



AURAL awe — section through the organ of Corti, in the human inner ear, showing four rows of hair cells (top right). Each cell contains around 100 individual hairs that translate sound into nerve impulses. SEM, $\times 1,500$. Taken from *Inside Information: Imaging the Human Body* by William A. Ewing. Thames and Hudson, £12.95 (pbk).

his way from the bank to his summer home in the Swiss Alps, perhaps he will also reflect on another of Lord Kelvin's pronouncements: "I can state flatly that heavier-than-air flying machines are impossible." (Did Lord Kelvin ever see a bird?) All this brings to mind an observation by Arthur C. Clarke so pregnant with relevancy that it is now enshrined in the literature as Clarke's first law: "When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong."

One of the more appealing aspects of Horgan's book is its sheer entertainment value. The go-for-the-jugular writing style, coupled with the fact that just about everyone who's anyone in the scientific world has been subjected to one of Horgan's interviews, gives the reader an opportunity to see world-class scientists as "demigods on stilts", to use Einstein's pithy phrase describing the residents of Princeton, rather than monk-like keepers of the sacred flame. Horgan's jaundiced squint at these notables has no doubt led to the weeping and gnashing of teeth in some circles; nevertheless, it is not without some considerable charm—especially for those who have ever met any of Horgan's subjects. But just as remarks are not literature, accounts of personality quirks do not constitute philosophy. And while the book is amusing and the issues it raises are of great importance, its philosophical thrust and argumentation are just plain unconvincing.

There is one genuinely interesting point struggling to emerge from this whole debate. It is not whether science as we know it is coming to an end. Rather, it is whether the real world may not be just too complex for the human mind to comprehend fully. In other words, are there limits to what we can ever hope to know by using the tools and techniques of what we call 'science'? By 'limits' I mean specific 'big questions' that can be easily posed but never answered. If they do exist, I am sure we would all like to know about them. But unless, as Horgan would have it, they happen to encompass every 'big question' that we can conceive of asking about the world, we would still be as far away from the end of science as we were at its beginning.

Heavier-than-air flight is of course alive and well. Unfortunately, so too are lighter-than-air frothings about the end of science. So, despite Horgan's lively portrayal of modern science and scientists, what remains after the rhetorical flourishes all fade away is little more than a shapeless bit of intellectual fluff, pure cotton candy for the mind. □

John L. Casti is at the Santa Fe Institute, Santa Fe, New Mexico 87501, USA and the Technical University of Vienna, A-1040 Vienna, Austria. e-mail: casti@santafe.edu

A few years ago, the Santa Fe Institute was formed to serve as a centre for the scientific investigation of complex adaptive systems. But the methods of choice for these studies are as different from the methods used in ordinary science as the use of the computer was to resolve the four-colour conjecture. Science, Santa-Fe-style, is based largely on the use of detailed computer simulations of real-world phenomena such as stock markets or the immune system. Such silicon surrogates provide a laboratory for carrying out controlled, repeatable experiments of the sort that are too expensive, too impractical, too time-consuming or simply too dangerous to do on the real-world system. And these are just the sorts of experiments the scientific method requires for the construction of a *scientific* theory of anything. Computers promise to change the frontiers of science fundamentally. For the first time in history, researchers will be able to observe phenomena such as the behaviour of a stock market under unusual economic circumstances or an ecosystem over several millennia of real time. And if history is any guide, such tools will generate a plethora of so far unstated 'big questions' that will serve as the basis for a bona fide science of complex systems in the decades to come.

One of Horgan's principle targets is exactly this claim. Part of his antipathy towards the development of a science of 'complexity' seems to be that such investigations do not emphasize the material and energetic structure of systems, the traditional foci of the scientific enterprise. Recalling Aristotle's theory of causation, one might say that the kinds of studies done at places such as the Santa Fe Institute are instead primarily concerned with

formal and final cause. So it is perhaps not surprising that Horgan (and others) find Santa-Fe-style science unconvincing, as it centres attention on issues of information and pattern that are basically orthogonal to the concerns of conventional science. But that is precisely why such investigations offer the potential of opening up whole new worlds of *real* science, rather than the so-called 'ironic' variant espoused by Horgan, which relies on vague personal opinions, subjective judgements on untestable hypotheses and semi-theological debate.

Unlike many of today's 'endologists' who hint darkly at the end of some field or other from their perspective as an active researcher in the area under scrutiny, journalistic members of the 'end-of-X' crowd have a predilection for invoking outside authority figures to buttress their claims. For some unaccountable reason, Nobel-prizewinning physicists seem especially popular in this regard. I, for one, am not sure that an eminent physicist, actively engaged in promoting his field, is the first person I would consult for a balanced, non-partisan view of the future of physics. Yet Horgan cites with benign approval Richard Feynman's remark that "[this] is the age in which we are discovering the fundamental laws of nature, and that day will never come again".

Let me appeal to the same shameless rhetorical trick in offering an antidote to Feynman's brand of misguided hubris. When told of the discovery of X-rays, Lord Kelvin, former president of the Royal Society, and one of the pre-eminent physicists of the late nineteenth century, solemnly intoned: "X-rays will prove to be a hoax." My friendly neighbourhood radiologist will no doubt ponder this point with great pleasure on his next trip to the bank. And on