STS C200, Week 4: Revolutions and Negotiations

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September 20th, 2020

The Structure of Scientific Revolution / Thomas Kuhn [1]

Kuhn proposes a framework for thinking about science that cements a theme arising in our last few weeks of reading—that science is not a linear accumulation of knowledge. He divides scientific development is divided into two recurring phases: normal science and scientific revolution. In *normal science*, puzzle-like research problems are studied within a given paradigm. When paradigms fail, a crisis results in a *scientific revolution*, replacing an existing paradigm with a new one. I elaborate on each phase next.

Normal Science Normal science happens under a certain set of norms dictated by past achievements, known as a *paradigm*. A paradigm guides scientists of a discipline by providing them a structure that determines the relevance of research questions, the format with which such questions can be formulated, and the valid methods for studying these questions.

A paradigm is formed of a body of work that is relatively successful in solving a limited set of problems recognized by the community as acute. The limited scope of these problems means that some problems are (explicitly) left unsolved by the paradigm itself. This is the space in which normal science occurs.

In normal science, paradigm-guided research is analogous to puzzle-solving, in that a solution is expected to exist and there are predetermined rules defining a valid solution.

Scientific Revolution It follows that the novelty of paradigm-guided research is limited; successful research clarifies facts determined by the paradigm, but is not expected to arrive at entirely new conclusions (with respect to the paradigm).

Still, reality does not always match expectations, and eventually *anomalies* appear. Anomalies point towards a failure of the current paradigm to explain reality, a failure which results in a *scientific crisis*.

A possible outcome of a crisis is the development of one or more new candidate paradigms. The candidates are evaluated by the community. This evaluation consists of testing which candidate offers theories that better match facts by, e.g., an application of Occam's razor, but also by a conversion of the (contemporary) scientists themselves into believers in one candidate or the other.

A victor paradigm emerges, destroying the previous paradigm and taking its place in a *scientific revolution* (this destruction seems to be a novelty of Kuhn's view). Previous theories are replaced and the scientific community's worldview is changed. The destructive nature of the revolution makes it appear as though no revolution has occurred at all; indeed, textbooks are rewritten (as opposed to enhanced), and the outgoing paradigm's works are seen as antiquated "classics".

Given this disruptive description of science, how and why does science progress? Or rather, in what sense does it progress? Of course, there is straightforward and easily-measurable progress in normative science. But, as observed, when paradigms replace each other in a scientific revolution, they do so in a destructive way. This seems to oppose constructive progress. Kuhn instead likens this progression of paradigms to an evolutionary process, with candidate paradigms selected as fittest among their competitors. This evolution increases the articulation and specialization of paradigms.

That said, paradigms do not evolve towards a universal scientific goal. In fact, Kuhn proposes "to relinquish the notion [...] that changes of paradigm carry scientists [...] closer and closer to the truth."[1] In later years, Kuhn fended off accusations of relativism by stressing that while this evolution is not "getting us closer to something," it is not entirely directionless as it is "moving us away from where we were" [3].

Proofs and Refutations / Imre Lakatos [4]

Lakatos narrows the discussion to the field of mathematics. By surveying the development of a specific result therein, he describes the progression of mathematical discovery. He describes a gradual investigation that consists of careful refinement and continuous dialogue. This is a different from Kuhn's abrupt and total revolutions, in which one paradigm replaces the other.

In the text, the mathematical process begins with a formulation of a *conjecture*. Next comes a proof, which is nothing but an argument decomposing the conjecture into sub-conjectures, or *lemmas*.

The next and crucial step is the criticizing of the conjecture and the lemmas. *Local* counterexamples disprove the lemmas, but do not refute the conjecture. On the other hand, *global* counterexamples refute the conjecture itself. To the unassuming student, a global counterexample marks the death of a conjecture, to be scrapped and soon forgotten.

Global counterexamples turn out to be just the start of the story. Defenders of the conjecture may designated the counterexample a *monster*, i.e., an unfortunate edge case that should be barred from consideration. In other words, the conjecture may be saved by arguing that the monster violates its premises, sharpning the definitions at their base.

A more nuanced approach is to examine the global counterexample and understand the essence of how it breaks the conjecture. Then, generalize this understanding and weaken the conjecture by adding premises that automatically rule out the counterexample. Note that as opposed to the *monster-barring* approach above, in this approach *the conjecture itself is modified*.

Thus, studying the truthfulness of a conjecture is an incremental (and passionate) discussion between provers and refuters, that together refine the mathematical concepts that lie at the basis of the conjecture and its proof. It seems that mathematics as a whole is the aggregation of all such discussions and refinements.

One can argue that Lakatos and Kuhn do not contradict each other, if only because Lakatos deals with mathematics whereas Kuhn's work is focused on (natural) sciences. Could it be that the nature of the two disciplines is so different?

Actually, I find it interesting that Lakatos's more linear progression is based, of all places, in the mathematical domain. If anything, I would expect the abstract essence of mathematics to lend itself to a total replacement of paradigms: by simply replacing the axioms at the foundations, a community can arrive at entirely new kinds of results and invalidate previous ones (or render them truly irrelevant). It is surprising that despite this feature, mathematics is described more linearly than natural sciences. This might hint at a fundamental difference between Lakatos and Kuhn's views.

Lastly, I want to highlight Lakatos's concept of proof (a decomposition of a claim into sub-claims), and note that it is quite different from the technical concept of 'proof' as used in mathematics and computer science. From the latter viewpoint, "a proof is whatever convinces [the verifier]" [5, Chapter 9]; that is, a proof is only meaningful in the context of a specific *proof system* that consists of a *prover* and a *verifier*. A proof (for a given claim) is then defined as an interaction between the verifier and the prover that convinces the verifier of the correctness of the claim. In contrast, Lakatos's proofs are valuable even if they do not convince the verifier—in fact, this is an essential part of the process of discovery.

There are works in computer science that consider *faulty proofs* (for certain kinds of proof system) [7]. However, the focus there is only on the verifier's rejection of faulty proofs, while the faulty proofs themselves do not have any value. Furthermore, faulty proofs are considered only for true claims, and in particular the claim is not modified or improved based on a faulty proof (cf. *lemma incorporation*, [4, p. 35]).

[1] Cf. Fleck [2], who noted the advancement towards an objective truth as a characteristic of the scientific thought style.

Questions and topics for discussions

- Are Kuhn and Lakatos in disagreement, or is their difference in perspective due to differences in the disciplines that each examine?
- What would a proof system (in the computer-scientific sense) look like if it is built on Lakatos's concept of *proof*?

References

[1] Thomas Kuhn, The Structure of Scientific Revolutions[1962], Chicago: Chicago University Press, 1996.

[2] Ludwig Fleck, Genesis and Development of a Scientific Fact[1935], Chicago: Chicago University Press, 1979.

[3] Thomas Kuhn, in an interview conducted by conducted by Aristides Baltas, Kostas Gavroglu, and Vassiliki Kindi, Athens, 1995. `https://www.youtube.com/watch?v=UH_kXuhRIoQ`

[4] Imre Lakatos, Proofs and Refutations[1976], Cambridge: Cambridge University Press, 2015.

[5] Oded Goldreich, Computational Complexity: A Conceptual Perspective[2008], Cambridge: Cambridge University Press, 2008.

[6] Irit Dinur, Oded Goldreich and Tom Gur, Every Set in P Is Strongly Testable Under a Suitable Encoding[2018], San Diego: 10th Innovations in Theoretical Computer Science Conference, ITCS 2019.

[7] Orr Paradise, Smooth and Strong PCPs[2019], Seattle: 11th Innovations in Theoretical Computer Science Conference, ITCS 2020.