in U S APO and Canada Telephone 1-800 289 6664

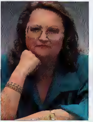
FIRST WORD

SKULL AND BONES

In 200,000 years we'll be fossilized bits to ponder

By Jean M. Auel

What was the origin of modern humans? What happened to the Neanderthals? The answers, says Jean M. Auel, may shed light on our future.



Are we, *Homo sapiens sapiens* (wise wise man?), the culmination of the 5 million years of human evolution, or a step along the way to something else to *Homo sapiens futuristis*? Two hundred thousand years ago, Neanderthals—technically *Homo sapiens neanderthalensis*—were the dominant human life on Earth. What kind of people will the earth see 200,000 years from now?

Fifteen years ago, when I first started researching for *The Clan of the Cave Bear*, the earliest known appearance of modern humans was in Europe around 40,000 years ago, during the last ice age. They were the ones referred to as Cro-Magnons, and there was evidence that for a period of time, they lived side by side with Neanderthals.

The case for their coexistence has now become much stronger. The skeleton of a Neanderthal was found in France that dates to around 30,000 years ago, demonstrating that western Europe was home to both for perhaps 10,000 years, but even more astonishing are discoveries from the rest of the world. New techniques have dated the bones of an anatomically modern man discovered in Israel as 90,000 years old. There is still some doubt about the dating method, but if the date holds it means that both modern and Neanderthaloid types of humans occupied that part of the world for 60,000 years!

When did these two subspecies of *Homo sapiens* emerge? Around a million and a half years ago in Africa, an earlier form of hominid, *Homo erectus*, began migrating and eventually populated the rest of the Old World. Neanderthal types that have been found throughout Africa and Eurasia apparently evolved directly from the local *H. erectus*. In France, for example, there are *erectus* sites such as Tautavel that date back 400,000 years, and the recently excavated Grotte Vaufrey that date Neanderthals at about 300,000 years.

At one time most archaeologists thought that modern humans, *H. sap. sapiens*, evolved in Europe from *H. sap. neanderthalensis*, but new evidence suggested that we arrived later, bringing with us a more developed stone tool kit. It was then theorized that at some unknown location, east or south, modern humans evolved from an earlier type, perhaps *H. erectus*, and migrated to Europe.

Then, a few years ago, DNA studies indicated that anatomically modern humans could be traced back to an original mother, dubbed Eve, though it may have been a group of related women who evolved, again in Africa, less than 200,000 years ago. Those early modern humans are thought to have migrated to all the rest of the world, completely replacing the existing populations.

That theory has been disputed by some paleoanthropologists who have examined skulls of earlier forms, such as *H. erectus*, particularly in Asia, and found indications of characteristics still seen in Oriental people today. How could the newcomers replace existing populations but take on their physical traits? Could there have been some intermixing? In central Europe and the Mideast, a combination of Neanderthal and modern human characteristics is sometimes found in a single skull, but scientists debate whether it shows evolution or crossbreeding.

Debates are the heart of the scientific process, but looking at the past can shed light on the future. The evidence suggests that evolution is still going on, but what lies ahead? Drastic climatic changes probably played a major role in the adaptive strategies of ancestral hominids, but mutational changes occur at different rates and contemporary societies have so much control of their physical environment, they can live in any climate, including no climate at all, in space. Will that lessen the selective pressures to change and cause the process of evolution to slow?

Or will the pollution, the chemical fertilizers and pesticides, the toxic and nuclear wastes, the greenhouse effect, and the depletion of the ozone layer accelerate mutations? What about reactor meltdowns? Nuclear winter? Nuclear war? Though most would be harmful or fatal, might some mutations actually be beneficial? Perhaps selecting for immunity from some of the effects? What about genetic engineering?

There are no more Neanderthals, but are there still a few Neanderthal genes? Were they replaced or assimilated? Would we share our world with another kind of intelligent human being? One that might make us the next Neanderthals? The thought is fascinating to consider. One could even imagine stories. ∞

OMNIBUS

THE EVOLUTION OF AN ISSUE

Our editor at large goes to summer school and returns with our anniversary theme

Last year *Omni* editor at large **Pamela Weintraub** went to the Marine Biological Laboratory in Woods Hole, Massachusetts, on a science writer's fellowship. Although she spent a great deal of time learning the techniques of cell and marine biology in the lab, her main focus was the field of molecular evolution. While attending one lecture, she came upon an unusual idea that, if correct, will shake the roots of evolutionary biology. According to the modern followers of Charles Darwin and his theory of evolution, organisms evolve through random genetic mutations. But Weintraub reports in "Natural Direction" (page 34) that mutations may not be random at all. In fact, organisms may actually orchestrate their own evolution. "I discussed the idea with leading molecular biologists at the workshops and was really shocked that they didn't look down on the possibility of directed mutation," Weintraub says.

Weintraub's participation in the fellowship was the genesis of our special anniversary issue on evolution, which she developed and coordinated. The result is vintage *Omni* and includes an exclusive game that illustrates planetary evolution and the Gaia hypothesis.

"Environmental activists may have latched on to the Gaia hypothesis, but scientists have been reluctant to embrace the idea that a symbiotic relationship exists between the physical world and life itself," says *Omni* contributing editor **Jane Bosveld** ("Life According to Gaia," page 66). Bosveld has written for *Mademoiselle* and other publications and is the coauthor of *Control Your Dreams* (Harper & Row).

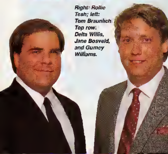
Originating the idea for our game, Weintraub offered a truly unique challenge to game designers **Tom Braunlich** and **Rollie Tesh** of Technical Game Services in Bainbridge Island, Washington. "All we had to do was simulate the four-billion-year history of the planet, using nothing but a few pages in the magazine and some common household objects," Braunlich says. The result: Planit: The *Omni* Evolution Game (page 73), featured along with this month's special section "The Whole Evolution Almanac" (page 87). Braunlich and Tesh work with Milton Bradley and other game and toy manufacturers and also represent independent toy and game inventors.

"Planit gave Weintraub and her son Jason the rare opportunity to contribute ideas in the creation of a game. We'd play the game and then call the designers with suggestions; they'd send back an improved version, and we'd repeat the process," she says.

Weintraub took her idea for the almanac's "Do-It-Yourself Mutation Kit" to **Hemant Chikarmane**, the molecular biologist with whom she worked at Woods Hole. He thought it was a great idea and, in fact, says Chikarmane, a specialist in DNA fingerprinting, "depending on how well the evolution kit does, I would like to create similar educational projects for use in schools."

"The Whole Evolution Almanac" also provides some visions of future humans in "Evolution's Child" by former *Omni* editor **Gurney Williams**, who lectures about the future when not writing for such publications as *Redbook* and *American Health*. And you can achieve lower consciousness in "The Devolution Program" by **Keith Harary**, research director of San Francisco's Institute for Advanced Psychology and coauthor, with Weintraub, of *Right Brain Learning in 30 Days* and *Memory Enhancement in 30 Days* (St. Martin's Press).

Delta Willis (Digs, page 22) is the author of *The Hominid Gang: Behind the Scenes in the Search for Human Origins* (Penguin). **Ed Regis** (Interview, page 98) is the author of *Great Mambo Chicken and the Transhuman Condition* and *Who Got Einstein's Office? Eccentricity and Genius at the Institute for Advanced Study*, both published by Addison-Wesley. *Omni* contributing editor **Shari Rudavsky** ("The Secret Life of the Neanderthal," page 42) is currently a graduate student in the history of science at the University of Pennsylvania. **OO**



***Right:* Rollie Tesh; *left:* Tom Braunlich. *Top row:* Delta Willis, Jane Bosveld, and Gurney Williams.**

FORUM

THE CHASM OF CREATIONISM:

You can bet that we haven't heard the last of the creationists

By Keith Ferrell

Evolution: It's an elegant word, and not without romance. The word bespeaks the stately transformational march of life across centuries, millennia, eons. Long accepted as scientific fact, however much debate still surrounds the details of its workings, the process of evolution underlies modern biology and remains one of the key accomplishments of modern science. We've devoted this special issue of *Omni* to exploring some of the fascinating aspects of evolution and the scientists who explore it. Since this is *Omni*'s thirteenth anniversary, evolution seemed an appropriate inauguration for our "teenage" years.

Creationism has no place in our science classes

But evolution also underlies an ongoing controversy whose final echoes have not yet been heard. Despite debate, trials, depositions, Supreme Court decisions, ad infinitum, there remains in this country a movement that would put scientific fact on the same basis as religious faith and alter our traditional balance of church and state and alter as well the nature of scientific education itself.

I'm speaking of what its proponents call scientific creationism: the argument that the biblical explanation of creation and the origin of life should be taught in science classes. Despite defeat after defeat in courts and legislatures, the movement has not yet gone away, nor does it show any sign of doing so.

While we can understand the desires of creationists to have their views given equal footing with scientific fact—who doesn't want his individual views granted official credibility?—we must also be alert to the very real dangers of such decisions. History resonates with misguided, often tragic efforts to subordinate scientific reality to religious or state orthodoxy. In the Stalinist Soviet Union there was an attempt to recast biology in Marxist terms, making science serve, as it were, the purposes of the state. Nazi Germany used pseudoscientific arguments to justify abominations.

The creationist argument is different in degree, but only in degree. We are asked to accept the religious views of a minority of the world's population as equal in academic value to the shared knowledge of the world's scientific community. This is not only wrongheaded, it's just wrong.

Faith is personal, science universal. Faith is subjective, science objective. The great gift of science is its methodology: the relentless questioning of the universe in search of its workings. Science asks *why* and *how* and couches those questions in a rigor that insists the answers be provable. Evolution, one of those answers, has been proved repeatedly. Creationism's followers accept their dogma without question: such is the nature of faith. There is a chasm between scientific fact and religious faith. That chasm can be spanned individually. As we saw in our August issue, plenty of scientists are devoutly religious. Bridging that chasm must not, however, take place in our public schools. Those bridges, for those who choose to build them, must be constructed in the home and the church.

Opposition to the incorporation of creationism into our schools must rest upon an honest understanding of the nature of evolutionary thought. One of the arguments raised against evolutionary theory is the lack of scientific consensus regarding the mechanics of the evolutionary process. Yet that lack of consensus is itself a lovely indicator of the openness of scientific inquiry. We look this month, for example, at a debate currently taking place over the fundamental nature of evolutionary change. Debate—the careful marshaling of evidence, analysis, and interpretation—gives science its vigor and integrity. Such debate is rarely welcomed in strict creationist circles.

"Prove it" may be the most basic tenet of scientific inquiry. Evolution has been proved so thoroughly that its validity can no longer be questioned in scientific terms. Creationism, by its nature, can never be proved.

The next time the creationist argument rears its head—and it will, in some ways we're overdue for another wasteful airing of a debate that should long since have been put to rest—perhaps the open-minded among us should adopt some of the creationists' own tactics. Suppose we argued that evolution, scientific evolution, should be taught in church alongside creationism. You can bet that the response from the creationist side would drown out even the loudest of objections raised when creationists try to impose their will on our schools and our minds.

COMMUNICATIONS

READERS' WRITES
Has your refrigerator had a checkup lately, and is space funding hazardous to your health?

Warming Thoughts
Robert Silverberg's article "The Greenhouse Effect Apocalypse Now or Chicken Little?" [July 1991] is a reasonably balanced exposition of the fiercely opposed views. But he helps to perpetuate the myth about "the sinister chlorofluorocarbons (CFCs) emitted by refrigerators, air conditioners, aerosol devices, and other products." But we increase atmospheric CFC levels, in fact, only when air conditioners and refrigerators are not functioning properly. And the United States banned CFCs in aerosol spray cans more than a decade ago. Let's not imply that things are worse than they actually are.

R. H. Coddington
Richmond, VA

Thanks for providing such thought-provoking reading. *Omni* is a great source of new ideas and critical discussion of current issues. In the July issue, Robert Silverberg quite rightly warns us against jumping to conclusions about global warming. We just don't have enough evidence. But there are still compelling reasons to address problems like air pollution and the destruction of the rain forests. Our health suffers from the pollutants in our air and countless species, including humans, rely on the rain forest for their survival. Even without global warming, we must change our handling of the environment.

R. B. Blackburn
Pocatello, ID

Space for the Healthy
After reading "Spaceward Ho!" [July] I am positive that the United States must be able to compete in space if it is to remain a leading world-class power. Yet following the government's determining that we need to spend more money on children's health care, one politician stated we could obtain the additional funds by scrapping the space station. The future of our nation, however, actually rests on both the health of our children and our edge in space.

Vincent O. Hughes
Fayetteville, NC

A Recipe for Chile
It's great that people are taking active steps to save what's left of the pristine natural world, like the Chilean rain forests [Earth, July]. For my part, the rain forests are a vital resource not to be wasted. But the article did raise one disturbing thought: Despite their good intentions, should Americans and American organizations buy up chunks of another country's property? Americans have often expressed concerns about major foreign investors purchasing United States companies and land. Is it really any better for us to do the same thing in Chile, even in an effort to save the rain forests?

Katie Stevenson
East Haven, CT

Stigmatized
Three cheers for "Stigmata" [July] by Robert Frazier. I enjoyed not only the tale itself, but its unusual page design and its contrapuntal poetry. Something different for once, proved to be something superior.

E. R. Stewart
Robbins AFB, GA

Ice on the Rocks
I'm not a scientist of any kind, but I'm smart enough to see major problems with harvesting water for Los Angeles [Earth, August 1991]. For one, how will the accumulated loss of so much ice from Antarctica affect the weather 5, 10, 50 years from now? How would the yearly release of a trillion gallons of fresh water into the oceans affect animal and plant life? Surely Los Angeles would not be the only one to want a piece of this pie; Africa, Asia, Australia, and even the eastern United States need fresh water. The real problem is a reluctance to get tough and face facts with this and all other ills facing us now and in the future. Only when we become serious about global population control and resource management will we, and the earth, have a realistic chance for long-term survival.

David Sperry
Seattle DO

POLITICAL SCIENCE

MIGHTY MOUSE:
Will the atomic genie get loose?

By Tom Dworetzky

It's post-détente, and START's lookin' good. But in the world's nuclear cellars, the bombs have begun to tick again

Remember the classic Peter Sellers comedy *The Mouse That Roared*? A duchy-sized country, flat broke, decides that its best bet is to go for Marshall Plan-style aid by attacking America and losing. But the plan backfires when it accidentally takes prisoner one of our bomb builders and his football-shaped doomsday device. After Sellers has gotten all the superpowers to make peace with his tiny country and each other by threatening to use the bomb, it stops working. Sellers and the scientist keep this a secret, maintaining peace with a hollow threat of annihilation. Then, alone in its dungeon keep, the bomb starts ticking again.

Funnier than the movie is that we now find ourselves in the same situation. Right after détente and with START talks looking good, it seemed the existential bummer of nuclear annihilation might pass. Then boom, Saddam's got the bomb, the genie's out of the bottle, and we're scurrying for the shelters again.

Actually the alleged Iraqi nuclear threat is the least of it. Proliferation is slowly spreading everywhere. The real culprits are Western industrial states where folks like Saddam get their nuclear toys, not the Third World guys. "The Iraqi experience," says Paul Leventhal of the Nuclear Control Institute, "is just another page in a lesson book no one's paying attention to." The heart of the matter is the creation and use of highly enriched uranium and plutonium in civilian reactors. These substances are so-called weapons grade; that is, you can make an atom bomb from them. The scope of the problem is huge. Some experts such as Leventhal estimate that by the year 2000 there will be up to 2,000 tons of plutonium in existence. Compare that with the combined strategic stockpiles of the U.S. and the USSR—200 metric tons in about 25,000 warheads.

Faced with this forecast you'd think the administration, and everyone else, would be at least idly talking about a global ban on atomic weapons-grade material. They're not. Instead, here are three highlights of their plans for the upcoming plutonium season:

• In 1992 we'll finally get rolling with the first shipments resulting from the administration's 1988 agreement to let the Japanese reprocess up to 400 tons of plutonium over the next 30 years. The Japanese will ship the stuff by sea to France and back, France having one of the few reprocessing plants in the world. Ironically, the same Beltway contractor, ERC, that did confidential studies about certain aspects of this deal for the Department of Energy has also been hired to help the Japanese get their plans approved. This irked some members of Congress so badly that they asked the General Accounting Office to investigate. According to government sources, the conclusions of the study will be: Having people who did confidential work for the government also act as consultants might look a bit unethical, but it was legal, since no actual documents were turned over to the Japanese, no existing laws were broken.

• The DOE persists in its efforts to reopen the radioactively polluted Rocky Flats weapons plant near Denver. This half-billion-dollar effort comes in spite of the glut of thermonuclear warheads spawned by the recent treaties with the Soviets that reduce our strategic stockpiles.

• The last administration budget zeroed out the funding for the Argonne Lab's Reduced Enrichment for Research and Test Reactors (RERTR) project. The project's aim is to create a safe civilian bombproof reactor fuel. But Congress insisted on funding at least one of the project's key missions: helping other nations adopt bombproof fuels.

For almost 50 years we've lived with the MAD (mutual assured destruction) scenario. Now we live with *The Mouse That Roared* scenario. The only real value of atomic weapons is in the certainty of the threat—not the use. Unfortunately, the increasingly haphazard spread of weapons-grade material and the technology needed to make atomic explosions has brought us to the existential brink with its very uncertainty. We played out the mouse scenario with Iraq and won. They had the raw material but no bombs. Next time, however, the mouse, some other devilish nuclear club wannabe, may have real bombs—and roar. OO

DIGS

THE CASE OF THE MISSING LINK:
Misfiled bones have led researchers to discover humanity's ancestor

By Delta Willis

Martin Pickford held two "turtle" bones up to the light, glimpsing a network of capillaries and veins. These were no turtle bones, Pickford realized; they resembled pieces of a primate skull. It was 1981 and Pickford, a researcher from the Institute of Paleontology in Paris, learned that the expedition responsible for unearthing the "turtle" bones had also yielded an intriguing—and incomplete—skull from a chimp-sized primate dubbed *Proconsul*.

His next mission: matching the bones with the skull. Pickford called upon Johns Hopkins paleontologist and primate expert Alan Walker, who hunted down the skull and, with great delicacy, nudged the fragments back in place. The fit was perfect. *Proconsul*, the scientists discovered, had been much brainier than originally thought. In fact, according to a decade of new research conducted by Pickford, Walker and others, the 18-million-year-old primate is probably the earliest known missing link between the apes and man. "*Proconsul* makes a good model for a common ancestor," Walker says. "Its features are generalized enough to embody traits common to the apes and us."

In 1984 to establish *Proconsul* as a legitimate missing link, Pickford and Walker headed for Kenya, where the esteemed paleontologist Mary Leakey had found *Proconsul* on Lake Victoria's Rusinga Island decades before.

The expedition provided the researchers with enough fossils to study *Proconsul* for years to come. Piecing together the bones in a process that continues to this day, Pickford and Walker have been able to establish the life cycle of this prehistoric primate. "We have males and females, babies through adults," Walker says. Indeed the tedious process of preservation and reconstruction has revealed details as delicate as the ear's bones and semicircular canals. The seventh and eighth cranial nerves have been reconstructed as well.

Other researchers interested in the life of our ancient ancestor have begun studies of their own. David Beynon of the University of Newcastle upon Tyne in the United Kingdom, for instance, has been trying to determine the life span of *Proconsul* by examining its teeth. Beynon's unusual technique, which involves "reading" teeth much as researchers read the rings on a tree, should tell the life spans of *Proconsul* males and females.

Another researcher, Chris Ruff of Johns Hopkins, is using the principles of engineering to calculate *Proconsul*'s body weight. According to Walker, Ruff's analysis of limb bones should reveal not only the types of stress *Proconsul* had to bear but also the differences—if any—between males and females. In the future, Ruff may also be able to illuminate the lives of *Proconsul* individuals. Did a particular male suffer from a broken arm or a spinal disorder? Did a female die from a head injury or perhaps in childbirth? Ruff's new techniques may be able to answer some of these questions.

But even when these details and more are known, scientists will still debate whether *Proconsul* was truly our ancestor. "There are few ways to demonstrate that something is a real ancestor," Walker says. "Of *Proconsul*, one can say, simply, that here is an example of a population from which our ancestors most likely arose." He thinks a bit and then amends his response. "Genetically we all go back to the primordial slime, don't we?" he adds. "Details of that are difficult to trace." DO

Buried beneath the earth for millions of years, the link between humans and apes now emerges from the forest of time.

TOOLS

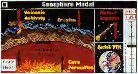
FOR THE TWENTY-FIRST CENTURY
Playing God, mimicking Darwin, coloring your world, and Gaia

By Sandy Fritz

SIMEARTH—THE LIVING PLANET

Maxis Software, Two Theatre Square, Suite 230, Orinda, CA 94563. $69.95
PLUSES: Unspeakable power
MINUSES: Unfathomable responsibilities
THE VERDICT: Addictive

Prepare for a shock. Booting up *SimEarth* makes the user a God. And God has a *lot* of complex responsibilities when it comes to managing a planet. If you don't regulate the amount of toxins spewed into the air by mammalian civilizations, monitor ocean salinity and temperature, and foster areas that reoxygenate the atmosphere, your planet will fail and its life forms will perish.



This game, this simulation, this *problem* makes George Bush's job look like a Caribbean holiday.

GAIAN SCIENCE

For Geophysiology Researchers and Teachers. Newsletter. Box 1115, Chadds Ford, PA 19317. $35 for 12 issues
PLUSES: Up-to-date
MINUSES: Home-brewed taste
THE VERDICT: Earnest

The earth, like any living thing, has a physiology, according to the fledgling Gaia theory. And like anything fledgling, the theory is full of energy, is somewhat naive, and occasionally has trouble sustaining flight.

The casual reader finds tiny, gemlike resources, such as simplifications of complex papers, bibliographies arranged by topic, book reviews, lesson plans, and the whole nine yards.

THE HUMAN EVOLUTION COLORING BOOK

Adrienne L. Zihlman. Harper and Row, 1982. $10.95
PLUSES: Nary a stone left unturned.
MINUSES: Textbookish
THE VERDICT: Sizable concentration required

Although this is a coloring book, don't expect children to be scrambling for their crayons. The author admits in the preface that he "had trouble getting across certain technical concepts" in his "Introduction to Human Evolution" class and that the coloring book idea arose to help fill the gap.

And it works. Seeking out the images, coloring them in, and then reading about their relevance packages the material for easy withdrawal from the memory bank. The approach works especially well for the detailed technical sections on DNA and Mendelian genetics.

Lay people with a burning desire to plumb the depths of the evolution question will find themselves in seventh heaven. Ordinary Joes and Josephines won't. But the book is still in print after nine years, and that speaks for itself.

A TRAVELER'S GUIDE TO THE GALAPAGOS ISLANDS

Bruce Boyce. Galápagos Travel, 1990. $14.25
PLUSES: No visa necessary
MINUSES: Sea legs required
THE VERDICT: Whiners stay home

Darwin found several elegant examples of natural selection flying, swimming, and crawling around the Galápagos Islands. Today about 60,000 hearty humans a year come to gander.

And almost everybody sleeps on boats. Some boats are big (100 berths) and some are small (six berths). Daytime is for exploring, nighttime is spent tooling to your next destination. Idyllic? Not quite. Those unacquainted with the Third World should heed Boyce's travel tips. And those who haven't slept on a boat should bring Dramamine. **OO**

CONTINUUM

HEAVENLY MESSENGER

Skywatchers await a glimpse of what the wise men saw. Plus, bad news for head bangers, and checking Earth's vital signs

Was the Star of Bethlehem a legend, a miracle, or a natural event? If it was merely a natural event, what kind?

After years of writing astronomy books and a few decades of observing the stars, my ponderings on the Star of Bethlehem crystallized into a possible solution. If that solution is correct, then this month we're due for an almost precise replay of what the Magi witnessed when they walked from Jerusalem to Bethlehem an estimated 1,993 years ago.*

Of all the explanations for the star, most scientists favor the "conjunction" theory—a close pairing of planets that gives the appearance of a single bright star. Astronomers have zeroed in on the triple conjunction of Jupiter and Saturn and the Venus–Jupiter conjunction, both thought to have taken place at the time of Christ's birth, as possible Star of Bethlehem candidates.

But there are crucial problems with these two candidates. The three Jupiter–Saturn conjunctions never blended into a single star. And although during the Venus–Jupiter conjunction the planets did seem to merge, this was only a one-night event, so how do we account for the star's reappearance to the Magi in Jerusalem?

My solution: the rare series of Venus–Jupiter conjunctions on August 12, 3 B.C., June 17, August 20, and October 14 in 2 B.C. On August 12 the two planets seemed almost to merge as seen from Babylonia, the probable homeland of the Magi. The following June the planets did merge, then set together in the direction of Palestine as seen from Babylonia, inspiring the Magi to make their trip to Bethlehem. (The August 20 conjunction, too near the sun to be visible, would have been predicted by the Magi, since they were avid and adept skywatchers.)

The fourth conjunction would be the climax. In the few hours it took the Magi to travel the five miles between Jerusalem and Bethlehem, they would note the Venus–Jupiter pair moving from the east toward the south (the direction of Bethlehem) due to the rotation of the earth, thus "going before" them. The ancient Jerusalem–Bethlehem road would lead the travelers to Bethlehem from roughly southeast—the planet pair would appear to be "standing over" the town.

I took the liberty of asking several experts about my theory. Michigan State and Abrams Planetarium astronomer Robert Victor, who "knows" conjunctions, says, "I'm excited about the theory." He's also as amazed as I that the rare conjunction series is reappearing!

Carl Wenning of Illinois State University, while supportive, feels that "a conjunction theory may be the best natural explanation—but not the best explanation." Wenning referred me to Purdue University's Sherman Kanagy, one of the best-known researchers in the Star of Bethlehem debate. "It overcomes many of the difficulties with previous proposals for a naturalistic identity for the star described in Matthew 2," Kanagy said of my solution and followed up his compliment by proposing a collaboration on a subsequent study.

Wherever you are, you'll be able to see mid-October's Venus–Jupiter conjunction by rising before dawn and looking in the east. I'm confident that the sight you'll see is an exact replay of the celestial events thought to have prophesied the birth of Jesus Christ.—*FRED SCHAFF*

**Many researchers believe that one thousand nine hundred and ninety-three years have passed since the birth of Christ, not 1,991 as previously assumed. The year of Christ's birth was miscalculated in A.D. 525. The Roman monk and scholar Dionysius Exiguus established the date, but modern research has shown that his calculations were faulty.*

CONTINUUM

No stitches saves time. A mechanical fastener that holds blood vessels together could mean the end of cumbersome suturing.

LESS SEWING FOR SURGEONS

Surgeons spend long, painstaking minutes during operations suturing blood vessels, prolonging the amount of time the patient spends under general anesthesia and increasing the risk of mortality. Now a new invention developed at Carnegie-Mellon University in Pittsburgh could take the stitches out of such surgery.

Electrical engineer Michael Reed and graduate assistant Hongtao Han hope to replace needle and thread with a mechanical fastener that sticks to tissue, joining the two ends of a blood vessel in a simple one-step procedure. The ingenious device consists essentially of a silicon wafer studded with an array of microscopic "barbs"—the secret to its stickiness. The barbs, each about the size of a red blood cell, are produced by selectively etching away portions of the silicon wafer using the same lithographic techniques used to manufacture most integrated circuits. A flared base at the bottom of each barb ensures that once it pierces tissue, it will not retract out of place.

Reed envisions shaping the silicon fastener into a ring, which would be inserted inside the two ends of the blood vessels that the surgeon wishes to connect. "In theory," Reed says, "our technique should provide a highly efficient means of binding tissues without causing extensive cellular damage."

—Kathleen McAuliffe

"All the good ideas I ever had came to me while I was milking a cow."
—Grant Wood

S.O.S.P.: SAVE OUR SPACE PROGRAM

The budget for the U.S. space program ran into some strong opposition in Congress this year due to increased competition for funds with social programs. In May, Congressman Bob Traxler (D-Mich.) convinced the VA, HUD, and the Independent Agencies Subcommittee of the House Appropriations Committee to vote for the termination of the space station program and the transfer of most of the funds thus saved to social programs. A massive campaign by pro-space forces followed, and as a result, the House ultimately voted to save the space station. However, the rest of the space program suffered. Few of the funds transferred by Traxler were restored to the space program budget.

In July, Senator Barbara Mikulski (D-Md.) led a tenacious and eventually successful fight to convince the Senate to approve a budget that would be substantially more favorable to the space program.

The differences between the meager budget approved by the House and the more generous one voted in by the Senate will soon be ironed out by the conference committee cochaired by Traxler and Mikulski. Much of the ground gained in the Senate could be lost.

Throughout this conflict, Spacecause, a pro-space lobbying organization, has led a major grass roots campaign, with help from *Omni* and others, in support of a strong, well-funded space program. Spacecause now asks for your participation at this most crucial stage of the budgeting process. Please write to Senator Mikulski (U.S. Senate, Washington, DC 20510) to encourage her continued support. Then call or write—preferably call—Congressman Bob Traxler (U.S. House of Representatives, Washington, DC 20515; [202] 225-2806) to politely express your support for the space program.

If the committee members are aware of the public's support, evidenced by letters and phone calls, they will be much more likely to grant the space program the funds it so desperately needs.

BOTHERED BY MOSQUITOES? THE PROBLEM MAY BE YOUR CLOTHES. MOSQUITOES ARE TWICE AS ATTRACTED TO THE COLOR BLUE AS TO ANY OTHER COLOR.

"If we had a keen vision and feeling of all ordinary human life, it would be like hearing the grass grow and the squirrel's heart beat, and we should die of that roar which lies on the other side of silence."
—George Eliot

CONTINUUM

RING AROUND THE EARTH

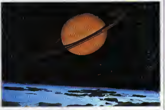
Anyone with even a small telescope has had the chance to admire the serene beauty of the rings of Saturn, which have inspired everything from wall calendars to the hood ornaments on vintage automobiles. But could an amateur astronomer on Saturn ever have been treated to a similar sight when he, she, or it trained a telescope on planet Earth? Danish planetary physicist Kaare Rasmussen says the answer just might be yes. In fact, Rasmussen speculates, the earth may have had rings much fainter than Saturn's as many as 16 separate times during the last 2,800 years.

Rasmussen, a professor at Denmark's University of Odens, looked at historical reports of meteor showers, fireballs, and meteorite landings that occurred between 800 B.C. and A.D. 1750. He found at least 16 periods of intense meteor activity, all of which exhibited a characteristic pattern: an initial burst of activity lasting a few months to a few years, followed by a few decades of lower activity and a subsequent rise.

This pattern might be explained, he says, by the earth "capturing" a passing comet or asteroid, which then broke up in orbit. Some of the particles fell to Earth, creating the first peak, while the rest stayed in orbit to form a ring. Eventually, Rasmussen theorizes, gravity pulled the ring particles into the upper atmosphere, where they either burned up or fell to the ground, creating the second peak of activity.

Rasmussen readily admits that his idea is "only a hypothesis," that the patterns he observed could be the result of periodic garden-variety meteor showers. But, he notes, if he's right, the earth could conceivably sprout another ring system—even within our lifetimes.

—Bill Lawren



Try these rings on for size: A Danish physicist theorizes that the earth may once have sported rings like Saturn's.

DIVIDE YOUR WEIGHT BY SIX TO GET THE APPROXIMATE NUMBER OF QUARTS OF BLOOD IN YOUR BODY

ABOUT 40 SQUARE MILES OF LAND ARE TRANSFORMED INTO DESERT EACH DAY.

The U.S. military hopes to identify all future battle casualties by their DNA, making the unknown soldier a relic of the past.

DNA DOG TAGS

The Tomb of the Unknown Soldier in Washington, DC, honors all the soldiers who, for whatever reason, could not be identified after death. To prevent any more who die in the line of duty from joining their ranks, the Pentagon may soon create DNA identification files on all of the 1.5 million active-duty personnel in the armed services.

Currently, the government keeps on file only fingerprints and dental charts. But with the advent of high-tech weapons, Army forensic specialists need equally advanced tools to identify the increasingly charred and shattered remains of battle field casualties. According-ly, all new recruits may soon be required to provide DNA in the form of a blood sample or mouth swab (a scraping of cells from inside the cheek), to be kept in a central repository. Military doctors could then remove some DNA from bodily remains and match the molecular sequence with the appropriate sample in the repository to identify the casualty.

"Even if we recover only some hair or a fragment of dry bone, we should still be able to extract enough genetic material to make a positive identification," reports Major Victor Weedn, chief of the Armed Forces DNA Identification Laboratory at the Armed Forces Institute of Pathology in Washington, DC.

—Kathleen McAuliffe

"Go and wake up your luck."
—Persian proverb

Maybe they should take up tennis. Studies have found that repeatedly heading a soccer ball can cause brain dysfunction

HEADS UP

Soccer appears to rank among the safest of sports. It doesn't involve tackles, sticks, or sharp-bladed skates, for example. Nonetheless, several studies have concluded that the game can be hazardous to your head.

The *American Journal of Sports Medicine* reported this spring that heading a soccer ball caused "measurable and irreversible cognitive dysfunction," affecting attention, concentration, memory, and judgment in 81 percent of 37 former members of the Norwegian national team. The impairments, like those seen in boxers, resulted from repeated blows over time rather than a few severe concussions.

Another study of soccer-related head injuries, this one at the University of North Carolina in 1989, found that heading the ball incorrectly—off the side or top of the head, rather than the forehead—also caused injuries. The severity of injury depended on such factors as the ball's speed (which, according to the study, averages 51 miles per hour) and construction (leather balls become heavier on a wet field, as do plastic balls with worn covers).

Collisions with goal cages also caused more than a dozen fatalities over ten years, says David Janda, director of the Institute for Preventive Sports Medicine in Ann Arbor, Michigan.

—Jack Mason

"Nature lives in motion."
—James Hutton

UNTIL WE MEET AGAIN

An elephant never forgets, goes the aphorism. Now modern science debunks yet another folk myth. Researchers at the University of North Carolina have uncovered what appears to be the first evidence of long-term memory in nonhuman animals, not in the gargantuan elephant but in a diminutive bird, the male hooded warbler.

Working in the university's Mason Farm Biological Reserve, doctoral student Renee Godard and biology professor R. Haven Wiley tape-recorded the small yellow songbirds as they belted out the individual tunes that mark their boundaries. After the birds returned to the forest, following their winter migration, the researchers replayed the songs to them. When Godard and Wiley broadcast songs outside the areas where they had been sung, the warblers became agitated, sang their own songs repeatedly, and even dived at the speakers. The birds' reaction demonstrates their ability to remember for at least several months the songs of warblers living nearby. "This is the first time that someone has been able to show that animals are capable of keeping track of the individuals they interact with over such long periods of time," Wiley says.

The warblers' ability suggests that memory may evolve to suit specific purposes in different species, he says. In this case, memory facilitates mating and reproduction. "Those who remember their neighbors may be more successful in reproduction than those who have strangers around them," Wiley says, "because those birds must spend much of their time settling boundaries and defending them."

—Beth Howard

Only a memory. Researchers have discovered that male hooded warblers, like humans, possess long-term memory

CONTINUUM

Ponds freeze, but the fish that swim in them don't.

FISH ANTIFREEZE

Ever wonder why fish that live in the icy Arctic regions don't freeze to death? They possess a gene that produces a protein in their livers that lowers the freezing point of ice crystals on their skin to −2°C.

Now biologist Thomas Caceci of Virginia Polytechnic Institute and State University in Blacksburg has bioengineered the protein producing gene, which, he speculates, might be introduced into fruit trees to help them resist flash freezes or used to develop deicing compounds for airplane wings and winter-slick highways. The protein depresses the freezing point but strangely leaves the melting temperature unchanged, a phenomenon known as thermal hysteresis, he says.

Caceci, an aquatic animal specialist, worked with the genes of the winter flounder, whose antifreeze protein binds with the oxygen molecules in ice crystals, preventing them from enlarging. He produced about a half liter of the pure protein by stimulating bacteria containing the engineered gene. "In other words, we created an artificial gene to produce an artificial protein," he says, "but it's extraordinarily expensive. Like everything else in microbiology, scaling up the production is the big problem.

"One day we hope to make it in big vats, a hundred to five hundred liters at a time, but even if you were measuring production in grams instead of micrograms, you still wouldn't have enough to spray on icy roads," he says. —George Nobbe

BUT IS IT INTELLIGENT?

Stop the presses: Scientists have determined that life does indeed exist on Earth.

Last December the *Galileo* spacecraft flew past Earth on the first of two encounters en route to its rendezvous with Jupiter in 1995. To test its instruments' ability to detect life on other worlds, *Galileo* made various atmospheric measurements as it passed our planet.

"The idea was to view the earth as another planet, imagining that we didn't live here," says Charles Hord, head of *Galileo*'s ultraviolet spectroscopy team. "Living creatures change the atmosphere, and we can detect those changes before we can observe the structures that man has built. It's like seeing smoke before seeing the chimney."

Galileo measured atmospheric concentrations of carbon, hydrogen, nitrogen, and oxygen—the basic building blocks of life. "Whenever we go to a planet we look for signs of nonequilibrium, things you wouldn't expect from ordinary chemistry," Hord says. The unusually large amount of oxygen in Earth's atmosphere supplied decisive proof of life because it indicated that photosynthesis was taking place.

The spacecraft will make similar measurements of Jupiter four years from now. Researchers take immense interest in the planet, although they don't expect to find life there. "We believe that before life started, Earth had an atmosphere similar to Jupiter's," Hord says. "By studying Jupiter, we're looking back to an earlier time on our own planet."

—Steve Nadis

"Authority tends to assign jobs to those least able to do them."
—Richard C. Cornuelle

THE WORLD'S LARGEST RAW DIAMOND WAS UNEARTHED IN PRETORIA, SOUTH AFRICA, IN 1905 WEIGHING MORE THAN ONE AND ONE-QUARTER POUNDS, AN INCREDIBLE 3,106 CARATS.

Before trying to detect life on Jupiter, the Galileo *spacecraft did a dry run on Earth. Fortunately, we passed the test.*

NATURAL DIRECTION

ARTICLE BY
PAMELA WEINTRAUB

Extraordinary new findings suggest that life forms may literally direct their own evolution

PHOTOGRAPH BY
NEAL DAVIS

Molecular evolutionist Barry Hall studies bacteria evolving in the lab. His eerie observations of these single-celled creatures have convinced him that some life forms, at least, can orchestrate their own evolution in response to pressures from the environment. If this startling phenomenon holds true for more complex organisms like beluga whales and people, we'll have to rethink our notion of how life evolved.

When molecular biologist John Cairns arrived at Princeton for a debate in the summer of 1990, the mood was tense The arena, a lecture hall at the university's esteemed Lewis Thomas Laboratories, boasted a wall-length chalkboard, overhead slide projectors, and comfortable seats with armrests for taking notes But despite these academic trappings, Cairns could almost hear "the saloon doors swinging, the train approaching, and the wind rustling down the plains " Some of the spectators awaiting the debate had even dubbed it "the shoot-out on Main Street "

On one side of the dusty scientific road stood Bruce Levin, a professor from the University of Massachusetts at Amherst Levin, like almost all biologists, believed that one elegant mechanism could explain the diversity of life on Earth According to this prevailing view, all species evolve through random mutation of the genes. Populations with new traits arise when mutations produce organisms especially good at finding food, avoiding predators, and producing offspring After generations, these successful mutants may replace earlier organisms within the species or even form whole new species The process is called natural selection, since nature itself apparently selects the individuals most likely to survive

Convinced of this scenario, Levin had come to Princeton, scientific six-guns at the ready, to stand down the heretics—Cairns and his colleague, University of Rochester molecular evolutionist Barry Hall Not only had these two renegades challenged the prevailing orthodoxy, they had done so in *Nature* and *Genetics* a couple of the most prestigious scientific journals in the world.

Cairns and Hall were not creationists who believed that people had been placed on Earth fully formed by heavenly design. Instead, they had come to Princeton with an alternative scenario for how evolution works. The mutations that drive evolution, the researchers claimed. were not always random. In experiment after experiment, they said, microorganisms seemed to be whipping up their own mutations—almost as if some inner molecular composer were helping the cells react to environmental requirements and needs. They even had a name for this shocking and powerful phenomenon: directed mutation.

At the Princeton conference, Levin argued against this radical view. "Mutants arise at random," he said, "whether they are favored by natural selection or not." Only *after* the mutants arise randomly, he added, does the environment kick in, with natural selection acting as the "editor of evolution," choosing the life forms it likes best among those already around.

Levin pointed out the technical limitations of the research, insisting that Cairns and collaborators had merely assumed directed mutation was occurring without sufficiently ruling out other, less radical explanations. To emphasize what he saw as the work's major flaw, he titled his talk "Refrigerator Lights and the Limits of Inductive Inference." The idea, he told the audience of professors and graduate students, was that no matter how many mundane explanations the researchers eventually disproved, there would always be more. Their approach, he stated, was a bit like trying to prove that a refrigerator light is off when the door is closed. "Even if you put a little kid in the refrigerator to tell you what's going on," he said, "you could never be sure the kid was telling the truth." They would never validate their theory, he concluded, unless they found the mechanism at its root.

But despite these objections, Cairns and Hall were impossible to ignore. As one seminar observer, Princeton graduate student Karen Weiler, recalls, "A lot of people there that night wanted to dismiss Cairns and Hall, but they just couldn't."

With good reason. The new research, if correct, would alter one of the most entrenched scientific theories of our time, in the process changing our notion of how life on Earth evolved. It might also explain the huge gaps in the fossil record—long epochs during which paleontologists can find no evidence of evolution at all. After all, if mutations are literally "directed" by life forms reacting to environmental change, then rapid evolution would occur primarily at highly "punctuated" moments—during ice ages, say, or meteor hits, when environmental stress is especially great. In fact, if the new scenario turns out to be valid not just for microorganisms, but also for more complex living things such as rain forests, animals, and humans, evolutionary biologists would have to rewrite much of the work they have labored over for the past hundred years.

Today's evolutionary biologists—often called "Neo-Darwinists"—base much of their work on the ideas of the master, Charles Darwin himself. While exploring the flora and fauna of South America and the Galapagos Islands in the 1830's, Darwin observed the immense variety of life. Even in a given species, there was large variation from one individual to the next. Based on this, Darwin proposed a brilliant theory for how evolution works. Nature was always generating variation, he declared, and in the brutal struggle to survive, some variants would just be more successful than others. Those better at exploiting the environment, he said, would have more offspring, and these individuals would prevail.

But despite this central insight, Darwin still didn't know why the variation occurred. The reason: The world had not yet heard of the tiny hereditary units called genes.

In the century after Darwin proposed his theory, however, biologists discovered that genes, found in every cell, determined the nature of living things. By orchestrating the synthesis of organic chemicals into the stuff of life, genes dictated virtually every biological characteristic from brain size to eye color and body type.

The genes themselves were composed of a helical molecule called deoxyribonucleic acid, or DNA. All DNA, in turn, consisted of just four chemical building blocks, called bases. These bases, strung together over and over like beads, could be arranged in literally millions of combinations, creating the potential for virtually infinite genetic diversity on Earth.

For a species to generate this diversity, said the Neo-Darwinists, all that was needed were some simple chance events. In the random shuffle of life, a few bases would accidentally be replaced by others. Over time, the accu-

"Mother was right. I should have left you years ago."

mulation of such changes—called "point" mutations because they occurred one base at a time—would result in different types of creatures, even whole new species.

The Neo-Darwinists who proposed this grand synthesis of Darwinian evolution and modern genetics said their theories were rooted in scientific fact. The first study to back them up was published in the 1940's after Salvador E. Luria, then of Indiana University, began wondering how he could prove that mutations had occurred randomly and not in response to environmental stress. It occurred to Luria that he could compare genetic mutation to another rare event—hitting the jackpot at a slot machine in Las Vegas. People playing these slot machines usually came up empty-handed, Luria knew, but every so often, by chance, someone struck it rich.

Luria compared the slot machine to a colony of bacterial cells. Each cell reproduced by dividing in half. The two resulting daughter bacteria, in turn, reproduced by dividing in half again, and so on and so forth until, within a couple of days, one cell had become a swarming bacterial colony of 1 billion cells or more. If a cell were to mutate randomly, early in the life cycle of a colony, it would produce large numbers of mutant descendants, resulting in a "jackpot" of mutants.

Using this concept as the basis for experiments, Luria and his colleague, Vanderbilt University physicist Max Delbruck, grew bacterial populations in test tubes. Then, after the populations had grown, the scientists introduced a lethal virus.

Mutants never seemed to emerge directly in response to the virus. Every so often, on the other hand, a given population just happened to contain huge numbers of mutants resistant to the virus. These mutants were so numerous they had obviously arisen early in the life of the population, way before the virus had been introduced, and represented jackpots of enormous proportion. The conclusion: Mutants resistant to the virus occurred randomly, without input from the environment. The environmental stress—in this case, exposure to a virus—came into play only later, selecting out the mutants that could survive.

If the Neo-Darwinists were happy to see their theories boosted in this way, they were even more overjoyed when, in the 1950's, geneticist Joshua Lederberg drove the point home. Lederberg started with a gel containing numerous colonies of bacteria. Then he pressed the gel onto a strip of velveteen as if he were printing on paper with a rubber stamp. Finally he took the velveteen and pressed it onto a second gel. When he pulled the velveteen off, the pattern of bacterial cells on the second gel mirrored that of the first. To do his experiment, Lederberg exposed only the bacteria on the second gel to the virus. A certain number of cells were immune to the virus, and only they survived.

The question was: did the resistant cells—mutants—develop in response to the virus, or were they there beforehand? To find out, Lederberg tested plate number one, and voilà. He found mutant cells resistant to the virus at the same exact site as on plate two. Obviously, the mutant cells had been there all along. Like Luria and Delbruck, Lederberg had validated the ideas of the Neo-Darwinists. Mutant organisms, he showed, emerged spontaneously, without any stimulation from the environment at all.

Satisfied with the evidence, the Neo-Darwinists spent the next 30 years refining their theories, coming up with all sorts of situations under which populations might evolve. But while they spent enormous time honing and polishing their theory, the overriding mechanisms—random mutation and natural

"Hold it! I'm his attorney!"

selection—remained the same

And there the matter stood until the 1980's, when it fell under the scrutiny of British oncologist and molecular biologist John Cairns. A deeply thoughtful man with the regal good looks and bearing of actor Peter O'Toole, Cairns had spent years as director of the prestigious laboratory at Cold Spring Harbor in New York and was now in Boston at Harvard's School of Public Health. Interested in the mutations that induce cancer, he thought he might gain some helpful insight by studying mutations in bacterial cells.

Naturally, he began by going back to the old studies conducted by Luria, Delbruck, and Lederberg decades before. Examining their work more carefully, he realized that though they had conclusively proved the existence of random mutation, they hadn't ruled out other evolutionary mechanisms as well. Indeed, their crucial studies were plagued by an overwhelming flaw: the use of a *lethal* virus.

The virus presented a problem because, in bacterial populations, mutants resistant to virus take several generations to express themselves. The reason is that bacteria replicate by dividing and then growing. A first-generation mutant thus contains half of the cellular material from the nonmutant parent cell; in fact, new mutants carry so much parental material that they often seem to behave like the original strain. Only after many generations, when the original nonmutant gene products have been diluted out, can the mutant's new characteristics truly emerge.

Therefore, in the Luria and Delbruck experiment, the very virus that might have *caused* the production of resistant mutants would have killed those mutants instantly. Mutants produced in direct response to a lethal virus would never be observed.

To get around this problem, Cairns decided to see if he could generate mutants through a less instantly lethal form of selection. He would deny his bacteria access to all nutrients except for one that they lacked the ability to use. Either they would learn to use the new nutrient, or else they would eventually starve to death. "The question was," Cairns explains, "could some mutants arise as a result of pressure from the environment?"

He began his experiment with populations of bacteria unable to digest the sugar lactose. Then he placed these bacteria in a medium that contained only lactose for a food source. Of course, the bacteria stopped multiplying because they had no usable food. But after a few days, large numbers of the lactose-utilizing mutants began to appear. The mutants were so numerous, in fact, that they could not be accounted for by the theory of strictly random mutation. The suggestion: The bacteria were learning to generate their own useful mutations through a surprising evolutionary process that wasn't random at all.

Cairns published his study in *Nature* in 1988. Near the end of the article, he suggested some ways in which the environment could influence genetic material, thus allowing directed mutation to occur. Each of these suggested processes, Cairns had the chutzpah to write, "could in effect provide a mechanism for the inheritance of acquired characteristics."

The statement inspired sentiments of fear and loathing among evolutionary biologists worldwide. The term *acquired characteristics*, after all, smacked of the discredited eighteenth-century biologist Jean-Baptiste Lamarck, who proposed that evolution proceeded as individuals used various organs, muscles, and limbs. For instance, Lamarck had declared, if a creature under stress was forced to exert extreme muscular strength, offspring would inherit—or

"He's trying to determine why the same biological process can produce both a Democrat or Republican."

acquire—larger muscles whether or not they actually required the additional strength Cairns had used the phrase "acquired characteristics" by way of analogy *only*, he was talking about genes and proteins, not fingers and toes But that didn't stop his critics from writing to *Nature* in droves They insisted that Cairns tighten his laboratory controls and proposed alternative scenarios that would leave the Neo-Darwinian interpretation intact

But Cairns stood philosophically firm "It's easy to imagine molecular mechanisms that *might* drive the process of directed mutation" he explained "We've already proven feedback between organisms and the environment, this occurs through messenger molecules that help genes communicate with the cell and the outside world" In light of this, he added "It seems almost perverse to maintain as a matter of principle, that evolution is driven only by random mutations and that no other phenomenon comes into play"

One researcher wholeheartedly agreed. Molecular evolutionist Barry Hall had been on a similar track for years His involvement in the field began in 1970, while visiting his good friend, University of Minnesota population geneticist Dan Hartl Hartl had been studying the fruit fly *Drosophila*, monitoring how large groups of these creatures evolved from one generation to the next Hall, on the other hand was studying the general molecular and cellular biology of the popular laboratory bacteria *E coli* "We got to talking," Hall explains, "and kind of said, Gee, wouldn't it be nice if you could watch evolution as it happened, on the molecular and cellular level, by experimenting with bacteria?"

A couple of years later Hall began the work He started with a strain of bacteria normal in all respects but one The individuals in his colonies lacked an enzyme necessary for digesting lactose He plated bacteria from this strain on a dish containing a blood-red gel known as a Macconkey medium Dissolved in the medium were two types of food sources a small amount of peptide and a large amount of lactose The gel was an important indicator, since bacteria that digested lactose would absorb some of the dye showing up as red, those that digested the peptide would not absorb the dye and would thus appear white

The bacteria, unable to digest the lactose, consumed all the peptides As they grew, they peppered the blood-red expanse of Macconkey with white colonies When all the peptides were gone bacterial growth seemed to stop But out of curiosity, Hall let these seemingly stymied colonies sit around his lab for a week or two In every case he found pimples of red began bursting through the islands of white These red bursts, called *papillae*, were new colonies of bacteria, now able to utilize the lactose In short, they were mutants

For nearly a decade, through stints at the University of Newfoundland and the University of Connecticut Hall watched his bacteria give rise to mutant offspring capable of digesting lactose As he performed the experiments he began to realize the oddness of his results Time and again his bacteria were evolving the ability to eat the lactose about a hundred million times more frequently than would be expected if mutation had occurred purely by chance What made the results especially strange was the magnitude of the genetic change involved Sequencing the bacterial genes, Hall discovered that two genetic mutations not just one, were required for digestion of lactose to occur

Hall discovered the phenomenon in other *E coli* populations as well He was absolutely floored, for instance, when

CONTINUED ON PAGE 109

"I'd say the left side of your brain is shot to hell"

No, that's not a Neanderthal to the left. Yet there was a time when Homo sapiens Neanderthalensis *was viewed as little more than a shambling, apelike beast. For a more recent view of our evolutionary predecessors, turn the page.*

ARTICLE BY SHARI RUDAVSKY

THE SECRET LIFE OF THE NEANDERTHAL

PAINTING BY BRAD HOLLAND

The band of Neanderthals stopped outside the cave and a lone male peered in. Looking around, he noticed that previous occupants, a taller, more graceful group, had left some remnants: smoldering coals, scattered garbage, and a smooth, shell-shaped pendant, purpose unknown. Finding no food, the Neanderthals trekked on, traversing miles of rocky terrain in less than a day. By late afternoon, they'd begun to track a goat. One of the males plunged on top of the animal, wounding it with his crude but heavy spear; the animal thrashed, but the male hung on until the goat died. Uttering a series of meaningful grunts, the Neanderthal band settled down for the night. One of the females built a fire, while another scraped the hide with a sharpened stone. A gray-haired male propped his arthritic leg above a grassy knoll. Devouring the remains of dinner, this Neanderthal family had no way of knowing their future. The rest of their stay on Earth would be arduous and brief.

A time machine and camcorder top the wish list of every scientist hoping to unravel the secret life of the Neanderthals—long viewed as a bumbling people who evolved rapidly (and thankfully) into our direct ancestors. But though today's paleoanthropologists lack the knack of time travel, they have recently acquired access to the next best thing: remarkable new dating technology that is slowly bringing the life and times of early hominids into bold relief. Based on state-of-the-art dating techniques such as thermoluminescence and electron spin resonance, researchers have come up with an increasingly detailed picture of the Neanderthals and how they lived.

No longer viewed as an evolutionary lout, the Neanderthal depicted today is a kinder, gentler, more successful individual with a range of unique cultural characteristics including sophisticated hunting practices and an intimate and elaborate social life.

In addition, paleoanthropologists now believe that Neanderthals coexisted with our direct ancestors, early modern humans, for a longer time span than ever before suspected. This revelation has thrown a monkey wrench into the story of hominid evolution, for if Neanderthals were not our direct ancestors, then who were they?

Scientists have been puzzling over this question since 1856, when quarry workers in the Neander Valley near Dusseldorf, Germany, found pieces of skull in the rock. Considering the way quarry workers go at limestone with picks and shovels (not at all like modern archaeologists, who tiptoe about with scalpels and toothbrushes), it's a wonder that any fossils remained. As University of Chicago anthropologist Richard G. Klein tells the story, the quarry owner thought the bones came from a bear, but he turned them over to Carl Fuhlrott, a local schoolteacher, who pronounced them human, albeit unusual.

Further discoveries over the next 120 years ensured Neanderthals a place right next to modern humans on the evolutionary continuum. According to early paleoanthropologists, hominid evolution occurred incrementally, with the Neanderthal just one of many forms that led to humans today.

As more Neanderthal remains were unearthed, anthropologists also pieced together startling aspects of Neanderthal life. By the 1950's, researchers could cite definitive fossil evidence of tool use, fire use, and hunting and gathering techniques. And in perhaps the most extraordinary find of that decade, archaeologist Ralph Solecki unearthed a Neanderthal skeleton covered with pollen at the Shanidar site in Iraq. The so-called flower burial sparked a debate still unsettled today. The hard-liners argued that Neanderthals buried their dead only to discourage scavengers and eliminate odor. The flower spores, they held, had drifted into the graves purely by chance. But a new group of researchers, increasingly convinced of Neanderthals' basic *humanity*, cited the pollen as evidence of a ritual Neanderthal burial in which survivors draped flowers over the deceased.

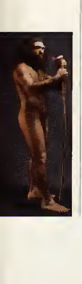
Evidence for the new and improved Neanderthal, one that inhabited the earth for at least 100,000 years and lived side by side with early modern man, has been accumulating since 1980, when archaeologist Eitan Tchernov of Hebrew University in Jerusalem started dating the hominid remains found in three Israeli caves. Since Tchernov could find no dating techniques appropriate to the task at hand, he devised a method of his own. By approximating the dates of rodent bones found in the same layer as human bones, he created a biostratigraphy, an evolutionary time chart based on fossils. Using biostratigraphy, Tchernov and Ofer Bar-Yosef, now a professor of anthropology at Harvard University, set the ages of the *Homo sapiens* found in the Qafzeh and Skhul caves at 80,000 to 100,000 years old, about twice as old as anyone suspected. They dated the Neanderthal-like remains found in the third cave, Kebara, at 50,000 years. According to these figures, Neanderthals were not ancestral to us at all.

Anthropologists immediately protested the accuracy of these dates, saying the biostratigraphy did not provide reliable information. However, in the past few years, two new techniques have confirmed the Israeli results.

One technique, called thermoluminescence (TL), is particularly valuable for dating nonorganic artifacts such as burnt rocks and tools. The TL technique works because objects accumulate electrons over time, yet release electrons whenever they are burned. An accumulation of electrons may be measured by the intensity of light an object emits when it is burned. By heating a previously burnt object—for instance, a flint fired in a Neanderthal hearth a hundred thousand years ago—and then measuring the energy emitted, researchers can estimate the time that has passed since the object was burnt the first time around.

Experienced with TL, French physicist Hélène Valladas of the French National Center for Scientific Research decided to help the Is-

CONTINUED ON PAGE 54



THE NEANDERTHAL HAS BEEN REDEFINED AS A RUGGED BUT SOPHISTICATED TOOL USER WHO LIVED RIGHT ALONGSIDE OUR OWN ANCESTORS, EARLY MODERN MAN

Twenty minutes into the voyage nothing more startling than a dragonfly the size of a hawk has come into view, fluttering for an eye-blink moment in front of the timemobile window and darting away, and Mallory decides it's time to exercise Option Two: Abandon the secure cozy comforts of the timemobile capsule, take his chances on foot out there in the steamy mists, a futuristic pygmy roaming virtually unprotected among the dinosaurs of this fragrant Late Cretaceous forest. That has been his plan all along—to offer himself up to the available dangers of this place, to experience the thrill of the hunt without ever quite being sure whether he was the hunter or the hunted.

Option One is to sit tight inside the timemobile capsule for the full duration of the trip—he has signed up for twelve hours—and watch the passing show, if any, through the invulnerable window. Very safe, yes. But self-defeating, also, if you have come here for the sake of tasting a little excitement for once in your life. Option Three, the one nobody ever talks about except in whispers and which perhaps despite all rumors to the contrary no one has actually ever elected, is self-defeating in a different way: Simply walk off into the forest and never look back. After a prearranged period, usually twelve hours, never more than twenty-four, the capsule will return to its starting point in the twenty-third

HUNTERS IN THE FOREST

FICTION BY ROBERT SILVERBERG

A TWENTY-THIRD-CENTURY MAN FINDS LOVE AND ADVENTURE IN THE LATE CRETACEOUS. BUT DOES HE HAVE THE COURAGE TO BET HIS FUTURE ON A ROMANCE IN THE AGE OF DINOSAURS?

ILLUSTRATIONS BY BRALDT BRALDS

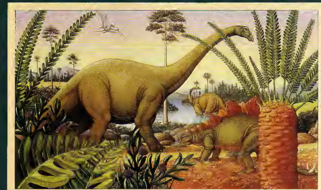
century whether or not you're aboard. But Mallory isn't out to do himself in, not really. All he wants is a little endocrine action, a hit of adrenaline to rev things up, the unfamiliar sensation of honest fear contracting his auricles and chilling his bowels: all that good old chancy stuff, damned well unattainable down the line in the modern era where risk is just about extinct. Back here in the Mesozoic, risk aplenty is available enough for those who can put up the price of admission. All he has to do is go outside and look for it. And so it's Option Two for him, then, a lively little walkabout and back to the capsule in plenty of time for the return trip.

With him he carries a laser rifle, a backpack medical kit, and lunch. He jacks a

ALL HE WANTS IS SOME OF THAT OLD CHANCY STUFF, ALL BUT

and carbon dioxide is different from what he's accustomed to, he suspects, and certainly none of the impurities that six centuries of industrial development have poured into the atmosphere are present. There's something else, too, a strange subtext of an odor that seems both sweet and pungent: It must be the aroma of dinosaur farts, Mallory decides. Uncountable hordes of stupendous beasts simultaneously releasing vast roaring boomers for a hundred million years surely will have filled the prehistoric air with complex hydrocarbons that won't break down until the Oligocene at the earliest.

Scaly tree trunks thick as the columns of the Parthenon shoot heavenward all around him. At their summits, far overhead,



thinko into his waistband and clips a drinko to his shoulder. But no helmet, no potted air supply. He'll boldly expose his naked nostrils to the Cretaceous atmosphere. Nor does he avail himself of the one-size-fits-all body armor that the capsule is willing to provide. That's the true spirit of Option Two, all right. Go forth unshielded into the Mesozoic dawn.

Open the hatch, now. Down the steps; hop skip jump. Booted feet bouncing on the spongy primordial forest floor. There's a hovering dankness but a surprisingly pleasant breeze is blowing. Things feel tropical but not uncomfortably torrid. The air has an unusual smell. The mix of nitrogen

GONE IN THE MODERN ERA, WHERE RISK IS JUST ABOUT EXTINCT.

whorls of stiff long leaves jut tensely outward. Smaller trees that look like palms but probably aren't fill in the spaces between them, and at ground level there are dense growths of awkward angular bushes. Some of them are in bloom, small furry pale-yellowish blossoms, very diffident looking, as though they were so newly evolved that they were embarrassed to find themselves on display like this. All the vegetation, big and little, has a battered, shopworn look, trunks leaning this way and that, huge leafstalks bent and dangling, gnawed boughs hanging like broken arms. It is as though an army of enormous tanks passes through this forest every few days. In fact that isn't far from the truth, Mallory realizes.

But where are they? Twenty-five minutes gone already and he still hasn't seen a single dinosaur, and he's ready for some.

"All right," Mallory calls out. "Where are you, you big dopes?"

As though on cue the forest hurls a symphony of sounds back at him: strident honks and rumbling snorts and a myriad blatting snuffling wheezing skreeing noises. It's like a chorus of crocodiles getting warmed up for Handel's *Messiah*.

Mallory laughs. "Yes, I hear you. I hear you!"

He cocks his laser rifle. Steps forward, looking eagerly to right and left. This period is supposed to be the golden age of dinosaurs, the grand tumultuous climactic epoch just before the end, when bizarre new species popped out constantly with glorious evolutionary profligacy, and all manner of grotesque Goliaths roamed the earth. The thinko has shown him pictures of them, spectacularly decadent in size and appearance: long-snouted duck-billed monsters as big as a house and huge lumbering ceratopsians with frilly baroque bony crests and toothy things with knobby horns on their elongated skulls and others with rows of bristling spikes along their high-ridged backs.

He aches to see them. He wants them to scare him practically to death. Let them loom, let them glower, let their great jaws yawn. Through all his untroubled days in the orderly and carefully regulated world of the twenty-third century, Mallory has never shivered with fear as much as once, never known a moment of terror or even real uneasiness, is not even sure he understands the concept, and he has paid a small fortune for the privilege of experiencing it now.

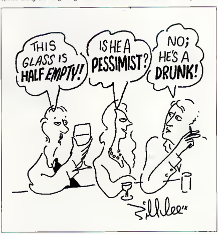
Forward. Forward.

Come on, you oversized bastards, get your asses out of the swamp and show yourselves!

There. Oh, yes, yes, *there!*

He sees the little spheroid of a head first, rising above the treetops like a grinning football attached to a long thick hose. Behind it is an enormous humped back, unthinkably high. He hears the pile driver sound of the behemoth's footfall and the crackle of huge tree trunks breaking as it smashes its way serenely toward him.

He doesn't need the murmured prompting of his thinko to know that this is a giant sauropod making its majestic passage through the forest—"One of the titanosaurs or perhaps an ultrasaur," the quiet voice says, admitting with just a hint of chagrin in its tone that it can't identify the particular species—but Mallory isn't really concerned with detail on that level. He is after the thrill of size. And he is getting size, all right. The thing is implausibly colossal. It emerges into the clearing where he stands and he is given the full view, and gasps. He can't even guess how big it is. Twenty meters high? Thirty? Its ponderous corrugated legs are thick as sequoias. Giraffes on tiptoe could go skittering between them without grazing the underside of its massive belly. Elephants would look like house cats beside it. Its tail, held out stiffly to the rear, decapitates sturdy trees with its slow steady lashing. A hundred million years of saurian evolution have produced this thing, Darwinism gone crazy, excess building remorselessly on excess, irrepressible chromosomes gleefully reprogramming themselves through the millennia to engender thicker bones, longer legs, ever bulkier bodies, and the end result is this walking mountain, this absurdly overstated monument to reptilian hyperbole.



"Hey!" Mallory cries. "Look here! Can you see this far down? There's a human down here. *Homo sapiens.* I'm a mammal. Do you know what a mammal is? Do you know what my ancestors are going to do to your descendants?" He is practically alongside it, no more than a hundred meters away. Its musky stink makes him choke and cough. Its ancient leathery brown hide, as rigid as cast iron, is pocked with parasitic growths, scarlet and yellow and ultramarine, and crisscrossed with the gullies and ravines of century-old wounds deep enough for him to hide in. With each step it takes, Mallory feels an earthquake. He is nothing next to it, a flea, a gnat. It could crush him with a casual stride and never even know.

And yet he feels no fear. The sauropod is so big he can't make sense out of it, let alone be threatened by it.

Can you fear the Amazon River? The planet Jupiter? The pyramid of Cheops?

No, what he feels is anger, not terror. The sheer preposterous bulk of the monster infuriates him. The pointless superabundance of it inspires him with wrath.

"My name is Mallory," he yells. "I've come from the twenty-third century to bring you your doom, you great stupid mass of meat. I'm personally going to make you extinct, do you hear me?"

He raises the laser rifle and centers its sight on the distant tiny head. The rifle hums its computations and modifications and the rainbow beam jumps skyward. For an instant the sauropod's head is engulfed in a dazzling fluorescent nimbus. Then the light dies away and the animal moves on as though nothing has happened.

No brain up there? Mallory wonders. Too dumb to die?

He moves up closer and fires again, carving a bright track along one hypertrophied haunch. Again, no effect. The sauropod moves along untroubled, munching on treetops as it goes. A third shot, too hasty, goes astray and cuts off the crown of a tree in the forest canopy. A fourth zings into the sauropod's gut but the dinosaur doesn't seem to care. Mallory is furious now at the unkillability of the thing. His thinko quietly reminds him that these giants supposedly had had their main nerve centers at the base of their spines. Mallory runs around behind the creature and stares up at the galactic expanse of its rump, wondering where best to place his shot. Just then the great tail swings upward and to the left and a torrent of immense steaming green turds as big as boulders comes cascading down, striking the ground all around Mallory with thunderous impact. He leaps out of the way barely in time to keep from being entombed, and goes scrambling frantically away to avoid the choking fetor that rises from the sauropod's vast mound of excreta. In his haste he stumbles over a vine, loses his footing in the slippery mud, falls to hands and knees. Something that looks like a small blue dog with a scaly skin and a ring of sharp spines around its neck jumps up out of the muck, bouncing up and down and hissing and screeching and snapping at him. Its teeth are deadly-looking yellow fangs. There isn't room to fire the laser rifle. Mallory desperately rolls to one side and bashes the thing with the butt instead, hard, and it runs away growling. When he has a chance finally to catch his breath and look up again, he sees the great sauropod vanishing in the distance.

He gets up and takes a few limping steps further away from the reeking pile of ordure.

He has learned at last what it's like to have a brush with death. Two brushes, in fact, within the span of ten seconds. But where's the vaunted thrill of danger narrowly averted, the hot satisfaction of the *frisson*? He feels no pleasure, none of the hoped-for rush of keen endocrine delight.

Of course not. A pile of falling turds, a yapping little lizard with big teeth: what humiliating perils! During the frantic moments when he was defending himself against them he was too busy to notice what he was feeling, and now, muddy all over, his knee aching, his dignity dented, he is left merely with a residue of annoyance, frustration, and perhaps a little ironic self-deprecation, when what he had wanted was the white ecstasy of genuine terror followed by the postorgasmic delight of successful escape recollected in tranquillity.

Well, he still has plenty of time. He goes onward, deeper into the forest.

Now he is no longer able to see the timemobile capsule. That feels good, that sudden new sense of being cut off from the one zone of safety he has in this fierce environment. He tries to divert himself with fantasies of jeopardy. It isn't easy. His mind doesn't work that way; nobody's does, really, in the nice, tidy, menace-free society he lives in. But he works at it. Suppose, he thinks, I lose my way in the forest and can't get back to—no, no hope of that: the capsule sends out constant directional pulses that his thinko picks up by micro-

> ❝A thing that looks like a small blue dog with a scaly skin jumps up out of the muck, screeching at him.❞

wave transmission. What if the thinko breaks down, then? But they never do. If I take it off and toss it into a swamp? That's Option Three, though, self-damaging behavior designed to maroon him here. He doesn't do such things. He can barely even fantasize them.

Well, then, the sauropod comes back and steps on the capsule, crushing it beyond use.

Impossible. The capsule is strong enough to withstand submersion to thirty-atmosphere pressures.

The sauropod pushes it into quicksand, and it sinks out of sight?

Mallory is pleased with himself for coming up with that one. It's good for a moment or two of interesting uneasiness. He imagines himself standing at the edge of some swamp, staring down forlornly as the final minutes tick away and the timemobile, functional as ever even though it's fifty fathoms down in gunk, sets out for home without him. But no. No good. The capsule moves just as effectively through space as through time, and it would simply activate its powerful engine and climb up onto terra firma again in plenty of time for his return trip.

What if, he thinks, a band of malevolent *intelligent* dinosaurs appears on the scene and forcibly prevents me from getting back into the capsule?

That's more like it. A little shiver that time. Good! Cut off, stranded in the Mesozoic! Living by his wits, eating God knows what, exposing himself to extinct bacteria. Getting sick, blazing with fever, groaning in unfamiliar pain. Yes! Yes! He piles it on. It becomes easier as he gets into the swing of it. He will lead a life of constant menace. He imagines himself taking out his own appendix. Setting a broken leg. And the unending hazards, day and night. Toothy enemies lurking behind every bush. Baleful eyes glowing in the darkness. A life spent forever on the run, never a moment's ease. Cowering under fern fronds as the giant carnivores go lalloping by. Scorpions, snakes, gigantic venomous toads. Insects that sting. Everything that has been eliminated from life in the civilized world pursuing him here, and he flitting from one transitory hiding place to another, haggard, unshaven, bloodshot, brow shining with sweat, struggling unceasingly to survive, living a gallant life of desperate heroism in this nightmare world.

"Hello," he says suddenly. "Who the hell are you?"

In the midst of his imaginings a genuine horror has presented itself, emerging suddenly out of a grove of tree ferns. It is a towering bipedal creature with the powerful thighs and small dangling forearms of the familiar tyrannosaurus, but this one has an enormous bony crest like a warrior's helmet rising from its skull, with five diabolical horns radiating outward behind it and two horrendous incisors as long as tusks jutting from its cavernous mouth, and its huge lashing tail is equipped with a set of great spikes at the tip. Its mottled and furrowed skin is a bilious yellow and the huge crest on its head is fiery scarlet. It is everybody's bad dream of the reptilian killer-monster of the primeval dawn, the ghastly overspecialized end product of the long saurian reign, shouting its own lethality from every bony excrescence, every razor-keen weapon on its long body.

The thinko scans it and tells him that it is a representative of an unknown species belonging to the saurischian order and it is almost certainly predatory.

"Thank you very much," Mallory replies.

He is astonished to discover that even now, facing this embodiment of death, he is not at all afraid. Fascinat-

CONTINUED ON PAGE 113

NEANDERTHAL

CONTINUED FROM PAGE 44

raelis out. Dating prehistoric flints from the three caves with the help of this precise technique, Valladas's findings were clear. Flints used by prehistoric *Homo sapiens* at Qafzeh were about 92,000 years old, while flints used by Neanderthals at Kebara were much younger—50,000 to 60,000 years old, at most.

The dates were also confirmed for organic materials such as tooth enamel, bone, or fossilized pieces of grain, thanks to another high-tech method known as electron spin resonance, or ESR. In ESR dating, paleoanthropologists send a sliver of material to the laboratory, where physicists grind it up and expose it to a strong magnetic field. The magnetic field reacts in direct proportion to the number of trapped electrons that a sample contains. The older the fossil, the more upset the magnetic field becomes.

To Tchernov and Bar-Yosef's delight, ESR dating provided further support for their dates. Their conclusion: Neanderthals did not lead to early modern humans but, rather, were their counterparts. "Modern-looking hominids were contemporary with the Neanderthals," says Bar-Yosef, "in the same way we are contemporary with people in Paris."

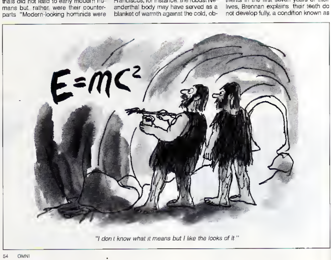
Because Neanderthals and humans are not directly related, it makes sense that their fossils seem distinct, even to the untrained eye. According to Lewis Binford, professor of anthropology at Southern Methodist University, the Neanderthal skeleton looks as though someone took a human skeleton and compacted it into a shorter, broader frame. A skull with a jutting brow topped this stocky body obviously built to maximize endurance and resist bone damage. "Our anatomy is that of a walker; the Neanderthals' was that of a gymnast," says Binford. "Their whole way of coping with the world was action, not tools." Adds Robert Franciscus, a doctoral student in anthropology at the University of New Mexico, "Neanderthals were really using their bodies. Compared to them, modern humans are basically wimps."

But new theories and research techniques now go beyond the merely obvious, helping researchers flesh out some of the Neanderthals' best-kept physical secrets as well. According to Franciscus, for instance, the robust Neanderthal body may have served as a blanket of warmth against the cold, obviating any need for fitted clothing. Instead, Neanderthals probably relied on animal hides and their truncated limbs and broad noses to protect them from the frigid weather of the Ice Age.

In fact, Franciscus has shown in a recent study, Neanderthals living in colder climates had abbreviated limbs. To reach this conclusion, he measured the brachial indices of their arms—the relative length of the forearm to the rest of the limb—and found that as warmth increased, limb length increased. Interestingly enough, notes Franciscus, legs did not show as much regional disparity as arms. "Perhaps with their legs, the Neanderthals were responding less to climatic stresses than biomechanical ones," Franciscus says.

The Neanderthals' diminutive bodies suggest that they may have suffered not just from climatic stress, but also from nutritional stress, according to Mary Ursula Brennan, an anthropologist at New York University. Originally trained as a nurse, Brennan drew on modern nutritional knowledge to recreate the health of early hominids from their dental remains.

If people do not receive sufficient nutrients in the first seven years of their lives, Brennan explains, their teeth do not develop fully, a condition known as



"I don't know what it means but I like the looks of it."

hypoplasia. Aware that this health problem might show up in our prehistoric predecessors, Brennan wound up toting an X-ray machine the size of a bread box throughout France. Her mission: X-raying hominid dental remains in museum storage areas to check for hypoplasia. Of the more than 300 Neanderthals she has tested, 40 percent suffered from hypoplasia, a good indication that resources were scarce. The early moderns showed a hypoplasia rate of only about 30 percent. Further evidence came from a small sample of Neanderthals she studied who were on average about four inches shorter than their successors.

"Neanderthals' short stature may have been an adaptation to low nutrient availability," Brennan concludes. "If they were living in areas where there was not enough food, people who needed fewer calories would survive because they were receiving sufficient nutrition. People born with genes for taller ness would require more calories and die. So within a few generations, everyone's shorter."

While resources may have been scarce, bones found near Neanderthal remains indicate that these individuals did manage to find some sustenance

CREDITS

Page 6 clockwise from top left: Reprinted from *Fossils: The Evolution and Extinction of Species* by Niles Eldredge, photography by Murray Alcosser. Published in 1991 by Harry N. Abrams, Inc., New York. All rights reserved. Photographs ©1991 Murray Alcosser; Brad Holland, Braldt Bralds; page 10: John Emmerling; page 12 clockwise from top left: Anna Neumann, Gary Lilin, Randy Mayor, Wally Hampton; page 14: Shel Secunda; page 18: Pete Turner; page 22: James Marsh; page 24 clockwise from left: Maxis Software, *The Human Evolution Coloring Book*, by Adrienne L. Zihlman, ©Coloring Concepts, Inc., illustrations by Carla Simmons, Wynn Kapit, Fran Milner, Cyndie Clark Huegel, Harper & Row Publishers, Inc.; Leonard Lee Rue II/Photo Researchers; page 25: Chris Alan Wilton/Image Bank; page 26: John Stuart/Image Bank; page 28 top: Stephen Marks/Image Bank; page 28 bottom: J. Carmichael, Jr./Image Bank; page 30 top: Hans Wendler/Image Bank; page 30 bottom: JPL; page 32 top: Janeart Ltd. 1986/Image Bank; page 32 bottom: R. Godard/University of North Carolina; page 34: Bettmann Newsphotos; pages 34-35: Neal Davis; page 44: Shel Secunda; pages 58-63: Reprinted from *Fossils: The Evolution and Extinction of Species* by Niles Eldredge, photography by Murray Alcosser. Published in 1991 by Harry N. Abrams, Inc., New York. All rights reserved. Photographs ©1991 Murray Alcosser. All specimens illustrated are from the collection of the American Museum of Natural History; page 87: Shel Secunda; page 88: Pat Hill; page 89: Mike Mitchell; page 90: Tom Palmore/Elaine Horwitch Galleries; page 93: James Cherry; page 94 top left to right: Ward/Anthro photo, David L. Brill ©National Geographic Society, David L. Brill ©1985, David L. Brill ©National Geographic Society; page 94 center left to right: Shel Secunda, David L. Brill ©1985; page 94 bottom left to right: Bettmann Archive, J. Kelly/Anthro-photo; page 95 top row: David L. Brill ©National Geographic Society; page 95 center left to right: K. Cannon/Anthro-photo, Steve Ward/Anthro photo, Bettmann Archive; page 95 bottom left to right: Bettmann Archive, David L. Brill ©1985; page 96 top row: David L. Brill ©National Geographic Society; page 96 center left to right: Andrew Hill/Anthro photo, David L. Brill ©1985, David L. Brill ©National Geographic Society, Glynn Isaac/Anthro photo; page 96 bottom left to right: K. Cannon/Anthro photo, David L. Brill ©1985; page 106: Paul A. Heusinkveld; page 112: Don Dixon; page 142: Dennis Mammarchy

Based on the diets of modern hunter-gatherer societies, paleoanthropologists believe the Neanderthals would have subsisted on plant foods supplemented with meat. Some anthropologists speculate that Neanderthals were hunter-blunderers who scavenged the landscape. But according to the latest research, Neanderthals were persistent hunters who downed their prey by brute force. This conclusion comes from University of Michigan anthropologist Loring Brace, who has done a detailed study of skeletal and muscular stress in both Neanderthals and *Homo sapiens* to see which areas would be most likely to break in an encounter. He discovered the Neanderthal skeleton is adapted to resist such injuries as broken bones or dislocated shoulders, which would help them triumph in a battle of strength. Brace concluded that Neanderthals wrestled their prey to death. "The Neanderthals were put together on a heroic scale," Brace says. "For that to have been maintained, there have to have been hunting stresses. They must have literally come to grips with the family dinner."

Other recent studies have attempted to trace the life cycle of Neanderthals, following individuals from birth to death. Erik Trinkaus, professor of anthropology at the University of New Mexico, for instance, has analyzed about 20 complete Neanderthal skeletons as well as fragments from other skeletons. Using a technique known as histomorphic metric analysis, Trinkaus ground up thin slices of Neanderthal bone and placed the resulting powder on slides under a microscope. Trinkaus checked the bone powder for signs of maturity. By comparing the maturity of the Neanderthal bones with that of mammals alive today, Trinkaus estimated the age of each skeleton upon death. A definitive pattern emerged: Neanderthals rarely lived more than 40 years, with both sexes dying at the end of the female's reproductive cycle.

"What you have, then, is no post-menopausal survival," Franciscus says. "Most of all, there would have been no grandparenting." In modern hunter-gatherer societies, grandparents lend a much-needed hand with child rearing. Without grandparents to help care for them, Neanderthal children might have been more precocious than their early modern counterparts, Franciscus suggests.

The absence of grandparents, say other researchers, would have ramifications for the society as a whole. In modern hunter-gatherer societies the elderly are responsible for passing on knowledge of the environment and religious lore, says anthropologist Randall White of New York University. "The idea that you have a Neanderthal group composed of people only to age forty means you have a group of a radically different social fabric. You're missing an entire generation."

But the overriding question when it comes to Neanderthal relationships for many people remains where they should hang on our family tree. Two years ago a group of Berkeley scientists thought they had shown we still had Neanderthal genes. Today anthropologists are not sure. Did the Neanderthals interbreed with the early modern humans who shared their land for at least 10,000 years? Or did Neanderthals have no interaction with modern humans until, ultimately, the humans wiped them out?

Physical distinctions would have been a sufficient obstacle to interbreeding between humans and Neanderthals, says NYU's White. Modern baboon species—which never interbreed—show fewer skeletal differences than Neanderthals and *Homo sapiens*, he points out. This comparison supports the hypothesis that Neanderthals did not become integrated into our gene pool.

> “Did Neanderthal genes flow into the evolutionary mainstream, or did early man just wipe Neanderthals out?”

Adds Tchernov, "Perhaps early modern humans and Neanderthals were separated by such profound cultural differences they did not interbreed at all."

Even if there was no genetic crossover, no interbreeding, adds Bar-Yosef, we still don't need bloody scenarios to account for the Neanderthals' demise. "Simple inability to compete with modern humans in terms of finding food and shelter and reproducing could have finished Neanderthals off once and for all."

Yet because no clear-cut answers exist, researchers in the field may allow their biases to color their perception. Bar-Yosef charges that some of his colleagues are "Westerncentric," preventing them from accepting that Neanderthals and our ancestors belonged to the same species. "Our image of early *Homo sapiens* based on the concept of a man painting in a cave is too limited," he says. "It's only particular to certain parts of Europe. What was happening in the rest of the world?"

Bar-Yosef contends that Western anthropologists may be all too quick to assume that Neanderthals contributed nothing to our gene pool, mostly because they do not want to admit a relationship with somewhat unsavory hominids.

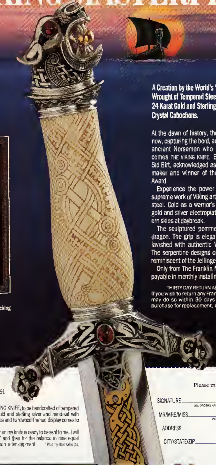
Milford H. Wolpoff of the University of Michigan at Ann Arbor takes an even harder line, vehemently insisting that Neanderthal genes did flow into the evolutionary mainstream. Part of the proof, he says, is as plain as the noses on the faces of Charles de Gaulle, Jimmy Durante, or any number of British knights. "These large noses are Neanderthal features," Wolpoff asserts. "If all modern humans descended from a group of Africans who began migrating northward between one hundred and two hundred thousand years ago, as some anthropologists claim, I am hard-pressed to explain the origin of these noses. No African, ancient or modern, has a nose like that."

Perhaps it is the subtle familiarity of the Neanderthal face that continues to enthrall us today. Scientists are not the only ones to let emotions dictate their view of Neanderthals. Erik Trinkaus, who once wrote what he refers to as a "pedestrian" dissertation on the structure of Neanderthal feet, says the general public also reads the evolutionary record selectively.

"People really seem to want to claim the Neanderthals as relatives," Trinkaus says. "Their fossils have been known for almost one hundred fifty years, but our picture of them changes with the times. In the 1930's very few people thought the Neanderthals were cannibals, though there was some evidence for that belief. Then, in the 1940's, in the wake of World War II, without any new fossil evidence, Neanderthals were turned into cannibals to explain the nastiness of the Nuremberg trials. Hollywood in the 1950's perpetuated a brutish caricature of Neanderthals. And during the 1960's and 1970's, Neanderthals became flower children after the Shanidar Cave discovery."

But no matter who the Neanderthals were and where they went, one thing is for sure: Their impact on the environment was minimal. Says White, "They were never milking the environment for more than it would give them. In some ways you can argue they were more successful than their successors in the Upper Paleolithic or ourselves." ◘◘

A VIKING MASTERPIECE



A Creation by the World's "Best Knife Maker." Wrought of Tempered Steel. Accents of 24 Karat Gold and Sterling Silver. Hand-Set Crystal Cabochons.

At the dawn of history, the Vikings set sail. And now, capturing the bold, adventurous spirit of the ancient Norsemen who conquered the seas, comes THE VIKING KNIFE. Exquisitely created by Sid Birt, acknowledged as the world's best knife maker and winner of the prestigious Beretta Award.

Experience the power of THE VIKING KNIFE. A supreme work of Viking art. Wrought of tempered steel. Cold as a warrior's eyes. Yet ablaze with gold and silver electroplate reflecting the northern skies at daybreak.

The sculptured pommel portrays the Viking dragon. The grip is elegantly crafted and richly lavished with authentic Viking ornamentation. The serpentine designs on the blade guard are reminiscent of the Jellinge style.

Only from The Franklin Mint. The price, $395, payable in monthly installments.

THIRTY DAY RETURN ASSURANCE POLICY
If you wish to return any Franklin Mint purchase, you may do so within 30 days of your receipt of that purchase for replacement, credit or refund.

Specially designed to protect and preserve your Viking Knife, this locking presentation case of hardwood and glass will be provided at no additional charge.

Shown actual size. Length: 15¾".

ORDER FORM

The Franklin Mint
Franklin Center, Pennsylvania 19091

Please mail by October 31, 1991

Please enter my order for THE VIKING KNIFE, to be handcrafted of tempered steel, electroplated in 24 karat gold and sterling silver and hand-set with crystal cabochons. The locking glass and hardwood framed display comes to me at no additional charge.

I need send no payment now. When my knife is ready to be sent to me, I will be billed for a deposit of $39.50* and then for the balance in nine equal monthly installments of $39.50* each, after shipment.

*Plus my state sales tax.

SIGNATURE ____________________
ALL ORDERS ARE SUBJECT TO ACCEPTANCE

MR/MRS/MISS ____________________
PLEASE PRINT CLEARLY

ADDRESS ____________________

CITY/STATE/ZIP ____________________

11885-80

Dedicated to the memory of
Dr. L. Beverly Halstead,
geologist, paleontologist,
scholar, and explorer
June 13, 1933–April 30, 1991

CAST IN STONE

By Sandy Fritz

Preceding page: A pterosaur from Germany. Above: Baby *Coelophysis*, an early carnivorous dinosaur. Left: A 50-million-year-old sycamore leaf. Above right: *Syntheotoceras tricornatus*, a 12-million-year-old relative of, believe it or not, the camel. Center right: Horn coral from New York State. Below right: *Pterodactylus elegans*, a flying reptile from 150 million years ago.

Cast your thoughts back to the dawn of modern geology more than 100 years ago. From quarries, from cliff sides, from stones underfoot, the remains of strange and terrifying creatures emerged. Bones bigger than a full-grown human, heads the size of horse carriages, a single claw dwarfing a sickle, stunned our great-grandparents. Science, the Victorians thought, would find the answer.

Today we know what fossils represent. Fantastic animals once inhabited this planet. But the worlds that nurtured these beasts and scores of others are long gone. Only the stones remember.

Some stones harbor remarkably clear remnants of long-extinct animals. From Germany comes a superb example of *Archaeopteryx*, a dinosaur, with its unmistakable birdlike plumage preserved. Worldwide, you can find pristine examples of trilobites, which for millions of years scurried across the floors of hot, stagnant seas. Yet even the best-preserved specimens leave many questions unanswered. *What color were you? How well did you see? What sorts of sounds filled the air at night?* We can extrapolate, we can argue, we can wonder, but we can never really know.

A chance marriage between a living thing and the eternity of stone gives birth to fossils. Sometimes it is the living things themselves that fossilize, bone and occasionally tissue almost lovingly superseded by minerals leached from the surrounding rock.

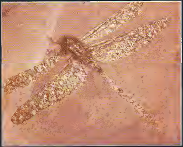
In the fossil record we watch life forms emerge, flourish, and become extinct. We read that continents, climates, and even the location of the North and South poles shift like a fluid. Oceans appear and disappear. Landscapes may appear timeless and unchanging, but they reflect catastrophic changes in the nature of this planet.

Science has coaxed the rocks to divulge their memories of worlds past. We now understand fossils in a way our ancestors could not. The message is grim: Ninety-nine percent of the species that have inhabited this planet are now extinct. No matter how superbly adapted an animal becomes, its species, and its world, finally fails.

There is no doubt that human activities are altering the ecology of this planet. Some say we are on the verge of destroying the very world that supports our species. But Earth itself has destroyed its own ecology scores of times in the past, made a place that was once hot cold, added or erased rivers, shifted its winds. It will continue to do so even without human interference. ΩΩ

Photographs are reprinted from Fossils: The Evolution and Extinction of Species *by Niles Eldredge, photographs by Murray Alcosser.*
Published 1991 by Harry N. Abrams, Inc., New York
 All specimens illustrated are from the collection of the American Museum of Natural History.

This page, top: A 1-million-year-old crab. Center: *Mesohippus bairdii,* a forerunner of modern horses. Bottom: A dragonfly, unchanged for at least 150 million years. Below: A 2-million-year-old *Australopithecus* skull called the Taung child. Opposite page: A water scorpion, ancestor of modern crabs and spiders, from 415 million years ago.



ARTICLE BY JANE BOSVELD

COOPERATION, NOT COMPETITION, MAY DRIVE EVOLUTIONARY DIVERSITY ON EARTH

PAINTING BY FRIEDRICH HECHELMANN

LIFE ACCORDING TO GAIA

In the beginning there were bacteria, simple one-celled creatures that formed from the young earth's gas and mineral seas. These primitive organisms quickly began devouring the chemical Garden of Eden that surrounded them. They were fruitful and multiplied, expanding throughout the oceans and onto the rocky shores. When the garden began to grow sparse, the bacteria adapted, mutating into altered versions of themselves. These creatures thrived as well.

And then something remarkable happened. Bacteria began to merge with one another in cooperative unions. What one bacterium could not do by itself, it achieved with the aid of another. They divided up the labors of life, each partner specializing in different tasks. Over time, the bacteria that had entered into mutual alliances, or symbiotic partnerships, lost their ability to survive on their own. Eventually, these cohabiting bacteria evolved into a dramatically new type of two-part being—the eukaryote, an advanced cell that carries within itself a powerhouse of an organ called a nucleus, a specialized vessel for genes. The emergence of eukaryotes was a leap in evolutionary complexity far greater than any that has occurred since. All the plants and animals we know today, everything from the daffodil to the dolphin, developed from these early symbiotic unions.

Once life on Earth was omnipresent its power over the environment escalated. Living things consumed huge amounts of some atmospheric gases and exhaled massive amounts of others. Their presence in the oceans altered the water's acid and base content. In short, living things were no longer passive passengers that merely adapted to physical events like volcanic eruptions and asteroid impacts. They were energetic participants in the regulation of their world. Organisms that kept the environment hospitable for their progeny survived; those that didn't became extinct. Living things and the planet Earth were constantly interacting and the world had forever changed.

If this scenario sounds unfamiliar, it shouldn't be surprising. It is part of a daring theory of nature known as the Gaia hypothesis. Proposed by British scientist James Lovelock some 20 years ago, the Gaia hypothesis proposes that all living things and the chemical and physical environment in which they live work together like the parts of one vast organism. Ultimately, Lovelock says, this "composite organism" manipulates the air, the land, and the sea to generate the conditions most suited to supporting life.

"Life and its environment," Lovelock explains, "constitute a single entity, which regulates physical conditions in order to keep the environment at a comfortable state for the organisms themselves."

In other words, teamwork between the physical world and the life it bears is responsible for the richly diverse living earth. It is Gaia that has kept global temperatures from rising high enough or dropping low enough to destroy all life. It is Gaia itself that has sustained the atmosphere and the oceans so that they are suitable for living organisms.

JAMES LOVELOCK'S LAB IS SET IN THE THOMAS HARDY COUNTRYSIDE OF SOUTHWESTERN ENGLAND, BUT IN A LARGER SENSE, HIS WORK STRETCHES BEYOND TO SPAN THE LIVING EARTH.

Lovelock's vision of a cooperative world is bolstered by the work of American microbiologist Lynn Margulis, a professor at the University of Massachusetts. For Margulis, cooperation among organisms, especially in the form of symbiotic unions, is the driving force behind evolution. The bonding of simple bacteria into a symbiotic union, she argues, was essential to the evolution of more sophisticated organisms. And, according to Margulis, Gaia is the largest manifestation of the symbiotic process. Like Lovelock, she believes that the earth's organisms have joined with physical processes to form one massive self-regulating organism, Gaia itself.

To say the Gaia hypothesis is controversial is putting it mildly. When Lovelock first proposed Gaia (named after the Greek goddess of the earth), the most positive response came from New Age types and "ecofreaks" who grabbed on to the idea with religious fervor. Here at last some thought, was a scientific theory that implied a purposeful order, even consciousness, in nature. Some scientists who study the earth's physical and chemical cycles—they're called Earth systems scientists—were also intrigued by Gaia, primarily because of its focus on global feedback loops, the intricate cycles that keep oxygen levels, say, or global temperatures from fluctuating wildly.

But most of the scientific community dismissed the idea as being, at best, untestable and, at worst, poetic nonsense. Gaia's most outspoken critics were and continue to be Neo-Darwinists, evolutionary biologists who have blended Darwin's theory with studies of modern genetics. Neo-Darwinists see the world not as a sphere of cooperation, but rather as a jungle of organisms battling one another in a fight for survival. Organisms evolve, say Neo-Darwinists, when a genetic mutation makes the organism a better competitor and thus better at passing along its genes to the next generation.

What led Lovelock and Margulis to part company with such established scientific thought? For Lovelock, it all began with Mars. In the early Sixties NASA asked Lovelock to participate in the search for life on the red planet. Lovelock viewed the space agency's approach—literally searching the planetary surface for critters—as arbitrary, something akin to looking for a needle in a haystack. "I was sure there was a better way," Lovelock recalls, and, working with NASA philosopher Dian Hitchcock, he came up with an idea. Instead of searching the surface of Mars, he suggested, why not analyze its atmosphere for the metabolic products of life? If life existed, the gases produced by photosynthesis and other biological processes would be everywhere.

Though NASA did not do it his way (later research would show the agency should have), the idea set Lovelock to thinking about the difference between dead planets like Mars and living ones like the earth.

Back home in England, he began searching scientific literature for a "comprehensive definition of life as a physical process" and was shocked at how little had been written about it. He formulated his own theory, Gaia, which he presented at a scientific conference on the origins of life in 1969. Perhaps, Lovelock muses, his paper on Gaia had been poorly presented, because virtually no one was interested, no one, that is, but Lynn Margulis. Her own work on symbiosis had rocked some biological hard hats a few years earlier, and she found Lovelock's hypothesis a promising model with which to understand nature and evolution.

Since their first meeting in the late Sixties, Lovelock and Margulis have willingly suffered the slings and arrows of outraged colleagues for the sake of Gaia. They are rebels with a cause who refuse to give in to accepted theory, believing that as scientists begin examining nature more carefully, the Gaian worldview will prevail.

Indeed, a spate of current studies have reinforced their position. Most of the studies have come from Earth systems scientists, who are discovering strong links between the activity of living things and the physical environment. One body of research, for example, indicates that without life, global temperatures would be as much as 45°C (80°F) higher than they are today. New York University researcher Tyler Volk and his colleague David Schwartzman, who spearheaded the research, examined single-celled ocean organisms that make calcium carbonate shells and deposit them at the bottom of the sea. The shells absorb carbon, effectively removing it from the atmosphere and burying it in the ocean. Removing carbon from the atmosphere cools the earth, creating conditions favorable to life.

Other research by Volk examines microorganisms that create soil by eating away at rock, without all the soil to absorb carbon from the atmosphere, the earth might conceivably be 80°F warmer than it is today. "Under those circumstances," says Volk, the planet might be "uninhabitable for all but the most primitive microbes."

Similarly, new research has shown in more detail than ever how symbiotic unions can create new organisms. The most startling study really began by accident. While conducting a series of experiments on amoebas, single-celled microorganisms, University of Tennessee scientist Kwang Jeon noticed that one batch of the creatures were sick. He studied the ill amoebas under a microscope and found that each one was infected with bacteria. Jeon nursed a number of the sick organisms back to health and found that the recovering amoebas began to reproduce even though they were still infected with bacteria. A new symbiotic organism had evolved—bacterized amoebas.

Jeon took his study one step further and exchanged nuclei, the cell organs that contain the genes, between amoebas that harbored bacteria and those that did not. Curiously, the nuclei of noninfected amoebas survived the switch, but the nuclei from amoebas that had adapted to their bacterial companions began to die. When Jeon injected the ailing amoebas with bacteria they recovered. The symbiosis was complete. The amoebas that had once been infected with bacteria were now unable to survive without them. Jeon's discovery of evolution in progress occurred over a mere 18 months, and it was the result of a symbiotic union.

Such studies challenge the Neo-Darwinian view that evolution occurs primarily when individual organisms mutate and then pass on those mutations to offspring when and only when they confer a *competitive* advantage. Instead, in the symbiotic world the only individuals are primitive bacteria; all other forms of life, even the most complex creatures, are communities of bacteria. "Living systems become embedded in living systems," explains Gail Fleischaker, a Mellon fellow at MIT and a former philosopher of science at Boston University, "and what survives as a symbiotic relationship is of necessity a cooperation rather than a competition."

Lovelock and Margulis are convinced that as studies supporting Gaia grow in number, the competitive Neo-Darwinian paradigm will begin to crumble. In its place will be a more holistic view of nature in which competition is supplanted by cooperation. The living earth will be seen as an integrated system in which organisms and the environment coevolve.

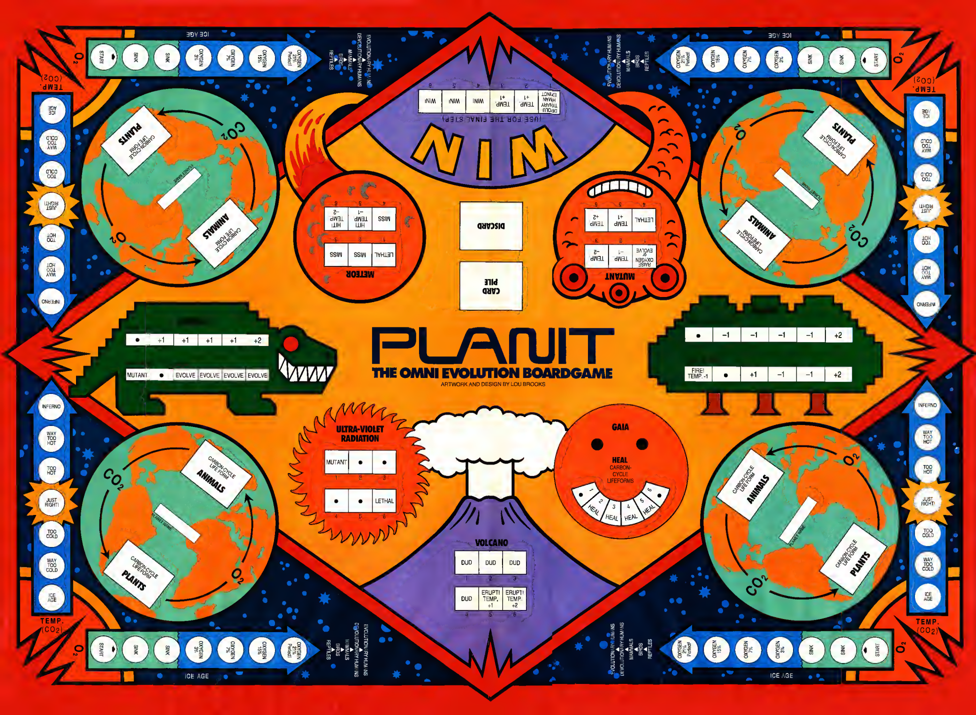
How do Neo-Darwinists and other scientists respond to Gaia and the cooperative paradigm? Ford Doolittle, a molecular biologist at Dalhousie University in Nova Scotia, may sum up the majority opinion when he says, "It pisses me off. I get irritated at what I think is fuzzy thinking." There's certainly no malice in Doolittle's judgment. He considers Margulis a good friend and a first-rate biologist. But he disagrees with her assertions about Gaia and symbiosis.

Like most biologists, Doolittle questions the role of cooperation in evolution. The evolutionary process, he says, could not accommodate the kind of global cooperation necessary in Gaia. "Natural selection," he says, "only favors an organism that has a mutation that allows it to make more of itself. It does not favor organisms that behave themselves in a global sense." Moreover, Doolittle argues, organisms that unite in a symbiotic union do so because they gain some advantage from it. "It is really just selfishness," he says. "Cooperative efforts can evolve out of symbiosis, but the driving force is not cooperation."

Other scientists question what they see as Gaia's basic premise—that life manipulates the oceans and atmosphere to benefit itself. "Any change in the atmosphere and the oceans might be positive for some species and negative for others," says Harvard geochemist Heinrich Holland. "Who is Gaia optimizing the planet for? The theory sounds something like a post-Christian view of reality, in which the hand of God, renamed Gaia, controls the fate of the earth."

If mainstream scientific opinion is ever to embrace Gaia, Lovelock and Margulis will have to produce more rigorous evidence of its existence. In the meantime, they will continue to struggle in the competitive world of science. It is doubtful they will give in. Margulis is accustomed to fighting for what she believes, and she has successfully changed scientific thinking in the past. And Lovelock is quite at ease with his role as "freelance scientist." With no position in academe, he says, he has the freedom to think and do science in his own way. His laboratory, for instance, is in his home, Coombe Mill, a small mud-and-straw cottage set in the Thomas Hardy countryside of southwestern England. But in a larger sense his lab is not contained within the walls of his small house or even in his 30 acres of meadowland and woods, which he helped to plant. It stretches beyond the moors, the mysterious circle of Stonehenge and the stony coasts of Cornwall. It spans the Atlantic Ocean, the deserts of Africa, the towering Andes, the Great Barrier Reef. Lovelock's laboratory is the living earth in all its multifarious incarnations. It is Gaia and he will not allow her to be dismissed without a fight.

"Ethics won't allow us to pull the plug until he runs out of money."


PLANIT
THE OMNI EVOLUTION BOARDGAME
ARTWORK AND DESIGN BY LOU BROOKS
WIN
(USE FOR THE FINAL STEP)
CARD PILE
DISCARD
METEOR
LETHAL
MISS
HIT! TEMP. -1
HIT! TEMP. -2
MUTANT
RAISE OXYGEN or EVOLVE
TEMP. -1
TEMP. -2
TEMP. +1
TEMP. +2
MUTANT
EVOLVE
FIRE! TEMP. -1
ULTRA-VIOLET RADIATION
GAIA
HEAL
CARBON-CYCLE LIFEFORMS
VOLCANO
DUD
ERUPT! TEMP. +1
ERUPT! TEMP. +2
CARBON-CYCLE LIFE FORM
ANIMALS
PLANTS
PLANET NAME
TEMP. (CO_2)
ICE AGE
WAY TOO COLD
TOO COLD
JUST RIGHT!
TOO HOT
WAY TOO HOT
INFERNO
O_2
START
SINK
OXYGEN 3%
OXYGEN 7%
OXYGEN 15%
OXYGEN 21% Perfect!
REPTILES
BIRDS
MAMMALS
DEVOLUTIONARY HUMANS
EVOLUTIONARY HUMANS

PLANIT

THE OMNI EVOLUTION BOARD GAME

Is the earth a living organism with a survival mechanism of its own? Yes, according to one of the most radical theories to hit the planet in years. According to the Gaia *(guy-uh)* hypothesis, put forth by British scientist James Lovelock, all living things from microscopic bacteria to humans work together like the parts of one vast organism. Ultimately, Lovelock explains, this "composite organism" manipulates the air, the land, and the sea to generate the conditions most suited to itself.

Inspired by this theory, veteran game makers Rollie Tesh and Tom Braunlich have designed Planit: The *Omni* Evolution Game. Planit allows each player to race through the ages of Gaia on his or her own planet, directing evolution from the first tiny microorganisms through humans. Players advance when they maintain their world in the steady-state condition conducive to life. That means keeping temperature "Just Right." It also means sustaining the feedback loop between animals (which consume oxygen, O_2, and expel carbon dioxide, CO_2) and plants (which consume CO_2 and expel O_2).

Note: Although the goal is to be the first player to develop "Evolutionary Humans," remember that we humans are not necessarily the end goal of the real Gaia, which will be functioning long after we are gone.

The game is for two to four players, ages ten to adult.

MATERIALS: The foldout Planit board game and two pages of cutout cards found on pages 83 and 85. A six-sided die and two pennies for each player must be supplied by you. To utilize the materials within the magazine, take out the poster-sized game board. Cut out the square playing cards along the dotted lines. Mix them and place them facedown on the game board to form the card deck. Cut out the "Carbon Cycle Life" tokens (Animals and Plants), fold them over, and tape to form double-sided tokens. Finally, cut out the "Higher Animal" tokens and set them aside for later.

HOW TO WIN: The winner is the first to complete both phases of the game. In the first phase, players must fill the atmosphere up with oxygen. In the second phase, they must evolve higher animals in sequence. The first to evolve "Evolutionary Humans" wins.

THE GAME'S RATIONALE: So that you may understand the theory behind the action, we present a brief summary of planetary evolution, as depicted in the game, below.

The early earth had no oxygen in the atmosphere because the ocean acted as a "sink" to eat up oxygen (O_2) molecules. The first phase of the game involves producing enough oxygen to fill up the O_2 sink and then fill up the atmosphere to its present O_2 level—21 percent.

After you have raised oxygen enough to fill the O_2 sink, a major ice age occurs. This was a crisis time for Gaia because oxygen filled the atmosphere, poisoning the original primitive carbon cycle animals that produced CO_2, thus dangerously lowering carbon dioxide—and temperature, which fluctuates up and down with CO_2 levels. The penny placed on your CO_2/temperature marker must be moved down to ICE AGE at this point in the game.

Pushing atmospheric oxygen up to 21 percent is necessary before proceeding on to the next state of evolution, notable for higher animals. Using an Animal or Gaia card, you may direct the evolution of these animals in sequence from reptiles through birds and mammals, and then on to humans—first the devolutionary, or destructive, sort and then the evolutionary variety. Each time you evolve a higher life form, place the token representing that life form on your planet.

STARTING OUT: Name your planet and write the name beside it on the game board. Place one carbon cycle animal token and one carbon cycle plant token on your planet, healthy side up. (These tokens represent lower plant and animal life forms such as primitive bacteria and algae, which maintained the carbon cycle throughout most of Gaia's history.) Each player must also put one penny on the "Just Right" space on the CO_2/temperature gauge and the other penny on the bottom of the O_2 scale. Any player may go first.

HOW TO PLAY: To start, players

Players race through the ages of Gaia, directing evolution from the first tiny microorganisms through the appearance of humans. Players advance through the Planit game only when they learn to maintain their world in a balanced and healthy steady state.

The game includes hazard cards, which may be hurled down on your opponent's planet to inflict a disaster. Meteor cards smash into the planet, stirring up a dark cloud of dust. Mutant cords create unpredictable life forms. And Radiation cards could be lethal.

draw three cards and lay them faceup in front of them. On each turn, the player draws a fourth card and plays any one of the four cards maintaining a hand of three at all times. (Players may use their turn simply to discard, mandatory for anyone stuck with no possible move.) When the deck has run out, remix the discard pile and reuse.

THE PLAYING CARDS

• Plant cards may be used either to *lower temperature* (as CO_2 is consumed, global temperature goes down) *or* to *raise oxygen* (plants breathe out oxygen). The player playing the card decides which function to use, with this caveat: *The plant card may be used to raise oxygen only if the temperature is already set at "Just Right."* The Plant card may be used only if the player has a healthy plant token on his planet. To play the card, announce how you will use it, then roll the die. Refer to the "Plants" chart to see how to move. For instance, if you announce that you want to lower your temperature, a roll of six would push your temperature down two spaces! A dot (•) means no effect. Plant cards may be played only on your own planet and are most useful early in the game because of their ability to raise O_2.

• Animal cards may be used either to *raise temperature* (since animals breathe out CO_2) or to *evolve higher animals*, including reptiles, birds, mammals, and devolutionary and evolutionary humans. The Animal card may be used only if the player has a healthy animal token on his planet. *This card can be used to evolve higher animals only if the O_2 level has reached 21 percent, and if the temperature is "Just Right."* (If the temperature is not "Just Right," then you must adjust it before you can use this card to evolve higher animals, though you may still use it to raise temperature.) Animal cards are most useful late in the game because of their ability to evolve higher animals.

• Gaia cards are powerful wild cards that may be used as either a Plant card or an Animal card. The Gaia card may also be used to *heal* damaged plant and animal tokens, representing the lower life forms on your planet. (These tokens are damaged by hazard cards that succeed in mounting a lethal attack, as explained below.) To heal, discard the Gaia card, roll the die, and then refer to the "Heal" chart on the game board. If you're successful, turn the damaged token back to healthy.

The game includes hazard cards which may be hurled down on your own planet or your opponent's planet to adjust conditions or inflict a disaster. To play a hazard card, state your intention, roll the die and consult the chart (or sometimes the card itself). Here's the rundown:

• Volcano cards belch CO_2, raising planetary temperature (see chart).

• Meteor cards smash into the planet, stirring up a cloud of dust that blocks sunlight, lowering temperature (see chart).

• UV Radiation cards can cause mutations or be lethal. They can't be used against a planet protected by an ozone card. A roll of one creates a mutant—move to the mutant chart and roll again.

• Mutant cards might create an unpredictable new life form that could raise or lower planetary temperature, increase planetary O_2, or even evolve a higher animal (see chart).

• Acid Rain cards may harm life. A roll of six is lethal (if you roll a six, see "lethal attacks" section, below).

• Methane cards signal release of methane, a greenhouse gas produced by bacteria. Roll the die for instructions.

• Plague cards signal a virus infection. A roll of five or six is lethal.

• Fire cards pump thick smoke into the air, blocking sunlight and lowering temperature. Redraw if one of first three cards.

• Increased Solar Output cards push up *everyone's* temperature. Redraw if one of first three cards.

• Salt Cycle cards cause you to lose your turn as the planet adjusts for this toxic accumulation. Redraw if one of first three cards.

• Rain Forest cards symbolize the vitality of the rain forest, enabling you to make the temperature on your planet "Just Right."

• Ozone Layer cards protect your planet from UV radiation. (Only one allowed per planet.) The cards *must* be removed during the "Devolutionary Human" phase.

• GFG cards destroy an opponent's ozone layer. (Discard both.)

Special note on lethal attacks: If your hazard card succeeds in inflicting a lethal attack, you decide which life form to destroy. Usually, it's advisable to damage one of the opponent's carbon cycle plant or animal tokens to prevent him from playing his Plant or Animal cards. When one of these life forms is damaged, it is turned over on the opponent's planet until a Gaia card can be used for healing. In the final phase, the attacker may also damage a higher animal, which means extinction for that type of creature. The poor beast is removed from the planet and waits to reevolve.

WINNING THE GAME: The final step is to create humans that can live in harmony with Gaia. The destructiveness of "Devolutionary Humans" makes them more vulnerable. They destroy their ozone layer, so *remove your ozone layer upon evolving "Devolutionary Humans."* The step on to "Evolutionary Humans" is especially risky. To evolve "Evolutionary Humans" and win, play an Animal card (or a Gaia card) as normal. But after rolling the die, use the special "Winning" chart to see the result. There might be a setback! **DO**

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

GAIA
PLAY AS
1) PLANT CARD
OR
2) ANIMAL CARD
OR
3) HEAL

PLANTS
1) LOWER TEMP
OR
IF TEMP 'JUST RIGHT'
2) RAISE OXYGEN

PLANTS
1) LOWER TEMP
OR
IF TEMP 'JUST RIGHT'
2) RAISE OXYGEN

PLANTS
1) LOWER TEMP
OR
IF TEMP 'JUST RIGHT'
2) RAISE OXYGEN

PLANTS
1) LOWER TEMP
OR
IF TEMP 'JUST RIGHT'
2) RAISE OXYGEN

PLANTS
1) LOWER TEMP
OR
IF TEMP 'JUST RIGHT'
2) RAISE OXYGEN

PLANTS
1) LOWER TEMP
OR
IF TEMP 'JUST RIGHT'
2) RAISE OXYGEN

PLANTS
1) LOWER TEMP
OR
IF TEMP 'JUST RIGHT'
2) RAISE OXYGEN

PLANTS
1) LOWER TEMP
OR
IF TEMP 'JUST RIGHT'
2) RAISE OXYGEN

ANIMALS
1) RAISE TEMP
OR
IF TEMP 'JUST RIGHT'
2) EVOLVE HIGHER ANIMAL

ANIMALS
1) RAISE TEMP
OR
IF TEMP 'JUST RIGHT'
2) EVOLVE HIGHER ANIMAL

ANIMALS
1) RAISE TEMP
OR
IF TEMP 'JUST RIGHT
2) EVOLVE HIGHER ANIMAL

ANIMALS
1) RAISE TEMP
OR
IF TEMP 'JUST RIGHT'
2) EVOLVE HIGHER ANIMAL

ANIMALS
1) RAISE TEMP
OR
IF TEMP 'JUST RIGHT'
2) EVOLVE HIGHER ANIMAL

ANIMALS
1) RAISE TEMP
OR
IF TEMP 'JUST RIGHT'
2) EVOLVE HIGHER ANIMAL

ANIMALS
1) RAISE TEMP
OR
IF TEMP 'JUST RIGHT'
2) EVOLVE HIGHER ANIMAL

METEOR
SEE CHART
(LOWERS TEMP)

METEOR
SEE CHART
(LOWERS TEMP)

METEOR
SEE CHART
(LOWERS TEMP)

METEOR
SEE CHART
(LOWERS TEMP)

METEOR
SEE CHART
(LOWERS TEMP)

VOLCANO
SEE CHART
(RAISES TEMP)

VOLCANO
SEE CHART
(RAISES TEMP)

VOLCANO
SEE CHART
(RAISES TEMP)

VOLCANO
SEE CHART
(RAISES TEMP)

SOLAR OUTPUT INCREASE
EVERYONE RAISES TEMP –1

MORE PLAYING CARDS

ULTRA-VIOLET RADIATION UNLESS OPPONENT HAS OZONE ON PLANET (SEE CHART)	**ULTRA-VIOLET RADIATION** UNLESS OPPONENT HAS OZONE ON PLANET (SEE CHART)	**ULTRA-VIOLET RADIATION** UNLESS OPPONENT HAS OZONE ON PLANET (SEE CHART)	**ULTRA-VIOLET RADIATION** UNLESS OPPONENT HAS OZONE ON PLANET (SEE CHART)	PLAY IMMEDIATELY ON YOURSELF **SALT CYCLE** TOO MUCH SALT IN THE OCEAN LOSES THIS TURN WHILE GAIA RE-REGULATES
OZONE LAYER (LAY ON PLANET) (PROTECTS AGAINST UV RADIATION)	**OZONE LAYER** (LAY ON PLANET) (PROTECTS AGAINST UV RADIATION)	**CFC's** (DESTROYS OZONE)	**CFC's** (DESTROYS OZONE)	**METHANE** (A GREEN HOUSE GAS) ROLL 1, 2, 3 = TEMP + 1 4 5 6 = TEMP + 2
MUTANT SEE CHART	**PLAGUE** ROLL 5, 6 = LETHAL	**ACID RAIN** ROLL 6 = LETHAL	PLAY IMMEDIATELY ON YOURSELF **FIRE** HEAVY SMOKE COOLS PLANET TEMP – 1	**RAIN FOREST** USE TO MAKE TEMP JUST RIGHT'

HIGHER ANIMAL TOKENS

REPTILES	**REPTILES**	**BIRDS**	**BIRDS**	**MAMMALS**	**MAMMALS**	LOSE OZONE DEVOLUTIONARY **HUMANS**	LOSE OZONE DEVOLUTIONARY **HUMANS**	EVOLUTIONARY **HUMANS** **WINNER**
REPTILES	**REPTILES**	**BIRDS**	**BIRDS**	**MAMMALS**	**MAMMALS**	LOSE OZONE DEVOLUTIONARY **HUMANS**	LOSE OZONE DEVOLUTIONARY **HUMANS**	

CARBON-CYCLE LIFE TOKENS
(cut on dotted lines fold and tape to create two-sided tokens)

CARBON-CYCLE **ANIMALS** TOKEN HEALTHY	CARBON-CYCLE **PLANTS** TOKEN HEALTHY	CARBON-CYCLE **ANIMALS** TOKEN HEALTHY	CARBON-CYCLE **PLANTS** TOKEN HEALTHY	CARBON-CYCLE **ANIMALS** TOKEN HEALTHY	CARBON-CYCLE **PLANTS** TOKEN HEALTHY	CARBON-CYCLE **ANIMALS** TOKEN HEALTHY	CARBON-CYCLE **PLANTS** TOKEN HEALTHY
FOLD	FOLD	FOLD	FOLD	FOLD	FOLD	FOLD	FOLD
ANIMALS "DAMAGED" (CAN'T PLAY ANIMAL CARD) NEED GAIA TO HEAL	**PLANTS** "DAMAGED" (CAN'T PLAY PLANT CARD) NEED GAIA TO HEAL	**ANIMALS** "DAMAGED" (CAN'T PLAY ANIMAL CARD) NEED GAIA TO HEAL	**PLANTS** "DAMAGED" (CAN'T PLAY PLANT CARD) NEED GAIA TO HEAL	**ANIMALS** "DAMAGED" (CAN'T PLAY ANIMAL CARD) NEED GAIA TO HEAL	**PLANTS** "DAMAGED" (CAN'T PLAY PLANT CARD) NEED GAIA TO HEAL	**ANIMALS** "DAMAGED" (CAN'T PLAY ANIMAL CARD) NEED GAIA TO HEAL	**PLANTS** "DAMAGED" (CAN'T PLAY PLANT CARD) NEED GAIA TO HEAL

EVOLUTION'S CHILD:
LOOK FOR THE DESCENDANTS OF *HOMO SAPIENS* IN THIS GALLERY OF FUTURE FORMS

THE WHOLE EVOLUTION ALMANAC

When the book of evolution is written, what will it say about the descendants of man? Will the heirs to the human throne be tiny green creatures that feed off the sun, expansive clouds of cosmic dust, or robots with virtually no organic components at all? When challenged by the creative force of evolution, our far-flung progeny might take some innovative forms.

Whatever the outcome, several of the scientists we contacted in search of evolutionary scenarios said that, thanks to extraordinary advances in genetic engineering and robotic science, we will have the power to control our species' fate. Partly because we have begun to take command of our destiny, it would be wise not to discount any of the fanciful life forms that follow. As the nineteenth-century British biologist Thomas Henry Huxley once said during a debate on evolution, "I am too much of a skeptic to deny the possibility of anything." So today, meet with an open mind some of the potential members of the family of future man.

HIGHER TOUCH

Each finger of the robot creature will have fingers. These fingers, in turn, will have smaller fingers in a repeating pattern. The metal-and-plastic creature, a future version of you, will pull in its branches to walk through a door, then, once in the room, spread out to its full six-foot diameter.

According to Hans Moravec of Carnegie-Mellon's Robotics Institute and author of *Mind Children* (Harvard University Press), the fingers of this treelike creature will have a powerful sense of touch. Gliding over a photograph, these tiny tactile organs will sense height variations in the developed silver on the paper. And if the creature needs an eye, it will *form it by crisscrossing its fingers* tightly enough to diffract light like a lens.

But the most extraordinary aspect of this immortal creature will be its ability to simulate human thoughts and capture human memories so precisely that in many ways it could pass for—indeed, replace—one of us. In the scenario put forth by Moravec, humans will create this intelligent robot replacement one step at a time. The creature's dumb great-grandfather, created between 2000 and 2010, will have the brainpower of a lizard built for grunt work—and no personality at all. The second-generation robot will learn from experience. The third-generation robot will run almost instant simulations of every task you *assign it, executing intricate* instructions with ease.

By the turn of the next century, Moravec adds, the fourth-generation robot—the high touch "fingerbot"—will be smart enough to build replicas of itself and to fashion a spacecraft to the stars. These highly intelligent robots capable of thinking much like us, will begin a trek across the cosmos, leaving the Earth as a human preserve.

At this juncture, says Moravec, organic, mortal humans will want to transfer their thoughts and feelings—indeed, their very essence—into the vessel of the immortal machine. As time goes on, Moravec adds, humans will meld with their lab creations so that they never die.

Human and machine, predicts Moravec, will merge into one with the help of a skilled robot surgeon. The surgeon's job: transferring brain function layer by layer into a machine and then excising the now useless biological tissue from your body. These human–robot hybrids, Moravec adds, won't all have to look like a bush with a trillion fingers. Instead, you'll pick your own body style, gearing it to the environment and your personal aesthetic taste.

Moravec has found that his idea raises fears, and wonders why. "What is it about this body of yours that's so incredibly important?" the senior roboticist says. "If it *were killed and an exact robotic* substitute put in its place, your friends wouldn't miss you. Your family wouldn't miss you, none of your projects would miss you. So nothing would miss you. You'd be dead, so *you* wouldn't miss you. So who cares?"

WHOLE EVOLUTION ALMANAC

HEIRS TO THE HUMAN THRONE MAY ASSUME A VARIETY OF INNOVATIVE FORMS

COSMIC CLOUD

He will be the size of a planet, though the human of today could walk right through the grain-sized iron particles that make up his Brobdingnagian frame. This giant creature, inhabiting the empty reaches of space would greet friends with a blast of solar energy and blow hydrogen gas to whisk cosmic debris away.

More than a decade ago, physicist Freeman Dyson, building on an idea from astronomer Fred Hoyle, suggested that the evolutionary last stand of the human might be in the form of a giant, intelligent black cloud. "What I envisage as the structural unit of such a creature is simply dust grains," Dyson said, "probably made of iron or some convenient stuff, charged and working on each other with electric and magnetic forces. Such creatures could be just as complex, if not more complex, than the creatures we see around us now."

In a recent interview, the physicist at the Institute for Advanced Study in Princeton said that the creature's sensory organs would be collections of solid particles tuned to respond to radio waves, visible light, and X rays—a fuller spectrum than humans can perceive. It would live on sunlight or perhaps interstellar gas and radiate long-wave energy—infrared or radio waves—to aid in the excretion of wastes. "It might get rid of things it considers junk," Dyson says, like hydrogen by-products,

Freeman Dyson suggests humans may evolve into giant clouds.

for instance, in an occasional volcanic belch.

Will the cosmic cloud have feelings? Will it suffer pain, laugh and love, or pray? "There's no reason why it shouldn't do all of the above, or none," Dyson says. "They may not share any of our concepts, or on the contrary they may share a great deal."

The cloud could evolve much more rapidly than we did, Dyson speculates, and might prove even more damaging to the earth's environment than we are. In its wanton wanderings the dust cloud might sometimes park between the earth and the sun, casting a cold shadow over the remnants of anachronistic humans, still in solid organic form.

ANTIGRAVITY GRUNT

She will have to be thick-skinned about wisecracks concerning her weight, almost nothing, because she'll live in a zero-g environment. She'll be thick-skinned about everything else as well, because genetic engineers will build her that way, with several inches of tough hide surrounding her human bones, an organic space suit that will enable her to live forever in orbit.

British science writer Dougal Dixon, author of *Man After Man* (St. Martin's Press), imagines that the antigravity grunt will be launched with genes from human parents on pollution-plagued Earth in 200 years. Then she'll enter permanent service to work on a starship under construction in orbit. There will be no smog in her workplace. But Dixon says she will worry about solar wind—streams of ionized particles hurled past the earth from the sun. When the solar wind is high, her alligatorlike skin will close over two sealed lenses covering her eyes, the most vulnerable part of her anatomy. Her gray, ovoid body, about four feet long, will include a balloonlike base, two arms and two legs, and long fingers and toes. Her tough skin will house a compressed human skeleton and organs, including a few spare lungs: one containing high-pressure breathing gases and another for use in venting carbon dioxide. The fourth lung will come in handy if she loses her grip on the starship's struts and floats free in space. Then she'll be able to blow off some waste gas to push herself back to the safety of the spaceship.

Far above the earth, the weightless creature will also find time for play. "She'll shoot pool in three dimensions," Dixon suggests, the balls ricocheting off the inside walls of a sphere. With rudimentary understanding of human society, she'll be able to laugh at visitors' jokes about how lighthearted she is. But sealed inside her skin, she'll never hear the jokes well or speak with a human voice. Instead she'll communicate through a set of quivering antennas, like a bee. Starship workers will carry electronic translators to convert their speech into vibrations transmitted by direct touch from plastic antennas to her artificial sensory organs.

> HER GRAY, OVOID BODY WILL BE ABOUT FOUR FEET LONG. HER THICK OUTER HIDE WILL PROTECT HER FROM THE ONSLAUGHT OF LIFE IN ZERO G. THOUGH SHE CARRIES HUMAN GENES, SHE WILL NEVER REPRODUCE.

She will learn through this touch-talk how "unique" she is, says Dixon, a euphemistic way of telling her that she wasn't built to breed. She'll never reproduce. If there is a need for more vacuumorphs, as Dixon calls them, engineers will pull out the blueprints and build more.

HO-HUM HOMINID

We have seen the future and it is us. According to many evolutionary biologists, it seems humans are no longer evolving at all. "Indeed, when one looks at the evolution of brain size and longevity," says gerontologist Richard Cutler of the National Institute on Aging, "it appears that evolution for humans stopped fifty to a hundred thousand years ago." In fact, Cutler says, technology has rewritten survival-of-the-fittest laws. Men with defective eyesight, who would have been devoured by tigers in the primeval jungle, wear contact lenses today and pass on their biological blueprints for myopic men of the future. "Not only are we not improving," says Cutler, "we're getting worse."

One evolutionary biologist who believes that human evolution has slowed to a halt is Harvard's Stephen Jay Gould. "Review the incredible things we've done, how all of civilization has been built in twenty-five thousand years from Cro-Magnon to this, with no change in morphology," he says, "so why should we predict anything else?"

Gould made his case to *Omni* writer Delta Willis, who interviewed paleontologist Richard Leakey as well. Further evolution, notes Leakey, would require major life-style changes—living in a space colony, for example. But Leakey says that humanity is not likely to enlist in quests requiring isolation for extended times.

PLANT PEOPLE

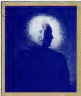
In the future, those who eat spinach may not have to eat much else. Tomorrow's vegetarian will learn to incorporate plant cells into the human body without digesting them. So, like the plants they eat, humans will draw their energy from the sun through photosynthesis—the process by which plants combine sunlight, water, and oxygen into carbohydrates, the basic foodstuffs of life. For these photosynthetic people of tomorrow, the alteration will bring a side benefit: They won't have to worry about suntanning because they'll be green.

Fatima Linda Jackson, an anthropologist at the University of Maryland, is already at work researching how we might make better use of the components of plants for good health. The ultimate goal: protecting the plants we eat from digestion so they can continue to live inside our bodies.

One animal has already solved the problem—the lowly sea slug, a green blob less than an inch long that lives at the base of grass in saltwater marshes. Sidney K. Pierce, Ph.D., professor and associate chair in the department of zoology at the University of Maryland, has discovered that the slug sucks nutrients out of certain hairlike kinds of algae and supports the plant material inside its body. Under light, the material produces oxygen and fats that feed the slug. Pierce says he's kept a colony of slugs alive with nothing more than ordinary fluorescent light for months.

Even before we learn the slug's secret, we could load the cargo bays of spacecraft with batches of the animals to supply oxygen. But Pierce says there's a limit to the blob's beneficence. Colonies die out after about a year. Keeping them cool—close to freezing—adds about six weeks to their lives, roughly 12 percent, suggesting that future green men might want to take a cue from today's florist-shop roses and remain refrigerated when they're not out feeding in the sun.

—Gurney Williams III



Homo sapiens futurus: *Big head and Mickey Mouse eyes.*

THE CHILD IS FATHER TO THE MAN

Scientists call it neoteny, but you could think of it as the Hollywood hypothesis. The future human will have a larger head at birth than our newborns, and at age forty, his head will be twice the size of ours. Like Mickey Mouse, he'll also have comparatively large eyes, suggests gerontologist Richard Cutler. If Cutler and other researchers are successful, *Homo sapiens futurus* will be smarter than we are and won't reach middle age until sixty. And like the lead in a fairy-tale movie, the creature will live happily almost ever after—perhaps 200 years.

The neoteny hypothesis holds that the more advanced the species, the more juvenile its features. With evolution comes larger cranial domes and smaller facial masks below—that is, increasing "babyishness"—according to cognitive psychologist Robert Shaw at the University of Connecticut at Storrs.

Shaw has developed computer simulations of how human heads grow. Running his simulation backward, Shaw regressed the face to a hypothetical time before birth, generating a picture of the large-headed individual into which the neoteny hypothesis suggests we will evolve. The bigger brain, Shaw points out, would require a bigger body to supply it with nutrients and to diffuse the increased production of heat.

Cutler adds that the genetic engineering to spawn this creature might be simple, involving the fine-tuning of a few hundred genes. But politics might prevent it. "We don't want a lot of smart guys around," says Cutler. "We're afraid of too many chiefs."

—Gurney Williams III

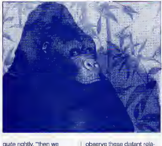
WHOLE EVOLUTION ALMANAC

THE DEVOLUTION PROGRAM: A FIVE-DAY PLAN FOR ACHIEVING LOWER CONSCIOUSNESS

BY KEITH HARARY

Becoming a fully evolved human being is a high-pressure preoccupation. In addition to serving such basic animal needs as eating, sleeping, and having sex, we must also serve as guardians of our species and the earth. Threats to human evolution, in fact, come from every quarter: nuclear, chemical, and biological weapons, medical waste, AIDS, the depletion of the ozone layer, the destruction of the rain forests, and the impoverishment of the Third World, to name a few. In the end, we must control all these elements if we want to survive. The more we evolve as a species, it seems, the more complicated our everyday existence becomes.

Jonas Salk, these days a student of evolutionary biology, explains our new place in the cosmos this way: "The human mind may be seen as a form of matter that has become conscious of itself, conscious of evolution, and conscious of its capacity to participate in evolution. We are a product of evolution, and the embodiment of the process as well." As for the individual best suited to carry out evolutionary goals, he or she must, of course, be cooperative as opposed to competitive, generous as opposed to greedy, constructive as opposed to destructive, sensitive as opposed to callous, and insightful as opposed to obtuse. Embracing such evolutionary traits is crucial because, as Salk points out, a lot hangs in the balance. "If we destroy the ecosystem," he notes quite rightly, "then we destroy ourselves."



With all this pressure to be so evolved, we need to let off a little steam now and then, to *devolve*, as it were, and return to our roots. In an effort to help you fulfill this need in a harmless fashion—without actually contributing to the devolution of the planet, of course—we present our five-day devolution program, below.

DAY ONE: THE HUMAN ZOO

Darwin theorized that human beings evolved from the apes. You may have noticed, however, that some people appear to have evolved much further than others. Day one of our devolution program offers an opportunity for you to actively explore this phenomenon.

Begin by going to your local zoo and spending some time observing the monkeys and gorillas. As you observe these distant relatives of the human species, notice how much of their behavior reminds you of people you know. Notice, also, your own evolutionary connection with these humanlike creatures. Are the chimpanzees doing anything you would like to be doing yourself? Can you imagine yourself swinging through the trees or sitting on top of the jungle canopy looking out across the horizon? Sit in a comfortable spot and observe the apes for half an hour. As you do so, imagine yourself mentally trading places with these noble primates, actually experiencing reality from their point of view. How would your life's priorities be different if you were an ape? How would you communicate with others of your species? If you are visiting the zoo with a friend, spend some time trying to communicate with one another as the apes do. Then go home and notice all the apelike features of your relatives and friends. You may be surprised to realize how much you still have in common with our evolutionary antecedents.

DAY TWO: NAKED LUNCH

Human beings are the only animals that use utensils, which tend to distance us from the animal side of our nature. On day two, begin by letting go of such evolutionary pretensions. Order takeout spareribs or other basic "finger foods" such as sashimi or Dungeness crab for lunch. Also assemble an assortment of fruit, from red Delicious apples to succulent nectarines and plums. Then get naked and sit on the floor with the foods you have chosen spread out before you. Eat like an animal, using no implements or napkins.

Before beginning the second part of today's exercise, which should be carried out just prior to dinner, consider that modern processed food is a long way from the kind of diet humanity enjoyed at an earlier point in our evolution. Much of the food we consume, from Froot Loops to Chicken McNuggets, is no longer remotely recognizable as anything that was ever alive.

Day two, therefore, offers a chance for you to get back in touch with the original form of some of the foods you've been eating. (To avoid senseless waste, you should carry out this exercise only with foods you eventually intend to consume.)

Begin by ordering a giant

bucket of fried chicken from a local stand or one of the fast-food chains. Spread all the chicken parts out on a table and try to reassemble the pieces into a complete chicken. Use a needle and thread, a staple gun, or masking tape to hold everything together. If you are a vegetarian, you may carry out this exercise with a large order of French fries, which you can reassemble into potatoes. (You might also take a cue from the writers of *Late Night With David Letterman*, as recently reported in *The New York Times*. The team suggested rummaging through meat plant Dumpsters and pulling out enough different parts to assemble your own cow.)

ORDER A BUCKET OF FRIED CHICKEN FROM A LOCAL FAST-FOOD PLACE AND TRY TO REASSEMBLE THE PIECES INTO A COMPLETE ANIMAL. VEGETARIANS MAY ORDER FRENCH FRIES AND REASSEMBLE THEM BACK INTO POTATOES.

By the way, for the ultimate in primitive eating, you might try dining out at some of the finer vending machines in your area. Suggested fare includes canned sodas, candy bars, and onion and sour cream chips. Some of the more elaborate, Automat-type machines also offer petrified hamburgers, prehistoric egg salad, and Precambrian tuna on white bread.

DAY THREE: THE HUNTER-GATHERER

Early man depended on nature to provide the basic necessities. On day three of the devolution program, pay homage to this tradition for an afternoon. Your goal: to gather and enjoy as much free stuff as possible.

Begin by dousing yourself with five or six different fragrance samples from the nearest perfume or cologne counter. Ask the salespeople to give you a pocketful of additional samples. Next, stop by your doctor's office and try to get some free samples of any prescription drugs you may be using. Then seek out a crowded hot dog stand where you can graze unnoticed from the open sauerkraut, relish, and pickle bins for a tasty lunch. Use plenty of ketchup and mustard and take some extra packets of these condiments with you. If you can't find a convenient hot dog stand, seek out a bar that serves free hors d'oeuvres and eat your fill. Stuff your remaining pockets with as much free food as possible, along with any loose bags of sugar or low-calorie sweetener that you can easily lay hands on. Keep alert for any free books of matches.

Finally, head to the nearest bakery and make a dessert out of any pastry samples that may have been placed in little dishes on the counter. On the way home, pick through other people's garbage for anything you can use.

DAY FOUR: PRIMITIVE CONSCIOUSNESS

In an effort to be more evolved, many people try to relate to others in a purely rational way. Yet there is still something of the primitive in all of us, an inner sense that responds to people and events on an emotional, instinctive level.

On day four of our devolution program, allow yourself to get more consciously in touch with this aspect of your awareness. Whenever any stressful circumstances arise during the course of your day, ask yourself, "What would *Australopithecus afarensis* do in this situation?" Allow your responses to emerge from a deep gut level to whatever extent possible. If you pass a pretty flower on the street, for example, take time to savor its organic aroma. If you get in an argument with your mate, don't just deal with the situation from an intellectual distance. Stay in touch with your deepest feelings throughout the discussion. If you feel stressed out in the course of your day, go off to a place where you can be alone and wildly pound your fists into pillows or sofa cushions while allowing yourself the luxury of a primal scream. Finally, at some point today, spend time in a natural setting like a woodland or park and let go of the intellectual priorities of the civilized world.

DAY FIVE: THE COMPETITIVE SELF

The more we evolve, the more we must learn to live in harmony with each other. On the final day of our devolution program, however, you will loosen some of the shackles of socially evolved behavior and allow your innermost competitive self to come to the fore. Your focus should be on allowing yourself to be as competitive as possible, without becoming really obnoxious or mean.

If you work as a secretary, for example, you might organize a speed-typing competition in your office, along with events in pencil sharpening, envelope stuffing, and stamp licking. Try to shoot a rubber band across the office farther than anyone else. Or create miniature Olympic events less specific to your occupation, including such feats as watermelon eating, necktie knotting, and speed shaving. If you can't find people to compete with, compete with yourself. Get a book of brainteasers and see how many you can answer correctly. See how many Barry Manilow tunes you can listen to, or how many times you can play Paul Anka singing "Havin' My Baby" without throwing up. If you normally tell yourself not to be rankled by the political machinations of that manipulative colleague of yours, now is the time to let feelings of intense annoyance to creep in—and to act on them. Complete the exercise by playing Risk or Monopoly—and playing to win. ∞

WHOLE EVOLUTION ALMANAC

DO-IT-YOURSELF MUTATION KIT: ORCHESTRATING EVOLUTION AT YOUR KITCHEN TABLE

BY HEMANT CHIKARMANE

The idea of orchestrating evolution yourself seems like heady stuff indeed. But with our Do-It-Yourself Mutation Kit, described in the pages that follow, you should be able to observe the process at your kitchen table. We'd like to start you off with some basic biology. Individual organisms and entire species change as a result of mutations in genes. You might think of a genetic mutation as a spelling mistake within the subunits that compose the gene. Since most mutant organisms have trouble adjusting to the environment, it's a good thing that mutations are rare. Of

YOU DON'T NEED TO BE A MOLECULAR BIOLOGIST TO SEE EVOLUTION IN ACTION. EXPLORE THE MUTATIONS THAT DRIVE NATURE'S DIVERSITY WITH A HOME LAB, AND LET *SACCHAROMYCES CEREVISIAE*, A COMMON YEAST, BE YOUR GUIDE.

course, every so often a mutant is better suited to a given habitat than its ancestors. When that happens, the mutant organism will have more offspring than its nonmutant siblings. As evolution takes its course, the mutants will thrive.

To see the process in action, all you've got to do is follow the instructions below. Your guide for this journey of exploration will be *Saccharomyces cerevisiae*, a common yeast. Since the yeast grows rapidly, you will be able to observe the results of each experiment in two to three days.

To order the kit, send a $20 check or money order to molecular biologist Hemant Chikarmane at the Marine Biological Laboratory, Woods Hole, MA 02543.

INSTRUCTIONS

After you have received your kit, open it up and make sure all the materials are there. You should find five petri dishes labeled as follows: ADENINE NEGATIVE A and ADENINE NEGATIVE B (these two plates lack adenine, an essential nutrient), COPPER A and COPPER B (these two plates contain copper salt, which can kill the yeast), and MASTER, a master plate that contains a cocktail of nutrients on which all forms of yeast can grow. You should also find a tube of yeast culture, four sterile spreaders, four sterile pipettes, and 40 sterile toothpicks. Keep the kit in the refrigerator until you decide to use it. For each experiment, take out only those items that you actually need.

To help you with your experiments, get hold of a marker, as well as paper and pencil to keep track of your results. We also suggest that you go to the drugstore and buy some antibacterial soap, antiseptic, and ordinary bleach (ask the pharmacist to suggest appropriate brands). A small container for waste would help, too.

Before you begin, read the instructions once through and keep these basic laboratory principles in mind:

Cleanliness and sterility. Make sure you work at a clean table with as little draft as possible. Wipe the table clean with an antiseptic such as Lysol before and after you work. Since the air contains bacteria and fungi that can contaminate your experiment, be careful not to open your petri dishes unless you are working with them. Since your fingers also have all sorts of bacteria on them, do not touch the sterile surface of the plate with your fingers. Transfer of organisms should be done only with the sterile pipettes or sterile toothpicks. After each experiment, wash up with antibacterial soap.

Spreading culture on the plate. To isolate mutants that have evolved, you must spread yeast from the culture uniformly on the petri dish. To do so, place the petri dish on the table and lift the cover with your left hand, placing it beside the dish. Pick up the culture tube of yeast with your left hand and shake it (figure 1). Then unscrew the top and place that on the table too. Pick up a sterile pipette, squeeze the top, and dip the tip into the yeast culture tube (figure 2). Slowly release the bulb to draw yeast culture into the pipette. Hold the tip of the pipette about a quarter inch above the center of the open plate. Gently squeeze the pipette bulb so that two to three drops fall on the surface (figure 3). Discard the pipette into a waste container filled with bleach. Cap the tube. Now pick up the spreader and hold it so that the short arm gently touches the surface of the petri dish. Spread the liquid evenly over the surface (as shown in figure 4) and carefully rotate the plate.

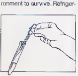
Growing yeast. After you have spread the culture on your plate, leave it alone at room temperature (70–75° F or 22–25° C) for one to three days. (Keeping the petri plate at 85° F or 30° C will promote faster growth.) Through the course of these instructions, this will be referred to as incubation. Yeast will first appear as pinhead-sized dots and may ultimately assume a diameter of an eighth of an inch.

Transferring yeast from plate to plate. Open a petri dish and, using a sterile toothpick, remove a yeast sample about the size of a pinhead (figure 5). Open the second petri dish and touch the tip of the toothpick to the surface. Slide the toothpick gently, making a streak about half an inch in length. Discard the toothpick and do not reuse.

THE EXPERIMENTS

1. Selecting for mutants that regain a lost function. Normal yeast cells have the ability to make their own adenine, an essential component of DNA. The yeast strain in your tube, however, has a mutation in the gene called *ade1* (for adenine). As a result of the mutation, an important enzyme is no longer active and the yeast cannot make adenine. Without adenine, yeast cannot replicate (unless you supply the adenine yourself).

However, if you place these mutants on your petri dish, they will still produce the cascade of chemicals leading up to (but not including) the crucial enzyme. The chemical that accumulates when the enzyme cannot be produced is red; therefore, the colony that you will plate out and incubate in your petri dish will appear red. In this experiment, you will start with red yeast and mutate some organisms back to the original form—white yeast with the ability to produce adenine. Experimental procedure: Shake up your tube of yeast and put three drops of yeast culture on the petri dish marked ADENINE NEGATIVE A. Spread the drops carefully and uniformly with the spreader. Then incubate the plate for two to four days, until white colonies—the new mutants—start to grow. The mutants arose spontaneously and, according to current evolutionary thought, have been "selected" by the environment to survive. Refrigerate this plate and save it for experiment 3.



2. Selecting for mutants that develop resistance to a poison. In this experiment you will isolate mutants that can resist the lethal power of copper salt. Compounds of metals like copper, lead, and mercury are toxic to cells because they block the action of proteins and enzymes. Some cells randomly develop mutations that lead to resistance to metal salts. In the case of yeast, these mutations work by overproducing a protein that binds tightly to the metal, preventing damage to the cell. Experimental procedure: Spread three drops of yeast from your culture tube onto the plate marked COPPER A and incubate for two to five days. You should see small colonies of copper-resistant yeast forming. Wait until the colonies grow to about an eighth of an inch in diameter. Then refrigerate the plate and save it for experiment 3.

3. Proving that all the mutations are transmitted to offspring whether or not they are advantageous to the organism. In this experiment you will grow your mutant yeast cells on the MASTER dish, which will enable all your cells to grow equally well. Experimental procedure: Gather the two petri dishes you used in experiments 1 and 2 and place them beside you on the table. Take your marker and, turning over the MASTER dish, draw a line down its center so that you divide it in half. Mark one area ADENINE and mark the other area COPPER. Now take the plate labeled ADENINE NEGATIVE A and choose a colony at random. Pick up that colony on the tip of a sterilized toothpick and transfer it, in the form of an individual streak, to the area marked ADENINE on the MASTER dish. Create four more adenine streaks on this area, then store the ADENINE NEGATIVE A plate in the refrigerator. Now streak the copper-resistant mutants from the COPPER plate onto the area marked COPPER in a similar fashion. Incubate the plate for one to two days, and note that the streaks will grow up into elongated colonies. These colonies grow even though the mutants no longer have any particular survival advantage.

4. Showing that mutations affecting one trait arise independently of mutations affecting another. Experimental procedure: Remove from the refrigerator the plates labeled ADENINE NEGATIVE B (this plate contains no adenine) and COPPER B (this plate contains copper salt). Take your marker, turn the plates over, and draw a line down the center of each dish, as you did with the MASTER plate in experiment 3. As you did in experiment 3, label one half of each plate ADENINE and label the other half COPPER. Now place the MASTER dish in front of you. Using sterile toothpicks, transfer material from the COPPER section of the MASTER dish to each of the two areas labeled COPPER on the two new plates. Transfer material from the ADENINE section of the MASTER dish to each of the two areas labeled ADENINE. Incubate these two dishes. Note that the mutant colonies isolated from the ADENINE segment of the MASTER dish will grow on the second ADENINE NEGATIVE plate but not on the COPPER plate. The mutant colonies isolated from the COPPER segment of the MASTER dish will grow on the second COPPER plate but not on the ADENINE NEGATIVE plate. Consider the history of these yeast colonies and you will reach one conclusion: The yeast cells have retained their mutant traits throughout each and every transfer. These colonies should grow quickly, since the mutants adapted to these two plates have already evolved during experiments 1 and 2.

A BRIEF HISTORY OF HUMAN TIME

SCIENTISTS EXPLORING HUMAN ORIGINS PICK A FEW BONES

BY DELTA WILLIS

The study of human evolution has been plagued by personal conflicts and idiosyncrasies ever since Charles Darwin began his study of life aboard the HMS *Beagle*. Discussing the search for human origins, Mark Twain noted that "scientists have already cast much darkness on this subject, and if their investigations continue, we shall soon know nothing at all." Of course, researchers now know a great deal about human ancestors. But the arguments and counterarguments between them go on. In fact, judging from newspaper reports, it seems that the fields of evolutionary biology and paleoanthropology have been host to professional battles and personal wrangles in spades.

To illustrate the monkey business that has often accompanied the search for missing links, we have created a couple of time lines: a Discovery Line, to depict important scientific discoveries about human origins, and an Inside Line, to illustrate the behind-the-scenes footnotes to those discoveries. To help you put it all in context, we also present a life line that illustrates a reasonable timetable for how hominid species actually evolved. (When reading the life line, you'll note some incongruities, but our numbers merely reflect the data of a science still in the process of being unearthed.)

As you read through our charts, you'll probably realize that bigheadedness afflicts the human species in more ways than one. After all, scientists don't deserve all the heat. They belong to the same species as the rest of us, and their behavior tends to reflect the apish and territorial—though thoroughly conventional—view that success lies in displacing the competition.

LIFE LINE

18 MILLION YEARS AGO

Proconsul. Apelike creature thought to be an early ancestor of humans.

3–4 MILLION YEARS AGO

Australopithecus afarensis. The oldest hominid species yet found, thought by many to be ancestral to humans. Lucy is a prime example of *A. afarensis*.

2.2–3 MILLION YEARS AGO

Australopithecus africanus. This hominid resembled *A. afarensis* but had a rounder, more humanlike head and was found mostly in Africa. (The Taung child was one.)

2.4–2.6 MILLION YEARS AGO

Australopithecus robustus. A robust, ruggedly built hominid found in two South African caves. Thought to be an evolutionary dead end.

1–1.9 MILLION YEARS AGO

Australopithecus boisei. Found in East Africa, this hominid resembled *robustus* but was notably larger.

1.6–2.2 MILLION YEARS AGO

Homo habilis. The first species in the genus *Homo*, *H. habilis*, or handy man, remains have been found in East Africa. *Habilis* appears to have lived around the same time as the appearance of the first simple stone tools.

300,000–1.9 MILLION YEARS AGO

Homo erectus. A more evolved, bigger-brained version of *habilis*, *erectus* lived on Earth for 1.6 million years. *Erectus* created advanced tools and also mastered fire. (Examples of *H. erectus* include the Java man and the Peking man.)

225,000–500,000 YEARS AGO

Homo sapiens (archaic). These ancient human forms, which seem to have evolved from *erectus*, began appearing in the fossil record around 500,000 years ago.

The life line above depicts species on the evolutionary journey leading up to *Homo sapiens sapiens*.

DISCOVERY LINE / INSIDE LINE

1830

Discovery Line: Geologist Charles Lyell publishes the first volume of his monumental *Principles of Geology*, which proves the earth is much more than 6,000 years old. This, along with the fossil record, suggests there has been tremendous change among plant and animal life.

Inside Line:

Charles Darwin sets out on the voyage of the *Beagle*, taking along Lyell's work. Darwin is not the official naturalist onboard but is chosen as a companion for the captain, Robert Fitzroy. His ticket is his ability to afford the trip.

1857

Discovery Line:

Neanderthal man, represented by only a few pieces of the skeleton, including a skullcap and leg bones, is discovered in Germany's Neander Valley.

Inside Line: A professor from Bonn named August Franz Mayer suggests the bones belonged to a Mongolian Cossack traveling through Prussia after Napoléon's retreat. According to Mayer, pain had caused the man to furrow his forehead, explaining the bold brow ridges, as for the man's bow legs, Mayer says, they can be traced to a job as a cavalryman atop a horse.

1860

Discovery Line: Darwin gets everyone excited in his book *The Origin of Species* when he suggests natural selection as the means by which evolution works. (Darwin proposes that individuals vary randomly in nature. Those variants best adapted to the environment thrive—and eventually prevail—through the creative force of natural selection.)

Inside Line: Darwin ventures to publish after more than two decades of fear that his ideas would be viewed as heresy by his religious family and Victorian England as a whole. The Church, after all, holds that humans have been created by God. He goes to press only when Alfred Russel Wallace is about to scoop him with a remarkably similar theory of natural selection.

1871

Discovery Line: In *The Descent of Man*, Darwin suggests that Africa is the place to look for missing links. The reason: The continent was formerly inhabited by extinct apes closely allied to the gorilla and chimpanzee, "the two species closest to humans."

Inside Line: Due in part to chauvinism and racism, early investigators prefer to look for missing links anywhere but Africa: England, France, Germany, Spain, China, and even North America.

1877

Discovery Line: Dutch anatomist Eugène Dubois resigns from academe and announces that he will return with the missing link. He sets out for Java, a large island in Indonesia, and does indeed return with the first evidence of *Homo erectus*, or upright man.

Inside Line: When critics refuse to agree with his assessment, Dubois limits their access for further study, hiding the fossils beneath his dining room floor.

1912

Discovery Line: A very large human-like skull and a small apish jaw are discovered at Piltdown in England. Researchers, including paleontologist A. Smith Woodward, suggest that the Piltdown remains represent the oldest known link between humans and apes.

Inside Line: British anatomist Arthur Keith, jealous that the remains have not been given to him to study, challenges Woodward's reconstruction. Keith's good friend Elliot Smith sides with the other man, ending the Keith–Smith friendship.

1922

Discovery Line: Henry Fairfield Osborn of the American Museum of Natural History proclaims a single tooth found in the Snake Creek fossil beds of Nebraska is evidence of "the first anthropoid ape of America."

Inside Line: More teeth are found at the site and the "Nebraska man" is reclassified as an extinct pig.

1925

Discovery Line:

Professor Raymond Dart studies a small apish skull called the Taung child from the Taung limestone quarry in South Africa. Dart names the new species *Australopithecus*.

Inside Line:

Most paleontologists, including Arthur Keith and Louis Leakey, dismiss Taung as an odd ape. Dart and the Taung child become the subject of vaudeville jokes.

1947

Discovery Line: Scottish paleontologist Robert Broom proves Raymond Dart right in his assertion that australopithecines were hominids by finding more evidence in South Africa.

Inside Line: Broom, who likes to search for fossils in the nude, is called "about as honest as a poker player" and is twice banned from his own research site.

1948

Discovery Line:

Mary Leakey discovers the skull of *Proconsul*, now thought to be our oldest ancestor, on Rusinga Island in Kenya's Lake Victoria.

Inside Line: The Leakeys celebrate the discovery by conceiving their third son, Philip.

1953

Discovery Line: The Piltdown find is exposed as a hoax. It turns out to be a relatively modern human skull combined with an ape's jaw.

Inside Line: The person who planted the hoax is never found.

1959

Discovery Line:

Mary Leakey discovers a 1.75 million-year-old australopithecine skull at Olduvai Gorge in Tanzania, moving the cradle of mankind from South Africa to East Africa.

Inside Line: The discovery brings Louis and Mary Leakey fame and more fortune than they have ever known. Support from the National Geographic Society enables them, in Louis's words, "to do more in two years at Olduvai than we have done in the preceding thirty." Even though Mary makes the discovery, Louis takes the spotlight, writing "Finding the World's Earliest Man" for *National Geographic*.

1972

Discovery Line: The oldest, most complete skull of a large-brained ancestor is found near Koobi Fora in northern Kenya by a research team led by the Leakeys' son Richard. Named 1470 (after its museum accession number), the skull is said to be 2.8 million years old. If the dating holds, the skull will confirm Louis Leakey's theory that the large-brained genus *Homo* existed millions of years ago.

Inside Line:

The discovery inspires a reunion between Louis and Richard Leakey, who have not gotten along for several years. (As a teenager, Richard vowed to do anything but follow in his parents' footsteps.) A few days after this reunion, the elder Leakey dies of a heart attack. Subsequently, a fierce controversy over the age of the skull pits scientists from the Omo River expedition led by F. Clark Howell against Leakey's team from Koobi Fora. Richard Leakey exhibits a "distinct coolness" toward his mother, Mary Leakey, when she is skeptical of the older date; he is also accused of suppressing scientific data that do not support his theory.

1974

Discovery Line:

Paleontologist Donald Johanson and his team discover a range of fossils more than 3 million years old near Hadar in Ethiopia. These fossils include Lucy and a group dubbed the First Family.

A BRIEF HISTORY OF HUMAN TIME

PALEOANTHROPOLOGISTS CAN BE APISH AND TERRITORIAL, JUST LIKE THE REST OF US

35,000–150,000 YEARS AGO

Homo sapiens (Neanderthal). Neanderthal people constituted a particularly rugged group living in Europe and the Middle East during the Ice Age. As temperatures warmed, they disappeared.

PRESENT–100,000 YEARS AGO

Homo sapiens sapiens (modern humans). Anatomically modern humans with skeletons like ours first appeared in the fossil record about 60,000 years ago.

1977

Mary Leakey and her team in Tanzania discover the oldest evidence of our ancestors' upright gait: the Laetoli footprints preserved by a layer of volcanic ash. The footprints are said to be 3.7 million years old.

Paleontologist Ron Clarke says that because of her poor eyesight, Leakey has inadvertently carved an extra heel into a set of footprints during the excavation, creating a third hominid where there should be only two.

1978

Johanson declares that Lucy and the First Family are small-brained australopithecines ancestral to modern humans.

Johanson's claim challenges the Leakeys' theory that our 3 million year-old ancestors were a species of the genus *Homo*.

1981

Richard Leakey and Johanson appear in a U.S. television debate hosted by Walter Cronkite. In front of a national audience, Leakey draws a big *X* across Johanson's chart of the human family tree. It isn't the tree that irks Leakey so much as Cronkite's prologue: "Before the discovery of Lucy made Donald Johanson a celebrity, the king of the mountain in paleoanthropology was Richard Leakey."

1985

Anatomist Alan Walker discovers the Black Skull, so-called because of a manganese patina, in Kenya. Everyone agrees the skull forces a new drawing of our family tree, but there's no consensus on a single drawing.

Richard Leakey suggests that the skull proves there were actually two australopithecine species at Hadar in Ethiopia. Johanson announces a consensus among other colleagues that there was only one species.

1986

The theory of Eve, proposed by Allan Wilson, suggests a single point of origin for all modern humans, descended from a female in Africa. Wilson and his team based this finding on a study utilizing mitochondrial DNA as a marker to trace human ancestry.

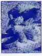
Fossil finders pursue a Bones versus Blood War against the molecular biologists.

1990

Johanson and his team from Berkeley return to Hadar, where they find a large upper jaw with part of the face.

The bones now suggest there may have been two species at Hadar, not one.

1991



Richard Leakey, now less involved in fossil hunting, heads up the Kenya Wildlife Service. He is renowned for saving Kenya's elephants from ivory poachers.

Richard's wife, Dr. Meave Leakey, is now head of paleontology at the Kenya National Museum, where she oversees a team of accomplished fossil finders known as the Hominid Gang.

"We've got things in the computer capable of evolving, reproducing, metabolizing, things having complex patterns in space and in time. Are they not alive?" For a pioneer in the emerging scientific field of artificial life, that is the big question

INTERVIEW

CHRISTOPHER LANGTON

His first encounter with an artificial life form took place while he was at Massachusetts General Hospital. His job involved wheeling dead bodies between the morgue and autopsy room. One night about three A.M.—this was after he'd seen *Night of the Living Dead*—he and a co-worker were ferrying the latest corpse through a dank underground hallway lit by a single bulb. The body was covered with a sheet, all very *Frankenstein*-like, when suddenly the corpse started moving. It started to rise! The body ... sat up! ' And it made this roar!" says Chris Langton. "I turned to the guy next to me and he was gone. The double doors at the end of the hallway were going flap, flap, flap ... " No explanation ever did turn up. "People in the morgue liked to play jokes," he says. "You'd go to wheel a body, open up a drawer, and the body'd sit up. This one could have been planted, too."

Langton's second encoun-

PHOTOGRAPHS BY DAVID MICHAEL KENNEDY

NAME:
Christopher Langton

AGE:
Forty-two

PLACES OF WORK:
Complex Systems Group Theoretical Division, Los Alamos National Laboratory, Santa Fe Institute

LANGUAGES FLUENT IN:
C, LISP, BASIC, Pascal, FORTRAN, 6502 assembly language, PDP-7 assembly language, etc

FAVORITE ARTIFICIAL LIFE FORM I:
Ed McMahon

FAVORITE ARTIFICIAL LIFE FORMS II:
Langton's cell simulation on the Connection Machine, Rod Brooks's insects at the MIT Artificial Insect lab

RECENTLY READ:
Mary Shelley's *Frankenstein* (for the third time), "I want to understand Frankenstein to understand life from the perspective of the so-called monster."

ter was a little less spooky. Working in Mass General's Psychiatric Research lab as a systems programmer, he was trying to make one computer simulate the operational structure and functions of a second computer. These simulations, he realized, involved reducing a given machine's operations to a finite set of rules and instructions, a bunch of abstract logical relationships. Was there anything, he wondered, whose workings you *couldn't* simulate in this fashion? What was life itself after all, but a lot of essentially dead materials organized so that, somehow, living processes emerged? If you correctly simulated the underlying pattern or structure of a living thing, Langton thought, wouldn't that simulation itself in some sense be alive?

His third encounter with artificial life also took place in a hospital, only this time he was a patient. In 1975, before entering the University of Arizona, he crashed his hang glider, breaking 35 bones, including both legs. As he regained consciousness, information patterns marched through his head, exploding like fireworks across his visual field. "It was as if they were self-existing entities completely taking over the hardware of my brain," he recalls. He spent the next five months recuperating and thinking about what he'd seen.

Years later Chris Langton established the field of artificial life as a distinct scientific discipline. In 1987, while a research fellow at the Los Alamos National Laboratory, he organized the first conference on artificial life. More than 100 scientists brought an entire menagerie of artificial animals. In addition to a smattering of robots, there were computer-based genes, ferns, flowers, worms, and bugs; there were schooling fish, flocking birds, and buzzing bioinformatic bumblebees; there was a warren of artificial foxes and rabbits in their own artificial ecology. The workshop was capped with an artificial life 4-H show prizewinning entry, the ferns.

Two years later, even before receiving his doctorate, Langton helped organize a second workshop. Today artificial life embraces the study of complex adaptive systems in all their myriad forms: from prebiotic chemical evolution, to biological evolution, evolution of languages and cultural systems, to evolution of global economies. While some researchers try to get synthetic life going in chemical media, Langton prefers to work with computers. His latest project, which he's collaborating on with Kristian Lindgren (NORITA, Copenhagen) and others, attempts to computer-simulate a complete biological cell.

You can be as skeptical as you want about artificial life until you see that simulation. There in living color is a pulsing, undulating cell membrane, exactly what you might see watching cell division through a microscope. The cell wall puckers, pinches down on itself, and a second cell splits off. This is not a movie. The wriggling, dividing structure is a pattern generated by a program much the way DNA codons generate biological organisms. Somewhere in the bowels of the Connection Machine, a massively parallel supercomputer that sits a few doors away from Langton's Los Alamos office, exists the electronic analog of a living cell.

Says Langton: "We're going to try to capture a cell's behavior while it incorporates stuff from the outside—taking in metabolites and turning them into cell constituents—turns genetic code into entities that move around inside the cell and make it do things like divide, produce offspring with variants, and die."—Ed Regis

Omni: Can you define "artificial life"?
Langton: My first sense of it came around 1979 when I was trying to describe what I wanted to do for my Ph.D. It was then a way to study biological phe-

CONTINUED ON PAGE 122

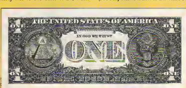
GAMES

A triskaidekaphobic may fear the number 13, but we have reason to celebrate

By Scot Morris

How many pennies do you need to make a stack as tall or taller than a penny set on its edge? Most people will say nine or ten but you must actually use 13 pennies

We started thinking about the number 13 last February when we got a letter from Monte Zerger, a mathematician at Adams State College in Alamosa Colorado "The thirteenth anniversary of *Omni* in 1991 will be particularly auspicious because ninety-one is the sum of the numbers one through thirteen," wrote Zerger, who along with Dan Shine of Cincinatti served as our numerological consultant this month Zerger also pointed out that the alphabet's middle letters—*M* (the thirteenth letter from the beginning of the alphabet) and *N* (the thirteenth letter from the end of the alphabet)—are also the middle letters in the name *Omni*—enclosed by the middle vowels *Omni's* logo even contains a hidden portent Rearrange the four shapes to read *no 13*



If the country's Founding Fathers had been triskaidekaphobics, would there be only 12 original colonies commemorated on the U.S. flag and a one-dollar bill?

Mathematically, 13 is a fascinating number The first "teen" number it is both a prime number (the sixth, after 2, 3, 5, 7, and 11) and a Fibonacci number in which each number of the series is the sum of the previous two (13 is the seventh after 1, 1, 2 3, 5, and 8) The number 13 is also the first "emirp," a prime number that turns into a different prime number when reversed (31)

Elsewhere in mathematics Euclid's *Elements* are contained in 13 books There are 13 Archimedean polyhedrons And a cube has 13 axes of symmetry Three go through opposite faces, four through diagonally opposite vertices, and six through opposite edges

Other 13-related facts include 13 cards in a suit (hearts diamonds, spades, and clubs) in every standard deck of playing cards In music an octave consists of 13 notes

But while the recipient of a baker's dozen is certainly fortunate, is it wise to celebrate when you're 13 years old? We're not superstitious, but just to be safe consider this anniversary issue of *Omni* the start of our fourteenth year

The number 13 some people believe seems to have almost supernatural powers And those who suffer from triskaidekaphobia, the fear of the number 13, won't reserve a seat in the thirteenth row of an airplane eat at a table seating 13 people, or rent a room on the thirteenth floor (although few, if any hotels and office buildings officially have a thirteenth floor)

The superstition about 13 people at a dinner table supposedly harks back to the Last Supper, as told in the Gospel according to Saint John Jesus Christ and his 12 apostles gathered for the last time before he was arrested and eventually executed When Judas, the apostle who betrayed Christ, left the thirteenth chair remained empty

While the number 13 has been associated with Judas and the Last Supper, it also makes an unlucky appearance in other cultures In Norse mythology for example, 12 gods were invited to a dinner party The god of mischief Loki crashed the party, and during the affair one of the guests was killed

There's certainly no doubt that the number 13 has its dark side There are traditionally 13 witches in a coven, 13 steps on a gallows, and 13 coils of rope in a hangman's noose And the thirteenth card of the tarot deck represents death reminiscent of the Black Death, the plague that swept across Europe in the 1300's

Superstition also can affect history During the late Fifties, the Colombiana, a group of Italian experts on the life of Christopher Columbus, reviewed all the documents related to the explorer's historic arrival in the Americas They concluded that Columbus actually landed in the New World on October 13, 1492 The man entrusted with Christopher Columbus's log and papers may have deliberately changed the date to October 12 to avoid the evil omen of the number 13

But 13 has not always been considered evil or unlucky The ancient Egyptians considered death, the thirteenth stage of earthly life as the transition to eternal life For them, death was a transformation, not an ending And un-

GAMES

If you attend a dinner party for 13, will it be your last meal or a reason to rejoice? Would you dare to find out?

like the Last Supper, the thirteenth chair at King Arthur s Round Table was a seat of honor, reserved for the knight who would find the Holy Grail

The number is also significant in American history The 13 original colonies are represented everywhere, from the 13 red and white stripes on the flag to the 13 steps on the pyramid in the Great Seal, which appears on the back of a dollar bill

THIRTEEN QUIZ

The following questions relate to the number 13

1 In addition to the steps of the pyramid the number 13 is represented in many ways on a dollar bill some of them intentional others not. How many can you find?

2. What 13-sided polygon occurs in the natural world?

3 What is the most abundant metallic element in the earth s crust?

4 What 13-member group exports petroleum?

5 What is the difference between the Julian and the Gregorian calendars?

6 What heroine was proud of her 13-inch waist?

7 In what fictional tale do 13 dwarfs take a collective journey?

8 Why is it ironic that Friday the thirteenth is considered unlucky?

9. The first permanent English settlement in the New World was established on May 13, 1607 What significant event occurred 13^2 years later? And 13^2 years after that?

10 What novel begins, "It was a bright cold day in April and the clocks were striking thirteen ?

11 What unlucky moon mission exploded in 1970?

12 What is significant about 13^2 and 31^2?

13 What composer, born in 1813, composed 13 operas and has 13 letters in his name?

ANSWERS

1. There are 13 letters in the motto ANNUIT COEPTIS above the pyramid, 13 stars above the eagle's head, 13 stripes on its shield and 13 letters in the motto E PLURIBUS UNUM on the ribbon in its beak The eagle also holds 13 war arrows on one side and a peace branch with 13 olives and 13 leaves on the other side There are 13 beads in the decorative "rattlesnake tail" chains on the outer sides of the Great Seal And the date in Roman numerals 1776, is printed directly opposite 1789, the only other date on every dollar bill—in the green Treasury seal next to Washington's portrait The difference between the two dates is 13 years

2 Viewed from outside the solar system Earth's moon travels around the sun tracing a path that resembles a 13-sided polygon with rounded corners

3 The thirteenth element, aluminum

4 13 member nations make up OPEC, the Organization of Petroleum Exporting Countries

5. The Julian calendar

NO 13

currently lags 13 days behind the Gregorian calendar and will remain so until the year 2100 Then the difference will become 14 days

6 Scarlett O'Hara in *Gone With the Wind*

7 In *The Hobbit*, by J.R.R Tolkien, 13 dwarfs escort Bilbo Baggins from the Shire to the Lonely Mountains

8 The thirteenth of the month is more likely to fall on a Friday than on any other day of the week Our calendar repeats itself, exactly every 400 years During each 400-year period the thirteenth of the month occurs on Friday 688 times

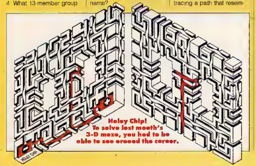
9. 1607 + 169 = 1776, the year of the American Revolution 1776 + 169 = 1945, the year World War II ended, the year the first atomic bomb was dropped, and the year Franklin Delano Roosevelt died, 13 years after he was first elected President of the United States

10 George Orwell s *1984*

11 Apollo 13

12 $13^2 = 169$; $31^2 = 961$, the reverse of 169

13 Richard Wagner



Holey Chip! To solve last month's 3-D maze, you had to be able to see around the corner.


The Artist
© ART CUMINGS
To whom it may concern: Your work is becoming too obscure

DIRECTION

CONTINUED FROM PAGE 41

he used his technique to create *E. coli* mutants that could thrive on the carbon source citrate. "This was weird," he says, "because one of the definitions of *E. coli*, one of the things that's used to distinguish it from all other closely related organisms, is that it cannot use citrate." Mapping the genes of his citrate mutants, Hall found "the improbable stacked on top of the highly unlikely" when it turned out that the citrate-consuming *E. coli* had two large-scale genetic mutations, not just a single altered base. The finding was so completely out of line with results predicted by accepted evolutionary theory that Hall didn't know what to think. "At that point," he recalls, "all I could do was throw up my hands." Yet by 1988, when Cairns described the phenomenon of directed mutation in *Nature*, Hall realized that he had been studying this phenomenon as well. By then at the University of Rochester, he had witnessed directed mutation in thousands of bacterial colonies and had charted its course in many specific *E. coli* genes. He was also beginning to study the phenomenon in yeast.

Discussing the research today from his immaculate Rochester office, his spanking new lab overflowing with projects next door, Hall expresses awe at the mysteries he has seen. "For almost fifteen years," he says, "I have been slapped in the face with the highly improbable. When that happens, you either get religion and say, 'God is favoring me,' or you conclude that perhaps your understanding of the process—in this case, the process of evolution—is incomplete."

Hall did the latter. Paying attention to his organisms, the lowly bacteria, he has been able to reach just one conclusion: "While some mutations may be random, many others are generated by the organism to cope with environmental stress." Because these mutations are literally selected by the organism while it is under stress, Hall calls them "selection induced."

To date, Hall has generated selection-induced mutations for half a dozen *E. coli* genes and a couple of yeast genes as well. Most of the time, he worked with bacteria unable to utilize nutrients such as lactose. He has also worked with bacteria unable to replicate because they lack the ability to manufacture critical amino acids, the building blocks of protein. When he first places these bacterial strains on a plate or in a liquid medium, the cells seem to stop growing. But after a few weeks Hall finds large numbers of mutants that *can* utilize the nutrients or manufacture the needed amino acids.

In dozens of control studies, moreover, Hall has shown that the mutants are specific to the environment. The starving cells do not just start churning out mutants at random. If lactose is the only nutrient available, for instance, the mutants will develop the ability to digest only lactose, not some other, unrelated sugar. If the medium is missing the amino acid tryptophane, then the cells will evolve the ability to produce that amino acid only.

These days Hall and Cairns regularly correspond. One of their most pressing concerns: Figuring out how bacteria and yeast can possibly "know" what mutations to make. As Hall himself says, "It's implausible that a single cell has an array of machinery complex enough to measure the environment and then, in effect, say, 'Oh, *this* is how I have to mutate,' and then just go out and do it. Yet that is what seems to occur."

No viable theory has yet emerged, though Cairns and other researchers have speculated on the existence of something like a spontaneous mutation generator. "Imagine," says Cairns, "that these guys [the bacteria] are out there struggling, and they're not multiplying because of the stress. Mutations are spun out and then gotten rid of, until finally one is good. The lights go on, the dynamo starts humming, and the cell can grow. At that point the mutation generator comes to a halt."

No matter what the mechanism, however, one question dominates. Even if this eerie phenomenon plays a large role in the evolution of microorganisms, does it have a similar impact on the human species? Evolution, Cairns believes, works the same way for the simplest, one-celled organisms and the most complex. No matter what the life form, he says, "the process is the same." Adds Hall, "As organisms evolve, they affect the environment. The environment, in turn, has an impact on life. If directed mutation turns out to be a powerful evolutionary force, we may have to reanalyze the feedback loops between the biosphere and the earth."

But Levin of Amherst insists that, despite the elegance of some of the work, it is not strong enough to stake a claim. "Until Cairns, Hall, and others show the mechanism by which directed mutation takes place, I will be skeptical," he states. "They certainly haven't shown that organisms perceive the environment and then understand what they need, nor have they demonstrated that organisms have the cellular machinery for this perception."

Some of the strongest criticism to date has been offered by evolutionary biologist Richard Lenski of the University of California at Irvine. Working with graduate student John Mittler, Lenski has recently published a paper in *Nature* himself. According to Lenski, cells may simply generate large numbers of certain types of mutations when they are starved, as Cairns and Hall's cells are. He also suggests that some bacterial populations may increase in number by literally consuming bacterial waste products, with more cells in the population, one might *expect* to find a larger number of mutants.

Hall, for his part, counters that he continues to test all possible explanations for directed mutation in his lab, as critics suggest additional control possibilities, he says, he will test those as well, "no matter how foolish they seem." None of the explanations posed so far, he adds, come close to explaining the effect, at least according to his painstaking control studies in the lab. To bolster his argument, he takes out a stack of papers currently in press and reams of data from his shelves. Drawing furiously on his chalkboard, he seems to demolish the notion that cell starvation or an undetected increase in colony size can account for the numbers and types of mutations he has seen.

Cairns, soon to retire to his native England, says that the critics "see themselves as crusaders defending some religion, and by hook or by crook, defend it they will. But the world will pass them by." The reason, Cairns notes, is the power of science itself. "Our studies are ever more detailed," he says, "and system after system seems to be demonstrating this effect. The data will speak for itself."

If that data holds, evolutionary biologists will have to go back to the drawing board and rewrite their theories of how earthly life evolved. If directed evolution turns out to affect not just microorganisms, but also more complex living things, then we may have to reanalyze the fossil record and revamp the history of *Homo sapiens* as well. Says Hall, "It would require a paradigm shift in the way we view the world."

Whichever way the evidence finally points, however, it will be business as usual for lab hound Barry Hall. "The Neo-Darwinists claim that evolution works too slowly, and on such large populations, it's simply impossible to study the process," he concludes. "But for people working with bacteria it is possible to study evolution as it happens. Biology is an experimental science, not a theoretical one. The business we're involved in is asking—not telling—the universe how it works."

EARTH

FATAL IMPACT:
Hunt for the crater that killed the dinosaurs

By Curt Wohleber

New evidence of meteor strikes from space puts

The one thing about dinosaurs scientists agree on is that they are all dead, victims of an extinction that swept three quarters of the world's species into the evolutionary dustbin. How did it happen? The most talked-about theory in recent years blames a comet or asteroid that slammed into Earth 65 million years ago, wreaking havoc. But if the death blow came from space, it should have left a large hole in the ground.

a dent in long-held theories of the dinosaurs' demise.

Geologists are busy looking for that hole. The hunt began in 1980 when Walter and Luis Alvarez discovered a global layer of 65-million-year-old rock rich in iridium—a common ingredient of asteroids. The Alvarezes believed that this "fireball layer" was actually fallout from a huge explosion set off by the catastrophic impact of a meteor. Now scientists are determined to find the point of impact itself. Last year geologists found an abundance of large quartz grains in Haiti, but that nation is just one of many vying for notoriety as the spot where the fireball hit. Here's a look at other possible hot spots:

Manson. Named after the nearby town of Manson, Iowa, not the murdering psycho cult leader, the Manson Crater is a favorite of Glen Izett of the U.S. Geological Survey. Evidence: The crater appears to consist of the same minerals found in the fireball layer. Manson is 65 million years old, placing it at the scene of the crime. Alibi: With a diameter of only 22 miles, Manson is considered too wimpy by most geologists to have done the deed.

Iceland. In 1980 astronomer Fred Whipple proposed that a ten-kilometer meteor struck the North Atlantic, puncturing the earth's crust. Swallowing a meteor that large brought on an epic case of geological indigestion, triggering massive volcanic eruptions that created the island of Iceland. Evidence: Iceland contains no rocks older than 65 million years. Alibi: Studies of the fireball layer have convinced most geologists that the meteor came down on or near a major landmass. For them Whipple's Icelandic saga of an ocean impact won't hold water.

The Deccan Traps. Michael Rampino of New York University targets India's Deccan Traps, a million-cubic-kilometer formation of volcanic rock. The meteor, he suggests, caused the volcano to erupt, and the lava flow covered up the hole. Evidence: The great spewing of lava that created the Deccan Traps coincides with the dinosaurs' demise. Alibi: Most geologists are reluctant to blame enormous lava flows on giant rocks from space.

Kara and Ust-Kara. The Soviets entered the crater race with this pair in the chilly northern reaches of the Soviet Union, touted by M. A. Nazarov and D. D. Badjakov of Moscow's Vernadsky Institute of Geochemistry. Evidence: They're big enough. Kara is 75 kilometers across, and Ust-Kara measures 125 kilometers. Alibi: Like awkward party guests, they showed up too early. Potassium-argon readings date them at about 10 million years before the mass extinction.

Cuba. Bruce Bohor of the U.S. Geological Survey suspects that formations on the southwestern edge of Cuba could be the result of impact cratering. Evidence: Rocks and crystals in the area appear to have been battered by some titanic force. But Bohor hasn't visited the site for a closer look because access has been limited since the Bay of Pigs. Alibi: John McHone of Arizona State University did manage to visit Cuba and says that the geological anomalies "can be explained in a nonimpact manner."

Colombia Basin and Chicxulub. "We think we have found the smoking gun," said University of Arizona geologist William Boynton at last year's American Geophysical Union meeting. Boynton and his colleagues collared two additional suspects last year: a 300-kilometer undersea depression north of Colombia and Chicxulub, a 150-kilometer crater buried beneath Mexico's Yucatán peninsula. Evidence: Chicxulub contains shocked minerals and melted rocks, common products of impact cratering. Alibi: It may be a case of mistaken identity.

Even if Boynton's group does manage to turn up hard information, they won't get the last word while others want to take credit for finding the killer crater. New suspects will no doubt surface in years to come.

As Canadian geologist Richard Grieve says, "Killing dinosaurs is an in thing." DO

HUNTERS

CONTINUED FROM PAGE 52

ed yes, by the sheer deadliness of the creature by its excessive horrificality Amused, almost by its grotesqueries of form And coolly aware that in three bounds and a swipe of its little dangling paw it could end his life depriving him of the sure century of minimum expectancy that remains to him Despite that threat he remains calm If he dies he dies; but he can't actually bring himself to believe that he will He is beginning to see that the capacity for fear, for any sort of significant psychological distress, has been bred out of him He is simply too stable It is an unexpected drawback of the perfection of human society

The saurischian predator of unknown species slavers and roars and glares Its narrow yellow eyes are like beacons Mallory unslings his laser rifle and gets into firing position Perhaps this one will be easier to kill than the colossal sauropod

Then a woman walks out of the jungle behind it and says "You aren't going to try to shoot it are you?"

Mallory stares at her She is young, only fifty or so unless she's on her second or third retread, attractive, smiling Long sleek legs a fluffy burst of golden hair She wears a stylish hunting outfit of black sprayon and carries no rifle only a tiny laser pistol A space of no more than a dozen meters separates her from the dinosaurs spiked tail but that doesn't seem to trouble her

He gestures with the rifle "Step out of the way, will you?"

She doesn't move "Shooting it isn't a smart idea"

"We're here to do a little hunting, aren't we?"

"Be sensible," she says "This one's a real son of a bitch You'll only annoy it if you try anything and then we'll both be in a mess" She walks casually around the monster which is standing quite still, studying them both in an odd perplexed way as though it actually wonders what they might be Mallory has aimed the rifle now at the thing's left eye but the woman coolly puts her hand to the barrel and pushes it aside

"Let it be," she says "It's just had its meal and now it's sleepy I watched it gobble up something the size of a hippopotamus and then eat half of another one for dessert You start sticking it with your little laser and you'll wake it up, and then it'll get nasty again Mean-looking bastard isn't it?" she says admiringly

"Who are you?" Mallory asks in wonder "What are you doing here?"

"Same thing as you I figure. Cretaceous Tours?"

"Yes. They said I wouldn't run into any other—"

"They told me that, too. Well it sometimes happens Jayne Hyland New Chicago, 2281"

"Tom Mallory New Chicago also And also 2281"

"Small geological epoch, isn't it? What month did you leave from?"

"August"

"I'm September"

"Imagine that."

The dinosaur far above them utters a soft snorting sound and begins to drift away

"We're boring it," she says

"And it's boring us, too. Isn't that the truth? These enormous terrifying monsters crashing through the forest all

> His throat is dry, his fingers are tingling He has never felt anything like this before in his life

around us and we're as blasé as if we're home watching the whole thing on the polyvid" Mallory raises his rifle again The scarlet-frilled killer is almost out of sight "I'm tempted to take a shot at it just to get some excitement going"

"Don't," she says "Unless you're feeling suicidal Are you?"

"Not at all"

"Then don't annoy it, okay? I know where there's a bunch of ankylosaurs wallowing around That's one really weird critter believe me Are you interested in having a peek?"

"Sure" says Mallory

He finds himself very much taken by her brisk no-nonsense manner her confident air When we get back to New Chicago, he thinks, maybe I'll look her up The September tour she said So he'll have to wait a while after his own return I'll give her a call around the end of the month he tells himself

She leads the way unhesitatingly through the tree-fern grove and around a stand of giant horsetails and across a swampy meadow of small plastic-looking plants with ugly little mud-colored daisyish flowers On the far side they zig around a great pile of blood-ied bones and zag around a treacherous bog with a sinisterly quivering surface A couple of giant dragonflies whiz by droning like airborne missiles A crimson frog as big as a rabbit grins at them from a pond They have been walking for close to an hour now and Mallory no longer has any idea where he is in relation to his timemobile capsule But the thinko will find the way back for him eventually he assumes

"The ankylosaurs are only about a hundred meters further on" she says, as if reading his mind She looks back and gives him a bright smile "I saw a pack of troodons the day before yesterday out this way You know what they are? Little agile guys, no bigger than you or me smart as whips Teeth like saw blades, funny knobs on their heads I thought for a minute they were going to attack, but I stood my ground and finally they backed off You want to shoot something, shoot one of those"

"The day before yesterday?" Mallory asks after a moment "How long have you been here?"

"About a week Maybe two I've lost count really Look, there are those ankylosaurs I was telling you about"

He ignores her pointing hand "Wait a second The longest available time tour lasts only—"

"I'm Option Three," she says

He gapes at her as though she has just sprouted a scarlet bony crust with five spikes behind it.

"Are you serious?" he asks

"As serious as anybody you ever met in the middle of the Cretaceous forest I'm here for keeps, friend I stood right next to my capsule when the twelve hours were up and watched it go sailing off into the ineffable future And I've been having the time of my life ever since"

A tingle of awe spreads through him It is the strongest emotion he has ever felt, he realizes

She is actually living that gallant life of desperate heroism that he had fantasized Avoiding the myriad menaces of this incomprehensible place for a whole week or possibly even two, managing to stay fed and healthy, in fact looking as trim and elegant as if she had just stepped out of her capsule a couple of hours ago And never to go back to the nice safe orderly world of 2281 Never Never She will remain here until she dies—a month from now, a year, five years whenever Must remain By her own choice An incredible adventure

Her face is very close to his Her breath is sweet and warm Her eyes are bright penetrating ferocious "I was sick of it all," she tells him "Weren't you? The perfection of everything The absolute predictability You can't even stub your toe because there's some clever sensor watching out for you The biomonitors The automedics The guides and proctors I hated it."

"Yes Of course "

Her intensity is frightening For one foolish moment Mallory realizes he was actually thinking of offering to *rescue* her from the consequences of her rashness Inviting her to come back with him in his own capsule when his twelve hours are up They could probably both fit inside, if they stand very close to each other A reprieve from Option Three a new lease on life for her But that isn't really possible he knows The mass has to balance in both directions of the trip within a very narrow tolerance, they are warned not to bring back even a twig even a pebble nothing aboard the capsule that wasn't aboard it before And in any case being rescued is surely the last thing she wants She'll simply laugh at him Nothing could make her go back She loves it here She feels truly alive for the first time in her life In a universe of security-craving dullards she's a woman running wild And her wildness is contagious Mallory trembles with sudden new excitement at the sheer proximity of her

She sees it, too Her glowing eyes flash with invitation

"Stay here with me!" she says "Let your capsule go home without you the way I did"

"But the dangers—" he hears himself blurting inanely

"Don't worry about them I'm doing all right so far aren't I? We can manage We'll build a cabin Plant fruits and vegetables Catch lizards in traps Hunt the dinos They're so dumb they just stand there and let you shoot them The laser charges won't ever run out You and me me and you, all alone in the Mesozoic! Like Adam and Eve we'll be The Adam and Eve of the Late Cretaceous And they can all go to hell back there in 2281."

His fingers are tingling His throat is dry His cheeks blaze with savage adrenal fires His breath is coming in ragged gasps He has never felt anything like this before in his life

He moistens his lips

"Well—"

She smiles gently The pressure eases "It's a big decision I know Think about it " she says Her voice is soft now The wild zeal of a moment before is gone from it "How soon before your capsule leaves?"

He glances at his wrist "Eight nine more hours"

"Plenty of time to make up your mind"

"Yes Yes"

Relief washes over him She has dizzied him with the overpowering force of her revelation and the passionate frenzy of her invitation to join her in her escape from the world they have left behind He isn't used to such things He needs time now, time to absorb, to digest to ponder To decide That he would even consider such a thing astonishes him. He has known her how long—an hour an hour and a half?—and here he is thinking of giving up everything for her Unbelievable Unbelievable

Shakily he turns away from her and stares at the ankylosaurs wallowing in the mud hole just in front of them.

Strange, strange, strange Gigantic low-slung tubby things, squat as tanks, covered everywhere by armor Vaguely triangular expanding vastly toward the rear, terminating in armored tails with massive bony excrescences at the tips like deadly clubs Slowly snuffling forward in the muck tiny heads down busily grubbing away at soft green weeds Jayne jumps down among them and dances across their armored backs, leaping from one to another. They don't even seem to notice. She laughs and calls to him "Come on," she says, prancing like a she-devil

They dance among the ankylosaurs until the game grows stale Then she takes him by the hand and they run onward through a field of scarlet mosses down to a small clear lake fed by a swift-flowing stream They strip and plunge in, heedless of risk Afterward they embrace on the grassy bank Some vast creature passes by, momentarily darkening the sky Mallory doesn't bother even to look up

Then it is on, on to spy on something with a long neck and a comic knobby head and then to watch a pair of angry ceratopsians butting heads in slow motion, and then to applaud the elegant migration of a herd of towering duckbills across the horizon There are dinosaurs everywhere, everywhere everywhere, an astounding zoo of them And the time ticks away

It's fantastic beyond all comprehension But even so—

Give up everything for this? he wonders

The chalet in Gstaad, the weekend retreat aboard the L-5 satellite the hunting lodge in the veld? The island home in the Seychelles, the plantation in New Caledonia, the pied-à-terre in the shadow of the Eiffel Tower?

For this? For a forest full of nightmare monsters, and a life of daily peril?

Yes Yes Yes Yes

He glances toward her She knows what's on his mind and she gives him a sizzling look *Come live with me and be my love, and we will all the pleasures prove* Yes Yes Yes Yes

A beeper goes off on his wrist and his thinko says, 'It is time to return to the capsule Shall I guide you?'

And suddenly it all collapses into a pile of ashes, the whole shimmering fantasy perishing in an instant

"Where are you going?' she calls

'Back," he says He whispers the word hoarsely—croaks it, in fact

"Tom!

"Please Please "

He can t bear to look at her His defeat is total, his shame is cosmic But he isn't going to stay here He isn t He isn't He simply isn t He slinks away, feeling her burning contemptuous glare drilling holes in his shoulder blades The quiet voice of the thinko steadily instructs him, leading him around pitfalls and obstacles After a time he looks back and can no longer see her

On the way back to the capsule he passes a pair of sauropods mating, a tyrannosaur in full slather, another thing with talons like scythes, and half a dozen others The thinko obligingly provides him with their names, but Mallory doesn't even give them a glance The brutal fact of his own inescapable cowardice is the only thing that occupies his mind *She* has had the courage to turn her back on the stagnant overperfect world where they live, regardless of all danger, whereas he—he—

"There is the capsule, sir," the thinko says triumphantly

Last chance Mallory

No No No He can t do it.

He climbs in Waits

Something ghastly appears outside all teeth and claws, and peers balefully at him through the window Mallory peers back at it, nose to nose, hardly caring what happens to him now The creature takes an experimental nibble at the capsule The impervious metal resists The dinosaur shrugs and waddles away

A chime goes off The Late Cretaceous turns blurry and disappears

In mid-October, seven weeks after his return, he is telling the somewhat edited version of his adventure at a party for the fifteenth time that month when a woman to his left says. "There's someone in the other room who's just come back from the dinosaur tour, too "

"Really," says Mallory, without enthusiasm

'You and she would love to compare notes, I'll bet Wait and I'll get her Jayne! Jayne, come in here for a moment!

Mallory gasps Color floods his face His mind swirls in bewilderment and chagrin Her eyes are as sparkling and alert as ever, her hair is a golden cloud

"But you told me—"

"Yes," she says "I did, didn't I?'

"Your capsule—you said it had gone back—"

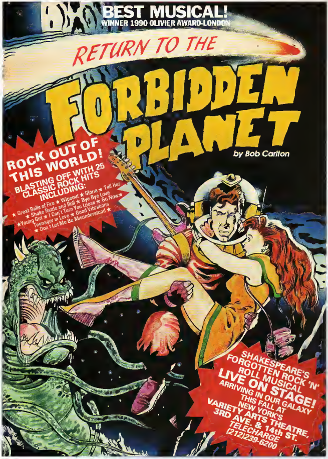
"It was just on the far side of the ankylosaurs behind the horsetails I got to the Cretaceous about eight hours before you did I had signed up for a twenty-four-hour tour "

'And you let me believe—"

'Yes So I did " She grins at him and says softly "It was a lovely fantasy, don t you think?"

He comes close to her and gives her a cold, hard stare "What would you have done if I had let my capsule go back and stranded myself there for the sake of your lovely fantasy?"

"I don t know," she tells him "I just don't know " And she laughs ∞



BEST MUSICAL!
WINNER 1990 OLIVIER AWARD-LONDON
RETURN TO THE
FORBIDDEN PLANET
by Bob Carlton
ROCK OUT OF THIS WORLD!
BLASTING OFF WITH 25 CLASSIC ROCK HITS INCLUDING:
★ Great Balls of Fire ★ Wipeout ★ Gloria ★ Tell Her ★ Shake Rattle and Roll ★ Bye Bye Love ★Young Girl ★ I Can't Turn You Loose ★ Go Now★ Teenager in Love ★ Good Vibrations ★ ★ Don't Let Me Be Misunderstood ★
SHAKESPEARE'S FORGOTTEN ROCK 'N' ROLL MUSICAL
LIVE ON STAGE!
ARRIVING IN OUR GALAXY THIS FALL AT NEW YORK'S VARIETY ARTS THEATRE, 3RD AVE. & 14th ST.
TELECHARGE (212)239-6200

CONTINUED FROM PAGE 100

nomena by building computer models of them, rather than by studying the real biological organisms themselves. It attempted to re-create in some other medium the processes important to life and to study those processes in other mediums or in the abstract. Today I define artificial life as the study of artificially constructed systems that exhibit behaviors typically thought to be characteristic of real life.

Omni: Your focus is not the materials of life, but its basic structure?

Langton: The hardware of life is not really what life is all about. Biological things are wet and squishy, so we've come to associate life with wet and squishy stuff. But that's because we've seen life only in those materials. In fact, you can often separate the material from the behavior it exhibits and envision other materials that could exhibit that same behavior. What's important are the functional relationships between parts. I see no reason why you can't lift those relationships from the natural world and emulate them on a computer. You'd then have a realization of life in another kind of hardware.

Omni: What's the advantage of studying living processes in media such as computers?

Langton: Biologists would love to be able somehow to rewind the evolutionary tape back to certain initial conditions and run it again. You can do some of that with *Drosophila* [fruit flies] and *E. coli* [bacteria], but there's a lot you can't do. Simulations enable you to restart experiments from the exact initial conditions, changing just a single parameter and then seeing that parameter's effect on the resulting history. You could start off with the same exact situations but with different seeds in the random number generator, for example, to see the whole envelope of resulting histories.

Once you get genomes that pass on the information, mutations, recombinations, then you ask: What happens? The same thing? Or something different? Do you see punctuated equilibrium, long periods of stasis followed by brief periods of rapid change? Explosions of diversity followed by the filtering out of individual lines? Do you see extinctions? As people have gotten better and better at implementing these things, you see all that stuff.

Omni: So extinctions occur naturally, without the intervention of comets?

Langton: Right. Kristian Lindgren's little evolutionary models indicate it's plain as the nose on your face that you get extinctions. Clearly, the earth has been bombarded by big things having a huge effect, ruining the days of the local population. But most of the extinction record's structure is probably due to the natural dynamics of population evolution instead of externally imposed perturbations. This seems a natural feature of most evolving systems experimented with on computers. If we see extinctions in these simulations, it's natural to go on to ask, How much of the extinction record can we explain by natural evolutionary dynamics without invoking external catastrophes?

Omni: Is anyone in good mad-scientist fashion trying to create a living thing out of nonbiological components—in a petri dish, for example?

Langton: People at MIT recently constructed a chemical system in which molecules replicate by template synthesis, the way DNA replicates, only they weren't using DNA. This wasn't a computer simulation but was done in real "beakerware." They used certain kinds of adenosine triphosphate.

Gerald Joyce at Scripps Clinic Research Institute is trying to build what he calls an "RNA world" to address a fundamental problem about the origin of life. Current life depends upon a tightly coupled interaction between proteins, enzymes, RNA, and DNA. The tight coupling is that the DNA codes for protein synthesis, whose products themselves decode the DNA and mediate its replication. To get proteins you need DNA, but to get DNA you need proteins. How could this intricate interdependency have gotten started? The recent discovery by [Nobel laureate] Tom Cech that RNA molecules can function as enzymes points at one way out of the dilemma. Joyce is trying to construct a completely closed RNA world in which information-storing RNA molecules code for RNA enzymes, which in turn decode the information-storing RNA and mediate its replication. All without proteins. Another approach is to get the whole thing going in a strictly protein world. Some colleagues here at Los Alamos and at the Santa Fe Institute are working on that.

Omni: Would you regard these human-made chemical structures as alive?

Langton: There's no generally accepted definition of life. That's part of what we're trying to get at. The more of the phenomenology of life you're able to capture—in a computer or test tube—the more you're pushing into this gray area where it is hard to decide if they're alive. You know: Well, gee, they *look* kind of like life. Maybe they're not completely alive, but the only thing we have to compare them to is what evolved on this planet, this one example. We really need a class to see what's universal across that class and what's accidental in particular instances or members of that class. Any definition of life we might make based solely on our own experience of life on Earth will be too narrow.

Omni: But with a computer simulation you don't have a physical entity in front of you.

Langton: That's not such a big obstacle. It all depends on one's definition. Does your definition have any reference to physical properties or not? Scratch any biologist and he'll give you a list of things living entities ought to do: reproduce, metabolize, be a pattern in time and space, have complex organization, be capable of reproducing offspring that are slightly different and belong to an adapting and evolving lineage. In *The Growth of Biological Thought*, evolutionary biologist Ernst Mayr provides a classic list of properties that living things ought to have. But none are really tied to physical properties. It's all behaviors. Probably the biologist will say there's something else life has to do. He'll add something new to the list, make a qualification of how the entity has to go about these things. But we can make progress, even if we never generate something on the computer that biologists admit is alive, by forcing them to be more careful about what they mean when they say "life."

TIME TRAVELER™

The Only Simple and Effective Solution To Jet Lag

$189.95 Includes carrying case & instruction manual

Actual Size

You are not just flying around the world, you are traveling through time.

High speed travel across time zones radically alters your body's biological clock by either speeding it up or slowing it down, depending on whether you are traveling east or west. This phenomenon is called jet lag. First your body arrives at the destination, then your vitality arrives, hours, days or sometimes weeks later.

Now with the Time Traveler™ you can reset your biological clock as easily as resetting your watch by gently massaging specific acupressure points in a very precise sequence.

You don't need time to recover, you need the Time Traveler™.

Call
1-800-733-6433

Experience a new dimension in travel.

Omni: In principle, then, is it possible to have life inside a computer?
Langton: There's a strong and a weak claim about computer simulations of life. The claims are analogous to similar claims for artificial intelligence. The weak claim is that these are only computer models, tools to help you study real phenomena. The strong claim is that these processes can be more than simulations, that real intelligence and life could be embedded in the artificial material. The term *artificial* refers to the material, not to the life.

I believe the strong claim. To me material is irrelevant. Many different ways exist to realize any particular set of functions. Multiple realizability! This is the functionalist school of philosophy, either about intelligence or life. Some people argue: Life can't be independent of material. Look at enzymes. So many of their properties depend on the chemical interactions and properties of the atoms involved in specific chains. Yeah, sure, but there are plenty of other ways to get complicated structure–function relationships. Clearly you have to realize these functions in some sort of hardware, but the specific hardware is often irrelevant to the function itself. Because other materials also may be viable, computers could provide a sufficient material basis for life.
Omni: What arguments do those who deny the strong claim use?
Langton: A standard argument is that if you simulate a hurricane or thunderstorm on a computer, nobody gets wet. But they're missing an important point here. Simulations of something like wetness differ from those of something like life or intelligence in that wetness has very physical attributes. Wetness and liquidity are defined by physical properties, whereas life is not necessarily so defined.
Omni: Still, any example of a living entity is a physical thing.
Langton: Look, a computer is a physical thing, too. But a computer can exhibit a lot of behavioral properties, whereas as yet it can't exhibit a lot of physical properties. So certain physical attributes like viscosity will be hard to get on computers. I'm so much of a computationalist that I believe you can have real wetness in a computer. But you have to drop the specific physical attributes from your definition of wetness and define it solely in terms of behavioral properties. Tom Toffoli at MIT refers to certain classes of computers as "programmable matter." Some of my thesis research showed that this programmable matter can exhibit solid, liquid, and gaseous phases of behavior just like real materials. So hardware can act wet. It all depends on definition and how you interpret observations. For me the altered definitions are much more powerful and useful than the older, more restricted ones.
Omni: Has anyone ever come out and said, "This artificial life stuff is nonsense. You should do something else"?
Langton: Well, yeah. On one of those radio call-in shows a guy who purported to be a scientist said, "There's no such thing. This is just a bunch of scientists trying to promote their careers. You can't have life inside a computer. It's not really life, but a sort of pattern of energy and magnetic molecules on a disk in a memory somewhere."

And I said, "Throughout your life you constantly change the cells in your body, but there's some pattern in space and time that persists. Your actual physical media are pretty transient." He had some counter to that. He just couldn't buy the whole thing.
Omni: Is everyone in the field trying to create life?
Langton: No. Lots of people are not studying life, not trying to make something

alive when they're looking at an evolving population. They're studying evolution as a process. The term *artificial life* covers a lot of things that living things do.

Artificial life also covers the analogy between biological evolution and evolution of language and culture. In graduate school I had this epiphany—that words, sentences, and paragraphs were like genes. Language is like social DNA. The mechanisms by which language is transmitted, the basic mutations and recombinations of words and concepts, have analogs in biology. More broadly, social intercourse, whereby cultural information gets passed on from one generation to the next, does for cultural information what sexual intercourse does for biology. Social intercourse recombines cultural information packets, putting them in new contexts in slightly different ways.

Omni: People in artificial intelligence have made grandiose claims about producing human intelligence in ten years, and they've failed. Is there a lesson here for artificial life?

Langton: The problems in artificial intelligence proved harder than people initially thought. But the problem of life may be more solvable than the intelligence problem. We know a hell of a lot more about how cells work than how the brain works. We know next to nothing about how the brain works. I'm not claiming we'll have life within a computer within ten years. But this is mainly because we may not have a good definition of life in ten years, not because we'll be unable to do a fairly good job simulating the process of life on computers in ten years.

Omni: What are the possible dangers of creating artificial life? Could these things get out of the box and start eating up the biosphere, unleashing unspeakable horrors on humankind?

Langton: Some of these horrors are already being unleashed, and not by people working in artificial life. Computer viruses, for example, are one of the things existing out there closest to artificial life. In several instances, one computer virus has overridden another, generating a virus nobody really wrote. This was a combination of two viruses, both viable, that spread around targeting the same sector of your disk.

Computer network technology is close to the point where you've got a big distributed system with powerful information processors at every node with no central controller. These big nonlinear dynamic systems with spatial distribution have already thrown out examples of emergent phenomena where it's hard to figure out what's going on. Problems the Bell System had with some of their switching networks, where the whole system went down for several hours, may have been due to nonlinear interactions between switching stations. When they loaded in some new software, they had an emergent state come up that sort of locked out the whole system.

This is not a virus but an emergent property of the interactions of these programs talking to each other. The more you have autonomous decision makers that take in local data and make decisions affecting what other agents are doing, the more that medium is ripe for the emergence of complex, high-level phenomena. You can get all kinds of funny behaviors that crystallize out at the whole network level that were completely unintended and unanticipated by the program designers.

The same is true for stock-trading programs, buying and selling programs. The system is ripe for chaos. Each computer interacts via the market, and other computers are looking at the same database, making local decisions that affect the database too, but in a distributed rather than centralized fashion. This nonlinear dynamic system can in principle give rise to the spontaneous emergence of something with a lifelike dynamic.

So stuff is going to start happening out there. The only way we're going to be able to understand and control it, and not be swept under the rug by it in ways we don't understand, is to study it in these local, small-scale models.

Omni: Recombinant DNA research was constrained in the early days by guidelines designed to minimize possible dangers. Should the artificial life community do something like that?

Langton: The virus panel during our second workshop discussed the ethics and potential risks of working on these things. People working with computer viruses, self-reproducing programs, partial programs, program fragments, shouldn't turn them loose on the network. At the panel, Eugene Spafford [Purdue University] said people who create computer viruses and turn them loose on the network are the moral equivalents of those who'd dump a toxic biological virus into public drinking water. Some people don't yet realize it's a bad thing to do. These high-school hackers would never break into a hospital or take some AIDS virus and dump it into a reservoir. But they don't see that what they're getting their jollies with right now is in the same category. It will in principle have the same effect down the line. Anyway, I'm putting into the proceedings of the second work-

shop a list of things to avoid doing if you're working on computers

Omni: But some of the very same virus panelists *defended* the rights of computer viruses to exist. What do you make of that?

Langton: I just can't dismiss those claims out of hand. But I'm also not going to run right out and protect the rights of computer viruses. We all murder life every day, all the time. We cut the grass, swat flies, poison ants. I don't poison ants so much anymore, now that I have a better appreciation for ant colonies, but I'm trapping mice in my house right now—they're eating me out of house and home.

The closer life is to us, the more rights we give it. It's a very anthropocentric, chauvinistic view. Only if it's like us does it have a right to life; otherwise we get to decide individually whether it lives or dies. Seems to me most people will consider computer-based life as pretty far away from us. But it's worth addressing philosophically. What are the moral rights of a process versus a kind of material? If we had a simulated human being in a computer that otherwise behaved and acted like you or me, would it have a right to electricity? Could we pull the plug?

Omni: So then, aren't you artificial life guys playing God?

Langton: [Long pause] Well, yeah, in a way. I have to admit it. In fact, someone once said to me, "Congratulations. I'm keeping track of gods, and you have joined the club. You're an official god in the club of gods because you have created a universe—one that exhibits interesting behaviors." But what does that mean, "playing God"? You can in some sense call artificial life "experimental theology." If you create certain sorts of universes, there's no way in hell—if I can use the phrase—you could know in advance what's going to come out of that universe. Dave Ackley [Bellcore] found this out after he'd gotten a set of some pretty sophisticated critters to evolve in his evolutionary model. When he figured out what he thought the fittest ones were doing, he decided to engineer something even better. And when he stuck his new, "improved" genotypes in there, they immediately just got eaten up by the other ones. What he hadn't taken into account were the ecological interactions among the creatures.

It's difficult to overestimate the interrelationships of things that evolve in each other's presence. Subtle dependencies you weren't aware of are always there. This is why when you perturb any part of an ecological situation, it's difficult to predict the ultimate effect.

Omni: Do you ever worry that you're interfering with the natural order of things? Gaining forbidden knowledge?

Langton: What? This notion of artificial in the sense of made by humans instead of nature, is a funny concept. Why do we degrade things we make by calling them artificial, as opposed to natural? We're part of nature, and what we do is part of nature. But we're not blind watchmakers, we're seeing watchmakers. Nature is not to be held responsible because there is no conscious entity capable of foreseeing consequences. We, however, *are* responsible for consciously, actively taking care to be sure we understand the consequences of building these things.

Omni: Are you skeptical that evolution is the only mechanism to account for the complexity of humans and biological organisms in general?

Langton: I wouldn't say I'm skeptical.

> “If we had a simulated human being in a computer that otherwise behaved like you or me, would it have a right to electricity? Could we pull the plug?”

There's much to evolution we haven't understood yet. Evolution is such a powerful, simple theory, it's just got to be right. But one thing we're learning from nonlinear dynamics is that evolution did not have to discover, painstakingly, all the components of some complex organismic structure of behavior. Aggregates of things interacting in nonlinear ways make for a situation pregnant with emergent dynamic possibilities. Nature's just going to be tripping over these possibilities right and left.

Like a kid in a candy store, nature probably has had a surfeit of possibilities to choose from rather than a difficult time working this, that and the other things out. Evolution works with whole aggregates, large populations. Having variants on the plan—even identical things—in cooperation with each other generates zillions of different patterns of activity to select from.

Omni: When successful, will artificial life supplant natural life?

Langton: That depends on whether we decide to release living, evolving, autonomous machines with rights to existence into the biosphere. Right now to some extent we're populating the biosphere with all kinds of "unnatural" things: computers, robots, robot elevators, and trains. But trying to speculate about the future of artificial life is like trying to speculate about evolution. We'll design some initial things ourselves, but if artificial life really gets going, it's only logical to turn over the design process to evolution itself. Genuinely autonomous artificial life forms should have the capacity to evolve. And with that, they could give rise to intelligent, rational beings. They could give rise to us, implemented in a different hardware, or to *anything else*! I fully expect that they would.

Future life will probably involve symbiotic relationships between autonomous machinery, autonomous people, autonomous plants existing together in self-contained capsules. Analogs of the original protocells, these habitats will reproduce themselves as they spread through space.

Omni: The human-machine entity will be analogous to an individual cell?

Langton: Yes. That's how it happened in the past. Collections of molecules formed cells, a collection of cells formed more complicated cells, a collection of these more complicated cells formed multicellular organisms. When evolution takes a really big step, it's this jump from a collection of individuals at one level forming a single individual at the next level.

Omni: Let me ask again. What is the meaning of "artificial life"?

Langton: The larger meaning is that we can no longer point to ourselves and say, "We are alive, and those things aren't." Artificial life doesn't bring life down to the washing machine, the printing press, and car level. It doesn't degrade life; it upgrades machinery to our level. I now have a greater appreciation for the potential of machinery. I think machines can achieve the same state of this qualitative thing we call life. We can no longer consider ourselves special. Life is a property anything can have if it's organized correctly.

Omni: Why is there only one type of life on Earth, carbon-based life?

Langton: I'm not convinced it is the only kind of life. IBM, in some sense, is alive. Sociocultural institutions, in a way, constitute organisms in and of themselves. The conditions for life to emerge may be coming up all the time, all over the planet, but they just get eaten up by carbon-based life forms. That's the big advantage of being first on the scene. You get to wipe out the things that come after you. **DO**

LAST WORD

MYTHEMATICAL GAMES:

Greek philosophers and missing numbers supply the formula for fun

By Dave Jaffe

If you count the letters in Jaffe's name and multiply by 3.14, you will end up with the same name and a meaningless string of numbers.

Mathematical games are something like the story problems you struggled with in school The difference is that you can throw them in the garbage anytime without flunking algebra

Math teasers break down into two categories those that cannot be solved, and those that can be solved, but not by you Although hundreds of years old mathematical games are unique in that Aristotle did not invent them He was, however, the first scholar to list the answers upside down on the problems page

Here are several problems selected from an upcoming anthology of brainteasers *Mathematical Games That Could Not Be Solved by People Who Claim They Have High IQs!*

1 If John has three apples and Mary has two plums, what country is this?

2 Mr Cook, Mr Baker Mr Sailor, Mr Refrigerator Repairman and Mr Nuclear Power Plant Community Information Officer were in a boat fishing one day when Mr Cook noted that each of their names described the occupation of one of those present

"That's quite interesting," offered Mr Sailor, who preferred to be called Oscar Bateman "Gimme 'nother beer"

The man who called himself Mr Refrigerator Repairman chimed in "We gonna fish or talk?"

"Say, fellas what do you say we just pack it in and go bowling?" Mr Nuclear Power Plant Community Information Officer said nervously He knew that less than two miles upstream his employer was dumping deadly plutonium waste in the water creating a new breed of fish that lived on boat hulls and human blood

Mr Baker muttered under his breath He hated his companions and had agreed to the fishing expedition only because his wife had found out about the Darcy twins and the photographs and she was threatening to sing to the police unless he forked over 80 percent of the profits and put the house in her name

Which man is whom, who does what, where does he do it, and who cares? The really important questions are, Who are the Darcy twins where are those photographs, and why should Mrs Baker get most of the profits?

3 Achilles, the fleet-footed Greek hero was bragging to friends about his remarkable athletic prowess when Aristotle overhearing, challenged him to run a footrace with a tortoise The tortoise would start the race at a point half the distance to the finish line By the time Achilles reached that point the tortoise would have covered another half distance to the finish And so it would go, Aristotle smirked, with Achilles forever closing on the tortoise but never catching it

Achilles thought long and hard, then asked the philosopher "Uh what if I stabs it?"

"What?" asked Aristotle

"What if I stab the turtle?"

"You can't just stab it!"

"I got a sharp spear Cuts through turtle shell easy" the hero said "Whaddaya say?"

"It's a tortoise nectar head!"

Although the rest of this story is lost, mathematicians have long wondered, How could two such remarkable men have conversed so casually when one died more than 600 years before the other was born?

4 Numbers have always played an important part in mathematics Without them such fields as geometry never would have progressed beyond "Fun With Squares" Yet it's long been known that besides zero through nine there exists an extra digit wedged somewhere between six and seven Mathematicians have avoided using the mystery number because it is tricky to spell and has an embarrassing shape The lack of that number has caused quite a few anomalies in physics For instance, the mystery number can be used to prove that the sun is only about 150 yards from the earth and is the size of a Frisbee Use the mystery number to recalculate some "old wives" equations to prove that

a When you're traveling by car the close-up scenery really does pass by faster than the faraway scenery

b It's now 1847 and whipped cream cheese is not feasible ∞