Chapter 2: Logical Empiricism, A First Attempt At A Computer-Friendly Philosophy of Science

The philosophy of science, like other areas of philosophy and the humanities more generally, is subject to fads. A new approach gets introduced, perhaps gets picked up by others, and is followed for a while. Eventually a subsequent generation may follow its own ideals.

What shall we do, given there is no consensus among philosophers over time? We could “cherry-pick” a philosophy that best appeals to us as computer scientists and rely on its philosopher-advocates to defend it.

**Logical Empiricism** (sometimes also called **Logical Positivism**) might be a good contender. It is based on logic, and there has been interest in automated theorem provers and other programs for logic since the 1960s both within the fields of Artificial Intelligence and Mathematics. However, Logical Empiricism has problems that many current philosophers of science consider insurmountable that make it untenable.

This chapter gives and overview of the history, tenets and perceived shortcomings of Logical Empiricism. It is not meant to be a definitive study of Logical Empiricism. Anyone wanting to learn more is encouraged to read *The Cambridge Companion to Logical Empiricism*.

2.1 The Vanguard of Logical Empiricism

Logical Empiricism was a philosophy of science that started in the German-speaking world after the First World War: chiefly Vienna and secondarily Berlin. Its beginnings were therefore influenced by German philosophical tradition.

**Immanuel Kant** was a large figure in that tradition. An important contribution of his was the attempted unification of the **Continental “Rationalist”** tradition with the **British “Empiricist”** one. Rationalism, lead by René Descartes and Gottfried Leibniz, held that reason provided the main path to knowledge. For Descartes this included not only clear-cut cases where reasoning discovered knowledge in mathematics but also the metaphysical foundations of the sciences.

The British Empiricist school, championed by John Locke, George Berkeley and David Hume, was skeptical of pure reasoning without experience. John Locke modeled a human as a “tabula rasa”, or “blank slate”, upon which experiences were written. For them experience was the key to knowledge: it determined the space of possible thought.

Kant was educated in the Rationalist school but was impressed when he later studied the Empiricists. In his *Critique of Pure Reason* he set out the unify the two. The empiricist Hume realized that basic principles of reasoning, such as cause and effect, were not derivable from senses alone. While Hume tried to resolve this issue with analytic reasoning, Kant used synthetic reasoning.

Kant’s argument was that *a priori* knowledge such as intuition and concepts provided a
structure for *a posteriori* knowledge (*i.e.* experience). Thus, humans innately had a concept of “cause-and-effect” and experience provided examples.

For Kant the tools for studying *a priori* knowledge could also be used to study metaphysics more generally. That is, a firm understanding of intuition might give us added tools to study the natures of souls, God, and other entities not amenable to empirical description.

Another large influence on Logical Empiricist was Reductionism, both in mathematics and in science. In math the logical empiricists greatly admired project of Alfred North Whitehead and Bertrand Russell to provide an axiomatic basis for the theories of sets, cardinal numbers, ordinal numbers and real numbers based on logic. Their *Principia Mathematica* was a modern attempt to extend what Euclid had done for geometry over 2000 years ago: provide the basis for important areas of mathematics from a choice set of axioms. They were also impressed by Ludwig Wittgenstein’s attempt in *Tractatus Logico-Philosophicus* to define the relationship (and show the limitations) between language and the reality it tries to describe.

Among the reductionist scientists that the Logical Empiricists drew from was Ernst Mach. Mach was famous for work on the wave theory of light including interference, diffraction and polarization, and well as for both theoretical and experimental studies of supersonic shock waves\(^1\).

Mach’s philosophy was very empirical: if something could not be directly observed it ought not to be believed. For example, he refused to believe in atoms; they could not be “seen”. This view was rather extreme in the late 19th century.

### 2.2 Logical Empiricism

After the First World War a group of thinkers gathered at a cafe in Vienna to consider ways of putting the study of science on firm philosophical footing. This group was lead by Hans Hahn and Moritz Schlick and became known as the *Vienna Circle*. Another group with Hans Reichenbach formed in Berlin, to be known as the *Berlin Circle*.

There were many contributors to Logical Empiricism with many goals. These goals, however, commonly included (1) removing cultural considerations from science, (2) outlining what a *lingua franca* for science would look like, and, (3) distinguishing science from “pseudo-science”.

Culture and *a priori* knowledge, to the Logical Empiricists, was poorly defined if defined at all. They dismissively labeled it “metaphysics” and wanted to remove it from science and the philosophical justification of science. They agreed with Kant’s goal of unifying empiricism with reason but rejected his approach of relying on metaphysics like *a priori* knowledge.

Metaphysics was to be replaced by sentences in logic, or their equivalent. These sentences would fall into two categories. **Correspondence rules** would map senses to concepts. This allows us to name our sensations: *hot* and *cold*, *heavy* and *light*, *white* and *gray* and *black*.

When a sufficiently rich language of sense terms had been devised it was then possible to

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\(^1\) The term “Mach” to refer to a multiple of the speed of sound honors his contributions.
defined theoretical terms. Such terms would correspond to the hidden nature of things behind the sensations, but they \textit{had} to have a firm empirical basis or definition. For example, when sufficient evidence and experience was gained the theoretical term “temperature” could be defined. It \textit{had} to be grounded in experience: one had to show how it could be defined experimentally, down eventually to sensation.

Finally, just because a field had removed metaphysics and adopted logic sentences to define sense and theoretical terms that field could not automatically be called a “science”; it had to uses those sentences logically and consistently.

To achieve these goals logical empiricists generally shared four tenets.

First, logical empiricists used some version of a \textbf{verifiability criterion} to it distinguish “scientific” models from non-scientific ones. The verifiability criterion stated that any sentence had to be ground in observation such that one could tell if it was true or false following a finite procedure.\footnote{Computer scientists should rejoice in the inclusion of the word “finite”, as it anticipates problems related to Turing’s Undecidability.} In particular, Logical Empiricists did not want “scientists” to use their models to justify both “x” when it occurs and “not (X)” when it occurs too. The model ought to justify just one or the other, if either. The flexibility (some might say “self-inconsistency”) to justify whatever observations that might occur was seen as a sign of a “pseudo-science”.

Second, the Logical Empiricists differentiated between the \textbf{logic of discovery} and the \textbf{logic of justification}. They knew that the thought-processes that gave rise to scientific theories were often non-rational. A famous example was \textit{August Kekule}’s reverie of a snake grabbing its own tail leading to the idea that benzene had a ring structure. However any idea, no matter how non-rationally begotten, was subject to the same empirical tests. What made it “scientific” was its justification, not its creation. The “logic” of discovery could be quiet illogical. The \textbf{logic of justification}, however, was to be rigorously empirical.

Third, the Logical Empiricists wanted to rigorously define the parameters for a logic language for science. This language would have predicates for both sense concepts (\textit{e.g.} “heavy” and “light”) and theoretical concepts (\textit{e.g.} “mass”).

Fourth, they saw the work of scientists as primarily being \textit{inductive}. Scientists should look at concrete cases in nature and guess at fundamental patterns that might underlie them. They should then express these relationships using theoretical terms.

The Logical Empiricist program developed in Austria and Germany until the early 1930s, when Hitler came to power. Many of them were leftist, if not necessarily Jewish, and left Central Europe eventually to settle in the United Kingdom and United States. Karl Popper left Austria for New Zealand, but settled at London school of Economics after the Second World War. Hans Reichenbach left Germany and went to Turkey, where President Atatürk was attracting European talent to modernize his country. Unfortunately for the new Turkish Republic Reichenbach left after a couple of years to join the faculty at the University of California, Los Angeles. Rudolf Carnap left Germany to go to the University of Chicago. Carl Hempel also left Germany to go to Belgium first, and then to join Carnap at the University of
Among the more prominent logical empiricists that stayed in Austria was Moritz Schlick. He was dismayed by the politics but remained a professor at the University of Vienna. In 1936 he was killed by a former student. The student was arrested but then paroled, and later became a member of the Austrian Nazi Party. (Schlick was not Jewish.)

After the Second World War Logical Empiricism entered a second flowering as the dominant philosophy of science in the Anglophone world. There already was the existing American philosophy of science of Charles Peirce but the Logical Empiricists soon stole the show.

At least two factors were responsible for logical empiricism's rapid ascent in the United Kingdom and United States. One was Alfred J Ayer; an Englishman whose 1936 book *Language, Truth and Logic* prepared the way for the Logical Empiricists by introducing their ideas to the English-speaking world. The other was the highly empiricist program of the Logical Empiricists themselves. The Logical Empiricists found that by playing up the empiricist nature of Logical Empiricism they found receptive audiences the United Kingdom and United States, both inheritors of the British Empiricists philosophical legacy.

The post-Second World War anglophone years saw the further development of Logical Empiricism. Many now thought about philosophy of quantum mechanics; the science brought to prominence at the close of the war. They also concerned themselves with pragmatic aspects of trying to develop their predicates and law templates for science. Carnap reformulated much of the Logical Empiricist effort into probability so that weighing evidence could make laws more probable instead of strictly “true”.

### 2.3 Problems with Logical Empiricism

Problems soon developed in the Logical Empiricist world-view. Some of the work, such as the shift from “logical” empiricism to “probabilistic” empiricism delayed the coming of the end during the 1950s but by the mid-1960s Logical Empiricism was on its way out.

Philosophers found several flaws with Logical Empiricism concerning the verification criterion, reductionism, and language.

The verification criterion was something of which logical empiricists may have been proud: a mechanism for distinguishing “science” from “pseudo-science” that did not rely on “metaphysics”. Unfortunately it led to unintuitive results.

For example, consider the nice Logical Empiricist law “*All ravens are black*”:

$$\forall x:\text{raven}(x) \rightarrow \text{black}(x)$$

The Logical Empiricists should like this sentence. It relates the theoretical entity “raven” to the sensed concept “black”, and makes a strong prediction.

Unfortunately “proving” this statement is impossible pragmatically. It requires that we examine all ravens: all that ever were, all that are, and all that ever will be. Thus we can never
hope to confirm it to the degree to which it was originally hoped. (Contrast this with the opposite “Not all ravens are black”, which allows us to stop after finding just one non-black raven.)

Ayer’s solution to this was to partition the verifiability criterion into a **strong** form and a **weak** form. The strong form demanded strict proof for a statement while the weak form allowed for more evidence for a statement versus its competitors. The weak form was compatible with probabilities.

Unfortunately that solution lead to a problem identifying what the relevant evidence was. The sentence “All ravens are black” and its contrapositive “If it’s not black then it’s not a raven.”

\[ \forall x: \neg \text{black}(x) \rightarrow \neg \text{raven}(x) \]

are logically equivalent. But while it is natural to place more belief in “All ravens are black” as one sees more black ravens, is it natural to place more belief in the equivalent sentence “If it’s not black then it’s not a raven” as one sees more non-black things that are not ravens? Should observing the blue sky count as evidence that “All ravens are black”?

Karl Popper took a more extreme approach to the verifiability criterion by abandoning it for something stronger: **falsification**. For Popper no theory could ever by verified, only falsified. Thus, for a theory to be scientific it had to be in principle falsifiable somehow by evidence. That is there had to be some prediction that a scientific theory should make, either “x” or “not (x)”. If the theory predicted “x” yet “not (x)” was observed then the theory was falsified. Likewise if it predicted “not (x)” yet “x” was observed. Yet even if the theory predicted all observations we still have no justification for calling it “true”, merely “not yet disproved”.

The duty of scientists was to create theories that was highly accurate and highly falsifiable: to make as strong and definitive claims as possible (for example by making predictions with high precision). If they succeeded their reward was to last until the next round of potentially-disproving experimental data.

Popper was criticized for being too hard on scientists. In particular scientists often use approximations that they know to be untrue in the strict sense, but useful just the same. For example, Newtonian Mechanics breaks down at the very small scale due to Quantum Mechanics and a the very large scale due to Relativity. However, for most problems Newtonian Mechanics serves us fine, and we get away with ignoring quantum and relativistic effects. Popper’s strong form does not allow for this.

Logical Empiricism also had at least one problem with Reductionism. Carnap nobly tried to actually outline a “sense-datum” language for the Logical Empiricist image of science. However, W. V. O. Quine had a problem with it. Carnap used sentences like

\[ \text{quantity}(x,y,z,t) = \text{value} \]
but Quine said that Carnap never defined “is equal to at”. It was not empirical, so it must be *metaphysical*. Quine concluded pure Reductionism was difficult, if not impossible.

Quine identified a problem with the Logical Empiricist notion of language too. The problem lies with the identification of analytic sentences, sentences that ought to be justifiable *a priori*. Consider the seemingly intuitively justifiable sentence “No bachelor is married”. It ought to be convertible to the equivalent sentence “No unmarried man is married” without resorting to any sort of empirical knowledge.

To convert between the two we need to know that a “bachelor” is an “unmarried man”. But where does that knowledge come from? “Bachelor”, of course, is a synonym with “unmarried man”. However, we need special knowledge (“*salva veritate*” meaning “complete interchangability” or “substitution without loss”) to decide how to use it properly. For example, just because “No bachelor is married” and “No unmarried man is married” are equivalent does not mean that “Bachelor’ is an 8 letter term” and “’Unmarried man’ is an 8 letter term” are.

However, *salva veritate* also needs knowledge, in this case the analytic statement “Necessarily all and only bachelors are unmarried men”.

So synonymy (“*bachelor*” equals “*unmarried man*”) needs *salva veritate* (rules to know when they are equivalent). Further, *salva veritate* needs analytics (in this case the sentence “Necessarily all and only bachelors are unmarried men”). Unfortunately, analytics needs synonymy (“*bachelor*” equals “*unmarried man*”). Friends, this is *circular reasoning*!

A second problem with the Logical Empiricist usage of language is that there seems to be no good demarcation between “theoretical” and “observational” terms. Grover Maxwell considered the following. One looks outside the window and observed that it is raining outside. This seemingly observation statement is suffused with optical theory. At least *some* optical theory is needed to predict how light reflected from a rain drop through the outside air, through the window glass, and throw the inside air, to one’s eye. What then is a pure observational statement?

A third problem with the Logical Empiricist usage of language is Goodman’s *grue*. Something is *grue* if it is *green* up to time $t$, and *blue* thereafter. Before time $t$ if an emerald appears *green*, then it also appears *grue*. Why shall we prefer *green* over *grue*?

One could argue that *green* (and *blue*) are a more natural, less time-dependent way of characterizing the world. However, how would someone from the *green/blue* culture explain the notion of *green* and *blue* to someone from a *grue/bleen* culture? They would say that “*green*” means *grue* up until time $t$ and *bleen* thereafter. *That is also time dependent*!

Goodman’s solution to this quandary is to rely on the inertia of language. Historically, most cultures use terms like *green* and *blue*, and not *grue* and *bleen*. We can, and should, continue to do so. But this is *a priori*, if not metaphysics!

### 2.4 Conclusion

Logical Empiricism started in Vienna in the 1920s with a lot of promise. Science was to be remade and rejustified in a rational, bias-free fashion. Sensations would be turned to symbols and language. Laws would then be induced from sensation patterns without resort to culture
of prejudice.

By the 1960s, however, Logical Empiricism seemed as if it had over-promised. Try as they might to kill metaphysics, problems with the verification criterion, reductionism, and language often had it at their cores.

Most of these problems were still presented within the logical empiricist framework. In the 1960s brand new approaches to how science could be studied became widely considered. In the next chapter we will consider both historical and sociological approaches to the study of science, and what came after.

References: