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Chapter 3

Information or Noise?

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Where is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?
— *TS Eliot*

Pigeons?

The pigeons were chased off with the bang of a shotgun. But a much bigger bang was soon to be "heard."

In 1960, Bell Labs built a 20-foot horn-shaped microwave antenna in Holmdel, New Jersey. It was part of an early effort to beam microwave communications across the globe by bouncing them off a large reflective balloon satellite called Echo. To pick up the weak signals reflected back to earth required a large highly sensitive microwave antenna. The experiment worked, but within two years, another far more efficient approach replaced the Echo project. A satellite called Telstar became the first communications satellite to collect and amplify radio signals and beam them back to earth. Telstar was thus the forerunner of all our modern communications satellites now crowding the heavens. But with this more effective technology to amplify the signals, a large supersensitive microwave antenna was not required. Indeed, today any household can mount a small "dish" antenna on their roof to pick up the vast amount of microwave-based TV and internet signals being beamed from the great great grandchildren of Telstar.

So in 1962, Bell Labs offered two astronomers — Arno Penzias from Germany and Robert Wilson from the US, both interested in the new field

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of radio-astronomy — the opportunity to use the antenna to search for microwave signals coming from interstellar space. While tuning the sensitive antenna, however, they noticed an annoying problem: there was a faint but constant background "hiss" always present. When this apparent radio static didn't change irrespective of whether they aimed it skywards or at New York City they determined that the problem was likely in the apparatus itself. They ruled out radiation from nuclear testing and seasonal variations because it didn't change with time. They then became suspicious of the pigeons that tended to roost in the large antenna. With a shotgun and a serious cleaning of bird droppings, they eventually dispensed that possible source only to find that it made no difference. The noise was unaltered no matter what they did. They checked and rechecked their equipment assuming that the noise had to arise from some electronic source, which was not unlikely, considering the sensitivity they were hoping to achieve. But no. To their frustration they couldn't seem to eliminate this constant uniform static irrespective of what they did to clean up the system.

After checking and rechecking, they eventually became convinced that the noise couldn't be originating from the device itself or from any specific local sources. So, by this process of elimination they had to conclude that it must be coming from outside. But this posed another even more counterintuitive problem. If the uniform static that persisted irrespective of where they aimed the antenna came from outside, then it must be coming from everywhere at once! As Conan Doyle's fictional sleuth Sherlock Holmes reasoned: "Once you eliminate the impossible, whatever remains, no matter how improbable, must be the truth."

If it wasn't locally or internally generated noise then it had to be "cosmic noise." And since it *was* coming from everywhere at once, it couldn't be coming from individual stars or galaxies. The only remaining possibility, as odd as it seemed, was that this "hiss" of microwave radiation was emanating from empty space itself — i.e. from the cosmic background. Does that make any sense?

Luckily, they were well informed about current debates in astrophysics and were also in the right place at the right time. Down the road at Princeton University an astrophysicist named Robert Dicke had theorized that the grand cosmic explosion — the "Big Bang" — that appears to have created the whole of the known universe should have left its signature in the form of heat radiated throughout the universe. Heat is radiated through space as infrared radiation, below the spectrum of visible light, but typically at a much higher frequency than microwave radiation. Since the Big

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Bang occurred over 13 billion years ago, the heat radiation from that event striking earth now would have originated over 13 billion light years away. Following the work of the astronomer Edwin Hubble earlier in the 20th Century it was known that radiation (e.g. light) emanating from stars and galaxies further away from our own galaxy is red-shifted (i.e. its wavelength is elongated and so its frequency is lower). This is because, as Hubble reasoned, these sources are all moving away from us as the universe expands in all directions, and because this expansion is taking place everywhere at once more distant cosmic objects are moving away faster than nearer objects. The consequence is that more distant radiation sources are more red-shifted than nearer sources. The most distant sources will therefore be hugely red-shifted, and nothing is more distant in space and time than the Big Bang.

Based on these considerations Dicke had predicted that the residual heat emanating from the Big Bang would be dispersed everywhere and massively red-shifted. He was designing an experiment to test this theory when he learned of Penzias and Wilson's finding.

Despite the fact that Wilson doubted Big Bang cosmology, the ubiquitous microwave "noise" picked up by the Bell Labs antenna had all the characteristics predicted by Dicke's theory. As a measure of heat it was appropriately a uniform random bell-curve of frequencies. It was massively red-shifted to the extent that it was registering heat at just slightly above absolute zero ($-270\,\mathrm{K}$), and it was coming from everywhere at once with no discernible differences, as would be appropriate since the Big Bang involved the whole universe at that distant time. It was a meaningful signal, not noise, despite all appearances.

Years later, Penzias and Wilson received the Novel Prize for their discovery, the Bell Labs antenna was dedicated as a National Historical Landmark, and the COBIE satellite mapped this cosmic background radiation with sufficient precision to demonstrate that there are indeed subtle inhomogeneities in its distribution after all.

A phenomenon that had been present since the beginning of the universe had become information *about* something — the heat of this originative cosmic explosion — once the technological and theoretical interpretive apparatus became available. It took years of doubting, testing and theorizing to reach consensus on what it represented. In this process Penzias, Wilson, Dicke and innumerable other scientists progressively updated their interpretations of this "noise" many times as they struggled to understand it as information *about* something else.

The moral: One man's noise is another's information.

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What Is It All About?

So whether it is random or organized, caused by the droppings of pigeons or just the residual heat left over after some unimaginably huge and distant explosion, even a ubiquitous static hiss can be about something if one knows what to look for. But when did the heat of the Big Bang become information? Was it always "about" the origins of the universe? Or was it just radiation traversing vast distances and time until it was noticed and correctly interpreted by these astrophysicists? Was it information when Penzias and Wilson were convinced that it was a flaw in their detection device, or that it was due to pigeon poop? And what if modern physics turns out to be wrong about this cosmic background? Would that hiss cease to be information? Or would it then become information about something else? Indeed, does it need to be about something in order to be information? Surprisingly, there is considerable confusion still lingering over such questions.

Our current era is often rightly described as "the information age." In our everyday lives, information is a necessity and a commodity. It has become ubiquitous largely because of the invention, perfection and widespread use of computers and related devices that record, analyze, replicate, transmit, correlate and encrypt data entered by humans or collected by sensor mechanisms. This stored and transmitted information is used to produce correspondences, invoices, sounds, images and even precise patterns of robotic behavior on factory floors. We routinely measure the exact information capacity of data storage devices made of silicon, magnetic disks, or laser-sensitive plastics. Scientists have even recently mapped the molecular information contained in a human genome and studied its correspondence to protein structure and regulatory processes inside cells. And household users of electronic communications have learned that the information "bandwidth" of the cable and wireless networks that they depend on for connection to the outside world matters for the clarity and reliability of their video entertainment.

Although we use the concept of information almost daily without confusion, and use computers and cell phones and vast data networks to exchange, analyze and store information, I believe that we still don't really know what it is. Despite our seeming familiarity with these many uses and aspects of information, it is my contention that we currently are working with a set of assumptions about it that are only sufficient to handle the tracking of its most minimal physical and logical attributes.

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Surprisingly, even our most sophisticated theories about information are insufficient to explain one of the most basic and elementary defining feature of information. That is they fail to explain what makes it possible for information-bearing media to be *about* something else, and what constitutes its significance and functional value. These are serious shortcomings that impede progress in many scientific and social endeavors.

The concept of information is a central unifying concept in the sciences. It plays critical roles in physics, engineering, computation, biology, cognitive neuroscience and of course the psychological and social sciences. It is, however, defined somewhat differently in each, to the extent that the aspects of the concept that are most relevant to each may be almost entirely non-overlapping. Although it is often said that questions about meaning and value are issues for philosophical reflection, not scientific investigation, all our scientific endeavors depend on assessing the meaning and significance of our observations and experiments.

In fact, debates about the nature of physical processes at the very small subatomic (quantum) scale turn on how we understand the process of measurement and the information it provides. While the adequacy of our mathematical descriptions of quantum effects are beyond dispute, what is meant by these formalisms is open to wildly diverging speculations. In other words, experiments performed to discern what is taking place at this extreme smallest limit of size provide information that we find difficult to interpret. In fact, nobody is certain what this information is about. Thus, a recent chronicler of the history of quantum theory, Jim Baggott, cites two of the most important names in quantum physics to make this point. Thus: "Niels Bohr claimed that anybody who is not shocked by the theory has not understood it. The charismatic American physicist Richard Feynman went further: he claimed that nobody understands it."[1] Feynman concludes that trying to understand what information from quantum level events is about is to go down a "blind alley from which nobody has yet escaped."[2] But how much of this is due to the intrinsic weirdness of what this information is actually about and how much is due to not quite understanding how information can be about anything? Perhaps at this tiniest scale the very nature of this "aboutness" relation becomes problematic. Without a clear physical

[1] J. Baggott (2011). *The Quantum Story: A History in 40 Moments*. (Oxford University Press, New York) (from the book description).
[2] R. Feynman (1994). *The Character of Physical Law*. (Modern Library, New York).

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account of how anything can be about anything else, however, we can't be sure how to even start to answer such questions.

Beyond the Bits

The most precise technical definition of information came from the work of Claude Shannon, who while working at Bell Labs in the late 1940s found a way to precisely quantify many of the most important factors affecting the transmission and storage of information. His theory enabled engineers to determine how much information could be transmitted over a given communication channel (whether conveying a phone conversation or a string of numbers), how many "bits" of data can be stored in a given medium (whether book or magnetic disk), and how one might be able to compress and decompress a signal in order to maximize the capacity of a given transmission or storage system. This theoretical breakthrough played a critical role in the development of information technologies over the next half-century. It has transformed 21st Century civilization in ways that no one could have predicted at the time.

As we will see, however, this progress came at the cost of entirely ignoring the ultimate defining property of information: being about something. So, this technical use of the term was effectively devoid of any trace of its original and colloquial meaning. On the one hand, by stripping the concept of its links to reference, meaning and significance, it became applicable to the analysis of a vast range of physical phenomena, engineering problems and even quantum effects. This made it the ideal tool for use in communication technologies and computation. But, on the other hand, this reduction of the concept to only refer to its minimal physical and logical attributes, specifically obscured those features that are critical to understanding living and mental processes.

In many ways, we are currently in a position analogous to the early 19th Century physicists in the heyday of the industrial age, with its explosive development of steam-powered machines revolutionizing transportation and industry. Their understanding of the concept of *energy* was still laboring under the inadequate and ultimately fallacious conception of ethereal substances, such as *phlogiston* or *caloric*, that were presumably transferred from place to place to animate machines and organisms. So even though energy was a defining concept of the early 19th Century, the development of a relational rather than substantive concept of energy took many decades of

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scientific inquiry to clarify. The contemporary notion of information is likewise colloquially conceived of in substance-like terms, as for example when we describe the "purchase" and "storage" of information, or talk about it being "lost" or "wasted" in some process.

The concept of energy was ultimately explained by recognizing that it was a quite general sort of physical difference, and that it could be embodied in many forms (elevated weights, heat differences, incident light, chemical bonds, etc.). Energy turned out not to be a thing but a relationship. It could be transformed but never created or used up. Eventually, scientists came to recognize that the presumed ethereal substance that conveyed heat and motive force from one context to another was an abstraction from a process — the process of performing work — not anything material.

Importantly, this abandonment of a substance-based explanation did not result in the concept of energy becoming epiphenomenal or mysterious. The fallacious conceptions of an ineffable special substance were simply abandoned for a dynamical and relational account that enabled precise assessment. Yet, as familiar as its use has become today, the term "energy" wasn't even coined until 1807. Even today, look for an explicit (not indirect) definition for "energy" and you will be disappointed. As Van Ness comments: "Pick up a chemistry text, a physics text, or a thermodynamics text, and look in the index for "Energy, definition of," and you find no such entry."[3] This does not mean that the concept is in any way imprecise or ill-defined for the physicist or engineer. Indeed, just the opposite is the case. Abandoning the colloquial meaning of energy that treats it as a substance that can be extracted, stored, bought and sold, and used up, has revolutionized science and technology. It was necessary to get over this more intuitive conception of energy to finally understand heat and chemical reactions, and eventually to make sense of such weird phenomena as super conductivity and nuclear fusion.

To understand the nature of information a similar reframing is necessary. But the figure/background shift required is even more fundamental and more counterintuitive than that for energy. This is because what matters is not an account of its physical properties or even its formal properties.

[3]From H. C. Van Ness (1969). *Understanding Thermodynamics.* (Dover Publications, New York).

What matters in the case of information, and produces its distinctive physical consequences, is a relationship to something not physically there: *what it is about.*

Ignoring this, the concept of information reduces to a physical attribute not fundamentally different from the arrangement of pebbles on a beach or stars in a constellation. These configurations can of course be precisely measured and analyzed. Studying these patterns might even provide evidence about how they came to be organized that way. But aside from being treated as potentially useful to a mind eager to discern these causal relationships, they are just physical arrangements. There is nothing that makes them intrinsically meaningful.

And the way that information causes things to happen is also unlike the way that other material and energetic processes produce effects. Consider a few typical examples.

Information about an impending storm might cause one to close windows and shutters, information about a stock market crash might cause millions of people to simultaneously withdraw money from their bank accounts, information about some potential danger to the nation might induce idealistic men and women to face certain death in battle, and (if we are lucky) information demonstrating how the continued use of fossil fuels will impact the lives of future generations might affect our patterns of energy use worldwide.

These not-quite-present, non-intrinsic relationships can thus play the central role in determining the initiation and form of physical work. It is in this way that something not immediately present can make a difference in the world. In contrast, the material features that mediate these effects (a darkening sky, a printed announcement, a stirring speech, or a scientific argument, respectively) do not in themselves have these sorts of causal consequences.

To develop a precise practical science of information, it was necessary to give up thinking about information as some artifact or commodity as well as some intangible meaningful stuff. A radical paradigm shift in the scientific understanding of information made this possible. Like the scientific reconception of energy in the mid 19th Century, a revolutionary reconception of information took place in the middle of the 20th Century. Like its 19th Century predecessor, it gave rise to a highly successful technical concept that transformed the world. This redefinition of information made it possible to understand how any physical phenomenon, whether signals traveling within wires and electromagnetic waves, or patterns of ink soaked

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into paper and charges embodied in semiconductor devices, could be quantitatively analyzed.

Information understood in this technical sense, however, had nothing to do with being about anything. This technical redefinition of the term 'information' referred to an intrinsic physical property of a given physical medium and became roughly synonymous with difference, order, pattern, or the opposite of physical entropy, depending on who was using it. Because "content" in the sense of meaning and significance were not intrinsically measurable attributes they were assumed to be non-physical, and therefore merely subjective glosses or causally irrelevant. Indeed, leaving these non-intrinsic non-physical attributes out of the technical definition of information proved to be essential for the explosive development of information technology that now underlies the vast web of human telecommunication and the computational tools that have transformed the society as well as the sciences.

But this redefinition of the concept of information, which is now the basis of nearly every technical use of the term, implicitly treats human thought and the meaning-making process itself as illusory. It is as though our mental experience is a mirage on the horizon of knowledge that will disappear as science draws us closer to the details of brain function. Indeed, many have argued that the traditional sense of "information" is an anachronism destined for the refuse heap of ideas, along with notions of phlogiston and the ether wind. Are these reports of the demise of the traditional concept of information exaggerated?

To step beyond this impasse, we must try to make sense of the representational function that distinguishes information as non-technically understood from other mere physical relationships. This requires finding a precise way of showing how what can be called the reference being communicated can be causally efficacious, despite not being physically embodied in the medium that "conveys" it. And yet at the same time this analysis must also maintain compatibility with the technical conception of information. To ignore either paradigm would be a mistake. But developing a bridge between these ways of conceiving information is not a trivial challenge. It requires overcoming some deep conceptual incompatibilities.

Inexistence

Tacit metaphysical commitments have significantly hindered attempts at a synthesis. This enterprise has been a casualty of a philosophical impasse

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that has a long and contentious history; the problem of specifying the ontological status of the contents of thought. These seemingly incompatible conceptions of information reflect the perpetuation of an intellectual schism that dates to the dawn of the enlightenment and which was eloquently articulated by René Descartes. In philosophy his argument became enshrined in what is known as the mind/body problem. But it is not merely of philosophical relevance. I would argue that it is implicit in the way that modern science still divides the world into the physical and semiotic sciences, with biology and psychology each internally divided into corresponding methodological subfields. It still motivates debates between those who believe that it will be possible to reduce mental phenomena to material relations and those who deny this possibility. This is paralleled by the debate about the definition of "information" between those who think that we can dispense with the concept of representation in favor of just analyzing physical correlations and those who argue that "aboutness" is something more than just physical correlation.

The enigmatic status of this relationship was eloquently, if enigmatically, framed in 1874 by the German philosopher Brentano's use of the curious word "inexistence" when describing mental phenomena. He says:

> Every mental phenomenon is characterized by what the Scholastics of the Middle Ages called the intentional (or mental) inexistence of an object, and what we might call, though not wholly unambiguously, reference to a content, direction toward an object (which is not to be understood here as meaning a thing), or immanent objectivity.
>
> This intentional inexistence is characteristic exclusively of mental phenomena. No physical phenomenon exhibits anything like it. We can, therefore, define mental phenomena by saying that they are those phenomena which contain an object intentionally within themselves.[4]

For a century and a half since Brentano's words were first printed, we have proceeded as though the existent and inexistent aspects of information needn't be related; as though the physical and the meaningful realms were incompatible conceptions of the world. Since then, whole realms of intellectual analysis and technical applications have flourished by explicitly bracketing out one or the other side of this dilemma and pretending that it can be ignored. But in each case something critical is sacrificed.

[4]F. Brentano (1874). *Psychology From an Empirical Standpoint.* (Routledge & Kegan Paul, London).

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The exclusively physical conception takes the referential use for granted, but then proceeds to bracket it from consideration, treating it as a sort of illusion, whereas, the exclusively intentional conception disregards the physicality of information and as a result renders the efficacy of this content thoroughly mysterious. Of course, there is the everyday compromise of sometimes working in one realm and at other times working in the other. Thus, for example, biologists feel equally at home describing the molecular basis of genetic inheritance as mere chemistry and also as information about bodies and their relationship to the environment. But the result is that even in the realm of scientific research we are trapped in Descartes' world divided against itself. Throughout popular culture, where the split is simply taken for granted and this dilemma goes unnoticed, its corrosive influence on social organization, interpersonal relations, ethics and spiritual traditions grows with every advance in communicative technology.

How did this dilemma arise? How could we ever have imagined that information is only physical stuff or that meanings only exist in some non-physical realm? Ideas and meanings clearly aren't ineffectual illusions and the sounds and pixels and electronic bits of charge that convey them aren't dispensable. It is obviously the content that matters, but matter gives this content its efficacy. But how? This is the challenge that a unified theory of information must ultimately address, and we shouldn't assume that just because we are now in possession of many unprecedented new tools for sharing, storing, manipulating and analyzing information that these questions have been answered.

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