“Superfluous”: The Stories of Einstein’s Special Relativity

Draft

Raymond Brock

November 7, 2022

Contents

Chapter 2

Can’t Live With ’Em Or Without ’Em : Plato and Aristotle

> “I think that modern physics has definitely decided in favor of Plato. In fact the smallest units of matter are not physical objects in the ordinary sense; they are forms, ideas which can be expressed unambiguously only in mathematical language.” Werner Heisenberg (1901-1976), theoretical physicist, Nobel Laureate

> “I imagine that whenever the mind perceives a mathematical idea, it makes contact with Plato’s world of mathematical concepts. . . When mathematicians communicate, this is made possible by each one having a direct route to truth, the consciousness of each being in a position to perceive mathematical truths directly, through this process of ‘seeing.”’ Roger Penrose (1931-), theoretical physicist, Nobel Laureate

2.1 Plato and Aristotle

Mutt and Jeff, Kirk and Spock, Abbott and Costello, Bogart and Bacall, Burns and Allen...Plato and Aristotle. One can't have one without the other and, just like the other pairs in that list, these last two are deep subjects. My need for Plato and Aristotle's contributions to the study of MOTION are for two ideas: following Pythagorean insipiration, Plato and his collaborators built the first spherical working model of MOTION BY THE EARTH and Aristotle expanded on it. They were both wrong.

And, while Plato didn't concern himself with MOTION ON THE EARTH (except in an almost impenitrable portion of his last book), Aristotle was all over MOTION ON THE EARTH and invented its systematic study. It took until the 17th century before we could be all over with Aristotle because it was all wrong.

So why is it that it's Plato's shadow that hangs around while Aristotle's importance for physics disappeared more than 400 years ago? We still talk about Platonic worldviews in physics, but nobody talks about Aristotelan-anything. In many ways my field of particle physics is relentlessly Platonic (but don't tell anyone that I said that!). Plato put important questions in play that remain troubling: What can we know? How do we know when we're right? And, most importantly, what is the role of mathematics in the fabric of the universe?

Athens' subjugation by Sparta after the two Pelopynesian Wars was tumultuous — governance of the city jerked back and forth between oligarchs and democrats. In the same way that the Golden Age of Classical Greece emerged during war with the Persians, in the midst of the city's internal chaos, western philosophy began and was followed quickly by the first systematic attempts to understand MOTION BY THE EARTH and MOTION ON THE EARTH by our two lead actors. Yet the catalyst to all of this progress was interested in neither. Socrates' persistent question was: how to live a virtuous life, not how do things move. As his talented accolyte, Plato adopted the older man's voice and wrote truly engaging tales, but expressed his own ideas and, while his program was ostensibly one of ethics, the Socrates/Plato approach opened a new front in the battle with the Parmenides Problem which resonates in modern physics today. And, as so often happens in philosophy (and physics), the next productive steps were in opposition, launched by Aristotle, one of the most remarkable intellects in all of Western history. Yet in physics: Plato endured and Aristotle is gone.

I enumerated the four Greek Research Programs and we'll see them carried forward by our Big Two:

1. **Is the universe constructed of fundamental building blocks?**
2. **Is the universe inherently mathematical?**
3. **How can we reconcile permanence with change?**
4. **How is the Universe structured and what are the rules that govern its beginning and current state?**

After dealing with Plato and Aristotle, in Chapter **??** we'll tour the Greek's growing sophistication with the heavens and the development of a worldview that stuck around for almost 2000 years.

It was the worst-kept secret sneak attack in history. Everyone knew that the Persians were coming as under King Darius' son Xerxes the Great's command, the invading infantry slowly marched along in parallel to the Persian navy counter-clockwise around the inside of the Aegean basin, subjugating the Ionians along the way. Anaximenes lived under that locally-sourced, Persian rule that drove Pythagoras to Italy. About 100 years before Socrates' execution following a 10 year advance in −480 the battle was joined with an amassed Persian force of at 150,000 soldiers and 600 warships. Athens was evacuated and the Persians destroyed the city.

The Greek confederation organized itself: the wounded Athens mounted the naval campaign and Sparta, the foot soldier command. What followed was a series of military maneuvers, still studied today. Spartan heroism of King Leonidas with 300 Spartan troops and a total of 9,000 allied soldiers met and slaughtered the Persians at the pass at Thermopylae. (The movie and the comic book series might jog your memory ("300" Snyder (2006). While this was going on, the Athenian navy engaged and overwhelmingly defeated the much larger Persian naval force. Finally during the summer of −479, they were defeated in a decisive land battle. Yet, war continued in one form or another for thirty more years until the Persians fled the Aegean leaving behind a Sparta with a greatly enhanced reputation. Proud Athens rebuilt after that disaster in −480 and under Pericles' leadership — throughout the decades of extended conflict, began its 75 year Golden Age when everything you think of as Greek in culture, art, architecture, and philosophy was intentionally created.

Ironically, even though Sparta could be credited as having been the major military force in the Greeks' victory, its isolated and belligerent nature simply did not equip it to lead during peacetime. In contrast, while Athens had been destroyed, its nature was to rebuild stronger, to politically organize, and to lead. All while doing what Greeks did best: fighting.

While that the Golden Age was unrolling, Athens simultaneously managed to battle with: Sparta −465; Corinth and Sparta −459; Samos −440; Corinth again

−433; Potidaea −433; Mageria −433; Sparta again − − 431 (Socrates was active as a soldier during this period), Sparta 1, Athens 0; Syracuse and Sparta −415, Sparta 2, Athens 0 ; Sparta now allied with Persia −414, Sparta 3, Athens 0. Game, Set, Match.

After that third war with Sparta,[1] Athens surrendered to Spartan general Lysander in −404. Plato was 23 years old and Socrates had five years to live.

Athens badly handled their unfortunate overreach and eventual defeat and in the final stages of the war they managed to: expel their major general. execute six other military leaders and flip from autocracy to democracy and back to autocracy. Socrates was on the autocracy side and it was the democrats who condemned him to drink the hemlock in −399.

It was amidst the Peloponnesian War and Athenian turmoil during Plato's early life, then the conquest of Greece by Macedonia later during Aristotle's, western philosophy was born.

2.2 Act VI A Little Bit of Plato

Plato (−429 to −348) is actually a nickname, suggesting someone of broad shoulders or perhaps a wrestler. The name on his driver's license would have been Aristockes and his aristocratic family had been influential for generations. Plato was no democrat and grew up during the Peloponnesian War (−431 to −405) and the subsequent subjugation of Athens by the victorious Spartans. In many ways Plato's idea of the correct form of government was clearly informed by the collectivism and brutality of the Spartan way.

> One of the signature events of his life was the story of his attempt to help form a government in Syracuse where he somehow got the idea that he could turn the tyrant Dionysius into a philosopher-king, since in Plato's opinion leaders should be philosophers. That got him imprisoned and even sold into slavery for a while (or so the story goes), until he was ransomed. He actually tried two more times, which brings to mind one's questionable mental state as per Einstein's observation much later about repeating the same mistake over and over and expecting a different outcome..

His life's direction was formed when he, like many young men in the newly democratic Athens, started to associate with **Socrates** (−470 to −399) who, after his (apparently distinguished) service as a foot soldier in the war, took philosophy on an entirely different course from investigating the nature of reality to how best to live a satisfactory life. Of course we all learn in school about Socrates' self-administered execution at the hands of the democratic Athenian politics—one of the reasons that Plato was distrustful of democracy. It wasn't his first choice

[1]who actually allied with Persia!

of punishment—it was traditional to give the convicted options, and Socrates suggested that his value to the city warranted that he be given free food for life. That was turned down and eventually death by poisoning was prescribed.

It might instead be reasonable to view the Socrates of Plato's dialogs as a literary invention, but he was known to broader Athens and even parodied in the *Clouds*, a vicious comedy by Aristophanes and figured in other writers' accounts, including in dialog form. But the world now knows of Socrates through Plato and he figures into every one of the more than 30 of Plato's dialogues as "that guy" who irritates everyone. His job is to ask simple-seeming questions (the Socratic Method) of an assembled group of friends (or foes), often about an ethical matter. What's temperance? What is virtue? What is justice? The course of these sorts of innocent sounding conversations is repeated: the folks being questioned are maneuvered into impossible rhetorical cul-de-sacs, shown to be incapable of any kind of logical thinking, and more often than not, shown to not know things that they should know. Meanwhile, Socrates rarely says what he thinks, in fact, he usually hides behind the assertion that he doesn't know either, but at least he knows that he doesn't know. Superior to a fault. These questions also often segue into something more than they seem, and many of them move to more weighty topics like how *do* you know what you know. That is, they form the beginning of serious Epistemology, one of the foundational philosophical disciplines.

Plato's output was large and I'll choose only a few topics that inform our scientific project. Unlike almost all of the previously considered Greek philosophers, we have complete writings in his chosen dialogue format. He famously started *The Academy*, a school that lasted more than 700 years whose star pupil was Aristotle, whom we will consider below. Bertrand Russell (in his Literature Nobel Prize *A History of Western Philosophy*) sums up what we're about to dive into appropriately:

> "Aristotle's metaphysics, roughly speaking, may be described as Plato diluted by common sense. . . He is difficult because Plato and common sense do not mix easily." Russell (1905)

My focused concern is with two aspects of his philosophy and then his physics and they're related. I'll leave his modeling in astronomy to a later section when I will consider all of the Greek astronomy at once, but I'll consider his overall approach to astronomy here. Of concern then (and now) are Plato's Epistemology—what does it mean to know something (from the *Meno* and *Phaedo*), his Metaphysics—what is the nature of reality (from *Phaedo*, *Parmenides*, and *Republic*), and his physics (from *Republic*, *Timaeus* and Book X of the *Laws*).

2.2.1 What Is True Knowledge?

Plato was deeply influenced by our Parmenides Problem and took this on with a study of the broader question of what actually constitutes true knowledge. Typical was the exchange between Socrates and the 16 year old Theaetetus in the dialogue by that name. Socrates teases out of the boy his ideas of three kinds of knowledge, and demolishes every one of them. First up, what do we learn by *perception* as a source of knowledge? That's easily dispatched by Socrates as untrustworthy. Next, is *belief* as a source of knowledge? That results in a blistering dissertation on subjectivity. And finally, what about *belief with a reason to hold that belief,* what's become known as "Justified True Belief"? This is sometimes incorrectly described as Plato's own theory of knowledge, but Socrates makes hash of JTB and leaves the question in an unsatisfying state. Let's look at a couple of examples.

J+T+B was considered to be among the best efforts into nearly the present day and relies on the three aspects memorialized in its name. The B: one can't claim knowledge about something you don't believe. (It's Tuesday and I know that, but I believe it's Monday certainly doesn't qualify as knowledge of Monday.) The T: the fact must be true (if the fact is not true, then you cannot be said to have knowledge of it.) The J: whatever you claim about the fact, you need to be able to justify it.

Consider this claim: It is 3 o'clock, I believe it's 3 o'clock, because I looked at my watch and see that time displayed. B, T, and J are all in play and this seems a reasonable example of knowledge.

> But there are holes and weaknesses. What about instead of that J, how about J2: It is 3 o'clock, I believe it's 3 o'clock, because 3 is my favorite number. I'm right, since it really is 3 o'clock but that justification is silly and certainly doesn't qualify as knowledge of the time. How about this: It is 3 o'clock, I believe it's 3 o'clock, because I looked at my watch and see that time displayed. But...I didn't know that my watch was broken and had stopped at precisely 3 o'clock. So it was just luck that my reading corresponded to the right time. So that's hard to accept as knowledge. In fact, it was only in 1963 that Edmund Gettier apparently found counterexamples to JTB which are now called "Gettier Cases."

Clearly Justification is the rub and many efforts have tried to turn J+T+B in to J+T+B+X... where X is some thing added to take care of the Gettier Cases. It's an ongoing problem. For scientific claims of knowledge, sometimes Justification weaknesses turn on problems with observation and even the senses so we're right back to the Parmenides Problem.

Plato had an answer and it turns out to be more than a theory of knowledge, but also a theory of what's real: fixing epistemological problems resulting in metaphysical commitments.

True knowledge for Plato can only come from permanent, unchanging things. Thanks, Parmenides. If something is true, it must be so forever, which means that it was never not true, nor will it ever become not true. He falls squarely in the Being camp, as opposed to the Becoming camp.

> Notice how this demand of permanence as the qualifying feature of true knowledge is an **unquestioned commitment**. There's no room for degrees of knowing which is not scientific, nor does it really function in everyday life. We all know things with varying levels of trust and this is especially true in science where not being able to question some assertion is actually now the very definition of "unscientific." I think that their insistence on permanence is a function of their being impressed with geometry and the fact that it was very early days in the brand new field of epistemology.

Plato he differed from ardent Eleatics like Parmenides by insisting that knowledge is indeed possible, but there's a catch.

He proposed that there are two worlds:

- The world of the Forms.
- The world of the senses.

2.2.2 The Forms

Arguably the most important idea of Plato's philosophy is that there is a realm—maybe outside of space and time and actually existing—in which there are permanent "essences," the only True beings. These "Forms" are permanent, you can't see them or touch them, and they can be known only through reason.

When I go to a furniture store I see hundreds of sofas. They're all different, but they all share... a "sofa-ness." They're all participating (sharing) in the Form of the Sofa which I can (only) know of in my mind. It's a perfect sofa. The Parmenides Problem is dealt with in a brand new way: there is a world of Being and a world of Becoming and they are connected, but in a hierarchical way. And, it's not just living room furniture that has Forms. There is the Form for everything: even Justice, Virtue, Beauty, and the Good... the latter of which is somehow a super Form.

2.2.3 The Republic

Plato's contribution to science is not any particular theory or practice, but as Lloyd (Lloyd (1970)) suggests it is more his philosophy of science that we value. This is laid out most explicitly in *Republic*, probably his most famous book, ostensibly a treatise on politics and good governance. It's here where he describes how a city should be ruled—definately not by popular election, but by the training of a special category of people bred and educated in order to be rulers, the philosopher-kings, the guardians. Their lives would be scripted from early ages, living communally, and essentially the pool of potential candidates for leadership. Their educations would be scripted as well, culminating in intensive study of mathematics. The goal is for them to be completely comfortable with the most abstract concepts, including Justice and what's Good and mathematics is a primary route to that appreciation. *Republic* includes a few analogies to try to get Plato's point across. Two are relevant for physics.

Analogy of the Divided Line.

Along with the Allegory of the Cave, the "Analogy of the Divided Line" is important for Plato and I think important for physics—as Galileo and modern physics will eventually enlighten for us. A rendition of the Divided Line is in Figure 2.1. What we can know is a hierarchy, from muddled to perfectly clear and divides into two broad "realms," one representing our *Becoming* world—the one we occupy in everyday life, and the other representing the *Being* world, outside of space and time and only recognized through thought.

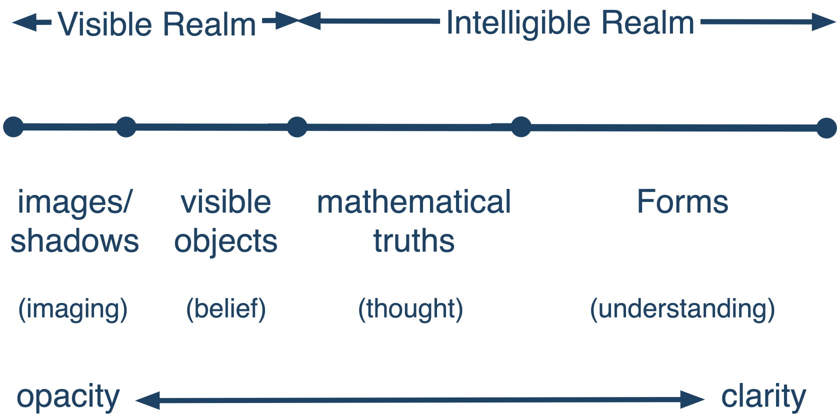


Figure 2.1: The line represents a kind of knowledge-hierarchy, from unclear to perfectly clear.

The Becoming realm is broken into two levels of which the objects of the first, and lowest segment are shadows and illusions of objects in our experience. The shaky knowledge we have about them are mere illusion and dreams. The objects of the second stage are actual ordinary, everyday objects themselves, and the knowledge we have about them are opinion and belief gleaned through our (untrustworthy) senses. Taken together these two stages constitute our knowledge of our everyday world, where things change: the Becoming or Visible realm in which we use our senses and dreams to navigate.

The Being realm is likewise divided into two more sophisticated segments which are only accessible through thought and reason. The first is knowledge gained by mathematics and hypotheticals (think high school geometry) about which we have knowledge through reasoning. And finally, the highest segment of the Being realm is of the Forms, the pinnacle of clarity, "beyond hypothesis" which is aspirational, not easily realizable.

Earlier I opined that degrees of knowing is a more modern way of thinking and the Divided Line actually sneaks up on just that. As we'll see when we study Galileo, there is a realm of the universe which is very hard to observe (on Earth) but which is our goal when we theorize about nature. So I'm not quite willing to pass this off as silly, while at the same time I don't agree with the realm of the Forms as an ethereal parallel universe that we cannot access but through rationality. Stay tuned.

Allegory of the Cave.

He famously tries to work out more of this progression in the *Republic* with the "Allegory of the Cave" and in the *Meno* with the idea of" Reminiscence." The Cave is perhaps familiar. Prisoners in a dark cave are shackled to the ground facing a wall. They can only look straight ahead and what they see are shadows of objects and puppets that are held in front of a fire behind them so that they project on the wall. If they see a sofa on the wall, it's because the Form of the sofa, which is behind them and out of sight, is projected as a shadow of the real Sofa in front of the fire.

Now, if one of the prisoners escapes her bonds and looks around she'll see the fire and the contrived circumstances. The light from the fire would hurt and she'd want to go back to her former spot. But if she were dragged out of the cave and into the sun, she's blinded but slowly she'd look around her and realize that there are actual things in the world and not just shadows. Notice that in the Allegory, she's moving from left to right in the Divided Line in Figure 2.1? She ventures back into the cave and tries to describe that true reality to her still captured colleagues. But in the dark she'd not see well and the prisoners would not allow her to persuade them to follow her into the sun since it apparently takes away one's sight. Plato even worries that the prisoners might kill the one who escaped.

Obviously, Plato is describing the daunting project that he's taken on as the enlightened prisoner trying to explain what's Real and True to everyday people who don't want to accept it. The similarities to Neo's trip out of the realm of perceptions and into the realm of the real is not an accident as the movie *The Matrix* is full of philosophical allegories, and the Cave is one of them.

What we can know of the world of the Forms is true knowledge. That's an aspiration of philosophy. What we can know of the world of appearances is simply opinion. The Forms inspired many in the centuries to follow, from Neo-Platonic Christian images to modern science. We'll come back to them in Galileo where finally, properly characterizing MOTION begins. By the way, Plato despised art. A painting of a mountain as nothing but an imitation (the painting) of an imitation (a sensible, actual example mountain) of the form of Mountain, which is the only real thing.

2.2.4 Mathematics For Plato from Republic

Plato's experience in Italy wasn't limited to a failed experiment in his theory of governance, but began as a deliberate project to study with Pythagoreans. Now, Pythagoras had been gone for a century by that point, but two schools grew up around his legacy. The *acusmatici* viewed themselves as the guarantors of Pythagoras' the man's legacy as a complete system. Not only his mathematics, but the other aspects of the Brotherhood were preserved and defended without expansion or elaboration. On the other side were the *mathematici* who bought into reverence for the man, but intentionally expanded the mathematics to new areas of research, an unwelcome sin in the eyes of the *acusmatici* who eventually died out.

Recall that Plato and Aristotle probably learned most of Pythagoreanism from Philolaus, but Plato's mathematical inclinations came from a contemporary, one of the mathematici that Plato befriended and learned from, **Archytas of Tarentum** (ca −420 to −355) who is one of the title characters in Chapter **??**. The other title character in the next chapter is **Eudoxus of Cnidus** (−408 to −355), a student of Archytas and the most significant mathematician before Archimedes. Both influenced Plato and Aristotle's cosmology, and that subject kicked off two millennia of modeling and eventually dogma. The mathematics required in the guardians' education came from Architas, arithmetic, geometry, astronomy, and harmonics. Plato didn't fully agree and added a fifth subject, solid geometry.

While the Forms may be hard to swallow, there is a branch of knowledge in which they figure prominently: your high school geometry class. Mathematical objects are typically perfect, lines with no thickness, perfectly straight. Triangles are perfect and their interior angles always add up to exactly 180°. And yet we see triangular objects all of the time in our everyday world. From a leaf to a piece of orange and yellow candy corn, all participate in that perfect Triangle-Form that you studied and manipulated in school. This is very much physics as we'll see. But maybe you can begin to understand Plato's elevation of mathematics—in the Greek life of his day, geometry and proportions—to the point of his famous sign above the door, "Let no one who is not a geometer enter." (Well, that sign only crops up in the 4th century AD, so it's probably a myth.) Geometry is venerated by Plato and all who follow for centuries.

This is hit directly in *Republic* where Socrates is extracts from Glaucon[2] the reasoning behind requiring astronomy for guardian training. As usual, Socrates/Plato starts out with a theme which in the course of explaining it, evolves into a matter of serious philosophical interest. Glaucon tries to guess at why astronomy is important. Maybe because it's useful for recognizing seasons, or timing agricultural events. Practical things. That doesn't go over well and so he tries again: maybe astronomy is "good for the soul"... that looking at they sky takes us away from looking at everyday things. Again, not productive for Socrates. Here's where

[2] Possibly, Plato's older half-brother's name.

geometry comes in and where Plato earns an uncertain reputation for suggesting that armchair astronomy is the only way to go: doing astronomy without every looking at the stars. Here's how I interpret this:

Take out a ruler and the sharpest pencil you have and carefully draw the most precise triangle you can create and now get the best protractor you can buy and try to verify that the interior angles of that triangle all add up to 180°. No matter how careful you are, you'll fail to perfectly measure 180.000...°. In fact, Socrates/Plato would tell you to not bother since studying an everyday triangle won't help. The perfect 180° is in your head and its truth is one of reasoning and geometrical proof.

Socrates/Plato suggest that the same is true for astronomy.

> "We shall therefore treat astronomy, like geometry, as setting us problems for solution", I said, "and ignore the visible heavens, if we want to make a genuine study of the subject and use it to convert the mind's natural intelligence to a useful purpose." Socrates/Plato

He says that you can look at the stars but discerning their actual motions cannot be done by measuring the apparent, but flawed motions of the imperfect stars and planets. You can only understand their motions by reasoning. He's sometimes accused of arguing for "armchair astronomy" without looking up! Like the triangle, you might get hints from the world of Becoming, but only through reasoning can you learn what the stars and planets do in the perfect world of Being.

> Here is **another unquestioned commitment** by Plato. That the stars and planets would necessarily execute perfect motion is an assumption. Again, this is the very earliest days of astronomy and philosophy and it's built on a variety of prejudices.

Plato's "Doctrine of Reminiscence" is another idea that comes from the Forms. In the *Meno* Socrates demonstrates that a slave boy actually knows geometrical proofs without knowing that he knows them! By asking questions, in his Socrates-way. In the *Meno* the protagonist, Meno (a real, young aristocrat) asks Socrates if Virtue can be taught and of course Socrates begins by asking the young man to define what Virtue is and then dismembers his multiple attempts at an answer. The scene degenerates into Meno now becoming frazzled and paralyzed as the discussion evolves. As often happens more than the problem at hand emerges, including what's called "Meno's Paradox": the realization that if you know something, you don't need to ask about it but if you don't know it, then you don't know enough to ask. Of course this all leaves everyone unsatisfied. (It's surprising to me that anyone ever wanted to talk to Socrates.)

The discussion turns to a religious view that the soul has always existed and will exist after we die and that the soul knows all that there is to know before and after and therefore, we already know everything. . . we've just forgotten it. He then proceeds to demonstrate this idea by asking a slave boy the geometrical proof of how to double the area of a square. By asking him questions, he actually induces the boy to give the right answer. (You can see the answer by following Socrates' questions in Appendix A.3.

> Now anyone who has ever faced a problem or derivation in mathematics (or mathematical physics) has probably come to the feeling when you reach the end that the solution was somehow there all along, that in the process of the derivation, you were revealing something that was always the case. That you kind of remembered it. Now this is the basic characteristic of Deductive Reasoning. It doesn't lead to anything new, but kind of reinforces—-or recalls— something that was already in the premises. This isn't what Socrates was aiming at, but I know I've had that feeling and I can understand why Plato chose a geometric proof to bring it out. What Plato was really after was the fact that the Form of a geometric proof was there all along, in that special realm all the time.

2.2.4.1 The Soul

The "Soul" is a very Greek idea which functions at multiple levels for Plato, in one dialogue, he assigns three separate jobs to the Soul. For our purposes, he's impressed with the idea that some things are inanimate — like a rock — and that somethings appear to be animate. The very word "animate" gives you a sense of what he thought might be the distinguishing feature between two kinds of objects: can they move on their own? So in some ways, this is a question of MOTION ON THE EARTH. He found it useful to ascribe to all things that can move of their own accord — he would speak of "self-motion" — as imbued with Soul. It's not only humans, but birds, flowers, even planets which appear to be able to execute locomotion on their own that enjoy their very own Soul. We'll see that this idea actually figures into some of his astronomy, so in a backdoor sort of way... this is an example of MOTION BY THE EARTH! It is this very talented Soul that moves objects, but persists before and after death and the glimpse of which we get when we do a mathematical deduction, as Socrates demonstrates with the slave boy.

2.2.5 Timaeus

Boy, the medievals must have been confused about Plato. The sole Latin translation of his works was just one: *Timeaus*. It's notoriously difficult, convoluted, and ripe for repackaging by the "neo-Platonists" up to Augustine. In this difficult late dialogue, *Timaeus* the title character, a fictional Greek statesman and scientist from southern Italy (ah, as we'll see, surely a Pythagorean), who when asked by Socrates at yet another get-together, tells the origins story of the universe. A sort of Greek Carl Sagan. Timaeus is less a dialogue than a monologue and it covers a lot of ground without Socrates being his usual, obnoxious self. Obviously, Plato had a lot on his mind in this book.

Plato was so enamored of mathematics that through Timaeus' voice, he builds what he calls a "likely story" of cosmology by mixing geometricized ideas of the atomists with a relentlessly Pythagorean numerology (that he learned directly from Archytas?), a major focus in Chapter **??**.

The universe was assembled (not created) through the actions of a spooky "craftsman," the Craftsman[3] who builds everything—animals, planets, stars—from a plan following eternal ideas—surely, the Forms.

The dialog begins with Socrates counting, "One, two, three,. . . " a portending of the strange, mystical use of numbers as the Craftsman does his job. I'll reserve the astronomy part of Timaeus for Section **??** and make reference here to only those parts of the dialogue that overlap with our project. That leaves most of *Timaeus* untouched.

The story begins with fables about Athens of 9000 years previously, among which are its war with Atlantis and the idea that Earth is periodically destroyed, erasing memories for everyone. . . but somehow, not the Egyptians. This leads to a discussion of how the universe began. Timaeus asks (with Parmenides looking over his shoulder?):

> What is that which always is and has no becoming, and what is that which is always becoming and never is? That which is apprehended by intelligence and reason is always in the same state, but that which is conceived by opinion with the help of sensation and without reason is always in a process of becoming and perishing and never really is. Now everything that becomes or is created must of necessity be created by some cause, for without a cause nothing can be created" Plato

Of course, this is a reference to the Forms ("always is and has no becoming") in contrast to particulars and everyday things ("process of becoming and perishing and never really is"). In sympathy to Parmenides' poem, Timaeus also tells about both kinds of knowledge. This is his stepping off point to the fact that the universe has "become" and so was not always around which implies a creation act or a cause, or in any case, a creator. That's the Craftsman's job who follows a plan which is an aspirational blueprint.

The universe isn't created out of nothingness (more Parmenides?) but rather the Craftsman works with the material at hand using the Forms as a blueprint and fashions it into an Earth-centric ("geocentric") model, which we'll talk about in the next section. Plato leaves the impression that the Craftsman does the best that he can — a best-effort universe! There is a difficult overall purposefulness and expectation that the Craftsman is ". . . .greatest and best and fairest and most perfect." This is the best possible world.

Suffice it to say that the Sun, Moon, and planets all take their familiar places according to a mathematical (even musical—Pythagoras, again) format and that

[3]In Greek, the "Demiurge"

Time itself is created along with the planets. In fact the motions of those most-nearly-perfect celestial bodies is the cause of time. The ancients told the days, months, and years by the motions of the Sun, planets, and stars and so it's maybe not a surprise that Time and those objects have a causal relationship to one another.

The Craftsman isn't omnipotent and is restricted to Empedocles' four elements — the materials at hand. The *Timaeus* outlines the way in which Fire, Water, Air, and Earth go together (again, in proportion) by assigning them solid shapes: Fire is made of tetrahedrons, air is made of octahedrons, water is made of icosahedrons, and finally Earth is made of cubes. The solids themselves are made of two kinds of constituent triangles; the isosceles and scalene triangles. The former is what results from cutting a square into two parts along diagonals and the latter is a triangle in which the hypothenuse is twice the length of the shortest side. Two scalene triangles, side by side, attaching the long sides... makes an isosceles triangle. So the atoms (in a modern sense) of the four elements are made of two elementary, triangular constituents (like modern atoms are made of electrons and nuclei): tetrahedrons (4 faces of equilateral triangles), octahedrons (8 faces of equilateral triangles), icosahedrons(20 faces of equilateral triangles), and cubes (12 equilateral faces).

Water then, could be broken down into fire and air as a isocahedron can be decomposed into two octahedrons of air and one tetrahedron of fire. In fact, that water evaporates can be modeled in his scheme by noting that two water solids can geometrically be reduced to five air solids. He's used up 4 of the 5 known three dimensional solid forms, historically (but inaccurately) called the Platonic Solids. So, having bought into a theory, he did what any theoretical physicist would do. If the solids are fundamental and only 4 of them seem to immediately come to good use, then there must above a job for the fifth shape, the dodecahedron, and he assigned that to some measure of the universe itself as it has so many faces, it's close to being a sphere?

So, Plato appears to be very much a Pythagorean. The world is geometry—pure, abstract form. But he's just getting started as his Pythagoreanism knows no bounds as we'll see when we consider his cosmology in Section **??**!

> Platonism is not just confined to philosophy or mathematics. The Medici family in Renaissance Florence was instrumental in reacquiring Greek philosophical texts from the Byzantine empire by importing Greek-speaking academics. They set up a school dedicated to Greek philosophy and a school for the children of the court. One of those children was a ward of Lorenzo and would have learned of this approach to the world. So when Michelangelo later noted, "I saw the angel in the marble and carved until I set him free" he was expressing a very Platonic idea that he absorbed as a young ward of Lorenzo di Piero de' Medici, modestly, Lorenzo the Magnificent.

2.2.6 Platonic Legacy

There was an aspect of Plato that contaminated scientific development for many centuries, the idea of "Saving the Phenomenon."

> "This was the method I adopted: I first assumed some principle, which I judged to be the strongest, and then I affirmed as true whatever seemed to agree with this, whether relating to the cause or to anything else; and that which disagreed I regarded as untrue." Plato, *Pleado*

Can you see how *un*scientific this is? First create the theory, and then interpret the facts only to support the theory. This is especially the case in his astronomy.

Plato is a very big subject, but his direct impact on the world was abstract. His ideas were reformulated a number of times and Neo-Platonism was a pre-medieval version that eventually found its way into Catholic Church doctrine, much through Augustine, only to be reassessed centuries later. We argue about his esoteric ideas, but he doesn't figure much into modern life.

What can't be overstated is the influence that Plato had on our project of describing the universe using mathematics: "Platonism" is an enduring feature of fundamental physics. Johannes Kepler in the 15th century was among the first truly Platonic (or even Pythagorean) scientists and as I joked earlier, my particle physics subdiscipline is very Platonic.

Notice that MOTION has not been a feature of my discussion of Plato. In part, we think of Plato's ideas about motion as focused on astronomical topics, which we'll cover later in this chapter. But also his ideas as expressed in *Timaeus* (and to some extent in the *Laws*) are so esoteric as to be mostly unintelligible. There we learn that the Soul is responsible in part for "self-motion." It's all very unsatisfying.

"Unsatisfying" is a good stepping-off point as we consider Aristotle and his huge negative impact on physics. For someone so wrong, it's ironic that we can't ignore him.

2.3 Act VII A Little Bit of Aristotle

> "Aristotle is a Foal. When a foal has had enough milk, it's known that it kicks its mother." ascribed to Plato

While Plato's practical impact on physics was limited to abstract and esoteric notions, not so with **Aristotle of Stagira** (−384 to −322) an even bigger subject. He was a systems builder with practicality and abstraction as joint projects. The extent of his intellectual reach was incredible and not only did he further philosophical ideas, he invented whole fields of science and philosophy.

He was born in Macedonia and was connected to Macedonian royalty as the son of the king's physician. He emigrated to Greece to study at Plato's Academy at the age of 17. . . and then stayed for almost 20 years. While he was in residence, probably beginning his writing, the Macedonian King Philip II began his conquest of northern Greek cities, including Athens. . . which came under his control through concession, and only limited conflict.

When Plato died in −348, Aristotle went to Assus in the northwestern area of modern-day Turkey, married, and began (or continued) an impressive series of biological, marine biological, and zoological researches which he wrote about in *The History of Animals* and *On the Parts of Animals*. He was a details-person and described animals and insects with minute detail through dissection and description, beginning the classification exercise that established the whole science of biology for centuries. He classified more than 500 different species into genus and species forming categories of likeness and habit of mammals, fish, reptiles, and insects. It was here that he established his insistence on observation as the source of knowledge, an evolution away from Plato that was obviously severe. Think of his approach as like taking a deck of cards that's all swirled together on a table, and ordering the mess it by identifying and sorting for like features. That kind of organization came naturally to Aristotle, it's very modern, and it seems to have first been apparent to him as a scientific practice.

In −343 he was summoned by Philip II back to Macedonia to tutor his 13 year old son, Alexander. That Alexander—Alexander the Great — who eventually conquered essentially the entire known world, from the Peloponnese through the Middle East, Egypt, and all the way to India. Until 2010, the last army to conquer Afghanistan was Alexander's. While on his travels, Alexander apparently had samples of plants and animals sent back to his former teacher. By this time, Aristotle was back in Athens where he established his own school, the Lyceum in which he created a library and which, unlike The Academy, was open to the public. When Alexander died under strange circumstances, and after he had basically proclaimed himself a deity demanding that Greeks prostrate themselves, remembering Socrates' fate, Aristotle decided it was not safe for a Macedonian in Athens and left, in order to prevent, in his words, Athens "to sin twice against philosophy."

His range was remarkable, covering: Law, physical science, psychology, natural science, philosophy, logic, ethics, and the arts. Words that we have from him include: energy, dynamic, induction, demonstration, substance, attribute, essence, property, accident, category, topic, proposition, universal. . . His metaphysics informed the development of his science and confused the awakening Western world from about 1100 to 1600. And, everything was a part of his system, and so abandoning one piece that might not make sense would bring the whole system down. It was a philosophical game of Jenga. In particular, his astronomy—and especially his physics didn't make sense—and we'll see that the Medievals knew that it didn't make sense. But selectively adjusting it seemed impossible.

One positive thing, if only his followers had preserved it: we have Aristotle to thank for dampening enthusiasm for the unwelcome Platonic idea of "Saving the Phenomena":

> "...speaking of phenomena, they [Plato and his school] say things that do not agree with the phenomena... They are so fond of their first principles that they seem to behave like those who defend theses in dialectical arguments; for they accept any consequence, thinking they have true principles–as though principles should not be judged by their consequences." Aristotle

We have three Aristotelian issues to consider for our narrow project which together only sample a small sliver of his whole universe: what is real, how does change happen, and his physical science.

2.3.1 Aristotle and What's Real and What's Knowledge?

Unlike Plato, Aristotle rejected the idea of a super-sensible realm housing the Forms. He had a different job for the Forms that linked them with actual substance, here on Earth. His focus—which was refreshing after the Parmenides Problem and now the Plato Problem—was on individual things which we learn about through a personal experience with the world, not through some intellectual abstraction. What's real for him are *particular objects*.

> "If we did not perceive anything we would not learn or understand anything." Aristotle

Like I said, refreshing.

Substance—stuff—and Form work together to make the world. The oft-used metaphor of a house is instructive. In order to make a house you need stuff—wood, nails, and so on—and a plan, an organizing principle. Substance and Form. An individual thing is then matter which has been given a form and you can't separate them. An individual thing must have both.

For Aristotle, perceived facts are the necessary ingredients for knowledge. We organize them in our memories, looking for commonalities and differences. We categorize our facts into bins of like and unlike with relationships among them. We have an individual perception of things, collect facts, ruminate on them by comparing in our memory with our internal database, and categorize. This is classical Empiricism, as opposed to Plato's classical Rationalism. So far, so good. (Think about that deck of cards, now abstracted as a philosophical goal.)

2.3.2 Change and Cause

But we still can't get away from the Parmenides Problem and Aristotle also did battle with change and permanence. Let's race through how he thought about change and how it functioned in his physics.

For him, Change relieves a... tension. An actual thing, what **is**, has within it a potentiality to become something new. As long as it's not in that newer state—it's "deprived" of it—and it is obligated to go there. Inevitably. So everything is also in a Hericlitean flux, but in a very particular and interesting way. In sympathy, perhaps, with Parmenides, in order for something to change into something else, it had to **be** in the first place and taking that all the way back, takes him into an abstract place where there needed to have been an original Unmoved Mover. We'll not follow that line of thought.

What's important about change for Aristotle, which fits into his bigger system, is that in order to acquire knowledge of something that changes means you can identify the Cause of change. Because: all change must be caused and what can be caused comes from within a the set of Aristotelian "Categories" (of being). The ten Categories is a complicated idea and we'll skim. They are: substance, quality, quantity, relation, time, place, position, state, activity, and passivity — his complete set of predicates that can be assigned in a statement. For example, what can you say about Galileo:

- Galileo was human (substance)
- Galileo was smart (quality)
- Galileo was 5 feet tall (quantity)
- Galileo was older than Kepler (relation)
- Galileo lived during the 16th and 17th centuries (time)
- Galileo lived in Florence (place)
- Galileo sometimes sat at his desk (position)
- Galileo sometimes wore shoes (state)
- Galileo sometimes wrote with a pen (activity)
- Galileo was sometimes ill (passivity)

A particular substance must be all of these things in order to be a thing. In order to exist. Like I said, you have to be impressed with Aristotle's ability to take a complex topic and break it into its constituents. Remember, he invented Logic.

Substances have "motions" but not the kind you're thinking of. They're very Greek motions and can be quite abstract. For Aristotle, motion is anything that goes *to* something. In this change a substance remains a substance, but Form defines a state in which a goal is not achieved to a state in which a goal is achieved. And that idea of a "goal" is very important and in part, where Aristotle's physics goes astray. Stay with me.

Motions can be of any of the Categories of being, but usually are among just three of them:

- change of quality
- change of quantity
- change of place

For example:

- Galileo changed from a boy to a man. That's a change of quality.

- Galileo changed from a person who weighed 50 pounds to a person who weighed 150 pounds. That's a change of quantity.
- Galileo moved from Padua to Florence. That's a change of place.

That last one, a change of place, is our modern idea of "motion" which he called "locomotion." But for him, locomotion is no more fundamental than any other kind of motion and that's very Greek. But, again, he's thought deeply and by accident, all three kinds of motion have examples today. Not just *loco*motion:

- Modern Change of Place: We tend to think of locomotion as the only one of his categories to apply to change in physics: objects moving from this place to that place, during some time.
- Modern Change of Quality: A phase transition like water boiling or freezing could be considered a change of quality.
- Modern Change of Quantity: Aristotle could not have imagined a nuclear or particle decay from one thing into three different things, like the decay of a neutron into a proton, electron, and neutrino.

As for goals, it's easiest to think of the nature of something and that involves potentiality and deprivation. An acorn becomes a oak tree. An acorn does not become a Galileo, so it has within it the potential only to be an oak from the beginning. That inevitability also is universal and directed and that even becomes an argument against infinity since there is no such thing as unrealized or unconstrained potential.

> "It is not what has nothing outside that is infinite, but what always has something outside it." Aristotle

Now we know what properties a thing must have in order to exist and we know what kinds of change can happen. Again, to have knowledge of a change one must understand the causes: in fact, four causes. They are the material cause, the efficient cause, the formal cause, and the final cause.

Take a statue:

- The material cause of the statue is the marble.
- The efficient cause of the statue is the action of the sculptor.
- The formal cause of the statue is the plan in the mind of the sculptor.
- The final cause of the statue is the purpose for which the statue was made.

There is sometimes a discussion about whether these function as causation or explanation. Are they the four "becauses"? In any case, the last one of them is problematic for physics as the notion that everything moves for a purpose (that "goal" again) doesn't work in modern terms. This is called "teleological." (There might be an argument in biology that there is some teleological logic to how organisms evolve.) Of the four (and there's a lot more detail in Aristotle than just enumerating them), Efficient Cause comes the closest to a modern physics cause. That's splitting hairs!

2.3.3 Aristotle's Physics

Aristotle inherited his ontology (the philosophy of being) from his teacher, who inherited it from Empedocles. That is the four elements of earth, air, fire, and water are supplemented by one more, "quintessence" which is outside of the earth-bound region of the universe. Like the reactions to Parmenides, Aristotle envisions "stuff" as mixtures of the four elements. But he goes further than just classification, as their makeup, Causes, and Categories all feed into his explanation for the sort of motion that we think of. So understanding locomotion is intimately tied to the entirety of the Aristotelean system.

With respect to our MOTION, he was very much an empiricist and locomotion in particular fits his overall philosophy. Watch a high kick of a soccer ball or a towering home run in baseball or a shot in the shot-put. The projectile will race to the top of its trajectory and then appear to fall steeper and faster than its rise. Drop a feather and a crumpled up piece of paper and a metal key. Will they hit the ground at the same time?

In each of these everyday examples it seems like the heavier object will hit the ground first. That fits his philosophy, or maybe his philosophy grew from watching things fall since the heavier an object is, the more deprived it is of its most natural place: the Earth. So any object seeks its place by virtue of the amount of earthiness it has in its composition. Heaviness is an attribute and the natural motion associated with heaviness is down, toward the center of the Earth. Lightness is also an attribute for Aristotle (for us, that's just less heaviness). Natural motion for a Light object is up, toward the sky. Below the orbit of the Moon, objects have two kinds of natural motion:

- Natural locomotion for heavy objects is down and natural motion for light objects is up. These Earth-bound motions — MOTION ON THE EARTH — both follow straight lines toward their preferred places. So firey things want to be at the edge of the Moon's orbit and earthy things want to be at the center of the universe (the Earth).

But the planets and cosmic objects don't move in straight lines and have no apparent pushing force, so they must be composed of different stuff from Earth, Water, Air, or Fire and have a different sort of natural motion:

- Cosmic objects are made of "quintessence" and have circular natural motion.

Like all motions, Earth-bound and cosmic objects away from their natural places are deprived and realization of their potential is to …go there. To fulfill their essence.

There is another kind of locomotion which is un-natural, dubbed "violent," and what causes violent motion must be a contact force. So throwing a ball is violent and unnatural, since it's not directed down. When the ball is in contact with your hand, you're making it move. When it leaves your hand? Well, here Aristotle had trouble and everyone knew it. The contortions that he went through to explain projectiles are pretty contrived. But he was wedded to his system and in spite of his scorn for Plato's Saving the Phenomenon, he was all about that here.

When the ball leaves your hand, it doesn't immediately head towards the center of the Earth but it makes a decided arc in that direction. So given his commitment to the idea that unnatural motion requires a contact force to make it go, he had to postulate that the air in front of a ball rushed around to the back and pushed the ball forward. I know. It makes no sense. Even less sense, as we'll see, when it's analyzed by the Medieval thinkers much later.

Unnatural motion loses out over the more urgent natural motion as a projectile makes its way through the atmosphere and the arc turns sharply to the Earth as natural wins out over unnatural. Like a soccer ball or baseball, such a projectile turns toward the Earth.

Aristotle didn't know algebra, but we can most easily summarize his points with some simple proportions. The mathematical symbol for "proportional to" is $\sim$.

He would describe the motion of a projectile with these ideas:

- Heavier objects (made of more earth than other elements and so highly deprived of its natural place) would fall faster than light objects: $t \sim \dfrac{1}{W}$ where W is the weight, a stand-in for earthiness.
- Heavier objects would then fall faster than light objects —have a higher velocity. He had some sense of the resistance of air and so the velocity is like $v \sim \dfrac{W}{R}$ where R is some measure of the resistance that air or water or some medium asserts on the falling object.
- This leads to a convenient conclusion. If there is no resistance, then $R = 0$ and the speed that if falls would become infinite. But nothing can be infinite in Aristotle's philosophy, so there is no vacuum allowed... no medium with zero resistance.
- And finally, for violent motion, which requires an external force in contact with the object, $v \sim \dfrac{F}{R}$. No force, no speed. More force, more speed.

Each of the bullets describe exactly what you and I experience every day in a sport with a ball or just life. So Aristotle is clearly a champion Empiricist. The above is what we all experience.

There's more. If linear motion is the only natural motion then the Earth must be stationary otherwise, we'd would feel the effects of some tangential wind-force rotating the Earth. And we don't, so the Earth does not rotate. Orbits are for quintescent objects which are outside of the Moon's orbit, as centered on the Earth. So the Earth cannot be in orbit itself by definition.

2.3.4 Summary of Aristotle and Locomotion

So to sum up the first real study of MOTION. . . ever.

1. MOTION ON THE EARTH is of two types:
   1. Natural motions are toward or away from the center of the Earth according to the degree of heaviness (among the four elements, Earth would dominate the others) or lightness (among the four elements, fire would dominate the others) that compose their substance. Natural motions are in straight lines. They represent the fulfillment of an object's potential.
   2. Unnatural, or violent motions are those which are not natural. They all require that an external force is applied throughout whatever trajectory a body experiences. Take away the force, and the motion would cease. These motions can be of any shape.
2. And MOTION BY THE EARTH?
   1. It's by definition zero. The Earth is stationary because no forces can be detected that would be required to make it move.
3. And celestial MOTION?
   1. It's circular. Objects outside of the Moon's orbit are of an entirely different substance that what we experience: quintessence. Why? Since if they were of the same material that that of and on the Earth, its natural motion would be in straight lines.[4]

Aristotle's theories of MOTION BY THE EARTH and MOTION ON THE EARTH are relentlessly empirical: they are theories of what we all observe in our everyday lives. His theories of motion are also wrong.

2.4 More of Plato and Aristotle

2.4.1 Modern Day Platonists

It's unlikely that anyone would wonder about the application of Aristotelianism into the physics of MOTION ON THE EARTH nor MOTION BY THE EARTH, but thousands of pages of writing (and links) have been devoted to the application of Platonism into modern physics, and especially in mathematics. Recall my party-question in the previous chapter: Is mathematics discovered or invented? Many mathematicians and physicists have concluded that it's discovered and that's the bumper-sticker version of modern Platonism: suitable for the 21st century.

In this "More of. . . " second I'll describe a more modern version of Platonism that might function in physics in two different aspects which I'll call "The Platonic

[4] some circular reasoning there, no pun intended

Process in Physics" and "The Platonic Reality in Physics." It's all about an evolved notion of the Forms.

2.4.2 The Platonic Process in Physics

The Forms was by far the Platonic idea with the most impact in science and mathematics. His premise is that reality consists, not of only everyday stuff (that's the Ionian "monist" position that all of reality is made of matter) but that there is an additional reality-realm which consists of non-material entities outside of space and time. This is the premise of the movie *The Matrix* in which Morpheus gives Neo the choice of two pills: if he takes the blue pill, he's choosing to continue to live his live in an artificial but comfortable world in which we don't examine what's true and happily accept opinion as knowledge. If he takes the red pill, he's chosen the more difficult path to live in the truth. The references to the *Allegory of the Cave* are obvious, but it's also the old biblical story of eating from the Tree of Knowledge.

Paying homage to Morpheus' red and blue pills, let's call our physical world, the Blue World (BW) and the ethereal, other more truthful world, the Red World (RW). And let me try to suggest that to be a modern physicist is to be partly a Platonist, working as if the simultaneous existence of both the BW and the RW is the best way to make progress.

Plato's classical RW is where the Forms reside and has two broad characteristics:

1. Forms exist in the RW which are permanent, outside of space and time, and represent the essences of all things and ideas. All objects in the BW — objects we would call physical objects — "participate" in the Forms. My example was sofas: a BW sofa, the one we sit on and buy at a store, participates in the more essential, perfect RW Form of the sofa. Sofaness is what our living room furniture participates in and in some sense the Form of the sofa is in our BW version. And Plato also goes beyond BW objects to include lofty notions like Justice, Beauty, the Good, and so-on. And, properties: my wife's car is red and so is that apple. So "red" exists as an independent property and to a classic Platonist they're both participating in the Form of "red."
2. The RW contains the only true things and so acquiring Truth (with a capital "T") means somehow realizing the Forms in their natural, unusual habitat through our intellect.

So Plato's is both a story about ontology (the philosophy of what exists) and epistemology (the philosophy of what we can know). Plato would say that the entities in the RW are the only true, real things and that we cannot know about them by examining BW objects. It's solely the province of the intellect.

The heated debates of the last 50 years about Platonism are largely within the philosophy of mathematics. It's not hard to find arguments about questions like whether Sherlock Holmes is real. Or whether the reality of a tree is different from the reality of $\sqrt{2}$. I think it's fair to generalize that there are broadly three schools of thought about mathematical entities that can be labeled as:

- Intuitionalism, where mathematics is just the product of mental activity and a mathematical entity is constructed by the mind and lives solely in the mind. This is also sometimes called "structuralism" or "constructivism."
- Formalism, is probably the most popular camp in which there is no truth-value assigned to any mathematical property or entity. It's all just the study of logical consequences. . . dubbed "if-thenism." There's no commitment to anything beyond the game of manipulating marks on paper.
- Platonism suggests that mathematics is the study of abstract entities that do have an existence as objective as science is objective. Then the question is: do abstract things exist?

I'm intrigued with a particular strand of Platonism that's due to **Willard Quine** (1908- 2000) in the 1950s through 1990's, and **Hilary Putnam** (1926-2016), who later found common cause with Quine. Together, their ideas are called the "Quine–Putnam indispensability argument" and a country-physicist (like myself) version of this is: science (read "physics") works and since mathematics is indispensable in physics, mathematical entities in the RW should enjoy the same level of reality as the objects of experiment in the BW. Why? Because physics works and it works this way. Quine and Putnam say that both the BW (physical reality) and the RW (mathematical reality) must go together or the standard idea of progress in physics falters.

> "[talk of" mathematical entities is indispensable for science. . . therefore we should accept such talk. . . [which] commits us to accepting the existence of the mathematical entities in question." Hilary Putnam

Quine called himself a "reluctant Platonist" and I think we've joined that club. And as I'll show, Galileo was the charter member and he showed us all how to make progress in unraveling MOTION BY THE EARTH and MOTION ON THE EARTH once the club's Platonism was embraced.

I've had the misfortune. . . or fortune. . . of doing physics research for half a century after a masters degree in the philosophy of science. That means that I've never been able to avoid standing back and looking at what I do and what my colleagues do and categorizing and analyzing process, what counts as a valid argument, what counts as a valid scientific question, and what counts as an acceptable answer.

I've concluded that we are relentlessly *both* Platonic and Pythagorean. We can't make progress nor explain the incredible success we've enjoyed without this joint PP connection. I'll talk about one of the early great Greek mathematicians in the next chapter, the Pythagorean, Archytas. His relationship with Plato is fascinating and he was on the receiving end of criticism from Plato over his research into music. The Pythagorean fascination with the music-mathematics connection could have been due to Archytas; his teacher Philolous, or inherited it from Pythagoras himself. In any case, Archytas' research on tones and the intricate mathematical arithmetic and mean values between tones, was sophisticated and beyond the bare bones description I outlined in the first chapter and ascribed to the early Pythagoreans.

Archytas was an expert in the music of his time and explicitly studied the sounds *as he heard them* and Plato attacked him for that! The abstract harmonies themselves should be investigated using only intellect. That's the difference between Pythagoreanism and Platonism. The former deals in the BW ("heard harmonies") while the latter shuns the BW and only deals in the RW (abstract harmonies among numbers). Archytas was Pythagorean because of his commitment to the BW of actual musical sounds.

What's a law of physics? It's really a statement about an abstraction. When we say that a projectile—a thrown ball, for example—travels in the path of a parabola, we assert that that's an important statement about how MOTION ON THE EARTH works. Look in any physics textbook in the last century and any student will come away with the conclusion that projectiles' paths are parabolic. But that's not true in our BW! Nobody—until we went to the Moon—has ever seen perfect parabolic projectile motion. All sorts of things get in the way: air resistance; deformation of the ball's surface; turbulence caused by a ball's rough surface; and variations of air density, temperature, and humidity in the path of the ball's trajectory. Each contributes to changing the shape of a trajectory from parabolic to something else. And yet, what do we consider the *actual theory* of projectiles? It's the basic set of kinematical equations that result in parabolas. Said differently: every projectile's path is different. There aren't as many laws of physics as their are thrown baseballs.

How do we know that those equations do represent the general motion of thrown objects? We test predictions and that requires both P's: Platonism and Pythagoreanism. Here's a sketch of the process:

1. I write down a model of motion that's in a perfect environment, let's call that theory, T which is a ball's motion in a RW. For all practical purposes, T exists for me and by writing it down in mathematical notation and solving the equations I'm working within a realm that's separate from the BW. Earlier, I referenced an oft-repeated question about Sherlock Holmes' existence. One version of modern Platonism suggests that fictional characters *do* exist, within a possible reality. Maybe my equation-writing qualifies as such. Additionally, to counter an argument that it's all between my ears only, I can communicate T in the form of those equations to another person. It's not in my head. It's public. My marks on the paper describe a possible world of abstraction that we share.

2. The modern question is: is T the right theory? We need to test it. That's where Pythagoras comes in.

3. I'm obligated to calculate a set of numbers that can be compared with physical motions in the BW consistent with measurement that can be done. I do that in two steps. T alone will not match the BW motion because of all of the "real world" effects that make the path deviate from perfect.

    - I must first ask myself what instrument I will use to measure motion in the BW. That tells me how precise my extrapolation from the RW to the BW must be. If my goal is to determine whether the ball comes down by Thanksgiving, the only time-measuring device I need is a calendar. If the goal is to fine the position every millisecond, then I need a more precise instrument.
    - Then I model the motion beginning with the RW mathematical theory, adding in the real world affects that would cause my BW measurement to deviate from the perfect RW model itself. If my measurement is crude, then perhaps air resistance is sufficient and I'll stop calculating after adding that effect to my original equations. If my measurement capability is refined, then I might add in additional perturbing effects. I only add as much as the measurement can detect.

4. The end result is a set of numbers which I predict will describe the motion of the ball in physical space and time and BW conditions.
5. If it matches well (within a precision appropriate to my measurement uncertainties), I'll declare that T is a good theory, even though by itself it doesn't do the job without the Pythagorean steps of computing numbers and matching numbers.

I assert that I go from a **Platonic prescription to a Pythagorean application** when I make and check a prediction of a theory. I can't limit myself to the Platonic realm —its demand of perfection would be unsatisfactory. The RW reality is not our BW reality. In the same sense, I can't start with the Pythagorean approach because there's no underlying theory on which to build the prediction.

Every single law or theory of physics follows this process and every one requires both P's.

This is not a philosophy book, but because the seminal mid-course discovery by Galileo is the adaptation of a philosophical idea, I wanted to set the stage. Throughout the book I'll take you through stories of discovery in which it will be evident that this Platonic-Pythagorean push and pull is the way to make progress. From Aristotle to Einstein, will be a steady accumulation of successes through this PP commitment. We don't even think about it any more. It's the nature of the profession.

One of the things that disturbs people about the Forms' existence—-and even Plato is self-critical in his dialogue *Parmenides*, is how does a RW idea get transferred to the BW by a human? Is there a third "mental world" in between the RW and the BW? I've argued that the intermediate stage is in part writing down the mathematics. It's concrete (doesn't disappear when I'm not looking), it's descriptive of a possible perfect world, and it's a language that is not personal but can be communicated and shared with others. But there's a more direct answer to this question of the RW–BW connection. Nature seems to have done it for us.

While the Process is my first commitment to Platonism. There's more. Go back to the *Analogy of the Divided Line* in Figure 2.1 on page 13. I'm about to argue that the separation between "mathematical truths" and "Forms" in the "Intelligible Realm" has been erased in modern physics.

2.4.3 The Platonic Reality in Physics

What I've described is process. But there's also an "ontology" —- a commitment, or maybe realization of what is actually real in physics that's thoroughly Platonic but in a 21st century way. There are many such realizations in "modern physics" but let me just note two.

2.4.3.1 Their Own Forms

There is no sofa that's identical to its form. Even two sofas designed and constructed in the same manufacturing facility will not be identical. Patterns on one will be slightly altered from the other. Tolerances on color or fabric structure or leg shape cannot be perfect. A BW sofa is not identical to it's RW Form.

The 20th century upended this very Platonic notion but Plato might have been intrigued with the result.

A molecule of hemoglobin in your blood contains 10,000 atoms of hydrogen, oxygen, nitrogen, and iron. Each of these atoms have protons, neutrons, and electrons. Isn't it remarkable that each of the many thousands of electrons in that single hemoglobin molecule are identical to one another?

Isn't it even more remarkable that each of those electrons in my blood is absolutely identical to an electron in an atom of hydrogen in the outer edges of the Andromeda Galaxy? Or to every electron that was flying around the early universe before atoms formed at 370,000 years after the big bang when the very first atoms of hydrogen were formed. (I might note that every hydrogen atom in your hemoglobin was in fact formed in the big bang.)

- **Elementary particles—electrons, quarks, neutrinos—are their own Forms.**
- **That is, $\mathbf{BW(electrons)} \equiv \mathbf{RW(electrons)}$.**

Recall from the last chapter, I noted that an electron is "-1, 1/2, 1, and 0.511." These numbers stand for very specific defining properties of what it means to be an electron: anything with electrical charge of -1, spin of $1/2$, lepton number of 1, and mass of 0.511 is an electron.[5] If Plato's craftsman was creating electrons from the material he had available, he would have created: "-1, 1/2, 1, and 0.511."

So the distinction between Forms and the objects in the BW that participate in the Forms evaporates as soon as we begin to deal with elementary particles. That is, when we begin to confront the universe as it is composed in the BW. But the idea of the Form still holds rather perfectly for elementary particles and that mysterious connection between RW and BW from the last section, disappears. So a commitment to reductionism—the idea that the whole of reality is built from the small parts and that one law builds on another from the simplest to the most complex—is a commitment to the idea that *elementary particles are their own Platonic Forms*.

2.4.3.2 Things That Go Bump In the Night Aren't Real, Right?

Quantum Mechanics is the basis of the elementary particle BW = RW story above. But Quantum Mechanics comes with a very strange commitment to a reality that we cannot see, hear, touch, or measure. Elementary particles are mathematically manipulated by calculating the evolution of the spooky entity called the wave function, ψ. The wave function's reality-status as a RW entity is the very definition of a mathematical entity. Essential to the physics, but existing outside of space and time (on paper only)—the very Quine-Putnam idea.

We describe the results of an experiment involving elementary particles by first preparing them in a beam or an atom and then mathematically evolving them in time using the functional form a particular equation (for a non-relativistic situation, the Schrodinger Equation) that takes $\psi(t_1)$ at this time and tells you precisely (with mathematical precision) where $\psi(t_2)$ will be at any time in the future. This works perfectly. Every time. But here's the rub: ψ is intrinsically undetectable. The only connection that ψ has with the BW and our measuring apparatus is the probability that a particle will be here... or there....or over there... or on the Moon. That comes from ψ^2.

That is, in a strictly determined fashion, we can calculate the value of ψ at any time or place in the future, but to connect with a measurement, we can only predict probabilities, no certainties are allowed. Ever. We cannot get to the equations of Quantum Mechanics to a measurement in the BW without passing through a RW Platonic manipulation of ψ.

This famously bothered Einstein, arguably the inventor of Quantum Mechanics! But if you ever needed a definition of a mathematical entity that behaves as if it has a reality in some realm, the wavefuntion, ψ, is the poster child for exactly that. To make the most precise predictions which always have always matched the most

[5] An alien culture might have different names for these four properties, but there would be only four and there would still be ratios and dimensionless properties that electrons would posses, which would grow out of *their* particular names.

precisely determined observables, we must work wholly inside of a very strange mathematical RW which indispensably (in that Quine-Putnam sense) is very real.

These are the important modern-day influences of and reliance on an evolved Platonism (and Pythagoreanism) for physics.

2.4.4 Aristotle's Legacy in Physics and Engineering

In everyday life, we all make arguments: "I'm right and you're wrong." What makes me right? Well, the facts could be on my side, or my argument can be unavoidably logical. Philosophers would speak of "validity" as distinct from "true." Think about these two arguments:

Table 2.1: How to not reason logically.

A	B
All who take the vaccine stay well. All who take the vaccine are smart. All who are smart stay well.	All who take the vaccine stay well. all who stay well are smart. all who take the vaccine are smart.

The argument in **A** doesn't make sense since the second sentence leaves open the logical possibility that a smart person might not take the vaccine, plus smartness and wellness don't necessarily go together. In **B**, the first two statements — the "premises"—force you to the conclusion in what we'd colloquially say, a logical way. In fact, if you can recall the transitive property of arithmetic (if $a = b$ and if $b = c$, then $a = c$) , you'll see that "circle" is evident in **B**. All who take the vaccine $\rightarrow$ stay well $\rightarrow$ are smart $\rightarrow$ All who take the vaccine.

The greatest gift that Aristotle gave us was a rigorous way to judge the validity of statements. It was quickly recognized that he'd maybe found the rules on how to think and importantly for him, and for two millennia's worth of people following him, the rules on how science should be done. Deductively. His system provides the structure for deductive reasoning.

That is, Aristotle invented formal logic. He figured out how tell you why the argument in **A** is not valid and how to construct arguments like **B** which are logically valid. Every time. His new-born subject of Logic is covered in a number of his books, including: *Categories*, *On Interpretation*, *Prior Analytics*, *Posterior Analytics*, *Topics*, and *On Sophistical Refutations*. The whole collection was much later dubbed "*Organon*" which means "instrument" which reveals a point of view as to Logic's utility as a tool, as opposed to a part of philosophy. It's firmly the latter camp now, but much broader than that. Here's what he had to say in *Prior Analytics* where the rules are most completely exposed:

> "A sullogismos [deduction] is discourse in which, certain things being stated... produce the consequence, and by this, that no further term is required from

> without in order to make the consequence **necessary**.[emphasis, mine]" Aristotle

"Necessary" is the operational word here. It means that when properly formulated, when one makes an argument arranged in a particular way, one cannot avoid a unique conclusion. "*Sullogismos*" is the Greek word for "deduction," although it's often loosely translated as "syllogism„,which is a very particular kind of deduction and has a specific structural form.

Logic is now studied by every student of physics and engineering in forms directly evolved from Aristotle. Officially, it is the study of the combinations of propositions that, when formulated in proper ways, can guarantee validity or invalidity. Think about the power this gives to a user. If an authority presents you with a set of propositions which are asserted to be the way things are, you can test them. If you're a rigid leader in the Catholic Church in late medieval times, you're unhappy with formal logic as we'll see in Chapter **??**.

For him there are only three kinds of statements,

1. Singular statements: Socrates is mortal.
2. Universal statements: Every man is mortal.
3. Particular statements: Some men are mortal.

It's always about swans for philosophers, but my concern is squirrels. Stay tuned. Look at statements:

Table 2.2: Examples of statements involving squirrels.

A	B	C	D
All squirrels are brown.	Some squirrels are brown.	Some squirrels are brown.	All squirrels are brown.
No squirrels are brown.	Some squirrels are not brown.	Some squirrels are purple.	Some squirrels are brown.

Categorizing statements like in Table 2.2 was a part of Aristotle's very careful setup for defining logical rules. He started at the beginning and codified the obvious and built the whole structure from scratch.

- In argument A "All squirrels are brown" directly contradicts "No squirrels are brown." (This is called the Principle of Non-contradiction.) They can't both be true.
- B is a different contrast, in which "Some squirrels are brown" and "Some squirrels are not brown" which is okay. There's nothing left but they cannot both be true. (called the Principle of the Excluded Middle)
- C suggests that an observation is required since one of the statements is an hypothesis.

- D notes that "Some squirrels are brown" must be inside of the all-encompassing statement "All squirrels are brown."

Nobody ever thought this way before — so clearly—-and in Aristotle's patented approach to system-building, he lays it all out out exhaustively.

His unique invention, which has stayed with philosophy and mathematics (and eventually, electrical engineering) for more than 2000 years was to create an *algebra of language*. Here is a seminal moment in history, from the first book of his *Prior Analytics*:

> "First then take a universal negative with the terms A and B. If no B is A, neither can any A be B. For if some A (say C) were B, it would not be true that no B is A; for C is a B. But if every B is A then some A is B. For if no A were B, then no B could be A. But we assumed that every B is A. Similarly too, if the premiss is particular. For if some B is A, then some of the As must be B. For if none were, then no B would be A. But if some B is not A, there is no necessity that some of the As should not be B; e.g. **let B stand for animal and A for man. Not every animal is a man; but every man is an animal.**" Aristotle

I don't blame you if you get bogged down quickly in this quote. Look at the sentences that I've highlighted: he's using variables A and B, to stand for particular things, here in his example, A = man and B = animal. So his first sentence says for this particular case, "If no animal is a man, neither can any man be an animal. For if some man (say Socrates) were an animal, it would not be true that no animal is a man: for Socrates is an animal." But you can plug in anything you want for A and B. It's the form of the argument, not the contents that determine whether the argument is valid.

Introducing variables as a placeholder for the subjects and objects in a statement is a seminal moment in the history of mathematics.

This is amazing. Out of this, your mobile phone was born.

There are a number of forms of arguments. For Aristotle, the syllogism is one of them and can be written in a structure in which there are two premises and a conclusion — he calls these "terms" and so there are three terms in a syllogism. The sentences have a subject and a predicate (and since his Categories are predicates, these topics were a part of his overall system) which are connected by a verb. If the terms are A, B, and C, then they can be put together into four arrangements which he calls "figures." Let's make a syllogistic argument about squirrels. I'll define A = squirrels, B = the group of all animals in my trees, and C = brown animals.

- squirrels belong to the group of all animals in my trees
- the group of all animals in my trees belong to brown animals
- squirrels belong to brown animals

Aristotle's use of the language of "belonging" didn't last. It's more common to phrase an argument as "All A are B" and so on. So, from about 500 AD, and now, we'd say:

- All mammals in my trees are brown animals
- and if all squirrels are mammals in my trees
- then, all squirrels are brown animals

The valid squirrel argument above—the one that looks transitive, is in fact the First Figure, Figure I. There are Figures II, III, and IV as well which are a part of the same song, just different verses.

The first column in Table 2.3 is that squirrel syllogism above, an example of Figure I. I've also listed Figure II in the second column to give a flavor of his approach. There are two other Figures.

Table 2.3: Two Figures of Aristotle's syllogistic quartet.

I.	II.
If A then B and if B then C, therefore A then C.	If B then A and if B then C, therefore A then C.

Then he goes on and describes the four classes that can exist between two items:

1. A belongs to all of B
2. A belongs to some of B
3. A doesn't belong to any B, and
4. A doesn't belong to some B.

That's the whole toolbox. Of the 256 possible combinations of subjects and predicates, 24 were thought to yield valid deductions. Maybe you can see why studying Logic became a matter of intense research following Aristotle's death and into the first 100 years of both Arab and Western philosophers. There was lots of work to do.

A word about deduction in general. First, mathematics is a deductive system. One could form a syllogistic validation for $2 + 2 = 4$ and many people in the last 19th and early 20th century worked very hard on a project just like this. This followed a particular success of the late 19th century when it became apparent that the geometry of flat space (called Euclidean Geometry) was not the only kind of geometry there was (after al, the surface of the Earth is a curved geometry), and it was found that there could be many different kinds of geometry and that all they could be unified into a single system...well, that set off a storm of activity to unify all of mathematics with the glue being Logic. It failed, spectacularly when in 1931, the Austrian mathematician Kurt Gödel showed through his "incompleteness theorem" that no set of axioms can prove its own consistency—so you can't use Logic to prove the consistency of Logic.

Another word about deduction takes me back to squirrels. Before I moved to Michigan, the only squirrels I'd ever seen where brown. Now my yard is full of black squirrels. They're everywhere. Now earlier, I'd shown an argument that logically proves that Squirrels are brown. So what went wrong?

A logical argument can be completely valid, but wrong! "Garbage-in, garbage-out": if any or both of the premises are not the case. *To be valid is not to be true*:

- Squirrels with superpowers can fly
- Rocky the squirrel has superpowers
- Therefore, that squirrel can fly.

This is a perfectly valid argument and completely false because in this case, both premises are false. The source of the premises in a scientific argument must come from a scientific hypothesis which is often the result of "Inductive" reasoning. Here was mine:

- (As a child) There's a brown squirrel
- (As an adult... many times) There goes another brown squirrel
- Wow... more brown squirrels and no other ones
- What is it with all of the brown squirrels?
- Gosh, all squirrels must be brown!

Until I moved to Michigan. All it took was the observation of one black squirrel, much less an entire herd of them, to defeat my premise. Squirrels are not only brown they're black. And, I guess, could be purple. Being a good inductive scientist and not willing to make deductions that would not hold up to experiment, I wouldn't say that squirrels can't be purple. By the way, Sherlock Holmes is reputedly the Master of Deduction. Well, sorry. That's not true. If you look at his stories you'll see very, very few examples of deductive reasoning. He's the Master of Induction![6]

> Finding a "logic of induction" was a failed project in the early 20th century when Logic had taken ahold of the philosophical community. Those philosophers were immensely impressed by Einstein's Special Theory of Relativity and sought to use it as an example of a prototype template for how science should progress. We'll see how later. But their program was to put inductive reasoning on as solid a grounding as deductive reasoning: the "logic of induction" was the research project and it failed. Successful physics is a matter of skillful inductive reasoning coupled with obeying the rules of deduction in the mathematics. And, all wrapped up in the Process and Reality of Platonism.

[6] Or more appropriately, the Master of Abduction. Look it up.

2.4.4.1 Your phone

Theophrastus (−371 to −287) was a favorite student of Aristotle's who stayed in Athens when his teacher fled to Macedonia. He continued the Lyceum in Aristotle's absence and then after his teacher's death, for 37 years. Aristotle even willed him the guardianship of his children and all of his library. While a devoted student, he went beyond his teacher and expanded and modified some basic Aristotelean notions—extending a concept of motion to all 10 of the Categories, for example. He also moved the study of botany forward and worked extensively in Logic. Theodor Geisel (Dr. Seuss) used "Theophrastus" as a pen name.

Our concern with him is his extension of the form of argumentation into a new direction with the invention of "modus ponens" which is an offshoot of the classical syllogism. Modus ponens involves only two items, rather than three of a syllogism and goes like this:

- If A is true, then B is true
- A is true
- Therefore, B is true.

Doesn't seem like much, but it's powerful and misunderstanding it is the source of many logical fallicies. Table 2.4 shows an example:

Table 2.4: A typical logical fallicy involving public health.

A	B
· If a power reactor leaks radiation, people nearby will get cancer. · The power reactor leaks radiation. · Therefore, people nearby will get cancer.	· If a power reactor leaks radiation, people nearby will get cancer. · People nearby got cancer. · Therefore, the power reactor is leaking radiation.

The first sentence is a "conditional." An "if-then." The argument in A is a valid example of modus ponens, while B is a classic example of the fallacy known as "Affirming the Consequent" and it's a regularly exploited tool for those intentionally making invalid claims. Especially those who dispute public health strategies.

Hmm. Two variables with two states and rules. Zeros and ones. This sounds familiar.

Let's make a plan to picnic outdoors which requires us to keep an eye on the weather since if it's raining that would have consequences and affect our planning. We'd reason naturally, but actually be using modus ponens in our thought process. Let's create four conditionals and let's make a table of the possibilities keeping in mind the truth-values of A and B and the result of the modus ponens conclusion. Table 2.5 describes that thinking:

Table 2.5: All of the logical possibilities for two pieces of a conditional premise: raining and wetness. Here's a picnic table (sorry):

If A, then B	it's raining?	it's wet?	A	B	If A is true and B is true, then:
If it's raining, then the ground is wet	Y	Y	T	T	T
If it's raining, then the ground is not wet	Y	N	T	F	F
If it's not raining, then the ground is wet	N	Y	F	T	T
If it's not raining, then the ground is not wet	N	N	F	F	T

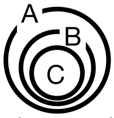
Let's read across the first line of the table:

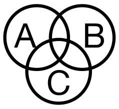
- If A, then B: If it's raining, then the ground is wet.
- Is it raining? (Y)
- So the ground is wet (Y)
- So A = T and B = T
- And the modus ponens argument is T: If it's raining, the ground is wet. It is raining, so the ground is wet.

Sometimes these are hard to unravel. I was taught that a way to analyze them is to treat them as "its not the case that A is true and B is false"... So the consequences of the third row: "If it's not raining , then the ground is wet" can be thought of as "It's not the case that it's not raining, then the ground is not wet"... not the case that it's not raining = "It is raining, then the ground is not wet"... which is true. Go lie down before we go on because it's about to get interesting and relevant.

Of course, the history of Logic starts with the Greeks, but eventually became the province of the Muslim intellectual community which collected, preserved, and wrote scholarly commentary on most of the Greek philosophical, medical, and scientific works. These subjects had been lost to the West, but burst on the scene through the Spanish arabs in the 1200's at which time Logic became a weapon more than an object of research.

Through the Enlightenment period, **Gottfried Wilhelm Leibniz** (1646-1716) attempted an algebraic formulation of logical postulates and failed in his broader project, but he did succeed in refining the binary number system. It wasn't until the late 19th century when **George Boole** (1815-1864) and **Friedrich Ludwig Gottlob Frege** (1848-1904) largely succeeded in creating such a language. Boole in particular, invented a notation and rule set that made it possible to rigorously construct logical arguments with any number of premises. Along with the use of diagrammatic techniques from **Leonhard Euler** (1707–1783) and especially **John**

Venn (1834–1923), Logic begins to take on the modern flavor that's a part of life today. For example, the original syllagism that I started with can be represented in a Venn diagram, 

[7] or a properly constructed Euler diagram, 

. In 1885, the philosopher and linguist **Charles Sanders Peirce** (1839-1914) worked out how logical operations could be done with electrical circuits! The rest came hand-in-hand with technological innovations. The first electrical device to perform the logical AND function on two inputs came in 1924 and was the source of the Nobel Prize for **Water Bothe** (1891-1957) in 1954.

What I wanted to show you is that your entire life now is based the ancient Greek Logic research program. For example, the 2022 iPhone 14 has 18 billion transistors in it and every one of them speaks through Aristotle to get their individual jobs done—or I should say their collective jobs done, since their language is forming and evaluating billions of logical two-term arguments in the same spirit as our raining-wet table.

One more bit of insight makes really complicated electronic digital design possible and came from the very strange, yet enormously influential philosopher **Ludwig Wittgenstein** (1889-1951) who invented the concept of the "truth table," which we've already used in Table 2.5. It's an orderly setup of all possible starting places (for two valued propositions) and their results when various operations are applied. Let's look at a three. True now is the bit 1 and False is the bit 0:

- The NOT operation: If I have an A then NOT–A creates the opposite of A. If we work in the zeros and ones world, then if A=1, then NOT–A = 0. The symbol for NOT is usually $\neg$ so if A = 1, then $\neg$ A = 0. (The $\neg$ symbol is the common notation used by logicians. Engineers and physicists would write $\overline{A}$ to represent the result of NOT–A.)
- The AND operation: This is between two states of, say, our A and B. In order for A AND B to be true, both A and B must be true—1— themselves. Otherwise, A AND B is false, or 0. The symbol for AND is $\wedge$ So A AND B = $A \wedge B$.
- The OR operation: This is the combination that says A OR B is true if either A = 1 or B = 1 and false otherwise. The symbol for OR is $\vee$.

There are 5 other logical combinations. Table 2.6 shows the truth table for AND and for OR. In the first set, the AND process, I've stuck to our T and F language, but the rest uses the zeros and ones language of engineering and binary arithmetic.

[7]This graphically shows that if All B are A and if all C are B, then All C are A

Table 2.6: Truth tables for the AND and OR functions plus the construction of modus ponens. The **symbol for AND is** $\wedge$, the **symbol for OR is** $\vee$, and the **symbol for NOT (negate) is** $\neg$. Notice that ($\neg$ A) $\vee$ B is a construction out of AND and NOT of the conditional that's the first premise of modus ponens.

AND			OR			Combined function				=
A	B	A $\wedge$ B	A	B	A $\vee$ B	A	B	$\neg$ A	($\neg$ A) $\vee$ B	If A then B
T	T	T	1	1	1	1	1	0	1	= 1
T	F	F	1	0	1	1	0	0	0	= 0
F	T	F	0	1	1	0	1	1	1	= 1
F	F	F	0	0	0	0	0	1	1	= 1

Let's look at the first line so that you get the idea.

For AND:

- A is T and B is T and the AND of two T's is itself a T.

For OR:

- A= 1 and B = 1 and the OR of 1 $\vee$ 1 is 1.

Then the combination:

- repeating the A and B conditions from the first and second columns A= 1 and B = 1.
- taking the NOT of A, takes 1 into 0.
- combining that with the B in an OR results in $\neg$ A $\vee$ B = 0 $\vee$ 1 = 1

The last column shows that this is the same as the first line result of our picnic decision making in Table 2.5. The rest of Table 2.6 builds that combination for all possible A and B states, first by negating A and then combining that by "ORing" it with B. The last column shows the original "If A then B" premise that we worked out about raining and wetness. They formula and our reasoning lead to identical conclusions.

Let's briefly fly over how this works in our modern world. The advent of semiconductor transistors made it possible to amplify signals in a controlled and more compact form than old vacuum tubes. The first digital computers relied on thousands of vacuum tubes and filled whole rooms with hot, clunky racks of tubes and wires—your phone has 10s of thousands of times more processing power than these first early 1950s computers. When the transistor became commercially viable in the 1960s the digital world came alive.

In the spirit of overview, Figure 2.2 shows two transistor arrangements and their modern "gate" symbol—please don't worry about the details! Just for flavor. (a) is the layout for a common transistor package that does the job of the logical gate

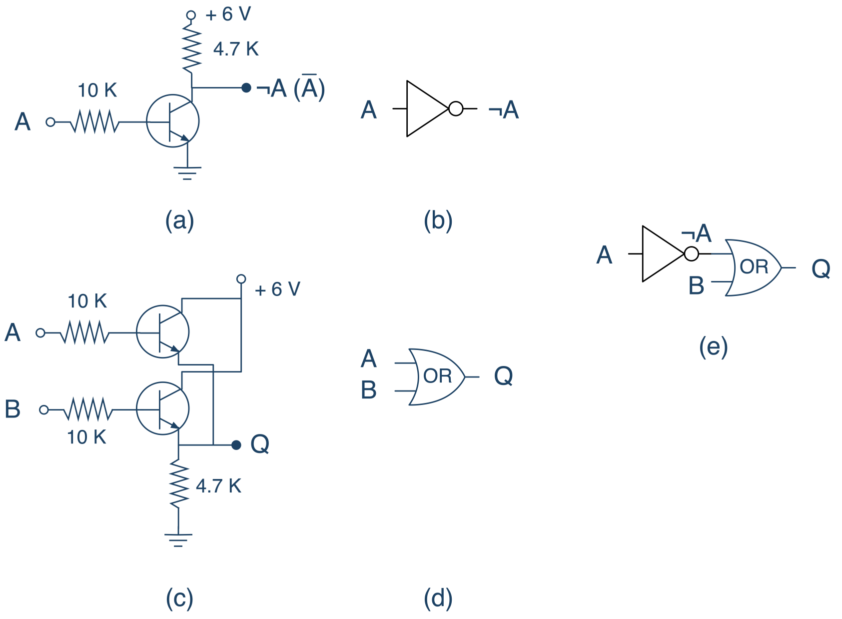


Figure 2.2: (a) and (c) are the transistor-equivalents of the two logic gates, NOR and OR in (b) and (d). The little circuit to evaluate rain causing wetness...or not...is shown in (e).

symbol shown in (b). It's the NOR operation. A comes in, and NOT–A comes out. (c) is another transistor layout that has two inputs and produces the logical OR combination—precisely what's in Table 2.6 and (d) is the logical gate symbol for performing that operation. I've shown just the NOT and the OR gates and their transistor-implementations, but there are only six more. (Think about that. The whole of our digital world can be made with these eight gate functions.)

Put together in a simple circuit and we've turned the questions from Table 2.5 about raining and being wet into a digital circuit and that circuit diagram is (e) where Q would be the last column in Table 2.6. With binary arithmetic, gates can be combined to do arithmetic functions, logical functions, and importantly, storage of bits. Digital memory consists of four so-called NAND gates, and so four transistors and is the basic cell of a computer 1-bit memory. It's a clever implementation of an input bit—to be stored—and an enable bit—which allows the output to change or not change.

All of these—and more—transistor components are actually imprinted in tiny silicon wafers in which a single transistor package might be only 20 nanometers in size. With the logical functions and the manufacturing techniques of today, my current Apple Watch has 32GB of random access memory (RAM) and so it can manage 32,000,000,000 Bytes of information, which is 25,6000,000,000 bits and so 102,400,000,000 individual transistors are inside, just for memory. The CPU and control circuitry would add millions of additional imprinted transistors and their gate-equivalents. All on my wrist. All speaking "Aristotle."

Obviously, the 2500 year path from Classical Athens to kitten videos on YouTube is full of breakthroughs and smart ideas. But it all started with Aristotle.

Appendices

Appendix A

Greeks Technical Appendix

A.1 Zeno's Paradox

A.2 Proof of Pythagoras' Theorem

A.3 Socrates' Geometrical Problem

Sources

Lloyd, G. E. R. (1970), *Early Greek Science Thales to Aristotle*. Chatto & Windus, London.

Russell, Bertrand (1905), *The History of Western Philosophy*. Simon & Schuster, New York, New York.

Snyder, Z. (2006), "300." Studio: Burbank, California: Warner Bros. Pictures. produced: Nunnari, G. and Canton, M.