# Defining and Presenting Data

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When I was asked to prepare this lecture, it was suggested that I should talk about the presentation of data. I thought about that for some time, and I asked myself, "What is data anyway?" There is no real problem in *listing* raw data; you need merely record it accurately in a readable fashion employing some understandable system.

But that had nothing to do with the *presentation* of data. You only present data after you have arranged it, analyzed it, studied it, and made some sense out of it. And why do you present it at all? Clearly you present the data in order to convince someone that your analysis, and the conclusions drawn from that analysis, are sound. What kind of data do you present in order to do this persuading? A great variety of kinds. Graphs are a form of data; so are maps; so are photographs, circuit diagrams, tables, questionnaire forms. Is there any way of describing how best to present these?

There is, I think, if you consider them all as forms of evidence. Once you conceive of them this way, you can begin to see what evidence, or data, to present, and how to present it.

Now the minute you use the word "evidence," most lawyers will think of "Wigmore." No one who has read a legal tome can avoid the name John Henry Wigmore, Dean Emeritus of the Law School of Northwestern University. Dean Wigmore's numerous books on evidence are cited again and again in legal briefs. I am going to rely heavily on Dean Wigmore's *The Science of Judicial Proof* in talking about evidence. Lest this seem rather remote from the problems of scientific and technical writing, let me add some ideas of Percy Bridgman from his book *The Logic of Modern Physics*, and from Anatol Rapoport's article "The Various Meanings of Theory."

Evidence is presented first of all to prove—this means to convince others to believe—the truth of a proposition. Therefore, the place to begin discussing evidence is in terms of the proposition. What is it you are trying to prove? What is the proposition? Secondly, what inferences led you to believe that this proposition is true? Or as the case may be, false? Thirdly, what supporting facts led you to these inferences in the first place? We thus have to work our way back down a deductive chain—a chain of inferences—to a set of facts that seem to be certain or sure. This is the way Dean Wigmore starts his discussion of evidence, and a little later I think you will see from Bridgman and Rapoport how closely this fits into the scheme of scientific thinking.

The proposition that the lawyer for the plaintiff is trying to prove is that his client—be it an individual, a corporation, or a governmental unit—has suffered an injustice and deserves some recompense. The lawyer for the defendant is trying to prove that *his* client acted justly and fairly and should *not* be required to recompense the plaintiff. Thus the lawyers for Allen Bakke set out to prove that he had been treated unjustly, while the lawyers for the University of California set out to prove that the University had indeed acted justly.

A scientist presents his case in a similar fashion, except that his client is himself. He sets out to prove that the relationship he has found between two phenomena is an actual, invariant, and repeatable relationship; while his opponents consist of the entire scientific community who contend that chance or accident, or some other explanation could account for the same relationship. Galileo set out to prove that the application of force results in successive *increases* in velocity, or *acceleration*, while most of the scientific community contended that Aristotle was correct in asserting that force produces simple velocity.

Both the lawyer and the scientist must present evidence, and each piece of evidence, or data, should be presented in order to lead us an inferential step nearer the eventual proposition to be proved true. No single inferential step will ordinarily do it; it takes a whole series of them.

There are two broad classes of evidentiary facts, according to Dean Wigmore. They are: (1) the thing itself, and (2) independent facts which lead us to believe that the thing is true. Evidence which consists of the thing itself, Wigmore calls "Autoptic Proference," that is, the thing is proffered to our own eyes. It is like producing a gun in court in a murder trial. For example, is there such a thing as a color picture produced from two black and white transparencies? Probably the best evidence here is autoptic proference. Some of you may have seen the Land effect, discovered by Dr. Edwin Land of Polaroid Land camera fame. If you haven't, it sounds unbelievable. Dr. Land takes two pictures of the same scene, one with a red filter over the camera lens, one with a green filter. The film is ordinary black and white film. The "red" picture is then projected on a screen through a red gelatine; the "green" picture is projected through a second projector on the same screen without any filter at all, ordinary white light. If you are very careful to get the two projected images to overlap exactly—all of a sudden, as if by magic, a color picture appears on the screen. If the two images do not overlap, the color fades away.

But what can you infer from this evidence? As a matter of fact you can infer nothing. That is, you cannot move logically from this evidence to another conclusion. At least you can't without adding some additional evidence. All you can really conclude is that this "Land Effect" exists. This is why Dean Wigmore calls this "Autoptic Proference" so you will remember that no inference is included in this sort of fact. The gun produced in court merely demonstrates that there *is* a gun. You should not infer that this gun is the murder weapon. Additional facts will have to be presented before such an inference is logically possible.

Now for the second class of evidentiary facts—independent facts from which we usually infer. This class is ordinarily subdivided into testimony, or testimonial evidence, and circumstances, or circumstantial evidence. For some reason many people have a bias against circumstantial evidence, or at least the term circumstantial evidence suggests to them something shady or corrupt. One TV script writer, who should have known better, had the characters in his drama condemn the district attorney for achieving a large number of his convictions on the basis of circumstantial evidence. If there is no witness to a murder, all that the police and other witnesses can testify to is the truth of the surrounding circumstances. That is, a witness can assert that he saw the accused enter the house and the ballistics expert can assert that the fatal bullet came from this particular gun, and the police officer can assert that this particular gun was in the possession of the accused a few minutes after the sound of a shot was heard in the house. From these circumstances we may, or we may not, infer that the accused is guilty. Most of the physical, chemical, and biological sciences rely almost entirely on circumstantial evidence—that is, on facts—from which we draw inferences exactly as in a legal case.

And testimonial evidence is notoriously subject to bias. First, there is the bias of *perception*. Did the witness really perceive what he thought he perceived? There are numerous examples from the field of pychology to demonstrate that our senses of vision, hearing, touch, taste, and smell are subject to our own internal biases.

Our famous illusion is the autokinetic effect. This is the effect of movement that you see when you view a small light in a completely darkened room. Although the light is firmly fixed, everyone, after a time, will see it move because their eyes cannot remain still. This caused some trouble to Navy pilots flying at night in World War II. The single small identification light in the tail of the lead plane seemed to move, and the wingman in an effort to follow his leader would follow the apparent movement of this light and chew off the leader's tail with his propellor. The addition of another light to provide a frame of reference solved the problem.

Another illustration. Sound carries very well under water. Rear Admiral Ben Bryant of the Royal Navy writes that during World War II more than one submarine reported that it underwent a severe depth charge attack when as a matter of fact what the crew was hearing was shell fire directed at a floating target many miles away.

In addition, a good deal of testimonial evidence is second-hand. That is, it is hearsay evidence. The witness can only testify to what other people said that they saw or heard. In court this is often, though not invariably, inadmissable. If the first-hand observer can be called upon to testify, the court will usually refuse to admit the testimony of the second-hand witness. But the first-hand witness may be dead or otherwise incapacitated; then hearsay evidence may be admissable in some cases. However, in the everyday practice of business we rely very heavily upon hearsay evidence.

When the foreman reports to the supervisor he is frequently forced to rely upon reports of the men in his crew; so what the supervisor gets is actually hearsay evidence. President Truman wrote that one of the hardest jobs of the President is to make sure that what he has ordered done actually gets done. Of course the President has to rely on hearsay evidence—someone's report of how a third person says he saw the job progressing. And our newspapers are, of course, almost 90 percent hearsay evidence. The reporter tells us what he heard someone else say happened.

This leads us to two other sources of bias in testimonial evidence—bias of *recollection*, or memory, and bias of *narration*, or communication. Bias of memory is easy to understand. We all tend to forget portions of what we have seen or heard, or sometimes we add details that were not originally present. It is sometimes difficult to tell whether the bias is due to memory or due to communication, but if we classify the following as bias due to memory there is a delightful illustration from the career of the famous Irish lawyer and politician, Daniel O'Connell.

O'Connell was defending a man named Pat Hogan on a charge of murder. The chief witness against Hogan was a neighbor who had discovered the body and had found near it a hat which he identified as Hogan's. O'Connell asked the witness how he could identify that hat, since it apparently looked like a great many other hats. "Well," said the man, "I know that hat." "But are you sure that *this* hat was near the body?" asked O'Connell. "Certain sure." O'Connell picked up the hat, examined it closely, turned up the sweatband and studied it. "And was the prisoner's name, P-A-T," he spelled slowly, "H-O-G-A-N, in this hat at the time you found it?" "Of course it was." "You couldn't possibly be mistaken?" "No, sir." "And everything you have told this court is as true as the name in this hat?" "Of course it is." "Then," said O'Connell, "my client goes free. My lord, you cannot convict my client. There is *no name* in this hat!"

Moreover, when we try to communicate accurately what we have witnessed we are often subject to bias. Dean Wigmore illustrates this with a little story about General Pershing. In his memoirs, General Pershing describes a tour of the trenches he made with Premier and Madame Poincaré. At one point two brash and carefree American soldiers stepped up and in an excess of democratic camaraderie shook the hands of the Premier and his lady. Irrepressible American democracy!

But the two soldiers tell quite a different story. Dirty, disheveled, and abashed they stood awkwardly at attention and Madame Poincaré walked up to them and proffered her hand. Under the iron glare of General Pershing the two soldiers didn't know what to do, so they gingerly shook the white gloved hand with their muddy paws. Irrepressible democrats? Or subdued subject of a military dictator?

The very way in which we are asked to testify may bias our testimony. Take Lord Nelson's testimony in the treason trial of Colonel Despard in 1803. Despard's attorney asked Nelson, "What impression did you form of the loyalty of the defendant during all the years you served together?" And Nelson replied, "During all the years we served together I found no man more zealous nor more loyal to his country than Colonel Despard. I had a high opinion of him."

But of course Nelson had to undergo cross examination, and the prosecutor asked only three questions. They were, "When did you last serve with Colonel Despard?" And Nelson replied, "Between the years 1779 and 1789." "Have you had any contact with him since?" "None." "Then you know nothing of his loyalty to his country during the last 23 years?" To which Nelson had to reply, "No, I do not."

So you see that testimonial evidence is subject to the bias of *perception*, of *recollection*, and of *communication*. Why then do we put such trust in it? Because we reason deductively something like this: "This class of people is likely to perceive accurately and without bias. This witness belongs to this class of people. Therefore, he probably did perceive what he says he did." If a physician asserts that so many grains of a certain drug were found in a body, we are likely to believe him. Only if someone opposed to the witness can show us that he belongs, not to the class of responsible people, but the class of careless or dishonest people are we likely to become suspicious of his evidence.

This is why the physical appearance of the witness is important. If a young man with long, greasy, uncombed hair and a black leather jacket testifies that he is a physician and that he found poison in the body, we are not likely to believe him. There is no law that says a physician cannot wear a leather jacket and have long, greasy, uncombed hair, but in our experience physicians seldom appear in such dress.

When we move on to circumstantial evidence we appear to reason in much the same way. And in the sciences we also mentally start from a general principle and fit the particular circumstance into it in order to arrive at an inferential conclusion. Henri Poincaré points out that all scientists start with the two general principles: one, that nature must be understandable, otherwise they wouldn't try to understand it; and second, that it is simple. This is why they tend to seek for the simplest description of nature; the complicated and complex description just can't be entirely correct, there must be a simpler, and more general formula to describe it. But we need to be very suspicious of these general principles.

In a legal case, for example, we may reason, "All persons within a closed room where a gun is fired will hear the shot. The accused was in a closed room where a gun was fired. Therefore, the accused *must* have heard the shot." But this reasoning is not necessarily valid. The gun may have been fitted with a silencer, or it may have been of such small caliber or of such a make that it made very little noise. Or the room may have been exceptionally noisy. Or the accused may be deaf.

The real test of circumstantial evidence lies in those premises. Are there exceptions to that major premise, or general principle? Is it an oversimplification which needs numerous qualifying phrases? Should it be rephrased to read, "All persons *of normal hearing* within a *quiet*, closed room when an *unsilenced, noisy* gun is fired will hear the shot?" If it can be demonstrated that just one of these qualifying conditions is not met, then we cannot infer with any certainty that the accused heard the shot. In a similar fashion, the scientist is very careful to eliminate, if possible, all of the other possible causative variables which might create exceptions to the major premise he is attempting to establish.

My friend, Mr. B. C. "Bertie" Brookes of University College, London, has an interesting example of why it is important to check up on the facts, the raw data, upon which an inference is based. During World War II the Royal Air Force asked him to analyze why one particular base for training aircraft gunners was so much less effective than other bases. Each base trained gunners by having them shoot from bombers at sleeve targets towed behind fighter planes. The gunners at this particular base scored fewer holes in the sleeve targets than did gunners at other bases. Why?

Bertie visited this base and asked if he could fly in the bomber and take shots at the sleeve target himself. Permission was granted, but when the tow plane went by his bomber, Bertie aimed his machinegun at the sleeve target but did not fire. Nevertheless, when he landed and asked for his score, he was informed that he had scored some hits. How could that be?

Bertie then asked if he could visit the crew which tallied up the holes in the sleeve targets. Again permission was granted. This crew was a considerable distance away. In fact, it consisted of four men and a sergeant stationed all by themselves on a rocky, snowcovered little island off the coast of Scotland. They were supposed to collect the sleeve targets the tow plane dropped to them, count the holes, and telephone the results back to base headquarters. There were no other people on the island and the crew had been stationed there for several weeks without relief. The work was boring in the extreme, so after the first week, instead of trudging through the snow to collect the targets, they remained in their warm hut and called in entirely imaginary scores. Since no one ever checked up on them, they got away with it, until Bertie arrived. Bertie says that the moral to this story is, "*Always* check the raw data and how it was collected before you accept an inference."

This is why it is so useful to have a devil's advocate—an opponent—who will, when you prepare your argument, suggest to you a variety of different ways of explaining the same effects. In his autobiography, Sidney Smith, Professor of Forensic Medicine at the University of Edinburgh, describes the case of Annie Hearn on trial for the poisoning of her elderly employer. The body had been exhumed and another very famous physician testified that he had removed tissue samples from the cadaver, and that these tissue samples contained arsenic of such and such concentration. The obvious inference was that arsenic had been instrumental in causing the old man's death.

But Sidney Smith offered an alternative explanation. Although the body had been exhumed, it had never been removed from the graveyard. The coffin had been opened in the dusty graveyard on a windy day so that tissue samples could be taken from the corpse; no precautions had been taken to prevent the tissue samples from being contaminated with particles of dust. And it just happened that the dusty soil of the graveyard contained exactly the concentration of arsenic that was reported in the tissue samples. As a result of Smith's testimony Annie Hearn was acquitted.

In scientific and technical arguments the general principles we frequently begin with we label theories. For example (this example is the one used by Anatol Rapoport in his article, "The Various Meanings of Theory"), the motion of a pendulum can be described by the formula $x = a \sin (mt)$, where x is the horizontal deflection of the bob, A is the maximum deflection, t is time, and m is a constant, the square root of the ratio of the acceleration of gravity to the length of the pendulum. This is a theory, or a general principle.

But is it always true? Not at all. It is an oversimplification; it depends upon idealizing assumptions, such as: no air resistance or friction, no mass for the supporting string, and so forth. So this general principle cannot be applied to each and every pendulum. Nevertheless, the theory is very useful because it enables us to deduce a variety of consequences which describe in a general way many other phenomena and relationships.

Professor Rapoport's description of a theory in the exact sciences is, I think you will see, in many ways similar to Dean Wigmore's description of the chain of inferences leading to the proof of a proposition. "In the exact sciences," says Professor Rapoport, "a theory is a collection of theorems." But what is a theorem? "A theorem is a proposition which is the strict logical consequence of certain definitions and other propositions. The validity of a theorem, then, usually depends on the validity of other theorems. This tracing of antecedents goes on until the rock bottom is reached . . . assertions which are not proved but simply assumed, and terms which are not defined but simply listed."

How does the scientist define the terms which make up his propositions? If at all possible he does this by performing a series of operations which enable him to *measure* the term consistently and reliably, given the same set of circumstances each time. In the modern International System of Units (SI) the seven basic definitions are: (1) the meter for length, (2) the second for time, (3) the ampere for electric current, (4) the kelvin for temperature (5) the mole for amount of substance, (6) the candela for luminous intensity, and (7) the kilogram for mass. Only the last, the kilogram, is defined in terms of an artifact, the standard kilogram kept near Paris. All of the others are defined in what Percy Bridgman called "operational definitions." This simply means that given the proper laboratory equipment a scientist anywhere in the world will get exactly the same definition, or measurement, of the term—provided he follows the prescribed series of operations.

Add to these seven terms the two mathematical ratios, the radian for plane angles, and the steradian for solid angles, and a scientist can combine these nine terms into propositions from which he can logically deduce a series of theorems and start building the deductive chain—the chain of inferences—which lead to the proposition he is attempting to prove.

Thus, if you keep in mind that data is evidence designed to lead the reader to infer the truth of a proposition, you will begin to see that you must lead the reader step by step from the definitions and assumptions you began with, through a series of reasonable inferences to a conclusion. From this conclusion, and from others derived in a similar way, you can lead him to infer a broader conclusion. In this way, you gradually build up a pyramid of evidence leading to the proposition you wish to prove.

This process will be different depending upon the types of science you are dealing with. That is why it is difficult to provide general examples. A theory in the exact sciences starts from agreed upon definitions and clear cut identities. But as you move away from physics up through biology toward psychology and sociology, it becomes harder and harder to define and identify phenomena upon which to base your pyramid. So, much time must be spent in these sciences in definition. Is there such a thing as a *normal person?* An *economic community?* A *political party?* We are back down near the bottom of the pyramid, close to the type of evidence presented in law court where we first began this discussion. And that seems to be a good place to declare this court adjourned.

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## NOTES AND REFERENCES

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