Chapter 4
Who Are You?

Recognition of Self and Individuals

My office is almost exactly equal distance from either end of the biology building hallway. Coming in from the parking lot, I enter the building and pass by the department's main office. As I glance in the open doorway, I can easily recognize the faces of my colleagues. Since there appears to be an early morning gathering, I walk in to greet each of them by name. One of my friends is about 6 inches taller than myself and has brown hair that defies any normalcy of combing. He has a self-described "Bostonian" nose that fits well with his longish face. Seated next to him is another of my close friends. All of his facial features, if taken individually, are well within what we would term average. His nose is neither large nor small. His eyes are neither round nor almond shaped. Yet, even though each of his features is wholly unremarkable, the composite picture is unique, well-defined, and unmistakable.

I pause for a second and begin to scrutinize each of the faces present in the office. For just a second, I focus my attention on a single but most prominent facial feature: the nose. Noses, in relation to our whole bodies, are small and yet play a role, as central as their location on our face, in our characterization as unique individuals. In this office alone is a suite of diverse shapes and sizes. There is the large bulbous nose that adds a touch of W.C. Fields or Winston Churchill to one person's face. Another is long and thin and, for some strange reason, reminds me of a stereotypical British school headmaster portrayed in many films. A third has a concave shape, the classic ski slope. Some noses are large and round while others are mere bumps. My own nose has a slight ridge in the middle, a remnant from an errant grounder on a bumpy softball field.

Although the nose is a prominent feature on the face, its functional use, smelling odors, appears to play a very small role in the recognition of others. I cannot recall any characteristic odor of any one of my friends present within the office. If we were suddenly plunged into a blackout, I would fail miserably at identifying these individuals. This is one of those areas that we have failed to use any of the olfactory abilities that nature is using so prominently. Still, I sniff to catch any faint traces of telltale perfumes or colognes that can be attached to someone present. My initial attempt fails to produce any odors, so I take a deeper smell while trying not to be too

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obvious. With this sample, I can detect a very faint trace of a cologne, but I have no clue to whom this odor belongs.

By broadening my gaze beyond their noses, I see an even greater breadth of characteristics that make us individuals. Blonde, brown, or red hair, long or short hair, curls, spikes, and bald palates all contribute to distinction. When a good friend of mine from Australia came over to the United States to start a new research position, he had long, black, slightly curly hair that reached the middle of his back. This was his trademark. After being here a year, he opted for a change in his life and promptly buzzed his hair to a length of ¼ of an inch. At first, I had to pause for a second or two to recognize him without the signature ponytail. Yet, over time, my pauses became shorter and shorter and eventually, the new shorter haired image replaced the one with the ponytail.

Other physical features can also be used to identify individuals, height, eye color, body shape. In addition to these obvious visual signals, more subtle differences in voice allow us to recognize individuals even when we cannot see them. My office is further down the hall from the main departmental office and when colleagues and students pass by with hellos, I can easily imagine their identities simply upon hearing their voices. Tone, volume, pitch, and even the tempo of the single word "Hello" can provide me with enough information to distinguish my friends. The departmental chair that hired me has a very distinctive voice, so unique that I find the description hard to construct: part gravel, a hint of high tone, and a weird mixture of softness and firmness. After talking to him a single time on the phone, I could recognize his voice the second time he called me. One of my colleagues sounds as if he has a resonator within his chest. I can only imagine how he sounds lecturing away in one of our bigger classrooms. You can hear him laugh all the way down the hall. Our minds are so in tune with the subtle differences in voice and style that we can often recall those voices just by mentioning their names. Think of all those distinctive celebrity voices, such as James Earl Jones or Fran Drescher. Our ability to recognize sounds and visualize the image that accompanies them allows us to instantly recall their faces even when we just hear a few phrases. As further evidence of our ability to recognize individuals, celebrities such as Rich Little and Dana Carvey have made whole careers out of "fooling" our ears into believing we are hearing someone else.

This is how we recognize those individuals that play an important role in our lives. The deep-bodied voice, the light golden hair, or the ski slope nose are familiar and comforting indicators. Sights and sounds carry to our waiting eyes and ears the subtle differences in friends and family. Often we take this ability for granted; imagine what life would be like without the ability to recognize each other. (One needs only to talk with an Alzheimer's patient or caregiver to realize how quickly these abilities can be lost and how painful the consequences.)

Using our perceptual abilities, we may even be able to recognize some level of relatedness in strangers. How often have you sat in a restaurant and noticed people that "must be sisters/brothers"? Or seen a child which clearly has its mother's nose. Even though each of us has a unique combination of genetic makeup and environmental influences, supplied by our mother and father, there are always strong traits that show through. The distinctive ears of the British royal family and the recognizable face and New England accent of the Kennedy family are examples of such relatedness. As in previous chapters, recognition goes beyond the sights and sounds of our friends. We shall see how the different organisms in nature have capabilities that far outstrip our meager abilities to recognize individuals using only the sights and sounds of our world.

4.1 Who Am I?

Several different types of recognition can be found in nature, some obvious and others not. Regardless of the specific type, they can all be based on some level of biological organization. Some of the levels of organization in nature and their subsequent types of recognition may seem quite trivial to us, but we need to step away from visual biases toward the needs of nature. In order to delve into the many roles that chemical signals play in the ability of organisms to recognize others, a system of the different types of recognition is necessary. To fully appreciate the roles of recognition, a more nuanced view of the inherent complexity of the biological world is needed.

Nature can be viewed in a hierarchical fashion of increasing in size and complexity. This view of nature allows a level of organization that is helpful for understanding different levels of recognition. The smallest of the biological units, important in the context of this book, are cells: the basic building blocks of life. Cells define life, namely who we are and what abilities we have. To say that without cells there would be no life is not too extreme; however, all cells are not created equally. There are large-scale differences in cellular structure, organization, and function. Some cells, such as those in unicellular organisms, perform every function that is necessary for life. Other cells, like some of those in our highly specialized bodies, are very adept at a single function but inept at all others. Thus, at a very basic level, organisms (and the cells within them) require the ability to recognize one type of cell from another. In a broader sense, this can be thought of as recognition of self from nonself.

At first glance, the concept of recognizing who you are and who you are not seems very trivial indeed. When I awake in the morning and plod down to the bathroom, almost as a force of habit, I look into the mirror. Maybe to see if I need a shave or to see if I am still alive, but I always recognize myself. Yes, that is me staring back. A little older each day and maybe a new wrinkle every so often, but without fail I know that face staring back at me is me. Holding up my hands, I see the boundaries of my fingers. I can easily recognize where I begin and end. If the bathroom mirror could provide us with an inner view of our body, we might find that the ability to recognize ourselves is not so trivial after all.

When we look at ourselves, we are really perceiving the composite image of many more than a million cells. Humans and all of the other larger organisms on this planet are multicellular; different groups of cellular units work in concert to perform the many functions of our daily lives. Brain cells are used for thinking, muscle cells for movement, epithelial cells for skin, and so on and so on. For multicellular organisms, a basic imperative is the recognition of our differentiated cells apart from each other. The functioning of these differentiated cells varies across our body and allows our organ systems to perform complex bodily functions. In order for these functions to be carried out, the right commands (i.e., release adrenaline in response to fear) need to be sent to the right cells (the adrenal glands instead of our lungs). Instead of a body composed of cells upon cells, imagine that each of us is a large city composed of millions of different people. The different cells in our body are now the different workers that are needed to run all of the systems in our city. There are workers at the power plant providing electricity to all of the other workers in the city, similar to our digestive tract providing chemical energy to our various cells. Sanitary engineers keep our streets clean by removing trash from the city, just like the cells within our kidneys and urinary tract. City hall is located in our brain with the numerous nerve cells functioning as the politicians. (Thankfully, our brain is far more efficient than a city hall.) Our circulatory system is the highway of the city full of trucks and drivers delivering goods across the city. Finally, the police and military are the white blood cells protecting our cities from outside invasion. If the city is invaded by an alien menace, the police and army jump into action and begin to repel the intrusion. But how effective could our city's forces be if the ability to differentiate the alien invaders from the happy workers is impossible? Our army would be useless without the ability to identify and recognize the difference between friend and foe, for without this ability the city would fall into ruins (Fig. 4.1).

These alien invaders are not part of some science fiction movie gone rampant but are the infamous bacteria, parasites, and potent viruses of nature. These organisms would love to usurp our biological machinery for their own nefarious ways, and, if successfully invaded, our bodies can become ill and maybe even develop a long-term disease. These invaders may cause something as innocuous as a cold but or something as deadly as AIDS or Ebola. Our body's police and army have the abilities to isolate, quarantine, or, in some cases, destroy the alien invaders, but without

Fig. 4.1 City of cells and organs

the ability to recognize an invading bacteria cell from a kidney cell or the parasite from the host, our immune system and white blood cells are powerless. The mode of detection of alien from non-alien is done through chemical signals which function as a national ID card for our bodies. In some cases, this cell/cell or self-/nonself-recognition can go awry, and this in part explains some aspects of our more serious diseases (more on this later).

As I shift my focus from this inner view, I wonder what would happen if my cells were not all housed within the shell of my body. What would become of me if my cells all had minds of their own? Along this vein of thought, there is a unicellular species that temporarily functions as a "multicellular organism." *Dictyostelium discoideum* is a very long and complicated name for such a small organism. Dicty, as it is known to it most ardent fans, is commonly called a slime mold. Being unicellular, Dicty has no muscles, no eyes, and no ears. This organism is just a single membrane that contains a number of different organelles. (Organelles are the subunits of cells and perform the basic biological functions that are necessary for cells to live. As the name implies, they are the cellular equivalent to our organs.) Dicty has such strange properties and behaviors (yes, a single cell can exhibit behavior) that this organism has become an essential element in the search for an understanding of the mechanisms involved in cell recognition, cell movement, and cellular determination (the process by which embryonic cells develop into functioning brain, muscle, or other cell type). So important is our microbe that the National Institutes of Health chose Dictyostelium as one of the first organisms to have its genome sequenced.

4.2 Come Together, Right Now, over Me

Dicty moves in amoeboid fashion, essentially a blob that slowly stretches out one section of its cell, firmly grasps the surface, and pulls itself forward. We can find slime mold just about everywhere on the forest floor, living among the leaves and ground litter on the soil. Dicty lives out its days slowly sliding along the leaves and twigs, eating bacteria, or reproducing. There are millions of slime molds in common forest litter and, thankfully for Dicty, bacteria are common in and around the leaf litter. Just as in other biological systems, there are periods in which food resources may become scarce and the good times are gone. If you were a tiny little slime mold living on the forest floor, what would you do if you were to run out of food?

We find that Dicty probably does what we would do if we were hungry and had no food: you contact your friends. During these periods of starvation, Dicty sends out its chemical equivalent of an SOS message. Waves of pulsed chemicals travel out in circles from our starving organism. The chemical (cyclic adenosine monophosphate [cAMP]) used by Dicty is ubiquitous within the world of biology and is found in virtually every nerve cell within our own bodies and is an essential element in many different cellular functions. cAMP is a critical link in the sequence of chemical events that allow our neurons to become active and to signal to each other.

Once cAMP is "smelled" by the surrounding Dicty cells, a miraculous and wonderful transformation occurs. If you were to put a Dicty cell underneath a microscope and watch its normal behavior, the cells would look like a drop of coffee spilled on the counter. Under the microscope, you would see that the cell has an amorphous shape with small blobs (arms) sticking out in various directions slowly pulling the cell this way and that way. Once the chemical call for help goes out, these cells assume their racing shapes and instead of a blob, they form a streamlined linear shape, almost like a toothpick. As if someone has yelled "CHARGE!" all of the surrounding cells surge forward, as fast as possible, toward the center of the circular waves of the chemical signal (cAMP). Once there and once 100,000 or so of their friends aggregate, this virtual city of independent cells forms a collective being and becomes a multicellular organism. A series of transformations occur that cause a group of single cells to collect and form into a mound. Here, by some unknown mechanism, cells choose to differentiate into two different types: prestalk or prespore cells. The prestalk cells are usually located on top of the mound, whereas the prespore cells are on the bottom. The consequence of this "decision" is that the genes of some cells, the prestalk cells, will live on to the next generation while others will not. At this point, previously separate and independent organisms are now communicating and coordinating their efforts into a single collective function similar to the way our own body cells communicate and coordinate. Without the ability to recognize and coordinate their efforts through the use of chemical signals, these tens of thousands of slime mold cells would die of starvation (Fig. 4.2).

At this point, the mound begins to form a skin-like surface, then slowly elongates and topples over to form the slug stage. The slug stage empowers the Dicty, giving the group of cells the mobility needed to escape the perils of famine. The slug form of Dicty exhibits a variety of behaviors, including sensitivity to light, heat, and chemicals, which are not present in the single cells. The slug, sliding on its path of slime, makes its way to the top of the nearest leaf to perform its last magical transformation. Dicty alters its cellular organization again to form a long, thin stalk.

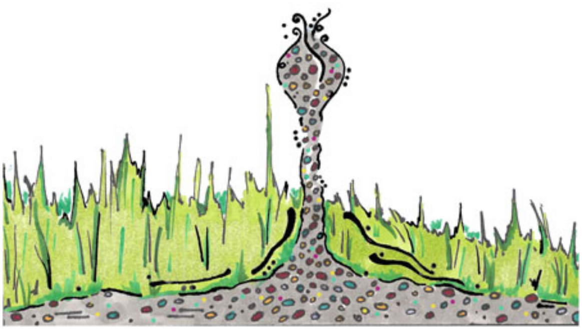

Fig. 4.2 Slime mold stalk

At the top of this stalk is a fruiting body that will release its spores to the wind in hopes of locating a more beneficial and abundant habitat or at least one with abundant food. Leaving the stalk and the rest of the slug behind, the spores alone carry the hopes of the whole "multicellular" Dicty organism for future existence. In the Dicty, we see nature's ability to solve the problem of starvation through the ingenious use of chemical signals. Through effective cell/cell communication and recognition, the *Dictyostelium discoideum* lives on for another day. But what would happen if the chemical phone lines are down?

Simply put, many physiological diseases, AIDS and cancer for example, are cases in which cellular communication malfunctions. Either our body fails to recognize the difference between our own cells and those of the invaders or individual cells no longer recognize and respond to chemical signals that mediate normal cell growth. The key to understanding and solving these diseases may lie in the ability to restore chemical communication in the body to its natural state.

Diseases are the result of cell communication gone awry, and there are even more nefarious ways organisms can intercept chemical messages and use them for purposes of which they were not intended. Parasitism is not necessarily an enchanting way of life, but from a biological perspective, parasites show remarkable versatility. At the base of every parasitic lifestyle is the effective commandeering of one organism's bodily functions (the host) to support the life of another organism (the parasite). This usually involves the parasite invading the host body and subsequently living off of the host's bodily fluids. Of course, the host does not always appreciate house guests, and its immune system often attempts to fight off the parasite and an intense physiological warfare ensues. A parasite's victory tends to lie in its ability to suppress the host's immune system or the self-/nonself-recognition mechanisms.

In World War II, the American and British forces invested an enormous amount of money and effort into both generating complex codes in which to embed hidden messages and to break the equally complex codes sent by enemy forces. Success was dependent upon the tremendous mental abilities of the code breakers, who often provided the American and British forces advance warnings of potential attacks. The code breaker's challenge was much like that faced by parasites. Parasites must understand and break the incredible chemical code of communication that allows cells within a single body to communicate, consequently allowing cells to recognize those that belong and those that do not belong. Once behind enemy lines, the parasite must break the code of chemical recognition and then begin generating false signals in order to instruct the enemy's soldiers (white blood cells and the immune system) to ignore its presence. This is a complex task, indeed, for the little parasites. Biological spies, nature's parasites, must become exceptional at cracking the chemical code of cellular communication or else risk their lives during invasions.

There are countless examples of successful parasites, but one group in particular is a master of unparalleled success. The rhizocephalans, or rootheads, are a group of barnacles that live on crabs as adults. When any other parasites attack crabs, the host crab cleans itself, a behavior that has evolved over time to remove parasites. Yet when a root head comes along, even though the crab is still capable of performing the cleaning and grooming behavior, the crab does not appear to recognize the rhizocephalan as something other than itself. The root head seems to have found the secret code—a chemical signal that either suppresses the immune recognition system of the host crab or even sends a false chemical signal to the crab that says "I am part of you." This parasite is not satisfied with simply fooling the crab with one simple chemical signal, rather the rhizocephalan is set on total domination of the host crabs body. Once the parasite has been successful at fooling the crab's perimeter chemical defenses, the parasite infiltrates the body of the host and begins to commence into phase two of the attack. The story of the root head has been worked out by Dr. Jens Hoeg at the University of Copenhagen.

Crustaceans, including crabs, are defined, in part, by the presence of a protective shell. Although an excellent adaptation for defensive reasons, the shell can get tight and cramped when the crustacean begins to grow. So, crustaceans go through a molting process where they turn in the old shell and grow a new one. Once rid of the old home, they swell up with water and "stretch" the softer new shell to provide some growing room. As the newer shell is exposed to the environment, the shell begins to harden and finally forms into the strong shell. The precise timing of the release of different hormones and chemicals controls this complex process of growth and molting. A side effect of molting is that any parasites or other animals that have attached themselves to the old shell are discarded, and for a root head, getting left behind with an empty shell just will not do.

To combat this process, the root head infiltrates the nervous system of its host and stops the molt cycle. [Thinking back to earlier in the chapter, the inner workings of a multicellular organism were compared to a large city where each worker requires precise communication between the groups of workers (or cells) to coordinate their individual efforts.] To stop the molt cycle, rhizocephalan needs to break the code of cell communication and begin to control what and when signals are sent. Since molting is controlled by precise hormonal methods, the parasite has yet another successful decoding session and starts sending false signals that would make any spy proud. (As a side point, the parasite also castrates the adult crab by commanding and controlling its nervous system, again, probably by chemical means.)

As the coup de grace of chemical communication, root heads cause male crabs to become females. This transformation is complete in both the appearance and the behavior of the crab. But whatever for? Many female crustaceans carry egg sacks on their abdomen which they try to protect and nourish through certain behaviors, including fanning themselves to help oxygenate the eggs and grooming themselves to remove parasites, fungi, and other egg pathogens. While most of the root head is inside the crab and functions to chemically control the animal, the parasite produces eggs and locates them on the abdomen of the infected crab, precisely where the crab's own egg mass would be. The root head manipulates the crab's own reproductive behavior, which evolved to benefit the crab's eggs, in such a way as to now benefit the health and well-being of the parasite larvae. The crab grooms and aerates the egg mass as if the mass was its own. Again, because this behavior is generated by the neural and hormonal signals in the crab's body, the root head has decoded these hormonal signals, seized control of the communication pathways, and has begun to generate chemical signals that control the crab's behavior for the benefit of the parasite. Finally, as the larvae mature and are ready to hatch, the rhizocephalan commands the crab to perform typical crab behaviors that help release and liberate the larvae from the underbelly of the crab. The larvae are scattered to the ocean currents to infect some other unsuspecting crab. Knowing how important the recognition of cells and self is to the existence of our lives, we can be rest assured that there are no human parasites that are as chemically sophisticated as the root head.

4.3 Who Are You?

It is 5:30 in the morning and the alarm is ringing. After tapping the snooze button one time, I roll out of bed. Almost routinely, I am the first one up in the house. Skipping the run this morning I hop into the shower and start another day. After a thorough cleansing, I return to the bedroom to get dressed. My wife is still asleep, but an unconscious morning ritual has occurred yet again. She has rolled over from her side of the bed to my side. Although she may not admit to it, I have some idea as to why this simple action has become a common morning occurrence. The secret lies in the nose.

On those mornings that my wife precedes my exodus from the bed, I, too, roll over to her side. There is nothing unique about our pillows; both are identical size and shape. She (and I) do not spread out to take advantage of the now spacious bed. We both simply roll over to the other side. Neither side of our bed is fluffier, warmer, or firmer than the other side, but there is something that the "other" side of the bed holds that my own side can never have: her individual and unique smell. Upon rolling over to her side, I embrace her pillow and am immediately wrapped within her smell. This is her. I have come to learn and love this fragrance. To me, the odor is her smile, her warmth, her laughter, and wit all wrapped into one single sensation. All carried by tiny molecules that drift from the pillow to my nose. This smell is her identity that I could identify anywhere.

A common advertising ploy is to perform blind taste tests comparing two products: Coke versus Pepsi or diet versus regular soda. We have all seen them on TV. The unsuspecting participant is handed two cups, each with a dark bubbly liquid in them. Upon tasting both, the participant declares that cup "A" is obviously the one that they commonly drink. "This is the one that I drink. The regular soda," they announce. Lo and behold, when the host reveals which is which, the participant is wrong and they have actually picked diet Coke over the regular Coke, or some variation upon this theme. Although this example involves taste, I am as equally confident that if presented with a blind pillow test I would easily be able to identify my wife's pillow using my nose. Yet, just like our imaginary participant, I would probably fail if presented only with her natural odors minus the fragrances of perfume, shampoo, and other artificial smells.

Our morning ritual is an anecdotal example of individual identification using odors. Individual recognition is the ability to detect an odor and to identify either the individual or some aspect of the individual (more on this a little later). For my wife, her odor is the distinct combination of perfume, shampoo, and deodorant mixed with her body's own fragrance, trapped upon her pillow every night during her slumber. Through our numerous close exchanges (hugs, walking together, etc.), I am exposed to this odor and, through time, have come to associate this with her. Her odor is not the only one imprinted in my mind. Every time I kiss my daughter or son on their head, I sneak a quick sniff and delight in their smell. As good as a bloodhound, I believe that I could pick their odors out from any lineup. Although they use the same shampoo and soap that we do, each of them has a unique odor unto themselves. Again, through our hugs and play sessions, I have come to learn and memorize their smell as either my daughter or son.

Our individual odors, unlike the rest of the animal kingdom, are generated through a mixture of self-produced scents, or body odor, and those artificial scents we use to either hide or enhance them. Chanel No. 5, strawberry shampoo, lavender soap, and mountain spring deodorant are just a few examples of smells that we have around the house. Each of these mixes with our own body's odor to produce the combination of smells that says, "Here I am." Nature has no perfumes, no fragrant soaps, and no store to purchase these artificial enhancements. Individuals of a species must use other means to become unique or to be identified as individuals.

Many animals have either the ability to identify individuals or maybe some aspect of the individual through odors. Just as I can identify my wife and kids through their odors, animals have the ability to recognize individuals through their odors, and these odors can carry very specific and important information. Some species have the capability to associate specific odors with specific individuals. Through association and learning, an odor can carry a message like "Hi, I am Bob and we met last week." Concurrently, a specific individual odor can carry information that allows the recognition of common trait, social position, or group affiliation that is essential for carrying on interactions with other animals. Odor can convey information on whether the animal belongs to a specific group, such as the ability to recognize nestmates, as was seen in the ants and their thieves from Chap. 1. Odor recognition can be such a very specific phenomenon that it essentially allows the animal that is smelling to penetrate through the outer layers of skin and muscle and perceive the very DNA of the animal sending the odor. These odors can express some form of relatedness, such as the ability to recognize siblings, parents, offspring, or other relatives. For those animals that live within very ritualized social systems, such as ants, primates, and even aquatic crustaceans, odors also provide information on other types of recognition, such as recognition of the sex of an individual or even the species. These may seem to be simple tasks at first glance but are essential for the survival of the individual and species.

4.4 Hello, My Name Is Inigo Montoya

The concept of individual recognition is prevalent within several large circles in biology, and a number of researchers have shown or hinted at the abilities of animals to recognize and differentiate individuals through odors alone. Given our own abilities to differentiate between people using other sensory modalities (as described in the beginning of the chapter), the thought of other animals being able to recognize

Fig. 4.3 Bosses name tag

individuals may seem ordinary. Describing the evolutionary advantage is also fairly straight forward, but individual recognition (with all of the undertones of social status and genetic relatedness) is certainly not as trivial as our own ability to recognize individuals by their facial features. Once animals have developed the ability to smell and identify individuals, a relatively small step forward is the development of very complex social systems based on individual recognition. In fact, one of the key elements in a stable social system is the ability to recognize and remember not only individuals but their status or social standing. Imagine how much trouble would be caused if we could remember the face of our boss, but forget that he is the boss (Fig. 4.3).

Many animal behaviors and traits are used to maximize survival and reproductive efforts. In evolutionary terms, these two things, survival and reproduction, are tied into the concept of evolutionary fitness (surviving and reproducing OR passing on one's genes). A quick glance at the diversity and wonder of nature shows us that animals have capitalized on a variety of methods to maximize fitness. Specifically with regard to maximizing reproductive efforts, it takes two to tango, as the saying goes, and this holds true for all sexually reproducing species. For many organisms, including some plants, bacteria, and animals, a solo tango works just as well as dancing with a partner. Even more complicated, some sections of nature have chosen to participate as both soloists and as part of a duet. Inherent in this choice of a reproductive partner and the consequences of that choice, we find the evolutionary advantage to those who can recognize individuals. Clear long term fitness benefits are provided to those animals who can recognize good mating partners (i.e., those that are most fertile and healthy) but also to those animals that can continue to recognize their mate and the offspring of the mating. Imagine an animal that chooses a partner, mates, and then leaves for a short period to forage or to chase off an intruder. Upon returning, if this animal cannot recognize their mate, all of their nest building, gathering of food, and protecting goes to waste. Worse yet, if they accidentally help a different nest, the effort goes toward another animal's evolutionary fitness. Although recognition may seem quite obvious, individual recognition allows animals to invest time and resources into those individuals that are related to them or those individuals who share a common evolutionary fitness, thus benefiting the individual either directly or indirectly.

A number of organisms are gregarious and have very complex social behaviors and social hierarchies. Although, the diversity of social systems found in nature is vast, at the heart of all these social systems is some sort of differential standing within the society. Primates have alpha males and females that obtain the preferred food, shelter, or mates, and social insects have queens that are the only ones who have the ability to reproduce. In mammalian systems, the social standing often arises, in part, from antagonistic interactions or from some level of aggression. The ability to win these interactions moves an animal up the chain of command while losing has the opposite effect. Whether the outcome is winning or losing one of these matches, the participants expend a significant amount of energy and can be hurt in the process. Within these social systems, there are numerous examples of individual recognition within a social context. If an individual has the ability to recognize a former opponent and remember the outcome of the encounter, they can possibly reduce their energy expenditures or the likelihood of receiving injuries. By being able to recognize a former opponent, a chimpanzee can say "There is Jim and I lost a fight to him yesterday. I think I will avoid him today." Another one may say, "I recall winning against Anne yesterday. I think I will go over just to reinforce my position." Recognition of individuals allows animals to make a more informed decision about whether to fight today or move on. As we shall see below, there are even more benefits to social recognition of individuals within your community. From these simple thought analyses, we can see a tremendous advantage in (or in evolutionary terms, large selection pressure for) the ability to recognize individuals.

Here we are faced with a problem that needs to be solved. How do you smell and remember something as unique as an individual? Organisms change their physical appearance through growth and development, and vocalizations often change through these same processes. Even the subtle shades of fur and skin change appearance throughout the day. During early sunrise or sunset, sunlight can often take on red hues, and cloudy days make the skylight appear gray. As we saw in Chap. 1, the catfish body odor can change through alterations in their diet. In order to smell an individual's identity in the light and in the dark, signals need to have two specific properties. First the cue or signal must be unique within the enormous world of natural diversity and, second, this cue must be constant.

There is a natural substance that fits this description perfectly: DNA. Each organism's suite of genes is unique throughout all of nature and remains essentially unchanged from birth to death. Smelling an organism's DNA would provide a perfect tool for recognizing individuals. So unique is the structure and pattern of an individual's DNA that DNA fingerprints have become a standard practice in law enforcement as an evidence of proof. Within the broader scheme of nature, studying the unique patterns of DNA has opened up new areas of research regarding evolution and speciation and has become essential for understanding the conservation of endangered species.

The only problem with detecting DNA is that this molecule is trapped within the body's cells and is not really accessible to the nose. Perhaps instead of smelling the structure of DNA, a signal could be related to an individual's DNA and maybe organisms can smell a product of DNA. Something that is as unique as DNA but that produces a signal that can also escape the boundaries of the cell and body. There just so happens to be such a thing and this system is called the MHC (major histocompatibility complex).

The MHC is a large region of the chromosomes that contain several closely related genes. The MHC is a section of DNA that works to control how our immune system performs self- or nonself-recognition. To truly understand how recognition could function, understanding how the MHC makes chemical products is necessary. The MHC produces a class of proteins called antigens that are inserted in the membrane of all of the cells in our body. This, as alluded to earlier in the cell recognition section, is how our immune system knows how to attack invaders to our system and to leave alone cells that are produced by our own body. Self-recognition is a key point to how our immune system can function so effectively and keep organisms healthy. Antigens are actually proteins and consist of sequences of smaller molecules called amino acids. Antigens can be hundreds to thousands of amino acids in length. Amino acids are the alphabet of proteins, and the structure and function of each protein is due to the types of amino acids present and the order in which they occur within the protein sequence. Change an amino acid and the protein is changed. The genes in the MHC complex are highly dense and can be found in multiple combinations. Given these properties, the MHC complex of genes solves the two key requirements for an individual odor. First, these molecules are unique and, second, the molecules remain consistent throughout development.

Insight into the role that the MHC plays in individual recognition has been provided by the work on mice by Drs. Kunio Yamazaki and Gary Beauchamp at the Monell Chemical Senses Center. Mice have the ability to discriminate between two different mice. Now, this may seem like nothing special. Of course, if the test mouse is provided with a large enough difference in the sensory perception of the two experimental mice, we would expect them to be able to differentiate between them. The key question is how sharp their senses are. Inbred mice consist of genetically identical mice. This means that mouse A has gene A then all other mice in the strain will also have that gene. Congenic strains of mice are derived from the inbred strain and are genetically identical to each other except for a single gene. What exact gene is different varies based on the congenic strain used. Dr. Yamazaki has shown that his mice are able to discriminate between different congenic strains of mice. If the mice are provided with only odors produced by congenic strains of mice, they still respond differently to the two strains. Also, the whole mouse is not needed to produce the key scent for discrimination. If you just provide the urine cues to the test mice, they perform just as well. Mice are pretty smart creatures and can be trained to perform all sorts of tasks, yet no amount of training could teach the mice to discriminate between two inbred mice. The mice are smelling the difference between the DNA of one animal and the DNA of another. How do Dr. Yamazaki's mice differ genetically? The only genetic difference in the congenic strains was located among the MHC complex. In addition, Dr. Yamazaki and Dr. Beauchamp showed that these mice have the capability to discriminate between two MHC molecules that differ only by three amino acids. Imagine reading the last three pages twice and noticing that the passages differ only by three words!

If the MHC makes proteins that are bound to cell membranes, how does the MHC influence body odors to the extent that allows for this level of individual identification? Urine appears to be the essential answer to this question. The MHC produces proteins that are not only found on cell membranes but some of the antigens are also found in the lymph, blood, and urine. The MHC proteins themselves are rather large and are not that volatile. One of the key properties of a potential chemical signal molecule for terrestrial animals is that the signal can be transported through the air from the sender to the receiver. Large nonvolatile molecules are just as useless as a perfume that doesn't travel through the air. These large MHC proteins are associated with some smaller molecules that are carried into the urine along with the MHC antigens. Once in the blood stream or in the urine, physiological processes begin to breakdown these molecules into smaller and smaller unique chemicals that are very volatile. The genetically unique mixture of MHC antigens would carry a unique mixture of smaller molecules into the blood and urine, thus providing an individual odor associated with urine. Although we tend to think of urine as something only worthy of flushing down a toilet, the animal world has developed urine as the single best book for the language of smell. As we shall see in future chapters, urine is used for reproductive pheromones, social odors, warning signals, and a host of other smelly signals.

Returning to our mice and their urine, another group of researchers, headed by Dr. Jane Hurst at the University of Liverpool, has looked beyond the MHC to another possible source of individual recognition. These odorous molecules are called major urinary proteins (or MUPs). The genes that encode for the MUPs are as polymorphic as the MHC group and code for proteins that bind small volatile molecules found in urine. The MUPs then slowly release the odor molecules in dried urine providing a long lasting and identifiable signal. Dr. Hurst and her coworkers have shown that a single mouse can have up to 7–12 different MUPs in their urine presumably based on genetic differences.

Mice are social animals and often mark territories with urine signals. On the borders of these territories, the mice often engage in a sort of chemical signal one-upsmanship. Intruders leave their own scent marks on the original, and the mouse in the home territory responds with a subsequent countermark. At this point, the mice are engaged in a veritable "pissing match" trying to cover their territory with their own marks, like dogs and fire hydrants. Interestingly, if the intruder is a experimentally manipulated brother of the original mouse (has a different set of MUPs), the counter marking is intense and aggressive. In this situation, the manipulated brother has a similar set of MHC genes as the original animal, but a different set of MUPs. Conversely, if a new intruder is introduced that is a brother who is not manipulated, same MHC and MUP, the counter marking is not worth noting. This work appears to point to a second group of genetic products that are critical to individual recognition. Regardless of whether the MHC or the MUP is the scent of choice, both provide the mouse with the ability to essentially "smell" the DNA of another animal and identify individuals.

4.5 Hey, Soul Sister

I really loved my time in Woods Hole, Massachusetts, and the small community really had accepted my wife and I as members. The Cape is a truly wonderful location, both from an environmental and scientific point of view, but the people are relatively slow to warm up to outsiders. Though, once you are a part of their community, there is a sense of lifelong loyalty that comes with the patience to win Cape Codders over. After my Ph.D. work in Cape Cod, I took a postdoctoral position as a researcher at the University of Colorado Health Science Center in Denver, Colorado. I had visited Denver in the past during some family vacations, but moving across the country was a completely new endeavor. Our move to Denver was marked with an early visit to the auto repair shop. Having moved in August, Denver was quite warm that day and the waiting room for the repair shop was not air conditioned. As I sat patiently, reading some magazine, an older gentleman came in after dropping his car off in the garage. With a quick glance in my direction, he offered to buy me a pop because he thought I needed a little refreshment. I politely accepted and he quickly noticed by my accent that I was not from Denver or even Colorado. This led into a rather pleasant conversation about the virtues of Colorado. In my 4 years in Cape Cod, I never experienced a stranger offering a pop (or soda in that part of the country) to me. Again, I love Cape Cod and the people in the Cape, but there is a different type of friendliness that is inherent to the Cape as opposed to Denver.

Now that I have settled in the Midwest of the United States, I am lucky enough that graduate students from all over the country (and some parts of the globe) come to work in my lab. The diversity of ideas, backgrounds, dress, and language make for interesting conversations during lab meetings and informal gatherings. What becomes readily apparent rather quickly in our conversations is the difference in words and dialects. Students from the South as opposed to the west or Midwest have the characteristic southern accent and drawl. Those from the Northeast have either a strong New England or Bostonian accent. Some students come in with such strong accents that a short explanation may be needed to understand what each of us is saying.

Even the lab's research animal, the crayfish, has numerous names across the country. Although the official scientific name is crayfish, the heart of the United States (Missouri, Oklahoma, Kansas, Nebraska, and Arkansas), as well as the west coast (California and Oregon) refers to our research animal as crawdads. The Deep South, the Atlantic coast, and some of the plains areas call these creatures crawfish. The upper Midwest and Northeast refer to them as crayfish. Finally, my Australian postdoc referred to the animals as yabbies. Thus, during our conversations, the listener can tell a little about the homeland of the speaker by the use of certain words as well as the dialect. Similar distinctive word choice can be done with the soda, pop, and coke triumvirate as well as the "you guys/you/y'all/you all" usage for a group of people.

Unlike the MHC recognition above (which is genetic), the type of friendly nature, the dialect spoken or word choice is a learned phenomenon based on the local environment in which the speaker grew up. These cultural and regional distinctions in language use or dialects are badges that serve to associate the individual with different groups like New Englander or a Southerner. The familiar pop or soda usage determines if someone is "from around here" or the potential "in" group versus a visitor from a different part of the country. Animals also have learned badges that allow them to distinguish neighbor from visitor or in the animal kingdom, friend from foe.

The paper wasp, *Polistes fuscatus*, builds large nests composed of "paper" that have a large number of individual cells hanging downward. The wasps need bits and pieces of wood and are usually found around woodlands. They chew on the wood and produce a paste mixture from which they build their nests. The female wasp that starts this process is called the foundress and she is the dominant wasp in this nest. The foundress begins to lay eggs in each of the chambers and as the eggs begin to grow and hatch, she continues to build other chambers for more eggs. This process continues on and on until the first eggs begin to hatch.

Once multiple wasps have hatched (all females at this point), some of the sisters and even the foundress can fly off to find other nests in which to build cooperative broods. Those sisters that stay on the original nest will help build more egg cases, defend the nest from intruders, and help forage for caterpillars. Upon the return from foraging flights, the sisters will share bits of masticated caterpillar with the larvae and with each other. Herein lies the problem for the paper wasps, how does the wasp know that a particular sister is returning with food or is an intruder?

Dr. George Gamboa has been studying paper wasps for 30 years and began to notice that paper wasps tolerated the presence of nestmate sisters more than nonnestmate sisters. This was true whether the encounters took place in the field or on the umbrella like nest. The friendly treatment also extended to the brood. Foundress wasps either ate or bit larvae and eggs from unfamiliar nests and treated larvae and eggs from their home nests with a far more gentle approach. Having carefully controlled for relatedness, the wasps did not appear to use a measure of genetic relatedness as the source of recognition. Unlike the MHC recognition outlined earlier, this

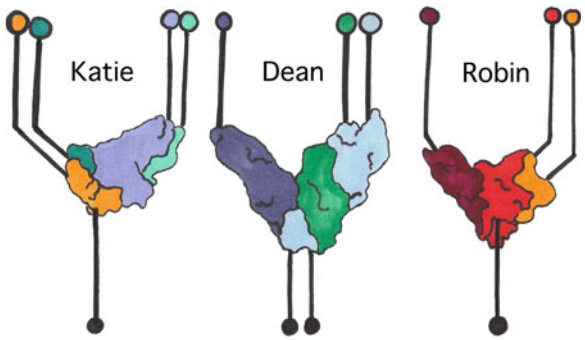

Fig. 4.4 MHC molecule

type of recognition appeared to be more related to the local environment or in other words, the nest itself (Fig. 4.4).

In a similar fashion to the salmon homing described in the next chapter, paper wasps "imprint" to the local food and nest smells and use this smell to recognize nestmates from non-nestmates. In a series of ingenious experiments, Dr. Gamboa and his students raised colonies of paper wasps from eggs to adulthood under identical conditions in his laboratory. The wasps were exposed to identical food throughout their life, identical environmental conditions, and nest making materials. Wasps exposed to other colonies were treated as nestmate sisters by the foreign colony. In addition, if the female wasps from different colonies were exposed to fragments of the same nest, the two different wasps treated each other as nestmates. It turns out that there are nest-specific chemicals that are "woven" and painted onto the nest by the queen as she strokes her abdomen on different parts of the nest. If the nest or other wasps are washed with a special solvent that removes these chemicals, the recognition is gone and the wasps are treated as intruders. Since the queen creates the initial nest, lays the initial eggs, and paints the nest with her chemical cues, the recognition signal is a combination of local environment interacting with the genetics of the queen.

Across college campuses, Greek life is a big part of the culture. Sororities and fraternities are easily marked by their three characteristic letters such as Delta Tau Chi. Sweaters, sweatshirts, hats, and bags all mark the wearers as sisters or brothers of a certain Greek group. Even off campus and later in life, if two people recognize that they share the same sorority bond (even across different campuses), they are sisters for life. For sorority sisters, there is an increased level of friendliness and a willingness to immediately help if needed. Three letters, say ΔTX, are all that are needed to signal a group. Within the paper wasps society, the chemicals that queens place on nests serve the same function as saying "soda" (indicating a New Englander) or crawfish (indicating a deep south location) or wearing a sweater with three Greek letters on the front. Paper wasps with the same nest and queen smell are sisters for life.

4.6 Are You My Mother?

Nestmate recognition is critical for maintaining and controlling important resources. Paper wasps invest a lot of energy and time into making their nest and the queen has invested enormous energy stores into producing eggs. Protecting that investment into their reproductive efforts through nestmate recognition provides the paper wasp an evolutionary advantage. In some bird species, the recognition of offspring or relatedness is not as fully developed and some bird species have evolved strategies to take advantage of this reproductive loophole. Cuckoos are one such type of species. Cuckoos will lay their eggs in the nests of other birds and then leave the parenting skills to the very accommodating host bird. This type of system is called brood parasitism, and the cuckoos are particularly adept at this lifestyle (Fig. 4.5).

Fig. 4.5 Cuckoo egg in nest

The cuckoo and another brood parasite, the cowbird, have evolved egg mimics. This adaptation is where the cuckoo or cowbird egg looks very similar to the host egg. The reed warbler is a favorite target of the common cuckoo. The warbler's egg is tan in color with darker colored speckles. Although the cuckoo's egg is about 50 % larger than that of the warbler, the cuckoo's egg is almost identical in color. The eggs are close enough in color that the host bird, in this case the warbler, raises the offspring as its own. There is a significant cost to the warbler in raising the cuckoo's offspring and often, the cuckoo is provided food at the detriment of the warbler's own offspring. Given the reproductive cost to the warbler, there is evolutionary selective pressure for recognition of its offspring. Thus, warblers that are more successful at detecting and rejecting cuckoo eggs will have a higher reproductive success rate than those warblers that are blind to the cuckoo eggs. Of course, there is selective pressure on the cuckoo also. If the cuckoo's eggs are significantly different in color from the warbler's eggs, then there is an increased chance of recognition of the cuckoo's egg which is often followed by rejection. The increased selective pressure for warblers to recognize eggs and the increased selective pressure for the cuckoos to decrease this recognition is termed an evolutionary arms race (as a reference to the cold war era arms race). Recognition of one's offspring by the parents is a critical aspect of reproductive success.

One of the parental hallmarks of mammals (and bird species) is the concept of extended and intense offspring care. Mammalian (including human) young are incapable of taking care of themselves, and thus, parental nourishment, protection, and learning are important for the successful rearing of offspring. The reproductive consequence of long periods of nurturing by mammalian parents is the loss of repeated and large scale reproductive efforts. In contrast, many invertebrate species have very little parental care and can invest more in large numbers of offspring in the hope that a small percentage of them survive to adulthood. The German cockroach is rather small from a cockroach perspective, but are champions when considering their reproductive efforts. A single female can produce over 10,000 offspring within a year. For cockroaches, the loss of a few hundred offspring is a common occurrence. For mammals, the loss of a single offspring is something of great concern.

Given the importance of rearing the few, but precious young, mammals have evolved a strong system for the recognition of their offspring, and this system is based on chemical signals. Rabbit pups are able to recognize and prefer their own nest over that of a different mother's nest as early as a single week after their birth. Similar work has shown that mice exhibit the same types of preferences where offspring are drawn to the odors of their own related mother as opposed to another unrelated mother. Returning to the work of Yamazaki and Beauchamp covered previously, this recognition is probably through the MHC complex, but with the parent offspring recognition, the offspring learn the appropriate odors that are associated with maternal recognition as opposed to some innate recognition.

As important as recognizing ones mother is, recognizing that an odor is coming from a dangerous parent can be just as important in the mammalian world. Infanticide is a phenomenon where an adult male or female within a social setting kills an offspring of the same species. This behavior, although not common, isn't rare in the animal kingdom and has been documented in a number of invertebrates, birds and mammals. A deeper explanation for the presence of this behavior across a number of species is beyond the scope of this book, but one of the main theories for the evolution of infanticide involves sexual conflict. In a number of mammalian societies, a single male often has access to a larger number of females for reproduction. Within these societies, this male (alpha or dominant male) spends a very short period of time as the top dog. If females within his group are currently caring for offspring from the previous alpha male, his reproductive success can be limited. Thus, the alpha male will frequently kill the offspring of his previous competitor which will allow the females to become fertile again. For mammalian offspring, the close presence of an unrelated male is often a sign of life threatening danger.

Infanticide is present within mice communities, and mice pups will produce more ultrasonic calls to mother mice in the presence of odor from male mice that have performed infanticide as opposed to male mice who have not killed any offspring. These pups will also attempt to move away from these infanticidal males, but will remain stationary to their own fathers. Although the specific chemical cue has not yet been found, there are odors produced by males who have killed offspring. Pups are sensitive to this odor that is missing from their own fathers or mothers. Presumably, the offspring are seeking the safety that their own parental odors represent.

4.7 That New Baby Smell

The offspring parent bond and recognition is as important within our own society as in animal societies. In many of the animal studies, researchers have focused on the chemical cues given off by either parent. These cues help control the offspring's behavior, mood, and overall health. The aromas of parents can promote a sense of calm, feeding, and reduce stress. More recent work has begun to demonstrate that the odors that babies produce (beyond their diapers!) could have significant and important impacts for parents even if the parents are unaware of these effects.

Psychologists have recognized for years that the bonding process between baby and mother is critically important for the health and survival of the baby. Work on bonding between babies and fathers started a little later than work on mothers, but has demonstrated the importance of this bond also. Bonding, as a psychological process, draws the parent closer to their baby and results in a much stronger physical and emotional attachment. As mothers and fathers cuddle or hold their baby, they may be doing something far more subtle than just providing a loving physical environment for their new child.

An interesting study, led by Drs. Johan Lundström (at the Monell Chemical Senses Center) and Thomas Hummel (Universität Wien), found that new mothers showed an increased neurological response when presented with infant odors as compared to women without children. The response was neurological rather than psychological because both groups of women gave the same verbal ratings for the odor qualities. The brain responses were measured by a machine called a Tesla MRi-scanner. The scanner measures both blood flow and oxygen concentration in different areas of the brain and areas light up (have increased oxygen and blood flow) as that part of the brain is being used. The women essentially had puffs of odor delivered to their nose that were derived from cotton undershirts worn by the infants for 2 days. Both the new mothers and non-mother women rated the odors equally for pleasantness, intensity, and familiarity. In addition, both groups, independent of whether they had offspring or not, showed more activity in the area of the brain (neostriate) that would cause them to care for the infant. The neostriate is associated with planning and movement. Thus, the possibility exists that odorant molecules in babies trigger an unconscious response to care for and about the health of helpless infants.

Furthermore, the new mothers showed increased brain responses in a different area of the brain (dorsal caudate nucleus). This part of the brain is associated with a number of cognitive functions such as learning, memory, emotions, and language. Finally, both of these areas of the brain (neostriate and dorsal caudate nucleus) have a preponderance of dopaminergic neurons. These neurons release the neurotransmitter called dopamine which is link to the reward mechanism in our brains. For example, if you are with a group of friends and tell a funny joke, the resulting laughter triggers little tiny jolt of dopamine and you feel some pleasure or happiness. This often promotes you telling other jokes just to receive additional jolts of dopamine. This cycle, dopamine to pleasure to seeking more dopamine, is a positive feedback loop that can lead to addiction. In this case, the odor may serve to find a good caretaker for the baby and to increase the bond between a mother and her baby. The fact that new mothers have an increased response in some areas of the brain to infant odor may further enhance this bond between the mother and child as opposed to a bond between a woman and unrelated child. In a way, these infant odors, which allow mothers to identify their babies, are sneaking their way

Fig. 4.6 Wispy baby rewiring brain

inside the brain and influencing the pleasure and reward system of the brain without the mother becoming consciously aware of that connection (Fig. 4.6).

In this chapter, I have written about the different identities that people and animals have and the roles that they play on a daily basis. Whether there is a need to recognize self from nonself in order to destroy dangerous intruders in our bodies or the need to recognize those in a unique or special social role such as our friends, our family, or our clan, chemical signals are there as sure as name tags and Greek letters. Some of these chemical badges are inherent to who we are because they are generated by the very DNA that determines our very being. These signals surely represent us to the world in a revealing way. Although we can change our clothes or hair color and we can attempt to cover our odor tracks through shampoos, deodorants, and perfumes, the chemical signals generated by the MHC complex within our bodies announce our DNA to anyone astute enough to pay attention to it.