Motion and Light From the Greeks to Einstein

The stories of how they became the Special Theory of Relativity

Draft

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Contents

Chapter 0

Series Preface: Read This!

> "PREFACE PROBLEM: Nobody reads prefaces.
> SOLUTION: Call the preface Chapter 1."
>
> - Donald C. Gause and Gerald M. Weinberg, 2011, *Are Your Lights On?*

> "Why not just call it Chapter 0?"
>
> - Raymond Brock, *...just now*

0.1 Why Do This?

Albert Einstein is usually imagined to be the very model of a modern major scientist. A brave genius, working entirely alone. And, it's certainly the case that it would have been hard to be more unknown than the 26 year old. Yet he had an idea that cured a slow-motion nervous breakdown inside of the world's physics community. His Special Theory of Relativity brought two inconsistent theories together by healing a contradiction between them: either James Clerk Maxwell's triumphant model of LIGHT (electromagnetism) or Isaac Newton's mature model of MOTION (mechanics) seemed to be wrong or incomplete. This series, *Motion and Light From the Greeks to Einstein* (let's give it a nickname, "G2E") follows parallel storylines of two very different theoretical clans: MOTION (in which there were three separate families: MOTION IN THE HEAVENS, MOTION BY THE EARTH, and MOTION ON THE EARTH) and LIGHT (where there were also three separate families: OPTICS, ELECTRICITY, and MAGNETISM). Those six different families separately developed, each merging into two single, but conflicting theories: MOTION and LIGHT which Einstein tied together.

G2E's subtitle, *The stories of how they became the Special Theory of Relativity*, emphasizes the theme of this work: stories. G2E is stories about people.

0.1.1 How We'll Do This

I've been a professional particle physicist for half a century and I've found that I suffer from an unusual affliction that affects my undergraduate and even graduate-level teaching and my research. Before I can learn something new or teach something old, I have to know its history. This isn't an especially efficient way to work but it's led to a fulfilling pastime and I suspect broad classroom experiences. I've become so sure of this approach that I even tell stories in mathematically intense (calculate! calculate!), advanced graduate physics classes. This series is a written version of my teaching approach, structured around 20 or so scientists, their lives, their times, their colleagues, their projects, and their accomplishments.

0.1.2 Projects

In trying to reverse-engineer the emergence of innovative ideas in physics, I keep coming back to what individuals do. I'm keenly aware that when I choose to spend my limited time and group resources on a project it's both a commitment and an opportunity loss for what I decided *not* to work on. So it's personal, requires good scientific taste, and ~~so~~ good choices often come from experience. For me: the model of the unit of behavior in science is what I'll call the Project which is a lot like how you might think of a project. But I'll be didactic about it in my stories.[1]

Simply put, each Project has inputs and outputs. In order to get a Project off the ground, one commits to these inputs:

1. **Numbers**. I'll have a set of factual commitments—numbers or parameters—about phenomena that I'll accept.

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[1] There is a more standard, but disappointing "unit of behavior in science" called the "Paradigm" which came from Thomas Kuhn's historic 1962 *The Structure of Scientific Revolutions*. We're doing Kuhn's "normal science" when we're working within a paradigm. At some point, a crisis emerges when the paradigm doesn't work any more and a revolution occurs. Kuhn had trouble explaining clearly what a paradigm was—21 different uses of the word were identified! Is it big, leading to historic Revolutions? Or was it small...lots of paradigms in a scientists' lifetime. It was meant to be a collective world-view but I think in terms of an individual's Project. By the way, in Kuhn's formulation, the passage of one paradigm to another is not progressive...just different. That was a problem as, at least for professional scientists, science is progressive! My model of Projects are progressive.

By contrast,

requires that
Projects

2. **Theories**. I'll commit to a set of theoretical concepts...accepted views of the world, so to speak.
3. **Techniques**. I'll have a commitment to set of best-practice mathematical and experimental skills and techniques.
4. **Norms**. I'll inherit and initially commit to a set of community norms and expectations about what Projects are worth exploring.
5. **Curiosity**. Finally, I'll be curious about some actual or imagined phenomenon. Maybe I just want to measure a parameter or do a "what if" theoretical calculation or build an amusing mathematical model. For the duration of the Project, I'll commit to it. Curiosity defines a Project's goals.

I've called these " commitments " because they are...until they aren't! If I make a discovery of importance that affects what *other* scientists choose to work on usually involves ~~my~~ modification of, abandonment of, or invention of the input commitments that I started my Project respecting. Finding those in past Project to Projects is interesting to me. If a Project is well-designed, we can identify each of these five commitments and as a pedagogical tool in our historical approach in G2E, that's exactly what I'll do:

-, it

new

- ▷ For each of our highlighted scientists, I'll try to persuasively enumerate each of their commitments (#1 through #4) plus what sparked their curiosity (#5).

into the stories

This necessarily brings both history and a focus on the state of affairs during each person's working life. It also points at collaborators.

virtually

That Einstein picture of the completely isolated genius? They don't exist in the practice of productive science. Let me explain. There might very well be completely isolated geniuses, but if their isolation is complete we don't know about them! (We'll see a few who only in retrospect were found to have been on the right track, but silent about it.) You see, an essential aspect of doing productive science is doing public science. Even the well-known "genius" scientists that we can all name had collaborators. They might have had real-time collaborators, or some of them really did work alone in their rooms but they all "collaborated" across time with people who came before them, relying on *their* previous projects. That's where the continuity and progress in science comes from: these real and virtual collaborations. It's even a little bit romantic which is maybe why physicists and astronomers enjoy teaching physics so much.

through books, ~~and~~ research, papers, and presentations

This idea of collaborating with me PSSA

Personal

But revolutions? They're a slow-walking event. If I'm to persuade you that my focus on unique individuals is a legitimate I should be able to identify when a revolution occurred ~~when~~ which reveals itself retrospectively. Here's what isn't an overnight revolution: Someone completes an interesting Project, perhaps having measured surprising new numbers or conceived a new model or invented a new technique. And if by using those new tools they solve some old problem or predict novel phenomena, then maybe that's attention-getting. But only when enough other scientists vote with their feet—and their precious time and resources— and adopt those new ideas as inputs to *their* Projects then, in retrospect, that original Project might be viewed as having been important—and should everyone in the community use those new tools, a revolution has occurred.

That's what interests me and forms the G2E program:

- We'll unpack those #1– #5 inputs for the Projects of almost 20 scientists and see when their work went from attention-getting to revolutionary toward service to Einstein's eventual Special Theory of Relativity.

Both words in the familiar phrase, "Copernican Revolution" annoy many modern historians. "Copernican" because it singles out an individual as special. "Revolution" because it suggests that there are abrupt changes in the flow of intellectual history. In his *To Explain the World*, (Steven Weinberg, 2015) chides (Steven Shapin, 1996) for the first line ~~of his~~ the latter's *Scientific Revolution*: "There was no such thing as the Scientific Revolution, and this is a book about it." Shapin is one of the voices of a movement that has recoiled against the idea of THE Scientific Revolution and certainly that a single person might be responsible. I've got a different take on this, especially since my career has actually straddled a bonafide revolution motivated by special individuals (Weinberg, among them).

After chastising Shapin, Weinberg closed his introduction to his Copernicus chapter with the comment, "There was a scientific revolution, and the rest of this book is about it."

I agree. There have been Revolutionary Scientists *and* there have been Scientific Revolutions and the rest of this series is about them: Claudius Ptolemy, Nicolaus Copernicus, Tycho Brahe, Johannes Kepler, William Gilbert, Galileo Galilei, Rene Descartes, Christiaan Huygens, Isaac Newton, Thomas Young, Michael Faraday, James Clerk Maxwell, James Joule, Albert Michelson, J. J. Thomson, Hendrik Antoon Lorentz, and Albert Einstein.

Every chapter follows a similar template. The main bodies have major sections that center on one or two scientists: "A Little Bit About Copernicus" or "A Little Bit About Newton," or Kepler, or Maxwell, and so on. We'll learn about their lives, their contemporaries, and yes, we'll analyze their Projects—what they brought to their work and how they stimulated conceptual change as a result. The last major section will be “Copernicus Today” or “Newton Today” and so on. Each of our physicists left legacies; world-views; and in some cases, even technologies that we still use today. Finally, for many of the chapters there are technical appendices which go deeper into the mathematics than would be welcome in ~~the body~~ of a series like this.

the main narrative

Volume 1: The Greeks

In this first volume in the series, *Motion and Light From the Greeks to Einstein: The Greeks*, we’ll tell the origins-story of what became international, science. This volume will be different from subsequent ones, its stories are of number of people, not all of whom would be classified as scientists. But we’ll close with the one of the earliest quantitative astronomers: Claudius Ptolemy.

as

Appendix A

Appendices

A.1 Greeks Technical Appendix

A.1.1 Proof of Pythagoras' Theorem

A.1.2 Zeno's Paradox

A.2 Plato–Aristotle Technical Appendix

A.2.1 Socrates' Geometrical Problem

A.2.2 Logic and Electronics

A.2.3 Aristotle's Legacy in Physics and Engineering

This section is a little more detailed than normal, but the payoff is large! Aristotle left us a legacy which instantly became an active research project for ancient and medieval philosophers and eventually, present day philosophers, mathematicians, engineers, and scientists! He created a tool that guarantees how to properly analyze and judge conclusions reached through argument: Formal Logic. Read the next seven pages in detail for the whole story, skim them for a taste, or jump to the punch-line on page 20.

In everyday life, we all make arguments but have you ever thought about what makes you successful in defending your case? The facts need to be on your side but your stated reasoning should also be "logical." We all have a sense of what "logical" means, but it's surprisingly nuanced. Consider the following reasoning:

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

This doesn't make sense because the first two sentences—the "premises"— are nonsense. And yet *it's a perfectly valid argument*! Appreciating the difference between a *valid* argument and a *true* argument leads us to Aristotle's amazing discovery that the rules of valid reasoning are due entirely to an argument's structure and arrangements of the sentences, not the specifics of the content. Your and my lives are now governed by Aristotle's invention of Formal Logic, his most important, lasting contribution.

Obviously, the distinction between *validity* and *truth* can be easy to spot. But the distinction between valid and invalid argument can be subtle. Think about these two arguments:

Table A.1: How to not reason logically.

A	B
Those who take the vaccine stay well.	Those who take the vaccine stay well.
Those who take the vaccine are smart.	Those who are smart take the vaccine.
Those who are smart stay well.	Those who are smart stay well.

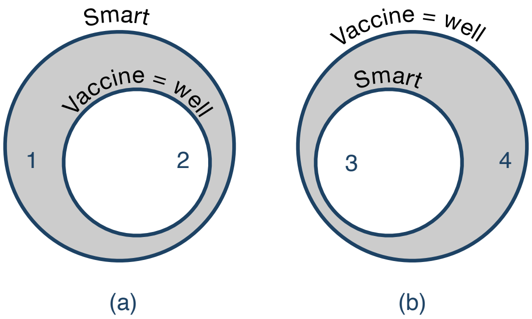

Figure A.1: A diagrammatic way to show that argument A in Table A.1 is invalid and that the conclusion of argument B is valid.

The argument in column A is invalid, not because the premises are ludicrous, but because of the form of the terms in the sentences. Read it very carefully with an eye on Figure A.1. Notice how the righthand and lefthand circles are different (not really Venn diagrams, but a cousin, called Euler Diagrams). The first premise in argument A is that if you take the vaccine you're going to be well. So in the lefthand diagram, everyone who took the vaccine is in region 2. The second premise in argument A says that those who took the vaccine are smart, but it doesn't rule out the logical possibility that some smart people didn't take the vaccine—region 1. So the conclusion, that if you're smart, you're well does not hold.

Argument B says things slightly differently. Again, smart=well. But then the second premise says that if you're smart, you took the vaccine, so all of the smart people are in region 2 and, they're vaccinated. That, of course leaves the possibility that there are people who took the vaccine, but aren't smart, region 4. That's good! But not the argument which leads to a valid conclusion: Those who are smart stay well (and because of the first premise, they also took the vaccine).

A.2.3.1 Greatest gift

Aristotle's greatest gift to us was his invention of Formal Logic which is a rigorous way to judge the validity of arguments. For example, he could tell you that the argument in column **A** is not valid and why and tell you how to construct arguments like column **B** which *are* logically valid. Every time. And sometimes surprisingly, independent of the actual subject-matter of the argument.

> Officially, Formal Logic is the field that studies reasoning and the various ways that conclusions can legitimately be drawn from premises.

This new-born subject is covered in a number of his books, including: *Categories*, *On Interpretation*, *Prior Analytics*, *Posterior Analytics*, *Topics*, and *On Sophistical Refutations* which collectively, were much later dubbed "*Organon*" which means "instrument" which suggest by that time, Logic was viewed as just a tool, as opposed to a part of philosophy. Now it's firmly the philosophical camp and even an important part of an entire branch of mathematics called Discrete Mathematics.

Logic became a research program almost as soon as he wrote it down (or lectured on it) and two millennia worth of people—to this day—study logical formalism, expanding it into new directions. It's studied by every student of physics and engineering in forms directly evolved from Aristotle.

A.2.3.2 Deduction and Induction

Broadly, there are two kinds of logic which you use every day. The first works according to strict rules which I think of it as the *algebra of reasoning* and you'll see why in a bit. Reason according to those rules, and you will reach correct conclusions. This is **Deductive Logic.**

The second kind of logic is less certain since it's not rule-bound and it delivers conclusions which can seem persuasive but aren't certain. This is **Inductive Logic**. From this point, when I refer to "logic" I'll mean deductive logic.

Among things that are obvious to us (and to everyday Greeks), Aristotle seemed to intuit as requiring bottom-up attention. He tightly defined terms and "obvious" ideas, dissected arguments finding rules along the way, and set down what it means to be clear with exquisite precision. Look at these two statements:

- All squirrels are brown.
- No squirrels are brown

1) Can these both be true at the same time? Of course not and this obvious idea has a name: *the law of contradiction.* Aristotle needed to be precise and actually provided multiple "proofs" to demonstrate this principle.

2) One of these must be true... there's nothing in-between, which is called the *law of the excluded middle*.

> "...there cannot be an intermediate between contradictories, but of one subject we must either affirm or deny any one predicate" Aristotle, *Metaphysics*.

Centuries of ink have been spilled over precisely understanding the implications of law of the excluded middle and how to symbolically state it unequivocally. But here's the first hint of our modern debt to him: his logic is two-valued, either true or false with no in-between. Hmm. Binary: True and false...one's and zero's.[1]

Last one:

- A squirrel is a squirrel.

This is called *the law of identity* and Aristotle didn't invent it and it sounds like Parmenides: "What **is**, **is**." These three ideas, collected together by him, are often called the Rules of Thought and were believed to be the bedrock for all of Logic. (That this was disputed in the 20th century shows that Logic is still a living-breathing subject.) Nobody ever thought this way before — so clearly—-and in Aristotle's patented approach to system-building, he lays it all out out exhaustively. As a master system-builder, he was the right man for the job.

His unique invention was to create an *algebra of language.* Here is a seminal moment in history, from the first book of his *Prior Analytics* (focus on the last sentences):

> "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, *Prior Analytics*.

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

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[1] Things didn't stop there. Now there is a multi-valued logic with degrees of truth and falsity with many engineering applications. "Fuzzy Logic" is a legitimate decision-making tool in transportation control systems, earthquake prediction, even home appliance efficiency.

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." Instead of men and animals, 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.

Amazing. Out of this, your mobile phone was born.

There are many different forms of arguments and for Aristotle, the **Syllogism** is just one of them. It's an argument written in a structure in which there are three sentences with a subject and a predicate[2]: two premises and a conclusion and inside those sentences are three "terms."

Here is one of the syllogistic forms:[3]

- premise 1: If all A are B
- premise 2: and if all C are A
- conclusion: then, all C are B

There are actually 256 possible argument-combinations of subjects and predicates and 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.

Let's make a syllogistic argument about squirrels. I'll define C = squirrels, A = the group of all animals in trees, and B = brown animals. One kind of syllogism would have the form:

- All mammals in trees (A) are brown animals (B)
- and if all squirrels (C) are mammals in trees (A)
- then, all squirrels (C) are brown animals (B).

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. Yet, my argument above seems to prove that squirrels are brown. So what went wrong?

My "Squirrels with superpowers" shined a bright light on the premises: they have

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[2] since his Categories are predicates, these topics were a part of his overall system

[3] Before 500 CE, Aristotle's original form was used:

- If A, then B
- If B, then C
- So, A is C

to be legitimate. In scientific arguments, premises might be . . . hypotheses, in which case a deductive argument describes a way to test those ideas. Aristotle was well-aware of induction, deduction, and how they might go together.

Back to my squirrels proof. I reasoned inductively:

- (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! (which was my premise)

Until I moved to Michigan. All it took to ruin my theory about squirrels was the observation of one black squirrel, much less an entire herd of them. Squirrels are not only brown, they're black. My proof founders on a false premise: "All mammals in trees (A) are brown animals (B)."

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![4]

A.2.3.3 Your phone

Theophrastus (-371 to -287) was a favorite student of Aristotle's who led the Lyceum for 37 years after his teacher's death. Aristotle even willed him the guardianship of his children...and his library. While a devoted student, Theophrastus went beyond his teacher and expanded and modified some basic Aristotelian 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.

He is probably the one who extended the form of argumentation into a new direction with the invention of "propositional logic" in which there are two items, rather than three of a syllogism. This is where the modern engineering action is. One form of such a proposition is called "Modus Ponens" (Latin for "method of affirming") which is an offshoot of the classical syllogism and is one of four possible "rules of inference." Modus Ponens goes like this:

- If A (the antecedent) is true, then B (the consequence) is true
- A is true
- Therefore, B is true.

Here, each line is a proposition (there can be more than two) with the first two being "premises" and the last, the "conclusion." The first sentence is a proposition

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

which is conditional: the antecedent implies the consequence and it's "affirmed" if the next statement is true. B here is the consequence of A. Here's a concise way to present this:

- $A \rightarrow B$
- A
- $\therefore B$

The → symbol means "implies" and is associated with an "If...Then" kind of statement. The ∴ symbol means "therefore." It doesn't seem like much, but it's powerful and misunderstanding (or misusing) it is the source of many logical fallacies. Table A.2 shows an example:

Table A.2: A typical logical fallacy involving public health.

A valid argument	A fallacy
• If a reactor leaks radiation (A), people nearby will get cancer (B). • The reactor leaks radiation (A). • Therefore, people nearby will get cancer. (B)	• If a reactor leaks radiation (A), people nearby will get cancer (B). • People nearby got cancer (B). • Therefore, the reactor leaks radiation (A).

The argument on the left is an example of Modus Ponens, while the argument on the right is a classic fallacy known as "Affirming the Consequent," a regularly exploited tool for those intentionally making invalid claims. Especially those who dispute public health strategies. Look at how the two columns are different. Remember, that in the proposition, B is the consequence of the antecedent, A and not the other way around. In the second row of the fallacious argument, the antecedent and consequence are reversed as compared with the valid argument. The fallacy is that people can get cancer from other causes than the proposition states.

Let's make a plan to picnic outdoors which requires us to keep an eye on the weather since if it's raining the ground would be wet and of course we wouldn't have a picnic if the ground is wet. We'd actually use Modus Ponens in our thought process and reason among ourselves:

- If it's raining, then the ground is wet
- It is raining
- and so the ground is wet.

Let's build a table—a picnic table (sorry)—that takes each line in the argument and makes it a column in a table. We could then ask a set of questions: Is it raining (Yes), is the ground wet (Yes)...was the proposition confirmed? Yes.

Table A.3: The picnic is cancelled because:

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

There are actually four complete ways in which the antecedent and consequence could appear:

- rain? Yes or No
- wet? Yes or No

So what about: suppose the ground is not wet (wet = F) then can it be raining? Well...no (rain = F). So if wet = F and rain = T, then the proposition would not be true since rain should imply wet. We can build up these four conditions into what is called Truth Table, which was invented in the early 20th century as an analyzing tool. Table A.4 describes the complete story:

Table A.4: 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

Sometimes these are hard to unravel. The first two lines are pretty obvious. It's asserted that when it rains that the ground is wet, so the second line is obviously false. The proposition requires "wet" with rain. The last line is pretty clear also. No rain, let's picnic since it will not be wet. The third one requires some thought. What does the if statement say about the ground if it's not raining? Nothing. You could be wet for other reasons so this does not falsify the proposition, so it's not F...and in a two-valued logic, the only alternative to F is T. Go lie down before we go on because it's about to get interesting and relevant.

Before getting to the punchline, let me make a couple of points:

- The → or if...then argument is one of six "connectives," all of which have truth tables like above. They are negation, conjunction ("AND"), disjunction ("OR"), conditional (that's the → conjuctive), biconditional, and exclusive OR.
- The Modus Ponens argument got its Latin name from the Medievals who seriously studied Logic. They identified it as one of four "Rules of Inference" which we use today: MP, Modus Tollens, Hypothetical Syllogism, and Disjunctive Syllogism.
- The Hypothetical Syllogism is just one form of the "regular" syllogism of our squirrel proof above. In fact, it can actually be proved to be the combination of two Modus Ponens arguments, one for A → B and the other for B → C. There's debate about whether Aristotle might have recognized his syllogism to have been an "hypothetical" in this sense with a deeper structure.
- In Appendix A.2 I've gone into some more detail logic gates as they're used in digital circuit design.

There are a handful of seminal discoveries about Logic that extend to our modern reliance on it. **Gottfried Wilhelm Leibniz** (1646–1716) refined binary arithmetic. In 1854, **George Boole** (1815–1864) invented the algebra of two-valued logic...how to combine multiple conjuctives into meaningful outcomes which can only be T or F, 1 or 0. In 1921 in his dense and very terse *Tractatus Logico-Philosophicus*, **Ludwig Wittgenstein** (1889–1951) invented the Truth Table, which can be used in logical proofs and complicated logical solutions to multi-variable inputs. Finally, in 1938 **Claude Shannon** (1916–2001) realized that Boole's algebra could be realized in electronic, "on-off" circuits. This was realized in the 1940's with vacuum tubes and then in the 1960's with transistors.

Notice that the picnic table can be thought of as a little machine: you input the four T-F possibilities in pairs for rain and wet and out comes the truth value of the proposition. Figure A.2 is a cartoon of such a machine.

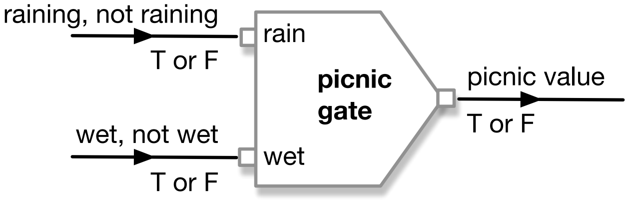

Figure A.2: A fake "picnic gate" machine that does the work of Table A.4

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The image in this figure is maybe suggestive of digital component representations which are called "gates." There are electronic gates for eight functions, which are a practical expansion of the conjunctives mentioned above. Think about that. The whole of our digital world can be made with these eight gate functions.

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.

A.2.3.4 The Punch Line:

Let's review what just happened:

We've found that Aristotle made a simple but profound discovery, namely that one could take a sentence, like "Fire engines are red or yellow" and turn it into essentially a mathematical statement, like "A are B or C" and then draw general conclusions about the combinations of general statements that don't involve the details. That sentence involving A, B, and C could also be a representation of the sentence, "All squirrels are either black or brown." This allowed him to then create a system of rules that could guarantee the validity of arguments, which, after all, are combinations of sentences.

The first kind of argument is now called the "categorical syllogism," and involves three variables and, like fire engines and squirrels, can be specific or more usefully, general, like:

All men are mortal.	A are B
Socrates is a man.	C is A
Therefore, Socrates is mortal	therefore, C is B

This evolved quickly into a rules guaranteeing validity of conclusions from a different form of argument involving two variables (an "hypothetical syllogism"):

If all men are mortal, then Socrates is a mortal	If A, then B.
All men are mortal	A is true.
Therefore, Socrates is mortal	therefore, B is true.

In fact there are variety of valid forms for each sort of argument but what's interesting in the second sort is that the truth value of arguments involving two variables can actually be created using electronic circuits using tables ("truth tables") of the different logical outcomes of the truth or falsity of the premises in an hypothetical syllogism. This was realized in 1938, built into vacuum tube circuits in the 1940's, and transistor digital electronics in the 1960's.

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.

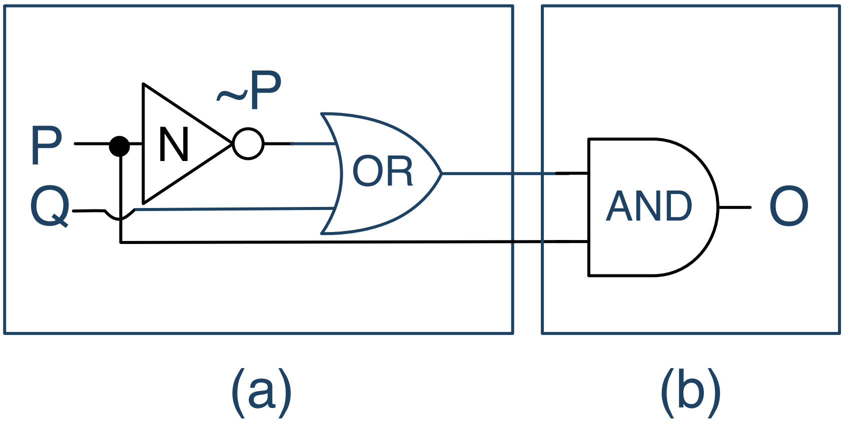

Figure A.3: (a) and (c) are the transistor-equivalents of the two logic gates, NOR and OR in (b) and (d). The little circuit to evaluate rain causing wetness...or not...is shown in (e).

In the spirit of overview, Figure A.3 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 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, and (d) is the logical gate symbol for performing that operation. Finally, (e) is the digital gate solution for the Conditional argument from Table A.4—it's a real-life engineering representation of the fake "picnic gate" in Figure A.2.

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 my watch, just for the memory! The CPU and control circuitry would add millions of additional imprinted transistors and their gate-equivalents. All on m

A.2.4 Digital Gates

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 A.4. 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   so if A = 1, then   A = 0. (The   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 A.5 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.

Table A.5: 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** . Notice that (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	A	(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 $A \vee B = 0 \vee 1 = 1$

The last column shows that this is the same as the first line result of our picnic decision making in Table A.4. The rest of Table A.5 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.

A.3 Greek Astronomy Technical Appendix

A.3.1 Plato's Timaeaus Cosmology—The Numerology

> "And he began the division in this way. First he took **one portion** from the whole, and next a **portion double of this**; the **third half as much again as the second**, and **three times the first**; the **fourth double of the second**; the **fifth three times the third**; the **sixth eight times the first**; and the **seventh twenty-seven times the first**. Next, he went on to fill up both the double and the triple intervals, cutting off yet more parts from the original mixture and placing them between the terms, so that within each interval there were two means, the one (harmonic) exceeding the one extreme and being exceeded by the other by the same fraction of the extremes, the other (arithmetic) exceeding the one extreme by the same number whereby it was exceeded by the other." Plato, **Republic**

Okay the numbers seem arbitrary. But there's an algorithm:

- one portion of the whole: ○, 1
- double of this: ○○, 2
- half as much again: ○ ○ ○, 3
- double of the second: ○ ○ ○○, 4
- three times the third: ○ ○ ○ ○ ○ ○ ○ ○ ○, 9
- eight times the first: ○ ○ ○ ○ ○ ○ ○, 8
- twenty-seven times the first: ○, 27

Now manipulate:

- The first four are the famous 1,2,3,4 and since they're the special numbers, they have a job to do:
  - Square each of the first numbers—remember, 1 is not a number— (Greeks knew how to multiply): and you get 4 and 9.
  - Cube those same first two important numbers: and you get 8 and 27.

So all of the numbers in that excerpt are some manipulation of the numbers 2 and 3—he stopped at 3 because there are only three dimensions. Collecting all of the numbers, but now into even and odd strings (remember, 1 is neither even nor odd for Pythagoreans and apparently also, for Plato):

Then, Timaeus says that if you take the number strings you actually construct the intervals of the diatonic musical scale. More Music of the Spheres. Whew. Wait until we get to Kepler.

A.3.2 Some Aristarchus Measurements

A.4 Medieval Technical Appendix

A.5 Copernicus Technical Appendix

A.6 Brahe-Kepler Technical Appendix

A.7 Gilbert Technical Appendix

A.8 Galileo Technical Appendix

A.9 Descartes Technical Appendix

A.10 Brahe-Kepler Technical Appendix

A.11 Huygens Technical Appendix

A.12 Newton Technical Appendix

A.13 Young Technical Appendix

A.14 Faraday Technical Appendix

A.15 Maxwell Technical Appendix

A.16 Michelson Technical Appendix

A.17 Thomson Technical Appendix

A.18 Lorentz Technical Appendix

A.19 Einstein Technical Appendix

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