Pretty Ugly

Why we like some songs, faces, foods, plays, pictures, poems, *etc.*, and dislike others.

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Pretty Ugly: Why We Like Some Songs, Faces, Foods, Plays, Pictures, Poems, Etc., and Dislike Others

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The Field of Beauty

A Wayward Walkabout

The tribe in New Guinea lived so apart from the modern world that they still used stone axes. None of them had ever seen a photograph, and anthropologist Edmund Carpenter wanted to know how they would react to seeing one for the first time. He showed them Polaroid pictures of themselves and saw complete incomprehension:

> At first there was no understanding. The photographs were…far removed from any reality they knew. They had to be taught to 'read' them. I pointed to a nose in a picture, then touched the real nose, etc. Often one or more boys would intrude into the scene, peering intently from picture to subject, then shout, 'It's you!' Recognition came gradually.[1]

Conventional studies of aesthetics assume implicitly if not explicitly the cultural preferences of the author's time and place. For example, the 11th edition of the *Encyclopedia Britannica* is known as the "scholar's edition" for its depth and erudition. Its main entry on music is 14,000 words. This article dates from 1910, almost the peak of the British empire. It does not deign even to mention Africa.

Nobody could imagine such an omission today. Today, any overview of music purporting to be comprehensive would mention complex African polyrhythms. On the other hand, our current attitude may also be a distortion of the times, a distortion by a contemporary value we have developed in reaction to our colonial past, the desire to appreciate cultures that we have been destroying. According to Princeton Professor Kofi Agawu, a musicologist from Ghana, most observations of African music involve "the pious dignifying of all performances as if they were equally good, of all instruments as if they were tuned in an 'interesting' way rather than simply being out of tune, of all informants as if a number of them did not practice systematic deception, and of dirge singing as if the missed entries and resulting heterophony did not result from inattentiveness or drunkenness."[2]

This book is an attempt to understand aesthetics irrespective of culture. Of course we are children of our place and time like everybody else, so we are subject to similar biases, but we are hoping to sidestep them by basing the book not on aesthetic appreciations but on science. We are building it from basic work on the sensation, perception, and cognition of adults, and from studies of babies, who were young enough not to have been acculturated. Moreover, we are not creating a self-contained theory with its own system of explanation, we are founding an explanatory framework on physics, physiology, and evolution. Indeed, the next chapter is an introduction to some key concepts of physics and maths.

However, we did not write this book specifically for scientists. We also wrote it for artists, musicians, architects, cooks, writers, readers—anyone who enjoys any of the arts. We shall work with concepts, not equations, and show numerous examples.

Our argument will draw from many academic disciplines, each of which has a rich and idiosyncratic jargon. This presents a problem.

Although jargon can be a shortcut to understanding, it is a shortcut only to initiates, and few readers will understand the jargon of all the fields we need to walk through. Moreover, jargon is a shortcut that tends to lead the mind along conventional paths, paths that we shall need to avoid. For these reasons we shall use specialized jargon only in rare instances where ordinary English simply cannot serve, and then we shall explain it.

Few readers will have read in all of the fields we shall wander through, so our first approach to every field shall be introductory. However, introductory does not mean elementary. If we seem to start with Music 101—well, we shall not stay at that level for long.

Unfortunately, the scope of this book will force us to fly through subjects quickly. During these flights we shall make many assertions that contravene conventional wisdom, and some of these may sound bold and bald. If you find yourself rolling your eyes—if you find yourself wondering how the stupid authors could ignore something obvious that everybody knows—please visit the endnotes. These contain additional discussions and entrées to the academic literature.

Nature and Nurture

When we began to research this book, we envisioned ourselves describing the interaction of genetics and the environment. However, although nature and nurture are the most common explanatory mechanisms, we found that explanations based on either of them seem always to lead to a dead end, even when the notions are more sophisticated than “natural beauty.” For example, inside the eye, three sets of conical, light-sensitive cells enable you to see different wavelengths of light as different colours. These cells respond to a limited range of wavelengths, so you cannot see any wavelengths outside that range. This is nature, this is how you are built. For this reason you will never hear a couturier wax lyrical about a lovely infrared or a soothing ultraviolet. However, to state this is merely to state that you cannot appreciate what you cannot see, which is neither helpful nor profound. Nor is nurture more helpful, because nurture by itself cannot explain why a suit of clothes might look lovely during the day but not at night.

Nature versus nurture is not a model that leads very far because physiology and learning are not separate and distinct, they are inextricable. Learning is not an abstract process, it is a physiological process, ultimately a chemical process, and chemical processes require both nature—the chemicals—and environmental factors like heat. For this reason, we tried to avoid the usual vocabulary of "hard wiring" and "environmental influences," and to seek more revealing explanations.

Ultimately we came to see the sense of beauty as an emergent phenomenon. An emergent phenomenon is something complex that arises from repeating something simple many times. An example is the office towers in a city. To prosper if not merely to survive, people need to exchange goods and services, so individuals have a fundamental need to trade. Proximity facilitates trading, so people decide to move near other people. A village forms. The concentration of people in a village attracts more people so the village becomes a town, then the town becomes a city. Eventually the city runs short of space. At that point people begin to build upwards and office towers emerge.

Physical beginnings—nature, if you will—always help to shape emergent phenomena. Amsterdam has soft soil at depths where New Amsterdam has bedrock, so taller buildings emerged in New Amsterdam (New York), but good harbourage saw dockyards emerge in both.[3]

Human bodies are another emergent phenomenon. Infinitesimally small chemical packets that we call cells combine with other cells, which combine to form the larger packets we call tissues, which combine to form organs, which combine to form a baby. At every stage in this process the packets do nothing more than react to the basic forces of physics and chemistry.

Genes do control the development of bodies but as geology controls the development of cities, not through active processes but through structural facilitation and constraint. This is apparent in the brain. The brain looks like a cauliflower and is formed in layers. Broadly speaking—very broadly—nerves to and from the body connect at the lowest levels, the middle levels run things, and the highest levels perceive and think. In none of these levels are the cells smarter than the cells forming a cauliflower. The brain's chemical structures are perfectly dumb, yet these dumb structures interact with one another in ways that permit intelligence to emerge.

Intelligence emerges primarily in the cortex, the outermost few millimetres that contain the highest levels of the brain. There as elsewhere in the brain, the environment of each neuron (nerve cell) consists of a chemical bath penetrated by erratic bursts of energy from one or another cell nearby. This energy reaches the neuron, passes along the neuron's surface in the form of a chemical chain reaction, then reaches the neuron's far end and crosses the chemical bath to nearby neurons. Its passage through the bath disturbs the bath's chemistry. It causes slight chemical changes that facilitate another passage of energy through the same route and inhibit the passage of energy through neighbouring routes. Those changes come to form neuronal pathways. From a vast number of these dumb pathways, intelligence emerges.

And our sense of beauty emerges from them as well.

Unfortunately, this emergence takes a confusing route—or rather, a confusing set of routes. To follow it we shall begin with some basic concepts of mathematics (without equations or numbers), then spiral upward repeatedly through vision and hearing. Eventually we shall reach art, architecture, dance, drama, literature, music, and sculpture. Halfway up the spiral we shall pause to sample tastes, smells, food, and drink.

Science *vs.* Philosophy

When we first thought about writing this book, we did not know what we could come up with. A framework that can hold all of aesthetics that is built upon basic physics—how to construct such a thing was not obvious. However, at physiological levels the brain is a machine, so we thought that we ought to be able to come up with something. In any case, we thought, the endeavour would be fun, because our research would take us to so many concerts and museums. That was 30 years ago.

A philosopher of aesthetics might have written a book like this faster. A philosopher could have forgone the museums and developed the argument from first principles using logic. But we are scientists, not philosophers. Scientists do not start from first principles, scientists try to make sense of what they see. In science, logic guides observations and explains observations, but observations come first and, although it sounds surprising, science does not follow the rules of formal, Aristotelian logic.[4]

To understand the reasoning of science, consider the basic paradigm of the scientific method:

1. Form an hypothesis. A new drug Memorine enhances memory.

2. Design an experiment to test the hypothesis. Give half a French class Memorine and half the class a placebo, and compare the two groups' vocabularies before and after the pill.

3. Run the experiment.

4. Examine the data and draw a conclusion. On average, students taking Memorine improved more than the others, so we infer that Memorine does enhance memory.

This sounds sensible and the conclusion may sound logical at first blush, yet that conclusion could not follow logically from any set of real data. We may see an improvement *on average* but among any group of students, some will learn more words than others for reasons having nothing to do with the drug. Among our group perhaps Alice heard a lot of French at her parent's cottage in Québec, and the Inuit Bunig never heard any French spoken until she went south to attend university, and Cora is a little dense, and Dorothy prefers dancing to studying, and Elena is already fluent in Spanish and Portuguese. We might be able to allow for some factors like these—perhaps we can exclude from our sample bilingual students—but we can never know about everything that might differentially affect students' learning. Thus, the most we can conclude is that Memorine *may sometimes* enhance memory.

This may sound like pedantry but it is not. Let us assert that all cats grow tails. If you have ever seen a Manx cat, you will contradict us. "No, it is false that *all* cats grow tails. *Not all* cats grow tails. *Some* cats grow tails but other cats do not." Now let's compare cats to Memorine. We hypothesize:

- All cats grow tails.
- Memorine enhances memory.

But according to Aristotelian logic, the results of our experiment show the *contrary* of our hypothesis:

- *Some* cats—*not* all cats—grow tails.
- Memorine *may sometimes* enhance memory.

Logically, no experiment can prove an hypothesis. All a scientist can do is assume that within an experiment, the influence of uncontrollable factors is the influence of random chance, and then calculate odds like a bookie. Instead of saying, "Memorine enhances memory," all we can do is report, "We saw an enhancement that would occur by chance less than *n*% of the time." That is the only logical conclusion we can draw.

Deductions like this are true insofar as they go but they do not go very far. To carry a man to the moon, or to analyze the elements in a gas, or to identify a pathogen, science requires sweeping inductions—generalizations from the particular to the general, like the generalization we accept as a law, that a body in motion tends to stay in motion. Yet according to the strictures of logic, all inductions are fallacies. No matter how many Italian meals you have eaten, you cannot conclude logically that all traditional Italian cooking uses garlic. Indeed, if you do conclude this, you will be wrong. Garlic was deemed the peasant's spice cupboard—sophisticates looked down on it—and Italian cuisine was developed not by peasants, who could afford little beyond grains and vegetables, but by folks with money in towns.[5]

THE ART OF SCIENCE

Science is not built from logical deduction, it is built from intuitive induction. Strengthening the inductions are associative reasoning—more about that shortly—and the mathematics of probability.

In principle these mathematics are simple. Let's illustrate them with our imaginary Memorine. A test of Memorine finds an amount of improvement that would occur by chance only five percent of the time. This may sound significant but it means the odds are five per cent that these results *did* occur by chance and that Memorine actually led to no improvement at all. To investigate further we test more drugs. We comb the pharmacopoeia and find 99 drugs in the same class as Memorine. We test each of them as we tested Memorine, and we repeat our test on Memorine as well. The result: five of these 100 drugs show results that would occur by chance five percent of the time. This result is exactly what one would expect by chance, so we see no evidence that this *class* of drugs is useful. However, one of these five drugs is Memorine, so now we have two studies each finding odds of five percent that Memorine can be effective. The odds that both studies found this by chance are lower. Next we test Memorine a third time and find similar results, so the odds become lower still. Now we feel justified to make an inductive leap, to conclude that, although most of the drugs seem useless, Memorine can be effective.

In principle that is how science works, but reality is dirty. Scientists do not enjoy repeating experiments, nor can we advance our careers by doing so. Scientists repeating an experiment will usually vary some circumstance, to extend what is known and to extend their lists of publications. Probably no one would retest Memorine with students learning languages but someone might test women in a nursing home on telephone numbers, and a neurophysiologist might give it to rats running mazes. Since each of these studies is different, we could not combine them mathematically. We would be adding apples and oranges. On the other hand, if they showed similar results, they would appear to be converging on a truth.

Converging evidence this is called. It is arguing by association rather than logic, so to a logician it carries no force, but it holds all of science together. For example, although no one can prove logically that all species evolved, yet (1) we have seen some species evolve in our lifetimes, (2) we can put together plausible evolutionary trees from physical evidence, (3) we can induce other species to evolve in the lab, and (4) no one has come up with an alternative more plausible than a *deus ex machina*. This evidence converges so strongly that scientists are forced to see the theory of evolution as more than “just a theory.” Overwhelming converging evidence forces us to conclude that evolution is a mechanism that is fundamental to the development of life in all its forms.

In this book we paint a picture from converging evidence. A large picture from an immense body of evidence, evidence from several

SELECTING EVIDENCE

When a teacher demonstrates a classic experiment, the result is seldom exactly what the theory predicts it will be. The world is too messy for theoretical perfection to exist. Moreover, once we leave the basic textbooks, theories cease to be complete and coherent, and observations begin to be so messy that experimental results may look real yet not be. For example, consider Memorine again. By convention, scientists in most fields deem a result to be significant statistically if it has no more than a five percent probability of happening by chance. This means that if our results were entirely random, the most extreme five percent would still look significant. They could not *be* significant, for they were random, yet out of every 100 tests, five results would *look* significant.[6]

This will happen often because scientists hunt in the dark. Although we aim at noises, most noises at night come not from animals but from wind. In experimental psychology something like one-half of studies find no data that are strong enough to publish, despite biases to see significance wherever the psychologist looks.

Even when we hear a noise so loud that we know something is present, still we cannot draw a clear bead on our target. No scientific study can control and measure everything well enough always to reveal a phenomenon that actually exists. For a typical study in experimental psychology the odds are only about one in two or three of finding (a) an apparent statistical effect that (b) is not random. In neuroscience the odds are usually lower. Thus, if a study fails to find an outcome that other studies predict, there is an excellent chance that the study is at fault.[7]

An essential part of science is discriminating meaningful results from meaningless results. Alas, journals rarely publish failures to replicate experiments—word of mouth is often the only way to learn of failures to replicate—and once a scientist enlarges his scope beyond the minutiae of his own research, where any paper is expected to discuss every other paper, he will be open to the charge of selecting his evidence to fit his conclusion.

But selecting evidence is not a scientific sin, it is a scientific necessity. Scientists must discriminate among studies based on a sophisticated understanding of statistics and methodology plus sufficient knowledge of a field to know where evidence converges. In science, sin does not lie in discrimination and selection, sin lies in applying prejudice to discrimination and selection.

sciences plus anthropology and the history of the major arts. Like all evidence of every kind, our body of evidence is not completely consistent, but we do not take inconsistencies lightly and we discuss the more important ones in endnotes. The body of evidence that we deem solid coheres along many dimensions.

Finally, we would like to end this introduction with a pedantic note on attributions. For brevity we sometimes use “we” to refer to only one of us, or—in the text but not in the endnotes—to refer to any set of colleagues and/or students with whom Daphne has collaborated. Also, in the text we ascribe studies to the lead author only. Almost every scientific study is actually a collaboration, so if you see only one name, please read an implicit *et al.* and check the endnotes if you want to know who the others are.

6

A Nose for Noise

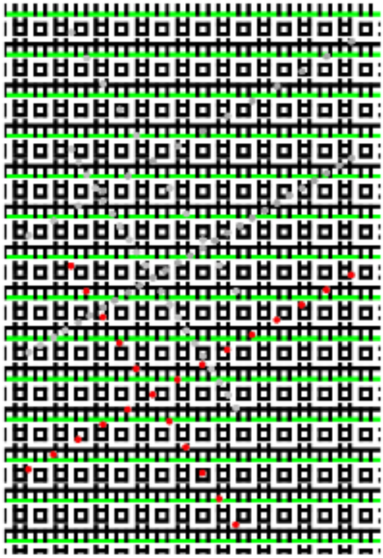
Categorizing Tastes, Smells and Colours

While we were writing this book we changed our telephone service. We switched from conventional telephones to voice-over-internet, from analogue signals sent through copper wires to digital packets sent through fibre optics. One of our first telephone calls on the new service happened to be from a violinist. “What’s wrong with your telephone?” he asked. “As soon as you stop talking, the line becomes silent. It doesn’t sound right.”

Nature abhors a vacuum and in a universe of noise and information, silence is equivalent to a vacuum. The nervous system has evolved within a universe of constant stimulation spanning a certain range, so it has evolved to function within that range. Inside the brain, every pattern of neuronal activity feeds directly into other patterns. This activity expends energy, so it requires a certain amount of chemical fuel plus the oxygen required to burn that fuel. Arterial structures make fuel and oxygen available constantly and the brain has no way to deal with a surplus, so the brain must maintain a normal level of activity even if that requires stimulating itself. Thus we dream and day-dream or, when sensory stimulation is lowered unnaturally in a psychology lab, we hallucinate. When sensory stimulation overall is within a normal range but is unusually low in some one area, we merely feel as though something is wrong. Thus to our musician, no auditory stimulation from the telephone sounded stranger than a low level of auditory stimulation carrying no information. The unexpected silence was more awkward than random noise.[1]

As the brain's structures evolved to expect a certain level of noise, its structures also evolved to detect signals through that noise. Some of these structures are synaesthetic reinforcements across sensory systems. You may not quite catch what somebody said but you are more likely to if you can see his lips, because the sight of his lips strengthens the sound.

At first blush this appears to be adding together redundant information—you hear a sound and see its source, so you add the two together—but combining senses actually *multiplies* information. For example, here are three crosses. The central cross is formed from twice as many dots as the left-hand cross, so it contains twice the density of spatial information. The red cross also contains twice the density of information but spread across two dimensions, space and colour. The next page shows the same three crosses masked with noise in both space and colour. The noise is enough to mask the two grey crosses but the second dimension, colour, allows the red cross to remain detectable. If the brain



merely added perceptual dimensions, then colouring the dots would be equivalent to doubling the number of dots.

This multiplicative mechanism is what enables police to catch drunk drivers. Every year at Christmastime, the police in Ontario erect roadblocks to look for drivers with sufficient alcohol in their blood to be charged with drunken driving. A driver stops and rolls down the window, the policeman looks inside the car, sniffs the air and asks the driver if she has been drinking. If he smells beer and the driver's speech is slurred, then the policeman has the driver blow into a breathalyzer. The police may stop one million cars and charge or warn 1000 drivers.[2]

To detect drunks, the police use a particular form of mathematical reasoning. They do this intuitively without using actual numbers, but we can follow their reasoning by inventing numbers. When a policeman approaches a car, the odds that this driver is drunk are one in 1000. When the driver opens the window, he smells beer. This raises the odds that the driver is drunk from one in 1000 to one in 100. The driver says that she has not been drinking yet she speaks unclearly. It is possible that the she is tired or has a speech impediment or is struggling in a second language, but drink is again a tenfold better bet. This raises the odds that the driver is drunk from one in 100 to one in 10. The policeman expects to test 10 drivers for every one charged, so he brings out a balloon.

Once a policeman stops a car, he calculates and recalculates probabilities as the evidence accumulates. In mathematical jargon the policeman makes a *Bayesian* calculation of probabilities. A mathematician does this precisely using a computer but all of us do it intuitively all of the time. To a large extent the neurochemical networks of the brain integrate with one another to function as a Bayesian calculator. That is why combining perceptual dimensions multiplies information, why the cross above stands out when it is red.[3]

TASTE

A young child will put anything in her mouth, including poisons, yet even before manufacturers and pharmacists started to use childproof packaging, remarkably few children ever swallowed enough poison to die. This is because our chemical senses have evolved as Bayesian processors that distinguish the relatively few things that are likely to be edible from the many that are not.[4]

Long ago our evolutionary ancestors evolved structures in the mouth and gut that respond to the most important categories of chemical that we might ingest, and instigate tropic responses that aid survival. We are aware of these structures in the mouth and call them taste buds. They influence what we swallow. The comparable structures in the gut we are unconscious of but they influence the release of digestive enzymes and may start us vomiting. Here are the categories. The + and – indicate innate attraction or repulsion.[5]

> **+ *Glutamates.*** Nuts, seeds, and meats contain glutamates—those foods with the highest concentration of calories. We sense glutamates as savoury and enjoy the sensation from birth. Cooked and fermented meats have especially strong concentrations, so they taste especially savoury, and this savouriness seems to have been instrumental in the prehistory of man. Tenderizing meat through cooking is probably what enabled early hominids to chew enough food to grow the brain to its current size. The taste buds for savouriness were discovered fairly recently by Japanese researchers, so this taste is often called by its Japanese name, *umami*.[6]

> **+ *Sugars.*** Sweetness signals calories and babies are born enjoying it. Sugars supply the calories in fruit and some sugars are formed when chewing starches.

> **+ *Salts.*** Our physiology requires salt and we lose salt through sweat, so man evolved a feedback system to regulate salt intake. A set of taste buds responds to salts, then low levels of the brain form a sensation of saltiness that is more or less pleasant, according to the body's need and experience. Babies evince this four to eight month after birth.[7]

– ***Acids.*** Many poisons are acidic, so taste buds have evolved to warn of acidity. These trigger the sensation of sourness and, in babies, a reflex to avoid it. However, most fruits contain acids and many fermented products are safe only when acidic enough. As we learn about these, we eventually come to enjoy some tart flavours like grapefruit or sour cream, depending upon the food or beverage and our experience.[8]

– ***Toxicants.*** It is possible to drink or chew a large assortment of poisons that are not acid, so our ancestors evolved taste buds to detect many of them. These taste buds trigger the sensation of bitterness and, beginning at birth, a reflex to spit out a bitter substance. However, just as we can learn to enjoy sour cream, so we can learn to enjoy bitter chocolate and coffee.

– ***Strong chemicals.*** Poisons may be potent enough to stimulate not just specialized taste buds but ordinary nerve endings. We feel these as burning and we may feel them first in the eyes. Children avoid such substances from birth but again, experience can overcome these aversions to a certain extent. Many people learn to enjoy raw onion on a hamburger or hot pepper in a stew.

These categories are so coarse and so approximate that they might not apply to an entire dinner. You might start with a succulent fish that is poisoned undetectably with botulism, then move to a tart salad alongside a spicy chili, both washed down with home-made mageu, which is deadly if insufficiently acidic. Bitter chocolate and espresso would make a nice finish. But although these categories imperfectly define what is edible, they are valuable nonetheless. Each of them represents an imperfect yet significant Bayesian indicator of nutrition or risk.

Smell, Taste and Flavour

Plants and animals are leaky bags filled with chemicals. The chemicals and seepage differ from one plant or animal to the next and from one minute to the next as a creature becomes fearful or hungry or horny, or when a plant becomes attacked by a predator. This seepage can be useful to other animals. To find food, to find mates, and to notice hidden predators, eons ago most animals evolved to identify trace amounts of these chemicals that escaped into the air.[9]

We sense chemicals in the air somewhat as we sense them in the mouth, although the sensors in the nose are more sensitive. These chemicals exist in three forms: (1) individual atoms, (2) bunches of atoms called molecules, and (3) tiny pieces of atoms called ions. You can visualize these as individual grapes, bunches of grapes, and loose grape seeds. All of these are vibrating and moving in every direction, like motes of dust floating in the air.

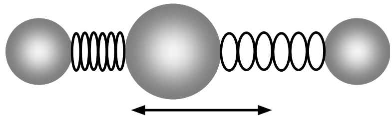
But these are not solid particles as we think of them. At atomic levels there is no clear distinction between a particle and energy. An electron, for example, is simultaneously a subatomic particle and the fundamental unit of electrical energy. We can imagine atoms more accurately if we think of them not as little solid bits but as little bundles of force—bundles of several sorts of force, including forces that resist other forces in ways that let us feel and measure mass.

If this seems incomprehensible, consider Parliament or Congress. The elements of these bodies are Members. Each Member is simultaneously a material body and a political force. As a material body, a Member cannot be divided into pieces. As a force, a Member is attracted to similar forces—he will often converse with other members of his party—but he is repelled by dissimilar forces, by Members belonging to other parties.

An atom is the smallest assortment of these forces that holds together stably, but usually an atom's set of forces is not maximally stable, so usually several atoms with complementary sets of forces clump together. These are molecules. A few molecules may also clump together into *ligands*, and many atoms or molecules may clump together into liquid or solid substances that we can see and handle.

At an atomic scale air is a sea of ions, atoms, molecules, and ligands. A chemist would categorize 78% of the molecules as nitrogen, 20% as oxygen, 1% as argon, and 1% as various miscellany. Amidst all of this, one molecule in a million or billion may represent something that we need to be aware of because it indicates something edible or poisonous. Those rare molecules we want to detect and discriminate among.

Our most rudimentary chemical detectors are the ordinary nerve endings at or near the surface of the eyes, nose, and mouth. Anything that bangs into one of those nerve endings with sufficient energy will set it off, including chemicals in the air. But more discriminating are systems that respond to specific combinations of a molecule's shape and vibrational structure. A molecule is held together by elastic forces, the subatomic equivalent of coiled springs. The atoms within a molecule bounce about. They swing one way and stretch the springs, then the springs contract and swing them back the other way, so that the oscillate like the pendulum of a clock, a clock that is kept wound forever by the energy of heat and, in the case of chemical receptors, by the energy of other molecules slamming into it.



The sensory tissue inside the nose is like a rocky stream with mucous replacing water. The rocks are proteins, large and complex molecules that cap the ends of sensory nerves. Ligands in air touch the mucous and are carried by it over the proteins. From time to time a ligand bumps against a protein with a complementary shape (i.e., a complementary set of forces) or a complementary rate of vibration. In either case the ligand sticks momentarily to the protein, and the momentary increment of force stimulates the nerve beneath. When this happens often enough, the brain detects an odour. Our taste buds work similarly, although the structures in our mouth are less sensitive and the ligands are carried by saliva rather than mucous.[10]

Chemicals in air enter the nose through both the front and rear entrances: the nostrils and the throat. Chemicals in water—food—we sense in the mouth. The neuronal signals from both the nose and the mouth pass through the same set of nerves into adjacent parts of the brain, where they merge into our perception of flavour. Of course they do not merge completely—we can smell things without tasting them when they are outside the mouth, and we can taste salt without smelling it—but for the most part taste and smell combine into a single perception.

Signals from the mouth and nose end up in the cortex of the brain alongside signals from the eyes and ears, so to some extent all of these signals are processed similarly. If you notice a bird in your peripheral vision and want to see where it is, you turn your head and eyes until both eyes bear on the bird and your sight of the bird is the strongest. If you hear a bird and want to locate the sound, you turn your head to the left and right until both ears pick up the sound equally and the sound is strongest. If you are a dog following a scent, then you will sniff to the left and to the right, and go where the scent is centred and strongest—*and if you are an undergraduate given the task of following a scent across a field, you follow the scent like a dog.*[11]

Chemicals seldom appear suddenly like a crash of thunder, they coalesce into gradients of concentration. A chemical's wafting and your moving and breathing cause concentrations to ebb and flow within your nose, so the energy impinging upon your sensory neurons ebbs and flows. Energy that ebbs and flows is a wave. Thus, much like sounds, smells are stimulated by waves, waves of chemical changes. Chemicals in the mouth create comparable waves of stimulation over the taste buds.

Smells and tastes change and develop over seconds. Flavours develop similarly. After swallowing a mouthful of wine, the flavour lingers for a time and gradually changes its characteristics as its constituent chemicals dissipate. One signal difference between a foul wine and a fine one is the development of these lingering flavours. A foul wine leaves a sour and/or bitter aftertaste; a fine wine evolves from one pleasant flavour to another as the phrases and lines of a song evolve.

Oenophiles enjoy sniffing wines, and some of them spend a lot of time discriminating among aromas and publishing the results in reviews. Unfortunately, every oenophile's characterization and categorization seems to differ, and to us at least, few of their descriptions seem intelligible. We used to think this a personal failing until we came upon a study of wine experts' terminology. Twenty-nine experts from New Zealand were asked for two words that best characterized the aroma of a particular chardonnay and a particular pinot noir. The next page shows the descriptors they chose and how often they used each descriptor. If you have ever failed to understand a wine critic's description—well, now you can see why you have had trouble.[12]

Oenophiles describe wines differently because human perceptions of odour do not fall into natural categories, not even when academics try to guide them. For example, a researcher at the University of California, Davis, worked out a standardized system of wine aromas "to facilitate communication among members of the wine industry."

Chardonnay

Description	Uses
Oak/oaky	10
Fruity	4
Butter/buttery	4
Minerally	2
Lime	2
Stonefruit	2
Milk	1
Wood	1
Toasty	1
Aged flowers	1
Mealy	1
Honey/floral	1
Grandmother's talc	1
Sweet	1
Ripe peach	1
Honey	1
Honey dew	1
Creamy	1
Nuts/cereal	1
Vanilla	1
Lemons	1
Banana	1
Sizzled butter	1
Syrupy	1
Herbal	1
Youthful/fresh	1
Malo/oak	1
Apricots	1
Citrus	1
Butter/cream	1
Fresh/crisp	1
Fresh	1
Peachy/buttery	1
Peach	1
Defined fruit	1
Smoothness	1
Ripe fruit	1
Oak/vanilla	1
Nectarine	1
Alcohol/hot	1

Pinot Noir

Description	Uses
Plum(s), plummy	7
Berry/berries	4
Cherry/cherries	3
Black cherry	3
Spicy	2
Black pepper	2
Blackberries	2
Jammy	2
Raspberries	1
Sun-dried tomatoes/savoury	1
Good sausages	1
Fresh	1
Cherry/plum	1
Savoury/mealy	1
Violet/floral	1
Berry/fruity	1
Fresh/clean	1
Volatile/acetone	1
Cassis	1
Dark berry	1
Strawberry	1
Nutmeg/spice	1
Smoky	1
Leafy	1
Geranium leaves	1
Sweetness	1
Tannins	1
Currant	1
Buttery	1
Nutty	1
Oaky	1
Earthy	1
Spicy oak	1
Pinot-like/Ribena	1
Liquorice	1
Brettanomyces [yeast]	1
Oak char	1
Green capsicum	1
Red currants	1

Twenty-nine wine experts used these descriptors when asked for two words best characterizing this pair of wines. The Chardonnay had been aged in oak.

Here is the standardized system. As you see, the subcategories of "fruity" include most of the fruits commonly seen in American kitchens and none of the many other fruits of the world. This may be a useful system but it is obviously artificial.[13]

Standardized System of Wine Aromas

Microbiological
- Yeasty
  - Flor-yeast
  - Leesy
- Lactic
  - Sauerkraut
  - Butyric acid
  - Sweaty Lactic
- Other
  - Horsey
  - Mousey

Floral
- Floral
  - Linalool
  - Orange blossom
  - Rose

Spicy
- Spicy
  - Cloves
  - Black pepper
  - Licorice, anise

Fruity
- Citrus
  - Grapefruit
  - Lemon
- Berry
  - Blackberry
  - Raspberry
  - Strawberry
  - Black currant/cassis
- Tree fruit
  - Cherry
  - Apricot
  - Peach
  - Apple
- Tropical fruit
  - Pineapple
  - Melon
  - Banana
- Dried fruit
  - Strawberry jam
  - Raisin
  - Prune
  - Fig
- Other
  - Artificial fruit
  - Methyl anthranilate

Herbaceous/vegetative
- Fresh
  - Stemmy
  - Grass, cut green
  - Bell pepper
  - Eucalyptus
  - Mint
- Canned/cooked
  - Green beans
  - Asparagus
  - Green olive
  - Black olive
  - Artichoke
- Dried
  - Hay/straw
  - Tea
  - Tobacco

Nutty
- Nutty
  - Walnut
  - Hazelnut
  - Almond

Caramelized
- Carmel
  - Honey
  - Butterscotch
  - Butter
  - Soy sauce
  - Chocolate
  - Molasses

Wood
- Phenolic
  - Phenolic
  - Vanilla
- Resinous
  - Cedar
  - Oak
- Burned
  - Smoky
  - Burnt toast/charred
  - Coffee

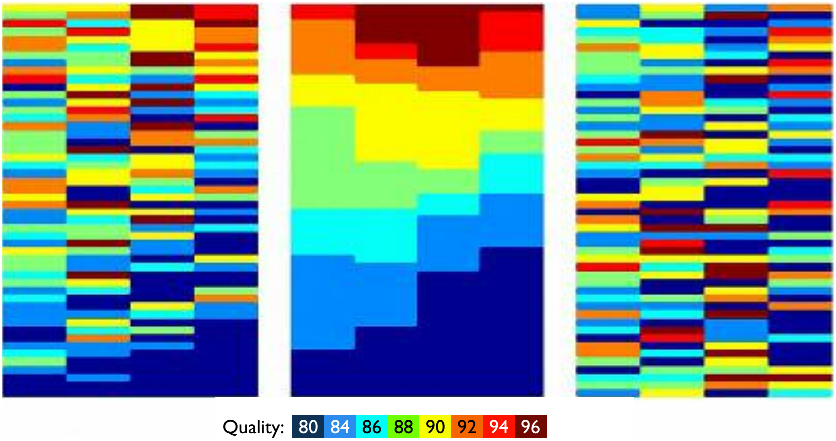
Earthy
- Earthy
  - Dusty
  - Mushroom
- Mouldy
  - Musty (mildew)
  - Mouldy cork

Chemical
- Petroleum
  - Tar
  - Plastic
  - Kerosene
  - Diesel
- Sulfur
  - Rubbery
  - Hydrogen sulfide
- Mercaptan
  - Garlic
  - Skunk
  - Cabbage
  - Burnt match
  - Sulfur dioxide
  - Wet wool, wet dog
- Papery
  - Filter pad
  - Wet cardboard
- Pungent
  - Ethyl acetate
  - Acetic acid
  - Ethanol
  - Sulfur dioxide
- Other
  - Fishy
  - Soapy
  - Sorbate
  - Fusel alcohol

Pungent
- Hot
  - Alcohol
- Cool
  - Menthol

Oxidized
- Oxidized
  - Acetaldehyde

The senses of flavour are so inchoate that even professional judges of wine are unreliable—inconsistent when rating multiple glasses of the same wine intermixed with others, and different from one judge to the next. For example, the left column below shows how four judges rated 50 wines at the California State Fair Commercial Wine Competition, before they discussed their ratings to arrive at a consensus. Each row is a wine, each column is a judge, each colour is a rating of quality. As you can see, they agreed on the two worst wines, and some of them agreed on other bad ones, but the rest are all over the map.



For comparison, the central panel shows how the results would have looked if the judges had agreed on which wines were the worst, which ones were best, and the order in between. The right-hand panel shows a set of random results. As the authors of the study conclude, "There is more randomness than consensus in wine ratings."[14]

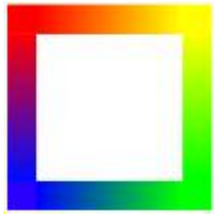
Elemental Tendencies

People tend to think that everything is composed of some number of basic elements. What we deem to be basic depends upon context and experience—we consider the elements of mayonnaise to be oil and eggs, not atoms of carbon, hydrogen, oxygen, etc.—yet the notion of elemental parts seems fundamental to our understanding of the world. Every educated person used to know that the body is formed of blood, phlegm, yellow bile and black bile; that the universe is formed of air, earth, fire and water; and that all Gaul was divided into three parts. Nowadays we know other things instead but the principle is the same: we perceive that everything is or ought to be divisible into elements.

This has engendered a continuing search for primary perceptions. However, it is one thing to break down a physical structure and another to break down a perception. Perceptions are the activity of neuronal pathways, and neuronal pathways are in constant flux. Energy impinges upon the body and then, depending upon the structure of the energy, it stimulates one or another set of sensory neurons. That particular set of sensory neurons releases a bolus of neurochemical energy into some adjacent neurons, beginning a chain reaction. The chain reaction follows the easiest route. The exact route depends upon where nerves feed into and through the brain plus extremely localized chemistry, chemistry that was formed by previous stimulation and is continuously being changed by other stimuli passing through the neighbourhood. For this reason, it makes little sense to look for fixed elements of perception, it makes more sense to search for elemental tendencies in how we process neurochemical energy.

Let's revisit the sense of taste taking this approach. Cellular structures on the tongue pass chemical energy into the nerves that serve the mouth. All of those structures will react to a variety of molecules but some of them are more responsive to specific molecular structures than to others—to the structures of sugars or acids or salts or alkalis, etc. Now, if you ask people in a lab to stimulate those structures by tasting a broad assortment of chemicals, you will find that the chemicals elicit tastes that people sort into six categories: salt, sweet, sour, savoury, bitter, and piquant. This demonstrates a natural, elemental tendency in how we process neurochemical energy.

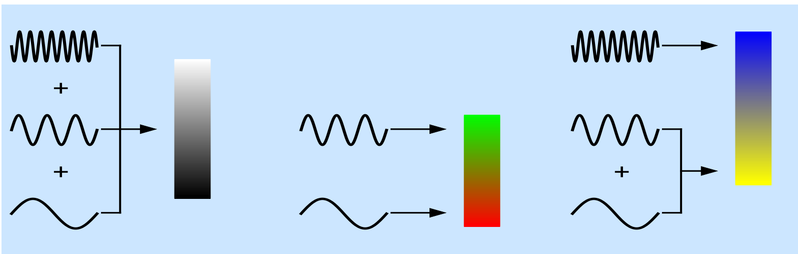
Another elemental tendency we see with colours. Psychologists have handed bundles of paint chips to people from many cultures, and asked them to sort the chips into colours. Invariably the chips end up in four piles: red, green, yellow and blue. Four-month-old babies see the same four categories. These four hues appear to be primary



in some way, and closer examination shows them to have a particular interrelationship. The primary hues at the corners of this diagram naturally merge into one another in these ways and only in these ways. We can perceive a reddish yellow reddish blue but we cannot perceive a reddish green.[15]

We see colours like this because the eye has evolved a peculiar mechanism for sorting out wavelengths. The light receptors we use in daylight are conical neurons called cones. Each cone contains one of three pigments. To some extent each of these pigments absorbs all the visible wavelengths of light, but they absorb the wavelengths differentially. One set is most sensitive to longer wavelengths, a second set is most sensitive to medium wavelengths, and a third set is most sensitive to shorter wavelengths. The signals from those cones feed immediately into neurochemical circuitry that adds and compares them. The box below shows how.

Wavelength to Colour



Left: brightness results from the sum of all the wavelengths. Centre: geen/neutral/red result from medium wavelengths compared to long wavelengths. Right: blue/neutral/yellow result from short wavelengths compared to the sum of the others.[16]

Note that this system evolved so that the short wavelengths have less import than the others. This is efficient. The sun emits less radiation at shorter savelengths, so there is little if any reason to respond to short wavelengths in the absence of longer ones.

Categorical Perception

Of the structural tendencies of human perception, perhaps the most profound is our propensity to divide the world into categories. All kinds of categories. Sweet wines/dry wines, classical music/popular music, art/erotica, liberal/conservative, fat/thin, rural/urban, smart/stupid—the list is infinite. Some of our categorizations are simple like those but others are remarkably complex, like the hierarchy of categories on the next page that describes your family dog to a biologist.[17]

But those are not the only categories we use for describing dogs. Kennel clubs distinguish different genres of dog—toy, hound, terrier, sporting, working, etc.—plus more than 500 distinct breeds, and of course everybody categorizes dogs in other ways as well, as large/medium/small, black/brown/white, quiet/yippy, playful/placid, long-haired/short-haired, healthy/sick, trained/untrained, friendly/aggressive, etc.[18]

Although we perceive these categories to be natural, when we look hard at individual specimens, it becomes clear that categorization lies more in the perception of the beholder than in nature. For example, Riesling comes in a continuous range from dry to sweet. Many pop songs are based on classical pieces. The serious artist Boucher painted sensual masterworks for *Madame la Pompadour*'s bedroom, to help King Louis get in the mood. Nor are scientific taxonomies always so clear on the ground as they are on paper. Given the chance, an appropriately sized *Canis lupus familiaris* will be able and willing to become familiar with 16 other species of *Canis lupus*, 14 of which are known as wolves. Indeed, it is difficult for ordinary folks to see why biologists deem a Siberian husky to be closer to a chihuahua than to a wolf.[19]

Of course our categories do reflect reality to some extent, but reality as it has been filtered and defined by our experience. Within the brain, when neurochemical energy passes along some route, that route changes chemically in a way that makes neurochemical energy coming nearby more likely to follow that route again and less likely to detour onto neighbouring routes. As additional bursts of neurochemical energy follow that route, the chemical changes become reinforced. This is the neuronal mechanism of category

A Biologist's Family Dog

Cellular organisms
- Eukaryota
  - Fungi/Metazoa group
    - Metazoa
      - Eumetazoa
        - Bilateria
          - Coelomata
            - Deuterostomia
              - Chordata
                - Craniata
                  - Vertebrata
                    - Gnathostomata
                      - Teleostomi
                        - Euteleostomi
                          - Sarcopterygii
                            - Tetrapoda
                              - Amniota
                                - Mammalia
                                  - Theria
                                    - Eutheria
                                      - Laurasiatheria
                                        - Carnivora
                                          - Caniformia
                                            - Canis
                                              - Canis lupus
                                                - Canis lupus familiaris

formation. It means that any given neurochemical reaction is more likely to be routed through network *A* or network *C* than through network *B* in the middle. This holds for small networks forming low-level sensations, it holds for large networks forming low-level perceptions, and it holds for networks of networks of networks that form our cognition and language.

This is, of course, the same mechanism as adaptation. Creating perceptual categories is how we adapt to stimulation that we have encountered before. For example, imagine yourself lost between the Amazon and the *Cerrado* (savannah) of Brazil, with no way to cook anything. You are starving but the only foodstuff you happen upon is cassava, a shrub you know to be bitter and poisonous when eaten raw. On the other hand, you also know that some cassava bushes have leaves that are only slightly bitter and can be eaten without evident harm. You are so desperate that you sample some. From a shrub here and a shrub there, you smell a leaf and sometimes take a bite. The bitterness comes from a poison, and the concentrations of poison in cassava leaves form a continuum, but instead of a continuum of cassava you will divide the leaves into two distinct categories, safe and poisonous, and you will be exquisitely sensitive to the degree of bitterness that forms the divide between them.[20]

This is a useful distinction to make but it is a curious distinction to be able to make. Instead of trying to imagine what cassava leaves taste like, consider coffee. In France a standard cup of espresso is about 25 ml and is brewed with 7 g of beans. In the centre of the United States, cafés use the same weight of beans to brew 10 times as much coffee. Between those extremes, the difference in bitterness is extreme. To a farmer in Nebraska, a French coffee tastes like poison, but a Frenchman will call the Nebraskan's coffee *jus de chaussettes*—the juice of socks. Each thinks the local concentration makes the best cup of coffee and the other extreme is not potable. Moreover, other people have different opinions. Their ideal cup of coffee has the same weight of beans making 60 ml of coffee, or 120 ml, or only 12 ml for an Italian *ristretto*. In their minds, each of these concentrations forms a category—a qualitative category, the category "good coffee."[21]

There is nothing whatsoever that makes any of these concentrations *qualitatively* different from any other—they differ *quantitatively*—yet any coffee drinker will be willing to describe any cup of coffee in qualitative terms, as good, or not so good, or bad. Any coffee drinker will take a point on this continuum of quantity and ascribe this point as the centre of a *qualitative* category. By any standard of logic, this is nonsensical, but although it is illogical, it is normal and natural: this point represents a neuronal network that has been etched more deeply than others by experience.

In fact, each of our sensory systems responds only to quantitative differences. Qualitative differences exist only within the brain. The qualitative differences of colour are induced within the brain by quantitative differences in the lengths of electromagnetic waves. Qualitative differences in sounds—timbres—are induced by quantitative differences in pressure waves. Qualitative differences in flavour are induced by quantitative differences in chemical pressure. Converting quantities into qualities is one of the fundamental functions of the brain.

To create categories, neuronal networks combine in complex ways, facilitating transmission here and inhibiting it there. We are reasonably sure that these mechanisms are deterministic, because we can create simple, deterministic models of neural networks in a computer and watch them develop categories in a human way. Of course these models are simpler than reality but we would expect the infinite complexity of real neuronal networks to be able to form in deterministic ways every category that we perceive.

Signal *vs.* Noise

We began this chapter by showing how combining several senses can clarify subtle signals by reducing noise. "Signal" and "noise" have specific meanings in specific fields of endeavour but a single broad statement subsumes them all: within a given context, anything of interest is signal and everything else is noise.

This distinction sounds banal but is not. To survive we must attend to things that might matter to us, and the only way we can do that is by ignoring things that probably do not. Human functioning—indeed, the functioning of any adaptive animal—requires constantly dividing sensory stimulation into things that might matter and things that probably do not. Within any given context, whatever might matter is signal and all the rest is noise. The absolute strength of a signal rarely matters, what matters is that a signal becomes evident as soon as it pokes its head above the noise.

Consider snakes, for example. Any snake large enough to harm you is large enough to be seen easily inside a cage at the zoo, but no snake is easy to see in the wild, because snakes blend in with the background. In the wild a snake presents just as strong a signal to the eye as it does in the zoo but in the wild, much of that signal is masked by noise. To survive in the jungle, our ancestors rarely needed to strain their senses to detect faint signals but they frequently needed to separate signals from noise. The same is true now in a city when crossing the street. We do not need to strain our eyes to make out a car that may run into us—that car will be big enough to see easily—but we do need to distinguish that car from all the other cars nearby. Or, from the driver's perspective, we need to distinguish somebody starting to run across the street from the parked cars and lampposts nearby. Discriminating signal from noise is so important that a neural mechanism evolved specifically for the purpose. This is the mechanism of attention. We began this chapter with it because it is also the underlying cause of categorization.

Let's journey back in time to visit one of our ancestors in Africa. It is nighttime. Our ancestor is asleep but hyenas and lions are not. The veldt is alive with noises but our ancestor needs to sleep through them—unless the noises are from hyenas or lions. Those noises must wake him up. This means that he needs to ignore most of the usual racket yet awaken at the slightest *unusual* noise. After morning comes, our ancestor walks down toward the river for a drink, and so do hyenas and lions. To avoid them he needs to look far ahead for mud-coloured patterns that stand out very slightly from the bank.

With both his ears and his eyes our ancestor needs to perceive signals that are embedded in a mass of noise. Both aurally and visually the ratio of signal to noise is low. Any structural propensity of the brain that could enhance this ratio would increase the likelihood of survival.

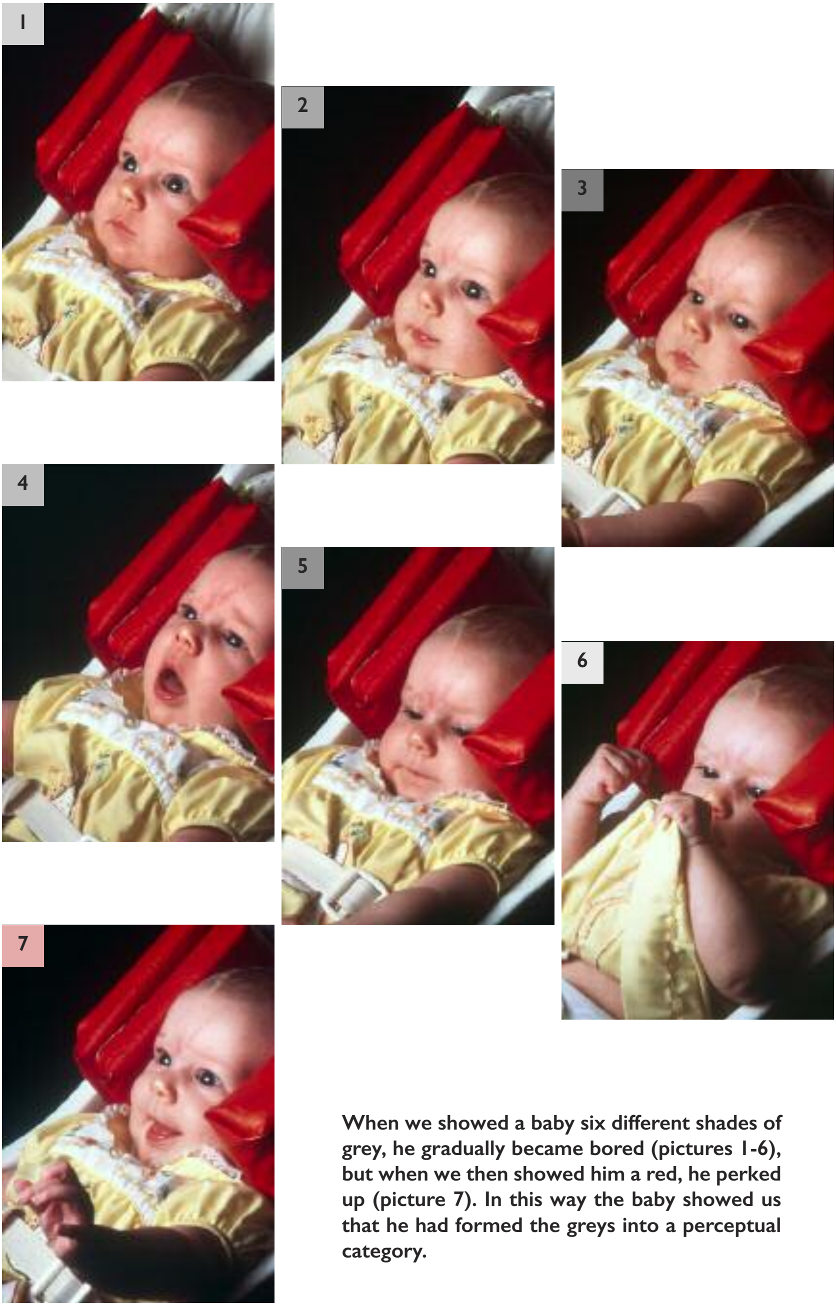
Low-level structures and functions evolved to do this. To see how, let's move our imagination to the city and look at cars. Imagine that you need to record how many cars of each colour drive down a busy highway. You realize that you are bound to make mistakes, so you ask some friends to help you out. You can employ them in two ways. The obvious way is to ask each person to do the same job, to check your work. However, if any one person is likely to average, say, one mistake in every 10 observations, then six people are likely to make six mistakes in 60 observations. The extra helpers will buy no improvement in the ratio of signal to noise. Better is to have each person look only for cars of a single colour then combine all of their results. Looking for a single colour is easier, so mistakes will be fewer. Both approaches will record all of the cars and colours, so both approaches will be equally sensitive to the signal, but specialization will lower the noise.

This is how the brain detects lions. Sensors within the eye react to spots of light—or rather, to changes in spots of light—and send neurochemical signals into the brain. Low levels of the brain aggregate those signals, sort them, and send them only a little higher, where neurons have evolved to react to lines in different combinations and at different orientations. If a number of these neurons suddenly fire, a change becomes obvious and a tropic reaction follows, a kick on the neurochemical accelerator. You start to attention. Now the firing reaches higher levels of your brain: you see a lion land on an antelope and tear open its throat. From this experience the neuronal pattern representing the shape of a lion becomes chemically etched in your brain. The next time you walk there, the sight of the place will spill energy into that neuronal pattern, thereby generating a memory, and you will react by boosting the neurological idle speed of the visual portions of your brain—i.e., by becoming more alert.

Adaptation

Attention, memory, and perceptual categorization are fundamental skills for an adaptive organism, so all three of these are evident at birth. If you show a young baby a sheet of grey paper, you will attract his attention, but if you show him one grey after another, he will lose interest. He will lose interest even if each of the greys is a different shade. He has remembered a succession of greys and formed them into a perceptual category. If you then show him red paper he will perk up. The next page illustrates this. A newborn baby behaves this way even though his visual cortex is barely functioning. These functions are built into the lowest levels of the brain.[22]

Once higher levels of the brain become involved and combine information from the lower levels, these functionalities merge into a



When we showed a baby six different shades of grey, he gradually became bored (pictures 1-6), but when we then showed him a red, he perked up (picture 7). In this way the baby showed us that he had formed the greys into a perceptual category.

complex perceptual stew. An adult does not merely stare at something, she interprets what she sees. To perceive a set of lines as the category *tiger*, an adult must remember what tigers look like and must pay attention to how the lines are similar and different from her memory. To remember what tigers look like, she must pay attention to how the lines resemble the category *tiger*. And to pay attention to similarities and differences she must remember the category *tiger*.

This sounds circular because it is. In adults the three functionalities form a logical circle:

- Perceptual categorization requires attention and memory.
- Memory requires perceptual categorization and attention.
- Attention requires memory and perceptual categorization.

Since each of these statements requires the other two, they form a logical unity. They are three faces of a three-sided coin, which looks to us like a single basic function of the neurology of the brain. We do not think they describe three distinct mechanisms of neuronal adaptation, we think they describe three views of a single mechanism.

Innumerable academic careers have been built on studying categorization, memory, and attention, examining specific characteristics under specific circumstances. This includes our own. However, when we concentrate on these details, we miss the larger picture. At a basic level it matters little to an organism which wavelengths of light most readily stimulate the eye, or which wavelengths the eye combines into categories, or which categories the brain most easily remembers. What matters is that the organism notice combinations of wavelength that differ *slightly* from others.

Very slightly. What matters is noticing that a vague hint of a stripe is not part of a tree. What matters is noticing this before a huge mass of colour charges you.

This is how the mechanism of adaptation helped higher animal species to survive and evolve. Since the mechanism of adaption is a function of the brain, under the hood it has a self-similar structure of neural networks, which enables it to function across a wide range of scales. At a coarse level it keeps us from walking into walls as a tropic automaton. At the other extreme it lets us notice a kink in a straight line that is finer than any line the eye can see. This mechanism, we are about to see, also forms a root of beauty.

Notes

Picture Credits

Picture credits are in the notes to the text where the pictures are discussed. Unless stated otherwise, all photographs and illustrations are by Charles Maurer.

The cover and frontispiece are from *The Enraged Musician* by William Hogarth.

Chapter 1: The Field of Beauty

1. Edmund Carpenter, *Oh, What a Blow That Phantom Gave Me!* (New York: Holt, Rinehart and Winston, 1973): 129. The photograph is a frame of Carpenter's film by the same name.

2. Kofi Agawu, "The Invention of African Rhythm." *Journal of the American Musicological Society* 48, no. 3 (1995): 380-395.

3. Sarah Bradford Landau and Carl W. Condit, *Rise of the New York Skyscraper, 1865-1913* (New Haven, Connecticut: Yale University Press, 1999): 24-25. René K. W. M. Klaassen and Jos G. M. Creemers, "Wooden Foundation Piles and Its Underestimated Relevance for Cultural Heritage." *Journal of Cultural Heritage* 13, no. 3, Supplement (2012): S123-S128.

4. An good introduction to Aristotelian logic is Louis F. Groarke, "Aristotle: Logic." *The Internet Encyclopedia of Philosophy*, ISSN 2161-0002, https://www.iep.utm.edu/, 12 May 2019.

5. Garlic "is always a rustic food, although it is sometimes artificially ennobled, as when it is inserted into the meat of roast goslings." Page 57 of Alberto Capatti, Massimo Montanari, and Áine O'Healy, *Italian Cuisine: A Cultural History* (New York: Columbia University Press, 2003). "Spice cupboard" from John Dickie, *Delizia!: The Epic History of the Italians and Their Food* (New York: Simon and Schuster, 2008): 6.

6. John P. A. Ioannidis, "Why Most Published Research Findings Are False." *PLoS Medicine* 2, no. 8 (2005): e124.

7. Marjan Bakker, Annette van Dijk, and Jelte M. Wicherts, “The Rules of the Game Called Psychological Science.” *Perspectives on Psychological Science* 7, no. 6 (2012): 543-554. When calculating statistical significance, it is easy to ignore aiming at nothing and aiming badly. It is possible to incorporate those factors into statistical analyses, but doing so usually causes the appearance of significance to evaporate. In a typical study of neuroscience with a small sample, a 5% probability of chance turns into an even flip of a coin. Katherine S. Button, John P. A. Ioannidis, Claire Mokrysz, Brian A. Nosek, Jonathan Flint, Emma S. J. Robinson, and Marcus R. Munafo, “Power Failure: Why Small Sample Size Undermines the Reliability of Neuroscience.” *Nature Reviews Neuroscience* 14, no. 5 (2013): 365-376. Denes Szucs and John P. A. Ioannidis, “Empirical Assessment of Published Effect Sizes and Power in the Recent Cognitive Neuroscience and Psychology Literature.” *PLoS Biology* 15, no. 3 (2017): e2000797. “Estimating the Reproducibility of Psychological Science.” *Science* 349, no. 6251 (2015): aac4716.

Chapter 6: A Nose for Noise

1. A classic study of sensory deprivation is William Harold Bexton, Woodburn Heron, and Thomas H. Scott, "Effects of Decreased Variation in the Sensory Environment." *Canadian Journal of Psychology/Revue canadienne de psychologie* 8, no. 2 (1954): 70.

2. In 2018 the Ontario Provincial Police set up 10,270 roadblocks. If we assume they stopped 100 cars per roadblock, that's roughly 1 million cars. They charged or warned 923 drivers. News release dated 4 January 2019 of the Ontario Provincial Police, "O.P.P. Charge More Than 500 Impaired Drivers during Festive Ride Campaign."

3. Bayesian probabilities are named for the Reverend Thomas Bayes, whose work on them was published two years after his death by his friend Richard Price in a letter to the Royal Society. Price presented Bayes's work as a proof of the existence of God:

"The purpose I mean is, to shew what reason we have for believing that there are in the constitution of things fixt laws according to which things happen, and that, therefore, the frame of the world must be the effect of the wisdom and power of an intelligent cause; and thus to confirm the argument taken from final causes for the existence of the Deity.... [Bayes] shews us, with distinctness and precision, in every case of any particular order or recurrency of events, what reason there is to think that such recurrency or order is derived from stable causes or regulations in nature, and not from any irregularities of chance." Richard Price, "An Essay towards solving a Problem in the Doctrine of Chances. By the late Rev. Mr. Bayes, F.R.S. communicated by Mr. Price, in a letter to John Canton, M. A. F. R. S." *Philosophical Transactions* 53 (1763): 370-418.

4. For example, among children under 10 in the UK from 1958 to 1977 there averaged only 30 deaths from poisoning per year. Neil C. Fraser, "Accidental Poisoning Deaths in British Children 1958-77." *British Medical Journal* 280, no. 6231 (1980): 1595.

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8. Y. B. Byaruhanga, B. H. Bester, and T. G. Watson, "Growth and Survival of Bacillus Cereus in Mageu, a Sour Maize Beverage." World Journal of Microbiology and Biotechnology 15, no. 3 (1999): 329–33.

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10. Richard L. Doty (Ed.), *Handbook of Olfaction and Gustation,* 3rd Edition (Hoboken, New Jersey: Wiley, 2015).

11. Jesse Porter, Brent Craven, Rehan M Khan, Shao-Ju Chang, Irene Kang, Benjamin Judkewicz, Jason Volpe, Gary Settles, and Noam Sobel, "Mechanisms of Scent-Tracking in Humans." *Nature Neuroscience* 10, no. 1 (2007): 27-29. For an overview of human olfactory capabilities see John P. McGann, "Poor Human Olfaction Is a 19th-century Myth." *Science* 356, no. 6338 (2017) doi:10.1126/science.aam7263.

12. Wendy V. Parr, K. Geoffrey White, and David A. Heatherbell, "The Nose Knows: Influence of Colour on Perception of Wine Aroma." *Journal of Wine Research* 14 (2003): 79-101.

13. Adapted from Ann C. Noble, Rich A. Arnold, John Buechsenstein, E. Jane Leach, J. O. Schmidt, and Peter M Stern, "Modification of a Standardized System of Wine Aroma Terminology." *American Journal of Enology and Viticulture* 38, no. 2 (1987): 143-146.

14. R. T. Hodgson, "An Examination of Judge Reliability at a Major U. S. Wine Competition." *Journal of Wine Economics 2008*, 3(02), 105-113. Jing Cao, "Quantifying Randomness versus Consensus in Wine Quality Ratings. *Journal of Wine Economics*, 9, no. 2 (2014): 202-213. The charts are corrected versions provided by Dr. Cao.

15. When adults are asked to sort a large number of chips into groups of those that go together, they always include these categories, plus black and white. They may also include subsidiary categories like orange, purple, and pink. This is the case regardless of the number of labels for colour that exist in the language they speak. Although linguistic terms affect sorting at the boundaries between these categories, they have little effect on the focal colours. Terry Regier, Paul Kay and Richard S. Cook, "Focal Colors are Universal After All." *Proceedings of the National Academy of Sciences* 102, no. 23 (2005): 8386-8391. Debi Robertson, Ian R. L. Davies, Greveille G. Corbett, and Marieta Vandervyver, "Free-sorting of Colors across Cultures: Are There Universal Grounds for Grouping?" *Journal of Cognition and Culture*, 5 (2005): 348-386. M. H. Bornstein, W. Kessen, and S. Weiskopf, "The Categories of Hue in Infancy." *Science* 191, no. 4223 (1976): 201-2.

16. M. D. Fairchild, *Color Appearance Models,* Third Edition. (Hoboken: John Wiley, 2013.)

17. National Center for Biotechnology Information <http://www.ncbinlm.nih.gov/Taxonomy/Browser/wwwtax.cgi?mode=Infoandid=9615andlvl=3andlin=fandkeep=1andsrchmode=1andunlock>. Retrieved 11 Aug. 2014.12.

18. At this writing Wikipedia lists 515 breeds. <https://en.wikipedia.org/wiki/List_of_dog_breeds> Retrieved 12 May 2019.

19. A Victorian biographer of Boucher wrote of these paintings, "In her [*la Pompadour*'s] hectic desire to keep the King from being bored—the King '*qui s'ennuyait*'—she stooped to the very deeps; stooped to drag down even the art of Boucher. She went to her favourite artist and begged him to employ his art's skill in the painting of a number of pictures in questionable taste…." These paintings now hang in London's Wallace Collection, where visitors view them as serious art without cracking a smile. Haldane MacFall, *Boucher, the Man, His Times, His Art, and His Significance, 1703-1770* (London: Connoisseur, 1908): 51.

20. "Although the…contents have a continuous character, the folk division has a dichotomous character". Page 1334 of Nivaldo Peroni, Paulo Yoshio Kageyama, and Alpina Begossi, "Molecular Differentiation, Diversity, and Folk Classification of 'Sweet' and 'Bitter' Cassava (*Manihot Esculenta*) in *Caiçara* and *Caboclo* Management Systems (Brazil)." *Genetic Recources and Crop Evolution*, 54, no. 6 (2007). Origins of cassava: Kenneth M. Olsen and Barbara A Schaal, "Evidence on the Origin of Cassava: Phylogeography of *Manihot Esculenta*." *Proceedings of the National Academy of Sciences* 96, no. 10 (1999): 5586-5591.

21. The formal standard for espresso is described in <http://www.espressoitaliano.org/files/File/istituzionale_inei_hq_en.pdf>. Bunn, who supply the coffeemakers used in most North American cafés and convenience stores, recommend 2 oz to 4 oz of coffee per 1/2 US gallon of water, which is 7 g per 117 ml to 234 ml. <http://www.nacsonline.com/YourBusiness/GettingStarted/Documents/CoffeeBrewingGuide_Bunn.pdf>. Both retrieved 6 April 2015.

22. The photographs show a two-month-old. We used this technique of habituation

at different ages to explore the development of many perceptual categories. R. Adams, D. Maurer, and M. Davis, “Newborns’ Discrimination of Chromatic from Achromatic Stimuli.” *Journal of Experimental Child Psychology*, 41 (1986): 267-281.