Free Radical

The Dragonfly and the Peering Locust

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One morning in the late summer, I sat on the deck on our rooftop. Despite the city surroundings, the air was clean and clear due to a heavy rain the previous night. The sun was beating down on the silver-painted surface of the roof, but hadn't yet been able to evaporate small pools of water that had accumulated there. Out of the corner of my eye, I noticed that a large dragonfly had been attracted to the pools, probably expecting to find some mosquitoes for a breakfast treat. For fifteen minutes or so, I watched the dragonfly perform a delicate dance over the shallow pools. I was amazed at how the dragonfly was able to skim the surface of the pool, rise up, and dive down just to touch the surface. Its movements were so precise, they didn't seem affected by the almost mirror-perfect reflection on the still water.

The shape of the dragonfly reminded me of the helicopters that I see flying along the East River every day from the rooftop. Of various shapes, colors and sizes, these helicopters patrol the area around the bridges, report daily traffic patterns, and provide transportation around Manhattan. I am always impressed by the skill of the pilots, watching as two helicopters hover in sync, stationed over the towers of the Queensborough bridge and then turn in tandem to continue to travel along the clear passageway created by the river. Like the wings of a dragonfly, the helicopter's propellers move so fast that they appear as a blur to the eye. Also like a dragonfly, a helicopter is designed for precision aerobatics. However, as I watched this dragonfly, I saw a precision of movement unlike any helicopter I have ever seen. The dragonfly could hover centimeters above the surface of the water and then suddenly swing up and into position high above the pool. To me, the movements were a signal of an extremely effective visual system, and it made me wonder how the visual systems of insects differ from those of humans.

Unlike our eyes, insect eyes are immobile. This makes depth perception much more difficult for an insect than a human. Insect eyes are also much closer together than human eyes, another obstacle to effective depth perception. How, then, was a dragonfly able to skim the surface of a reflective pool of water without crashing into it?

Although the compound eye of the insect lacks the depth perception abilities of mammal eyes, insect eyes are adept at perceiving motion. Perhaps it is this detailed motion vision that helps the insect navigate. In experiments with locusts by G.K. Wallace in the late 1950s, researchers determined that the fast, seemingly chaotic motion exhibited by insects and other invertebrates (for example, crabs skittering along a sandy beach) is part of the animals' depth perception. Wallace observed locusts performing a series of head movements before moving toward an object. He determined that this action, an action he called the 'peering' of the locust, was used by the insect to determine the distance of the object. [1]

Adjacent to the rooftop garden where I was sitting that morning is the off-ramp to New York's Queensborough bridge. While Manhattan's skyline itself is an extraordinary sight from the rooftop, the roof also allows for an almost 360 degree panorama of the city. I find myself wishing that I had the wide angle vision of an insect eye to fully appreciate the view. From my vantage point that morning, moving my head in several directions, I noticed that the most dominant part of the visual scene was the highway. Like every other day, the flow of traffic on the bridge was a constant, steady stream. Over the years, I have found that not once at any hour of the day or night has the bridge been clear of moving vehicles, although it is possible to discern a pattern of traffic flow density at different times of the day.

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As I watched each car exit the bridge, I thought about my own experiences driving. The process of driving itself is an improvisation. Drivers make choices based on the presence or absence of other drivers or just on a whim. They respond to events on both a macroscopic scale (for example, choosing a route) and a microscopic scale (such as stepping on the brake in a split second in response to a moving obstacle). The decisions drivers make are influenced by many factors, from the visibility of other cars from inside a particular model or make of car, to the maneuverabilty of a particular car, to the position of a car on the road and even to the state of mind of the driver. Despite the many factors that influence driving behavior, the rules of the road serve to help create an organized pattern of traffic flow, like the organization created in computer simulations of flocking and swarming.

Computer flocking and swarming algorithms were developed as a way to accurately simulate the behavior of large groups of animals. Rather than a model of the entire sensory system and specific behaviors of each animal, flocking algorithms are a subset of artificial intelligence in which representations of creatures like birds or buffalo are given a simple set of behaviors. These simple rules function like the rules of the road in organizing the represented creatures. If the rules are designed just right, the result can be a striking visual representation of a flock, herd, or swarm of animals. For example, with a flocking algorithm, a bird may be programmed to stay within a certain range of another bird without colliding with this bird or any other obstacles. It's fascinating to look at the resulting visual simulation when a group of these creatures interact with each other, and to watch the flocks and swarms respond to novel situations such as obstacles and intersecting flocks. [2]

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Breve is a 3D environment for the creation of simulations of artificial life and decentralized systems <http://www.spiderland.org/breve/>. In the demo section of the Breve application, there are a number of visual simulations based on flocking algorithms that can be customized through programming. One of these demos is called 'vision flocking.' In the code of 'vision flocking,' an aspect of a bird's behavior is actually based on a very simple simulation of the bird's ability to see. Simply put, an individual bird is only able to detect other birds that come within its line of sight which is defined as a 20 degree radius of vision, unlike in simulations without vision, in which each bird detects other birds along a radius of a full 360 degrees. The resulting simulation of this flock of multiple birds surprisingly appeared to me as less random than a flock simulation without the vision restriction. The birds in the limited vision flock appear to have a sense of purpose and direction whereas birds in flock simulations who have omnipotence (or 360 degree vision) appear to fly much more randomly. It is as if the birds in the vision-restricted simulation have less degrees of freedom, limited to move along a track or highway in the sky rather than cutting a more chaotic path.

Human beings have experienced the high-speed motion of a train or highway for only about 100 years. In the timeline of evolution, this is far too short for any significant adaptation of the visual system to the radically new kind of stimulus created by driving or riding in a fast moving vehicle. Despite this, driving is an everyday experience for many of us. Unfortunately but not surprisingly, traffic accidents are one of the leading causes of death in the United States and many other countries. In 2002, there were over 40,000 deaths on US roads and almost 3 million injuries. [3] It's literally a matter of life and death that we understand how the human perceptual system works in the novel situations in which technology places us and that we do everything possible to develop tools to more accurately analyze and understand how the body responds to these situations. It's not enough to give humans increased abilities through technology, researchers must make sure that the human perceptual system is able to handle these new capabilities and, if it doesn't, create ways to augment human perception appropriately.

The development of technologies for brain imaging -- like positron emission tomography (PET) activation images have allowed researchers to locate specific areas of activation in the brain during perception. The human ability to see motion has been isolated by using PET imaging on patients exhibiting a rare disorder called motion blindness. Gisela Leibold was stricken by a stroke that damaged a very specific pathway in her brain. After the stroke, she was unable to see motion. In a crowd of people, she became panicked and disoriented, seeing people disappear and appear suddenly in a different location. Riding an escalator or crossing a street was terrifying to her, and pouring a cup of coffee was almost impossible as she would see the stream of coffee entering the cup as a solid, motionless shape. [4] Gisela's condition, a severe impairment in the ability to recognize the motion of objects, is called akinetopsia and has been found to occur following bilateral lesions in a specific area of the brain called V5. [5]

About half of the brain of an insect is devoted to visual processing. Although the vision of insects is of a significantly lower resolution than human vision, there are aspects of motion vision that humans share with insects. For example, experiments with bees have provided strong evidence that insects experience the motion aftereffect, also known as the 'waterfall illusion.' The waterfall illusion occurs when looking away after observing motion. The visual system perceives movement in the opposite direction. Another visual effect humans share with insects is the negative afterimage. After staring at a high contrast picture and looking away, the visual system perceives a negative of the picture superimposed on the visual field. [6]

The afterimage effect in humans has been exploited in the development of the moving image. To the human mind, a series of still images appear to be moving due to what is called the phenomenon of persistence of vision. In this phenomenon, an afterimage of a still image stays on the retina long enough to produce the appearance of smooth motion.

In the early 1880s, Etienne-Jules Marey conducted research in the portrayal of motion using photography. He worked in a giant open-air laboratory he constructed outside Paris, called the Station Physiologique. His method of moving unexposed film, "chronophotography," allowed him to study the mechanics of motion, and many of his images attempted to isolate the 'purity' of motion by dressing models in all black, with white stripes, dots, and electric lights placed lengthwise along the limbs and at axis points, very much like contemporary models equipped with motion tracking sensors used in animation and game design. Within the medium of photography, Marey, Muybridge, and others experimented with the portrayal of the body in motion and helped to bring about moving picture technology. To Marey and many others at the time, motion could be broken down into a series of short, discrete time intervals. [7]

In 1912, Max Wertheimer, the founder of Gestalt Psychology, was one of the first to describe apparent motion or the 'phi phenomenon.' The phi phenomenon is the perceptual fact that stationary objects can appear as though in motion under certain circumstances. Wertheimer writes that his study of the phi phenomenon was inspired by a perceptual experience he had while riding a train. As he watched various lights blinking, he realized that if two lights blink on and off at a certain rate, he perceived them to be one light moving back and forth. Wertheimer's perceptual observations were happening at the same time as the early stages of the development of moving pictures, and he must have been aware of toys like the zoetrope and flipbooks that exploited persistence of vision. So, what was particularly new about Wertheimer's observation and subsequent developments in Gestalt theory? What was new, besides breaking down the phi phenomenon into very specific rates of time, was the idea that the mind's perception of a temporal experience is continuous and cannot be broken down into a series of snapshots. In other words, our minds do not work like flip books or zoetropes, cutting up our perceptual experiences into a string of still images. Instead, our minds process the information as it unfolds over time. The phi phenomenon works in tandem with the phenomenon of persistence of vision to make the experience of the moving image in film so compelling. [8]

Around the same time when Wertheimer was defining the phi phenomenon, Frank and Lillian Gilbreth were beginning an extensive research project studying workplace efficiency in the industrial age. The married couple produced over 2000 glass plate photographic images between 1910 and 1924. These works included various long exposures of workers on assembly lines, operating typewriters, laying brick, involved in basically any working activity of the time. Besides being a great document of working life during the early 20th century, these photographs helped to define photography's role as a scientific research tool. The technique they created -- using timed exposure of workers with lights attached to their hands and feet -- serve to distill motion into a simplified form that can be more easily evaluated for efficiency. This essence of motion that the Gilbreth's broke down into a combination of basic building-block movements looks very much like motion paths described by contemporary computer animators. Unlike the discrete blocks of frozen time in the filmic model of motion, movement is represented by a smooth, continuous line in the Gilbreth visual model of motion over time. [9]

Wertheimer's ideas emerged from the results of work done by experimental physiologists. Between 1865 and 1868, Franciscus Cornelis Donders performed a series of experiments attempting to break down the exact amount of time taken up by decision making. His work influenced many experimental laboratories to start measuring reaction times. The assumption implicit in the study of reaction times is that perception and thought are processes that occur over time. This assumption informed Wertheimer's work which posed that, if perception unfolds over time, then events that happen over time can have a gestalt, or be grouped into perceptual units, just like aspects of still images or scenes are grouped into identifiable units by the mind. The larger philosophical issue implicit in Donders' work is that if thinking is a process that takes time, then it could be a material process, not metaphysical or spiritual. [10]

When Wertheimer was observing the lights from the window of a train, he at first might have thought that another train was passing next to his train. Or, perhaps his mind didn't immediately make a judgement about what he was seeing. For some minute amount of time, Wertheimer may have observed the lights without a determination. Then his mind may have started to negotiate the various stimuli. He may have begun to differentiate between the reflection of lights from the inside of the train and the lights outside. He may have done this through slight movements of his eyes and head. He may have had to differentiate various visual artifacts, like scratches on the window of the train or specks of dust floating on the surface of his eye. Smoke from the train may have distorted his vision of the lights. Negotiating all these artifacts and differentiating them from the actual scene made the experience of viewing the visual scene a constantly unfolding process. A speck observed in the visual scene had to be analyzed and placed in a group. Was it a passing train, a light inside the train, or a station far off in the distance? For a very small but certain amount of time, aspects of the scene would be unidentified, until it would be placed into a category through examination.

So there are two ways to look at the human experience of movement through vision. On the one hand, movement is a continuous, what you might call an analog, process. Like the Gilbreth images or motion paths created by computer animators, movement can be broken down into a 3-dimensional line in space that represents the trajectory of movement. On the other hand, according to gestalt theory, the human mind understands motion as a series of discrete chunks, and our visual system can be fooled to see a series of still images as a moving object if they are changing at the right rate.

The theory that the visual scene unfolds over time has become an established area of machine vision research, called Active Vision. Active Vision is a task-oriented approach, and the idea is that a machine's (or human's) perception of a visual scene is enhanced through interaction with the environment. Active Vision is a concept that is opposed to the idea of Pure Vision. The Pure Vision concept is that a scene is analyzed by the mind using a hierarchy of information and representations that flow from bottom to top. That is, low level representations (like color and basic forms) lead to higher level representations (like a building). The Active Vision concept opposes this idea by saying that visual perception is not hierarchical and that information flows both ways, informed heavily by memory. [11]

Active Vision implies a constant process of evaluating and re-evaluating a visual scene based on past experiences and best guesses. Active Vision also implies a purpose-oriented viewing, that is, perception to satisfy direct needs. This approach has been useful in the design of effective machine vision systems, but also in the development of videoconferencing applications that use the Active Vision model to enhance the flat screen image. [12]

How was the Active Vision model developed and why now? One reason might be that, through new technology, perception science researchers' have recently been able to make observations in the real world, outside of the laboratory setting. According to Johannes M. Zanker and Jochen Zeil of the Visual Science Group, Research School of Biological Sciences at Australian National University, several factors have made it possible for scientific researchers to move out of the controlled environment of the laboratory and begin to study perceptual systems in the field, allowing for a look at perception under real-world conditions. These factors are: technological innovation in the area of temporal and spatial high resolution portable recording devices; new theoretical approaches that involve the analysis of complex systems; new knowledge of neurophysiology and the ability to monitor and record nerve cell activity; and advances in robotic technology that allow the systems to be put to test interacting with the real world. Zanker and Zeil believe that studying perception in the real world has had and will continue to have a huge impact on scientists' ability to study and understand human motion vision. They see a theoretical understanding of complex systems as essential to the process. [13]

Just as scientific and technological development has made it possible for researchers to make field observations and understand more of how complex systems work in the real world, technology has made our real world more complex. Take the case of driving, where a human is interacting with a complex machine. This human-and-machine combination has to negotiate a complex environment filled with other human-and-machine combinations faced with the same challenge. But that's not all, the negotiation has to happen at speeds faster than any speeds we humans have experienced in our evolutionary history.

The move of field research into the nature of perception is actually a return to an earlier way of working. Historically, most of the study of vision and perception was done through analysis of observations in the real world. Observers like Goethe and Descartes were hybrid philosopher / scientist / artists who drew from their own experience and imagination. However, since the 17th century when experimental sciences began to dominate the scientific method, experimenters from all areas moved into the laboratory. This constrained system allowed for a detailed empirical study of a specific process and accelerated the development of science. What Zanker and Zeil are now arguing is that the development in technology, combined with a theory of complex systems, now makes it possible for experimenters to return to the field and combine the best of both worlds: interaction in the real world with the detailed analysis possible in the laboratory.

Scientists moving back into the real world -- armed with knowledge gained in the laboratory -- open the door for a renewed interaction between the sciences and the arts. Although some artists choose to isolate themselves in the studio for specific ends, most contemporary artists choose to work and live in the real world. For artists, this interaction is essential to the artistic process, and in fact, many contemporary artists have gone so far as to as to refuse to separate art from life. For example, the artist Sophie Calle's projects have blurred the boundaries of art and life. She works as almost a private investigator, following a chosen stranger in the 1983 book project Suite Venitienne, or exposing the private life of an acquaintance through his misplaced address book as in The Address Book, also from 1983. She exposes her own life, too, documenting her job as a stripper in a Paris nightclub and her Las Vegas wedding to filmmaker and collaborator Greg Shephard in their film Double Blind. Calle often works like a private investigator or scientist in the field. In 1986, she asked a series of people born without sight to describe their personal image of beauty in a project called The Blind. In its artistic context, The Blind underlines notions of beauty in relation to the visual since most of her subjects spoke of visual images and she presents the work as a series of photographs. However, it is also possible to look at this project as a kind of scientific investigation. Although the artist did not specifically follow a quantitative scientific method, The Blind reveals aspects of human experience and perception from a qualitative point of view. [14]

Almost 100 years ago, in 1909, the Futurist Manifesto was written in Italy by Filippo Marinetti, creating one of the longest living art movements of the 20th century. At the time of its writing, Marinetti and his artist colleagues were all under 30 years of age, and true to its name, the manifesto is a testament to the future, embracing the developments of technology and science that were rapidly becoming a part of daily life at the time, especially the automobile. Reading the manifesto today, one has to be struck by its ominous connections to the Fascist movement and by its glorification of war, but also by its unabashed embrace of technology. The manifesto embraces the technology of the changing environment as a new aesthetic -- "We declare that the splendor of the world has been enriched by a new beauty: the beauty of speed" -- and violently rejects the traditional definition of art: "We want to demolish museums and libraries." Referencing the widespread idea that the development of the steam engine brought on an annihilation of time and space, the manifesto states "What is the use of looking behind at the moment when we must open the mysterious shutters of the impossible? Time and Space died yesterday." [15]

In collaboration with artists, scientists can bring new tools and knowledge of these complex systems to the field, while artists contribute a working process of observation and analysis that never abandoned the real world for the laboratory. This is creating individual scientist / artist hybrids similar to Goethe and Descartes, but with new experimental and experiential knowledge.

Although many aspects of the Futurist Manifesto still appear radical, the aesthetic appreciation of technological development and even the rejection of the museum are ideas that are embedded in our contemporary media art practice. Today, the role of the museum is constantly called into question with endless discussion on how museums need to evolve and adapt to new media technologies, and new media artists themselves strive to adapt to developing technology, in many cases even participating in the development of these technologies through individual research or in collaboration with scientists and engineers. This research brings technology developed for the scientific investigation of perception, which 50 years ago would have initially been confined to a laboratory setting, into the real world much sooner. In collaboration with artists, scientists can bring new tools and knowledge of these complex systems to the field, while artists contribute a working process of observation and analysis that never abandoned the real world for the laboratory. This is creating individual scientist / artist hybrids similar to Goethe and Descartes, but with new experimental and experiential knowledge.

Stuart Antsis of the Department of Psychology of the University of California San Diego is one researcher whose laboratory includes real-world observation and whose work is making a difference in the area of perception and technology. If you ever had to drive on a highway in a dense fog, you know the terror of encountering a fast-moving car at close range with no warning, and in 2002, there were 1200 fog-related vehicle accidents in Wisconsin alone. The danger of a driving situation in fog is caused by more than just decreased visibility; there is also an optical illusion of motion that occurs. Dr. Antsis and his team have determined that in addition to low visibility, fog also creates the effect of low contrast and that objects appear to move more slowly in low-contrast situations. Drivers not only fail to see fast moving cars in a dense fog , but drivers misjudge their own speed and the speed of other cars. Dr. Antsis' work details the nature of the low contrast movement illusion and suggests that even some simple graphic indicators on or around the road might save lives. [16]

Anthony Hornof and his colleagues in the Department of Computer and Information Science at the University of Oregon are working on a series of projects using eye tracking. One aspect of their project that is interesting to me is that they are working with The Cognitive Modeling and Eye Tracking Lab at the University of Oregon, a lab that analyzes eye movement data for scientific research. Traditionally, eye tracking data is analyzed at length after the experiment because of the complexity of the information, but the Hornof team suggests that a sonification of eye movements in real time could provide some information to researchers before the data is analyzed in detail. [17]

Although eye movements and attention have been determined to be separate, there is an important link: attention is focused on a particular stimulus a split second before the eye is directed to look at it. The Volvo corporation has accepted the link between eye movement and attention and is using it as the basis of a new driving system that keeps track of the driver's eye movements and delivers a warning if the driver is not paying enough attention to the road.

Of special interest to Volvo is helping professional drivers monitor drowsiness. This work is the contemporary equivalent of Frank Gilbreth's work in the 1930s on workload management for machine operators. In the case of Volvo, there is an attempt to measure mental energy through the monitoring of eye movements rather than the physical energy monitoring of Gilbreth's photographs. [18]

Interactive moving image technology presents a unique opportunity to not only portray objects and subjects in motion, but to portray the experience of the observer in motion. Computerized vision systems have to be able to distinguish form and color in various lighting situations, and perhaps most importantly, they have to be able to perceive various kinds of movement. Robotic vision systems also have to be able to differentiate between internal movement (i.e. the movement of the robot itself or the camera input) and external movement. Since most computer vision systems use digital video as the input source, it is possible to detect a change in pixels from one frame to the next and compare the changes to camera movement data and other information.

In an attempt to create realistic computer gaming experiences and intelligent robot movement, researchers have begun to study how biological creatures are able to perceive and resolve the motion of their bodies. There has recently been an increasing interest in the visual systems of insects by researchers designing computer vision for use in robot navigation. For example, researchers at The Center for Visual Science at Australian National University (ANU) in Canberra and the Department of Computer Science at Curin University in Perth are collaborating on a project exploring robot navigation inspired by principles of insect vision. [19]

Imagine trying to develop a way for your car to travel without you or any person as the driver. Although it would be convenient to have your car do errands for you while you stayed at home, it would certainly be a challenge to design your car to respond to all the unexpected events that happen while driving. You might be able to easily program the basic sequence for starting the car, accelerating, stopping, and turning, but it would be impossible to predict every situation your unmanned drone car might encounter. So, you might consider giving your drone car a basic perceptual system. As you start to consider all the ways in which the drone car might need to respond, the perceptual system starts to require more and more capabilities. Then you might consider that the perceptual system you design perhaps shouldn't be an exact model of human perception. For example, you are aware of the motion-based illusion that occurs in fog and was discovered by Dr. Antsis, so perhaps the perceptual control system for the drone car should behave in a different way.

If you imagine increasing the complexity of the problem of the drone car to a helicopter, you have the problem that Professor Mandayam Srinivasan of the Vision Sciences Group at ASU is trying to solve. Small, pilotless aircrafts called 'drones' are in high demand by the defense industry. By operating planes without pilots on board, a military operation obviously risks the lives of fewer soldiers. However, not having a pilot on board means that there is no pilot able to perceive and respond to the complex situation. One of the Visual Sciences Group's possible solutions to that problem is the Bee Chopper. [20]

Srinivasan has discovered that bees are able to navigate down the center of a narrow tunnel through evaluating the speed of motion on either side of the tunnel. It turns out that the wider angle of view afforded by the insect eyes and the fact that the eyes themselves are immobile is actually a feature and not a bug (pardon the pun). A perceptual system of an organism that estimates location and navigation through estimating movement around it benefits from having more information about its surroundings. Hence the benefit of a wider angle of view. How does an organism tell the difference between its own movement and the movement of its eyes? Well, in the simplified system of the insect's visual system, at least, the need to distinguish between an eye movement and a body movement is not part of the picture since the insect's eyes cannot move. By observing bees and their fantastic ability to navigate long distances through the air only to gently land on a specific flower petal, Professor Srinivasan and his research group are finding a model that solves the complex problem of unmanned flight and are shedding light on ways that artificial vision systems might assist humans in adapting to rapidly changing technology. The dragonfly, the bee, and the peering locust are also helping to illuminate this world of vision in motion.

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