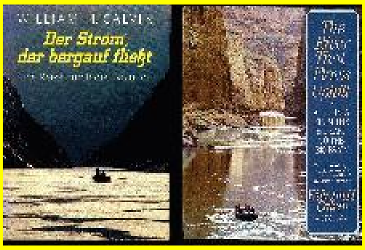

The River That Flows Uphill (Sierra Club Books 1987) is my river diary of a two-week whitewater trip through the bottom of the Grand Canyon, discussing everything from the Big Bang to the Big Brain. It became a bestseller in German translation in 1995.

AVAILABILITY limited; the US edition is now out of print. There are German and Dutch translations in print.

- ***http://www.amazon.com***
- **University Book Store** in Seattle stocks new hardcover copies.
- **Powell's Books** in Portland lists both new and used copies in their web database.
- Interloc, Bibliofind , and Advanced Book Exchange will locate used copies.
- All chapters webbed, with inline photographs and sound files from Leonard Thurman's *Grand Canyon River Running* web pages.

The River That Flows Uphill

A Journey from the Big Bang to the Big Brain

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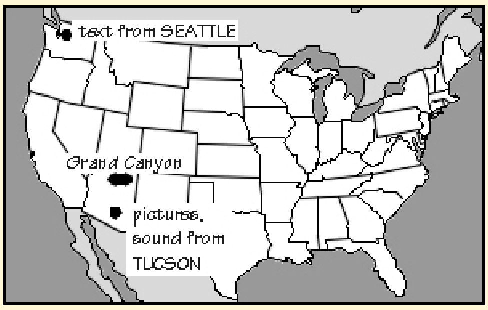
This is a *Deluxe edition* in an unusual sense: the photographs and sound files are from Leonard Thurman's Grand Canyon River Running web pages. What you get on your web browser is assembled, before your very eyes, using text delivered from Seattle (Washington State USA, near the Canadian border), and pictures and sound being sent from Tucson (Arizona USA, near the Mexican border).



DAY 6

[The late Arthur Koestler] radiated a rare passion for life, a deep merriment in the face of the unknown. He seemed to exemplify Nietzsche's insight that there is in men and women a motivation stronger even than love or hatred or fear. It is that of *being interested* -- in a body of knowledge, in a problem, in a hobby, in tomorrow's newspaper. Koestler was supremely interested.
.....the literary critic **GEORGE STEINER**

Happiness goes like the wind,
but what is interesting stays.
......the artist **GEORGIA O'KEEFFE**

Mile 93
Monument Creek

MONUMENT CAMP LOOKS DIFFERENT by morning light. We're still deep in the inner canyon, surrounded by schists veined with granite. Marsha came over as Rosalie and I were standing by the water's edge, sipping coffee. She held out her hand to Rosalie.

"See? All four colors. The gray worked, I used some wet stones that I found by the river this morning. And the chocolate ones are getting darker and darker."

"Been sleeping on them all night?", Rosalie smiled, then finished off the last of her coffee. She clipped the Sierra cup back onto her belt loop and picked up the beads to examine them.

"Do you have a sewing kit?", asked Marsha. "I need some heavy thread to string them on."

"No sewing kit, but I'll bet there is some heavy suture thread in my medicine bag," Rosalie said. "Let's go look."

"Are you a real doctor?", asked Marsha as Rosalie rummaged through a compact metal box holding an assortment of medical supplies. "I mean, not a professor like the others?"

"Both, I teach neurology. And I have even been known to sew up a wound -- ah, here's that heavy thread."

"Gee. That's thick," Marsha replied. "Just right for the necklace. You really sew up wounds with thread this thick?"

"Not usually. The last time I used any of that thread was when my suitcase was slashed open at the airport, by one of their mechanical baggage-handlers. So I sewed up the hole in the leather with the proper interrupted stitches that I learned during my training in the emergency room. I kept hoping that the leather would heal so that I could take out the stitches!"

Rosalie draped the thread around Marsha's neck. "Is this long enough for you?" Marsha opted for a longer length, and then they sat down to string the beads.

"Well, what protein can I create with these beads?", asked Marsha, laying them out on a flat rock.

"How about a nice short chain, maybe a string of five amino acids making a little peptide hormone?", answered Rosalie. "Do you know about enkephalin?"

"No. What does it do?"

"Reduces pain. It's one of those drugs that the brain manufactures for itself. Acts rather like morphine."

Rosalie thought for a few seconds, glancing out across the river at the sunlit wall of the Canyon. She turned and asked me, "How does that sequence of amino acids go? I seem to remember it as tyrosine, glycine, another glycine, phenylalanine, and finally leucine." I nodded and said that sounded familiar.

"That makes morphine?", Marsha asked me.

"No, but enkephalin is sometimes called the brain's own morphine," I replied. "Morphine might look just enough like enkephalin to impersonate it under some circumstances."

"That's neat. A real pain-killing necklace. So what beads do we use?"

"Well, first we have to specify tyrosine," said Rosalie. "The genetic code for that is -- well, there are two that mean tyrosine. Let's use UAU. So we need an unfinished one, an amber, and then another unfinished."

Marsha tied a knot in one end of the thread and started stringing the beads in the proper order. "There's the instruction for tyrosine."

"Next comes glycine. You can specify that with GGG, so three gray beads are needed in the RNA string to fasten a glycine molecule onto the chain." Rosalie sorted through the juniper nuts.

"Three gray beads, coming up," Rosalie said, passing them to Marsha.

"Great," Marsha said, "Just like what goes on in the cell nucleus."

"Not quite," Rosalie corrected. "The amino acid chain that is going to become the protein actually gets constructed outside the nucleus. The messenger RNA is a copy of the master set of instructions kept in the DNA within the nucleus. This RNA copy goes out into the cytoplasm. There, just like a tape being fed into a mechanical loom, it starts up the assembly of the amino-acid chain."

"Oh, I remember!" exclaimed Marsha. "We saw that funny film in class of the dancers acting out protein synthesis. The RNA triplets --

wearing balloons -- selecting the proper amino acid and then adding it to the growing protein string. Snake dancers!"

"I remember that film," laughed Rosalie. "With all the narration in the style of Lewis Carroll's Jabberwocky. What was it that the Bandersnatch did in the dance?"

I said that I thought the Bandersnatch danced the part of the enzyme that cut loose the new protein from the ribosome, when the stop code came along. It's something like the worker in the automobile plant who unhooks the car from the assembly line after it is finished.

"That's right! I remember!" Marsha was inspired to get up and imitate the Bandersnatch's dance, and eventually came swooping down on the necklace held by Rosalie, going "Snicker-snack, snicker-snack." We all collapsed laughing at the memory of the outrageously costumed dancers, gyring and gimballing in the wabe of RNA.

"So what's next?", Rosalie asked herself, rubbing her eyes. "Next is another glycine. Three more G's, so three more gray beads."

Marsha slid three more gray beads onto the string. Which was indeed beginning to look like a proper necklace. "Then phenylalanine, which is UUU. So here are three unfinished beads. And the last amino acid is leucine. Let's see, there are several different triplets that specify leucine. Let's use CUU. A chocolate, an unfinished, then another unfinished. There you have it. The instructions for making the brain's own morphine!"

Marsha held it up around her neck. "Do you suppose anyone'll guess what it is? I mean, they won't know that the unfinished ones mean U, the auburn ones mean A, and so on."

Rosalie pondered this, contemplating the necklace with a raised eyebrow. "I suppose that we could drop some hints. But that would be cheating." Rosalie kicked the rock at her foot, shaking the sand off her shoe. "I know! We can add the start and stop codons."

"You mean, those special three letter groups that mark the beginning and end of the code string for a protein?"

"That's right," Rosalie said. "But beware the frumious bandersnatch, my child! So we'll start the necklace with AUG, the start code. Then we'll have the fifteen beads coding for the five amino acids, then three more beads for the stop code. UAA is the stop triplet that I remember. That'll be a good hint. They'll see two auburn beads on the right end and another auburn one starting the string on the left side. Then maybe the unfinished ones will suggest U to them." Rosalie was looking pleased with herself. For Marsha, this was taking on the aspects of adventure, a secret mystery in the making.

Marsha was delighted as she strung an unfinished bead and two auburn ones onto the end. Then she undid the knot at the other end of the string and slid on an auburn-unfinished-gray sequence. "There are only twenty-one beads, total. That's really all it takes to tell the brain how to make morphine?"

"Well, if they were really the RNA bases, that's all it would take to tell a brain cell how to construct leucine enkephalin," answered Rosalie. "Simple, isn't it? There are even laboratory machines that can mimic the cell in constructing the chain. I mean, if you were to show that necklace to the people in the lab down the corridor from my office, they might be able to construct synthetic enkephalin from it. That's the code for it. And it was probably invented in evolution before these rocks were made," Rosalie gestured at the Redwall across the way.

I was sworn to secrecy. Piltdown revisited? One always wonders about the great Piltdown hoax, in which a whole generation of anthropologists was misled because someone placed an artificially aged human skull, together with part of an ape jaw, right where it could be found in an English gravel pit in 1915. Was it an elaborate practical joke that got out of hand, or was it a fraud, done with malice aforethought? But this is a river trip, I remembered, and surely they'll think of practical jokes before anything else.

WHILE WE WERE STANDING AROUND waiting for the final packing to be done, several people noticed Marsha's necklace and promptly nicknamed her the "Indian Princess." Were the nuts substitutes for a string of pearls, she was asked? No, she teased, who would want to wear a collection of oyster kidney-stones? Some of the laughter was, I thought, a little strained. When asked how she drilled the holes, she explained all about what she called the "holy" virtues of juniper nuts.

And, having everyone's attention, she also explained that she'd copied the pattern for the necklace directly from a real Anasazi necklace at the Mesa Verde museum. And threw in a few facts about Aztec record-keeping. Did anyone know what this pattern meant?

GRANITE RAPID turned out to be a real washing machine. If any one rapid had to be selected as the "Boat Wash," this would be it. Granite works just like the agitator in a washing machine --first we were met by a big lateral wave from the left, then another from the right overlapping it, then another from the left to slap down atop the previous one. Something like shuffling a deck of cards. When we emerged from Granite, we felt as though we'd been to the laundry. J.B., thirsty as usual after a rapid, discovered that his big coffee cup had been left full of water. He sipped it with gusto and said, "Thank you, Granite."

Mile 95
Hermit Rapid

HERMIT is certainly one of the longest rapids we've ever seen, stretching out over several city blocks. We are viewing it from upstream, at our scouting spot on the left shore. When an ordinary amount of water is flowing down the river, Hermit is a long roller-coaster of swells, a series of giant standing waves, sometimes one-and-a-half stories from peak to trough. It is relatively predictable as rapids go. There is even a quiet route through it -- just stick to the left side of the river. But no one wants to miss riding the roller-coaster on the right. The boats are to go through in two groups, the first group getting to photograph the second group and vice versa. Most rapids aren't suitable for such "photo runs"; the only other such rapid, we hear, will be Lava Falls, a week down the river from here. Lava is a 10; after yesterday's string of heavies, I don't want to even think about it. But Hermit looks like sheer fun, even if rated a 9.

I am riding with Jimmy Hendrick today, trading stories with him about other parts of the world. He too spent some time in Jerusalem, working as a security guard at United Nations headquarters there after a stint in the Marines, before knocking around Africa, before training as a paramedic, and then as a boatman. Jimmy is an amazing young man, one of the most natural athletes I have ever seen, though I have no idea what his favorite sport might be -- but sports are only artificial outlets for the kinesthetic skills. Being a Grand Canyon boatman is a more natural outlet, more akin to the activities of our ancestors, whose successes shaped our skills.

All of the boatmen are perfectly at home in the outdoors -- all natural guides, well-suited to their rowing and hiking lifestyles. Many have been teachers or graduate students, and they are all learned as well as passionate ecologists. But Jimmy, who is redheaded and modest in stature compared to handsome giants like Alan and Sandy, does everything with not only energy and confidence but often with grace as well. It reminds me of watching a ballet star making effortless leaps and spins, convincing one that gravity encumbers only ordinary mortals. It is hard to imagine Jimmy in an office job or cooped up in a library or laboratory, rather than in graceful motion. In addition to his fund of knowledge about the world, he is passionate about the Grand Canyon, knowledgeable about the ancient Anasazi, acute in his judgments of western politicians and water politics. I hate to imagine a world without varied outlets for people like Jimmy; he's a reminder to us that exceptionally talented people are found everywhere, not merely among those who choose to pursue advanced degrees or high salaries in the city canyons or suburban strips.

We row back upriver a little, just to get positioned on the far side of the river channel, since the entrance to the roller-coaster is to the right. Jimmy likes to stand up on the seat as the boat approaches the lip of the pond, just before being washed into the waves. Planning his moves, he sits down after his last-minute fix and then strokes us into the fastest moving water. We are carried up to the top of the first swell.

In a roller-coaster, the passengers tend to rise up out of their seats as the top is crested. We don't travel that fast. Yet just before we reach the top, while the boat is still nose-up by 30 degrees, Jimmy rises up out of his seat, hops atop it, and catches a quick look ahead over the bow, at the previously hidden downslope. And manages a quick stroke on the left oar as he sits back down again. We again are carried along the fastest of the currents, speeding downhill at a steep angle. It looks as if it would be easy to miss the path, to be carried around the side of the next swell. But we climb up it, dead in the center of the ridge of current, Jimmy rising up again as we start to crest, ascending to his full height atop the seat, then stroking us downhill. Again and again we rise and fall. These are steep hills, and out of the corner of my eye I see the photographers on the left bank catching us at dramatic angles. Each crest sees Jimmy, perfectly coordinated and full of grace, carrying the boat through the very top of the wave. It is like seeing someone make love to a rapid.

Eventually we swing toward the right bank. Well trained by now, I automatically reach for a bailing bucket. Then I realize that there is no water in the bilges. Indeed, we scarcely got splashed. All of the water is below the tops of the waves, and we rode the tops.

THE RIGHT BANK is getting the morning sun, and we warm up quickly while waiting for the second group of boats to get their act together. Passengers from the first two boats have scattered along the rocky shore, hiking back upstream from where we put ashore below the rapid, trying to find the best vantage points from which to photograph the various standing waves. I join the laziest group, the one which figures that the penultimate wave is as good as the first for dramatic pictures.

Seeing that my camera has only a few shots left on its roll of film, and not wanting to have to change film in the midst of the run, I snap a few portraits of my distinguished companions. Gone are the attempts at sartorial elegance of our first day on the river. We are now all windblown and achieving a well-worn look. Like a pair of jeans which has been through the wash numerous times, we too have gained character. We fit better.

As I change the film, I hear the first mention of Howard's father since yesterday. "If," Barbara asks, "there is a place in the brain for reading, is there also one for writing?" And, Ben jokes, for spelling? Several people agree that they must have lost that part somewhere along the way.

Strangely enough, while there are several sites for reading surrounding the visual part of the brain in the rear of the head, there is no one place for writing. Writing may be disrupted, of course, but only as part of numerous other symptoms. When you do see a writing-but-not-reading disturbance, it is usually from poisoning of some sort -- carbon monoxide, for example -- causing widespread damage to the left brain, out in the periphery (the "watershed") of the middle cerebral arterial tree.

No spelling area has yet been found -- spelling is probably one of those skills which requires wide areas of the brain working together as a committee, not just one group of neighboring nerve cells. It's likely that the committee can limp along without a few of its usual members, so that less-than-massive strokes seldom eliminate the function.

Indeed, I asked, why should the brain have a reading area at all? Writing has only been around for 5,000 years, since the Sumerians, and surely a reading area hasn't evolved in that short a time. Now a special area for recognizing faces, that would make some evolutionary sense. Our prehuman ancestors may not have needed to read, but they certainly needed to recognize one another from rock-throwing distance to tell friend from foe.

This prompted Rosalie to tell a tale about a stroke patient who couldn't recognize his own wife. At least, not by sight; once she said something, though, he could tell who it was that had entered the room. Indeed, he could recognize her by her footsteps. He wasn't blind; he could look at yearbook portraits and match up twins. It was just remembering particular faces that gave him trouble. So is there really a special area for facial recognition or memory in the brain? The strokes that damage this ability are mostly in the rear of the brain, along its undersurface, but they aren't very discrete -- they're usually associated with a lot of damage to the visual association areas and the underlying white matter. You'd expect a lot of other problems too from such widespread damage, and indeed, many of these patients have blind regions and color-vision problems.

Perhaps faces are just one application for the specialized neural machinery for recognition, and the specialization is more general than that. Indeed, that seems to be the case with the patient who cannot recognize his wife. They tested him on cars. While he can pick out different makes and models, try to get the face patient to pick out a picture of his automobile from a collection of pictures of very similar automobiles, and he'll have trouble doing that too. Recognizing one particular face, from among the memories of many faces, or recognizing one particular automobile using its distinctive dents or embellishments, suggests that the visual area destroyed by the stroke has something to do with recognizing unique individuals among populations of similar items. These stroke victims seem to have trouble recognizing and resolving the near-identical in their memories. Some would say that these strokes destroy the area where the detailed long-term memories of faces (and cars) are stored.

> ...to study Metaphysics, as they have always been studied, appears to me like puzzling at astronomy without mechanics [physics] -- Experience shows that the problem of the mind cannot be solved by attacking the citadel itself. ....**CHARLES DARWIN**, the N notebook, 1838

A FEW READING-DISTURBANCE-ONLY PATIENTS cannot even tell the different letters from one another. Not even a "T" from an "I". But it is now possible to say how normal people probably do it. There are some nerve cells in the rear of the human brain that become specialists in recognizing vertical lines, and others in horizontal lines. There is probably a committee of cells, including representatives from both the horizontal and vertical specialist groups, that works together to identify a "T". And another committee, some of whose members probably also belong to the "T" committee, likely specializes in "L". We may not yet understand how the brain distinguishes words such as "now" from "how," but we're starting to get the letters down.

We have gotten that far rather recently in the history of science, in about one generation of neurophysiologists. Indeed, it was Keffer Hartline, the father of Dan and Peter (and Fred, a biophysicist who is not along on this trip), who first realized in 1938 that individual nerve cells in the visual pathways were specialists in contrasting light and dark. They're most involved when something changes, either a light patch becoming dark or vice versa. For a cell to show sustained interest in what's going on, there may have to be a dark area adjacent to a light area (this spatial contrast aspect was later discovered by Stephen Kuffler). Contrast in time, or contrast in space: without one or the other, a cell may pay little attention to the visual world.

The eye is not like a television camera, faithfully registering the light intensity in each cell of the retinal mosaic of rods and cones (the nerve cells that act as "photo cells"). There are a hundred times more photosensitive cells in each eye than there are lines leading back to the brain in the optic nerve: the information has to get funneled down. Keffer Hartline and his followers showed that cells did this by playing off one group of photosensitive cells against a neighboring group, so that messages were sent only when the neighbors were seeing something different from what the first group was seeing. For example, a small white spot of light caused a report to be sent back to the brain, but a bigger spot, which also illuminated the neighbors, would cause a different message to be sent. Indeed, sometimes, no message was sent at all.

This work led to the realization that a cell could be attuned to some particular configuration of light. Frogs weren't interested in the difference between "T" and "I," but they were sure interested in moving black spots on light backgrounds -- such as an insect to eat. The lines back to the brain weren't carrying a television-like report for some viewer back in the brain -- they were carrying reports which, in effect, said "delicious fly at three o'clock."

"You mean that my eyes don't tell my brain about everything they see?", asked Abby.

"That's right," I answered. "They censor things. And rearrange things."

"But how do I know what's really happening out there?"

"Isn't your eye part of you?"

Abby was impatient. "Oh, you know what I mean. That's just a piece of machinery like a camera. How come it censors things? Why don't I know about everything that comes into it?"

Brian is also puzzled. "And how do you keep from seeing everything upside-down? I mean, the lens projects the image of the sky onto the bottom of the eye, the ground onto the top. Where are things turned back right-side up?"

The little person inside the head. A philosophical problem that bedevils our thinking about the brain, and about ourselves. It's a point of view. Literally. No matter how much of the optic and neural apparatus is explained, we keep thinking that the "real me" is somewhere deeper inside, viewing the sensory inputs just like a person watching television.

"But there is no one place in the brain where an executive sits, receiving reports and issuing orders," I attempt to answer. "The real me is a little bit of everywhere in there. It's a committee of nerve cells."

Rosalie attempts to rescue me. "It's like asking exactly where this rapid is located. Sure there is the approach, when you pass the lip of the pond upstream and enter, just like there is a boundary between the outside world and the surface of the eye. But the rapid goes on for a long time -- although damned if I can tell you, looking down that river, where the rapid stops. It's spread out along the river. And the little person inside the head is spread out too, all through the brain. From the sense organs leading into the brain, to the muscles on the pathway leading out."

Abby was not convinced. "But I have a single sense of myself -- a unity of consciousness, if you will. I can focus my attention from listening to you to watching the rapid, from fantasizing Lava Falls to recalling the eclipse. It doesn't all happen at once, out of control. Your committee description of the brain sounds like a Tower of Babel."

I concede the inadequacy of the metaphor. "But in the brain business, we try to stand before we walk, walk before we run. Or dance. To understand the neural machinery that operates the legs, we don't start out by trying to explain dancers or gymnasts or Jimmy -- we start with what keeps you standing up straight when your knees start to buckle. For reading, we don't start with a sentence, or even a word or letter. We start with simple patterns of light and dark like the little dots that make up an Impressionist painting or a newspaper illustration's halftone, and build our way upward. So far, we're about to the level of understanding where we can make an educated guess about how the brain handles one letter."

The first boat of the second group now appears at the top of Hermit and claims our attention. It slips over the edge of the pond and into the swirl that leads to the first standing wave. The boatman has it just right, with the boat in the center of the wave, and they crest the wave riding high. Now they head downhill at a steep angle. Up again, with the boatman trying to see over the crest, picking his way down the center of the channel so as to soar over the very tops. Down again, up again. It is a kind of music.

WHILE WAITING for the boats to get underway again, Abby admired Marsha's necklace and asked how to make one for herself. Marsha gave her 21 juniper nuts, some of which were the leftover beads from the first necklace. The pattern of beads began to replicate itself.

We soon passed through Boucher Rapid, a 6. It is named for Louis Boucher, a turn-of-the-century prospector who did a little mining down here. He also had a grove of 75 fruit trees just up the side canyon. And a garden where he grew tomatoes year-around. He even built some little cabins for tourists hardy enough to hike down and back. It wouldn't be surprising if the Anasazi had farmed that side canyon too, though they probably stuck to beans, corn, and squash. We pulled in to stop briefly on the beach below, to deliver some supplies to a team of researchers working there, studying the bighorn sheep.

BALONEY BOATS are giant rafts the length of a truck, with two outrigger tubes looking rather like big sticks of baloney. The tubes are lashed together, forming a center platform on which up to twenty passengers ride among the freezer chests. They are propelled by a whining outboard motor, and we usually hear one coming up behind us long before we see it. We now hear that distinctive announcement, back up the canyon. Purists, we have come to resent motors. I irrationally consider the baloney boats roughly on a par with the F-15 fighter jet that illegally buzzed us yesterday in the inner gorge. I have since heard that it was probably one of the jet jockeys from the Air Force base outside Phoenix, which trains foreign pilots as part of our massive arms sales abroad.

It is not only incongruous to be suddenly buzzed by a high-performance jet when you're floating quietly down the river, it is doubly incongruous when buzzed by a joyriding Middle Eastern fighter pilot in the bottom of Arizona's deepest canyon. And now we're about to be buzzed instead by a floating All-American beer-drinking party. Grrr. I think that I'm a little irritable today, maybe worried about Crystal Rapid up ahead (which some boatmen say is more of a real worry than Lava Falls).

Soon two of the baloney boats approach us. It is only mid-morning, but nearly every passenger on board has a beer in hand. Which they raise in greeting to us. We wave politely, empty-handed. Little is said. Their party looks to have been in progress for days. I cannot imagine them hiking up side canyons. The baloney boats grind past, the Doppler shift of the motor's whine dropping its pitch to announce they've taken the lead. The gasoline exhaust forms a leaden haze atop their wake, and the headwind blows it back toward us. Smog seems the final insult.

We naturally feel superior. The us-and-them psychology of groups being what it is, they probably think themselves superior to us too. I think that our boatmen are used to seeing some "oar jingoism" develop, for they assure us that the motor boatmen are really nice guys who run good trips, even if they're not privileged to row such fine small boats. Into this headwind.

We are not convinced, already nationalistic to the core without even being a nation. If we can become so us-and-them in just six days, one can imagine how hard real tribalism and nationalism will be to eliminate. Finally, perhaps fifteen minutes after the baloney boats first whined into sight, they disappear around a downriver bend. Quiet again, thanks to entrenched meanders. We begin to notice the bird songs once more. But the mood of Hermit is gone.

The baloney boats seldom stop to scout rapids. They just plow right on through, their length and weight serving to span holes and flatten out waves. While we take two weeks to cover 225 miles, they may spend only three to six days on the river. In the late 1970s, the Park Service proposed to phase them out, restoring the Colorado to oar-powered boats only. But the plan got shelved by a new government in power, whose Secretary of the Interior boated down the river for several days and then had himself helicoptered out. The river trip was, pronounced James Watt, "boring." Conservationists, kept busy trying to keep Reagan and Watt from selling off the remaining wilderness, had no time to speculate about what might happen if Watt had tried to improve the river tour, to make it a little snappier and keep it moving right along. His tastes in water transport probably ran to hovercraft, but he never got around to doing more than reprieving the baloney boats. And letting the river tour companies markedly expand the number of boats in the Canyon at any one time (that's obviously "good for business").

We resolve to change the topic of discussion. Back to brains.

THERE ARE TWO DIFFERENT CAMPS of brain researchers, too, though not quite as different as our group and that particular motor-trip party. There are the top-down types and the bottom-up types and we all get along fairly well together.

In a top-down approach, one starts with something general, like reading. Or recognizing faces. A neurologist studies a stroke patient and discovers that his problem is a failure to match up the face he sees with a face stored in his long-term memory, rather than merely an inability to spot yearbook portraits of twins, which only involves short-term memory mechanisms. Dissecting this further with clever tests, the neurologist discovers that the patient has a problem distinguishing between long-term memories within the same broad classification, not merely familiar faces but familiar cars or other high-order forms of ambiguity. This is an example of top-down in science, working from the general to the particular.

Bottom-up is another way to approach the visual part of the brain. Here we first attempt to understand the building blocks, then the architecture created by them. Cells, then circuits of cells such as reflexes, then brains. The followers of Keffer Hartline (he got the Nobel Prize in Physiology in 1967 for his discoveries) have, in the last quarter century, discovered many varieties of the building blocks. And they have followed the architecture up through more than a half-dozen stages in the brain's analysis of the images focused on the back of the eyes.

The two approaches should meet in the middle someday, when enough stages have been uncovered at each end. Then we will get a picture from start to finish of how the brain recognizes a face as an old friend, of the many stages through which the upside-down image from the eye must pass before "eureka" or "familiar friend" is triggered. Then we should be able give a more adequate description of the "committees" of nerve cells that carry out each task along the chain, of how the shape of a friend's face is stored in memory, of what "eureka" consists in neural terms.

The key concept in the bottom-up approach to vision consists of describing the world from the viewpoint of a single nerve cell, as if you were inside the nerve cell and seeing only what its inputs provided it with. In fact, you're only seeing the net sum of its inputs, not the individual entries. Whenever you get confused, remember that essential viewpoint.

If it's a photosensitive cell like the rods and cones of the eyes, then you've got to shine a light on the cell via the optics of the eye. Shining light on other photoreceptor cells doesn't (usually) matter. But for the other nerve cells in the long chain leading back into the brain, the view is via other nerve cells: all a neuron back in the brain "sees" is what some other neurons tell it. Dan Hartline points out that a brain cell is like a general getting telephone reports of a battle that he does not personally observe.

Some of the inputs counteract others, just as withdrawals counteract deposits in determining the balance of your savings account. It's all a matter of balance between push and pull. As you gaze upon a newspaper halftone (which, like those Impressionist paintings known as Pointillist, is comprised of lots of little dots), some of those dots are providing positive inputs to the cell, while other dots are producing negative inputs via inhibitory synapses. The balance in the cell is not measured in dollars but in volts: the nerve cell is a little computer, keeping a tally of what hundreds (sometimes thousands) of inputs tell it, using voltages about a hundred times smaller than those in our flashlights.

For any one nerve cell, you can make a map of the halftone dots which cause positive inputs to this one cell, marking down a little "+" at each such dot, and marking down a "-" for a dot from which the cell evidently gets a negative input. Most dots in the picture don't affect the cell at all. But there will be a little cluster of "+" and "-" symbols. In some cases, it will be a circular cluster of "+" signs but with the very center of the cluster all having "-" signs instead. Something like a donut.

Now take away the newspaper halftone, so that the eye is staring up into the cloudless sky instead. Light falls evenly on the cluster of photoreceptors, some of which were connected to this cell to yield pluses, some minuses. The cell may give no response to the even illumination of this cluster: the "-" area in the center may contribute a negative input that cancels out the positive input from the periphery of the cluster. Despite all the input, the cell does nothing, sending no message to other cells further back in the brain. But let a fly come along, a black spot on the light background. The photoreceptor mosaic is no longer uniformly illuminated anymore. If that fly is imaged onto the center of the cluster that leads back to this cell, all the negative inputs to the cell disappear. Only the positive ones are left, and the cell goes wild, crying the neural equivalent of "Fly! FLY!"

The cluster of "+" and "-" inputs predicted how this one cell would respond to a natural input: it said that this cell ought to be pretty good at detecting a fly if its image were centered on the cluster. It is as if the cell constituted the neural template for a fly, always silently sitting there observing the world and getting excited only if a fly happened by. Neurophysiologists tend to call these templates "receptive fields": they are really just descriptions of what a particular cell likes, of what turns it on. And different cells like different things, simply because they are wired up to the retinal mosaic of rods and cones in some other way. To call a cell a "fly-detector" because it responds well to the fly can, however, be misleading as the cell doesn't correspond to an Aristotelian category; it's more analogous to what the mathematicians call a "fuzzy set". Such a cell also responds to other objects that almost look like flies, even to part of the letter "T" if it were imaged to include the cell's cluster.

And a map isn't a complete description of what the cell likes, because the cell is sensitive to time sequences as well as spatial contrast. Moving a light spot from the "-" area to the "+" area, for example, is usually the most effective stimulus for a cell, producing a much greater response than merely turning on the stimulus to the "+" area *de novo*. This means that moving stimuli, such as a fly flying along, get preference over stationary stimuli: they're literally "seen" more intensely. Most cells have some version of this movement preference property and there are analogous phenomena at many levels of the nervous system. So the functioning of the cell depends on both a map and a motion -- in a sense, it serves as a search template for them. I'd hate to attempt Aristotelian logic with such fuzzy elements, but that's the brain's way.

Shapes more complex than flies are analyzed by the brain using combinations of the donuts. The donut shape of the search templates favored by retinal cells is rearranged by the time the cerebral cortex goes to work at analyzing the image. A cortical cell looks at what a series of cells are doing "upstream" from it. And the ones it chooses to examine give rise to a new type of favorite input. Rather than favoring small dots with dissimilar neighbors, the cortical cell favors lines and edges. Just as one can construct a black line with a series of black dots, so the cortical cell seems to have inputs whose template centers just happen to lie along an imaginary line in space. And so instead of a "black fly detector," the cortical cell becomes a "black line detector."

Unlike dots, lines have orientations. Some cortical cells specialize in vertical lines, others in horizontal lines. And for every angle in between, there will be some cortical cell that likes it better than other degrees of tilt.

Granted, the black line may have to be in just the right place -- if it is moved sideways a little, the cell may not like it any more. But another cell will. And so among the millions of cells in the visual cortex, there are specialists in all sorts of lines in all sorts of places. The image of the world, projected camera-like onto the back of the eye, has been taken apart during its transmission through about six cells in the chain that leads from the eye's photoreceptor mosaic back to the visual cortex. It has been taken apart into lines and into edges between regions of different brightness or color.

And what happens next? Does the next cell in the chain look at several such line-loving templates and specialize in the letter "X" or "T"? Well, that may happen somewhere down the line but the next stage is not that specialized. At the next stage, a so-called "complex cell" will like lines or edges of a certain tilt -- but they can be anywhere within a somewhat bigger region of space. Move the line sideways a little, and the complex cell will still respond to it (whereas the just-described "simple cells" won't). And so the restriction on exact location has been relaxed somewhat. Yet change the tilt just a little and the cell will become uninterested in the line. Thus, the principle of this next stage of image analysis seems to be position generalization.

Next? Probably line length -- there are "hypercomplex" cells interested in lines only if they are of a certain length and tilt, though they are not particularly fussy about the line's exact location. But it gets hard to talk about stages, because this network of nerve cells isn't a chain. It's really a web, where a cell may look at what many inputs -- not all from the same earlier "stage" of analysis -- are doing. Still, one can see how a nerve cell might come to specialize in a "T" but not an "I". Whether there is, in fact, a "T" detector cell isn't yet known. Personally, I'd bet that T's are detected by a committee of cells -- that the committee has abilities that no one committee member alone has. Color sensation, for example, is probably coded by no one cell but by a committee of cells that compares the signals from three different types of receptors in the retina; it is the relative size of those three signals which tells us the hue, but color sensation may not correspond to the actions of any one specialist cell or cell group. (Taste works the same way in all likelihood, for all but the most basic sensations such as salt and sweet). Emergent properties again --hue emerges from the merger, and doesn't have a separate existence.

Perhaps three "stages" of analysis occur within the so-called primary visual cortex, a region at the rear of the brain that is easily defined by its twice-the-usual packing density of cells (one layer of tightly-packed cells forms a stripe easily seen without a microscope, hence the name "striate cortex"). If there is a "T" detector cell type, or one specializing in the image of your grandmother's face, it certainly isn't in that primary visual cortex.

But there are a series of secondary visual centers, some surrounding this primary one, others further forward in the brain, near the centers for hearing and language. At last count, there were over a dozen such secondary centers. Some specialize in depth perception, in telling us how far away something is located. Some do rather fancy jobs. There is the one that I mentioned earlier, just above the right ear of most people, which specializes in looking at a person's face and analyzing whether it looks happy, sad, mad, surprised, disgusted, and so on.

The wonder of it all is that we can see so much, things for which evolution did not prepare us. Such as reading books. Neurobiologists didn't really appreciate this until about 1959, when four MIT neurophysiologists published a paper entitled "What the Frog's Eye Tells the Frog's Brain." It turned out that the nerve cells going back to the brain carried few signals at all when the frog was merely looking at a stationary scene. No TV-like picture was being transmitted back to its brain, from which it could have reconstructed a scene such as we see. Even the frog's favorite food, a fly, caused no signal -- unless it was moving. But if a moving fly did happen by, then all sorts of nerve cells got interested. In fact, the frog evidently couldn't even see the fly unless it was moving. A high school teacher later noted that she knew that all along, since frogs in captivity won't eat dead flies placed on the floor of their cage. She invented a merry-go-round, with dead flies (or little meat balls) dangling from the ends of black threads and twirling around -- that the frogs then snapped up.

> Curious, I took a pencil from my pocket and touched a strand of the [spider] web. Immediately there was a response. The web, plucked by its menacing occupant, begin to vibrate until it was a blur. Anything that had brushed claw or wing against that amazing snare would be thoroughly entrapped. As the vibrations slowed, I could see the owner fingering her guidelines for signs of struggle. A pencil point was an intrusion into this universe for which no precedent existed. Spider was circumscribed by spider ideas; its universe was spider universe. All outside was irrational, extraneous, at best raw material for spider. As I proceeded on my way along the gully, like a vast impossible shadow, I realized that in the world of spider I did not exist. ......the anthropologist **LOREN EISELEY**

THE BRAIN'S CELLS not only individually have map-like sensory templates of the outside world, but there is another map which arises because of the way the cells are located in the brain itself. Cells that individually seem to specialize in the same patch of the visual world also tend to cluster together within the cerebral cortex. And the same mapping principle holds for other sensory surfaces as well, such as the surface of the skin.

"This is the little-man-in-the-brain map?", asked Barbara, "where the arm region is next to the hand region, which is next to the face, and so on?"

"That's it, all right. Except that the amount of brain devoted to each body part tends to be proportional to the number of nerve cells coming from that region -- there's as much space devoted to your thumb as to your whole arm," I replied, "but that's because the thumb is so richly endowed with sensory nerve cells."

"The face is next to the thumb?" asked Ben. "Is that what Barbara said?"

"It sure is -- if you listen in on the electrical activity of a nerve cell in the thumb region of the brain, you'll find that it takes notice when a small region of the thumb is touched. And no other place will stir it up. But then move toward the ear just a fraction of a millimeter, and listen in to a nerve cell there. You'll find the cell will only respond to a region of the face," I added. "Move a little further to the side, and you'll listen in on cells that will only respond to the tongue, or the larynx. It's called the sensory strip."

"It comes this way in a newborn baby, or does the baby's experience cause it to arrange itself that way?", asked Barbara. "Nature, or nurture?"

"Both. It comes that way at birth in monkeys, but the standard map can also be later rearranged by experience. Suppose the monkey loses one finger as an adult? The patch of brain representing that finger doesn't just sit there inactive for the rest of the monkey's life. Within a day that inactive patch of brain will start specializing in the adjacent fingers."

Rosalie remarked, "We're always telling stroke patients that the brain recovers after damage -- that they usually get better, recover some of the functions that they are initially missing -- but what happens to one of those big maps of the body surface if it's damaged?"

"At least in monkeys, it rearranges itself within days. Kill the nerve cells specializing in the thumb, and pretty soon the rest of the finger map will have rearranged itself to devote less space to each finger, while still representing all five fingers. The brain map seems to be constantly changing, though just a little. In some brain areas it may be quite rigid after infancy -- such as the primary visual map, for example -- but in others it may be in a constant state of remapping. Dynamic mapping, even when you're an adult. That may be why some areas recover better than others after a stroke, for example."

"Whoa," requested Ben. "What do you mean, the map's always changing?"

"Well, one day the neurophysiologists tested hundreds of cells and found out where the boundary between the thumb and the face was located -- the region of the brain where "thumb" cells had neighbors on one side which weren't interested in the hand at all -- these neighbors were more interested in some region of the face. They photographed the little surface blood vessels in the area so they could locate this patch of brain again with great accuracy. Then, a week or two later, they went back in and recorded from another few hundred cells and once again located the thumb-face boundary. It had moved. Not much -- less than a millimeter, but it sure looked as if there were cells that had been thumb cells several weeks before and had changed in the meantime to become face cells."

"But what had they done to cause that to happen?", asked Barbara.

"Nothing, so far as they knew. The animal had just been playing in its cage. It sure makes me think that the face and hand are always competing for space in the brain, and that the truce line moves around from week to week."

"Suppose the whole hand region is killed off by the stroke?"

"Well, there's always one of the secondary maps. Last time I counted, there were six complete body maps of the skin surface in the monkey cerebral cortex."

"Are they backups, like the various backup systems for lowering the landing gear in an airplane if the main hydraulics fail?", asked Ben.

"I doubt it. I suspect they're all working, all the time. In tandem."

"Are there extra visual maps too?", asked Barbara.

"Yes, those were the first duplicate maps discovered, in fact, back about 1942. But now there are more than a dozen complete maps of the visual world, and that's in monkeys again -- who knows how many we have?"

A second map of the body musculature was discovered long ago -- it's forward of the motor strip; since it was smaller, it became the "supplementary motor area." Additional motor maps have now been found. For hearing, there is a brain map of the tonal scale; indeed, four such maps. I haven't heard of any orderly maps for smell or taste but, if one is found, I confidently predict a few duplicates will also be located.

Duplicating a sensory map must surely be one of the easier tasks of brain construction, something like making a second casting of a bronze statue once you've got the first one done. The first time, though, is harder: it takes a lot of self-organization to wire up the cortex in such a way that neighboring areas on the retina remain neighbors in the cortex. Imagine you had to move the flashcard section from one side of the football stadium to the other, each person having to pass single-file through a narrow corridor. Getting them reseated so that neighbors are still neighbors might be a little tricky, especially if there weren't seats with numbers on them. The brain's "developmental manager" has solved that problem, not by an efficient clipboard-holding traffic cop but by self-organization principles that make natural neighbors congregate.

Furthermore, the wiring patterns leading up to the cerebral cortex produce the ability to detect line orientation and to compare the left eye's image with the right eye's. There is a standard way of doing all of this wiring, called a hypercolumn; it's like one square in a patchwork quilt. Within this small patch of the visual world, both eyes and all possible orientation angles are represented. In the brain, one hypercolumn occupies the space beneath a 1x2 mm patch of brain surface. In monkey brains, the whole primary map (the "quilt") is created by simply repeating the genetic instructions for wiring up a hypercolumn over and over, up to about 400 times, until the whole visual map is constructed.

Making an extra whole map is only a little extra work. Just let branches of the nerve cells go to another area and organize themselves according to the same set of genetic instructions. So the second map is just a repeat, like making a second casting of a work of art. What, however, is the advantage of an extra complete map? Let alone a dozen? Sheer numbers is one possibility, particularly in the case of the primary visual cortex where the cells are already packed in twice as tightly as is usual for cortex. To get more cells to operate on the same region of visual space, it may have been easier to simply duplicate the map elsewhere and then coordinate things. There are circumstances in which having two cells do the same job and pooling their results can be useful for improving precision and reducing uncertainty.

But I expect that the big advantage of duplicated maps lies in the ability to have the new one eventually specialize in something slightly different from the original. So-called "Visual 4," the fourth map of the visual world discovered in monkeys, has cells duplicating most of the properties of those in "Visual 1", the primary map -- but many of the "Visual 4" cells exhibit slight changes which make it easier to detect how far away an object is located from you. In "Visual 4," the further specializations are for depth perception or for color discrimination. It looks as if "visual 1" was duplicated, but that "visual 4" then proceeded to diversify a little.

Is the principle here duplication, then followed by diversification? Repeated 12 to 20 times? And that's only in monkeys -- no one knows how many maps a human has.

DUPLICATION, THEN DIVERSIFICATION may also be a principle at the level of genes. Duplication of DNA itself is, of course, something that DNA does very well, very reliably. That is, after all, how cells divide -- by first duplicating the chromosomes which contain the stored DNA strands, then pinching in the cell membrane between the two sets, and then separating into two cells -- the original photocopy machine. Both halves of the chromosome pair are duplicated. That's mitosis, the process used in almost every organ of the body to make new cells.

In the sex cells of testis and ovary, another step follows, which pares down a cell to a half-set of chromosomes, 46 chromosomes down to 23 in the case of humans. Thus when a sperm and ovum unite, the offspring winds up with the standard set, but roughly half from each parent. The production of that half-standard sex cell is called meiosis; it has an interesting twist, in that your two matching chromosomes (one from each parent) are first shuffled before separating, a process called "crossing over" which insures that the offspring winds up with some combination of its grandparents' genes, not just either its grandfather's or its grandmother's.

Some strange things can happen during crossing over; some DNA strands may, for example, be broken at inopportune places. A strand may be replaced upside-down so that it reads like nonsense when the cell goes to use it as an instruction for assembling a protein. Sometimes the two half-standard sex cells produced by meiosis do not wind up with an equal split of the DNA (analogous to the deck of cards not being split evenly), one getting more than the other. Indeed, some DNA sequences may wind up being kept in duplicate so that, once fertilization occurs, the paired chromosome now has three copies of a particular gene rather than two.

Missing information may well prove fatal to the zygote, and many zygotes are probably spontaneously aborted at an early stage of development and never seen. But an extra set of some genes may prove useful (though an extra whole chromosome is often unfortunate; in Down's syndrome, for example, there are three rather than two copies of chromosome 21). Whatever the mechanism for the duplication, the chromosomes seem to have a lot of DNA sequences which are virtual duplicates of others.

"But what are the duplicate genes used for," asked Abby. "Backup copies, in case there's a mutation in the original?"

"Maybe, but genes have proofreading mechanisms that correct simple errors. Another case of nature inventing it before the computer designers," I explained.

Ben brightened. "Perhaps they're just for playing around with? When a computer programmer wants to make some improvements in a program that's already operating, the first step is to make a duplicate. Then you make your modifications in the copy, and save the original."

"And, of course, the modified program usually doesn't work at first. So it's a good thing you kept an unmodified copy," smiled Cam. "It's only after I've fiddled around with it for awhile that the new version works at all. Much less working better than the original."

"So duplicated genes, however they might arise, would be handy for evolving a new improved version of a living thing," Rosalie said. "And there are sure a lot of near-duplicates of genes in the cell nucleus, strings of DNA which are almost like the ones that make the proteins, but not exactly the same."

"Of course, if the changes are made randomly, with no intelligent programmer masterminding the modifications, you'd expect that a lot of the DNA sequences would be nonsense, simply nonfunctional," I added. "Nothing but junk."

"So that's what is called junk DNA?", asked Abby. "Or is it garbage DNA, I forget?"

"Someone once called it garbage DNA, but the more appropriate name is junk. After all, garbage can be thrown away. Junk is the stuff that you never manage to get rid of," Rosalie said, laughing.

"So why can't the cell get rid of the DNA that isn't useful? Wouldn't natural selection eliminate it?", asked Abby.

"No, not if it wasn't actively harmful," I said. "It's a lot easier to photocopy a whole notebook, for example, than it is to sort through all the pages and make individual decisions about what's worth saving. And the cell probably doesn't have the intelligence to make such decisions anyway. And just duplicating is so easy -- at least for a cell."

So evolution at the gene level may well involve extra copies of genes, kept off-line in the genome, where they don't do any harm if they're a little crazy, with diversification arising when accumulated modifications of some genes happen to provide a better-than-original version. Duplication, then diversification. The expression of such a modified duplicate gene (when, for example, the regular gene was damaged beyond repair) might even have caused a cortical map to duplicate.

It is now suspiciously quiet on the river. Ever since Boucher, we have been in "Crystal Reservoir." We are approaching Crystal Rapid, considered the most unpredictable and dangerous rapid on the river by many boatmen. An angry young rapid that thrashes around.

Mile 99
Crystal Rapid

BEFORE 1966, Crystal was a minor rapid. Then there was a storm which dumped 350 millimeters (14 inches) of rain on the North Rim within a 36-hour period. Three-story-tall walls of water came roaring down both Crystal and Bright Angel creeks. The sound alone must have shaken loose rock fragments from the nearby cliffs. That massive a flash flood is capable of moving house-sized boulders. Many lesser boulders were carried all the way into the river channel, creating a new Crystal Rapid overnight. Big Ponderosa pines, which grow only on the North Rim, are seen in the debris, testifying to the origins of the flood waters as well as to their force.

I'm reminded of the river below Phantom Ranch, in the mile from Bright Angel Creek to the talus slope where we deposited Howard, where it's very rough and splashy, unpredictable from one minute to the next. That too is from the 1966 flood. Crystal is similarly unpredictable, but on a much larger, more threatening scale. In the space of a city block, the river drops nearly two stories -- that's how much water is dammed up by the new boulders. Its rating of 9-10 depends on how "big" the water is, boatmanese for how much water is being released from Lake Powell every second. The holes of white water where the river pours over a big boulder -- which can trap and overturn boats -- keep changing around as I watch them, waves cresting and crashing, then building again. Every so often, one will grow larger as the river current shifts a little. I watched a hole in mid-channel briefly expand to include the right channel as well, as the wave feeding in to it built up and then crashed down.

The boatmen huddled and appraised Crystal from our upstream vantage point. One catches the mood of a rapid, and this is no Hermit.

Crystal Rapid at Mile 99, from **Leonard Thurman**'s Grand Canyon River Running web pages.

Flash floods do something this spectacular every few centuries, somewhere along the Colorado, thanks to the steep gradient of many side canyons. Some twelfth-century Anasazi ruins were destroyed by the 1966 flood, showing how long it had been since this area experienced a flood of that magnitude. But most rapids aren't such bad actors as Crystal is -- they've had time to be smoothed out a little. Over the centuries, the predamnation river's Spring floods pushed around the new loads of boulders, rearranging them into stable positions in the river, sorting them by size as the small ones were carried farther downriver than the big ones. Now, without the flushing action of the natural floods, the managed river will eventually turn into a series of waterfalls as the rapids fill up -- provided, of course, that Lake Powell doesn't fill up with silt first, which dam critics say will happen within several centuries.

So spring floods are a thing of the past: that's what many said prior to 1983. They assumed that the people who run the Colorado River dams knew what they were doing, were competent to manage the lake levels and release rates during the spring snowmelt. But the dam managers' promises and their performances are two different matters. Early in 1983 they promised to limit peak releases to about 900 cubic meters (31,500 cubic feet) per second; that's double a typical release. In June 1983 they admit to having released 2,600 cubic meters every second (92,000 cfs); at one time, the Bureau of Reclamation (known hereabouts as "BuRec") reported 3,000 (108,000 cfs) to the Park Service, so the boatmen suspect revisionism.

This flooding was not done intentionally for old-times sake, to mimic a predamnation spring runoff. It happened because BuRec mismanaged the dams so badly that Lake Powell overflowed in a big way. And the dam managers nearly destroyed Glen Canyon Dam itself, quite without any help from the Monkey Wrench Gang (see Edward Abbey's 1976 novel of the same name).

There had, of course, been a lot of snow in the Rockies that winter; the National Weather Service predicted that two winters' worth of water would be coming down the river that spring, and they were quite accurate. But to watch the performance of the dam people, you'd never have known it wasn't an average year. Beginning in May, the river people were getting worried because Lake Powell was pretty full; the dam managers were still hoarding every drop of water, turning down the river flow at night when they couldn't sell the electrical power. Surely, the boatmen thought, if they intend to open up those big spillways and flood the river, they wouldn't keep hoarding water at night, which only makes their situation worse.

But the damn dam's controllers practice a form of logic that few can recognize. So there was little warning when they finally flip-flopped and the flood came roaring down the river, all that extra water that should have been released gradually over the nights and days of the preceding months. Here at Crystal, three of the giant baloney boats capsized (those inflatable tour buses weigh four tons each and are normally regarded as unflippable). One person died; dozens were hurt. Some passengers bobbed along in their life jackets for eight miles, being carried through seven other major rapids before reaching shore. Helicopters evacuated 140 people in the aftermath.

The problem, of course, was that a rapid melt of an oversized snowpack filled up Lake Powell behind Glen Canyon Dam. That should have presented no problem: the managers are supposed to release a lot of water during the winter to make room for any flooding in the spring. Anyone knows that -- one learns it as a child, to let water out of the bathtub before rinsing off with the shower.

But it had taken 17 years to finally fill Lake Powell to its designed maximum (a matter of some embarrassment to the dam-builders, as they'd predicted it would fill up much more quickly), and the water managers were reluctant to draw down the lake during the early spring as a precaution, even when presented with the measurements of the giant snowpack waiting to melt up there in the Rockies. The room they left was only one-fourth of what they needed -- not just a slight underestimate, but a major screwup. I can remember Subie saying, in 1980, that something like this was sure to happen, given BuRec's attitudes about keeping Lake Powell close to full. This suspicion was widely shared among professional boatmen. They were right.

And so the dam managers caused a disaster: for the boaters, who got surprised in midtrip by water much higher than "allowable" and by helicopters dropping messages of worse to come. And it was a disaster for the river ecology, as the river forever lost sandy beaches with their wildlife habitats (unlike the predamnation spring floods, the upriver sand will not be replaced, since the dam traps any new upstream sand and keeps it from entering the Grand Canyon). It was also a major disaster for the people downstream in Arizona, California, and Mexico, whose supposedly safe farms and towns were flooded out.

The managers even caused $50 million in damage to the dams they were supposed to be managing. Indeed, they almost lost Glen Canyon Dam, things were so serious at one point. When they finally opened up the two giant spillways to cause the "Fool's Flood of 1983", the four-story-high tunnels, poorly designed in the first place, were damaged by all the water that came thundering through. The thick concrete walls broke apart in places, and the torrent of water tore into the sandstone cliff between the spillway and the adjacent dam. A three-story-deep hole was dug in the cliff under one section of the west spillway. The huge stream of water arching out into the river turned red, the color of the Navajo Sandstone comprising the canyon wall. To some, it looked as if the dam was bleeding to death.

The bleeding cliffs. The dam managers got even more worried when house-sized boulders of sandstone started flushing out into the river. I should think that they'd have been "sweating blood" themselves. Does civil service protect the job of a bureaucrat who destroys a dam?

For a while it looked as if they were going to have to shut down the spillways to prevent the cliff from being torn apart. The cliff, of course, forms the edge of the dam, that concrete plug which keeps all of Lake Powell from washing down the river. The cliff could also have collapsed from all the vibration, dropping sandstone into the spillway and plugging up the river's new path.

The managers were not very happy about this prospect. They now had a new, urgent reason to reduce the water released. But there was no room left in the reservoir because they had foolishly left themselves no safety margin: the gates on the spillways were as high as they would go. So they added 2.4-meter (8-foot) panels of plywood atop them, raising the lake to new record heights, all the way up to within a meter of spilling over the top of the dam itself. And creating a magnificent 50-story-high waterfall.

A little more sunshine up on the Rockies and they'd have had the second disaster scenario: the waterfall washing away the powerhouse at the bottom of the dam. It wasn't built to withstand the force of the Colorado River falling on it from a height of 50 stories. And so in two different ways, they almost lost a dam -- what would have been the biggest, if not the most spectacular, dam failure of all times.

WHAT CAUSES THE DAM MANAGERS to disregard elementary precautions such as safety margins? First, there is the western states' fear of drought -- "saving" water behind the dam (where a goodly percentage evaporates anyway) is easier than conserving water by modern irrigation practices. Then there is the petty bickering between the states over the water that caused the Glen Canyon Dam to be needlessly built in the first place. Phillip Fradkin's book *A River No More* tells the sad story.

Even the resort uses of Lake Powell create pressure, since commercial interests like Del Webb Corporation (the major concessionaire at Lake Powell, who runs the hotels and marinas) have advertised the lake as a resort lake rather than a working reservoir. The promoters cringe when paying guests have to traipse over mud flats littered with tattered styrofoam and shredded plastic bags (from their previous paying guests) in order to get to the boat dock or a "beach." And so Del Webb et al want the dam managers to keep the lake full, with no unsightly bathtub ring. The resort operators aren't local residents who remember the predamnation Glen Canyon; hotel and transportation conglomerates run the Park Service concessions in this region (small businesses are not "in" these days); the hotel manager is likely to be an imported management trainee with his eyes set on the big time. Del Webb makes Lake Powell an exception to the rule, but don't cheer yet: besides its expertise in casino gambling, Del Webb is a giant land developer in the Southwest; having any developer run Lake Powell always reminds me of the tradition of putting the fox in charge of the hen house.

Finally, there is peaking power, the cause of the daily tides on the river downstream from the dam. Dams are better suited to handling the peak loads of midday, because they can be turned on and off more rapidly than coal-fired power plants such as the nearby Navajo Power Plant which pollutes the clean air of the Grand Canyon; furthermore, the government can sell that peak-hour electricity for four times as much as the electricity produced in the middle of the night. And so the dam people are moving, without first researching the legally-mandated environmental impact statement (EIS), to using the dam so as to create daily floods on the river, closing it down at night (they can't dry up the river entirely since the dam leaks too much; there are even small waterfalls down its western seam with the canyon wall). They are spending many millions of the taxpayers' dollars to rewind the eight big generators at Glen Canyon Dam's powerhouse, so as to better operate under peak power conditions; this is the equivalent of a developer saying "we'll get around to doing an EIS -- after it's built."

When one visits the dam's visitor center, not only are there no exhibits showing the beauty of the drowned Glen Canyon (see Eliot Porter's book *The Place No One Knew*) but the BuRec is a little selective about recent history as well -- one gets no sense of the bungling and near catastrophe of 1983, which a few newspaper clippings of the time would have nicely illustrated. There are engineering pictures of the spillway damage and the contractor's efforts to repair them -- but to read their accompanying messages, one would think that the heavy snowfall the winter before was the sole cause of the problem. The commissioner of BuRec, a Las Vegas politician, also tried to blame the computers. There was nothing mentioned about insufficient safety margins, a matter very much under BuRec's control.

Now how would you react to a child practicing brinkmanship in the bathtub, who explained that the bathtub overflowed because someone else turned on the shower too hard? Plug? What plug? Who, me? People of that mentality are running the dams on this river, controlling the plug in the drain. It is not reassuring to us river-runners, nor to the people living downriver. So much for the wisdom of the Bureau of Reclamation. A Congressional subcommittee held oversight hearings a few months afterward but, since the western water politicians were as much to blame as the dam managers, they were very low-key and dwindled off into praise of BuRec for preventing a worse disaster. For something that was the Three Mile Island of the water power industry, the Fool's Flood has been strangely hushed up.

And if you think the BuRec learned anything from 1983, you'll be interested to know that in 1984 they again allowed the lake level to creep up above "full" while both spillways were inoperable, as workmen in them repaired the previous year's damage -- and then proceeded to shut down half of the "river outlets" in use (the junior-sized versions of the spillways) to keep the overfull lake level from dropping. Safety margins seem not to be part of their vocabulary, suggesting that legislation is needed to establish simple rules for these gamblers to follow, so that the dollars from power generation will not become their sole monomaniacal focus.

Did this bungling imitation of a predamnation spring flood tame Crystal Rapid a bit by rearranging the boulders? They're rearranged some, but there's still that nasty rock bar at top right which pushes you left, and still that series of constantly changing holes all down the left channel that you can be swept into. The boatmen haven't downrated Crystal one bit. Alas, there was no silver lining to the Fool's Flood of 1983.

We made it through Crystal. Jimmy insisted that I crouch down much lower in my corner than I usually do, and it was a good thing, too. You could get whiplash from that rapid. We'd barely bailed the boat before we hit Tuna Creek Rapid (a 6) half a mile later, and felt somewhat frazzled by the time we staggered ashore at Mile 104 to make lunch. But the sun warmed us.

Comparing notes once ashore, it sounds as if Howie's boat had a more exciting trip through Crystal than we did -- Dan Richard says he'll never forget skirting past a gaping hole in the river. And looking down one story deep into churning waters. I shuddered. It does give one a new perspective on why they're named "holes."

> Looking up the Colorado, the tongue of Crystal Rapid appears broad and silky, but the smoothness is deceptive. The water actually powers down Crystal's initial drop at speeds approaching 20 miles per hour.... Along the tongue small rocks and their ensuing holes pock the right side of the river. Increasing in frequency and size, they funnel the Colorado inexorably toward a truly unbelievable hole.... It exists because of several enormous rocks directly at the end of Crystal's long, racing tongue. Most of the Colorado River plunges over the rocks and down twelve feet into this hole. Rebounding, the water shoots twenty feet into the air. It is this mountain of water that fills boatmen's nightmares... The hole is only a quarter of the way through the white water. Below it and slightly to the right is a rock that many Grand Canyon veterans think of as the worst on the river. Actually it is rather pretty: orange in color and nicely smoothed, a block of Supai sandstone. The problem with this rock is its location. Boats slamming off the right side of the big hole will, if the boatman loses control, wash directly into the orange rock and then careen onto a barely submerged island of large boulders.
> ....**ROBERT O. COLLINS** and **RODERICK NASH**, *The Big Drops*, 1978.

Mile 104
Onyx Rapid

HAWKS AND FALCONS can often be sighted in the Canyon, soaring along on the updrafts near the cliffs, and they become our after-lunch preoccupation as we lie on the sandy beach. Several days ago we spotted a red-tailed hawk circling high over a side canyon. The local falcons are kestrels. We haven't seen a kestrel catch anything yet; besides cicadas, they prey on small birds. And while the small birds are plentiful, they are also cautious when it comes to hawks and falcons: they recognize the profile of the predator seen from beneath and take evasive action promptly. Does this mean that birds have special "hawk templates" in their brains? Is it inborn, or do they have to learn it?

> [When a redtail hawk] spots something live and edible, down she goes at an angle of forty-five degrees, feet first, talons extended, feathers all aflutter, looking like a Victorian lady in skirts and ruffled pantaloons jumping off a bridge.
> ......**EDWARD ABBEY**, *Down the River*, 1982.

When they spot a hawk, young birds crouch down, remaining immobile against the ground. Shadows and movement help a soaring bird to spot prey against the background camouflage, so this stationary posture reduces the nestling's chances of being detected and getting eaten. But how do they know to hide when the hawk flies over? Presumably they haven't learned by getting half-eaten once -- experience would seem grossly inadequate as a means of protecting young birds. Thus we might conclude that the young bird comes with a built-in template for the shape of a hawk (short neck, wings set forward unlike geese, that distinctive fan tail -- the "trigger features" for the protective reflex). A little more observation of animals would have saved the philosophers from mistakenly thinking that the young brain was a tabula rasa, a blank slate on which experience wrote.

When the ethologist looks more closely at the behavior of young birds, however, it turns out that nestlings react defensively to all birds flying past. It's just that they will stop doing it for the familiar birds. They may react to robins, but they eventually tire of it. The shape of a robin no longer triggers the reflex. But the shape of a crow still does -- until the nestling gets enough exposure to crows too. Just as we eventually become habituated to strange noises in the night, so the birds get used to the repeated, harmless profiles. Once they habituate to the shapes of the common birds in the region, the only birds that then trigger the reflex are the uncommon ones.

So is it only strange, exotic birds that now trigger the reflex? Not solely. Birds may be infrequently seen in a particular place for two reasons. They may be exotic (literally, from another place), just a few travelers passing through. Or they may be from a local species whose numbers are naturally few, a species that the food supply cannot support in large numbers. And there are very few hawks in comparison to other bird species because hawks prey on small animals rather than more abundant insects or seeds.

That's a simple and well-known consequence of a food chain: there is not much room at the top. To put on a gram of body weight, a predator may have to eat ten times as much. Not only is digestion inefficient, but warm-blooded animals waste a lot of what they eat, just in keeping their body warm around the clock. Furthermore, predators are usually larger than their prey (a big fish, for example, has to eat a lot of small fish to survive). So there cannot be as many predators as prey -- indeed, many fewer. And thus any bird that preys on other birds must be pretty rare, compared to robins and ravens. That may be the reason why nestlings freeze when a hawk flies overhead. Hawks are relatively rare and nestlings just never have the chance to get used to them.

And so nature provides this general way for young birds to avoid predators, taking advantage of this order-of-magnitude difference in population densities between bird-eating birds and other birds. Instead of wiring up the young bird with a built-in template for the hawk profile, it wires it up so that a rough template fitting many different bird profiles will trigger the reflex. And then, with experience, a series of more specific templates are formed for each common bird species. If none of these fit the passing bird, the alarm sounds.

If the nestling were born into a different habitat with different predators such as falcons, the end result would still be the same: the rare predator would still trigger the reflex. That's a rather different design principle than providing the baby bird with a genetic template for specific predator species. It's a more general principle, suitable for many different times and places. So long as the young birds can initially afford all the false alarms, the population statistics of the food chain will shape the triggers for the protective reflex against the youngster's true predators. This shaping process may, of course, have other side effects -- a general suspicion of strangers, for example, which could have been avoided with the inborn exact template method. The rough-template defense mechanism is yet another example of a young animal being "tuned up" by early experiences so that its brain is better wired for the particular environmental circumstances in which it finds itself.

> Perception is not determined simply by the stimulus patterns; rather it is a dynamic searching for the best interpretation of the available data.
> ......**RICHARD GREGORY**, *Eye and Brain*, 1966

> ...each person's knowledge base is made up not of isolated facts but of established mental codifications of behavior patterns and of generalized theories about the world. We are able to handle information rapidly only because the regularities of the world, as well as our routine dealings with it, are internally represented as schema. When available information (derived either from the senses or from memory) is sketchy, we draw on certain schemata -- old ideas and generalizations -- to fill in the missing data.
> ......**JAMES REASON**, 1984.

SERPENTINE CANYON RAPID is only rated a 7, but it has one of the biggest "holes" of any rapid on the Colorado River. But the hole is easy to avoid. We just ferried sideways across the river channel long before reaching it, and swept past, getting a good view from a safe distance. It was indeed a giant, frothy pit, quite capable of trapping a big boat. Because the frothy water has so much air in it, its buoyancy is reduced (uplift, saith Archimedes after issuing his "Eureka!", depends on the weight of the water you displace). And so that a boat can literally sink if the water it displaces weighs only half as much as normal. Like a black hole in space, these "white holes" may not give back what they take in.

LEARNING is, of course, often a more complicated matter than mere habituation. We learn associations, just as Pavlov's dogs came to salivate at the sound of the bell. Sometimes we gradually learn something, as when we practice a new skill. Other times, once is enough for a strong memory to be formed.

As compared to other primates, we humans aren't fussy about what we eat. Indeed, we'll seemingly try anything, once. We're always putting something new in our mouths to taste, maybe chewing on it a little. There are a lot of advantages to being an omnivore, as compared to sticking to salads and bamboo like a gorilla. For one thing, there is more to choose from, and that gives you more choices of places in which to live. The gorilla is stuck in a rut: by eating only its favorite plants, it must stick to where those grow in quantity.

But there is an obvious hazard to eating a new food -- it might be disagreeable. Skunks may defend themselves with smell, but plants often defend themselves from browsing animals by incorporating toxic chemicals. Which is what taste is all about, small samples being taken and analyzed before subjecting the gastrointestinal tract to large quantities of the potential food. And so, if you are going to eat a new food, you need to remember what it tastes like (yes, it also helps to remember how it looks, but taste is a more sensitive, definitive test). One needs to remember the item's taste for as long as it takes to get sick from it, so that it can be avoided next time by taste alone.

Prehumans didn't exactly invent that strategy for avoiding toxins. Even lowly animals like snails and slugs have this one-trial learning ability. Feed a slug some fancy exotic lettuce which it has never eaten before. Then, an hour later, inject it with something that makes it retch. The next time the slug encounters the lettuce, it will taste but not ingest -- presumably on the theory that it was the exotic lettuce which made it sick before. But the one-try taste mechanism isn't foolproof. We too indiscriminately avoid foods that we mistakenly associate with getting sick; one should never eat favorite foods while coming down with the flu, as it may ruin one's taste for these foods forever (this is probably why some people can no longer stand the taste of chicken soup!). It's not too surprising that the slug commits the logical error of *post hoc, ergo propter hoc* (after this, therefore because of this); it seems that we're not much more logical most of the time ourselves.

And so there seems to be a lingering memory of the taste of the lettuce, lasting long enough for the gastrointestinal tract to discover any toxins in it. Furthermore, the reaction to the toxin somehow "develops" the lingering memory of the taste, just as a photoprocessor develops a latent image on a film. The developed memory is then made into a permanent sensory template for detecting the taste of the toxic food, and is apparently then provided with strong connections to the "Ugh" circuits of the brain. Wildlife ecologists have been trying to explain this to farmers, so that they won't poison coyotes and eagles. It may be sufficient to put out some bait loaded with a drug that makes the predator briefly sick, so that he will think that chickens taste bad. Just as in spraying for pests once a year, farmers can train a new generation of predators every year.

So much for explaining bad tastes. But why, Abby asks, do we take such pleasure in good tastes? Where did that come from? Why is dinner likely to taste so good tonight? We are stumped.

> A coherent natural philosophy will only be possible once we have understood how the brain, itself an object of physics, generates the description of the physical world.
> ......the neuroanatomist **VALENTINO BRAITENBERG**, *Gehirngespinste*, 1977.

THE RIGHT TIME TO LEARN, for the slug's taste avoidance system, is only after the slug has gotten sick. Learning is similarly programmed in other types of animals.

Back on the river, Alan reminded us of the beekeeper's wisdom about moving beehives. If a hive is moved in the middle of the day, the bees become disoriented and confused. But get up in the middle of the night, to move the hive before their first flight of the day, and they'll come and go from the new location with no trouble: a bee memorizes the landmarks that it will need for its return flights during the rest of the day as it flies away from the hive on its *first* flight of the morning.

And a bee does not learn the smell of a flower by hovering around it. The odor of the flower is learned only if the bee is actually standing on the flower. Furthermore, if any aspect of its food source changes, such as its location or color, the bee must relearn the whole thing: it's stored all together, not as separate fragments. Thus bees are carefully tuned learning machines: just as their eyes see only certain aspects of their environment, so a new memory is recorded only when the conditions are just right.

This kind of memory is not the gradual tuning up which the hawk template suggests; rather, the bee seems to take a sensory "snapshot" when the right conditions trigger the shutter. But we humans seem to be open for learning much of the time. It seems to be stored in two different forms. In episodic memory, we seem to record a series of events almost like a motion picture camera, storing a whole sequence of memories of a particular episode: say, of getting into a car and driving it to the grocery store. And we can, if we try, distinguish this episode from other episodes, such as going to the store the previous day.

But the more common kind of memory, seen more widely among the animals, is the schema. This would be the generalized concept of "car", not any particular car but all cars; what we use to distinguish it from a truck. There can be a subschema for a particular car, what we use to tell our car from others of similar appearance. Our vocabulary is composed of schemata, which examine sequences of sounds to see if they approximately fit a word template already stored in our memory.

> Symmetry, as wide or as narrow as you may define its meaning, is one idea by which man through the ages has tried to comprehend and create order, beauty, and perfection.
> ......the physicist **HERMANN WEYL**, 1952

SYMMETRY IS ONE ELABORATION OF A SCHEMA, a handy way of generalizing upon an observation. The human body seems to be two halves, each the mirror image of the other. Surface appearances are deceptive, however. Inside any mammal, you can see that the huge liver has no counterpart on the left side. Indeed, it has enlarged so much as to make the right lung smaller, pushing the heart over to the left side of center.

As for the paired organs like the kidneys, we still assume they're identical twins, just mirror images of one another (surgeons know better). But aren't the two sides of the brain just mirror-images of one another? Not at all, they do different things, and they aren't even anatomically symmetric. Not even in rats.

How the presumption of symmetry crept into our teaching -- that's how I learned it myself when I took neuroanatomy at Harvard Med back when I first met Subie -- probably has something to do with our notions of symmetry in the universe. Or with esthetic considerations, which play a bigger role than nonscientists might guess in our formulations of how nature seems to work.

But its origins are not the issue, so much as how it has persisted for so many years. Even freshman biology students in my human brain lab can spot the differences in the two halves of a human brain if you ask them to look for differences, rather than prejudicing the issue by saying "Of course, they're just mirror-images." You only have to look inside a typical skull (a real one, not a plastic replica that an artist has tidied up) to see that the hollows made by the front of the brain are different on the two sides (the right frontal tip is usually larger than the left), and that the back of the left brain produces a bigger hollow than the right side.

One way in which the notion of anatomical symmetry has persisted in textbooks is that the author's rough sketches for illustrations are forwarded to a medical artist for a professional redrawing. They always come back looking much nicer than you can manage yourself. They are sometimes even beautiful. But esthetics once again enters the picture -- the artist, too, thinks that brains are symmetric. A few years ago, when George Ojemann and I were making up the 88 illustrations that went into our paperback book, *Inside the Brain,* we carefully sketched the right front and left rear of the brain as protruding beyond their neighbors. But the finished illustrations came back looking like mirror-images. As far as the artist was concerned, we had obviously been sloppy in our preliminary sketches (not, I admit, an unreasonable assumption in most cases!). I think that I disturbed a cherished notion about the universe when I explained to the artist that brains really aren't symmetric.

Of course the primary blame must be laid at the feet of the people like me who teach the subject, for not noticing the natural asymmetry themselves and then educating others. I am reminded of how the biology textbooks and reference books, back when I was in school, all proclaimed that human cells had their genes arranged on 24 pairs of chromosomes. Ahem. We really have 23 pairs. The textbook karyotypes indeed show 23 pairs. Someone couldn't count. And then no one blew the whistle for some time.

How can careful scientists make such glaring mistakes? And how can other scientists take so long to correct them? Scientists belong to the same general culture as everyone else. Unless a matter is important for some specific reason (and brain asymmetries and absolute chromosome numbers haven't been really important in anyone's analysis until recent years), they may not take careful note of it. Or if they do notice, they may not think it worth the trouble to proclaim that the emperor has no clothes unless they're sure that it makes some important difference.

When one of these fictions is unmasked, you usually find that the people in the field will say with some impatience: "Yes, of course. Everyone in the field knows that, has for a long time." Some of that is covering one's tracks, but it does represent a truth of sorts. There is always a lot of knowledge about a subject which isn't published: things that aren't sure yet, things that are out of fashion, things that "everyone knows" so that claiming credit for the discovery by writing it up yourself seems presumptuous. The only way to find out about such unpublished things is to listen carefully in seminars to the questions afterward, or to the gossip at tea time among the professors and graduate students.

One of the things that makes science different from other enterprises is that everything is fair game, always up for possible revision (if you can find the time and money to tackle it). There is a real sense of correct and incorrect, it's just that explanations are assumed to be imperfect. A plurality of competing viewpoints is assumed to be the normal, desirable state of affairs once one gets beyond simple facts such as chromosome number and brain symmetry. We like -- even though we do not always immediately practice -- the principle that juniors can correct their seniors and the textbooks.

> This elaborate cartoon on plate tectonics was assembled, and it was beautiful, except for one detail: The earth was rotating the wrong way. When I pointed that out, nobody... could really see it being that important. What was the big deal? I came to realize that 'wrong' means something different to an artist than to a physicist. The artists thought we were just being argumentative, quarrelsome, picky, when we said things were wrong. To us, a fact is either right or wrong. To them, 'wrong' is more of an aesthetic question.
> **......SCIENCE ADVISOR TO A TELEVISION PROGRAM**, 1980

AND WHAT ABOUT brain functioning: How symmetrical is that? When we think of right-handedness and language -- which are most strongly developed in humans -- it's obvious that human brain functioning isn't symmetric. But we still tend to think that the other animals are largely symmetrical in their brain organization, that humans are the exception to the rule. That's not the case: animals have a great deal of asymmetry when one observes them closely. Rats usually circle to the left, and their tails also curl left. In pressing a bar to avoid a shock, a large percentage of lab rats prefer to use their left paw. And when one looks inside the brain, there are various asymmetries in chemistry as well as anatomy. Some of them are more pronounced in male rats than in females.

When one looks at "emotional" behaviors, one finds that the brain anatomy can predict emotionality. There is, of course, lots of variation in a population, even in an inbred strain of laboratory rat. If you find a rat with a much larger right hemisphere than its left hemisphere, it will probably be cautious when exploring a new environment, taking a long time to visit all the corners and sniff them. And it will likely be an unhesitating mouse-killer, unlikely to live-and-let-live if a mouse is placed in the same cage. Rats with a less pronounced size difference between the hemispheres exhibit more exploratory behavior, and have more of a tendency to coexist with a passing mouse. The rats that explore the most, and mouse-kill the least, are those uncommon rats whose left hemisphere is bigger than the right.

It is thought that the right hemisphere is more emotional, and that the left hemisphere holds it in check, since splitting the brain or removing the left hemisphere causes more mouse-killing and more cautious exploration. There has been some suggestion of this in humans, which was once symbolically illustrated by a drawing in the *New York Times* showing a split-brain patient swinging an axe with his left hand (controlled by the right hemisphere) but with the right hand swinging over to grab the axe on its way down.

So the things we notice most easily -- human right-handedness and left-hemisphere language -- may have developed from a foundation that was already skewed in early mammals by this "emotional" specialization. Are humans like the rats, being less likely to explore, or coexist with a passing mouse, if they have an oversized right hemisphere? I don't think anyone has looked.

SCHEMATA IN SCIENCE

> The flame of conception seems to flare and go out, leaving a man shaken, and at once happy and afraid. There's plenty of precedent of course. Everyone knows about Newton's apple. Charles Darwin said his Origin of Species flashed complete in one second, and he spent the rest of his life backing it up; and the theory of relativity occurred to Einstein in the time it takes to clap your hands. This is the greatest mystery of the human mind -- the inductive leap. Everything falls into place, irrelevancies relate, dissonance becomes harmony, and nonsense wears a crown of meaning.
> ......the novelist **JOHN STEINBECK**, 1954

> It is a wondrous thing to have the random facts in one's head suddenly fall into the slots of an orderly framework. It is like an explosion inside.... I think that I spend half my time just talking and listening to people from many fields, searching together for how [plate tectonics] might all fit together. And when something does fall into place, there is that mental explosion and the wondrous excitement. I think the human brain must love order.
> ......the marine geologist **TANYA ATWATER**, 1981

> What's beautiful in science is that same thing that's beautiful in Beethoven. There's a fog of events and suddenly you see a connection. It... connects things that were always in you that were never put together before.
> ....the physicist **VICTOR WEISSKOPF**

> There are not many joys in human life equal to the joy of sudden birth of a generalization.... He who has once in his life experienced this joy of scientific creation will never forget it.
> ....the geographer **PETER ALEKSEYEVICH KROPOTKIN**, 1842-1921

> Intelligence... is the capacity to guess right by discovering new order.
> ......the neurobiologist **HORACE B. BARLOW**, 1983

River Camp at Mile 114, from **Leonard Thurman**'s Grand Canyon River Running web pages.

Mile 109
Bass Camp
Sixth Campsite

GETTING WET in the bottom of the Grand Canyon is usually something that happens in the daytime, incidental to running a rapid, taking a bath in the river, or getting involved (sometimes with malice aforethought on a hot afternoon) in a waterfight between adjacent boats. The nights are usually comfortably dry. Though river-runners carry along tents, they don't expect to have to use them in June or early July in the Canyon. And it's a good thing too, because the nighttime temperatures often stay high enough so that you don't want a tent between you and the breeze.

This year the monsoon season started early, the cumulonimbus clouds building in the late afternoon as the heat rose from the Canyon to push the moist upper air from the oceans to higher altitudes, producing a lightning show for dessert. Peach flambee -- canned peaches, but with the fire in the sky reflecting off the juice. Tents that had been carried for years but never unrolled were reluctantly erected, that being the surest known way of making the rain fall elsewhere.

My own tent stayed home; instead I had brought a tube-tent, the closest thing to a single-use throwaway item included on my packing list, never unfurled in over 10 years (and for good reason, given their soggy reputation for interior rainfall via condensation). Forsaking seconds on the peaches, I too joined the brigade of pole-and-string architects in the fading twilight. To my surprise, the "instant tent" was intact and didn't shred into a million pieces from age.

We are still in the inner gorge and the metamorphic rock sticks up here and there within the sandy camp, providing me with two places to tie up the tent.

As the freshening winds were added to the lightning, it became evident that our superstitious ploy for avoiding the rains was going to fail. So I decided that I might as well stay up to watch the show. Though there were surely better places than from inside that tube tent. Grumble, grumble. Nevermore. I'll bring a real tent next time.

Fortunately there was a cave nearby. Not in the Redwall, where we found caves upriver, but inside a very large, room-sized boulder. The boulder was really a chunk of old riverbed conglomerate, a lot of medium-sized rocks that had been cemented together and later dumped near our campsite. At some point it had lost some of its constituent rocks, leaving a considerable cavity in one side. The resulting "cave" was full of nooks and crannies, just the place for a scorpion or a rattlesnake to live. Luckily, I was able to inspect the smooth sand in front of the cave for footprints and snake tracks. It seemed uninhabited -- except, perhaps, for bats. If they lived there in the daytime, they were surely out gathering insects at night. So I crawled in and hoped that they wouldn't return just because of the storm.

In short order a magnificent desert thunderstorm began, heralded by ruffles and flourishes. Lightning, thunder, driving rain, blowing brush tumbling past, wind waves on the river. Added to the colors of the sunset on the high walls of the Grand Canyon, it had its virtues. It became one of those scenes that you could lose yourself in. Its wonders were hypnotizing. Rumbling bass notes, cracks of thunder. Sheets of lightning, then jagged extravaganzas. Thor outdid himself. Fresh cool breezes on the face, new smells brought in by the storm. And a little rain on one leg and foot, which didn't quite fit inside the one-person instant cave.

DURING A LULL when the rains stopped and the hypnotic spell wore off, I stood up and stretched, shook the dry foot which was tingling from lack of blood. The bats were still out working hard at making their living. For humans of even modest size, the cave was hardly suitable for sleep, only for long nights contemplating the elements.

Surely, it occurred to me while awaiting the second act, I was not the first person to take shelter from a storm in this little cave. This boulder has been lying here for many thousands of years while Indians had been hunting in the Canyon. Nearby, up on the hill behind our campsite, are numerous Anasazi ruins. Where I had reclined, with most of me inside the enclosure, had probably been where a lone hunter took refuge during a similar thunderstorm in ages past. In this very place, he probably looked out and saw much the same sights, felt the same damp breeze, was shaken by the same thunder claps. And worried about similar rattlesnakes. Unless he was a lot smaller than I am, he got one foot wet too.

He was undoubtedly in better shape than I am physically -- certainly his feet were less tender and he could run farther. But he was probably hungry, and his teeth were surely worn down from eating too many gritty roots or too much corn (sand gets mixed into it when grinding with the Anasazi *mano*, which is made of sandstone). He was probably half my age, since a man past forty was ancient and perhaps toothless back then, unless extraordinarily lucky. Those conditions made it rather hard to accumulate knowledge, especially if you were also on the move all the time, just trying to get your children to a self-sufficient age before you passed from the scene yourself.

It was really his level of culture that made the difference between us, not just his lack of agriculture or technology. A properly organized culture means that the dead can speak to you.

Archimedes speaks to me from thousands of years ago, his "Eureka" echoing whenever I wonder why I float better in my lifejacket. But not as well in white water.

Ptolemy too speaks to me about the stars from back then, just as Galileo speaks from four centuries ago about the planets.

Isaac Newton speaks to me from three centuries ago, telling me the laws that apples and planets both obey.

James Hutton speaks to me from 200 years ago whenever I contemplate the layer-cake geology of the Grand Canyon, even though he never set foot near this greatest geological spectacle on earth.

Ben Franklin speaks to me from that same era when I look up at the lightning, telling me of nature's electricity. And I still use Clerk Maxwell's equations relating magnetism to electricity, the first of the "field" theories in physics, one of the magnificent intellectual achievements of the nineteenth century.

As also was Charles Darwin's achievement; he still speaks to me, each time that I contemplate the simplest problem in evolution, just as Paul Broca and Hughlings Jackson speak to me about brain organization from the nineteenth century when I struggle to understand maps in the brain.

Albert Einstein's words of 1905 still speak to me about space, time, and the packaging of energy.

The venerable Hans Bethe speaks to me from only decades ago, telling me how distant supernovas created the very carbon atoms which are now found in every cell of my body, indispensable to the simplest motion or metabolism. And he continues to speak to me in this decade, about how it is absolutely essential to control nuclear weapons.

And my scientific contemporaries speak to me constantly -- across the dinner table, when I visit their labs, in the hallways and conference rooms, in print and on television. It is an exciting time to live, as most of the scientists who ever lived are alive today. Our river-running group is just a microcosm, biased toward those who concern themselves with how brains work. Neurobiology has developed so recently that even young researchers are likely to meet and talk with the pioneers -- real two-way talk, in which you can still ask questions of the pioneers and get answers.

THE SECOND ACT has started, and I am back in the Anasazi's mini-cave. I see brief snapshots of the Canyon during each lightning flash. Certainly the difference between that Anasazi and myself is not biological. The human gene pool has changed significantly over 100,000 generations (for example, the brain has tripled in size), but hasn't changed much over the last 40 generations, the last 0.04 percent of hominid evolution. At birth we were probably very similar, as similar as any two babies born yesterday in the same hospital in Los Angeles. But all that neural hardware in the brain is versatile -- it can tune itself up to detect a bighorn sheep hiding amidst a thicket of mesquite trees on a slope of jumbled rocks. Or to recognize an arbitrary symbol like the letter "T." Or to piece together a faint buzzing sound, when walking down a hot, dusty trail, with a mental representation of the combination that results in "Stop. Rattlesnake. Look before leaping."

That Anasazi could have spotted many more bighorn sheep than I've seen so far this trip. He probably had a dozen names for that spectrum of canyon colors that I merely call red, reddish-orange, and orange. He surely knew the stars better than I do, having long, clear winter nights in which to contemplate them without the distractions of books and television. The names of many of the constellations come down to us from well before the invention of writing 5,000 years ago. And recognizing a constellation by fitting seven stars to your mental image of a ladle -- well, that's schemata for you, par excellence.

We see if things fit the mold. These are all schemata, mental templates for situations, which come to mean something. A schema (as in schematic outline) is pieced together from those simpler neural templates that Keffer Hartline began studying, using those higher-order cells of visual cortex that specialize in lines and edges, those cells in the dozen even-higher cortical regions that carry out even more complex analyses of the visual images we see, those committees with emergent properties.

Some schemata are probably inborn, perhaps the common primate fears of snakes and deep water. Babies are certainly born with a firm idea of what a human face ought to look like, as newborns will cry if shown drawings of faces with a missing eye or misplaced nose. But we acquire most schemata during life. Some, perhaps, are acquired much as the baby bird is tuned up to the overhead profile of the hawk, by editing some connections between schemata. Surely, however, some of our new schemata are created by building up, more like a carpenter does with building blocks, than by selectively removing material as a carver does.

We are always trying out new sensory information against our resident schemata, seeing what mold they fit among the multitudes in our cephalic library. And the human brain seems to have acquired an almost unlimited capacity to create new schemata. Indeed, given our compulsions to distinguish this from that and thus create dichotomies, we might be said to have a passion for new schemata, creating a new mold when the old ones don't quite fit.

We also have a passion for creating new molds for concepts as well as facts, for lumping various elements together under a new heading. For discovering new order. We love to distinguish one thing from another -- and that's an evolutionary clue. To some extent, that which gives us particular pleasure is likely to have once been important in evolution -- and the singular sense of pleasure we get when things fall into place testifies to the importance of forming new schemata.

Watching the stars and galaxies that first night on the river, we contemplated the evolution of matter such as the elementary particles. That night waiting for the eclipse, we contemplated the evolution of the organization of matter, not just into stars and planets but into life itself. But here -- this is a new kind of evolution, one that involves mental structures, webs of relationships. In a sense, they have become emancipated from the material world, living a life of their own on a new plane of existence. And as these webs, these schemata, become established and stable, they serve as building blocks themselves, as when the "journey" schema helps build new schemata such as "run-around" or "grid-lock." Supporting further evolution into more complex, higher forms.

And since behavior usually is the first thing to change, with anatomical variants only later being edited to streamline the body shape to optimize the new behavior, so a new schema is often the first step in evolving a flying squirrel -- or snake!

Schema evolution -- and its behavioral counterpart, cultural change -- happens on a time scale far faster than biological evolution. It is transmitted to others without biological reproduction as the medium -- rather through gestures, drawings, words, images, books, inventions. As the sociobiologist Richard Dawkins has proposed, we can call this cultural unit the "meme" -- as in mime. They are contributions to the culture pool to be mimicked, rather than contributions to the gene pool. Mimicking genes, memes propagate themselves by metastasizing minds -- sometimes even against your will, as when an advertising jingle keeps running through your head despite your best efforts to shut it off.

And onto this new evolution, we can attempt to impose humane values, those considerations largely missing from earlier evolution. When the foundation of these values rested only on an appeal to a higher authority (by analogy to the parental "You'll do it that way because I told you so"), the responsibility wasn't firmly in our laps. If the emerging facts of primate societies say what I think they say, we humans have made some important choices along the way of evolving our societies -- we call them ethics, values, sometimes morality -- that make our high civilization a far better place to live than some other human and primate societies. They may not be inevitable and, if we value them, we'll have to work hard to retain them in the face of the vicissitudes of time. What is natural isn't always good.

THE LADDER OF LIFE is an old metaphor, standing for the gradual progression to more intricate forms of life. But since a branching tree better describes the world of our ancestors, ladders are somewhat out of fashion; yet they do seem applicable to the hierarchy of schemata in the brain, to more complex ways of representing information. But a ladder is not quite the right metaphor. A staircase is better, simply because one can imagine resting on each step. Without slipping backwards. As a matter of esthetics, I like to imagine a spiral staircase. DNA makes a lovely spiral staircase, those C, G, A, and T bases being the steps.

Darwin marshalled a mighty weight of evidence for the existence of evolution, an idea that had been around for many decades. But Darwin also put his finger on a crucial piece of the mechanism of evolution, natural selection. The survival of the fittest, as his contemporary Herbert Spencer later phrased it, leads to plants and animals that are even more cleverly suited than their ancestors to the environments in which they live. Since the climate keeps changing, the life forms gradually change too, becoming even more complex in order to beat out their less versatile competitors.

As Darwin presented it, this process is gradual. Rather than a spiral staircase, one imagines a spiral ramp, like one of those spiralling driveways that connect different levels of a giant parking garage. With life gradually creeping up the ramp to higher and higher levels, driven by natural selection.

THE PARKING GARAGE is an attractive metaphor, now that I think about it, since the floors attached to the spiral ramp suggest the ability of life-forms to spread out on a stable level. While a minority continue to creep up the spiral ramp and change, others may have a population explosion to populate a new empty level -- the empty niche of the ecologist's lingo. In this parking garage, the Model T's would be on the bottom level, the finned cars of the 1950s on some middle level, and our latest creations on the top level.

If you were an archaeologist digging up a parking garage, nearly all the cars you'd uncover would be parked on one level or another; few would actually be on a ramp between levels. And so it is with the evolutionary history uncovered by paleontologists. As they dig deeper, they find relatively sudden changes in animal species, not the gradual changes they might have seen had they been lucky enough to locate the spiral ramp off on the edge of the garage. One of the things which has happened in the century since Darwin is the realization that new species arise off in isolated corners, not out in the middle of a floor. This "allopatric speciation" was first argued convincingly by the evolutionary theorist Ernst Mayr some decades ago.

The point has been made even more forcefully of late -- by people like Niles Eldredge, Stephen Jay Gould, and Steven Stanley -- that there really are floors, that species as a whole do not change gradually. Indeed, large populations are surprisingly resistant to change, contrary to what one might expect from the Darwinian idea of gradual natural selection. The floor of the garage is the equilibrium of punctuated equilibria. When the creep up the spiral ramp -- Darwinian gradualism occurring to an isolated population off in a corner -- reaches a new stable level, there will be a population explosion to fill the new floor (a new niche, in ecological terms). So that to the historian digging down through the layers, the fossil record will appear to be one of punctuated stability.

And our cultural evolution looks much the same. Writing wasn't gradually invented everywhere, but rather by what was probably a small group of tax accountants in Sumer, and then the idea spread around. Mathematics and geometry owe much to what happened on the Greek island of Samos in the sixth century B.C. among the followers of Pythagoras. Because ideas reproduce themselves in virgin minds, thanks to our passion for new schemata, our thoughts have come to have lives of their own, and thus an evolutionary history of their own.

THE SPIRAL RAMP is not just for life forms and ideas -- genes and memes-- but is perhaps a metaphor for the entire physical and prebiological history of the universe. There is, of course, a romantic tendency to think big when looking out at the stars in the clearings between the passing thunderclouds. But it is an exciting idea, one I cannot avoid pursuing. If we are ever to contemplate the grand sweep of evolution, from the Big Bang through all the intermediate stages to the Big Brain, it will have to be with the aid of some such metaphor. Is this the forest, whose trees we have been individually describing?

Of course there are many gaps in our knowledge -- it is a spiral ramp seen through the clouds, still obscured in places, still fuzzy in others. Many a floor is missing because it disappeared long ago, having served only as scaffolding for another floor. But the metaphor of the spiral ramp with attached floors expands on Jacob Bronowski's notion of stratified stability, encompasses evolutionary species and ecological niches, and handles the hierarchy envisaged by the old one-dimensional ladder of life. It provides a chance to rise above the details and contemplate the grand sweep of all of evolution.

I feel like shouting "Eureka!", awakening the camp. But caution reasserting itself, I satisfy myself with a broad smile instead, and look overhead at the drifting clouds. I must try this out, see just how much of the universe's known mechanisms can be appreciated from this new viewpoint.

Suppose, even if it were true, that I woke someone up and announced the spiral-ramp parking garage as the grand metaphor for the mechanisms of the universe? Hmmm. I'll have to see what I can do to improve that image. It just doesn't have the elegance of Michelangelo's God reaching down from the ceiling of the Sistine Chapel to create life on Earth. Or even Einstein's Watchmaker God, who supposedly made the universe and then started it running, leaving it alone thereafter (presumably having better things to do than rescue individuals from their follies), watching it go on to eventually invent its own customer complaint departments, and provide its own limited warranties.

THE SHOW'S OVER, I think. The luminous clouds have drifted farther west and darkened, the air seems warm again, and the lightning hasn't been seen for quite a while now. I contemplate extracting myself from the boulder to wend my way in the quiet darkness through the trees and tents, back to my imitation of a tent.

Then a great sheet of lightning brightens the camp. And I dimly and distantly see a nude female figure coming up the path from the river, her right hand stabilizing a towel wrapped around her head obscuring her face, her left hand holding a tube of shampoo. The light flickers out, and the apparition silently disappears into the dark camp. I await another flash of lightning, but see only faint shimmers deep inside the retreating clouds.

> What is there in life except one's ideas,
> Good air, good friend, what is there in life?

......**WALLACE STEVENS**, *The Man with the Blue Guitar*

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If we assume all river flow downhill then all the rivers in the world that reverse direction must be going uphill. This does happen when the sea tide overcomes the river every day in some rivers of the world. The Tonle River in Cambodia changes direction twice a year: when the monsoon arrives the flow from the Mekong backs up to the central plain and when the rains end the river reverses direction and empties the flood back out into the Mekong. During hurricanes rivers often reverse direction along coastal routes : The Mississippi River reversed direction after Hurricane Isaac in 2012. Althoug

The river that flows uphill : a journey from the Big Bang to the Big Brain. byCalvin, William H., 1939-. Publication date 1986. Topics Neurobiology, Brain, Human evolution. PublisherSan Francisco : Sierra Club Books. Collectioninlibrary; printdisabled; internetarchivebooks; americana. Digitizing sponsorInternet Archive.