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Review of Joseph C. Pitt, *Heraclitus Redux: Technological Infrastructures and Scientific Change*

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Heraclitus Redux: Technological Infrastructures and Scientific Change
Joseph C. Pitt
Rowman & Littlefield, 2019
128 pp.

> A sawing job that would be just ridiculously hard and lengthy using a hand saw would be accomplished with a power saw. Likewise, certain cuts and materials would cause the smaller power saws to overheat or seize up altogether and therefore called for larger power saws. But even with the biggest power saw in the shop, Bobby Shaftoe always got the sense that he was imposing some kind of stress on the machine. It would slow down when the blade contacted the material, it would vibrate, it would heat up, and if you pushed the material through too fast it would threaten to jam. But then one summer he worked in a mill where they had a bandsaw. The bandsaw, its supply of blades, its spare parts, maintenance supplies, special tools and manuals occupied a whole room. It was the only tool he had ever seen with *infrastructure*. — Stephenson 2000, 270 (emphasis in original)

Bobby Shaftoe, one of the protagonists of Neal Stephenson's sprawling epic *Cryptonomicon*, learns that some tools have infrastructure: the systems necessary for their successful operation far exceed what any one individual could hope to control. But the potential of such tools also far outstrips individual effort: "the most noteworthy thing about the bandsaw was that you could cut anything with it and not only did it do the job quickly and coolly but it didn't seem to notice that it was doing anything. It wasn't even aware that a human being was sliding a great big chunk of stuff through it" (270).

Joseph C. Pitt, in his new book *Heraclitus Redux*, makes a related observation about the tools necessary for modern science: it "relies on this technological infrastructure, in which large components involve work in which engineers play a major role" (38). The technological infrastructure is "an historically determined set of mutually supporting artifacts and structures that enable human activity and provide the means for its development" (36). In other words, it encompasses not just heavy engineering, but also "the range of things that make science possible: funding agencies, universities, private corporations, technicians, labs, graduate students, journals, and so on" (34). (Hence the National Science Foundation, for example, is in Pitt's terms, a social technology (4).) Unless these components are in place and suitably coordinated, then modern scientific research cannot get off the ground. This is a crucial observation for any philosophy of science that hopes to engage with contemporary scientific practice. Although this is not a novel perspective, it is useful to have a self-contained, concise and trenchantly argued volume to make the case for it.

One ostensibly paradoxical consequence of Pitt's perspective is that "engineering research is more fundamental than scientific research" (33). This thesis has wide-ranging implications for the philosophy of science. Pitt argues that "we have the sciences we do because they are embedded in certain technological infrastructures that facilitate certain ways of doing things and discourage others" (15). As a result, "basic notions we associate with science like 'evidence,' 'observation,' and 'explanation' also change over time and are science specific" (4). It is this emphasis on change, not just at the first-order level of ongoing scientific research and its output, but also of the means of understanding such research and its implications, that underpins Pitt's choice of title. His vision of science is "Heraclitian" since "what we call 'science' is a set of multifaceted social processes in a constant state of change" (1). Indeed, philosophy itself is for Pitt also a technological infrastructure, since "it provides the techniques and criteria for critical inquiry regarding our place in the world" (101).

Embracing the Problematic

Pitt rejects the Kuhnian account of scientific change as insufficiently Heraclitian in suggesting the survival of some more or less unchanged criteria throughout the lifespan of a given paradigm. Kuhn's broader influence has led to increased philosophical focus on case studies, but Pitt also cautions that "we don't really know what constitutes a case study" (8). Echoing an earlier article, he argues that case studies do no real philosophical work: even if they are not cherrypicked to support the author's thesis, they are insufficient to support an inductive generalization (Pitt 2001). (For one rejoinder, see Rittberg and Van Kerkhove 2019.) Instead of either the paradigm or the case study, he advocates the "problematic": "an issue or a set of related issues that have attracted the attention of a number of thinkers over a period of time" (9). The problematic avoids the rigidity of the paradigm and the inanity of the case study, if at the expense of requiring heroic amounts of historical contextualization.

Pitt pursues the implications of his Heraclitian account beyond philosophy of science into "the incredible complexity of our contemporary society and how viewing it in terms of technological infrastructures helps to expose that complexity" (91). He works through some of the consequences of the U.S. federal government shutdown of 2018-19 as an illustration of "the extent to which we are captives of our technological infrastructures" (105). Events in 2020 have provided us all with a similar example of vastly greater scale: few people would now dispute that "This shutdown is an excellent example of the interrelatedness of things. It also shows, in the modern world, how complicated it all is and how tied up with our technologies we are" (96). Shutdowns also demonstrate that Luddism can be no solution to the social problems posed by the ubiquity of technological infrastructures: "If we were to live our lives acting only on that about which we could be absolutely certain, we wouldn't live our lives" (60).

Instead, Pitt offers some directions in which a solution might be pursued. One answer would be to turn the problem against itself, by developing a technological infrastructure to cope with the complex problems posed by our dependence on technological infrastructures: "one way to anticipate unintended consequences is to model it using the increasingly powerful computers we are building" (103). A more fundamental response is educational. We cannot hope to respond adequately to the challenges posed by technological infrastructures if we do not understand how they work: "the more complicated the science and the more simplified the public explanations, the more readily we tend to accept those fantasies" (50). Hence our dependency on technological infrastructure makes public understanding of science, and the philosophy of science, all the more urgent.

Indeed, one of the principal strengths of the book is pedagogic. In particular, Pitt makes effective use of examples drawn from contemporary science. Hence we learn not only of

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Galileo's use of the telescope (Chapter 3) and of scanning tunneling electron microscopes (Chapter 5) but also of the spherical aberration in the main mirror of the Hubble telescope and the complicated systemic failings that led to its being launched with this defect (Chapter 6) and of KATRIN, the Karlsruhe Tritium Neutrino experiment, an exemplary piece of twenty-first century Big Science (Chapter 7). Pitt works through these examples with care, thereby reinforcing not only familiar concerns about the theoreticity of observation, but also his deeper point that the theories at issue continue to change in profound ways. His discussion of the role of artificial intelligence in science demonstrates this point effectively (Chapter 9). What are we to make of research in the biosciences in which "a computer program designed the experiment. The scientist in charge does not know what the experiment is supposed to do" (86)? Or the use of machine learning techniques, such as generative adversarial networks, to improve the output from scientific instruments? Unlike more conventional computer software, these methods are effectively black boxes, their inner workings in principal inscrutable to the scientists who develop them—let alone the scientists who employ them in other fields. All of these examples are thought provoking and calculated to catch the imagination of philosophy of science students—and their instructors.

There are a few regrettable errors, some trivial, some more consequential. The "immortal words ... 'Follow the money'" (104) are of course from *All the President's Men* (1976) not *The Graduate* (1967). It was not Georg Joachim Rheticus who "wrote a preface [to Copernicus's *De Revolutionibus*] in which he described the theory as a purely mathematical account" (30), but Andreas Osiander, much to Rheticus's disgust. Indeed, Rheticus is known to have defaced multiple copies of *De Revolutionibus* by striking out Osiander's preface (Danielson 2006, 112). And, in the context of a discussion of carbon emissions, it seems doubly confused to refer to "bright spots such as ... the decision by France to phase out its nuclear plants" (104). Firstly, France has made no such decision, although there have been some inconsistent moves to reduce France's uniquely high level of nuclear power generation; Pitt perhaps intended to refer to Germany, which made such a decision in 2011. But, more importantly, from the perspective of climate change remediation, the German nuclear phase-out has been a disaster: it is estimated to have led to an increase in "CO_2 emissions of 36.3 Mt per year" (not to mention "more than 1,100 additional deaths per year" from increased air pollution) (Jarvis et al. 2019, 25). Since nuclear power has never produced as much as a quarter of German electricity but consistently produces more than two thirds of French electricity, a similar phase-out in France would be even more catastrophic for climate and public health.

Broader Applications

Pitt's book should be of value to a broad range of philosophers of science. As a case in point, my own specialism is the philosophy of mathematics, which Pitt does not address directly. Yet his work holds much interest for the philosopher of mathematics—indeed he echoes several recent developments (and philosophers of mathematics have made use of his earlier work: e.g. Rittberg and Van Kerkhove 2019). Technological infrastructure in mathematics can be understood in several distinct ways and Pitt's work holds potential for all of them.

Firstly, and perhaps most obviously, computers have in recent decades come to be used in more and more fundamental ways by mathematicians. The rise of "computer assisted" proofs in turn gave rise to a philosophical debate over the legitimacy of such results which directly parallels debates in (philosophy of) the empirical sciences over the legitimacy of computer assisted observations (MacKenzie 2001).

Secondly, progress in mathematics itself can be understood in terms of the development of purely mathematical tools of ever greater complexity (Marquis 1997). Mathematical tools, such as Galois theory or *K*-theory, provide relationships between mathematical objects of apparently quite different kinds. Once such a relationship has been rigorously established, it is possible to prove results about objects of one kind by studying the related, presumably more tractable, objects of the other kind. In recent decades, the scale and scope of such innovations has come to dwarf much of the previous history of mathematics (Zalamea 2012).

Lastly, but perhaps most directly in the spirit of Pitt's work, some recent research into mathematical practice has drawn out the significance of social machines, combinations of people and computers understood as unified problem-solving entities (Martin and Pease 2013; Shadbolt et al. 2019). The computers within mathematical social machines are generally not doing the mathematics (although that is a foreseeable development, at least for routine computation). Rather they facilitate the collaboration and interaction of human mathematicians by providing an appropriate infrastructure. In recent decades, this has helped to transform the way much mathematical research is conducted. In sum, attention to mathematical practice reveals multiple instances of increasingly indispensable and innovative infrastructure. Doubtless close attention to the recent practice of many other sciences would yield similar insights. *Heraclitus Redux* is a valuable roadmap for philosophers of science setting out to explore such developments.

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