Q & A

Patrick Cavanagh

Patrick Cavanagh graduated in Communications Engineering from McGill University in 1968. An interest in artificial intelligence led to a Ph.D. in cognitive psychology from Carnegie-Mellon in 1972. He taught at the Université de Montréal in Psychology until 1989, when he moved to Harvard as a Professor of Psychology. Along with Ken Nakayama, he founded the Vision Sciences Laboratory at Harvard in 1990. In 2007, he accepted a Chaire d'Excellence at the Université Paris Descartes where he continues as the head of the Centre and Attention and Vision of the Laboratoire Psychologie de la Perception. He is an Emeritus Professor at Harvard and a Research Professor at Dartmouth. He is a member of the Society of Experimental Psychologists and received a 2012 Honorary Doctorate from the Université de Montréal.

What turned you on to neuroscience in the first place? In Montreal, I was an electrical engineer interested in programming intelligent computers, but it was soon clear to me that the brain was a much more interesting computing device. It didn't come with a manual, but it was infinitely more powerful and mysterious. I read Donald Hebb's *The Organization of Behaviour* and I was stunned to see a plausible neural mechanism for mental function, written in 1949 (and still influential today). It convinced me to switch to neuroscience, starting with Hebb's own psychology classes and then a PhD program led by Herb Simon and Allan Newell at Carnegie Mellon, a hot spot in the cognitive revolution of the time.

Shortly after arriving in Pittsburgh, I read a *Science* article by Dan Pollen and colleagues where they proposed that the visual system analysed images using Fourier transforms. It was the beginning of a golden era of vision science when computer vision, biological vision, physiology, and philosophy all were interacting. The Fourier hypothesis, though it did not live so long, seemed to combine all of these and triggered my interest in neuroscience and in particular a PhD thesis on a neural holographic model of short-term memory. The holography part led to several interactions with the 'holographic' theorists of the day, including Karl Pribram. Karl was so taken by the holographic process he once asked if the universe were a holographic projection of our mind. Holography has long died away as a model for brain processes but I am always predicting a revival.

What was it like working at the Université de Montréal? When I began work at the Université de Montréal, my French was rudimentary but I found that giving courses in French was a good way to learn. It was painful, but apparently even more painful for my students. It was at the height of the separatist movement that almost succeeded in turning Quebec into a strictly French speaking, independent country. Nevertheless, my French was evidently so bad that some students called out from the back of the class "Speak English please".

Our research group in Montreal combined physiology, led by Franco Lepore, and later neuropsychology, led by Maryse Lassonde. While in Montreal, I began projects with Stuart Anstis on motion and colour perception and V.S. Ramachandran on depth perception that convinced me that vision research was much more exciting than neural modeling and memory studies. OK, perhaps it was the two of them more than the content but, under their tutelage, I switched completely to vision science. I also became an associate member of the Canadian Institute for Advanced Research (CIAR), a group of scientists from across Canada in several disciplines that formed a 'university without walls'. We had cross-disciplinary meetings with a level of excitement perhaps unmatched in the rest of my career. With Steve Zucker, Mel Goodale, Anne Treisman, Danny Kahneman, David Lowe, Geoff Hinton, Zenon Pylyshyn, and others from genetics and astrophysics, we covered lots of topics in remote resorts around Canada. Later at Harvard, research groups were more focused and I never heard any more genetics or astrophysics mixed with vision and I missed the possible crossover of ideas that seemed so tantalizing at the CIAR.

What did you like about Harvard? At Harvard, together with Ken Nakayama, we created a vision science lab that was bustling with research and teaching and outstanding students and postdocs. It was like having a big Irish family with dozens of children, cousins everywhere. They were all doing great work, and getting good jobs all across the world. The number of human and computer vision scientists in the Boston area was staggering and we had interactions with MIT, BU, Brandeis, and Northeastern. As for teaching, Harvard had amazing resources. If we wanted a rocket launch during a class, it was set up. And the students were not bad. The campus politics were also entertaining.

What were your most interesting experiments? Two come to mind, not for their outcome but for the process. In the first, with Stuart Anstis, Daphne Maurer and Terri Lewis in Toronto, we were evaluating our recently developed test for colour blindness on new born babies. To validate the test, we had to find babies we knew to be colour blind at birth. Given the genetic rules for X-linked colour blindness, that meant their mothers had to be colour blind (very rare) and expecting a baby boy. Radio advertisements actually brought in two such mothers and their infants confirmed that our test worked. Unfortunately, no one really cares if their child is colour blind, and since anyway there is no cure, the work went no further.

In the second, we had developed a visual test for seeing lights from outside the visual field. A optic fibre probe was attached to white part of my eye, the sclera, and for given angles of gaze the pulse of light delivered by the fibre and transmitted to the retina below would be visible in space in front of me but, for other directions of gaze, where the light would have corresponded to a location inside my cheek or brow, the light delivered to the same point on the retina was no longer visible. To attach the fibre to my eye we had a prosthetic sclera made at a specialist firm that makes replacement eyes for the injured. They first made a mold of my eye by inverting a funnel over my eye and pouring warm plastic into the funnel until it completely covered my eye. The part I treasured and wished I

could have had as a movie was when the plastic was slowly approaching and then contacting my eye, slowly engulfing the world in darkness. And strangely warm. Science can be exciting in unexpected ways.

What is the best advice you've been given and what advice would you offer someone wondering whether to start a career in biology? The best advice I was given was to listen to your data. It may not be telling you what you expect or what you want, but it is a message from the natural world that must be treated with respect to be heard. Of course, sometimes it has to sit in a computer file for several years before you are ready to understand it.

As for advice to someone who is wondering whether to start a career in neuroscience, my advice is, if they are wondering, they shouldn't. It needs to be a passion that draws you in and offers ever more wonders the further you get. Wondering whether to become a neuroscientist means you probably have not got the passion yet. Wait until it hits you. It's like lightning strike, a coup de foudre.

If you knew what you know earlier on, would you still pursue the same career path? Being a scientist is a privilege and supporting scientists is a luxury that only affluent societies can afford. I am deeply grateful for the opportunity and would choose the same interests again. Research in neuroscience is an adventure of discovery, full of surprises and challenges, with the pleasant company of ingenious colleagues and students. We are like tourists observing and describing the mysterious customs and rituals of the brain and its visual system. OK, sometimes the weather turns bad, the luggage is lost, and we take the wrong road. But what a fabulous trip.

Why did you leave the US and move to France? Adventure, politics, better baked goods, new science opportunities in Europe and in Paris. The research funding is better and more varied but the bureaucracy is epic. The salaries are lower but there is so much to see and do.

What has been your biggest mistake in research? My biggest mistake has been to mention at times in the past to research assistants and students what I think our data should look like or suggest that there is an expected outcome. With enough time and enough people, this can lead to someone falsifying data. Luckily, if you check all your data before publishing, especially data that look too good, you might catch it before it is too late. After it has left your lab, no one will know who was responsible. Much better to encourage a culture of respect for the data, to underscore how all outcomes are equally important, even, or especially, those results that overturn your own theories. Who better to lay to rest your own work than yourself. You should not entrust this to someone else.

What is your favourite conference? I like most conferences. You get to catch up with new theories, see friends, exchange ideas. It is party time for the mind. OK, some conferences are more rewarding than others. Mid-sized ones seem to give more scope for personal interaction.

Do you have a scientific hero? My favorite scientist of all time is ibn al-Haytham, an astounding polymath from the 11th century. Known as Alhazen in the west, ibn al-Haytham was a well-known mathematician and pioneer contributor to optics (discovered the lens, the pinhole camera, and, some say, the scientific method). His books were translated into Latin and, until Kepler, they were the fundamental texts in Europe for optics; at least his first book of optics was. In his amazing second and third books of optics, he outlined his very modern theory of unconscious inference. These books founded the field of high-level, vision science and were much less well known. They were undoubtedly read by von Helmholtz as he repeated Alhazen's concepts without credit and almost word for word in his own work in the 19th century. I admire Alhazen not only for his ideas that still underlie current research in my area, and for his broad contributions to science, mathematics, and optics that are still influential, but also because he promised to dam the Nile and then feigned insanity when he realized it could never be done. He was both a genius and a trickster, the Richard Feynman of the Middle Ages.

Any thoughts on the electronic revolution in publishing? I do love having everything being available on line, and I am not particularly dogmatic about who pays for my access. On the other hand, the best way to involve the less developed world in science is to have all the journals freely available. How many Einsteins could there have been by now if all the world's science were available to all.

What is your greatest ambition in research? Herb Simon had said that the role of science is to turn the magical into the commonplace — explaining the mysterious and making it predictable — but that makes it sound like we scientists ruin all the fun. However, in vision sciences, in particular with visual illusions, we can have it both ways. Even once we understand the source of an illusion, it remains effective. As Zenon Pylyshyn pointed out, knowing that the two lines in the Muller-Lyer illusion are identical in length does not make them look so. Vision is an independent, intelligent agent with its own inference mechanisms. It does not get pushed around by what the rest of the brain knows. My modest ambition is to add new illusions that reveal how the brain functions but forever retain their magic when we see them.

Was it difficult to combine a career in teaching and research? Teaching is a big challenge and requires a serious investment of time and spirit. I have had periods of pure research with no teaching and periods of combined teaching and research. I can report that my research always improved when I was also teaching. The reason is that teaching makes you explain your work to students who mostly would rather be elsewhere. I believe this is the bottleneck theory of teaching that Geoff Hinton once described to me, in a brief connectionist format of course. Since only simply structured explanations can be successfully transferred to the students, you are forced to distill your work into a small number of dimensions. The payoff is that not only the students understand what you are doing, but at last, you do too. If you are not teaching and you only present your work to specialists, you can get by

with explanations that are a vast tangle of multidimensional jargon and you never really understand what is going on in your work. At least that is my experience. Besides, teaching can be great fun in vision science where any good class should be punctuated by screams of surprise and delight for the in-class demonstrations.

What do you think is the big question to be answered in your field? Our big question is consciousness. This is on a par with the nature of matter, space, and time, and the origin of the universe. It was once a dark, unfundable subject but thanks to the efforts of a few like Christof Koch, Francis Crick, Bernie Baars, Dan Dennett, Stan Dehaene and others, it has taken its deserved central place in science. Studying consciousness is one thing but, in my opinion, understanding its mechanisms will require a whole new physics. There is no known physical property that can produce the unity of experience from the interconnected activity of billions of neurons. So off the top of my head, let me suggest, as others have, that information itself is consciousness: the current informational state, of the brain, of your smartphone, or of a rock, comes with a unified experience of that state. That experience just stands on its own — it is what an information state feels like, in and of itself, not needing any particular organism or homunculus to experience the experience. Now, confession, I just made that all up to answer this question, and that is the attraction of research in consciousness and in neuroscience, its theoretical landscape is wide open, as yet no more constrained than current new theories of the nature of space, time and matter. The difference is, we are trying to explain the existence of our inner world and all it can represent whereas physicists have to be content with explaining just the existence of the external world. My personal opinion is that the understanding of consciousness is the greater prize.

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Quick guide

Apicoplast

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What is it? An apicoplast (apicomplexan plastid) is a vestigial plastid found in parasites belonging to the phylum Apicomplexa. Plastids are better known as the green, subcellular compartment of plants and algae in which photosynthesis occurs. Apicoplasts are non-photosynthetic, pigment-free versions of plastids. Phylum Apicomplexa comprises some 6,000 species of parasites, the most notorious of which is the genus *Plasmodium* that causes malaria in humans, other primates, rodents, bats, birds and reptiles. Less deadly, but more common, is *Toxoplasma gondii*, an apicomplexan that infects most mammals (Figure 1). Apicomplexa also cause coccidiosis of fouls, red water fever of cattle, and babesiosis (tick fever) of cattle and dogs. The common human diarrhoeal apicomplexan *Cryptosporidium* is the only parasite in the group known to lack the apicoplast, though it might also be absent from gregarines, a large but poorly studied group of Apicomplexa that infects mostly invertebrates and protists.

Where did it come from? Plastids arose by endosymbiosis of a cyanobacterium approximately one billion years ago, and apicoplasts ultimately trace their ancestry back to this same event. After the initial (primary) endosymbiosis, secondary endosymbioses, in which one eukaryote engulfed and retained a plastid-containing eukaryote, created several new lines of photosynthetic organisms. Apicomplexa are the descendants of such a secondary endosymbiosis. The discovery in Australia of the coral symbiont *Chromera* solved the protracted debate about what kind of secondary endosymbiont apicomplexans acquired. Apicomplexa clearly harbour a red algal symbiont acquired by the common ancestor of *Chromera*, dinoflagellates and Apicomplexa ~400 million years ago. This ancestor was probably a symbiont of invertebrates. Its descendants developed into the

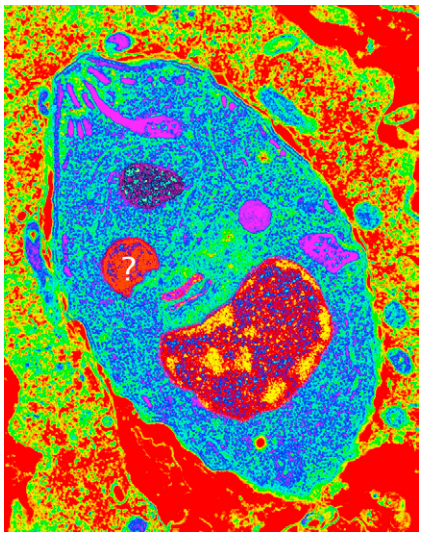

Figure 1. *Toxoplasma gondii*.
Electron micrograph of *Toxoplasma gondii* parasite inside a human fibroblast (pseudo-coloured) showing the apicoplast denoted with a question mark.

dinoflagellate zooxanthellae that live in corals, anemones, jellyfish and molluscs, while a separate lineage converted to parasitism and lost photosynthesis to create Apicomplexa. These parasites have likely co-evolved with their animal hosts for almost as long as animals have existed, evading immune attack and adapting complex life cycles to multiple hosts.

What does it do? When first identified in 1996, it was not at all obvious what the apicoplast did. Every apicoplast has a small circular genome (DNA) that encodes about 50–60 genes, but the sequences of the genes gave no clue to the organelle's vital role in parasite survival. The apicoplast seemed little more than a device for making copies of itself. Clever genetic and pharmacological experiments showed that apicoplasts are indispensable: without it parasites die. The full nuclear genome of the malaria parasite yielded the first clues to the apicoplast *raison d'être*, showing that apicoplasts make essential cellular building blocks such as fatty acids, isoprenoid precursors, haem and iron/sulphur clusters. Because apicoplasts have the same ancestry, the way they make these components is identical to the way plant plastids do. Although the genes provided a window into the apicoplast's potential for synthesis, they didn't tell us about the *when* or the *why*. Apicomplexan