# Preface

This book has had a long gestation. It is, in effect, a follow-on of a book I wrote in 1994, entitled *Information, Entropy, and Progress* (Ayres 1994). That book was an attempt to explain evolution in terms of accumulation of "useful information," as distinguished from just information. I was reminded of this yesterday when I read a surprisingly favorable review of a new book entitled *Why Information Grows: The Evolution of Order, from Atoms to Economies* by Cesar Hidalgo (Hidalgo 2015). I could have used that title for my 1994 book or for this one.

There is only one problem, really. Information, in the proper sense of the word (as in information theory), is not wealth. In fact, it is mostly junk. At any rate, too much can be as harmful as too little. Information technology may have "progressed" by leaps and bounds, and it has made a lot of people wealthy in Silicon Valley. But there is little or no evidence that the rest of us have prospered thanks to smartphones or Facebook (or even Google, which I couldn't live without). A better word than "information" would be "knowledge." Economists do use the term "knowledge economy," where "knowledge" is intended to convey something like the "essence of information."

But knowledge is not well defined, and its role in driving growth is very unclear. I'm afraid Hidalgo—like many in the "commentariat"—has put the cart before the horse. While the rich countries have more information processing and denser information flows, that is not necessarily why they are rich. Having better universities would be a better explanation of relative wealth, but having a lot of oil in the ground probably helps even more. The real connection between economic growth (useful) information and knowledge is much subtler. It is what the latter part of this book is about.

So why the long delay between from 1994 and 2016? That is partly because a group of us with backgrounds in physics or other sciences have been arguing with mainstream economists (but not being heard) for many years. The topic of the argument is the proper role of energy in economic science. (The role of entropy in economics is not being discussed at all, so far as I am aware.) This is not the place

to summarize arguments (which still continue) except to say that progress is agonizingly slow because there is a widespread conviction among supposedly well-educated people, including business leaders and decision-makers, that they don't need to know anything about basic science to make good decisions.

I went to the University of Chicago to study physics in 1954 at the time when its president, Robert Hutchins, and his sidekick, Mortimer Adler, were famously promoting the *Great Books of the Western World* (Adler et al. 1990). The original 54-volume set included only two on economics (Adam Smith Vol. 39; Marx and Engels Vol. 50), plus a scrap of J.S. Mill. Science was covered only slightly better (Ptolemy, Copernicus, and Kepler Vol. 16; Gilbert, Galileo, and Harvey Vol. 28; Newton and Huygens Vol. 34; Lavoisier, Fourier, and Faraday Vol. 45; Darwin Vol. 49). In the second edition (Adler et al. 1990), Volume 56 was added. It included Einstein, Eddington, Planck, Bohr, Heisenberg, and Schrödinger.

The fact that the choices of who to include, or not, were not made by physicists is clear from some of the obvious omissions in physical science: Boltzmann, Carnot, Clausius, Dirac, Fermi (who was at the University of Chicago at the time), Feynman, Gell-Mann, Gibbs, Leibnitz, Maxwell, Mayer, Mendeleev, Pauli, Prigogine, and so on (to the end of the alphabet). In economics, the absence of Arrow, Jevons, Keynes, Malthus, Marx, J.S. Mill, Ricardo, Samuelson, J-B Say, Schumpeter, Solow, Veblen, von Neumann, Walras, and Max Weber makes the same point.

Nothing in the first edition of the *Great Books* mentions the most important laws of nature, namely, the first and second laws of thermodynamics. The first law is conservation of energy and the second (entropy) law says that all spontaneous processes in nature go in one direction ("time's arrow"). Whether Volume 56 in the second edition mentions either of these laws, I do not know. But the fact that the non-scientists who compiled that list of "great books," and the "great ideas" in them, were unaware of those laws—and a lot else—is shocking.

After leaving Chicago, I spent 2 years (1956–1958) at King's College of the University of London, working on a Ph.D. in theoretical physics. It was impossible not to notice that the higher levels of the socioeconomic strata in Britain at the time were heavily recruited from students with honors degrees in *Literae Humaniores*, known as "The Greats" at Oxford University. That course was (and is) focused on reading the Greek and Roman classics (Homer, Virgil) in the original languages and writing weekly essays on a variety of topics. The ability to quote appropriate passages in Latin was one of the criteria for being "one of us" at the top levels of British society.

The prevailing attitude, as conveyed by the media, was that scientists were "boffins in the back room" where they were paid very modestly to discover or invent things for the rest of society, which the rest of society didn't necessarily want or need. The 1951 Ealing comedy "The Man in the White Suit," starring Alec Guinness, made that point very clearly. The fact that those clever "boffins" had also invented jet engines and radar, decrypted the German codes, and created the atomic bomb was very disconcerting. The nerdy people who made such a huge contribution to winning the war were ignored or (in one notorious case) actively persecuted.

This gap—a chasm—was central to the novels of C.P. Snow and his famous "Two Cultures" lecture at Harvard in 1959. But that didn't open the doors of the elite clubs on Pall Mall to boffins, nor did the great companies bring scientists into the executive suite or onto their boards of directors.

Back in the USA, working in my chosen field, I could not help but notice the rise of the Harvard Business School. (My sister-in-law, in the 1970s, divorced my brother in order to go to HBS. Her great ambition was to become the first female VP of Generous Electric, Inc.) But the point here is that HBS and its upcoming rivals were teaching smart young people that "management" is a science and that to be a good—or great—CEO of a company like GE it is not necessary to understand what they produce or how they produce it. All of that detailed stuff can be left to the "boffins in the back room." What CEOs do is grand strategy, which turns out to be about some combination of finance, law, stockholder relations, labor relations, and lobbying the government regulators. In other words, HBS thought that it is possible to run General Electric Co. without having a clue about how electric power is generated and distributed, or how it is used to do work, still less about the laws of thermodynamics.

Sadly, most of the people who run the world now have a grossly inadequate grasp of important ideas that are fundamental to how the world (and the economy) works. That degree of ignorance among the powerful is dangerous. Energy and entropy are among the fundamental ideas that cannot be safely ignored. But thermodynamics is inadequately understood because it is badly taught, or not taught at all (except in specialized science courses), in schools and universities. This book started as an ambitious—probably overambitious—attempt to explain energy and entropy to otherwise educated people who thought that energy is the secret ingredient of "Red Bull," or the reason for drinking coffee in the morning, or is just a topic for nerds with calculators. (This book has evolved somewhat *en route*.)

As for exergy and entropy, the words are scary and unfamiliar, but they should not be. I use the word "should" in the normative sense. *Exergy* is that part of energy that can do work. *Exergy* is what gets "consumed" and "used up." Engineers say that energy is "destroyed" when it does work, but that is a little overdramatic. *Anergy* is the useless part of energy that cannot do any work. *Entropy* is a measure of the state of the world that increases after every spontaneous change and whenever exergy is consumed.

Entropy is invisible and intangible. It is not a substance. There are no "entropy meters." It was originally defined by a relationship, much as positrons and neutrinos (and the former planet Pluto) were discovered: because they were missing pieces of a puzzle needed to satisfy a law of nature. For the record, the relationship is simple: the difference between total energy E and exergy B (in a chemical system) is the product TS of temperature T times entropy S. Of course T is measurable on a thermometer. Does that help? Probably not, if you didn't study science. I won't mention it again in this book.

Recently I realized that there is a deeper connection between the origin of the universe and the reality of today. This book is my best attempt to explain it. In brief, the second law of thermodynamics isn't only about irreversibility, the "arrow of

time," or the "heat death" of the universe. It is far from it. The keyword in the title of this book is "complexity." I could have used the words "order" or "structure" or even "resilience."

Yet, the universe is 13.77 billion years old (according to the Big Bang theory), and apart from being very large, it is extremely diverse. There are many billions of galaxies containing millions of trillions of stars, many of which have planets, some of which probably have carbon-based life. Where there is life, proliferation and organization occur, resulting in increasing complexity. When the complexity reaches a certain level, intelligence emerges. Intelligence creates more complexity and, ultimately, knowledge.

Speaking of our own planet Earth, the variety of life forms—past and present—is astonishing. And within our own species, the variety of social organizations, religious beliefs, business plans, scientific theories, chemicals, products, artworks—and book titles—is also very large. My point is that the cooling and aging of the universe have been accompanied by an explosion of different, increasingly orderly, configurations of matter on all scales, from the microscopic to the cosmic.

In fact, the increasing complexity of the universe is causally related to the second law of thermodynamics and irreversibility. This book will explain some of the reasoning behind that statement. I hasten to point out that the underlying idea that biological evolution, in particular, is a consequence of the entropy law has been stated before, by others. I will cite the sources in due course.

This brings me to "wealth," the word in the title of this book. The first definition in a typical dictionary is "A great quantity or store of money, valuable possessions, property, or other riches." Is that what you thought the title of this book was about? Well, it is but only up to a point. It was the second definition that I had in mind: "A rich abundance or profusion of valuable resources, or valuable material possessions." In particular, I stress the notion of profusion or diversity. The reason a lot of money is called wealth is that it offers a lot of different choices. The more choices you have, the greater your wealth. If there is nothing for sale in the shops, as in Zimbabwe a few years ago or in Venezuela today, money is worthless. When the Berlin Wall came down in 1989, it was the range of choice—including bananas and oranges—in the shops of West Berlin that was so attractive to the people who had been trapped for so long behind the Wall.

The idea that increasing wealth is a consequence of information flow is being bandied about. There is undoubtedly some truth in that proposition. The Internet does seem to promote social organization. It can also destroy it. But I would emphasize the importance of knowledge, rather than information as such. We are all surrounded by a flux of useless information, much of which is counterproductive if not toxic. (Think about "cyber-wars" and all the complex and wasteful efforts to secure "privacy" and protect personal information of little value.) Information is not a source of wealth, except insofar as information contributes to knowledge. Knowledge is hard to define and hard to measure, but increasing knowledge surely explains why "produced" wealth keeps increasing while natural wealth is being dissipated.

This book concludes with several chapters on economic theory, as regards energy flow, economic growth, and wealth accumulation. For a rigorous discussion of those relationships, I recommend *The Second Law of Economics* by Reiner Kümmel of Würzburg University (Kuemmel 2011). The present book is much less mathematical (and less rigorous) than his but considerably broader in scope. There is no need for me (or anyone) to recapitulate the mathematical derivations in that book. They constitute a permanent contribution to economic growth theory. Instead I have tried to write for a larger but less mathematically sophisticated audience. I believe there is room for both books and that they should be viewed as complementary rather than competitive.

However, I think there is more to be said that less specialized readers—especially people interested in science—may find interesting. Darwinian natural selection plays an important role in economics, of course. But the role of complexity, as a precursor of selection, is rarely mentioned in the academic literature.

And here I should say for whom I am writing this book. One group consists of people who read books like Weinberg's *The First Three Minutes* (Weinberg 1977) or Lederman's *The God Particle* (Lederman 1993) or *What is Life*? (Schrödinger 1945) or *From Being to Becoming* (Prigogine 1980) or *Into the Cool* (Schneider and Sagan 2005) or the books by Carl Sagan or Jared Diamond or *Scientific American* and other comparable science publications. But I also want to speak to people who read popular economics books, like *The Constitution of Liberty* (Hayek 1960), *Capitalism and Freedom* (Friedman 1962), *More Heat than Light* (Mirowski 1989), *Debunking Economics* (Keen 2011a), or *The Global Minotaur* (Varoufakis 2011). In short, I will present some ideas relevant to both camps of C.P. Snow's *Two Cultures*, and I hope to convey some new ideas to both groups.

Fontainebleau, France Robert Ayres

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Ayres, R.

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