A Mathematical Theory of Communication: An Exploration of the Life and Times of Claude Shannon | Jimmy Soni

June 5, 2018

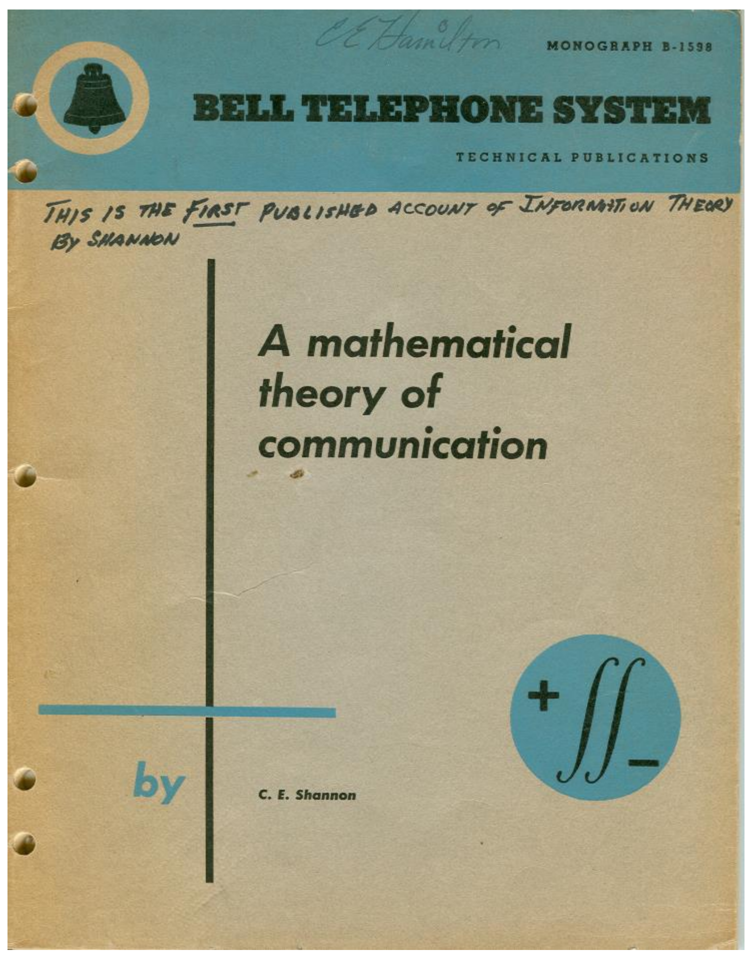
The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point. Frequently the messages have *meaning*. – Claude Shannon (1948)

INTRODUCTION

What's up everybody? Welcome to this week's episode of Hidden Forces with me, Demetri Kofinas. Today, I speak with Jimmy Soni, a New York based author, editor, and speechwriter. He's the co-author of *Rome's Last Citizen,* a biography of the ancient Roman Senator Cato, and *A Mind at Play*, a biography of the late mathematician, engineer, and father of information theory, Claude Shannon. The latter won the Neumann Prize for the top book in the history of mathematics for 2017 and was named one of the best books of the year by Nature and Bloomberg. Jimmy has also served as an editor at the Huffington Post, the New York Observer, and the Washington Examiner. Jimmy, welcome to Hidden Forces…

WHY DO I CARE?

As an amateur historian of the information sciences, my interest in the life and times of Claude Shannon comes naturally. Truth be told, I'm less interested in Shannon's life than I am in discussing the ways in which his ideas and those of his colleagues have come to inform the world we live in today. The proliferation of information technologies – first, with the advent of the telegraph in the mid-19th century and then with the proliferation of telephone, radio, and television in the early and mid-20th – were as fundamental to the reorganization of American life as were the railroad and the steam engine. Without elevators, people could never have populated cities full of skyscrapers, but without the telephone, business men and women would have been trapped in towers of informational isolation. What were all of these inventions – the telephone, telegraph, radio, television, and later, the computer – trafficking in? By 1948, the same year in which Shannon published A Mathematical Theory of Communication [1], more than 125 million conversations passed daily through the Bell System's 138 million miles of cable and 31 million telephone sets. Yet, before Shannon's "bomb" as one of his colleagues referred to it, no one knew, let alone had a name for what these lines were carrying. It is worth mentioning that this was the same year in which Bell Telephone Laboratories announced the invention of the electronic semiconductor, later to be known as the "transistor." The later has been etched into public memory, popularized by Moore's Law. The former remains unknown to almost everyone. One could argue that Shannon's paper was the more significant of the two.



WHY SHANNON?

1. **The Book** — How did the idea for this book come together? What was it that compelled you to write it? How much was this the editor/entrepreneur in you who recognized

an opportunity to fill a gap in the popular record and how much was born from a fascination about the work of Shannon and his contributions to the forming the world we live in today?

2. **The Process** — How did you and your co-author, Rob Goodman, go about researching and writing the book? How did you go about pitching it and how long did it take from then until you sent the final drafts to the publisher? How much low-hanging fruit on Shannon was available, and how much extra work did you need to put in in order to secure meaningful information about him? What were some of the biggest breakthroughs and/or resources?

THE EARLY YEARS

Frontier Culture ● Playful Nature

3. **Born a Tinkerer** — You make the point early on in the book that "Shannon was a born tinkerer." Why do you feel that this was important to state outright? How do you think this distinguished him from the great scientists, technologists, and inventors that we celebrate today? How common do you think this approach to life and work is among engineers and mathematicians? Is this where you got the name "A Mind at Play"? ***Something he returns to towards the end of his life.
4. **Family Life** — How important was Shannon's family and upbringing to informing the man he would become? Was he always recognized as a genius? How important has the fact that he was born and raised in the Midwest, where inventors such as John Froelich (gas powered tractor), Thomas Edison, and Henry Ford came? Was the frontier culture of this part of the country a contributor to a kind of playful "take a whack at it" approach to technology that Shannon and his family seemed to exhibit? (east coast had already been industrialized)

THE FORMATIVE YEARS

Temperament

5. **A Practical Man** — How would you describe Claude Shannon's temperament and personality? Despite his playful nature, Shannon was practical; he was interested in solving practical problems. Does this express a sort of contradiction, or was his interest in practical problems a derivative of his playful nature (i.e. the childish curiosity of taking things apart and putting them back together again)?

Math & Elec. Engineering ● Boolean Algebra

6. **Math & Engineering** — During his time at the University of Michigan (1932-1936), Shannon majored in both electrical engineering and mathematics. Today, these two disciplines are often seen as complementary (i.e. software engineering), but at the time, how unusual was such a pairing? Do we know anything about why he chose mathematics and electrical engineering to focus on? What did electrical engineering prior to the onset of WWII primarily consist of? What types of fields did someone who studied electrical engineering tend to fall into? How important was his introduction to the work of George Boole for his later work in information theory? Was most, if not all work in mathematics and logic focused on putting philosophy on a sound footing (abstract objectives) and not on the practical problems of information content and communication (practical problems)?
7. **Analogue to Digital** — Shannon began his graduate studies in electrical engineering at MIT (1936-1940) where he worked under the tutelage of Vannevar Bush. How important was Shannon's relationship to Bush and his work with the differntial analyzer in helping shape his thinking about information? You write in the book that "in the midst of his work, he came to understand that he knew another way of

automating thought, one that would ultimately prove far more powerful than the analog machine." You then cite a quote by a certain logician at the turn of the 20th century regarding Shannon's insight about building a general purpose machine (Bush's differntial anayzer was a special purpose machine): "As a material machine is an instrument for economising the exertion of force, so a symbolic calculus is an instrument for economising the exertion of intelligence." "Logic, just like a machine," you write "was a tool for democratizing force: built with enough precision and skill, it could multiply the power of the gifted and the average alike." It seems that here, Shannon took his lessons in Boolean algebra/logic and applied them to what he was learning in analogue computing. From your research, what have you been able to understand about how Shannon experienced and underwent this process of merging these two fields in the service of creating something new? Shannon began his working using Boolean algebra to write out the equations that would stand in for the logic board of electric switches and relays (i.e. digital logic gates). This is the subject on which Shannon wrote his masters thesis: *A Symbolic Analysis of Relay and Switching Circuits* [2]. Shannon proved in the paper that his switching circuits could be used to simplify the arrangement of the electromechanical relays that were used then in telephone call routing switches. Next, he expanded this concept, proving that these circuits could solve all problems that Boolean algebra could solve. This seems to have been the key – combing bolean logic with electrical engineering. How much of Shannon's later groundbreaking paper in 1948 was directly informed by his 1938 thesis?

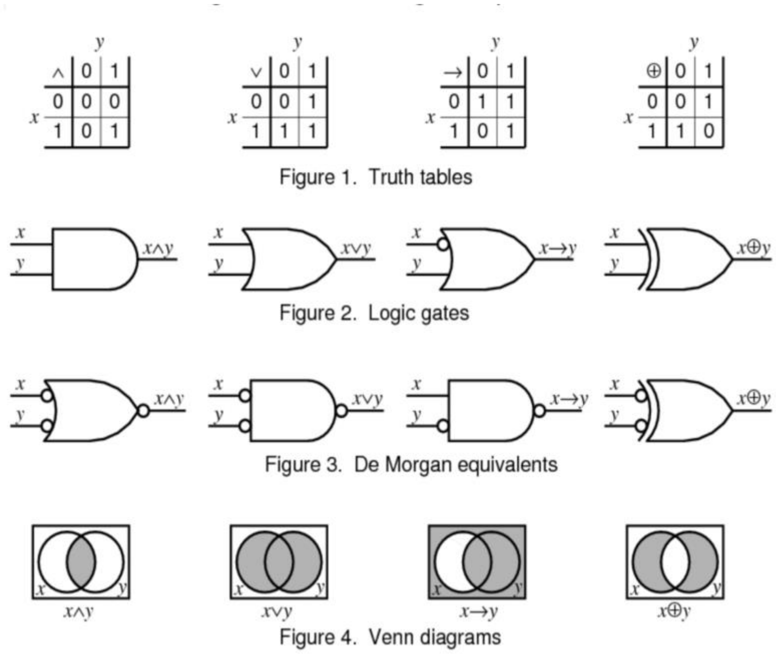


Figure 1. Truth tables
Figure 2. Logic gates
Figure 3. De Morgan equivalents
Figure 4. Venn diagrams

THE WAR YEARS

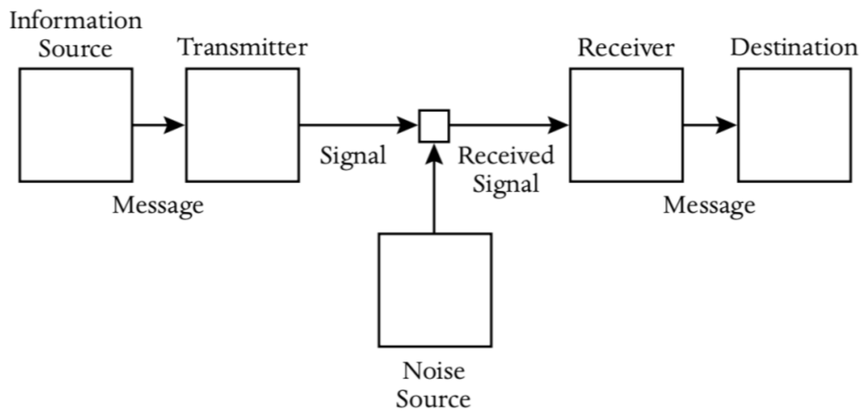
8. **Cold Spring Harbor** — Shannon received his Ph.D. degree from MIT in 1940, around which time Vannevar Bush suggested to him that he should work on his dissertation at the Cold Spring Harbor Laboratory, in order to develop a mathematical formulation for Mendelian genetics. This research resulted in Shannon's Ph.D thesis, *An Algebra for Theoretical Genetics* [3]. What should we take from Shannon's time at Cold Spring Harbor? What was the reason for his stay there and what did his research suggest about his interdisciplinary nature? How important was his exposure to disperate ideas and disciplines in helping him formlate his most significant breakthroughs in information theory?
9. **Princeton** — In 1940, Shannon became a National Research Fellow at the Institute for Advanced Study in Princeton, New Jersey. In Princeton, Shannon had the opportunity to discuss his ideas with influential scientists and mathematicians such as Hermann Weyl and John von Neumann, and he also had occasional encounters with Albert Einstein and Kurt Gödel. What was the signficance of this period? How important was it for Shannon's intellectual development that he was able to continue working *freely* across disciplines? How might this ability contributed to his later development of a mathematical theory of communication? This was also a personally trying period for him. He got divorced after only a year of marriage, and along with the normal uncertainties present in the life of a young man starting his career, Claude had to deal with the prospect that he might be drafted to fight in WWII. How long did this period of melancholy last for Shannon and what impact did it have on him during and after?
10. **Bell Labs** — After the US enters WWII, Shannon joins Bell Labs to work on fire-control systems and

Alan Turing

cryptography. For two months in early 1943, Shannon would meet regularly with Alan Turing for teatime in the Bell Labs cafeteria. Turing was in the US in order to "kick the tires" on the intellectual capabilities and qualifications of the American cryptographers charged with protecting communications across the Atlantic. What do we know about the types of conversations that these two were having? Was this in some sense, a microcosm of what was going on across academia and enterprise during the war? Departments and organizations that would have otherwise been at odds now found themselves in one large, collaborative effort. What was the lasting impact of such collaborations? What pairings or introductions did this period create that served the informational sciences in the years and decades to come?

Private Working

11. **The Bomb** — You title the chapter that introduces Shannon's breakthrough on information theory as "The Bomb." Why this title? Was Shannon unusually solitary in his work style, and is this evidenced by the way in which he managed to keep his work secret? Was this on purpose or just happenstance?



The Fulcrum: Statistical Structure of Information

12. **What is Information?** — In his magisterial work "The Information," James Gleick refers to Claude Shannon's publication in The Bell System Technical Journal in 1948 as "a fulcrum around which the world began to turn." What do you think this fulcrum was in Shannon's paper? I've heard Rob Goodman attribute to Shannon the statement that "information resolves our uncertainty." This is another way of speaking about probabilities. Shannon recognized that messages of any sort – a page of text from Ulysses, a photograph, a pile of garbage, etc. – carry a certain amount of information. The question was, *how much?* How much information does each message carry? In this sense, messages that are information poor offer no new information: they have lots of redundancy. Messages rich in information are full of surprise: they offer little in the way of compression. Predictability. Simplicity. These are characteristics of low information density. Randomness. Complexity. These are characteristics of information dense messages. Was it this insight of couching information theory within statistics that was the real breakthrough, and not the logic of Boolean algebra, per se, which simply provided the framework for computation? Probability theory provided the metaphysics of information, as it were…

Information Entropy

13. **It from Bit** — In addition to his insights around statistics, probability, and logic, Shannon also mentioned entropy 151 times in his paper, perhaps most revealingly in his subtitle "The Entropy of an Information Source." It's hard to overstate the importance of connecting information to entropy. Even today, people have a hard time imagining information as a physical thing. After all, the only way in which we experience information is as an idea, and ideas are not physical are they? How novel was this idea at the time? Where did Shannon get this idea to connect physical properties with metaphysical notions? How far did he take his ideas of entropy? How impactful was his work in providing bridges across which quantum theorists and mathematicians would later crisscross?

Bits	Choices
1	2
2	4
4	16
8	256
16	65,536

14. **Computational Universe** — There were some other prominent mathematicians and scientists at the time (or who came before) whose work shared many touchpoints with Shannon. Shannon's information theory was deterministic. Given sufficient information, one can know everything that there is to know.

If you are given the letter Q, you know with almost absolute certainty what letter will follow. Deterministic systems are theoretically computable, are they not? But computable by who? By us? "Chance is only the measure of our ignorance," Henri Poincaré famously said. "Fortuitous phenomena are by definition those whose laws we do not know." This notion of computability came up for Turing as well, who proved that some numbers are not computable. An incomputable problem is synonymous with an undecidable proposition. The uncertainty principle in quantum physics and the laws of Brownian motion also seem to hold sway here. Is there a relationship between Heisenberg's uncertainty principle, Gödel's incompleteness theorem, incomputability, and randomness? What is the relationship between computability and compression? Between an algorithm and a cipher? (patterns and order reflect computability…the shorter the algorithm, the more computable the number…) Is the extent of something's computability an indication of how much information it holds? The more computable, the less information? Complexity vs. Simplicity. What does it mean for something to be random? Is it possible to know if a number is truly random? Is there some relationship between the intelligence of a computer or a system and its computational capacities? Are more intelligent beings able to discover more redundancies in a message than others? Is complexity science simply the best framework that we can devise for understand a deterministic universe whose "laws we do not know" as Poincaré said?

15. **Back to MIT —** In 1956 Shannon joined the MIT faculty to work in the Research Laboratory of Electronics (RLE). He continued to serve on the MIT faculty until 1978. What did his life at MIT look like? What did he concern himself with in these decades?
16. **The Later Years —** You write at some length about how Shannon never let go of his urge to "tinker." Over the course of his life, he is credited with having invented many devices, including a Roman numeral computer called THROBAC, juggling machines, a flame-throwing trumpet, a digital computer trainer that was sold to the public (through Scientific Development Corp starting in 1961), and the first wearable computer along with Edward Thorp that was used improve the odds at winning in roulette. How much of this tinkering went on during his years at MIT, and how much time did he spend inventing odd-ball things after his retirement? Were there any particularly notable devices he created or thoughts he put to paper that stand out for you?