Brave New Monkey

By creating the first genetically altered primate, scientists take one step closer to allowing parents to custom-order their child’s genetic traits

By SHARON BEGLEY

E’S A FRISKY LITTLE FELLOW, swinging from a ring in his doll-size white T-shirt with the black belt, clambering over and through an elaborate cat-scratching post, sucking his thumb and ducking for cover when playmates Sandy and Sammy ambush him. To all appearances, A.NDi (we’ll explain soon) is an ordinary rhesus monkey. But appearances deceive. Born by cesarean section last October, A.NDi is the first genetically altered primate ever created. If he were human, he’d be called a designer baby. And that makes him the embodiment of the greatest hopes as well as the worst nightmares here at the dawn of the age of genetics: that desirable genes will be inserted into human eggs, producing “genetically enhanced” children.

Although that was not the purpose of the research that produced A.NDi, the little guy with the soulful eyes is a landmark proof of concept. “At some point in the future,” admits Anthony Chan of the Oregon Regional Primate Research Center, who performed the manipulations that created A.NDi, “it is conceivable that others may attempt this technique to enhance humans.”

The researchers say they had no such goal in creating A.NDi. Instead, they hope to create primate models of human diseases, and they had to start simply. They first retrieved a well-studied gene, called the green fluorescent protein gene, from jellyfish. True to its name, the gene makes a protein that, in blue light, glows green. They then put copies of the gene into viruses, since (as anyone with the flu knows), viruses are adept at penetrating cells. Each virus dutifully carried the green gene into 224 rhesus-monkey eggs, where it slipped into the monkey genes like a foreign spy hiding in a crowd. The eggs were then fertilized through microinjection of sperm. After 126 of the fertilized eggs grew and divided beyond the four-cell stage, Chan selected what looked like the 40 best embryos and transferred them into 20 surrogate-mother monkeys. Five pregnancies resulted. One set of twins miscarried. One embryo failed to implant. Three monkeys were born. Sandy and Sammy show no sign of the green gene. But A.NDi does. Hence his name: short for “inserted DNA,” backward.

The next step is to give rhesus monkeys human genes that play a role in Alzheimer’s disease, cancer, hereditary blindness, schizophrenia, Parkinson’s or other scourges. A primate version of such a disease, scientists believe, should lead more quickly to vaccines or treatments than the mouse models that currently exist. In addition, genetically altered monkeys carrying a gene “for” Alzheimer’s or prostate cancer, say, might show whether the suspect gene always causes the disease, or whether environmental factors like diet or activity can cheat genetic destiny.

The researchers chose the green gene because its presence is so easy to detect, not because they wanted glow-in-the-dark monkeys. In fact, A.NDi looks nothing like a hairy green Lava lamp; the gene, although present in every tissue the Oregon scientists tested, seems to be dormant. Since A.NDi shows no sign of the trait that was supposedly engineered into him, viruses—which insert the foreign gene randomly—may not be the way to produce genetically altered animals. For genetic enhancement, and perhaps even for making a monkey model of a human disease, you have to get the gene to the spot in the chromosomes where it will be properly controlled.

Until A.NDi, genetic engineering had meant slipping a bit of healthy DNA into cells of a patient who is suffering from a genetic disease such as cystic fibrosis. A.NDi breaks that mold, bringing us a step closer to tinkering with an individual’s genetic endowment before birth, and with the genetic legacy of generations unborn. The Oregon scientists don’t know whether A.NDi’s sperm contains the green gene, and they won’t know for four years, when the little guy reaches sexual maturity. But if A.NDi’s sperm does carry the green gene, he will pass it on to all his offspring. And then the first genetically altered primate will claim another title: father to a genetically altered race.
Present at the Creation

Until now, genetic engineering has meant getting healthy genes into a few of a patient's cells. But ANDi was created in a way that should get a foreign gene into all his cells—and his descendants.

Although Oregon's Gerald Schatten is emphatic that "we don't support the extrapolation of this work to people for genetic enhancement," some regard that step as an act of medical humanitarianism. Engineering eggs so that a healthy gene replaces a disease-causing one should help both the child-to-be and his or her descendants, lifting a family curse of cancer, atherosclerosis, schizophrenia or another disease with a strong genetic component. "If you could prevent future generations from having grave genetic diseases, it would make the life of our species a little less terrible," says bioethicist Arthur Schafer of the University of Manitoba.

Even genetic enhancement for reasons that fall short of life and death has advocates. If parents want a tall, thin, hazel-eyed, athletic, brainy kid, whose business is it of anyone else's? Today's well-off parents hire tutors, music teachers, private sports coaches and SAT advisers for their children, if they can afford to. No one calls for banning SAT tutors in the interest of egalitarianism. "But genes are dif-
ferent," argues bioethicist Margaret Somerville of McGill University in Canada. The human genome—the collection of some 70,000 genes carried by every human—is "the patrimony of the entire species, held in trust for us by our ancestors and in trust by us for our descendants. It has taken millions of years to evolve: should we really be changing it in a generation or two?" And Schaler warns of new social divisions: in addition to haves and have-nots, we will have the gene-rich and the gene-poor.

At infertility clinics, couples are not clamoring to choose their would-be child's traits the way they choose options on a car. At least not yet. "Some request a particular gender, but no one has asked for a specific gene," says Dr. Paul Gindoff of the George Washington University in vitro fertilization clinic in Washington, D.C. "The traits that couples might care about—eye color, hair color, height, intelligence and personality—don't come from a single gene anyway, but from a complex combination. We are orders of magnitude away from being able to offer traits to order." The closest couples come to their own private eugenics is embryo selection, says Dr. Martin Keltz of St. Luke's-Roosevelt Hospital Center in Manhattan. In this process, clinics screen the embryos they create to determine whether any carries a deleterious gene that runs in either partner's family. If it does, that embryo is discarded; only healthy-seeming ones go into the woman's uterus. But if today's patients aren't asking for custom-made babies, tomorrow's might. When a March of Dimes poll asked people if they would "improve" their child's appearance or intelligence through genetic tinkering, 42 percent answered yes.

Whether society allows that will likely depend on what might be called the "ick" factor—a sense of repugnance at treating children as a product, at robbing life of its sacredness. Society emitted a collective "ick" at the first test-tube baby, the first surrogate mother, the first baby born to its biological grandmother. But "ick" tends to dissipate; more than 300,000 test-tube babies have been born. Science now has the power not merely to create, but to manipulate creation as never before. In a 1944 essay, novelist C. S. Lewis warned that "the final stage is come when Man by eugenics, by prenatal conditioning ... has obtained full control over himself." That day is now a little closer.
The achievements of modern science seem to contradict religion and undermine faith. But for a growing number of scientists, the same discoveries offer support for spirituality and hints of the very nature of God. By Sharon Begley

THE MORE DEEPLY SCIENTISTS SEE INTO THE SECRETS OF THE UNIVERSE, YOU'D EXPECT THE MORE GOD WOULD FADE AWAY FROM THEIR HEARTS AND MINDS. BUT THAT'S NOT HOW IT WENT FOR ALLAN SANDAGE. NOW SLIGHTLY STOOPED AND WHITE-HAIRED AT 72, SANDAGE HAS SPENT A PROFESSIONAL LIFETIME COAXING SECRETS OUT OF THE STARS. PEERING THROUGH TELESCOPES FROM CHILE TO CALIFORNIA IN THE HOPES OF SPYING NOTHING LESS THAN THE ORIGINS AND DESTINY OF THE UNIVERSE.

As much as any other 20th-century astronomer, Sandage actually figured it out: his observations of distant stars showed how fast the universe is expanding and how old it is (15 billion years or so). But through it all Sandage, who says he was “almost a practicing atheist as a boy,” was nagged by mysteries whose answers were not to be found in the glittering panoply of supernovas. Among them: why is there something rather than nothing? Sandage began to despair of answering such questions through reason alone, and so at 50, he willed himself to accept God.

“It was my science that drove me to the conclusion that the world is much more complicated than can be explained by science,” he says. “It is only through the supernatural that I can understand the mystery of existence.”

Something surprising is happening between those two old warhorses science and religion.

Historically, they have alternated between mutual support and bitter enmity. Although religious doctrine midwifed the birth of the experimental method centuries ago (following story), faith and reason soon parted ways. Galileo, Darwin and others whose research challenged church dogma were branded heretics, and the polite way to reconcile science and theology was to simply agree that each would keep to its own realm: science would ask and answer, empirical questions like “what” and “how”; religion would confront the spiritual, wondering “why.” But as science grew in authority and power beginning with the Enlightenment, this
detente broke down. Some of its greatest minds dismissed God as an unnecessary hypothesis, one they didn't need to explain how galaxies came to shine or how life grew so complex. Since the birth of the universe could now be explained by the laws of physics alone, the late astronomer and atheist Carl Sagan concluded, there was "nothing for a Creator to do," and every thinking person was therefore forced to admit "the absence of God." Today the scientific community so scorns religion have been like God, is for centuries the thought. After him, medieval scientists see their role as uncovering the divine plan.

Physicists have stumbled on signs that the cosmos is custom-made for life and consciousness. It turns out that if the constants of nature—unchanging numbers like the strength of gravity, the charge of an electron and the mass of a proton—were the tiniest bit different, then atoms would not hold together, stars would not burn and life would never have made an appearance. "When you realize that the laws of nature must be incredibly finely tuned to produce the universe we see," says John Polkinghorne, who had a distinguished career as a physicist at Cambridge University before becoming an Anglican priest in 1982, "that conspires to plant the idea that the universe did not just happen, but that there must be a purpose behind it."

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From Georgetown to Berkeley, theologians who embrace science, and scientists who cannot abide the spiritual emptiness of empiricism, are establishing institutes integrating the two. Books like "Science and Theology: The New Consonance" and "Belief in God in an Age of Science" are streaming off the presses. A June symposium on "Science and the Spiritual Quest," organized by Russell's CTNS, drew more than 320 paying attendees and 33 speakers, and a PBS documentary on science and faith will air this fall.

In 1977 Nobel physicist Steven Weinberg of the University of Texas sounded a famous note of despair: the more the universe has become comprehensible through cosmology, he wrote, the more it seems pointless. But now the very science that "killed" God is, in the eyes of believers, restoring faith.

Some clergy are no more tolerant of scientists. A fellow researcher and friend of Sandage's was told by a pastor, "Unless you accept and believe that the Earth and universe are only 6,000 years old [as a literal reading of the Bible implies], you cannot be a Christian." It is little wonder that people of faith resent science: by reducing the miracle of life to a series of biochemical reactions, by explaining Creation as a hiccup in space-time, science seems to undermine belief, render existence meaningless and rob the world of spiritual wonder.

But now "theology and science are entering into a new relationship," says physicist turned theologian Robert John Russell, who in 1981 founded the Center for Theology and the Natural Sciences at the Graduate Theological Union in Berkeley. Rather than undercutting faith and a sense of the spiritual, scientific discoveries are offering support for them, at least in the minds of people of faith. Big-bang cosmology, for instance, once read as leaving no room for a Creator, now implies to some scientists that there is a design and purpose behind the universe. Evolution, say some scientist-theologians, provides clues to the very nature of God. And chaos theory, which describes such mundane processes as the patterns of weather and the dripping of faucets, is being interpreted as opening a door for God to act in the world.

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who shared the 1964 Nobel Prize in Physics for discovering the principles of the laser, goes further: "Many have a feeling that somehow intelligence must have been involved in the laws of the universe."

Although the very rationality of science often feels like an enemy of the spiritual, here, too, a new reading can sustain rather than snuff out belief. Ever since Isaac Newton, science has shared a clear message: the world follows rules, rules that are fundamentally mathematical, rules that humans can figure out. Humans invent abstract mathematics, basically making it up out of their imaginations, yet math magically turns out to describe the world. Greek mathematicians divided the circumference of a circle by its diameter, for example, and got the number pi, 3.14159... Pi turns up in equations that describe subatomic particles, light and other quantities that have no obvious connections to circles. This points, says Polkinghorne, "to a very deep fact about the nature of the universe," namely, that our minds, which invent mathematics, conform to the reality of the cosmos. We are somehow tuned in to its truths.

Since pure thought can penetrate the universe's mysteries, "this seems to be telling us that something about human consciousness is harmonious with the mind of God," says Carl Feit, a cancer biologist at Yeshiva University in New York and Talmudic scholar.

To most worshipers, a sense of the divine as an unseen presence behind the visible world is all well and good, but what they really yearn for is a God who acts in the world. Some scientists see an opening for this sort of God at the level of quantum or subatomic events. In this spooky realm, the behavior of particles is unpredictable. Perhaps the most famous example, a radioactive element might have a half-life of, say, one hour. Half-life means that half of the atoms in a sample will decay in that time; half will not. But what if you have only a single atom? Then, in an hour, it has a 50-50 chance of decaying. And what if the experiment is arranged so that if the atom does decay, it releases poison gas? If you have a cat in the lab, will the cat be alive or dead after the hour is up? Physicists have discovered that there is no way to determine, even in principle, what the atom would do. Some theologian-scientists see that decision point—will the atom decay or not?—as one where God can act. "Quantum mechanics allows us to think of special divine action," says Russell. Even better, since few scientists abide miracles, God can act without violating the laws of physics.

An even newer science, chaos theory, describes phenomena like the weather and some chemical reactions whose exact outcomes cannot be predicted. It could be, says Polkinghorne, that God selects which possibility becomes reality. This divine action would not violate physical laws either.

Most scientists still park their faith, if they have it, at the laboratory door. But just as belief can find inspiration in science, so scientists can find inspiration in belief. Physicist Mehdi Golshani of Sharif University of Technology in Tehran, drawing from the Koran, believes that natural phenomena are "God's signs in the universe," and that studying them is almost a religious obligation. The Koran asks humans to "travel in the earth, then see how He initiated the creation." Research, Golshani says, "is a worship act, in that it reveals more of the wonders of God's creation." The same strain runs through Judaism. Carl Feit cites Mai-

1687 Isaac Newton's gravitational theory, published in the "Principia," completes the mechanistic vision of the cosmos. Newton leaves in a sliver of God—as the "first cause" of the universe.

1802 In "Research on the Organization of Living Bodies," the chevalier Lamarck posits an evolutionary view of animal species—contradicting the idea that God created them in immutable, constant form.

1842 Richard Owen determines that recently found fossils belong to an extinct animal group he calls dinosaurs. Some see further evidence of mutating species, others the effects of Noah's flood.

Charles Townes
PHYSICIST AND CHRISTIAN
He shared the 1964 Nobel Prize in Physics for discovering the principles that underlie the laser. "As a religious person, I strongly sense...the presence and actions of a creative being far beyond myself and yet always personal and close by," he says. Now at the University of California, Berkeley, Townes believes that recent discoveries in cosmology reveal "a universe that fits religious views"—specifically, that "something intelligence must have been involved in the laws of the universe."

William Stoeger
ASTRONOMER AND JESUIT PRIEST
Stoeger, who joined the Jesuits at 17, now teaches at the University of Arizona and is a member of the Vatican Observatory. "I did have one conflict between science and religion, in sixth or seventh grade," he says. "I got a book on paleontology from my uncle Don, so I read it only at night when no one else was around. This conflict [between evolution and Genesis] was wonderfully resolved in high school." Stoeger says, when a priest showed him that the Bible could be read metaphorically.
monides, "who said that the only pathway to achieve a love of God is by understanding the works of his hand, which is the natural universe. Knowing how the universe functions is crucial to a religious person because this is the world He created." Feit is hardly alone. According to a study released last year, 40 percent of American scientists believe in a personal God—not merely an ineffable power and presence in the world, but a deity to whom they can pray.

To Joel Primack, an astrophysicist at the University of California, Santa Cruz, "practicing science [even] has a spiritual goal"—namely, providing inspiration. It turns out, explains Primack, that the largest size imaginable, the entire universe, is 10 with 29 zeros after it (in centimeters). The smallest size describes the subatomic world, and is 10 with 24 zeros (and a decimal) in front of it. Humans are right in the middle. Does this return us to a privileged place? Primack doesn't know, but he describes this as a "soul-satisfying cosmology."

Although skeptical scientists grumble that science has no need of religion, forward-looking theologians think religion needs science. Religion "is incapable of making its moral claims persuasive or its spiritual comfort effective [unless] its cognitive claims" are credible, argues physicist-theologian Russell. Although upwards of 90 percent of Americans believe in a personal God, fewer believe in a God who parts seas, or creates species one by one. To make religions forged millennia ago relevant in an age of atoms and DNA, some theologians are "incorporating" knowledge gained from natural science into the formation of doctrinal beliefs," says Ted Peters of Pacific Lutheran Seminary. Otherwise, says astronomer and Jesuit priest William Stoeger, religion is in danger of being seen, by people even minimally acquainted with science, "as an anachronism."

Science cannot prove the existence of God, let alone spy him at the end of a telescope. But to some believers, learning about the universe offers clues about what God might be like. As W. Mark Richardson of the Center for Theology and the Natural Sciences says, "Science may not serve as an eye-witness of God the creator, but it can serve as a character witness." One place to get a glimpse of God's character, ironically, is in the workings of evolution. Arthur Peacocke, a biochemist who became a priest in the Church of England in 1971, has no quarrel with evolution. To the contrary, he finds it in signs of God's nature. He infers, from evolution, that God has chosen to limit his omnipotence and omniscience. In other words, it is the appearance of chance mutations, and the Darwinian laws of natural selection acting on this "variation," that bring about the diversity of life on Earth. This process suggests a divine humility, a God who acts selflessly for the good of creation, says theologian John Haught, who founded the Georgetown (University) Center for the Study of Science and Religion. He calls this a "humble retreat on God's part"; much as a loving parent lets a child be, and become, freely and without interference, so does God let creation make itself.

It would be an exaggeration to say that such sophisticated theological thinking is remaking religion at the level of the local parish, mosque or synagogue. But some of these ideas do resonate with ordinary worshipers and clergy. For Billy Crockett, president of Walking Angel Records in Dallas, the discoveries of quantum mechanics that he reads about in the paper reinforce his faith that "there is a lot of mystery in the nature of things." For other believers, an appreciation of science and the wonder of nature is "a God-given spiritual comfort."
deepens faith. "Science produces in me a tremendous awe," says Sister Mary White of the Benedictine Meditation Center in St. Paul, Minn. "Science and spirituality have a common quest, which is a quest for truth." And if science has not yet influenced religious thought and practice at the grass-roots level very much, just wait, says Ted Peters of CTNS. Much as feminism sneaked up on churches and is now shaping the liturgy, he predicts, "in 10 years science will be a major factor in how many ordinary religious people think."

Not everyone believes that's such a hot idea. "Science is a method, not a body of knowledge," says Michael Shermer, a director of the Skeptics Society, which debunks claims of the paranormal. "It can have nothing to say either way about whether there is a God. These are two such different things, it would be like using baseball stats to prove a point in football." Another red flag is that adherents of different faiths—like the Orthodox Jews, Anglicans, Quakers, Catholics and Muslims who spoke at the June conference in Berkeley—tend to find, in science, confirmation of what their particular religion has already taught them.

"Take the difficult Christian concept of Jesus as both fully divine and fully human. It turns out that this duality has a parallel in quantum physics. In the early years of this century, physicists discovered that entities thought of as particles, like electrons, can also act as waves. And light, considered a wave, can in some experiments act like a barrage of particles. The orthodox interpretation of this strange situation is that light is, simultaneously, wave and particle. Electrons are, simultaneously, waves and particles. Which aspect of light one sees, which face an electron turns to a human observer, varies with the circumstances. So, too, with Jesus, suggests physicist F. Russell Stannard of England's Open University. Jesus is not to be seen as really God in human guise, or as really human but acting divine, says Stannard: "He was fully both." Finding these parallels may make some people feel, says Polkinghorne, "that this is not just some deeply weird Christian idea."

Jews aren't likely to make the same leap. And someone who is not already a believer will not join the faithful because of quantum mechanics; conversely, someone in whom science raises no doubts about faith probably isn't even listening. But to people in the middle, for whom science raises questions about religion, these new concordances can deepen a faith already present. As Feit says, "I don't think that by studying science you will be forced to conclude that there must be a God. But if you have already found God, then you can say, from understanding science, 'Ah, I see what God has done in the world.'"

In one sense, science and religion will never be truly reconciled. Perhaps they shouldn't be. The default setting of science is eternal doubt; the core of religion is faith. Yet profoundly religious people and great scientists are both driven to understand the world. Once, science and religion were viewed as two fundamentally different, even antagonistic, ways of pursuing that quest, and science stood accused of smothering faith and killing God. Now, it may strengthen belief. And although it cannot prove God's existence, science might whisper to believers where to seek the divine.

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‘HOW THE HEAVENS GO’

Science and religion are supposed to be antagonists. History tells a more complicated story. BY KENNETH L. WOODWARD

That many contemporary scientists make room for God in their understanding of the cosmos should hardly be surprising. For most of history, religion and science have been siblings—feeding off and sparring with each other—rather than outright adversaries in the common human quest for understanding. Only in the West, and only after the French Enlightenment in the 18th century, did the votaries of science and religion drift into separate ideological camps. And only in the 19th century, after Darwin, was the supposed irreconcilability between “God” and “science” elevated to the status of cultural myth. History tells a different, more complicated story.

In the ancient world, religious myth invested nature and the cosmos with divine emanations and powers. But this celestial pantheism did not prevent sober observation of the heavens and sophisticated mathematical calculations. By 1400 B.C. the Chinese had established a solar year of 365 days. Ancient India formulated the decimal system. Ancient Greece bequeathed Euclidean geometry. Ptolemy’s map of the solar system and Aristotle’s classification of living organisms, which served biologists until Darwin.

But none of these advances seriously disrupted religion’s more comprehensive worldviews. Buddhists, for example, showed no interest in investigating nature since it was both impermanent and, at bottom, an illusion. Islam made great advances in algebra, geometry and optics, as well as philosophy. But Muslim scholars left the mysteries of physics—motion, causality, etc.—to the power of Allah and to the aphorisms of Aristotle, whose works they recovered and transmitted to the Christian West.

The Bible, of course, has its own creation myth, and it is that very story that eventually led scientists to realize that nature had to be discovered empirically and so fostered the development of science in the Christian West. The universe created by a rational God had to be rational and consistent—that much the Greeks already knew. But a universe created out of nothing, as Genesis described, also had to be contingent. In other words, it could have turned out other than it did. It was only one of an infinite number of possibilities open to a wholly transcendent deity. Gradually, scientists realized that the laws governing such a universe could not be deduced from pure thought—as Aristotle supposed—but instead needed to be discovered through experiment. Thus was experimental science nurtured by religious doctrine.

“For a long while, the scientific revolution did occur in Europe early in the 17th century, and researchers for the first time began to regard the world as a mechanism whose workings they could probe through the scientific method, its nature was God’s existence that was thrown out in doubt. Rather, it was Aristotle’s ‘sacred geography,’ in which Earth and the heavenly bodies were fixed and eternal. Relying on Aristotle, medieval Christianity had imagined a tidy geocentric universe in which nature served man and mankind served God. “In a certain sense, religion got burned for locking itself too deeply into a particular scientific view which was then discarded,” says Owen Gingerich, a professor of astronomy and the history of science at Harvard.

First Copernicus, then Galileo (aided by one of the first telescopes) and Kepler demonstrated with ever greater precision that the earth and other planets circled the sun. Humankind, it seemed, was peripheral to God and the universe. All three scientists, however, were devout Christians who defended their new worldview as most worthy of the Creator. But Copernicus and Kepler were denounced by Martin Luther for views he thought contradicted the Bible, and Galileo was tried and condemned to house arrest by the Roman Inquisition. Although Pope John Paul II declared in 1992 that the church had erred in condemning Galileo, the incident was never a simple conflict between science and religion. Galileo overstated the proof he could provide for a heliocentric (sun-centered) cosmos and incautiously caricatured the pope in a published tract. Yet he could also quote one of the pope’s own cardinals in his defense: “The intention of [the Bible] is to teach us how one goes to heaven, not how the heavens go.”

In subsequent centuries, however, scientific theories of “how the heavens go” increasingly determined the place and power of God. The “celestial mechanics” of Isaac Newton produced a god who designed a world machine and somehow sustained it in motion. Theologians readily accepted whatever proofs for God’s existence the new science chose to give. The result was a diminished “god of the gaps” inhabiting whatever dark corners science had not yet brought to rational light. In this way, says Jesuit theologian Michael Buckley of Boston College, theologians themselves cooperated in the advent of modern atheism by relying on science to explain God and ignoring “the traditional sources of religious insight and experience that make belief in God intelligible.” By the 18th century, astronomer Pierre Laplace could explain nature as a self-sufficient mechanism. As for God, he told Emperor Napoleon, “I have no need of that hypothesis.” Nor, a century later, did Darwin in his theory of evolution.

Now, at the end of the millennium, religion and science are beginning to talk, though neither answers to the other’s authority. Pope John Paul II consults with his Pontifical Academy of Science—most of whom are not Catholic. Philosophers of science examine the often-hidden assumptions on which scientific theories rest. Confronted by dimensions of the world no scripture has encoded, theologians are discovering a God who resists domestication into any single theory of how the world works. And at the center—still—are flawed and fragile human beings trying to understand a universe that has the uncomfortable feel of a home away from home.
WHAT MAKES US DIFFERENT?

What does it mean to be human? This question, and the attempt to find an answer, permeates and propels the important new book "Shadows of Forgotten Ancestors," by Carl Sagan and Ann Druyan, to be published tomorrow by Random House. Pulling together a vast body of scientific information to trace the origins and evolution of life on Earth, the authors address some of the fundamental questions of life itself. In this excerpt, they examine the behavior of other animals and measure it against human ability.

We humans are the dominant species on the planet. Why us? Of all the promising life-forms—implacable killers, professional escape artists, prolific replicators—why did one primate species, naked, puny and vulnerable, manage to subordinate all the rest and to make this world, and others, its domain? Why are we so different? Or are we?

Most of the philosophers conventionally adjudged great thought that humans are fundamentally different from the other animals—because of an immaterial "something," for which no scientific evidence has been produced, that resides somewhere in the bodies of humans but not in any other on Earth. Only a few argued, as Charles Darwin did, that the differences between our species and others are only differences of degree.

It is not enough that humans have a different assortment of the qualities evident in the other animals—more of some traits, fewer of others. A radical difference in kind, not some fuzzy-edged difference in degree, is needed, longed for, sought. The uniqueness of humans has been claimed on many grounds, but most often because of our tool-making, culture, language, reason and morality. We have them; the other animals don't, and—the argument goes—that's that.

Blasé, matter-of-fact, she carefully positions the hard-shelled fruit on the log and smashes it open—using a stone tool procured for the purpose. Hammer and anvil. No lightbulb goes off above her head. There's no chia to fist, no hint of insight struggling to emerge, no moment of revelation, no strains from Thus Spake Zarathustra. It's just another routine, humdrum thing that chimps do. Only humans, who know where tools can lead, find it remarkable.

Although many chimps literallv do not know enough to come out of the rain, they're able to use tools. Not only that—they're able to make tools and premeditate their use: A chimp breaks off a long grass stalk or a reed so she may use it later, hundreds of meters away, more than an hour in the future, to lure delectable termites out of a log or termite mound. She must remove superfluous leaves and twigs, shape it, shorten it, insert it into the termite tunnel with a deft twisting motion to follow the interior contours, shake it seductively to attract termites onto it, and then, with great care, remove it without scraping off too many. Chimps take years to perfect their technique and routinely teach it to their young, who are avid pupils.

How difficult is chimpanzee termite-fishing? What depths of intellect and manual dexterity are required? Suppose you were dropped naked into the Gombe National Park in Tanzania and, like it or not, discovered that termites are your principal hedge against malnutrition or starvation. You know they're an excellent source of protein; you know that self-respecting humans in many parts of the world regularly eat them. You manage to put aside whatever compunctions you may feel. But catching them one at a time is not going to be worth the effort. You're going to have to make a tool, repeatedly insert it into their meter-high mound, introduce the tool into your mouth, and strip off the clinging termites with your teeth and lips as you withdraw the tool from your mouth. Could you do as well as a chimp?

The anthropologist Geza Teleki tried to find out. He spent months in Gombe under the tutelage of a chimp named Leakey. Teleki found that, after months of intensive effort, he hadn't a clue to finding the entrances to the mounds that the termites wall up each evening and that the chimps effortlessly uncover in the morning. He couldn't select the best stalks, prepare them, or insert and withdraw them so termites would be clinging to them. He failed miserably. It's a little daunting to discover—on the very technological grounds on which human superiority is claimed—that, after months of apprenticeship, human scientists cannot do as well as preadolescent chimps.

While we associate culture with art, music, dance and literature, in its most general form it is a set of customs that some groups of people have and others don't.

And not just people. Scientists have witnessed the emergence of cultural norms in a kind of monkey called a macaque on Koshima, a small Japanese island. The natural food supply there had become inadequate, so if the monkeys were to survive, they had to be provisioned—with sweet potatoes and wheat dumped on the shore. As anyone knows who has ever been to a picnic at the beach, sand sticks to food and makes it unpleasantly gritty. In September 1953, a young female named Imo figured out that she could rinse the sand off her sweet potatoes by dunking them in a nearby brook. Very slowly, others copied her—a playmate, Imo's mother, Imo's brother, sister and niece, then other youngsters, then their mothers and, only after a long delay, the adult males. Three years later, Imo dropped a handful of mixed wheat and sand in the brook. The sand sank, the wheat floated; soggy, but ungritty, it could also be eaten. Others began copying her again.

COVER PHOTOGRAPH BY GWENDOLEN CATES

BY CARL SAGAN AND ANN DRUYAN
A bonobo types out a request on a keyboard of 256 abstract symbols. Apes seem much closer to humans in their abilities to use rudimentary language than had once been thought.
It has long been claimed that only humans make tools, use language, reason, have culture and morality. Not so, say the authors. Philosophers and scientists confidently offer up traits said to be uniquely human, and the monkeys and apes casually knock them down—toppling the pretension that humans constitute some sort of biological aristocracy among the beings of Earth. Instead, we are more like the nouveau riche—incompletely accommodated to our recent exalted state, insecure about who we are, and trying to put as much distance as possible between us and our humble origins. It’s as if our nearest relatives were a rebuke to the explanations and justifications we offer of our current dominion over the Earth. So, as counterweights to human arrogance and pride, it is good for us and our humble origins. It's our only edge. We live at a moment when our relationships to each other, and to all the other beings with whom we share this planet, are up for grabs. As we reconfigure our social structures—and, in the last few centuries, we've been tinkering with them like mad—in't it better and safer to have our best understanding of human nature firmly in mind? Our intelligence is imperfect, surely, and newly arisen; the ease with which it can be sweet-talked, overwhelmed or subverted by other hard-wired tendencies—sometimes themselves disguised as the cool light of reason—is worrisome. But if intelligence is our only edge, we must learn to use it better, to sharpen it, to understand its limitations and deficiencies—to use it as cats use stealth, as الحكومة use camouflage—to make it the tool of our survival. Isn't there much to be proud of in the lives of the monkeys and apes? Shouldn’t we be glad to acknowledge a connection with Leakey, or Imo, or Kanzi? Remember those macaques who would rather go hungry than profit from harming their fellows; mightn’t we have a more optimistic view of the human future if we were sure our ethics were up to their standards? And, viewed from this perspective, how shall we judge our treatment of monkeys and apes?

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