Cryptographic City

Decoding the Smart Metropolis

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13 Hiding in the Multiverse

In 2021, Facebook and other technology companies committed to developing the "metaverse," "a set of virtual spaces where you can create and explore with other people who aren't in the same physical space as you."[1] People with mobile phones and who communicate via video link are accustomed to "being with" someone who isn't with them in person.[2] But to frame this experience in terms of the metaverse implies that it is possible to occupy a realm other than the world of everyday embodied experience. The evasiveness of these metaverse experiences entitles us to think of them as yet another aspect of the cryptographic city. As I will show, cryptography enters the discourse as writers and scientists speculate about communications between such covert places. Theoretical quantum physics adds some credence to the existence of multiple worlds. That leads me to quantum computing, the prospect of which impacts the way we think about encryption.

Hidden Dimensions

A book from the 1960s by Edward Hall bears the promising title *Hidden Dimensions*. The term *hidden dimension* is alluring for the cryptographic city as it implies some properties of spaces beyond ordinary perception. The book is about *proxemics*, the study of how people organize and use space in their interpersonal communication. Hall indicates what he means by hidden dimensions as he explains the spatial arrangement in an office. It consists of three zones: "1. The immediate work area of the desktop and chair. 2. A series of points within arm's reach outside the area mentioned above. 3. Spaces marked as the limit reached when one pushes away from the desk to achieve a little distance from the work without actually getting up."[3]

He advocates that designers take account of the fluid and practical dimensioning of space that goes beyond mere room dimensions. These are the dimensions of movement defining "kinesthetic space,"[4] an important element of people's everyday experience. Hall draws attention to certain social practices that pertain to such hidden dimensions. These are less obvious than the visible and *observable* sizes and shapes of rooms and need to be inferred or otherwise discovered. A dimension is simply a measure, and here a *hidden dimension* is a measurement of the space formed by someone's movements, distances they stand from other people, and spaces defined by where occupants place objects, for example, things you put close (your laptop, personal photos, reminder notes, your lunch) and objects that can be further away (reference books, the printer, old files, armchair).

These spatial affordances are also contingent elements of a so-called subarchitecture[5] and are apprehended in the context of practicalities and various sensory modalities and can be designed for, interpreted openly, and finessed. Theorist of sound and space Brandon LaBelle writes that subarchitectures admit into consideration "the minor practices of space."[6]

The concept of *dimension* normally equates to a gridded world of three dimensions along x, y, and z axes, thanks to Descartes' definition of objects in space by the variables of length, breadth, and height. A one-dimensional world is defined along a line, just one axis of the grid. Two dimensions involve a world as drawn on a flat sheet of paper (xy).[7] The introduction of a fourth dimension is less accessible to direct human experience. Some think of the fourth dimension as *time*, though you cannot move backward and forward along a time axis as you can the three primary dimensions.[8]

Descartes was a mathematician and pioneered methods in geometrical algebra and calculus. We can also thank Descartes for identifying and naming an "imaginary" number, *i*, which is the square root of –1. And thus developed methods for plotting impossible numbers on the complex number plane. Those multicolored filigree images you see in online videos if you search for "Mandelbrot zoom" have at their core a simple looped algorithm to visualize the contoured fringes of this infinitely varied self-similar fractal space.[9]

Dimensionality is a mathematical concept, and there are many attempts to visualize n-dimensional and complex number space on a flat computer screen, and with stereopsis in virtual reality. The basics of geometry, visualization, and extrapolation lead people with imagination to speculate on "hidden dimensions" that evade perception by the usual exercise of the human senses. To pick up on another geometrical metaphor some scholars and fantasists think of *parallel* worlds.

These imaginative spatialities seem to defy rationality. As they cannot be perceived via the usual sensory channels, they epitomize for some people the idea of a hidden place. From a psychoanalytic perspective we could say these supposed hidden dimensions are mental surrogates, something we can discuss in a detached manner, without probing into the inner recesses of human minds where real secrets reside. It is easy to dismiss such places as those "of which we cannot speak,"[10] but imaginative concepts leak though into the practical everyday domain. They inform, test, and challenge concepts in our lived realities. They imply entry to and exit from a place that requires a secret code, a key, a passcode. For the time being I'm content to concede, or at least speculate, that such imagined realities are embedded into the fabric of the urban lifeworld.

A Multitude of Multiverses

Gardens and cities provide the two main models of places beyond everyday experience. There are the Garden of Eden and the Celestial City. Italo Calvino's *Invisible Cities* presents each of any city's characteristics and infrastructures as if a separate city, of water supply, internment, drains, or signage.[11] Darran Anderson's *Imaginary Cities* collates further imaginative features of cities.[12]

Many terms come to our aid in identifying such places. A search online for the term *multiverse* returns several variants: parallel universes, alternate universes, interpenetrating dimensions, parallel dimensions, parallel worlds, multiple worlds, parallel realities, alternate realities, alternate timelines, alternate dimensions, dimensional planes, quantum universes, and quantum realities.[13] I would add some further variants: planes of existence and hidden dimensions.[14] Numerous science fiction, fantasy and speculative novels and films play on the multiverse theme. The *Flatland* story by Edwin Abbott published in 1884 tells of commerce between worlds each defined by one-, two- and three-dimensional geometry.[15] Philip Pullman's book *Northern Lights: His Dark Materials* taps into a multiverse of realities.[16] The book opens with a quote from John Milton's *Paradise Lost*, in which the poet speculates that the creator might "ordain His dark materials to create more worlds." There are multiple multiverses. I have already alluded to the "hidden dimensions" of our practical, everyday lifeworld. Here is my attempt to tease out some further distinctions. Multiple universes appear in narratives about framing, altered states, ancient concepts dividing the material and the ideal, multiverses in theoretical physics, and geometry. I'll review these briefly.

Alternative universes feature in the identification of delusion and dishonesty. Commentators frequently described the forty-fifth U.S. president as living in an alternative universe, variously described as immaterial, parallel, imaginary—conjuring up a universe of misinformation.[17] This style of critique points to an alternative framing of reality, to a plurality of points of view, different interpretations, framings, lenses, through which we each see the world according to our own perceptions, preconceptions, biases, and expectations. An authoritarian will say only their particular framing is valid. Contrary to that fixed position lies a naïvely relativistic "multiversality" in which we think anyone's view of reality is as valid as any other. Either extreme will be dominated by the affordances of the world views posited by the loud and powerful.

A more prosaic expression of multiversality focuses on altered states. To transition from one dimension to another is to change from one state to another. Water changes from vapor to liquid by lowering the temperature. If this transition is about a shared universe of human experience, then altered states are as common as changes in the weather. If we are referring to psychological or emotional states of the human being then there are therapies, stimulants, and depressants to assist, or a change of scene, exercise, company, or a good night's sleep.

The legacy from which multiversality draws relies on long-standing distinctions between the physical and the spiritual, the material and the ideal, earth and heaven, waking and dreaming, conscious and unconscious, real and imaginary—each expresses long-standing alternative realities. Here, "alternative" is the correct term to use, as these are alternating, binary distinctions and "universes." I am enough of a structuralist to recognize the complex priorities involved in the formulation of such binaries. The Neoplatonists articulated hierarchical orders of reality. Some states, worlds, or conditions are more real, virtuous, wise, or enlightened than others. I would also group fantasy and science fiction parallel universes within this category. At least, these genres of popular fiction give expression to deep-seated cultural and psychological conditions related to our being.

Certain scientific and philosophical discourse that focuses on *cosmology* promotes the multiverse to explain the nature and origins of the universe. In an article in *Scientific American* Alexander Vilenkin and Max Tegmark write: "Intelligent observers exist only in those rare bubbles in which, by pure chance, the constants happen to be just right for life to evolve. The rest of the multiverse remains barren, but no one is there to complain about that."[18] Concepts of an infinite array of different universes with slightly differing laws of physics, constants, constraints, and circumstances help explain how the unlikely existence of a universe, our particular universe, is able to generate sentient organic life, especially humans who are able to reflect on such ideas as the multiverse. There is a spectrum of discourses here. They range from the multiverse as a stimulating thought experiment to mathematical models such as those offered as a means of explaining the paradoxes of quantum physics.[19] I will look into quantum physics and the quantum Internet toward the end of this chapter. Arguments against the multiverse theory include its lack of falsifiability. How could you ever know if other universes exist, especially as these varied universes are beyond our "cosmic horizon"?

I introduced concepts of hidden dimensions through spatial geometry. This is of most interest to my commitment in this book to urban cryptography and secrets, not least as it implicates space and representations of space in computer systems via mappings, transformations, projections, complexity, non-Euclidean models, video gaming, virtual reality, and immersive experiences. My own fascination with the putative experience of these universes resides not just in their characteristics but also in how we supposedly transition from one to the other.

Portals

Where do these parallel universes exist? That's an obvious question for an architect invested in the materiality of the physical environment. The answer could be geographical. These putative worlds could be millions of miles apart. They could exist at different times. Then there's the relationships between them. One may exist as a different state of the other, as solid and liquid are different states of water. Under a psychological account, such universes might exist under different cognitive or bodily conditions, such as waking or dreaming. One world may be subsumed or hidden inside the other as in a steganographic image. One may be secreted in the other's geometry, a scaled-down microscopic version, like a Mandelbrot fractal, or as an image reflected in a mirror. Some worlds may be made of different materials, beyond substance, or even beyond description as substances—invoking distinctions that are after all ineffable.

In this chapter I have taken the view that it is sufficient to accept other worlds as elements of language and storytelling, let alone raw human experience, to regard the possibility of other worlds as a legitimate subject of urban inquiry. At the very least, many elements in fantasy and science fiction stories deal in allegories about a current condition, are vehicles for speculative thought experiments, challenge world views, or simply offer recreation or respite. The multiverse is a way of talking. So, I can reasonably inquire how such narratives deal with transitions between worlds in much the same way that visitors would inquire how they are to get from the Garment District to the Financial District in New York.

If talk about parallel worlds is simply a figurative account of differing points of view, frames of reference, biases, or preconceptions, then the means of transition fits within the usual processes by which we submit to persuasion, challenges to beliefs, correction, revision, openness, and empathy. A psychological "awakening" might suffice as a way of explaining a portal between parallel worlds. As I have already suggested, if talk of the multiverse involves transition between psychological or emotional states then therapies, music, body practices, medications, and mood-altering substances can assist. Stories of multiverses present the process as such, though the means are diverse.

If the parallel worlds belong within metaphysical discourses, such as Plato's Ideas, an afterlife, Nirvana, seven heavens, then there are time-honored methods of transition: contemplation, meditation, death, rebirth, and instruments of conversion, redemption, and salvation.[20]

Cosmological parallel universe theories of the multiverse imply the impossibility of communication between such worlds. By this reading, transitioning between universes in the multiverse is meaningless. By most accounts, the multiverse is a byproduct of a series of mathematical models or speculations about models. The multiverse is a thought experiment.

That limitation doesn't prevent the imagination from entertaining further speculation. Portals between worlds built on whatever foundation are a mainstay of science fiction and fantasy.

Video games, CGI, and immersive VR provide obvious media for exploring the geometries of other-world transitions. In the case of VR the usual means of moving in and out of virtual places includes the head-mounted displays (HMDs) and other physical paraphernalia, and their spectacularization in science fiction. Video games include virtual in-game portals. How players and audiences transition from one universe to the other, or how one universe transforms into another, involve creative computer modeling, code, and the inventive use of geometry and visual effects. My observations here are informed by my recent foray into the video game *Obduction* by Cyan, the original developers of *Myst*. In *Obduction* the player moves between worlds via spherical metal mechanisms that, when activated, take the player to different parts of the alternative worlds. In most fantasy narratives about other worlds the means of getting from one to the other constitutes a puzzle. The means of transmission is a secret. The existence of the other, parallel universes is hidden, as are the means of getting there.

We can also resort to cryptographic allegory to explain such transitions. Like the contents of an encrypted hard drive the parallel reality appears as random noise. We need the private encryption key for the universe's algorithms to transform it into something that makes sense. Another touch point with the cryptographic city is communication. Whether or not a human agent wishes to move from one universe to the other, they may wish to speak with beings who are in it. There is communication in plain text and plain speech, but it's likely that to preserve its hiddenness, the communication is in code.

After Life

Technologies amplify the idea and possibility of a universe beyond everyday experience, often referred to as the *supernatural*. Technologies of communication and transportation help explain, simulate, or suggest what the supernatural is or would be like, especially as people's imaginations extend beyond the limits of current devices, technologies, and infrastructures. In this and other respects technologies provide a pool of metaphors from which to draw in explaining, developing, and even creating the supernatural. Rapid transportation suggests instantaneous appearance and disappearance—levitation, dematerialization, transcendence. Cables and switches, not to mention magnetism and the wireless, point to action at a distance—a staple of the popularized supernatural. After all, early developments in sound recording were accompanied by speculation about contact with the dead. The gramophone provided a means of memorializing "the last words of a dying person" according to its inventor Thomas Edison, from which it was a simple extrapolation to think of communication beyond the grave.[21] Most important, technologies of sound extract and preserve something from the human body that is already evident as a separable "essence," namely our breath, particularly as part of the operations of the voice. The latter already suggests spirit and soul, and technologies of communication amplify this sense of the "soul's apartness."[22]

Media theorist Friedrich Kittler suggests a correspondence between the invention of Morse code and attempts to hear and receive messages from the spirit world: "The invention of the Morse alphabet in 1837 was promptly followed by the tapping specters of spiritistic seances sending their messages from the realm of the dead."[23] An article by media scholar Anthony Enns concurs with a helpful account of this peculiarly Victorian practice: "The main similarity between the spiritualist practice of 'rapping' and the development of electrical telegraphy was that they both involved the translation of messages into codes."[24]

Two young sisters Margaret and Kate Fox famously conducted seances in the United States in the mid-1800s. They toured the UK in 1852, and impressed Arthur Conan Doyle, who explained (via a narrator) the apparent rapping response of a spirit at one of their seances: "I then asked: 'Is this a human being that answers my questions so correctly?' There was no rap. I asked: 'Is it a spirit? If it is, make two raps.' Two sounds were given as soon as the request was made."[25] Enns draws on Conan Doyle's book then reiterates: "The practice of 'rapping' thus involved the use of a binary code that closely resembled the 'dots' and 'dashes' used in telegraphy."[26]

These apparent communications represent a further coded dimension to the cryptographic city, especially the city as a site of hauntings, with otherworldly dimensions, and as a "spiritual" place. "Spirit" has several connotations. There's the "spirit of the times" (Zeitgeist), and the "spirit of place" (genius loci).[27] The "spirit of the city" is also the city of spirits, in other words, the city of mysteries, if not the city of codes.

Nano Worlds

Cities are lessons in physical scale, from over-scaled ambitions such as Bitcoin City's masterplan to the teaming world of microorganisms and intracellular parasites (viruses). Worlds may go undetected as they are at a scale that evades the senses—until an epidemic pauses the life of a city. Developments in biotech also impact the cryptographic city, not least as we consider DNA as a coding medium.

To the popular imagination, DNA is a code system. A strand of DNA is a complex structure consisting of sequences of four molecules connected in pairs in a double helix configuration. These nucleotide molecules are adenine (A), cytosine (C), guanine (G), and thymine (T). The DNA in a human cell is made up of around 3.2×10^9 of these pairs, normally tangled into twenty-three paired strands (chromosomes). ACGT sequences in DNA strands offer the potential to hold vast amounts of binary data, but the processes of manipulating DNA sequences are time consuming and expensive as are the processes of reading these sequences. Biotech researchers consider other methods of exploiting the properties of DNA strands in data storage and encryption.

Genetic engineers use enzymes found in bacteria to cut and join strands of DNA at specific sites along the strands. Strands of DNA can also be reproduced and multiplied by injecting them into bacteria cells. DNA strands can be sorted into different lengths via an apparatus that draws them through a gel toward a positively charged electrode. Genetic engineers can cut DNA strands in a way that creates conditions at the ends of the strand fragments that encourage other strands to connect. Geneticists harvest, sort, filter, and store DNA strands in liquid solutions. The combinations of nanoscale DNA strands can be inspected via electron microscopy.[28]

These particular processes of synthetic biology exploit properties of DNA strands that are independent of how a DNA sequence might actually function in a living organism—to synthesize other complex molecules that perform cellular functions. The artificial processes treat DNA as molecular matter, as bricks, blocks, plates, tubes, and planks to be layered, joined, stacked, and folded. The production process typically involves titrating precise quantities from solutions of each strand with specific properties into a mix that is heated and cooled at some optimal rate to encourage nano shapes to form.

Computer-aided design systems (e.g., caDNAno at cadnano.org) assist with designing 3D shapes, generally following a voxel geometry (i.e., much simplified versions of the kind of voxel art shown in figure 9.6). Data from the CAD system is channeled to robotic titration machines that produce the solutions/suspensions from which these nano shapes can form. There is generally some wastage. One of the goals of the process is to minimize the production of mis-formed shapes and fragments.

Genetic engineers use these techniques to fabricate, isolate, and deploy a class of short DNA strands (twenty or so DNA base pairs) known as *staples* (oligonucleotides). There are techniques for inserting these staples into long DNA strands at specific locations to cause the strand structures to fold. So the double helix of a strand of DNA is effectively a tube able to be bent and folded by the judicious placing of these staples to make shapes. That is *DNA origami*. It is ex-vivo synthetic, controlled lab work, and is independent of operational DNA in living cells.

A helpful article by Swarup Dey and colleagues identifies the range of applications of DNA origami, including, for example, its use in providing masks or templates for printing patterns for nanoscale electronic circuitry. They also mention "light-harvesting antennas and photonic wires with long-range directional energy transfer."[29] Folded DNA strands have a negative charge, a feature that can be exploited to induce rotation. Swarup Dey and colleagues state: "A major goal for DNA nanotechnology is to create molecular machinery and motors that do not just switch between states upon sensing some external change but also are progressively fueled through a closed state path and generate change externally."[30] One popular application is delivering drugs to specific sites in the human body. Dey's article includes an image of a microscopic cube-shaped box with a hinged lid: "DNA origami structures can also serve as containers with docking sites in their interior or within dedicated cavities, protecting the payloads from the environment and the environment from the payloads."[31] This is architecture and nanoscaled urban design of a sort: designed, constrained, responsive to environment, functional, consequential, socially influential, speculative, and risky—but invisible.

DNA origami is predicated on various tropes of hiddenness: nanoscale locked "boxes" made of folded DNA strands to conceal active molecular agents (enzymes, drugs, active DNA material) from their immediate environments where they may be damaged or cause harm. Nano objects are in any case hidden from direct view, only detected via sensing apparatus such as electron microscopes and spectrographs.

Such invisible nanosynthetics engender similar suspicions to encryption, secret messaging, and secrets in general. According to a Reuters fact check site, "Social media users have claimed the presence of lipid nanoparticles in a COVID-19 vaccine means it could contain small robots or computers."[32] The secretive world of cryptography elides with mistrust of difficult science and invisible technologies.

An article "DNA Origami Cryptography for Secure Communication" spells out an interesting method for hiding information in DNA strands that resonates with the manipulation of visible and tangible physical matter.[33] This is not the instantaneous encryption and decryption of binary data in volume, but the secure delivery and preservation of short and discrete blocks of data, such as long-term storage of passcodes and persistent cryptographic keys. The method starts by coding a short message as a grid of dots, a little like braille. Zhang and colleagues illustrate this with the letters H, E, and Y. Each letter is represented on a simple 3×3 array of dots that are either on or off. The bottom row in the array indicates the position of the letter in the message. That is needed as the message eventually appears as a coded "alphabet soup," like random dominoes, and the recipient needs to reorder the letters. These dot patterns are imprinted as identifiable DNA markers on folded DNA nano-"scaffolds," typically flat plates formed of folded DNA strands. The pattern of folding is crucial as the dots will appear in different positions to the original message if the folds are misplaced. The physical DNA mixture is passed from the sender to the receiver: a test tube (or impregnated paper) with the fluid containing the relevant DNA mixed in with other DNA material extraneous to the message but important for the decryption process. Both sender and receiver have access to the "defined DNA origami folding scheme"[34] which is secret data already agreed.

The folding scheme provides the composition of DNA strand chemicals needed to reestablish the scaffold on which the dots are "printed." The recipient essentially mixes chemicals to reestablish the folds (staples) to reform the transmitted DNA nano-scaffold. Centrifuge filters remove surplus short DNA strands, and chemicals are added so that the dots show up on scans. The dot configurations appear on the scaffolds under special fluorescent light (stochastic optical reconstruction microscopy—STORM) and the patterns are interpreted and ordered back into the plain text message: “HEY.”

The decryption process in the experiment so described in the Zhang et al. article involves the physical exchange of DNA material; it is painstakingly precise. They describe an experiment in which it took one to two hours to decode each pattern, which I take to mean per character in the message. The process is clearly costly, noisy, and error prone. Nevertheless the researchers claim that the method holds promise of much better security than the Advanced Encryption Standard (AES). They write in summary that their method “uses information-based DNA self-assembly to create physical puzzles, resulting in extraordinarily strong all-around protection of a secret message.”[35]

The method recalls the old string cipher method of delivering a secret message described in chapter 2 (figure 2.1), in which a plain text message is coded as a series of knots in a length of string. When the string is unfurled and zigzagged across a correctly proportioned wooden template (scaffold) the knots line up against the letters of the alphabet to reveal the secret message. Both parties have to have a scaffold to the same design. I think the method I have described here serves to defuse any suspicion that genetic engineers are on the verge of using DNA to transmit hidden messages that will impact directly on organic life or human physiology.

Obvious possibilities for nanotechnology in the city reside with innovations in medicine, agriculture, the manufacture of new materials, and other outcomes of bioengineering. The design of hinged intracellular containers and mechanisms recalls my discussion in the introduction of the affordances of ordinary hinged doorways. I’m prepared to think that the physicality of nanotech methods and artifacts entitles architects and urbanists to include the field within the orbit of the city. That these technologies might also be used as tools for encryption draws them further into the cryptographic city. To build on the theme of different scaled worlds, if cryptography is relevant at this intracellular nanoscale, then it also applies at the interstellar scale.

Interstellar Cryptography

Other worlds may exist simply as other places spatially distant from us across interplanetary and interstellar distances. Such expanses are sufficient to facilitate physical transportation from one world to another but at exorbitant cost. Communication with those worlds provides similar challenges.

We might presume that the aim of cryptography is to make a signal as obscure as possible to anyone but the designated recipient. *Anticryptography* is a loose term to designate a type of cryptographic message that is legible to someone who has *no* knowledge of the plain text language from which the message derives. Nor do they have access to the method of encryption, or anything like an encryption or decryption key. Nor is the message meant to be secret. The message is coded in such a way that a codebreaker from any language group, culture, or context has a good chance of decoding it.

Why would anyone want to create such a code that is designed to be easy to decipher? It is for sending messages to extraterrestrials and making a good guess at how alien intelligences might already try to communicate with us: "Probably the one overriding principle of the outer-spacelings will have been to make their message as clear as possible. It will be coded, but in a code designed for clarity and not for obscurity—a kind of cryptography in reverse, . . . an anticryptography."[36]

The coding system called *Lincos*, from "lingua cosmica," was invented by the mathematician Hans Freudenthal (1905–1990) who describes the system in his book *Lincos: Design of a Language for Cosmic Intercourse*.[37] The book is dryer than the title suggests. Figure 13.1 shows a sample dialogue in a symbolic language derived from lincos.[38] Freudenthal was invited to develop his code by the British Interplanetary Society in the 1950s.[39]

Lincos qualifies as a cryptographic system rather than a *language*. The sender assumes that the potential recipient has no knowledge of the system, or even that a signal they receive is a coded message. The recipient has to be able to detect that the transmitted signal is likely to contain a message and is not random noise or an extraneous signal generated by natural phenomena. Freudenthal assumes the medium for a Lincos message is electromagnetic pulses. Whatever the medium, the message has to repeat to increase the chances that it will be picked up by someone or something that can read it. The pattern of the repetition may also offer a clue that the signal is a message from intelligent life. According to Kahn, "Lincos would have to be taught to the creatures of outer space before it could be used as a medium of communication, and Freudenthal proposed to do this by transmitting the statements of Lincos, which he hoped would be relatively self-evident, over and over again until the recipients catch on to their meaning."[40]

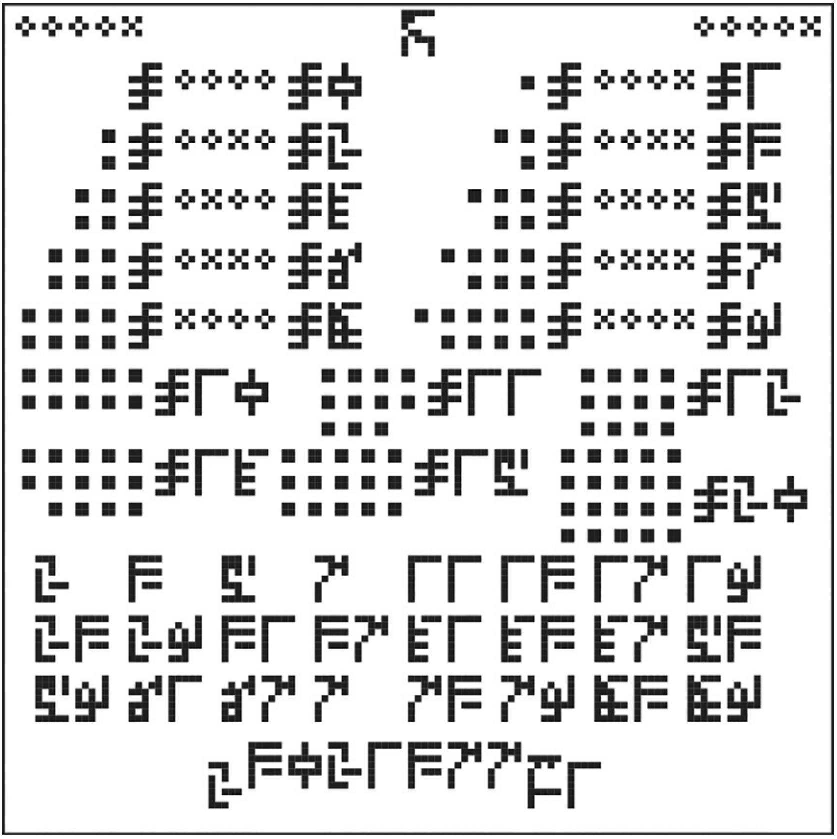

Figure 13.1
The first page of code transmitted from the Evpatoria radar telescope in Ukraine on May 24, 1999. Inspired by Freudenthal's Lincos system it begins by defining arithmetic operations, the elements, units of measurement, and our solar system. The last four lines of the first page show the first ten prime numbers, ending with the highest prime known at the time. Each symbol is 5x7 pixels and designed so that if a single pixel in a symbol is misplaced in transit, then the symbol will not be misread. For an explanation of each symbol see Daniel Oberhaus, *Extraterrestrial Languages* (Cambridge, MA: MIT Press, 2019), 179–191. *Source:* MIT Press, used with permission.

The aim of delivering messages in such a way that the means of interpretation and translation are part of the code recalls my argument in chapter 3, and the idea that urban artifacts tell us how they are to be used without explicit instruction but in the way they are designed. The process is even more difficult in the case of communicating with putative aliens as we do not know if they share the same relationships with their environment as we do with ours.

The motivation for interstellar signaling came from speculations about life on Mars. Once detected by telescopes, observation of the "canals" on Mars encouraged people to invent means of communicating with Martian life, with the best chance of contact occurring when the orbits of Mars and Earth brought them closest. The polymath Francis Galton (1822–1911) identified the need for such communication as early as the 1890s.[41] He proposed "scintillations of light" [42] as the likely means for Martian intelligence to reach out to us.

Others have proposed less-general means of communication. Karl Friedrich Gauss (1777–1855) had proposed planting a massive forest across Siberia in a configuration of triangle and squares that would leave an extraterrestrial in no doubt that we earthlings know Pythagoras' theorem. Sprawling cityscapes and their illumination would now provide similar signs of earth life. Unsurprisingly, attempts at a celestial code center on the assumed universality of mathematics. A second component is the context of the signal. A potential receiver might expect the communication to establish and identify the location of the sender, which could be correlated with other observations about our own planet's location in the universe. The astronomer Frank D. Drake has added the likelihood that any extraterrestrial codebreaking would involve teams with different expertise, as it would on Earth. Kahn quotes Drake who writes as if the communication had already succeeded: "In preparing the message, an attempt was made to place it at a level of difficulty such that a group of high-quality terrestrial scientists of many disciplines could interpret the message in a time less than a day. Any easier message would mean that we are not sending as much information as possible over the transmission facilities, and any harder might result in a failure to communicate."[43]

I doubt many earthlings would have the time or the inclination now to learn precisely how Lincos operates. Kahn provides a useful summary: "He began his program by sending a series of messages to teach the terms 'plus' and 'equals.' His first message might be beep beep beep beep bloop beep beep tweet beep beep beep beep beep beep. Next he might send beep beep bloop beep tweet beep beep beep. After sending enough of these for the outerspacelings to catch on to the idea that bloop is 'plus' and tweet is 'equals,' he might transmit a message with a new signal, like beep beep beep blip beep tweet beep beep. Soon the spacelings would realize that blip means 'minus.' Similarly, Freudenthal would build up an entire mathematical vocabulary."[44]

As I have already suggested, the idea that a cryptographic code might be designed to be broken is interesting from the perspective of the built environment. Anticryptography is a version of the challenge we encounter all the time in communication. It is the challenge of learning one's first language as an infant. We don't have to memorize a code before we can speak and understand. We learn language as we use it, from mimicry, context, feedback, and a certain inbuilt propensity to communicate with highly variable combinations of sounds. As explored in chapter 3 on urban affordances the process is the same with the built environment. Devices, machines, buildings, streets, furniture, and parks convey the means of their understanding, or they could if designed accordingly.

Simultaneous States

Arguments for the existence of the multiverse find support from theories within quantum physics. Related ideas about the quantum Internet (QI) impact on operations within cryptography and add further layers to communications infrastructures in the city.[45]

I will start with lasers. Laser technology is ubiquitous in the city, not least in LiDAR for measuring, surveying, and scanning (figures 5.1 and 6.1). A laser beam is a concentrated beam of coherent light within a narrow color band (i.e., frequency range). An experimenter can point a laser beam at a piece of card that has two slits cut close together into it.[46] Some of the laser light will pass through the slits. A surface on the opposite side of the slits to the laser light source will show an interference pattern of light and dark bands. That is because light beams propagate in a wave pattern. The light waves are refracted by the two slits and spread out creating two wave patterns. The interference pattern appearing on the surface is brightest where the light waves reinforce one another, and will be darkest where they cancel each other. So light seems to behave as waves do.

Light is also observable as individual particles, photons. Experiments that track the passage of low-intensity laser light with countable numbers of photons shows that individual photons do in fact exhibit this wave characteristic when observed en masse. A sensor can count the photons and record their positions as they arrive on the surface in the two-slit experiment.

Photons are discrete particles and don't exhibit degrees of luminance. Nor do they reinforce or cancel each other like waves. The light patches on the screen are simply where the photons land in higher numbers. The dark patches have no photons. If one of the slits is covered over, then the photons entering the open slit will fall on the screen without any interference banding.

This two-slit experiment highlights one of the paradoxes in the behavior of light or the movement of any subatomic particle. It is as if photons passing through one slit take account of the photons passing through the other slit so they agree, concur, or conspire where they will fall if the light was moving as waves. The results of these experiments imply that under the right conditions photons from the same source coordinate with each other. To avoid the language of agency, that linkage is termed *quantum entanglement*. The description I've just presented is standard fare in physics textbooks.[47] The two-slit experiment establishes that photons exhibit quantum entanglement. The behavior of one particle depends on what happens to any other particle emitted from the same source, even though they are observed at different times and places. Hardware engineers and scientists have recruited this phenomenon to propose and develop a radically new class of computers. These are *quantum computers* that exploit the properties of quantum entanglement.

Quantum computers are extremely fast computational devices that exploit quantum phenomena. They exist in labs and theoretical models at present, but promise to outperform current, everyday supercomputers by many orders of magnitude. As well as the two-slit interference phenomenon, in quantum computing the characteristic of the photons of interest is their *spin*. Subatomic particles such as electrons, protons, and photons spin in two directions, usually described as "up" or "down." It is tempting to think of a ball spinning rapidly, stopping and changing direction, oscillating from one to the other or rotating about two axes. Were you to freeze a few frames in a video of the spinning ball you would catch it in one direction or the other, or catch it between states. This is the wrong model, though. Spinning electrons do so in two directions simultaneously and with no intermediate states where they transition from one to the other. Specialized sensors can detect and measure the spin direction of a photon. Until the spin of a photon is measured, it is in both states (up and down) at once, simultaneously. Laboratory experiments can exploit the property of quantum entanglement to coordinate the measurement of the spin states of two photons that have come from the same coherent light source, even though the photons have moved far apart.

The basic unit of arithmetic in a computer is the bit, an electronic component in a microchip that can be in one of two states.[48] It is either on or off, 1 or 0. Microchips contain circuitry that stores and manipulates strings of bits at billions of times per second. Unlike a binary computer, the basic unit in a quantum computer is the *qubit*, a cute name that indicates a unit that stores a value of either 1 or 0 or both 1 *and* 0. The condition of being in two states at once is the nub of the quantum mechanical property of subatomic particles. This is the middle state of a qubit. In the case of a spinning electron it stays in that dual state until someone interferes to measure it. Then the spin is either up or down according to some probability.

A quantum computing microchip has circuits that exploit arrays of supercooled subatomic particles spinning in this controlled quantum state, but without extraneous electromagnetic interference or measurement, until monitored to record their states at that moment. The idea of "recording" doesn't do justice to the mechanism here, which under quantum logic is to both measure and create. The state of an array of qubits is computationally interesting. Fifty or so qubits connected each to the other provides an instantaneous parallel processing unit. The size of the array doesn't impede the quantum calculation, and the computational power increases exponentially with the addition of extra qubit processing capability.

There are parallels here with chemical processes in which molecules interact without iteration as required in normal computer simulations. So biotech is one of the key areas motivating the development of quantum computing. That and security, fintech, and the possibilities of a QI.

Exploiting the procedure of the two-slits experiment, it is possible to emit two photons from a lab device made up of a laser and refracting prisms. The photons will have the same initial quantum state. As they come from the same coherent light source, they will exhibit quantum entanglement. The two photons remain entangled as long as nothing interferes with them.

They will continue in this quantum state as they pass through space or a fiber optic cable. Experiments show that a pair of photons can retain quantum entanglement even though they travel away from each other—up to 100 kilometers. Even though the spin of the photons is indeterminate, were someone to measure the spin of one of them it would be either up or down with a probability of 50 percent. If someone were positioned with the other photon, then they would get the same reading as the photons are still entangled at a distance. The senders of a message cannot change the spin of a photon, but once they have detected the spin they can be sure (to a known probability) that the recipient has the same reading. That has implications for securing communications. The phenomenon does not permit message sending "faster than the speed of light," though that is an alluring imaginative scenario.

To take a reading is to erase the photons' quantum entanglement. Once the two photons become disentangled then the ability to predict the state of one photon by knowing the state of other is broken. So a quantum network made up of photons coursing through a network requires a stream or steady pulse of photons. Physicists have invented "quantum repeaters" that enable these networks to be extended. One of the main advantages of widely distributed networks that support quantum communications is in connecting quantum computers together so that they can share processing of large scale problems (e.g., in bioengineering).

The security advantage of the quantum Internet is that the state of a qubit cannot be copied. The quantum entanglement between the photons would be severed were someone to take a reading of one of the photons while it is in transit. That is, interference would be detected at either end of the communication channel.

A further advantage of quantum communication is accurate synchronization between equipment on earth and in satellites. The GPS (global positioning system) relies on accurately synchronized clocks on the satellite transmitters and the earthbound GPS receiver to determine distance and hence triangulate the location of the receiver, your GPS-enabled smartphone. An article in *Nature* predicts geolocation that deploys quantum communication with accuracies in the order of millimeters, improving on the one meter accuracy of current GPS.[49]

The quantum Internet suggests a new layer to urban communications infrastructures. Discussion about the QI involves network nodes positioned across cities. Though the QI will not enable communication without radio waves or other media, it has the potential to enhance secure communications: "Entanglement can't directly transfer information, because that would mean data is traveling faster than light. But entangled particles can be used to create secret 'keys' that enable extraordinarily secure communication."[50]

Quantum computers also afford risks to the security of conventional communications. They can potentially remove the need to iterate through the huge numbers of combinations required to break a code, reconstruct an original source document from a hash string, or derive the key used to encrypt a file. Some cryptography experts suggest quantum computers could thereby break the blockchain underlying bitcoin and other cryptocurrencies. Without some remedial action, the wealth tied up in cryptocurrencies would disappear.

These risks have spawned an industry of *postquantum* encryption algorithms designed to thwart the capabilities of these computers of the future. Cryptographers are also developing encryption methods based on quantum computing that will be even more robust than current methods. Keith Martin's book *Cryptography: The Key to Digital Security, How It Works, and Why It Matters* provides a helpful summary of some of the issues in a section ominously titled "Weapons of mass decryption."[51] Competition to develop practical quantum computing internationally and commercially is intense and the stakes in leading in this technology are high. China has already launched a "quantum satellite" as reported in *New Scientist*.[52]

Forking Paths

Explanations of quantum physics involve mathematical formulations incorporating concepts to which I've already alluded in this book, such as hidden variables, coefficients, wave functions, signal processing, spectrographs, probability, and navigating through spaces of potential solutions. I won't here attempt an integrated mathematical theory connecting quantum physics with cryptography. But outside of the mathematics, the field has long prompted physicists and philosophers to propose interpretations about what quantum phenomena mean for our understanding of the world—Neils Bohr (1885–1962) and Werner Heisenberg (1901–1976) among them.[53]

The most interesting theory from the standpoint of the discussion in this chapter pertains to the *many worlds hypothesis* advanced by the physicist Hugh Everett (1930–1982) in a seminal 1957 article. In chapter 5, I discussed the labyrinth to introduce a series of concepts that pervade the cryptographic city. Moving along a branching path, or through a city, involves decision points, junctions at which the traveler continues the journey along one of several paths, even looping back at times. The idea of forked timelines provides a means of accounting for the paradoxical observations evident in quantum physics. Everett's innovative contribution is grounded in mathematics, though he explains the theory in everyday terms as a branching process. He maintains that the observer of the state of a spinning particle is in multiple states: "With each succeeding observation (or interaction), the observer state 'branches' into a number of different states. Each branch represents a different outcome of the measurement and the corresponding eigenstate for the object-system state. All branches exist simultaneously in the superposition after any given sequence of observations."[54] By "eigenstate" he means the definite measured value of a particle state such as the orientation of its spin (up or down). "Superposition" is the combination of two quantum states (both up and down).

This formulation is analogous to traversing each path leading from a junction in a maze simultaneously. The mathematical formulation by which Everett derives his assertion about branching states puts the focus on the timeline of the human observer: "The 'trajectory' of the memory configuration of an observer performing a sequence of measurements is thus not a linear sequence of memory configurations, but a branching tree, with all possible outcomes existing simultaneously in a final superposition with various coefficients in the mathematical model."[55] Though quantum physics is counter-intuitive in many respects, Everett claims that it accords with experience, at least in the laboratory: "The theory based on pure wave mechanics is a conceptually simple, causal theory, which gives predictions in accord with experience."[56]

Others extend quantum theory beyond laboratory experiments.[57] I would note that Everett's many worlds theory does resonate with everyday human experience, in particular the human propensity to speculate about alternative courses of events, to breathe a sigh of relief when things work out, or regret when they don't. The idea of branching timelines predates quantum physics, though the latter has injected a semi-scientific aspect to such narratives.

Two films in the 1990s give expression to branching states existing somehow in parallel. *Sliding Door* (dir. John Madden, 1998) shows what happened to her timeline when a woman was either on time or too late for the closing door of a subway car. *Run Lola Run* (dir. Tom Tykwer, 1998) delivers a series of narratives and subnarratives in a twenty-minute dash by a woman to get a large sum of money that would save her boyfriend's life. The return and replay of events are marked by an extended primal scream from Lola at crucial moments of regret. The connection between alternative timelines and quantum physics is explicit in the mini-series *DEVS* (2020) directed by Alex Garland. It weaves alternate scenarios into a high-tech narrative about a quantum computer. At one point in an episode one scientist dares the other to test his faith in the multiverse by letting go of the guardrail while balancing on the edge of a dam wall. Whether he stays safe or falls depends on the path adopted by this nihilistic drama. Our awareness of risk, the excitement of not knowing an outcome, and the impulse to gamble participate in this multiverse sensibility. That the young scientist both falls and returns to safety in branching timelines is not verified, except we can see such multiple outcomes in fiction, film, and our imaginations. Branched narratives are of necessity selective to create a compelling story, though sometimes the offer of alternative timelines become part of the narrative.[58]

The experiential aspects of quantum physics yield interpretations that appeal to scholars invested in a phenomenological and pragmatic understanding of the world.[59] Further support for this pragmatism comes from the quantum pioneers themselves. Neils Bohr noted the way measuring instruments are complicit in the phenomena observed. He saw that for observations and calculations about subatomic particles "no sharp distinction can be made between the behavior of the objects themselves and their interaction with the measuring instruments."[60] Heisenberg (1901–1976) inflected that insight with his assertion that "what we observe is not nature in itself but nature exposed to our method of questioning."[61]

Everett's theory about parallel worlds relates to multiple timelines in the case of laboratory observations. If quantum states are under constant "observation" by animate and inanimate matter, and via sentient and insensible agency then the proliferation of many worlds extends infinitely.

Drawing on such sources, theoretical physicist Karen Barad in her book *Meeting the Universe Halfway* develops a phenomenological account of quantum physics, inflected by her readings in feminist critical theory and posthumanism: "Phenomena are not the mere result of human laboratory contrivances or human concepts. Phenomena are specific material performances of the world."[62] In other words, "meaning is an ongoing performance of the world."[63] She mentions quantum cryptography in passing as a potential source in her argument. I think that such insights into the world as performance resonate with ideas that place has agency, is its own code—that elements within settings such as cities communicate and deliver not only messages, but also the means of their decryption, which is to say their interpretation. There's a pleasing confluence here, a conflation of "observer and observed, knower and known"[64] or "words, knowers and things."[65]

In this chapter I expanded the hidden dimensions of space and geometry to spaces as products of the imagination. Cities so defined are cryptographic in that they are hidden, require some investigation to uncover, and require some process of communication to transition between them. How do we enter these alternative universes? Here, the allegory of cryptography overlaps or underpins urban imaginaries. These themes come to prominence when we think of the alternative worlds suggested by digital manipulation, virtual reality, cybercities, and many worlds. Like the contents of an encrypted hard drive the alternative reality appears as random noise, until the private encryption key makes sense of it. That is via a portal requiring a code, a key, a secret knowledge. We need the private encryption key for the universe's algorithms to transform the apparently unknowable into something that makes sense. Note the use of visual noise on the computer screens in *DEVS*. In that fiction, images of the past and future emerge from a fog of random pixels as the quantum processing improves.

Speculations about extraterrestrial communications emphasize that the means of decoding are in the code, and developments in quantum physics expand further the human fascination with parallel universes and secret realities, each of which impinges on encryption methods and the cryptographic city. That leads me to consider again that the means of decoding the city are already within the city, though specialized technologies and algorithms provide innovative means of supporting urban affordances.

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