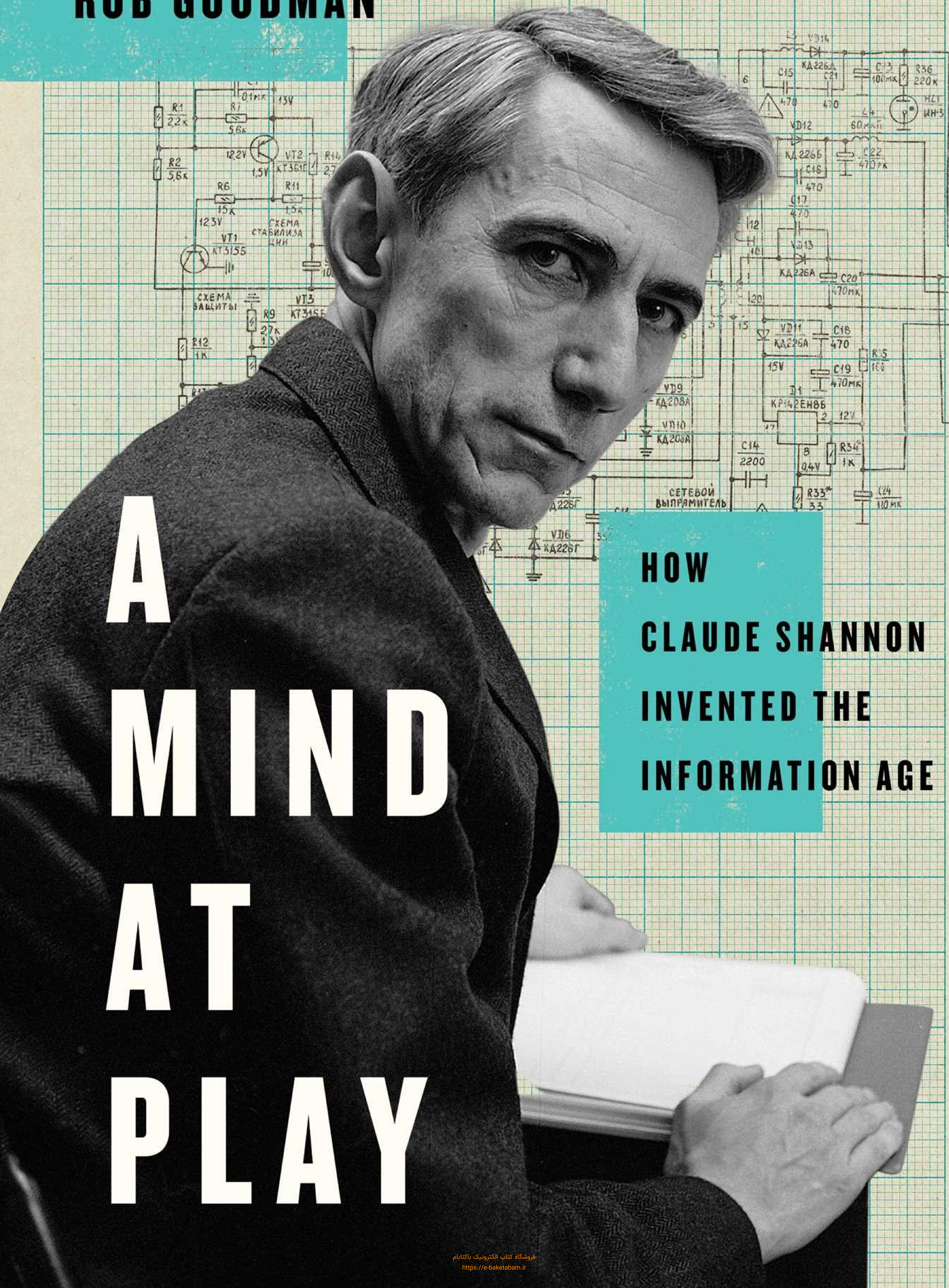
JIMMY SONI & ROB GOODMAN



A MIND AT PLAY

HOW CLAUDE SHANNON INVENTED THE INFORMATION AGE

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A MIND AT PLAY

How Claude Shannon Invented the Information Age

JIMMY SONI

AND

ROB GOODMAN

SIMON & SCHUSTER

New York London Toronto Sydney New Delhi

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For Abigail, born 6/22/15

—R.G.

For Meagan

—J.S.

Geniuses are the luckiest of mortals because what they must do is the same as what they most want to do and, even if their genius is unrecognized in their lifetime, the essential earthly reward is always theirs, the certainty that their work is good and will stand the test of time. One suspects that the geniuses will be least in the Kingdom of Heaven—if, indeed, they ever make it; they have had their reward.

—W. H. AUDEN

INTRODUCTION

The thin, white-haired man had spent hours wandering in and out of meetings at the International Information Theory Symposium in Brighton, England, before the rumors of his identity began to proliferate. At first the autograph seekers came in a trickle, and then they clogged hallways in long lines. At the evening banquet, the symposium's chairman took the microphone to announce that "one of the greatest scientific minds of our time" was in attendance and would share a few words—but once he arrived onstage, the thin, white-haired man could not make himself heard over the peals of applause.

And then finally, when the noise had died down: "This is—ridiculous!" Lacking more to say, he removed three balls from his pocket and began to juggle.

After it was over, someone asked the chairman to put into perspective what had just happened. "It was," he said, "as if Newton had showed up at a physics conference.

It was 1985, and the juggler's work was long over, and just beginning. It had been nearly four decades since Claude Elwood Shannon published "the Magna Carta of the Information Age"—

invented, in a single stroke, the idea of information. And yet the world his idea had made possible was only just coming into being. Now we live immersed in that world, and every email we have ever sent, every DVD and sound file we have ever played, and every Web page we have ever loaded bears a debt to Claude Shannon.

It was a debt he was never especially keen to collect. He was a man immune to scientific fashion and insulated from opinion of all kinds, on all subjects, even himself, especially himself; a man of closed doors and long silences, who thought his best thoughts in spartan bachelor apartments and empty office buildings. A colleague called Shannon's information theory "a bomb." It was stunning in its scope—he had conceived of a new science nearly from scratch—and stunning in its surprise—he had gone years barely speaking a word of it to anyone.

Of course, information existed before Shannon, just as objects had inertia before Newton. But before Shannon, there was precious little sense of information as an idea, a measurable quantity, an object fitted out for hard science. Before Shannon, information was a telegram, a photograph, a paragraph, a song. After Shannon, information was entirely abstracted into bits. The sender no longer mattered, the intent no longer mattered, the medium no longer mattered, not even the meaning mattered: a phone conversation, a snatch of Morse telegraphy, a page from a detective story were all brought under a common code. Just as geometers subjected a circle in the sand and the disc of the sun to the same laws, and as physicists subjected the sway of a pendulum and the orbits of the planets to the same laws, Claude Shannon made our world possible by getting at the essence of information.

It is a puzzle of his life that someone so skilled at abstracting his way past the tangible world was also so gifted at manipulating it. Shannon was a born tinkerer: a telegraph line rigged from a barbed-wire fence, a makeshift barn elevator, and a private backyard trolley tell the story of his small-town Michigan childhood. And it was as an especially advanced sort of tinkerer that he caught the eye of Vannevar Bush—soon to become the most powerful scientist in America and Shannon's most influential mentor—who brought him to MIT and charged him with the upkeep of the differential analyzer, an analog computer the size of a room, "a fearsome thing of shafts, gears, strings, and wheels rolling on disks" that happened to be the most advanced thinking machine of its day.

Shannon's study of the electrical switches directing the guts of that mechanical behemoth led him to an insight at the foundation of our digital age: that switches could do far more than control the flow of electricity through circuits—that they could be used to evaluate any logical statement we could think of, could even appear to "decide." A series of binary choices—on/off, true/false, 1/0—could, in principle, perform a passable imitation of a brain. That leap, as Walter Isaacson put it, "became the basic concept underlying all digital computers." It was Shannon's first great feat of abstraction. He was only twenty-one.

A career that launched with "possibly the most important, and also the most famous, master's thesis of the century" brought him into contact and collaboration with thinkers like Bush, Alan Turing, and

John von Neumann: all, like Shannon, founders of our era. It brought him into often-reluctant cooperation with the American defense establishment and into arcane work on cryptography, computer-controlled gunnery, and the encrypted transatlantic phone line that connected Roosevelt and Churchill in the midst of world war. And it brought him to Bell Labs, an industrial R&D operation that considered itself less an arm of the phone company than a home for "the operation of genius." "People did very well at Bell Labs," said one of Shannon's colleagues, "when they did what others thought was impossible." Shannon's choice of the impossible was, he wrote, "an analysis of some of the fundamental properties of general systems for the transmission of intelligence, including telephony, radio, television, telegraphy, etc."—systems that, from a mathematical perspective, appeared to have nothing essential in common until Shannon proved that they had everything essential in common. It would be his second, and greatest, feat of abstraction.

Before the publication of his "Mathematical Theory of Communication," scientists could track the movement of electrons in a wire, but the possibility that the very idea they stood for could be measured and manipulated *just as objectively* would have to wait until it was proved by Shannon. It was summed up in his recognition that all information, no matter the source, the sender, the recipient, or the meaning, could be efficiently represented by a sequence of *bits:* information's fundamental unit.

Before the "Mathematical Theory of Communication," a century of common sense and engineering trial and error said that noise—the physical world's tax on our messages—had to be lived with. And yet Shannon proved that noise could be defeated, that information sent from Point A could be received with perfection at Point B, not just often, but essentially always. He gave engineers the conceptual tools to digitize information and send it flawlessly (or, to be precise, with an arbitrarily small amount of error), a result considered hopelessly utopian up until the moment Shannon proved it was not. Another engineer marveled, "How he got that insight, how he even came to believe such a thing, I don't know."

That insight is embedded in the circuits of our phones, our computers, our satellite TVs, our space probes still tethered to the earth with thin cords of 0's and 1's. In 1990, the Voyager 1 probe turned its camera back on Earth from the edge of the solar system, snapped a picture of our planetary home reduced in size to less than a single pixel—to what Carl Sagan called "a mote of dust suspended in a sunbeam"—and transmitted that picture across four billion miles of void. Claude Shannon did not write the code that protected that image from error and distortion, but, some four decades earlier, he had proved that such a code must exist. And so it did. It is part of his legacy; and so is the endless flow of digital information on which the Internet depends, and so is the information omnivory by which we define ourselves as modern.

By his early thirties, he was one of the brightest stars of American science, with the media attention and prestigious awards to prove it. Yet, at the height of his brief fame, when his information theory had become the buzz-phrase to explain everything from geology to politics to music, Shannon published a four-paragraph article kindly urging the rest of the world to vacate his "bandwagon." Impatient with all but the most gifted, he still knew very little of ambition, or ego, or avarice, or any of the other unsightly drivers of accomplishment. His best ideas waited years for publication, and his interest drifted across problems on a private channel of its own. Having completed his pathbreaking work by the age of thirty-two, he might have spent his remaining decades as a scientific celebrity, a public face of innovation: another Bertrand Russell, or Albert Einstein, or Richard Feynman, or Steve Jobs. Instead, he spent them tinkering.

An electronic, maze-solving mouse named Theseus. An Erector Set turtle that walked his house. The first plan for a chess-playing computer, a distant ancestor of IBM's Deep Blue. The first-ever wearable computer. A calculator that operated in Roman numerals, code-named THROBAC ("Thrifty Roman-Numeral Backward-Looking Computer"). A fleet of customized unicycles. Years devoted to the scientific study of juggling.

And, of course, the Ultimate Machine: a box and a switch, which, when flipped on, produced a whirring of gears and a mechanical hand that emerged from the box, flipped the switch off, and disappeared again. Claude Shannon was self-effacing in much the same way. Rarely has a thinker who devoted his life to the study of communication been so uncommunicative. Seen in profile, he almost vanished: a gaunt stick of a man, and a man almost entirely written out of a history defined by self-promoters.

His was a life spent in the pursuit of curious, serious play; he was that rare scientific genius who was just as content rigging up a juggling robot or a flamethrowing trumpet as he was pioneering digital circuits. He worked with levity and played with gravity; he never acknowledged a distinction between the two. His genius lay above all in the quality of the puzzles he set for himself. And the marks of his playful mind—the mind that wondered how a box of electric switches could mimic a brain, and the mind that asked why no one ever decides to say "XFOML RXKHRJFFJUJ"—are imprinted on all of his deepest insights. Maybe it is too much to presume that the character of an age bears some stamp of the character of its founders; but it would be pleasant to think that so much of what is essential to ours was conceived in the spirit of play.

1

1

Gaylord

Here are 110 diamonds, “not one of them small,” 18 rubies, 310 emeralds, 21 sapphires, one opal, 200 solid gold rings, 30 solid gold chains, 83 gold crucifixes, five gold censers, 197 gold watches, and one monumental gold punch bowl, and they are exactly where the code said they would be. They are a pirate’s hoard, buried five feet down in the South Carolina soil, in the shadow of a gnarled tulip poplar tree. But the tale doesn’t end with the treasure; it ends with the code.

William Legrand found it on a parchment washed up from a shipwreck. For months, he sat up learning cryptanalysis by firelight to crack it. And now that the hoard is his, he’s content to leave the diamonds counted in a corner while he explains himself at great length to the young man he enlisted to dig it up.

It is simpler than it looks:

53‡‡†305))6*;4826)4‡.)4‡);806*;48†8’60))85;]8*:‡*8†83
(88)5*†;46(;88*96*?;8)*‡(;485);5*†2:*‡(;4956*2(5*-4)8’8*;

4069285);)6†8)4‡‡;1(‡9;48081;8:8‡1;48†85;4)485†528806*81
(‡9;48;(88;4(‡?34;48)4‡;161;:188;‡?;

Count how often the symbols appear and then compare them with the most common letters in the English language. Assume that the most frequent symbol is the most frequent letter: 8 means "E." The most common word in English is "the," so look for a repeated three-letter sequence ending in 8. The sequence ;48 recurs seven times: if it encodes "the," we know that ; means "T" and 4 means "H." Follow those three letters to new letters. ;(88 can only be "tree," and so (means "R." Each symbol solved solves new symbols, and soon the directions to the treasure resolve out of the noise.

Edgar Allan Poe wrote sixty-five stories. This one, "The Gold-Bug," is the only one to end with a lecture on cryptanalysis. It is Claude Shannon's favorite.

Here is where Gaylord, Michigan, ends. The roads turn dirt and give out in potato fields. Main Street is only blocks behind. Ahead are the fields and feedlots, the Michigan apple orchards, the woods of maple, beech, birch, the lumber factory digesting the woods into planks and blocks. Barbed wire runs along the roads and between the pastures, and Claude walks the fences—one half-mile stretch of fence especially.

Claude's stretch is electric. He charged it himself: he hooked up dry-cell batteries at each end, and spliced spare wire into any gaps to run the current unbroken. Insulation was anything at hand: leather straps, glass bottlenecks, corncobs, inner-tube pieces. Keypads at each end—one at his house on North Center Street, the other at his friend's house half a mile away—made it a private barbed-wire telegraph. Even insulated, it is apt to be silenced for months in the ice and snow that accumulate on it, at the knuckle of Michigan's middle finger. But when the fence thaws and Claude patches the wire, and the current runs again from house to house, he can speak again at lightspeed and, best of all, in code.

In the 1920s, when Claude was a boy, some three million farmers talked through networks like these, wherever the phone company found it unprofitable to build. It was America's folk grid. Better networks than Claude's carried voices along the fences, and kitchens and general stores doubled as switchboards. But the most interesting stretch of fence in Gaylord was the one that carried Claude Shannon's information.

Where does a boy like that come from?

Reporting on the wedding of Claude Shannon's parents, the *Otsego County Times* declared itself bamboozled: "Shannon-Wolf Nuptials: Wedding Took Place at Lansing on Wednesday—Date Had Been Kept a Profound Secret." By the paper's account, Claude Shannon Sr. had managed to get married without anyone in town being the wiser.

That Tuesday, August 24, 1909, toward the end of Shannon's third summer in town, a sign appeared on the door of his furniture store: "IF ANYTHING IS WANTED CALL J. LEE MORFORD." That night, Shannon Sr. took the midnight train to Lansing, to the home of the parents of his bride-to-be, Mabel Wolf. “The unconcern which Mr. Shannon displayed as he waited for the train which was nearly an hour late showed that he was perfectly satisfied that no one had gotten wind of his leaving town,” reported the paper. The following day, he married Mabel in a quiet ceremony at six o’clock. The bride wore a “wedding gown of white satin with a yoke of lace, and a net veil made with a coronet edged with seed pearls.” It seems that the groom concealed the information about the wedding only to keep the party down to a manageable size.

If the paper feigned shock at Shannon’s surprise trip to Lansing, the rest of the piece was all small-town sincerity and good wishes. “Mr. Shannon, the groom, has since his residence in this community, made many warm friendships in a business and social way,” the paper noted, “and Miss Wolf, the bride, during her many years teaching in the high school here, endeared herself to the people of this community. Mr. and Mrs. Shannon, accept the congratulations of the *Times* and your many friends in this community.”

That a run-of-the-mill wedding announcement constituted front-page news says much about the smallness of Gaylord, Michigan. But then, the Shannons were the kinds of people whose wedding date ought to have been common knowledge. Claude Sr. and Mabel were bright threads in Gaylord’s fabric. They were neighborly and active in the Methodist church. In downtown Gaylord, two well-known buildings were the work of Claude Sr.: the post office and the furniture showroom with the Masonic lodge tucked upstairs.

Born in 1862 in Oxford, New Jersey, Claude Elwood Shannon Sr. was a traveling salesman who arrived in town just after the turn of the century and bet on its fortunes. He put down his stake—bought out the business dealing in furniture and funerals—and lived to see it pay. "Something which should be found in every home. Nothing more sanitary. The new styles are more attractive. Come in and look over our New Line of furniture," read a typical advertisement in the paper from "C. E. Shannon, The Furniture Man." In Claude Jr.'s childhood, Gaylord was a town of 3,000, and Claude Sr. was a town father: school board, poor board, county fair board, undertaker, Arch Mason, Worthy Patron of the Eastern Star, the kind of Republican for whom the word *staunch* was invented.

His most significant stretch of employment, and the one that earned him the title of "Judge Shannon," was the eleven years he spent as Otsego County probate judge. He settled estates and minor financial disputes, served as notary public, and played the part of local politician and worthy. His service, though modest and conducted in his spare time, was widely appreciated. In 1931, a two-column profile celebrating the twenty-fifth anniversary of his "advent" described Mr. Shannon as "one of our most public-spirited citizens. . . . The years have told the story of a successful business career, due largely to his excellent executive ability and persistency of purpose." Claude Jr., later on, found less to say about him: clever, distant. "He would sometimes help me with my Erector set," he said, "but he really didn't give me much scientific guidance." Claude Sr. was already sixtynine at Claude's high school graduation; Claude was the son of his old age.

Mabel Wolf was Claude Sr.'s second wife, and she had married him at age twenty-nine, late for a woman of that era. She was eighteen years younger than her husband. Born in Lansing on September 14, 1880, she was a first-generation American. Her father emigrated from Germany to the Union army, survived the Civil War in a sharpshooters' company, and died before he could know Mabel, his last child. Her widowed mother struggled to bring up six children alone in a strange country. Few women in rural Michigan were college graduates—Mabel Wolf was. She arrived in Gaylord with "glowing recommendations" from her professors and took up what was, at the time, the usual work for a woman of intelligence and independence: teaching.

In time, Mabel became principal of Gaylord High, serving in that post for seven years. She was, by all accounts, an active and energetic schoolteacher and administrator. She coached the school's first-ever girls' basketball team and raised money for uniforms and trips. But for all her success, the paper reported the following in 1932:

> At a meeting of the school board it was decided not to hire any married women teachers during the coming school year due to economic conditions. It was decided that when a husband was capable of making a living it would be unfair competition to hire married women. Mrs. Mabel Shannon,

> Mrs. Lyons, and Mrs. Melvin Cook will be out of the school system due to this ruling.

By that point, at least, there was much in her private life to occupy her. She was a singer and musician of local note. She joined the Library Board and the Pythian Sisters, and she served a term as president of the Gaylord Study Club. When she wasn't volunteering with the Red Cross or the PTA, she lent her contralto voice to town functions and funerals and hosted music clubs in the Shannon living room. In 1905, she landed the leading role of Queen Elizabeth in the operetta *Two Queens* at the local opera house.

Situated in the middle of northern Michigan's central plateau, Gaylord took its name from an employee of the Michigan Central Railroad, which linked many such off-the-beaten-path towns to the rapidly growing hub of Chicago. Gaylord's destiny was shaped by topography and climate perfect for growing millions of acres of forest.

The trees drew the lumber industry, and the first visitors and inhabitants were willing to contend with the climate for the rich cache of white pine and hardwoods. But the environment was austere, with subzero temperatures and thick lake-effect snow. A local history from 1856 concluded, perhaps self-servingly, that the harsh climate offered a brand of moral education: "The fact that [Northern Michigan's] pioneers had more to struggle against in order to provide homes for themselves and the necessary accompaniments of homes developed in them a degree of aggressive energy which has remained as a distinct sectional possession . . . a splendid type of manhood and womanhood—self-reliant, strong, straight-forward, enterprising and moral.”

By the time Claude Sr. and Mabel became parents—their daughter, Catherine, was born in 1910, and Claude Jr., the baby of the family, in 1916—the pioneers had come and gone. The town’s limits and industries were well established: Gaylord would make itself known for farming and forestry, and a bit of light industry. As the railroads ramified, Gaylord found itself at the intersection of key lines. It became the county seat. Banks and businesses cropped up on Main Street, and the town’s population grew and settled around them. But Gaylord remained more village than city, its roots in the making of things: ten pins, sleighs, massive wheels for the transport of timber.

Gaylord was the kind of place in which just about any event was newsworthy. Consider the headlines and snippets from the county newspaper: “WISCONSIN GIRL KILLS WOLF WITH MOP STICK”; “A woman smoking a cigarette on the Midway caused some attention, not all of which was favorable”; “LUMBERJACK DIES OF APOPLEXY”; “VERN MATTS LOSES FINGER”; “MEETING CALLED TO DISCUSS ARTICHOKES.” And one September, a paragraph-long ode to a glorious run of fall weather, the lakes like blue mirrors by day and “splotches of silver” by night, a waxing moon bright enough to light up a printed page.

Claude was three years old when the local diner called the Sugar Bowl opened (also headline news). It was, the paper reported, “the first business on Main Street to errect [*sic*] an electric sign outside. Main

Street was so dark in those days that the Village Band once gave an after-dark concert under the sign."

Biographies of geniuses often open as stories of overzealous parenting. We think of Beethoven's father, beating his son into the shape of a prodigy. Or John Stuart Mill's father, drilling his son in Greek at the tender age of three. Or Norbert Wiener's father, declaring to the world that he could turn anything, even a broomstick, into a genius with enough time and discipline. "Norbert always felt like that broomstick," a contemporary later remarked.

Compared to those childhoods, Shannon's was ordinary. There was, for instance, no indication in Claude's earliest years of overbearing parental pressure, and if he showed any signs of early precocity, they were not memorable enough to have been written down or noted in the local press. In fact, his older sister was the family's standout: she aced school, mastered piano, and plied her brother with homemade math puzzles. She was also reported to be "one of Gaylord's most popular girls." "She was a model student, which I couldn't quite follow," Shannon admitted. He later suggested that a tincture of sibling rivalry might have driven his initial interest in mathematics: his big sister's talent for numbers inspired him to strive for the same.

Claude had some successes of his own in his early schooling. In 1923, at the age of seven, he won a third-grade Thanksgiving story-writing contest, for his work "A Poor Boy":

> There once was a poor boy who thought that he was not going to have a Thanksgiving dinner for he thought all his playmates would forget him.
>
> Even if they did, one man did not forget him because he thought that he would surprise the little boy early Thanksgiving morning.
>
> So very early on Thanksgiving morning when he awoke, he found a basket of good things at the door. It was filled with so many good things and he was very happy all the day and he never forgot the kind man.

He played the alto horn and performed in the school's musicals. Fifty-nine years later, he still remembered his classmates' names. He wrote to his fourth-grade teacher:

> Some names that come back as through a glass darkly after a half century are Kenny Sisson, Jimmy Nelson, Richard Cork, Lyle Teeter (who committed suicide), Sam Qua, Ray Stoddard, Mary Glasgow, John Kriske, Willard Thomas (a portly boy), Helen Rogers (a portly girl), Kathleen Allen (smart girl), Helen McKinnon (a pretty girl), Mary Fitzpatrick, and of course Rodney Hutchins.

He held in his hands a copy of a black-and-white photo of the fourth-grade class of 1924–25, so reduced in the copying that it took a magnifying glass to resolve the children's faces, and his own eight-year-old face bubbled and then flattened under the moving lens.

Gaunt and shy even in those days; piercing eyes. He remembered, too, no doubt from experience, that "boys in those grades tend to fall in adolescent love with their pretty teachers."

Reflecting on his education with the benefit of hindsight, Shannon would say that his interest in mathematics had, besides sibling rivalry, a simple source: it just came easily to him. "I think one tends to get into work that you find easy for yourself," Shannon acknowledged. High school lasted three years for Claude; he graduated a year ahead of the other children in the photo. That said, he wasn't at the top of the class. When a 1932 report in the newspaper recognized three students with straight A's in his high school, Shannon was not among them.

He loved science and disliked facts. Or rather, he disliked the kind of facts that he couldn't bring under a rule and abstract his way out of. Chemistry in particular tested his patience. It "always seems a little dull to me," he wrote his science teacher years after; "too many isolated facts and too few general principles for my taste."

His early gifts were as mechanical as they were mental. Claude's field of vision, for hours at a time, was often the rudder of a model plane or the propeller shaft of a toy boat. Gaylord's broken radios tended to pass through his hands. On April 17, 1930, thirteen-year-old Claude attended a Boy Scout rally and won "first place in the second class wig-wag signalling contest." The object was to speak Morse code with the body, and no scout in the county spoke it as quickly or accurately as Claude. Wig-wag was Morse code by flag: a bright signaling flag (red stands out best against the sky) on a long hickory pole. The mediocre signalers took pauses to think; the best, like Claude, had something of the machine in them. Right meant dot, left meant dash, dots and dashes meant breaks in the imaginary current that meant words; he was a human telegraph.

These gifts were in the family—but perhaps they skipped a generation. It seems that Claude took after his grandfather, David Shannon Jr., the proud owner of U.S. Patent No. 407,130, a series of improvements on the washing machine, complete with a reciprocating plunger and valves for the discharge of “dirt, settlings, and foul matter.” David Shannon died in 1910, six years before his grandson’s birth. But for a boy of Claude Jr.’s mechanical bent, a certified inventor in the family tree was something to brag about.

And the grandson inherited the tinkering gene. “As a young boy, I built many things, working with mechanical stuff,” he recalled. “Erector sets and electrical equipment, built radios, things of that sort. I remember I had a radio controlled boat.” One neighbor, Shirley Hutchins Gidden, offered to the *Otsego Herald Times* that Shannon and her brother, Rodney Hutchins, were a conspiratorial pair. “He and my brother were always busy—all harmless projects, but very inventive.” She told a different reporter, “Claude was the brains and Rod was the instigator.” One experiment stood out: a makeshift elevator built by the two boys inside the Hutchins family barn. Shirley was the “guinea pig,” the first to take a ride on the elevator, and it says something about the quality of the boys’ handiwork (or her luck) that she lived to tell the tale to a newspaper seven decades later. It was one of many such contraptions, including a trolley in the Hutchins backyard and the private, barbed-wire telegraph. “They were always cooking up something,” said Gidden.

Predictably, Claude grew up worshipping Thomas Edison. And yet the affinity between Edison and Claude Shannon was more than happenstance. They shared an ancestor: John Ogden, a Puritan stonemason, who crossed the Atlantic from Lancashire, England, to build gristmills and dams, and with his brother raised the first permanent church in Manhattan, two miles and three centuries from the office where his descendant Claude Shannon would lay the foundations of the Information Age.

It was finished by the spring of 1644, a twin-gabled Gothic church at the island’s south tip, hard by the wall of the Dutch fort; the wood shingles on its roof were meant to turn bluish over time and rainstorms, into an imitation of costlier slate. Ogden, who planned it from quarry to weathervane, is said to have been lean, hawk-nosed, and stone stubborn; he was one of the New World’s first builders.

Most of us, Claude included, are less demanding than we might be in our choice of idols: from the universe of possible heroes, we single out the ones who already remind us of ourselves. Maybe that’s the case for Claude and his distant cousin Edison—even if it was only years after leaving Michigan for good that he discovered the link. Good fortune to learn that one’s idol is one’s family—and Claude’s fortune was better than most.

2

Ann Arbor

A's in math and science and Latin, scattered B's in the rest: the sixteen-year-old high school graduate sent his record off to the University of Michigan, along with an application that was three pages of fill-in-the-blanks, the spelling errors casually crossed out.

8. Have you earned any money during your high-school course?

Yes.

How?

Pedd~~e~~ling papers and del~~e~~ivering telegrams.

The same year he applied to Michigan, his sister graduated from it. Claude was admitted as well, and Ann Arbor was the biggest swarm of humanity he had ever seen.

One hundred and ninety-five miles southeast of Gaylord, Ann Arbor was a city of steep hills and valleys, interrupted by the muddy banks and low gradient of the slow-flowing Huron River. The Huron sealed Ann Arbor's fate as a mill town: sawmills and flour mills punctuated the river banks and powered the economy. Immigrants poured in, most from Germany, but also Greece, Italy, Russia, and Poland. Their ethnic ties ran deep, and churches reinforced the affiliations of caste and clan. By the beginning of the twentieth century, half of Ann Arbor's population was either foreign-born or born to immigrant parents.

It was a population that suffused the city with an irrepressible optimism. On the threshold of a century that would see the Depression and two world wars, a 1901 issue of the *Ann Arbor Argus Democrat* was moved to declare that "the century to come is undoubtedly destined to be the richest and best that man has experienced." After the stock market crashed in October 1929, the *Ann Arbor Daily News* covered the brief recoveries in stock prices rather than report on the devastating declines. Even in December 1929—after more than $30 billion in wealth had evaporated, banks had called in loans, and manufacturing had cratered—Ann Arbor's mayor, Edward Staebler, remained unfailingly buoyant, assuring locals that the economy would recover and that the city would weather the storm.

In the presidential contest of 1932, Ann Arbor defied the state of Michigan. Franklin Roosevelt had won Michigan and forty-one other states in an electoral landslide—but Ann Arbor remained a steadfast Herbert Hoover stronghold. Editorials in the *Daily News* promised recovery and urged voters not to lay the blame for the economy's troubles at President Hoover's feet. His fellow Republicans held on to local offices in Ann Arbor, one of the few places where the president's coattails did more good than harm.

The University of Michigan copied its town's calm confidence. "I am not at all discouraged," university president A. G. Ruthven said in 1931. "I must admit that the curtailment of our resources has permitted me to make certain changes in the organization which I believe will be of lasting benefit." Yet, by the time Claude Shannon arrived at the university in the fall of 1932, that unflinching positivity had run its course. The financial collapse had forced the University of Michigan, Ann Arbor's largest employer and its economic engine, to shave enrollments, halt production on long-planned buildings, and cut pay by 10 percent.

Still, Shannon's timing was fortuitous. Had he arrived a decade or two earlier, he would not have been the beneficiary of the transformation of the university's engineering program during the early years of the twentieth century.

Under the leadership of Dean Mortimer Cooley, an unusually enterprising university administrator, the College of Engineering's "enrollments . . . grew from less than 30 to more than 2,000, the faculty from three instructors teaching several courses to more than 160 professors and staff teaching hundreds of courses, and a temporary shop of 1,720 square feet to over 500,000 square feet of well equipped buildings." The number of engineering students surpassed even the number of students in medicine and law. When it threatened to exceed the enrollment of the university's largest school, the Literary College, Dean Cooley grew excited, and “with his characteristic chuckle, exclaimed [to Professor Harvey Goulding], ‘By Jove, Goulding, we’ll pass them yet.’ ” Urbane, well-traveled, and politically savvy, Cooley had first come to the University of Michigan on a Navy billet, as Professor of Steam Engineering and Iron Shipbuilding. Four years later, the Navy allowed him to resign his commission, and the university offered him a proper professorship.

In 1895, the then-dean of the engineering school, Charles Greene, had been asked to create plans for a new building to house the school’s growing student body. Greene’s request—$50,000 for a small, U-shaped structure—was granted. He died before he could carry out the construction, and Cooley succeeded him as dean. Asked to judge his predecessor’s plans and funding needs, Cooley replied, “Gentlemen, if you could but see the other engineering colleges with which we are forced to compete, you would not hesitate for one moment to appropriate a quarter of a million dollars.” Something about Cooley’s understated certainty swayed the board, and his request was swiftly approved.

A public exhibition in 1916 showcased the spoils of the expansion, as close as a university has probably come to something like a world’s fair. Ten thousand people came to tour the facilities and take in the latest technological marvels. Electrical engineers sent messages over a primitive wireless system. Mechanical engineers “surprised their visitors by sawing wood with a piece of paper running at 20,000 revolutions per minute, freezing flowers in liquid air, and showing a bottle supported only by two narrow wires from which a full stream of water flowed—a mystery solved by few." Two full torpedoes, two large cannons, and "a complete electric railway with a block signal system" rounded out the demonstrations. "For the average student as well as for the casual visitor, the Engineering corner of the Campus held mysteries almost as profound as the deeper mysteries of the Medical School," observed one writer.

Cooley's project to expand the engineering college changed the university's core educational program, as well. Eight years before Shannon was born, the college began teaching courses in the theory of wireless telegraphy and telephony, meeting the growing commercial need for engineers trained in wireless transmission. Engineering's rising profile began to draw the attention of deans in other quarters of the university, and disciplinary lines began to blur. By the time Shannon began his dual degrees in mathematics and engineering, a generation later, the two curricula had largely merged into one.

That appealed to Shannon, who admitted that his choice of a dual degree wasn't part of a grand design for his career; it was simply adolescent indecision. "I wasn't really quite sure which I liked best," he recalled. Earning two degrees instead of one wasn't particularly onerous: "It was quite easy to do because so much of the curriculum was overlapping. I think you needed two extra courses and some summer school to get degrees in both fields," said Shannon. Those studies gave him his first taste of communication engineering, which he found "especially to my liking" for its blend of practice and theory

—because it was "the most mathematical, I would say, of the engineering sciences."

Though the dual degree was common enough, Shannon's variety of indecision, which he never entirely outgrew, would prove crucial to his later work. Someone content to build things might have been happy with a single degree in engineering; someone drawn more to theory might have been satisfied with studying math alone. Shannon, mathematically *and* mechanically inclined, could not make up his mind, but the result left him trained in two fields that would prove essential to his later successes.

He joined Radio Club, Math Club, even the gymnastics team. Shannon's records of leadership during this time are two. One is his stint as secretary of the Math Club. "A feature of all meetings," a journal recorded, "was a list of mathematical problems placed on the board and discussed informally after the regular program. A demonstration of mathematical instruments in the department's collection made an interesting program." The other was news enough that the hometown paper saw fit to print it as an item of note: "Claude Shannon has been made a non-commissioned officer in the Reserve Officers Training Corps at the University of Michigan."

In the Engineering Buildings, where Claude spent the bulk of his time, his classmates tried the strength of shatterproof windshield glass, worked to muffle milk-skimming machines, floated model battleships on a sunless indoor model sea. But the real life on campus was outside the classroom.

In the spring of 1934, Claude's sophomore year, an unusually misanthropic editor got a hold of the yearbook's anonymous comedy section and turned it into an account of student life narrated by an escaped mental patient convinced he's an anthropologist:

> Breakfast at the dining hall: "The stories of last week-ends parties assume a fundamental sameness . . . 'We went to ______'s (dance hall, night club, apartment, or fraternity) and had______highballs,______beers and______shots of______. After the party______got sick and______and I had to carry him all the way from______to______.' "

Someone spills his glass of orange juice on a coed's lap, and everyone laughs for five minutes, until they forget what they're laughing about and go silent again. "It is very quiet now. . . . The business of laughing seems to have taken something out of every one." Breakfast breaks up at eleven and they spend the rest of the morning going through the motions of hilarity.

Yearbook blurbs on the big men on campus were usually a string of mild in-jokes, but there was some acid to them in the spring of 1934. There is the track star who each night "removes his legs (they being in some wise attached to his body) and places them in a gold and glass case for all and sundry to admire." The student politician, "parading down State street with seven stooges at his heels, well fortified from contradiction or blasphemy." The newspaper editor, "wistfully pounding a typewriter in the secrecy of his cupboard office, attempting to veil the fact that he has nothing to veil."

Claude, by contrast, was a small man on campus. But he and the editor may have had a hunch in common: the introverted suspicion that they are surrounded by animate machines, detachable parts and all, all surface and funny motions. It takes a cynic or an engineer to discover “the business of laughing.” Later on, a girlfriend remembered Claude’s own laugh: “He laughed in small explosions as though he were coughing, and had never quite learned how to be merry.” It was his own funny motion of diaphragm and throat.

In the spring of Shannon’s sophomore year, a stroke ended his father’s life. For fifteen months Claude Sr. had fought illnesses and lived confined at home, his seventy-one years catching up with him. In the days after his death, the town of Gaylord shut down in his honor. The funeral was at the Shannon home at two o’clock on a Tuesday afternoon; the pallbearers, Claude Sr.’s business associates, were august. By Wednesday, Claude was on his way back to the university.

Soon after his father’s death, something broke between Claude and his mother. His sister was grown and gone, the town father was in the ground, and Claude and Mabel were alone together for the first time. It ended disastrously. It seems the rupture was caused, absurdly enough, by a plate of cookies: she saved the good cookies for guests and offered Claude only the burned ones. Whatever the cause, Claude spent his remaining school vacations at an uncle’s. He and his mother would barely interact for the rest of his life.

He completed his time as a student, distinguishing himself enough to earn admission as a senior to both the Phi Kappa Phi and Sigma Xi honor societies. In the spring of 1934, at the age of seventeen, Claude Shannon claimed his first publication credit, on page 191 of the *American Mathematical Monthly*. He had worked out the solution to a math puzzle and landed a spot in the "Problems and Solutions" section. The editors of the section welcomed "problems believed to be new, and demanding no tools beyond those ordinarily furnished in the first two years of college mathematics." The problem Shannon solved had appeared in the previous fall:

E 58 [1933, 491]. *Proposed by R. M. Sutton, Haverford College, Pa.*

In the following division of a three-place number into a five-place number each digit has been replaced by a code letter. Assuming only that the remainder, Y, is not zero, reconstruct the problem and show that the solution is unique.

```
L M N)R S T U N(U X
      R T Y X
      -------
        T Y Y N
        T Y Y J
        -------
              Y
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Coming as it did in the back of the journal, after the weightier work of math papers and book reviews, Shannon's six-part solution to the problem was nothing notable—except for the fact that it existed at all, a sign that his childhood fascination with codebreaking was starting to pay adult dividends. Buoyed, we imagine, by this first success, Shannon again submitted a solution and was again published in the *Monthly*'s back pages, in January 1935, in answer to this problem:

E 100 [1934, 390]. *Proposed by G. R. Livingston, State Teachers College, San Diego, California.*

In two concentric circles, locate parallel chords in the outer circle which are tangent to the inner circle, by the use of compasses only, finding the ends of the chords and their points of tangency.

Modest as they are, these early efforts are a window into the education of Claude Shannon. We can infer from them that the college-aged Shannon understood the value of appearing in a professional public forum, one that would earn the scrutiny of mathematicians his age and the attention of those older than him. That he was reading such a journal at all hints at more than the usual attention paid to academic matters; that his solutions were selected points to more than the usual talent. Above all, his first publications tell us something about his growing ambition: taking time out from the usual burdens of classes and college life to study these problems, work out the answers, and prepare them for publication suggests that he already envisioned something other for himself than the family furniture business.

His something other would begin, in earnest, with a typed postcard tacked to an engineering bulletin board. It was an invitation to come east and help build a mechanical brain. Shannon noticed it in the spring of 1936, just as he was considering what was to come after his undergraduate days were over. The job—master's student and assistant on the differential analyzer at the Massachusetts Institute of Technology—was tailor-made for a young man who could find equal joy in equations and construction, thinking and building. "I pushed hard for that job and got it. That was one of the luckiest things of my life," Shannon said later. Luck may have played a role, but the application's acceptance was also a testament to the keen eye of a figure who would shape the rest of Shannon's life and the course of American science: Vannevar Bush.

3

The Room-Sized Brain

If you were searching for the origins of modern computing, you could do worse than to start here: on Walnut Hill, just north and west of Boston, in 1912, where an overdressed lawnmower man was trudging up a grassy incline behind his machine. He took a moment to pose for a grainy photo, hands on the tiller, eyes on his work, face turned from us; the white of the grass, the black of his two-piece suit, the black of the machine. You'd deduce in a second, of course, that its purpose is something stranger than lawn care: the tall grass is untouched, and where there ought to be blades there is a blank box, riding slung between two bicycle wheels.

It was the failed first invention of a college senior, and though it ran just as promised, it bored nearly everyone beyond its twenty-two-year-old creator. Inside the box hung a pendulum, and a disc powered by the back bicycle wheel. Resting on the disc were two rollers: one measured vertical distance and wielded a pen, one measured horizontal distance and turned the drum of paper beneath. It was a geography machine, a device aimed to put land surveying teams out of