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Introduction

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The 34th Darwin College Lecture Series, held in 2019, addressed Vision. The aim of these lectures, as with all the Darwin College Lectures, was to provide an interdisciplinary study. The lectures range widely: they survey the mechanisms of visual perception, and the evolution of eyes; they address the mental processes underpinning vision, and the nature and significance of private visions and hallucinations; they explore the vision and imagery of artists and of scientists in their endeavours to elucidate the world. The discussions encompass astronomical observation, which enables us to look back over the evolution of the Universe to the earliest epochs, and they extend to foresight, with a vision of a digital future. We conclude this volume with a review of the current developments of computer vision, which increasingly underpin our day-to-day experience of surveillance and of automation.

In the opening chapter, Professor Dan-Eric Nilsson surveys the evolution of eyes. Eyes have evolved many times in many different animal lineages. It is remarkable, however, that all eyes share similar structures in their photoreceptor cells, which all incorporate the same light-sensitive proteins (opsins). This common heritage reveals an ancient origin for vision, and we can conclude that the earliest eyes emerged sometime between 650 and 550 million years ago. Nilsson reviews the multiple strands of eye evolution, from the early animals which could only sense the presence of light, to those which could form crude images of their surroundings, and culminating in animals with an acute sense of vision which enables complex interactions with other animals. At each stage of this development it is possible to identify an adaptive advantage which continued to drive evolutionary progress towards today's diverse multitude of sophisticated eyes.

In the second chapter, Professor Paul Fletcher discusses the significance of visions and other 'illusions'. Our visual machinery has emerged from a process of Darwinian adaptation which emphasises not so much an accurate perception of the world, as a useful means to navigate and survive within it. In consequence, normal vision is not necessarily so far removed from illusion, hallucinations, and 'visions'. Indeed, there are many circumstances in which normal vision favours utility over accuracy, and mental expectation plays a key role in what we see. In extreme cases, induced for example by fatigue, fear, illness, or drugs, an entire reality can be created which conflicts with the reality perceived by others. Such conditions of psychosis offer important insights into the mechanisms of mind and serve to illuminate the processes involved in 'normal' vision.

In the third chapter, Professor Anya Hurlbert presents an extensive survey of the multiple roles of colour in vision. Colour is deeply subjective and can elicit strong, and often contradictory, responses from different viewers: J. M. W. Turner utterly transformed his seascape *Helvoetsluys*, in response to an artistic threat posed by a glorious Constable canvas exhibited on the opposite gallery wall, with a single blob of red lead, which he applied after his picture had been hung; Claude Monet, in order to realise his vision of Rouen Cathedral at different times of day, managed to transcend a strong innate tendency we all share, which modifies our perception of colour, to take account of the perceived, or assumed, ambient lighting conditions.

Colour has long been a topic of intellectual debate, not only in the visual arts, but also in philosophy, psychology, and physiology; how does colour create and convey meaning, and how does it evoke emotion and aesthetic appreciation?

In the fourth chapter, Professor Carlo Rovelli turns his attention to the role of vision in understanding the world. We have already observed that vision is honed by Darwinian adaptation, so it is not surprising that the world can be very different from what we see. In consequence, much of modern physics is considered obscure, and appears to depend entirely on a purely mathematical understanding of reality. Rovelli strongly disagrees with this view, and argues that visual images play a fundamental role in elucidating and creating scientific theory. Our minds, even when dealing with abstract and difficult notions, rely on images, metaphors, and ultimately on the mental mechanisms of vision itself, to distil understanding from what the world presents to us.

In Chapter 5 Dr Carolin Crawford reviews how we explore the cosmos. Since the earliest times humanity has been engaged in looking at the stars, using these observations for practical purposes including the management of farming, conducting religious rites, predicting the future, and gleaning an understanding of the world. Before Galileo these observations were conducted solely with the naked eye, but over the last few centuries telescopes have greatly enhanced what we can see and what we can learn about the world. We are now living through a golden age of astronomy. Most remarkably, astronomical observation has provided a window into the past, and with modern instruments we can look far back into the history of the Universe. The earliest observable structure, the Cosmic Microwave Background, dates from about 400,000 years after the Big Bang, which amounts to about 0.03 per cent of the age of the Universe, and our investigations are likely to be extended even further back in time as gravitational-wave imagery comes into its own. Crawford describes the next generation of telescopes, both ground-based and space-based, which will provide the data to further accelerate the progress made over recent decades in our understanding of the evolution of the cosmos and of fundamental physics more generally. These new instruments observe not only visible light, but also gamma-rays, X-rays, and far-infrared light, as well as gravitational waves and exotic particles.

In Chapter 6 we turn from exploring the Universe, and its past history, to articulating a vision of the future. While artificial intelligence (AI) is held by some to facilitate a utopia, others are fearful, and AI is frequently cited as presenting the most likely existential threat to humanity (eclipsing pandemic and famine). Ms Sophie Hackford is a futurist, with broad experience of AI including her own AI companies, and her role as director of WIRED magazine's consulting business. She expounds her belief that the way in which computers 'see' the world is becoming our dominant reality. Machines already view us in great detail; indeed, Hackford believes we are turning the world into a computer, and she describes how this digital 'mirrorworld' is already heavily influencing our lives. We are actively creating a physical Internet, and before long, avatars may represent us in our interactions with corporations and with society, and autonomous companies may soon become significant players in the economy.

In the final chapter, Professor Andrew Blake addresses computer vision, which is already ubiquitous, and is rapidly infiltrating much of our existence. Professor Li Fei-Fei, Google's Chief AI Scientist, recently went so far as to describe computer vision as 'AI's killer app'. Computer vision encompasses far more than mere camera surveillance; it incorporates the basis for decision-making derived from a digital analysis of images. This technology provides the means to steer an autonomous vehicle, decide on the health state of an individual, direct surgical procedures, or direct a military drone to a human target, as well as an ever-expanding list of other applications. Blake explores the reliability of these inferences, and the degree to which it is safe, or dangerous, to use the information gleaned from computer vision. Many of the vision algorithms are based on neural networks, where decisions are often opaque since the algorithmic path to a decision is difficult to discern; this can make it difficult to trust a decision. Moreover, it has been demonstrated that neural networks can be hacked by 'adversarial' counterexamples, which points to a more general fragility in a network's operation. How then, can we be sure that a computer makes good visual judgements and decisions?