JACOBSON'S ORGAN

AND THE REMARKABLE NATURE OF SMELL

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THE PENGUIN PRESS

The most mysterious, the most human thing, is smell …

COCO CHANEL, in *Her Life, Her Scents*

Contents

Right under our noses

We have a nose for things. We sniff out problems and follow our noses, moving to a successfu conclusion in directions that are often far from obvious. And yet we persist in belittling our olfacto abilities, dismissing the human nose as a blunt instrument.

It is true that most animals have a more acute sense of smell. Dogs are a million times more like to pick up social scents, hedgehogs ten thousand times better equipped for finding food. But, eve with olfactory centres that occupy just one-thousandth of our cranial capacity, we humans a remarkably good at detecting, recognizing and remembering odours.

We can identify our relatives by smell alone, or follow the menstrual cycles of our friends ar lovers. We can diagnose disease, detect danger, and distinguish between good and bad food just wi our noses. We know, along with Rousseau, that 'Smell is the sense of memory and desire.' We realiz with Diderot, that smell is the most voluptuous sense. And we acknowledge the truth in Helen Keller contention that smell, while representing the 'fallen angel' of the senses, nevertheless remains 'potent wizard that transports us across thousands of miles and all the years we have lived'.95[*]

So why the ambivalence? It seems we are missing something. I think we are, and I believe I kno what it is. It is an obscure body part. One that has been there, right under our noses, all the tim Science has known about it since 1811. Biologists are familiar with it as the structure in the roof of snake's mouth which 'tastes' molecules collected by the reptile's flickering tongue. And a fe dedicated anatomists have tracked down something similar in the nasal passages of possum anteaters, bats, cats, rabbits, and even a white whale. But, though this body part was also discovere and described in humans a century ago, it has since mysteriously disappeared from the textbooks.

There are passing mentions of it in medical and technical journals dedicated to comparativ anatomy and olfactory physiology, where it tends to be dismissed as something vestigial, a anatomical ghost that makes a transitory appearance in the human embryo, vanishing well befo birth. And yet it still exists: a study in 1991 of a thousand randomly selected adult human subjec found it in the noses of almost every one.

This elusive feature is the Organ of Jacobson, named after the sharp-eyed Danish anatomist wh discovered it nearly two centuries ago. It is easy to miss. The external evidence consists simply of pair of tiny pits, one on either side of the nasal septum, a centimetre and a half above every huma nostril. But the fact that it does exist changes everything. With it, we reinherit the possibility of powerful and ancient chemical sense: an ability to enter once more into a system of sublimin signalling that continues to give other animals access to a world we thought we had lost as a result our emphasis on sight instead of smell.

Jacobson's Organ rescues our most underrated sense from obscurity. But it is not simply supercharger, making us more sensitive to odours. What it seems to do is to open up a channel qui separate from the main olfactory system. It feeds an older, more primal area of the brain, one th monitors airborne hormones and a host of other undercover patterns of information, makir physiological changes that have profound effects on our awareness, on our emotional states and on o most basic behaviours. Recent research suggests that this system could be the mechanism necessa for operating a true 'sixth sense', one that may account for our sometimes apparently supernatur ability to receive information not normally available to the traditional five faculties.

If all this is true, Jacobson’s Organ could be the most important key to unravelling the mysteries o our ~~minds since the discovery of the unconscious. As an evolutionary biologist and anthropo~~logis that possibility excites me enormously.

Aristotle associated the four fundamental elements of earth, air, fire and water with the four bas senses of sight, hearing, touch and taste. But he also recognized a fifth element, the most essenti substance of all, called *quintessence* – and connected this to the sense of smell. That, he suggested, la at the heart of perception, linking the other four senses. Ever since then, five has been the establishe number of the senses in Western culture. I have no argument with Aristotle, but I believe it is time t extend his fifth sense, already at the centre of awareness, into new areas, expanding smell in ways th give our Cinderella sense its proper due.

Lyall Watso
Castlemehigan, Ireland, November 199

PART ONE

GETTING ORGANIZED

Smell is the forgotten sense. There are no agreed measures of its nature, no societies dedicated to i ~~appreciation, no descriptions of it except those borrowed from our overbearing sense of sight.~~

Smell is our most seductive and provocative sense, invading every domain of our lives, providi the single most powerful link to our distant origins. But it is also mute, almost unspeakable, defyi description and collection, challenging the imagination. All that stops it slipping entirely through th net of language is a few brave attempts to pin it down – beginning with the work of a very tidy-mind Swede.

Carolus Linnaeus (1703–78) was the Great Indexer. He studied medicine at Uppsala University, b his heart was always in botany. He began his green studies with a survey of all the flowering plants Lapland, completing this task in 1737 with the aid of a revolutionary new system of defining a describing every species. And during the next twenty years he engineered a huge expansion in natu history, publishing his *Systema naturae* and docketing everything in sight, changing for ever the w we think about the world around us.[114]

Knowing the names of things gives us power over them: the power to isolate them from nature. Th separation remains artificial but also extraordinarily useful, making it possible for us to set the tre aside for a moment and concentrate instead on the composition and coexistence of the fore Labelling is an essential first step in coming to terms with ecology, and Linnaeus, in his fever catalogue all of existence, applied his art even to the elusive world of smells, scents and stench There were, he decided, seven major classes of odour, ranging from the pleasant to the unpleasa from those he described as 'kindly and desirable to our nerves and even to life itself' to those th were patently 'repellent to life'.[115]

Linnaeus published *Odores medicamentorum* in 1752 and there have been dozens of attempts duri the last two and a half centuries to refine this system, approaching it from the vantage points psychology, chemistry, physiology and perfumery. Some of these refinements are convenient f cosmetic chemists and those working in the fragrance industry, but even the most sophisticated ne taxonomies are unsatisfactory and inconsistent in the end. They founder on the accidental nature most smells and on the lack of a specialized vocabulary for the act of smelling in any language.[115]

There is no semantic tradition, no critical study of the origin and function of words used to descri smells in any country, and no learning process in any culture assigned specifically to the sense smell. So I find myself returning, time and smell again, to the classification provided by the m whom novelist John Fowles calls 'The Great Warehouse Clerk of Nature'.[57] And finding solace, ev a surprising new depth of meaning, in the resonant succession of Fragrantes (fragrant), Hircin (goaty), Ambrosiacos (ambrosial), Tetros (foul), Nauseosos (nauseating), Aromaticos (aromatic) a Alliaceos (garlicky).

Linnaeus was far more than just a pigeon-holer. He was a master organizer, sorting out and tidying the unruly strands of life in all its guises. But he was also wonderfully intuitive at it, coining nam and creating patterns which for the most part still work, and which help to reveal real relationshi and affinities where none are immediately obvious. He enriched sight with insight and gave tantalizing glimpses of a grand design. It was he, of course, who gave us a place in the natural worl

He allowed us to be *sapient* – which refers to someone who is not necessarily ‘wise’, but mo properly and modestly ‘would-be-wise’ – perhaps by coming to our senses.

In the Andaman Islands, the Ongee people consider smell not as an isolated sense, but as fundamental cosmic principle. For them, odour is the source of personal identity. It produces life an causes death. When Ongee – or anyone in modern Japan – refer to ‘me’, they put their forefinger o the tip of their nose. That is where the spirit resides, and too much or too little of it can cau problems. A healthy person is one who has their smell ‘tied tightly’. Losing your odour entirely ca kill you.[29]

The ideas of life and breath and spirit and smell are intertwined in many cultures. Some Mexica still believe that the smell of a man’s breath is more responsible for conception than his semen is. An in the Andamans, they tie everything very tidily together in a tradition of communication by sme which they call *mineyalange*, which literally means ‘to remember’.

Nothing is more memorable than a smell. Ask anyone to recall a childhood home or friend, and th details are likely to be sketchy. But provide just one whiff of a familiar scene, and the memories com rushing back, not piece by piece, but as a whole, with all the flavours of the original experien miraculously intact. And the effect is explosive. As Diane Ackerman says, ‘a complex vision leaps ou of the undergrowth’.[1]

Indeed it does. Perhaps this is because smell is the only sense you can’t turn off. You can close you eyes, cover your ears, refrain from touching or tasting. But we smell all the time and with eve breath, twenty thousand times a day. And if I am right about Jacobson’s Organ, all that information filed away somewhere – not in the grey matter of the conscious brain, which is far too busy wi things of the moment, but in the warehouses of long-term memory, in those parts of the brain mo touched by sensibility than mere sensation. There is a big difference between sense and sensibilit And because my exploration of a possible sixth sense will take in several kinds of olfacto experience, it is important here, at the outset, to know something about how smell works.

Noses are conspicuous. They hold centre stage on our faces, reaching out into the world, demandi attention. We don’t count mouths, we count noses. We look down them, pay through them and run th risk of having them put out of joint.

We breathe through our noses, warming incoming air, but any simple opening would have suffice for that. What we have instead is an exaggerated profile involving a canopy supported by a clear purposeful piece of cartilage. This keeps the rain out, deflects water when we swim, and may even ad resonance to our speech, but functionally it has most in common with a ventilator hood – somethi like an air scoop fitted to the deck of a boat. The nose projects away from the olfactory confusion the face, avoiding self-smelling, inhaling the rest of the news. Testing the air for early warnings giv those who stand guard, usually the men, noticeably larger nasal structures.

All our noses are alike inside, opening into a pair of cavities separated by a septum. These a surprisingly large vaults, occupying almost as much space in the skull as our famously big brain Most of this is air-conditioning apparatus, divided up into three horizontal chambers by thin, scroll bones covered in vascular tissue which expands and shrinks in tune with a variety of reasons an

seasons. So the flow of air through the left and right nostrils is seldom equal, giving us alternati
~~rather than parallel passages, and creating conditions which are always turbulent. Perhaps, again~~, wi
good reason.

High on the roof of the two upper chambers, roughly on a level with our eyebrows, there is a pat of yellowish tissue in a pair of clefts. Each patch is just one centimetre square. Put together, the pa would fit on a postage stamp, but both are richly endowed with several million fringed receptor cell This is where smells are collected.

The position of these olfactory epithelia, hidden away in the back of the nose, seems awkwar Logically, they ought to be out there where the action is, bathed in a constant stream of air. But lik the other sense systems, the olfactory organ needs variety. Just as spontaneous tiny eye movemen provide an essential variation of stimulus to the retina, so the nose thrives on subtlety and change. lies in wait for a whiff of something new and interesting, and then it demands attention – and w wrinkle up our noses and sniff.

Smell is a chemical sense. What the receptor cells in the nose do is translate chemical informatio into electrical signals. These travel along olfactory nerves into the cranial cavity, where they gather the olfactory bulbs. These, in turn, feed the cerebral cortex, where association takes place an nameless signals become transformed into the fragrance of a favourite rose or the musky warning an irritable skunk.[5]

Trained noses can identify hundreds of thousands of odours, far more than our minds can describ Smells sit right on the tops of our tongues and linger there, because we cannot utter their names. It almost impossible to describe even the most familiar scents to someone else who has never smelle them. And part of this confusion exists, I believe, because of the way we ourselves experience them.

The odour-to-nose-to-brain sequence I have just described in very bald terms is *not* the only way w smell. Our nasal chambers are connected to the outside air directly through the nostrils, and indirect through the throat by 'inside air' that comes perfused with the flavours of food and drink, and th products of digestion. All this information goes to the olfactory bulbs of the brain. But riding on th side of each of these swellings in our heads are other smaller lobes called the accessory bulbs, whic get their news of the world from an altogether different source: the twin-tubed Organ of Jacobson.

Twenty years ago, hardly anyone believed in such a thing. There were old reports from Victoria anatomists, but the modern anatomical consensus was that humans don't have such an organ. All th changed at the University of Colorado in 1991. Bruce Jafek was a practising surgeon then, specializin in nose jobs, until he became curious about Jacobson's Organ. He and microscopist David Mora devised a simple nasal speculum to help in the search, and by laying people on their back and shinin a light up their nose, they discovered the organ in every one of the two hundred people the examined.[129]

Once you know exactly where to look, finding it isn't difficult. The openings can usually be see with the naked eye as tiny, pale pits, near the front of the nasal septum, about a centimetre and a ha in from each nostril, just above the floor of the nose. Sometimes the pits are relatively large, a coup of millimetres across; sometimes a binocular microscope is necessary to find them. But everyon regardless of age, sex or race, has a pair – unless you have had the sort of cosmetic surgery whic removes that part of the nasal septum entirely.

These pits lead to two short tubes equipped with sensory cells quite different from those in norm olfactory tissue. Moran said, ‘They don’t look like any other nerve cells I have ever seen before in th human body.’[214] But in 1990, physiologists Luis Monti-Bloch and Larry Stensaas, of the University Utah, examined a further four hundred subjects and found that all of them had such twin tubes, an every one they tested was indeed using these organs to send messages to the brain.[128]

But the most interesting thing is that Jacobson’s Organs are not receptive to ordinary odours. The respond most often to a range of substances which have large molecules, but often no detectab odour. And they communicate not with the olfactory bulbs and the cortex, but with the accessory bulb and that part of the brain that coordinates mating and other basic emotions. Recent evidence sugges also that the two separate and parallel systems of odour detection cooperate in surprising ways produce novel sensibilities not achievable by either of them on their own.

Moran, Jafek, Stensaas and Monti-Bloch are now part of a small group of distinguished scientis who believe they have discovered a new sense organ, one that detects chemical signals previous thought to be beyond the scope of human sensitivity. They call it the *vomeronasal organ*, rather tha Jacobson’s Organ. But by any name it has put them at odds with conservative physiologists an neurologists who want more concrete evidence, preferably from humans willing to have dyes injecte into their systems, so that their brains can later be scanned to see where the tracers end up. Such foo dragging in the face of facts has a familiar feel to it. The last time I saw anything like it was in th 1960s, when diehard geologists made last-ditch stands against the tide of continental drift.

I am impressed by the evidence we already have for an organ I continue to credit to its Danis discoverer, and I am fascinated by the potential it has for all students of the unusual. The Organ o Jacobson seems to feed the primitive brain. It is not our olfactory link to consciousness, but rather chemical clearing house for subliminal impressions, for all the things that lead to what science writ Karen Wright calls ‘bad vibes, warm fuzzies, instant dislikes and irresistible attractions’.[214] Just th sort of will-o’-the-wisps with which any decent sixth sense ought to be concerned.

But before exploring the stranger fringes of the sense of smell with this in mind, I want to do what good evolutionary biologist should, and look back, with the help of Linnaeus, on how it all began.

Fragrantes

For this group of odours, Linnaeus specified floral sources such as jasmine, saffron and wild lime all of which are distinctly perfumed.

But there is something in his description which suggests that, as a Latin scholar, he was aware o possible confusion between the verbal roots fragrare ('to smell'), and flagrare ('to burn') and felt th both were appropriate.

Saffron is not just fragrant, but also fiery, glorious, even gaudy, giving Alexander Pope good reaso to describe the fleet in which Odysseus set sail as 'a cruise of fragrance, *formed of burnished gold*'.

Saffron is a crocus. Crocus *is the Chaldean name for the iris family. And Iris is the Greek goddes of the rainbow and messenger of the gods.*

There is more than enough biological and mythological coincidence in all this to keep a classic scholar happy and to augur well for the evolution of a sense able to appreciate something both brig and beautiful.

1

A nose is born

Smell was our first sense. It is even possible that being able to smell was the stimulus that took primitive fish and turned a small lump of olfactory tissue on its nerve cord into a brain. We thin *because* we smelled.

The argument is simple. Before sight and sound hijacked our attention, we shared with all life a so of common sense, a chemical sense that depended on direct contact with matter in the water or the ai And for 90 per cent of our time on Earth, that was how things worked.

Then the emphasis shifted. We learned to live instead with waves of energy, making sense of chao and becoming conscious. Which, of course, was a good thing … but we need now to go back and pi up some useful talents that we abandoned on the way.

Four hundred million years ago, in the Devonian period, fish were the most important and advanc animals on Earth. And the most abundant of them were jawless, heavily armoured forms, filterin their food out of thick coastal muds. Theirs was a world of direct sensation. Behaviour was simpl Any unusual stimulus, a bright light, a loud sound, any abrupt contact, produced much the san response: one of aversion. They pulled back and tried again later, taking life one taste at a time.

In the beginning, it was difficult to separate taste and smell. In the mud, sensation followed contac You bumped into things and then tested them to see whether they were worth avoiding or eating. Th tests were chemical ones, made by cells designed to analyse molecules dissolved in the water.

Many crustaceans still work this way, using cells on their legs which respond only to amino acid providing a ready distinction between organic and inorganic matter. Filter-feeding fish didn't need be much more discriminating, extracting what was useful from the mud and rejecting the rest. B instead of just oozing around everywhere with their jawless mouths wide open, it would have helpe these mindless pioneers to have some way of finding the most nutritious muds. What they needed w the ability to test and taste from afar – and that is where smell comes in.

Smell is a long-distance sense, a way of stretching time and finding out in advance what lies ahead. expands both awareness and opportunity, providing a need for analysis that normally never touch the lives of bottom feeders. But it was, in fact, one of those mudsuckers that made the big leap. Ar the result is visible still, frozen in the life histories of a few modern species of jawless, limbles boneless and often blind hagfish and lampreys.

Hagfish are patient scavengers, spending most of their lives embedded in soft mud with only the blunt snouts protruding, waiting for the same chemical signal that attracts crustaceans to putrid fis

But these primitive fish have an advantage over lobsters and shrimps. They have a single openi ~~above the mouth that leads to a paired chamber in which scents can be isolated, analysed and perhap~~ even located. They have, it seems, the world’s first noses.

Armed with these secret weapons, hagfish have flourished. At least twenty species survive, some s well that they have become a nuisance to modern fishermen, burrowing into catches of haddock ar cod and consuming netted fish from the inside out, turning them into bags of bones. Hagfish s nothing, but clearly smell very well, swimming up a gradient of fishy flavours, travelling wi undulating movements, turning always in the direction of the strongest stimulus, choosing the rig odour corridors, keeping on going until they get there.

Their relatives the lampreys have refined the process even further, responding instinctively to ju one aromatic chemical that forms part of the normal body odour of live schooling fish such as trou Sensing this, they left their muddy larval haunts, developed functional eyes, and now actively purs and parasitize such hosts. Once within range, the swift eel-like lampreys use their rasping teeth to ho on to any soft part of a trout, sucking out its body fluids like aquatic vampires, keeping their victim blood flowing just as bats do, with anticoagulants in their saliva.[102]

The unpleasant habits of round-mouthed hagfish and lampreys are vividly described as ‘suctoria Theirs is a mode of life made possible by having gills which open directly into the throat, so that the can continue to respire while still sucking blood. They are sufficiently well adapted in this respect have survived for over four hundred million years, despite their many other primitive features. B there is one important way in which they have changed: they have not only noses, but also a *nos brain.*

The nervous system of these suckers is rudimentary. There are no sympathetic or autonomic nerves all: none of the networks which, in more modern vertebrates, serve the intestine, the liver, all glan and the heart. But the nerves from the nose gather in a bundle in the head which is already substanti and beginning to spread out sideways, expanding in direct proportion to its employment. The mo exciting feature of this growth is that, even in this early stage, it is starting to take on the shape something new. It is a burgeoning forebrain, bursting into life in direct response to an olfactory need

In a habitat where sight is limited and sound cannot be localized, only smell can pick up traces th provide solid information from afar. But smell on its own is not enough. There has to be a way telling where a smell is coming from. Hagfish and lamprey put themselves into an odour corridor b swinging their bodies from side to side, sampling water on a broad front with their single nas opening. But most later fish have two external ‘nares’, or nostrils, and practise ‘stereo smell’, whic improves with the distance between the openings. The wider the head, the better the chance smelling in stereo. And somewhere in the space between the nostrils, there was room for coordinator: a place where information about smells could be analysed and acted upon.

Fish live in an environment where even substances that are only partially soluble find their way chemically sensitive areas of the body, making it possible for extraordinary feats of detection. Th Common European eel, for instance, has been shown to have a very uncommon affinity for son alcohols, responding to just a few molecules at a time in concentrations as low as one part in 10^{1} This represents the sort of dilution you would get by tipping a single shot of vodka into a body water the size of Lake Erie.[189] These eels are, of course, teetotallers. But they spawn and die in th depths of the Sargasso Sea, leaving leaflike larvae to make their own way, unguided, across fiv thousand kilometres of open ocean, back to ancestral haunts in the pools and lakes of Poland an Germany, in a journey that lasts three years. How they do this remains mysterious, but it seems have something to do with smell.

Experiments with salmon show that they are able to distinguish between plain water and water which an aquatic plant has been briefly rinsed. Young salmon probably imprint on the particula flavours captured by their home streams from the unique combination of plants that grow only in th watershed. It is difficult to imagine how young eels manage without such crucial early experience, y they do. They are driven by instinct, and by the presence or absence of just a few special molecules, make decisions on which the very survival of their species is at stake.[74]

Smell *is* stimulating. It stirs things up and makes us nostalgic – a wonderful word which literal means ‘ache for home’ – which serves to inspire new circuits in the brain. Enough, in simpler specie to form a simple nose-brain. In migratory fish such as salmon, this centre has split into a paired orga more befitting species that have begun to perceive and to perform bilaterally. These are the *olfacto bulbs.*

Many sharks find their food by smell. If water in which live fish have been kept is siphoned into shark tank, the residents respond with hunting behaviour. And if the stream comes from injured dead fish, they can be provoked into a feeding frenzy. The excitement of the sharks increases direct with signs of stress from their prey. They detect and respond to the smell of trouble, and do so wi extraordinary accuracy. In one experiment with a white-tip shark, an injured fish was allowed to swi the length of a tank before taking cover. When the shark was released soon afterwards, it followe exactly along the same zigzag line, duplicating every movement made by the now-invisible prey.[190]

It seems that smell leads these predators to their prey from a distance, but the final move, the ki may be triggered by another sense. For some species, in clear water and in daylight, this is ofte vision. In others it may be pressure waves detected by sensory cells along the flank. But in sma bottom-living sharks such as the spotted dogfish, the focus appears to be a weak electrical fie produced by another fish’s muscles. And all these impressions seem to be enhanced by smell, eve linked with it in some strange way.[91]

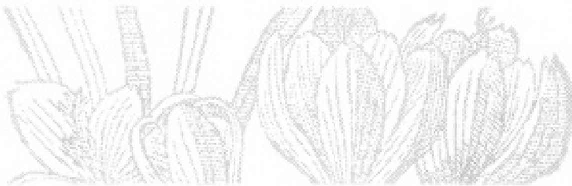
Such synesthesia, the blending of one sense with another, is vital. Even in the lives of fishe sensation is seldom a matter of one thing or another. Senses overlap. The lines between them ofte tend to be blurred, and the best that we can manage, by way of description from the outside, is to sa that the senses of fishes appear to dominate one at a time.

In the case of the spotted dogfish, smell slides seamlessly into an awareness which, if the fish cou tell us, it might have to describe as a flavour rather than an odour. I find it fascinating that this ver dogfish is renowned for having a forebrain which is not only large, but also equipped with a pair swollen olfactory bulbs, each proportionately larger and better differentiated than those of almost an other fish. It is well prepared for blurring sensory boundaries in the same way that we, when face with perceptual confusion, resort to metaphors, talking of ‘loud smells’ or ‘bright sounds’.[177]

Dr Johnson experienced the colour scarlet as ‘the clangour of a trumpet’, and the poet Rimbau described the sound of the vowel *a* as ‘a black hairy corset of flies’. And it can be no coincidence th natural synesthetes, those who experience intense sensory crossovers on a regular basis, hav problems with their limbic systems – those areas of the brain that, in mammals, grew out of the o olfactory bulbs.

One physiologist has even described human sensory blenders as ‘living cognitive fossils displaying a memory of how our early vertebrate ancestors once saw, heard, touched, tasted an smelled.[119] It is a fact, too, that our cerebral hemispheres, those walnut-folded swellings of gre matter that dominate the forebrain and now control most of our conscious behaviour, also develope directly from olfactory tissue.

The limits of sensory evolution in fish are defined very largely by their habitat. Water is physicall supportive, carries some kinds of odour well, and is kind to sound – letting it travel several tim faster than air will allow, but it inhibits other more personal kinds of communication. Much mo becomes possible when scents are released into the air. Breathing air is a liberating experience. freed our ancestors from the constraints of staying wet or having to remain within easy reach of wat for refuge, respiration or reproduction. But the biggest change it made in our lives was to expose us a whole new range of sensory experience.



Air is traditionally ‘thin’, but the more we learn about our atmosphere, the more substantial becomes. In some places it is so filled with inorganic flotsam that it is almost thick enough to ploug in others, it has become so primed with the by-products of life that it comes close to being a livin tissue in its own right. Even the cleanest air, at the centre of the South Pacific or somewhere ov Antarctica, has two hundred thousand assorted bits and pieces in every lungful. And this count rises two million or more in the thick of the Serengeti migration, or over a six-lane highway during rus hour in downtown Los Angeles.

Most airborne material consists of minute particles of salt, clay, and ash from forest fires an distant volcanic eruptions. And mixed in with, or growing on, or simply being carried along by th fertile soil is a garden of exotic flora and fauna. Every lungful of air we borrow from this gruel likely to contain a few stray viruses in transit between their hosts; four or five common bacteria; fif or ~~sixty fungi, including several rusts or moulds; one or two minute algae drifting in from the~~ coas and possibly a fern or moss spore, or even an encysted protozoan.[202]

All of which is inevitable. This is, after all, the stuff of life. We share our planet quite naturall with a permanent aeroplankton; a buoyant ecology too soft to hear, too small to see, but heavy wi mood and meaning. Imagine being aware of all these airy inclusions – and you can begin understand how it might feel to be able to smell really well.

Air-breathers do things differently. Their olfactory sense cells lie, not in isolated nasal sacs, as fishes, but strategically placed in a nasal passage, a thoroughfare through which air passes on its wa to the lungs. And that simple fact gives noses a new slant. The difference is most dramatical demonstrated in an intermediate animal, one that has a nose in both worlds, something like a frog or toad that is amphibious, literally leading a double life. The African clawed toad is the white rat of th arena.

Every gynaecological laboratory has one, largely because it provided the first reliable way testing for human pregnancy. An unfertilized female toad lays eggs within hours of being injecte with urine containing hormones that are characteristic of newly pregnant women. But these smoot streamlined, strange-footed toads – whose triple claws are used for digging for food on the bottom South African ponds – are rapidly becoming equally popular with geneticists.

At the Institute of Zoophysiology in Stuttgart, work on the toad genome has revealed that 'Stran Foot' has an equally strange genetic repertoire. This includes hundreds of genes that code for the wa in which its olfactory sense cells (called *receptor cells*) can function. That is no great surpris mammals have thousands of such genes while fish have very few, so it was predicted that amphibia would be intermediate between the two. And so they are. Their olfactory genes fall into families two distinct kinds.[58]

Aquatic animals are exposed to water-soluble molecules such as amino acids, while air-breathe have access to a far greater variety of more volatile odorants. And as an amphibian, adapted to bo aquatic and terrestrial life, the clawed toad was expected to have roughly equal numbers of both gen and receptor cells. It doesn't. There are far more cells of the mammalian air-breathing kind, probab because there are far more airborne than waterborne odours. But the big surprise is that the two kin of receptors are found in separate areas. Strange Foot has two noses and two senses of smell: one f use underwater, the other for life in the air.

The toad's nose is neatly divided into two separate sacs or chambers. Just inside each nostril the is a flap of tissue which acts like a valve between them. Underwater, the flap swings to seal off th main chamber, exposing another one, a cul-de-sac filled with receptors sensitive to water-bor odours. And when the toad surfaces and raises its nose into the air, the flap swings the other way seal off the aquatic chamber, exposing the main one, which is lined with cells sensitive to volati odours in the air. And after serving this chamber, the airstream passes on to provide oxygen to th lungs.

Living in the air demands more of the sense of smell. But the challenge seems to be one that eve the most primitive amphibians are ready to meet.

Mexican toads, in the process of learning to negotiate a maze, have been trained to remember ali scents such as geraniol, vanillin and cedarwood.[70] Both the spotted chorus frog and Strecker's choru frog have shown that they can pick up the odour of their own breeding ponds many hundreds of metr away.[69] North American leopard frogs, blinded by severing their optic nerves behind the eye, ca nevertheless navigate their way back to a familiar pool, whether they are released upwind downwind of their homes.[41] But it is the olfactory skill of the Californian red-bellied newt that tak one's breath away.

This newt is lizard-like, with large dark eyes and tomato-red markings that warn of a poisono secretion in its skin. It has few problems with predators in the coastal mountains where it lives, b has been persecuted instead by local biologists interested in its almost unbelievable navigation skills. It can be taken away from its usual damp haunts in one valley, carried across a mountain divi three hundred metres high, and still make its way unerringly back home.[193] If moved in any directio it will succeed, even in totally strange territory, in orienting itself quickly and directly towards home

Blinding this nostalgic little animal doesn't slow it down for a moment. And squirti formaldehyde into its nose to kill the epithelium – the thin lining of tissue that contains olfacto sense cells – results only in what has been described as 'a significant loss of orientation ability'.[67] Th only way, it seems, to prevent it from getting home is to sever its olfactory nerves entirely. Suc invasive studies distress me. But the fact that they were thought to be necessary is a measure of o frustration when faced with behaviour for which we have no easy explanation. Such mysteries lie every part of natural history. Even the simplest creatures have the capacity to surprise us when w think boldly enough to ask them the right kinds of questions. And the answers are never easy, exce in hindsight.

In the case of the wandering newts, however, there may be a clue. There is something I have so f failed to mention about amphibians, something that began with those frogs and toads whose nos have divided into the two chambers appropriate to their schizophrenic lifestyle. It is this: some them, including this newt, also have a third nasal space which is not directly involved in detecti smells, either underwater or in the air. And this could be involved in a new and different kind awareness.

The olfactory sense cells of all vertebrates are, on the whole, surprisingly alike. And also very strang They are, for a start, unique in that they are in direct contact with the outside world. Most other sen organs lurk under the skin, embedded deep in protective tissue, picking up sensations by remo control. But smell cells go unadorned: naked neurons, each one right out there in the open, like unicellular organism, meeting molecules, making its own way in the world. And, strangest of al ~~small cells wear out after a few weeks and need to be replaced on the front lines. They regenerate~~ ways no other nerve cells in our bodies ever do.[184]

The number of olfactory sensory cells operating at any one time varies from one species to anothe depending on the emphasis a species places on having a good sense of smell. Humans, for exampl have about six million cells; rabbits fifty million; and sheep dogs over two hundred million.

In all species the cells are thin, with projections, or processes, at either end. One of these exten inside the body, usually through a hole in the skull, to make contact with the brain. The other proce is far shorter and stays on the outside in a knob topped with a tassel of fine sensory hairs, called cili The number of cilia varies too, according to the species. Domestic cattle, for example, all have exact twenty-seven microscopic lashes on each sensory cell. Tiny newts have fewer such hairs, but theirs a four times as long.[52]

It is generally agreed that the function of these frills is to bind odour molecules and convert the chemical signals into electrical ones for transmission to the olfactory bulb in the brain. So it interesting to discover that, in addition to typical sensory cells in the main and side chambers of son amphibian noses, there are other cells in a deeper chamber that look very different. They are flas shaped, with long necks. They have no cilia, but have knobs decorated with a tuft of short bristle sometimes called microvilli, that makes them look like sensory cells with a crew-cut. And the tissu in which these bristle cells lie has none of the glands which, in normal olfactory sensory epitheliur produce the mucus that helps to trap and hold airborne chemicals.[53]

No one knows exactly what these strange cells do. I suspect that they give air-breathing animals new sensory edge. This extra faculty may be related to the sense of smell, and might even partial replace it, but it has a different, more multi-sensory bias, and a whole new perceptual agenda th becomes truly obvious only in the first fully terrestrial vertebrates – the reptiles.

Some reptiles differ very little from amphibians in both their lifestyle and their nasal structur Marine turtles are as water-dependent as clawed toads and have very simple nasal passages that ru almost in a straight line, from the external nostril to an internal opening in the throat. Land tortois possess larger olfactory structures, and crocodilians have a surprisingly sophisticated series chambers and sinuses which provide additional surfaces for the usual olfactory sense cells.

Marine snakes, tree-living lizards and chameleons are all conservative about smell, but it is amor ground-living lizards and snakes, those closest to the source of many scents, that the greatest chang have taken place. And the most dramatic of these is a concentration of the mysterious bristle cells in pair of separate chambers of their own.[139] This, finally, is Jacobson’s Organ.

The discoverer of the organ, Ludwig Levin Jacobson, was born in 1783 in Copenhagen. He qualified ~~surgery at the age of just twenty-one and went to study in Paris with the great anatomist~~ Baro Georges Cuvier, who believed that the habits of an animal determine its form. Cuvier also refined th taxonomic system of Linnaeus by showing how all organisms could be classified on the basis of the anatomical differences. And it was probably he who drew Jacobson's attention to the work o Frederick Ruysch, a Dutch embalmer who in 1703 described the anatomy of a number of animal including a snake with unusual pits in its palate.[161] So Jacobson looked for, in 1809 discovered, and 1811 published a report on the organ which still bears his name.[84]

The Organ of Jacobson remained a zoological curiosity until the late nineteenth century, whe interest in it was revived by one of the most charismatic figures in Victorian science. Robert Broo was a Scot and a physician with a very curious mind. One of the last great individualists, he foun fault with a place or a practice only if it offered 'too much medicine and too little natural history'. In later life he became one of the world's great palaeontologists and physical anthropologists, doin pioneer work on the origins of humans in Africa, but his first enthusiasm was for reptiles, their origin and the significance of Jacobson's Organ. In between practising medicine he scoured museu collections and studied animals in the wilds of Australia and South Africa for material to include in doctoral thesis, 'On the comparative anatomy of Jacobson's Organ', which he submitted to Glasgo University.

'It would seem,' said Broom, 'that the Organ of Jacobson is the organ in the body that is least liab to become altered by change of habit. I can almost identify an animal by examining this organ an often tell of its affinities.'[16] He went on to do just that for the mammal-like reptiles that once roame South Africa, most of which he found himself and modestly described as 'the most important foss animals ever discovered' because 'there is little doubt that among them we have the ancestors o mammals and the remote ancestors of human beings'.[17]

Recent research confirms Broom's suspicions about Jacobson's Organ. Signs of it appear, lik portents, in the embryos of all higher land mammals, although in some, such as tree-living lizard aquatic turtles and nearly all birds, it never actually materializes. There is no need for it. In other such as ground-living lizards and most snakes, the organ comes into being, not simply as pouches o the nasal cavity, but as a pair of blind chambers that open directly into the mouth.[47] Why should th be? What happened to make this development not just useful, but necessary?

Robert Broom, who could put flesh on the bones of a fossil even while it was still in the groun described minute channels on the skulls of some of his finds in the fossil beds of the Karroo Desert, marks which suggest that Jacobson's Organ arrived on the scene during the Triassic, perhaps tw hundred million years ago. It appeared, he believed, to meet a need that could best be understood b looking at lizards or snakes that live today in similar habitats.[18]

The most obvious sensory feature of all living snakes is that they have two olfactory systems. In on external nostrils lead to nasal cavities containing sensory cells with cilia, embedded in a tissu containing glands. The other consists of cells without cilia, in a tissue without glands or mucu housed in a pair of dome-shaped structures on either side of the nasal septum. Access to this secon sys~~tem is restricted to a pair of tiny pits in the roof of the mouth, leading to ducts that pass through th~~ bony palate.

The first system is the main olfactory apparatus, often simply known as the organ of smell, thoug neither of those descriptions is totally accurate. It is not the only organ, nor even necessarily the ma one, involved in smell. The second is Jacobson’s Organ, comprising a rival chemical sense system th is becoming the focus of very active research and debate, much of it based on one common little snal that has been studied in the field by David Crews and his colleagues at the University of Texas.[37]

Garter snakes are the most widely distributed reptiles in North America. They can be found at a altitudes, ranging from coast to coast and from Canada all the way south to Costa Rica. They a slender, graceful snakes, seldom more than sixty centimetres long, marked with dark spots ar longitudinal red stripes, giving them some resemblance to those fancy coloured garters that onc supported every gentleman’s socks. But their appeal to biologists in the last two decades is mo sensory than sartorial.

Plains garter snakes in cool areas have the habit of gathering, ten thousand at a time, in der established in underground caverns where they spend the long winters in hibernation. At these tim their blood becomes as thick as mayonnaise, and they barely move for up to six months. But in Ma as soon as the outside temperature reaches 25°C, dormancy ends and the tangle of bodies stirs ar turns into a writhing mass that flows out of the den.

First the males emerge en masse and wait near the entrance, sunning themselves, showing r interest in food or drink. Then the slightly larger females come out, one at a time, to find themselv heavily outnumbered and soon entangled in a mating ball of perhaps a hundred hopeful suitors. Fiftee minutes later, carrying a load of sperm in her oviducts, each solitary female sets off on a migration t summer feeding grounds, where she will restore her body fats and give birth to up to thirty live your garters in the autumn. And by late September, she and thousands of her kind gather once again in th familiar scent of some shelter or hibernaculum.[36]

This busy cycle of mating, migration, feeding, gestating and returning to hibernation, spans litt more than the three summer months and presents a number of zoological problems. Some are easi resolved. The sperm each female receives in spring is stored in her oviduct for up to eight weeks, un her follicles are ready to be fertilized in midsummer. The male’s reproductive organs also build u post-nuptially, expanding rapidly during the summer, when the living is easy, and he goes int hibernation packed with sperm, ready for the following spring, when the population is concentrat once more and mating is most likely to succeed. Other questions raised by the behaviour of gart snakes took longer to answer.

John Kubie and Mimi Halpern at the State University of New York have spent twenty years setting u a series of eloquent experiments designed to find out exactly how garter snakes feed ar communicate.[106] They began with the common observation that snakes follow odour trails to loca their prey. Newborn young snakes of several species have been found to follow the scent of the usu prey of their species without any experience or instruction. Their ability and willingness to do s

seems to be under genetic control. And when exposed to such a scent, their immediate response is t
put ~~their heads down close to the ground, flick their tongues out to actually touch the trace, and~~ to g
on doing so more and more rapidly as the stimulus grows in strength.

Kubie and Halpern set out first to establish whether a snake in such a situation uses its nose or i
mouth, its olfactory epithelium or its Jacobson's Organ. They trained plains garter snakes to follow a
extract-of-earthworm trail through a maze ending with the reward of an actual worm. Then they c
the nerves leading from Jacobson's Organ to the brain of some of their trainees, and found that th
snakes failed all the tracking tests dismally. Their ability to follow a scent was totally disabled, whi
control snakes that went through the same surgical procedure, but without having the nerves cu
performed as well as they had before the operation.[108]

In a second experiment, the same researchers severed the nerves from the olfactory sense organ
the garter snake's nose, and found that this operation had absolutely no effect. These snakes followe
the trail and fed as successfully as they had before the surgery, and there was no sign of any ill effec
or compensation for the loss of the nasal system.

Garter snakes without their noses carry on feeding as though nothing has changed. It seems cle
that snakes can follow and find their prey without their nasal apparatus, but not without the
Jacobson's Organ.

While searching for a scent, most snakes are exploratory, moving slowly, swinging their heads fro
side to side, taking the long view, flicking their tongues out only once in a while. But once a scent h
been found, the tempo changes. The snake then moves more quickly, keeping its head close to th
ground, touching the surface with its tongue on almost every quick flick. There is a perceptible ge
change from one mode to another, a shift perhaps from reliance on the nose and smell, to the wa
things 'taste'.

This shift may also represent a move from volatile scents that blow by to heavier non-volati
scents, the sensing of which depends on actual contact. It is even possible that Jacobson's Organ ma
have evolved specifically to deal with the sort of large molecules and heavy odours that the ho
cannot handle. This is an important idea. It suggests that smell operates at two levels, that it involv
two parallel systems with different functions, different receptor systems and different sites in th
brain. There is certainly a growing body of neurological evidence to support such a dichotomy.[153]

In all vertebrates so far studied, the olfactory nerves that run from the nose to the brain go
bundles in the olfactory bulbs, while those that leave Jacobson's Organ travel instead to the accesso
bulbs. The fact that information collected by Jacobson's Organ in the garter snake does go to th
accessory bulbs, has been nicely demonstrated by attaching electrodes to its head. Every time th
tongue is flicked at a trail containing prey scent, an electrical charge can be recorded in the bulbs.[124]

If the main bulb is the 'nose' brain, then the accessory structure, in snakes at least, is a sort of 'fac
brain, collecting information that lies somewhere between taste and smell. Beyond the olfactory bulb
nose news goes to the olfactory cortex for assessment; while face feelings move to another neur
swelling called the *nucleus sphenicus*, about which we know very little. It seems, however, to b
analogous to that part of the mammalian brain in which old impulses may be integrated with mo

recent experience.

~~In this light, Jacobson's Organ begins to look like an unconscious partner to the nose.~~ It deals wi the hypothalamus rather than the more modern thalamus. It is in touch with what neurophysiologi Paul Maclean at the National Institute of Mental Health has called the 'reptilian brain', rather than th 'mammalian brain'.[117]

Jacobson is the name of the brain's olfactory autopilot.

Reptiles have relatively simple brains. In most of them Jacobson's Organ appears to provide all th information a cold-blooded animal needs to go about the daily business of finding its way about an feeding. The organ also seems to play a vital role in successful mating.[107] In the orgies of spring, ma snakes approach an emerging female and explore her with tongue flicks before rubbing their low jaws all along her back and sides in fervent courtship. Something they find there excites them, despi the fact that the skin of garter snakes has no known glands. And as soon as one of the male snak succeeds in mating, the other suitors immediately disperse and leave the pair to themselves. None this happens for snakes without working Jacobson's Organs.

Careful research on intact animals has shown that the male interest is sparked by a fatty substan that females produce as a precursor to egg yolk. This substance seeps from the bloodstream into th skin, and is released from gaps between the scales that open when females breathe deeply durin courtship. And the substance that switches off the interest of rival males turns out to be produced b the kidneys of the mating male and to be abundant in the gelatinous plug he leaves in her cloaca. Th not only acts as a mechanical obstruction to further mating, but it makes the mated female positive unattractive to other males, even rendering impotent those who happen to come into close contact wi her.[71]

Mimi Halpern and John Kubie conclude that garter snakes 'depend on a functional vomeronas system, but not on a functional main olfactory system'.[72] The simple fact is that no snake behavio has yet been discovered which depends in any critical way on the nose.

This is a startling finding. No naturalist has ever doubted that snakes and lizards have a sense of sme You only have to watch one explore its surroundings, flicking its tongue out to test the ground ahea speeding up the response as it encounters anything of interest, to be certain that this is an olfacto process. Western whiptail lizards shoot their tongues out 700 times an hour, which represents serious expenditure of energy – something not to do without good reason.[173] Smell is reason enoug and the fork-tipped tongues with matching pits in the palate are clear evidence of an oral route chemical sensation. But none of us guessed that this was the main organ of smell, that the nose didn really matter any more.

It looks as though ancestral reptiles were faced with a choice. On emerging from the water, the ~~already had two-chambered noses. They also had good tongues. And as far as chemical sensitivity~~ concerned, evolution seems to have been equivocal. The nasal route was followed, up to a point. B for ground-living species at least, the existence of a highly elastic tongue provided an attracti alternative, and soon hijacked the rival bristle-cells in their nasal pouch, and re-routed their ducts the mouth.

Today there is a clear division of olfactory solutions among reptiles. Aquatic turtles stuck with th simple amphibian solution. Land tortoises have slightly larger and better developed noses, but als show some development of Jacobson’s Organ. And ground-living snakes and lizards have gone all th way with Jacobson, to the apparent exclusion of the nose. Crocodiles are complex, showing bo systems at an equivalent level of development, as befits a group that spent time on land befo becoming secondarily aquatic.

But the most interesting adaptations show up in tree-living snakes and lizards. Up off the groun smell becomes less useful, and heavy odours and most contact scents disappear altogether, and wi them the need for Jacobson’s Organ. Chameleons don’t have one. And neither, it seems, do birds. S why do we?