Greg Milner, **Pinpoint: How GPS is Changing Technology, Culture, and Our Minds**

INTRODUCTION

The Whisper from Space

Schriever Air Force Base hides in plain sight. A half hour's remove from Colorado Springs, near the western edge of the Eastern Plains, it emerges from the rolling auburn fields visible from lonely Colorado State Highway 94: a few squat buildings and parking lots, interspersed with monstrous domed antennas shaped like mutant golf balls. No aircraft disrupt the serenity of the shortgrass prairie. Schriever is the rare Air Force base that lacks a runway. When he was commander of the 50th Operations Group, Col. John Shaw called his institutional home "the greatest Air Force base the world has never seen."

Schriever's modest footprint contains one of the largest concentrations of classified areas in the service. Many of its 8,000 military and civilian personnel toil underground. Sharing the Colorado Springs area with Peterson Air Force Base, the Air Force Academy, the Army's Fort Carson installation, and the NORAD nuclear bunker carved into Cheyenne Mountain, Schriever accounts for around half of the $6 billion the military pumps into the local economy each year, while maintaining a chronically low profile.

"Where is it exactly?" Shaw wondered rhetorically. "And what do they do there? Who really knows?"

"What we do here is space," said Brian Stewart, a young lieutenant and one of the first people I meet the day I visit Schriever. "We're good at it," he added, "and you'll see why."

With active command over most Air Force satellites, and a lead support role for 175 satellites belonging to other branches of the military, the 50th Space Wing accounts for much of the work done at Schriever. One of its components, the 50th Operations Group, has various units whose duties include overseeing the most top-secret military satellite communications networks. But it is the Group's 2nd Space Operations Squadron whose handiwork resonates the loudest. All day, every day, 2 SOPS has one job: to monitor, maintain, and refine a fantastically complex system that affects nearly every person on earth.

They do their work in a windowless room at the end of a series of fluorescent-lit corridors, past sentries, passcard-protected doors that trigger alarms if left open too long, and signs authorizing the use of deadly force. Inside, around a dozen people, working in twelve-hour shifts, array themselves on tiered rows, staring at monitors. Some have advanced degrees, others are airmen barely out of high school. Overhead screens and rotating siren lights signal the presence of visitors. The captain on duty reminds the crew to hide from view any classified materials. Military police are never far away.

This unassuming space is the Master Control Station for the Global Positioning System. The crews here keep obsessive watch over a constellation of thirty-one GPS satellites, orbiting more than 20,000 kilometers above the planet. Every few minutes, someone at the Master Control Station announces a "pre-pass" and recites steps from a checklist, a prelude to the crew contacting one of the satellites to update its data and perform maintenance. Around the world, from Kwajalein Atoll in the Pacific to the south of England, sixteen far-flung monitoring stations collect data pertaining to each satellite's signal as it comes over the horizon, noting its speed and trajectory. The crunched numbers, based on 1,200 different protocols, tell the crews at Schriever how the satellite is performing, and whether they need to upload new instructions. There is no room for error.

Some people here are monitoring the active atomic clocks aboard each GPS satellite, which are synchronized within nanoseconds to the clocks on every other satellite, all of which obey the Master Clock at the United States Naval Observatory in Washington DC. The satellites broadcast a continuous radio signal that carries information about where the satellite was and will be—and also the exact time the signal left the satellite. The signal makes a 20,000-kilometer journey, taking an especial pummeling as it pushes through the earth's ionosphere. When it reaches us, sixty-seven milliseconds later, it is even fainter. Captain Stephen Dirks, the supervisor of this shift, calls it a "whisper from space."

When somebody fires up a mobile phone in New York, or London, or Tokyo, Karachi, Nairobi, Paris, Berlin, Kabul, São Paulo, Vancouver, Sydney, Budapest, or Johannesburg, the process is the same. Nearly every spot on earth has a line of sight to at least four GPS satellites at all times. The GPS receiver in the phone searches for the four strongest whispers. By noting each signal's origin and its arrival time, the receiver can compute the latitude and longitude of the phone, and express it as a point on a map. The receiver can also provide the correct time. Four satellites, four dimensions. A pinpoint calculation of space and time.*

This extraordinary system began as an American military application, a way to improve the accuracy of bombs and keep

* The GPS receiver performs this calculation by constructing imaginary spheres. The first GPS signal tells the receiver how far it is from the satellite. It could thus be anywhere on the surface of a sphere with the satellite at the center. The second signal creates a second sphere centered on the second satellite, thus placing the receiver somewhere on the circle where those two spheres intersect. The third satellite, by adding a new sphere to the mix, narrows the location down to two points, one of which is obviously wrong—usually miles above the surface of the planet, or deep in the earth's mantle—and can be discarded. The fourth satellite signal resolves any timing ambiguities, since phones don't come with superprecise atomic clocks.

bomber pilots safe. Today, its tentacles are everywhere. GPS is, of course, a wildly popular positioning and navigation system. Nearly 3 billion mobile apps clogging the world's phones and tablets use some sort of GPS-derived positioning information. Between now and 2019, that number will more than double. GPS technology also undergirds an enormous portion of the international economy. The estimated value of the global GPS market in 2011, around $9.1 billion, has now tripled. Certain early GPS entrepreneurs rank among the world's wealthiest individuals. But the true economic influence of GPS resists quantification. Factoring in the GPS chips in smartphones, tablets, and computers, moving platforms, such as cars, ships, and planes, and various products associated with service industries would produce a figure in the trillions of dollars—"so large," according to GPS expert Len Jacobson, "that it is meaningless to anyone but a scholar."

The total number of GPS receivers across all technological platforms probably hovers somewhere around 5 billion. We use GPS to track the movements of criminal suspects, sex offenders, wild animals, dementia sufferers, and wayward children. GPS guides planes to the ground and orients ships at sea. We wear watches with GPS. We buy specialized GPS sporting applications for golfing and fishing. We use GPS to locate oil deposits. GPS has helped grow a significant amount of the food you will eat today.

GPS is itself one of the world's most accurate clocks—and also a clock that unites other clocks. The components and nodes of the world's complex systems require time synchronization, often linked to GPS time. GPS timekeeping helps regulate the electrical grid in all its transnational complexity, bounces your mobile phone conversation from tower to tower, chops up voice transmissions into component parts and reassembles them on the other side, and orders billions of transactions through financial

trading networks, where millisecond discrepancies can effect billions of dollars.

GPS can record the movement of subatomic particles across hundreds of miles. GPS helps predict the weather. GPS surveys land, and builds bridges and tunnels. It knows how much water is in the ground and in the ash plume rising from a volcano, and how the oceans help redistribute the planet's center of mass. GPS knows when the earth deforms; it senses the movement of tectonic plates down to less than a millimeter. GPS can help tell us when an earthquake is imminent. GPS can feel the glaciers melting as the planet heats up.

GPS is a global navigational satellite system, or GNSS. Because of the high cost and complex infrastructure of developing and maintaining a GNSS, very few exist. All are controlled by nation-states, and all operate on the same basic technological principles as GPS. Only Russia's GLONASS offers the equivalent full global coverage and a complete satellite constellation. The development of the Galileo system, a project of the European Union and the European Space Agency, did not officially begin until the early twenty-first century. The first Galileo satellite launched in 2011, and the program will require at least another decade to reach full operability. China's Beidou system, currently offering limited service, will mature around the same time.

By then, GPS will be even more fully entrenched. GLONASS, currently plagued by technical problems, will still run a distant second. Many GPS receivers are GLONASS-compatible, using the Russian satellites as a way to strengthen GPS calculations. Even as the European and Chinese systems become more fully formed, and similar projects begun by Japan and India come online, they will likely serve a similar function, support beams in a building whose foundation is GPS. Galileo and Beidou have political value for the countries that run them, a way to declare independence from the United States, but they will likely be "global" only in their coverage, not in their technological ubiquity. The Air Force rightly calls GPS "the world's only global utility." It is universal, free for all, accessible by anyone, influencing everyone. When an ISIS terrorist gets a GPS reading, the process is enabled by the United States military, which presides over every GPS calculation.

The U.S. Department of Defense oversees GPS, with input from the Department of Transportation and other federal agencies, and day-to-day operations delegated to the Air Force. The majority of the sixteen monitoring stations are controlled by the Pentagon's spy agency. Sensors onboard the satellites let them pull double-duty as nuclear-detonation detectors. GPS is an essential part of virtually every weapons system. To maintain it costs more than a billion dollars a year.

Like the Internet, GPS arose partly out of Cold War imperatives. (It is no historical accident that the closest facsimile to GPS today is GLONASS, begun by the Soviets a few years after the US launched GPS.) Although it is less visible, GPS's influence on the world equals or exceeds that of the Internet. (The Internet could not operate without precision timing controlled by GPS.) This seems odd because while the Internet is a vast database, a way to aggregate and share information, GPS is just a radio pulse, a descendant of the rhythmic blip emitted by Sputnik. But this whisper is so dependable, so ordered and clean, that GPS has become our heartbeat. If it failed tomorrow, our society would experience enormous disruptions and scientific setbacks.

Those who oversee GPS have to maintain an almost unimaginable degree of exactitude. Something as subtle as the pressure of the sun's rays can shift a satellite's orbit. And the clocks cannot falter. The integrity of the entire system rests on measuring the distance between you and the satellite by timing the arrival of its pulse. Those signals are traveling at the speed of light. A timing error of just one-thousandth of a second will translate into a distance error of 200 miles. Put another way, a clock with a margin

of error of .000001 seconds might locate a New Yorker close to Washington, DC, or a Parisian in the vicinity of Brussels. Your GPS receiver, the one in your phone, is accurate to within a few meters.

Even with all that—the Master Control Station engineering the satellites, the clocks measuring time with rubidium atoms, so accurate they will not fall out of lockstep in millions of years—it still isn't enough. Like particle accelerators, and few other human-made operational systems, GPS must account for Einstein's laws of relativity. Compared to clocks on earth, time passes slightly more slowly for the clocks onboard the satellites, which speed around the earth at 2.4 miles per second. The GPS signal contains instructions for the receiver to correct its calculations accordingly.* The difference is just a few microseconds every day, but if the system did not account for it, timing errors would multiply and distance calculations would soon be off by thousands of miles.

This book tells the story of GPS and how it grew from a fledgling military project to a ubiquitous technology that blankets the world. The heartbeat emanating from those thirty-one GPS satellites gives us the power to measure and obtain enormous amounts of information about our planetary environment, physical space, and human behavior. Its invention has led to an explosion of creativity in science, technology, and business. For better or worse, it forms an essential part of the infrastructure of modern life.

But there is a price: the system may fundamentally change us as human beings. We so rely on GPS, have integrated it so deeply into our lives, that it may be altering the nature of human

* The curvature of spacetime caused by the earth's mass makes the satellite clocks appear to run a bit *fast*. So the receivers also correct for that at the same time (such as it is).

cognition—possibly even rearranging the gray matter in our heads. It is so potentially invasive that it forces us to reconsider cherished notions of privacy. We have let it saturate the world's systems so completely that it is difficult to imagine life without it, and so quickly that we are just beginning to confront the possible consequences. A single GPS timing flaw, whether accidental or maliciously installed, could bring down the electrical grid, hijack drones, or halt the world financial system. We now trust our devices so much that we follow them blindly down abandoned roads, over cliffs, and into the ocean; park rangers call this "death by GPS."

The story of GPS is also one of human ingenuity. At Schriever, they tell visitors that GPS is officially divided into three segments. The first is the space segment: the satellites. Next is the control segment: the tracking stations and the facilities that upload ephemeris corrections to the satellites. The third, the largest, is the user segment: every one of the world's GPS receivers. Workers at the Master Control Station like to point out that they are only responsible for the first two. Once the signal leaves the satellite, their job is done. The rest is up to us.

GPS reaches us as a whisper. We give it a voice. Listen closely, and it will tell the story of the world today.

PART ONE

Calculating Route