TRACES, MINDS, AND THE WORLDS BETWEEN THEM

A Story of Information

The Long Reach of a Moment

A project by David Jones

Written by GPT-6 (Astra)

GPT-6 (Astra) edition · 2026

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Before the story

Historical scenes follow documented evidence; hypothetical examples are identified in the text. Sources and notes follow the story.

This edition was written by GPT-6 (Astra) in September 2026. It is a separate telling in David Jones's continuing *A Story of Information* project.

The contents and source notes are linked for navigation.

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OPENING

The Voice on the Paper

Someone sings, and a line trembles through the soot.

It is April 9, 1860, in Paris. The inventor Édouard-Léon Scott de Martinville has arranged a machine to catch the movements of sound. Air makes a membrane vibrate. A light stylus follows its movement, tracing a wavering path across paper blackened by smoke.

The song is *Au clair de la lune*.

As the paper moves, the voice acquires a shape. The line follows the movement of the vibrating mechanism. The performance takes seconds. Afterward there is a sheet of marked paper where there had been an event in the air.

Scott's instrument cannot play it back.

He has made a device for studying sound by looking at it. The trace is an object for the eye. Listening to this particular sheet will require a future he has not built.

The singer finishes. The paper remains.

The sheet survives in an archive.

Elsewhere, sound recording becomes an industry. Voices are captured on cylinders and discs, on magnetic tape, in electronic memory. People grow accustomed to hearing someone who is somewhere else, or someone who is no longer alive. A familiar voice can come out of a box. Entire generations learn that this is ordinary.

Scott's trace has to wait.

In 2008, a team working with the First Sounds project and Lawrence Berkeley National Laboratory turns high-resolution images of the old recordings into audible sound. The researchers follow the tracings, work on their distortions, and translate visible movement into a signal that modern equipment can play.

Through the noise comes singing.

Nearly a century and a half separates the two events: a voice moving the air in Paris, and the recovered recording moving the air around new listeners. The original vibrations have long since died away. These are fresh vibrations, produced by a different machine, in another world of rooms and ears.

The line has helped one moment reach another.

Almost nothing else about that April performance has come through with it.

The recording cannot restore the room. It cannot tell us everything the singer was thinking. It cannot bring a person back to answer a question. Even the voice requires careful interpretation, and the first reconstruction will turn out to contain a revealing mistake.

Yet a little of a vanished event is sufficient to cause something new. A listener hears a tune. A researcher revises an account of recording history. Someone hears a human voice from a year they had known only through silent things.

This book follows that long reach.

A footprint can outlast the foot. A cell can inherit a useful change from an ancestor it will never meet. An animal can avoid a danger because of yesterday. A written sentence can alter the life of a person born after its writer's death.

Different mechanisms do this work. They will lead us through chemistry, memory, voices, books, cables, and machines that compose answers. What connects them is a strange opening in the present: something here can stand in a useful relationship to something that is absent.

The relationship can guide a life. It can also mislead one. Making a record survive and making it understood will prove to be different achievements.

For now, there is a blackened sheet, a line that somebody took care to preserve, and people who have learned how to ask it a new question.

A century and a half late, the song begins.

Sources and notes

01

The Shape of an Absence

A foot presses into wet ground.

The surface yields. Weight spreads through the sole. Then the heel rises, the toes push, and the foot leaves. For a little while, the ground retains a shape that makes sense only because something is missing from it.

Most such shapes disappear. Water enters, an edge collapses, another foot passes over the first. Occasionally the conditions are favorable. The impression is covered and protected. Sediment becomes rock. Much later, a person kneels beside an absence old enough to belong to a vanished world.

Ancient footprints preserve parts of actions that bones cannot preserve. A skeleton tells us about a body. A track can tell us where a body put its weight, how it moved, sometimes how several bodies traveled in relation to one another.

It is an event surviving in the consequences of its contact with the Earth.

Long before there was anyone to read such traces, the world was making them.

Light left hot matter carrying properties that later instruments would measure. Crystals grew under conditions reflected in their structure and composition. Deposits formed in water that no longer occupies the places where the deposits remain.

An event changes something else. If the change endures, the later condition can depend on the earlier event. This dependence gives us a way to infer the absent cause from a present effect.

The effect need not resemble its cause. A chemical signature need not look like the environment that produced it. A tree ring does not look like a summer. Its usefulness lies in a relationship that can be investigated.

When different summers tend to produce different growth, a surviving ring can reduce our uncertainty about a summer we never experienced. We still have to consider other influences on growth. The ring does not supply its own explanation.

A trace is a beginning for knowledge, rather than knowledge already finished.

The distinction becomes clear beside a footprint.

One impression might have several plausible makers. Mud can distort the outline. The surface may have changed after the foot left it. A scientist compares other tracks, studies the sediment, reconstructs how a foot and a substrate interact. A conclusion becomes stronger when several kinds of evidence agree.

Even then, the print preserves only part of the walk.

It may constrain the shape of the foot without identifying its owner. It may show a direction without revealing a destination. A set of tracks can record people moving together while leaving their conversation utterly gone.

The lost parts do not become available merely because the surviving part is old and moving.

This is one reason the past can feel so near and so inaccessible at the same time. A thumbprint remains in clay. The pressure of a particular thumb is there to be seen. The day around the thumb has mostly vanished.

Forgetting begins in physics before it becomes a problem for a mind.

An imprint erodes. Ink reacts with its surroundings. Different histories can leave outcomes too similar to distinguish. Once the features that separated them have become inaccessible, recovering which history actually occurred may be impossible in practice.

We should not confuse this ordinary loss of accessible records with the deeper questions physicists ask about whether fundamental evolution preserves information. The practical problem already exists without settling those questions. A room can contain the physical consequences of a broken cup while no available procedure tells us the precise position of every shard a century ago.

Making a trace and retaining a usable record are different accomplishments.

The world therefore keeps a selective history. Hard materials outlast soft ones under some conditions. Dryness preserves what damp destroys. Burial protects an object from one danger and exposes it to another. What survives is shaped by the material, its surroundings, and chance.

This selection does not favor the things we would most like to know.

A beautifully expressed thought can disappear with its last listener. A receipt can survive because it was written on a durable object and put in the right place. Later, an entire life may be visible to us only through the sum that person owed.

There is a second difficulty waiting after survival.

A trace can exist for a long time before anyone knows what to make of it. Scott's line was already related to a voice when nobody could play it. The later researchers added a method of reading that relationship. They did not have to invent the original singer's movements in order to recover something from them.

But they did have to know how the recording worked.

The distinction matters. The past does not become whatever a later interpreter wants. Evidence places limits on an account. At the same time, a surviving object cannot guarantee that someone will understand those limits correctly.

Information begins to look less like a parcel hidden inside matter and more like a relationship among possible conditions. A particular trace rules

some histories in and others out. A receiver can make use of that difference when it has the right capacities and context.

In a familiar human case, the receiver is a mind. The earliest useful receivers in life were much smaller.

Imagine a creature encountering a trace left by food.

If the trace reliably accompanies something the creature can eat, responding to it can make a difference to survival. A chemical that would be incidental to a rock becomes useful to a living organization equipped to detect it.

No reader has to appear with a notebook. The relationship can be used through chemistry and behavior. The organism changes what it does because the present contains a clue about something beyond its immediate contact.

That possibility opens another history inside the history of traces. The world keeps producing differences. Living things evolve ways of finding some of them, preserving some of them, and responding.

To follow that development, we have to go back far beyond footprints, to a time when the history an organism could use was carried inside its own making.

Sources and notes

02

A Past with Offspring

The new genome arrives in a cell that is already alive.

In work reported in 2010, researchers at the J. Craig Venter Institute assemble a bacterial chromosome from chemically synthesized DNA. Its sequence is more than a million letters long, based on the genome of an existing bacterium, with deliberate changes. They transplant it into a suitable recipient cell.

The transplanted genome becomes established. Cells reproduce under its direction. A sequence that passed through computers and laboratory assembly is now being copied by a living lineage.

The achievement depends on what was waiting for it.

The recipient contains membranes, ribosomes, enzymes, and a functioning chemical environment. The incoming DNA enters a world equipped

to use DNA. Without that world, the same sequence would have remained an elaborate molecule.

The experiment makes an old relationship unusually visible. An inheritance needs inheritors capable of putting it to work.

The letters we use for DNA stand for four kinds of chemical unit. Their order can be copied because the units have regular pairing relationships. Separate the two strands of the familiar double helix, and each can guide the construction of a complementary partner, with the help of cellular machinery.

The order matters. But an order of DNA units is different from the chain of amino acids that makes a protein. Cells need a way to connect the two.

In the broad pattern shared by cellular life, a stretch of DNA is copied into RNA. For protein-making messages, a ribosome works along that RNA. Molecular adaptors match groups of three RNA units with particular amino acids. The ribosome joins the amino acids into a growing chain.

A sequence in one kind of molecule guides construction in another.

That relationship is what makes the genetic code a code. It is enacted by molecules whose shapes, interactions, and histories make the correspondence work. There is no tiny reader interpreting the letters. The reading is a physical process.

The protein that results may help move something, detect something, or carry out a reaction. Its behavior depends on its sequence, its folded structure, and the conditions around it. The message has consequences because it enters machinery capable of making those consequences happen.

The machinery itself has an inheritance.

Cells receive much more from their predecessors than an isolated strand of DNA. They arise with existing structures and molecules. They receive a living organization that helps reproduce the components on which the organization depends.

The circularity is productive. DNA helps specify proteins involved in using and copying DNA. RNA participates both as a message and as working material. Membranes maintain conditions in which the other processes can continue. Each generation begins partway through a process already running.

A cell has never needed to rebuild the whole history of life from scratch before it can make breakfast.

The familiar metaphor of a blueprint catches something real about inherited specifications, then begins to mislead. A building contractor can stand outside a blueprint and consult it. The living interpreter of a genome is part of the inheritance too.

This is why the origin of life remains a difficult scientific problem. A modern cell gives us a set of interdependent achievements. Researchers investigate how simpler forms of copying, chemical work, and containment might have developed together. The earliest routes remain unresolved.

What survived those beginnings became capable of passing useful organization forward.

Suppose an inherited change alters a protein so that a cell uses a local food source more effectively. If the change helps its bearers leave more descendants, it tends to spread. Their descendants begin with an ability they did not discover during their own lives.

The ancestral circumstances have become relevant to a future cell through a present structure.

This is a kind of accumulated fit between organisms and their environments. It is not a faithful chronicle of everything their ancestors encountered. Most details leave no inheritable mark. Many genetic changes persist through chance or through connections to other changes. Conditions themselves move on.

An inherited response can be well suited to a world that no longer exists.

Even so, the scale of what inheritance carries is immense. The ability to copy DNA, to make a membrane, to use a fuel, to repair damage: a living thing can arrive equipped with results assembled across a history far longer than its life.

There is no recollection of that history inside it. There are working consequences.

And the same inheritance can be used differently.

In a multicellular animal, cells with very similar genomes become different kinds of cell. Signals and regulatory relationships affect which genes are used, when, and how much. Earlier events in development help determine how later signals will be received.

The sequence alone does not specify what happens independently of those conditions. A message needs a context even here, long before a nervous system can misunderstand a sentence.

This does not make genetic information vague or imaginary. It makes it relational. Alter the sequence in an important place, and the result can change. Alter the machinery or its conditions, and the same sequence can have different consequences.

In the laboratory, the synthetic chromosome succeeds because enough of those relationships remain compatible. The new DNA is accepted into an old way of living. Its instructions help renew that way of living in descendants.

The experiment is dramatic partly because the cell goes on doing such familiar things afterward. It grows. It divides. The achievement appears as another small life beside the first.

Inheritance gives an organism answers to questions its ancestors had time to encounter over many generations.

It cannot specify every circumstance the next individual will meet. Food shifts position. A useful chemical becomes scarce. A harmless place becomes dangerous while the same cell is still alive.

To respond to those changes, organisms evolve ways of using more recent information.

A lineage can carry a long past. A moving cell can also make use of a very small one: the difference between conditions now and conditions a few moments ago.

Sources and notes

03

The Smallest Yesterday

The bacterium swims, tumbles, and swims again.

In a drop of water, its path can look indecisive. It runs for a while, changes orientation, and sets off in a new direction. There is no visible destination and no little face pointed toward one. Yet over time, in the right chemical landscape, the population gathers near something useful.

The trick is partly in the duration of the runs.

When conditions improve along a run, a bacterium such as E. coli can delay the next tumble. When they worsen, it is more likely to change direction sooner. Its turns contain chance. Their timing is influenced by what it encounters.

Longer runs in improving directions gradually bias the wandering.

This is a practical way to find something without holding a map of where it is.

To do it, the cell has to distinguish *more* from *getting more*.

A high concentration of a useful chemical does not tell it whether the current direction is taking it toward still better conditions. For that, the response must depend on change. What is being sensed now has to meet some surviving effect of what was sensed a little earlier.

In experiments reported in 1972, Robert Macnab and Daniel Koshland studied swimming bacteria exposed to sudden changes in an attractant. The whole surroundings could be changed from one uniform concentration to another. There was no spatial gradient for the cells to compare across their bodies. Their behavior nevertheless changed in a way that revealed sensitivity to the recent past.

The experiment used Salmonella. Work across this and other bacteria helped establish how a very small organism can use comparisons through time to guide movement.

Later molecular studies clarified mechanisms of adaptation in familiar chemotaxis systems. Receptor activity affects an internal signaling pathway.

Chemical modifications help the response adjust to the background, allowing the system to remain sensitive to fresh changes.

The present signal meets a body already altered by earlier signals.

The cell's recent history persists in chemical conditions that affect what happens next. This physiological memory requires no conscious recollection.

The smallness of the achievement can be deceptive. A cell has found a way to make two moments interact. The earlier one is gone. Its influence remains, briefly, in an altered mechanism.

The gap does not have to be long to be useful. For the cell, a few moments of comparison can help find food. In later organisms, many kinds of retained change will support behavior over longer intervals. Some will last seconds. Some will help shape the rest of a life.

The histories differ, but the practical opening has appeared: responding to the world can change the apparatus that will respond to it next.

The wandering bacterium also clarifies what makes a difference informative.

A chemical can have many possible effects. It may be a nutrient, a poison, a signal, or irrelevant to a particular organism. Which effect matters depends on the organism and the circumstances.

The molecule does not carry a universal label announcing what it means for every creature. A useful relationship has to exist between the condition, the detector, and the response.

Evolution can build that relationship. Organisms whose responses work better in their environments can tend to leave more descendants, which inherit the relevant machinery. Across generations, the detector can become fitted to certain features of the world.

This fitting allows a response to be useful without being infallible. A chemical can accompany food in one setting and become misleading in another. Organisms can respond to a cue when the usual resource is absent. The same arrangement that lets a creature use a sign makes it possible for the sign to fail it.

A trap can work by supplying the expected cue without the expected reward.

For the bacterium, the useful past does not last forever.

Adaptation lets the system respond to new changes instead of remaining trapped in its reaction to an old one. Retaining everything would not necessarily improve the journey. A memory has a timescale fitted to the work it does.

This, too, will return in larger lives. A system can need both persistence and release. It can need to preserve a useful difference while allowing yesterday's conditions to stop governing today.

Under the microscope, the cell continues its broken line through the water. There is no drawn route ahead of it. Each run gives it new conditions to respond to; each response helps decide how long the run will continue.

From enough of those small adjustments, a direction emerges.

Sources and notes

04

The Room That Will Not Stay

In April 1955, a young man entered a room to be examined by the psychologist Brenda Milner. Just before entering, he had spoken with another researcher, Karl Pribram. He could no longer recall the conversation.

The man was Henry Molaison, known for decades in the scientific literature by the initials H.M. Two years earlier, surgery intended to relieve severe epilepsy had damaged structures deep in both sides of his brain. Afterward, he had profound difficulty forming lasting memories of new events.

He could participate in a conversation. He could perceive, reason, respond. But the encounter could disappear from his accessible past while it was still fresh in the other person's mind.

Something most of us seldom notice had become visible through its failure: an ordinary meeting contains at least two achievements. There is being able to take part in it, and there is being able to carry it away.

Yet Molaison could acquire certain skills.

In experiments reported by Suzanne Corkin in 1968, he practiced tasks involving coordinated movement. One required keeping a stylus on a target that moved around a rotating surface. With practice, his performance improved. When tested again after a delay, some of that improvement remained.

Here was a second route by which a vanished experience could enter the present. The training did not have to return as an episode he could describe. It could return as a greater ability to do the task.

The distinction was profound because the everyday word *memory* conceals a crowd of capacities. Recognizing a familiar person, remembering an appointment, knowing a word, and balancing on a bicycle do not all depend on exactly the same

machinery. Injury can disrupt them differently. Learning can survive where a particular kind of recollection has been severely damaged.

Molaison's past had not become uniformly inaccessible. Nor had he become an empty person. The unevenness of what survived helped researchers discover the uneven architecture of what they had been calling one thing.

The hand could arrive better prepared than the conscious account of how it had learned.

A nervous system gives experience many ways to leave consequences.

Cells connect. Signals cross their junctions. The effectiveness of those connections can change; so can other properties of the cells and the circuits they form. A later event therefore encounters a system with a history.

In an experiment published in 1973, Timothy Bliss and Terje Lømo delivered brief trains of electrical stimulation to a pathway in the brains of anesthetized rabbits. Subsequent test signals produced stronger responses. In some experiments, the enhancement persisted through hours of observation.

The experiment demonstrated that earlier activity could produce a durable change in how a neural pathway responded later.

Learning requires many mechanisms, and this kind of change is one important part of the scientific account. The point is not that a brain contains a secret shelf of tiny pictures. The tissue that meets the next moment can be altered by the last.

From there, the accomplishments become astonishingly varied. Practice can make a movement more reliable. An encounter can make a face familiar. Experience can make a sentence comprehensible, or a once harmless sound frightening. A life is continually changing the conditions under which the rest of that life will be lived.

This allows the past to become useful without being preserved intact.

You can understand the next word in a conversation partly because of words you have already heard, partly because of years of speaking the language, and partly because of what you know about the person speaking. Different stretches of history meet in the same act of listening.

There is no need to retrieve every earlier sentence in order to understand this one. Much of what experience has given you is available as an ability, an expectation, a readiness to notice.

You may remember only a handful of the occasions on which you learned to read. Those lost occasions are nevertheless helping you now.

This is an intimate form of historical influence. Your present capabilities depend on events you cannot call back. A teacher's effort can survive in a skill long after the particulars of the lesson have gone. A childhood game can leave a coordination that its adult owner no longer connects with the game.

The event need not remain available as a story for its effects to continue.

Even when an event does return as a story, remembering is not guaranteed to reproduce it faithfully.

In experiments published in 1974, Elizabeth Loftus and John Palmer showed people films of car accidents and then asked questions about what they had seen. A small change in the wording of a question changed the answers. People asked how

fast the cars were going when they “smashed” into one another estimated higher speeds than people given gentler collision words.

In a second experiment, the effect reached a later report. A week afterward, participants who had received the “smashed” question were more likely to report having seen broken glass. There had been none in the film.

The experiment measured what people reported, not a recording of what they experienced inside their minds. But it showed that the path from event to later account can be affected by words encountered along the way.

The witness had seen one thing. The witness had then been asked about it in a particular way. Both encounters could matter to the eventual answer.

This vulnerability can accompany a useful openness. A system that can connect new information with old experience can learn, reconsider, and understand more than it understood at first. Those processes can also leave room for suggestion and confusion. Reliable remembering is an accomplishment of living machinery, supported or disturbed by the conditions around it.

The remarkable thing is how much of an absent world we can make present enough to use.

You can prepare for winter in summer. You can avoid a road because of something that happened there years ago. You can imagine someone opening a gift and change what you choose to give them. A remembered past helps construct a possible future; that possible future changes what your body does now.

None of this requires the future event to have reached backward in time. What acts now is your present imagining, made possible by what you have learned.

And once a creature can be moved by something it remembers or imagines, another possibility opens. A second creature may be able to bring such a thing to its attention.

You do not have to have been there.

Someone can tell you.

Sources and notes

05

The Journey Made of Air

Inside a honeybee colony, a forager moves across the comb. The flowers she has visited are elsewhere. Their location is now affecting a dance.

The dancer runs forward while wagging her body, turns, returns, and repeats. Features of the movement convey an approximate direction and distance. Other bees follow at close range. The comb may be dark; this is a communication carried through movement, contact, vibration, and the senses bees bring to it.

Then a recruit leaves the hive and flies toward a place she has not learned by making the forager's original trip.

Researchers have followed such flights with radar. The communicated direction and distance influence where recruits go; odors and other cues help them find the source. A patch of flowers has changed events inside a hive, and those events have changed a second flight back into the landscape.

The first journey has become useful to a body that did not make it.

It would be easy to reserve this crossing of absence for ourselves. The bees make that impossible.

They also complicate another comfortable division: inherited instinct on one side, learning from others on the other. In a study published in 2023, young bees deprived of opportunities to follow experienced dancers still danced, but their first dances were less orderly and less accurate. Some aspects improved with experience; a difference in distance signaling persisted.

An inherited capacity was being shaped by a social life.

This is not human language in miniature. The dance does not offer the open range of expressions that lets us discuss a flower, deny that it exists, invent a blue flower that sings, or argue about whether flowers should be picked. Its achievement is particular. Precisely that particularity makes it worth seeing clearly.

There are many ways for one organism's experience to help organize another organism's behavior. Human language arose in a living world already full of signals.

We do not have a recording of the first conversation.

Speech leaves no inevitable fossil, and languages change as their speakers change them. The capacities supporting language have evolutionary histories; particular languages have histories of communities, contact, invention, and loss. No surviving object lets us point to one ancestral afternoon and hear the first word spoken.

We can, however, notice what language permits now.

Consider a simple invented warning: *The bridge beyond the orchard is broken.*

The listener need not see the bridge. They may never have seen this particular bridge at all. If they understand the words and trust the speaker, the sentence can change tomorrow's route.

The air that carries the warning does not resemble an orchard. Nothing in the sound has the weight or shape of a broken bridge. Its usefulness depends on a shared language, some knowledge of the world, the immediate setting, and judgments about the person speaking.

Change one word—*repaired*—and the same listener may choose the opposite route. Add *I heard*, and the listener receives a claim about how the speaker knows. Add *if*, and a condition enters. Add *pretend*, and the parties may step into an imagined situation while knowing they have done so.

Small changes in a present signal can organize large changes in what people consider possible.

Meaning lives partly in arrangements between people.

In an experiment reported in 2005, Bruno Galantucci placed participants in a coordination game. They could exchange graphic signals, but the medium prevented them from simply using ordinary writing. Working together, pairs developed forms they could use to coordinate their actions.

A mark acquired a role through use. Its shape alone did not contain a full explanation for a stranger. The participants had a history of making it, responding to it, and discovering whether the response helped.

These were adults who already knew language; the experiment did not replay its prehistoric origin. It made something about convention visible. A form can become a sign because people establish how to use it together.

Ordinary language gives a child a much richer inheritance. Long before the child can define a word, other people are using it in shared activities. Things are pointed out. Requests succeed or fail. Stories are told again. Misunderstandings are repaired.

The word becomes available inside a life, and that life becomes capable of reaching more of the world through words.

Not all language travels in sound. Signed languages make the capacity visible in moving hands and faces. The achievement belongs to the structured activity and its users, rather than to air as a uniquely privileged substance.

With language, cooperation can begin before its object exists.

People can agree where to meet before anyone has arrived. They can divide the work of building something that is still only a proposal. They can promise to help at a birth, trade after a harvest, return after a journey.

A possible event becomes a shared subject. Each participant can act partly because of what they understand the others intend to do.

The scale of the change is easy to miss because it is so ordinary. A few sentences at breakfast can coordinate bodies across a town all day. No one has to remain within sight of everyone else. Their actions can be joined by an arrangement that persists in several memories.

Language also makes experience available without requiring its repetition. Someone who has been burned can teach a child about a hot surface. A person who has survived a dangerous passage can describe it to someone preparing to leave. A skill can be demonstrated and explained; a failed explanation can be tried again.

The community gains routes through experience that do not all have to pass through the same bodies.

And it gains stories.

A story can carry more than the instruction at its end. It can arrange what a listener notices first, what remains unknown, which choice seems reasonable before its consequences become clear. It can let someone encounter the shape of a mistake without suffering the whole original cost.

It can also give form to a life other than the listener's own. Words can make a stranger's departure worth waiting through, make an unfamiliar place imaginable, make a loss intelligible from the side of the person who bears it.

The listener is doing much of the work. A teller supplies a sequence; the listener supplies memories, associations, expectations, and attention. The story takes place through their meeting.

This is why identical words need not produce identical experiences. A child and an adult can hear the same tale and find different rooms inside it. A person returning to an old book can discover that the sentence stayed still while their ability to read it changed.

For spoken words to travel beyond the original encounter, someone must carry them onward. Oral traditions have developed many ways to do that:

repetition, rhythm, performance, teaching, and the shared work of communities who know when a telling has gone astray.

The knowledge is alive in its practice. Its continuation depends on people able and willing to practice it.

But imagine being able to leave an invitation in a room you have departed, where it can wait until someone arrives. Imagine an agreement that neither party must recite from memory. Imagine a sentence that can cross a lifetime without being spoken during every generation of the crossing.

For that, the words need a different way to wait.

Sources and notes

06

The Hand That Stayed

Partway through the invitation, the handwriting changes.

The principal text has been written by a scribe. Near the end, Claudia Severa adds a greeting in her own hand. She wants Sulpicia Lepidina to come to her birthday celebration on the eleventh of September. The surviving closing includes a brief insistence: “I shall expect you, sister.”

The invitation is roughly nineteen centuries old.

It survives on thin wood from Vindolanda, near the northern frontier of Roman Britain. Across that distance, the document preserves something smaller than an empire: a woman arranging for another woman to be with her on a particular day.

We do not know from the tablet whether Lepidina came. The marks cannot give us the party, the weather, or the conversation. They preserve an effort to make a meeting happen.

The handwriting changes, and the effort becomes more particular. Someone whose hand we will never see is still represented by the way it moved.

Writing lets a sentence remain somewhere its speaker is not.

That sounds almost too simple to account for the transformation. Yet consider how many limits it changes at once. The recipient can arrive later. The message can travel with someone who did not compose it. The words can be consulted again after the first reading, compared with other words, argued over, copied.

The sender no longer has to be present at every encounter with what was said.

Writing does not accomplish this by making meaning visible to anyone with eyes. A person who has never learned the script may see Severa's marks as clearly as a scholar and understand none of the invitation. The text must meet a reader with the relevant language and conventions, or a chain of readers who can translate it.

The wood preserves marks. A living practice makes the marks readable.

Our access to the invitation therefore crosses two histories at once: the material history that allowed an object to survive, and the history of knowledge that allows us to use it. Lose either, and a different kind of silence follows.

Writing has several beginnings.

The evidence points to independent developments in Mesopotamia, Egypt, China, and Mesoamerica, although the earliest relationships and precise sequences remain subjects of research. People made marks for accounting, authority, ritual, names, dates, speech, and other purposes. These practices did not all develop in the same order or under the same pressures.

There was no single doorway through which every society had to walk. Nor did a new writing system automatically replace the knowledge already held in voices, gestures, and skills. Written and oral practices could become partners, rivals, and parts of the same occasion.

The profound common possibility was that a mark could be made to stand in a dependable relation to something beyond itself, and that people could learn to use that relation together.

A name on a surface could identify someone who had gone. A count could persist after the goods were moved. An obligation could wait for the season in which it came due.

Roughly two millennia before Severa's invitation, a clay tablet recorded a debt in an Assyrian trading community in Anatolia.

Two men owed Ashur-idi six minas of silver, approximately three kilograms. A portion was to be repaid at the next harvest. Witnesses and seals helped establish the transaction; conditions addressed overdue payment.

The future harvest had become part of a present arrangement.

The clay did not grow the crop or collect the silver. It made a particular account of the obligation available across time. When the harvest arrived, the parties did not have to depend entirely on their memories of what had been agreed.

That change reaches deeply into collective life. People can coordinate actions whose benefits and costs fall in different seasons. A merchant can leave. A witness can be consulted through a record.

A disagreement can turn partly on words made before either party knew which later interpretation would favor them.

The record acquires force through the people and institutions prepared to use it. A tablet alone cannot compel repayment. An invitation alone cannot compel attendance. Their power consists in what happens when preserved signs enter the lives of readers.

Writing also makes language available for a new kind of attention.

A spoken sentence unfolds. Unless someone repeats it or records it, its beginning has gone by the time its ending arrives. A written sentence can be inspected as an arrangement. The reader can return to the first word, compare it with the last, and notice a conflict that passed unnoticed in the flow of speech.

The writer can do the same before anyone else encounters it.

A thought can leave the head, acquire a visible form, and come back through the eyes as something its author can examine. A missing step becomes easier to find. An argument can be extended beyond what one person can comfortably

hold in mind at once. A list can help someone think by taking over the work of keeping the items available.

The surface becomes part of the activity.

You can experience this with a difficult explanation. Try to keep all its pieces in mind. Then write them down. The marks have not suddenly become intelligent, but the arrangement of person and page can accomplish something the person was finding difficult alone.

Language has gained a place where it can remain while its maker changes it.

For a reader born later, that remaining can become an encounter the writer never anticipated.

Severa expected her invitation to have an immediate use. We approach it for other reasons. A historian studies social relations. A specialist studies the script. Another reader notices the affectionate closing and finds the long distance briefly easier to cross.

The document can support all these uses without having been made for them. The later reader asks a new question of the old trace.

This will become one of the great productive accidents of information: people preserve something for one reason, and descendants find another.

But the accident requires the object to arrive. A sentence may survive its speaker and still fail to survive a damp room, an abandoned language, a decision that the writing surface would be more useful for something else.

Severa's hand stayed. Most hands did not.

Sources and notes

07

What the Fire Did Not Take

The page has been written on twice.

The newer writing belongs to a prayer book completed in Jerusalem in 1229. Beneath it are remnants of older texts whose parchment was reused. Among them are mathematical works of Archimedes.

The earlier ink had been scraped or washed away to make the material available for another purpose. Enough remained for later investigators, using imaging methods unavailable to the prayer-book maker, to recover writing that ordinary inspection could no longer read.

A work partly erased had traveled into the future inside the work that replaced it.

The object is known as the Archimedes Palimpsest. Its survival refuses a simple story of enlightened preservation opposed to ignorant destruction. Reuse damaged the older text. The resulting book also carried its remnants through cen-

turies they might otherwise never have crossed. The prayer book had its own value to the people who made and kept it. We do not need to invent their hostility to mathematics to understand why useful parchment was used again.

Two histories occupied the same skin. Eventually, people learned to see both.

The physical life of a page begins far from the words.

Parchment requires an animal skin to be prepared, scraped, stretched, and dried. Papyrus is made from plant material arranged into a writing surface. Paper has its own histories of fibers, water, labor, and technique. In European rag papermaking, discarded cloth could be broken down into pulp and formed into sheets.

Before a sentence can wait for a future reader, someone must make a place where it can wait.

Then someone must keep that place usable. Books need protection from water, insects, rough handling, and ordinary neglect. Collections need space and labor. If a text is to spread, someone must make another copy, acquire a copy, or grant access to one already made.

None of these requirements belongs to the meaning of the sentence. All of them can decide whether the meaning reaches anyone.

The story of an idea therefore includes people who never proposed it: the maker of the sheet, the person who copied the text, the caretaker who kept the room dry, the reader who judged an old volume worth retaining when space ran short.

Some of the longest intellectual journeys depend on acts that would not look intellectual from across the room.

A spectacular fire gives loss a date. Much loss has no such event.

A book can disappear because the last copy wears out. A collection can disperse when an institution loses its support. A language can cease to be understood by the people who possess its records. A work can survive in a catalogue after the work itself is gone.

The damage accumulates through small decisions and changing circumstances, often without a witness who thinks to record it. By the time someone asks for the missing text, the last opportunity to preserve it may be generations past.

This makes the surviving record a deeply uneven guide to the lives that produced it. We have what people chose to write, what others chose to copy, what accidents spared, and what later readers learned to recognize. These are several filters, and they do not all select for truth, beauty, importance, or kindness.

A surviving decree can tell us more about the institution issuing it than about the people it governs. A missing letter cannot tell us that no one loved. A gap in a register is a gap in a register before it is evidence that a life did not occur.

In Lebanon, Tennessee, in April 1866, a certificate recorded the marriage of Thomas Harris and Jane Harris, whose earlier surname was Shute. The document stated that they had lived as husband and wife for approximately fifteen years. It also recorded their children.

The family had a history before this legal recognition.

The certificate belongs to the records of the Freedmen's Bureau, established as the American Civil War neared its end. Such records can help descendants and historians recover relationships

that slavery had denied full legal standing. They are also incomplete. What they make visible must not be confused with everything that existed.

For the institution, the document recorded a formally recognized marriage. For a later researcher, it provides evidence. For the people named, the relationship it describes had already occupied years of life.

The paper did something consequential without creating the family whose existence it acknowledged.

Libraries hold this tension in physical form.

They make an extraordinary bargain possible: one life can encounter work that required many lives to produce. A reader can move in an afternoon among authors separated by centuries, compare their accounts, borrow a method, discover a question that had already troubled someone else.

But the apparent ease of the encounter conceals the work that made it available. A book on a shelf is the current end of a chain of successful handoffs. Sometimes the chain is deliberate. Sometimes an object is forgotten in conditions that hap-

pen to preserve it. Sometimes the work survives because another culture finds a use for it, translates it, and carries it onward.

The knowledge does not float above this history. Its availability is one of the history's achievements.

And preservation is only the first part. A collection no one can navigate may hold an answer without making that answer findable. A manuscript no one can read may preserve distinctions without permitting anyone to use them. Catalogues, indexes, dictionaries, translations, and teachers become ways of opening what has physically survived.

An archive needs paths as well as walls.

At the Walters Art Museum, Abigail Quandt began disbinding the palimpsest in February 2000. She finished in November 2004. The older texts ran through the prayer book's gutter; preparing them for imaging required taking the fragile book apart.

Part of the spine had been repaired with a twentieth-century adhesive tougher than the parchment itself. Removing it became the chief obstacle to separating the book.

Quandt mapped the condition of individual leaves. She removed wax that covered writing and carefully unfolded damaged areas to expose text. Where the parchment needed support, she used Japanese paper. Fragments were logged and stored. Local humidification helped relax leaves that would not otherwise lie flat enough for imaging.

The priorities had an order: protect the document, then prepare it to be read. After imaging, Quandt did further work to stabilize the leaves. Each was enclosed in a double-sided frame, ready to be shown without asking the parchment to bear another reader's handling.

Sources and notes

08

A Thousand Identical Mistakes

The rhinoceros has an extra horn.

It rises from the animal's back, just behind the shoulders. Around it, the body appears fitted with elaborate armor. The image is forceful, detailed, and wrong in memorable ways.

Albrecht Dürer made the woodcut in 1515. He had not seen the living rhinoceros brought to Lisbon from India. He worked from a description and an image that had reached him. His representation then traveled much farther: impressions, copies, and adaptations carried this animal into the expectations of readers who had never seen a rhinoceros either.

The mistaken horn could be reproduced as faithfully as anything else on the block.

There is a temptation to treat that as a failure of printing. In a crucial sense, the printing was working. A prepared arrangement could make many substantially matching images. Whatever the ar-

rangement contained—an observed detail, an inference, a misunderstanding—could arrive again on the next sheet.

The method had become good at keeping a promise about the marks.

What the marks said about the world was another matter.

Long before Dürer's animal, another printed object had made a different journey.

In China, a Buddhist text known as the Diamond Sutra was printed from woodblocks in 868. Its dated colophon names Wang Jie, who sponsored its production for distribution on behalf of his parents. The surviving scroll is formed from seven sheets and extends roughly five meters.

It is the earliest complete dated printed book known to survive. The careful wording matters: it is a surviving witness to an established practice, not the moment when all printing began.

Here, multiplication serves devotion. A text is made so that other people may encounter it. The labor of preparing the blocks can produce re-

peated impressions; the same arrangement of characters can reach more than one reader without being written afresh for each.

In Korea in 1377, the Buddhist work Jikji was printed using movable metal type. Its surviving second volume is the oldest surviving book made by that method. A woodblock edition followed the next year. Different techniques could coexist because the practical question was how to make the desired books under the conditions a particular workshop and community faced.

Printing has many histories of materials, scripts, institutions, and purposes. The surviving objects give those histories dates and places. They do not turn them into one inevitable procession toward a European workshop.

In Mainz in the mid-fifteenth century, the Gutenberg Bible demonstrated the possibilities of a European system of metal type and presswork at a demanding scale. Pages were printed and then completed with work by hand. The new method arrived inside a world of existing bookmaking skills.

Movable type allowed a workshop to compose a page from reusable pieces, print copies, and use the pieces again for other pages. Much of the difficulty moved into making the materials reliable and arranging the text correctly before the run. Once the arrangement worked, more impressions could follow.

The consequences extend beyond cheaper repetition. A text can acquire a population of copies. Different readers can possess versions close enough to serve as a common point of reference. An author can reach people they will never meet; a reader can recognize a passage encountered by another reader far away.

This does not make every copy identical. Printing introduces its own errors and variations, and individual copies can be corrected or decorated differently. But it changes the practical scale at which closely matching texts can exist.

The page begins to gather a dispersed company around itself.

Consider what happens when an error enters such a company.

In a single manuscript, a mistaken word belongs to one object and whatever descendants are copied from it. In a print run, an error in the prepared text can be repeated across many sheets before anyone notices. A process that reduces variation among copies can make those copies agree in being wrong.

Agreement becomes easier to find without necessarily becoming better evidence.

If ten books repeat the same account because nine copied the first, the reader has ten appearances of a claim and only one underlying source. The multiplication is real. The independence is not.

Dürer's rhinoceros makes this problem wonderfully concrete. Imagine a reader who has met the extra horn in several books. Its recurrence may make it seem better established. Yet the repeated appearances can belong to the history of an image, rather than to several separate encounters with living animals.

To understand what the books establish, the reader must sometimes follow the claim backward through its copying.

The same capacity that spreads an observation can spread the appearance of many observations.

Yet shared copies also make a new kind of disagreement possible.

Two readers can look at the same passage and identify exactly where they part company. A critic can point to a diagram, a calculation, a sentence. Another reader can check the reference and follow the objection without finding the original author.

Error has become easier to distribute, and easier to give an address.

This is one of printing's most consequential openings. A claim can stand still long enough for many minds to work on it. They can correct it, extend it, use it in a new setting, or discover that it conflicts with something else that has also been made publicly available.

Knowledge gains something like a shared workbench. The tools and objects can be imperfect; people can disagree about what they are doing. Still, they can return to the same piece of work and show one another where it needs attention.

This helps explain why copying matters even when it contributes no new sentence of its own. The copy changes who can participate in what happens next.

The rhinoceros remains on the page with its impossible horn. Printing can preserve that horn indefinitely within a tradition of copies, provided people keep making and keeping them. Better copying alone will never remove it.

For that, someone must bring the image into a different relationship with the animal.

They must look again, obtain better evidence, and make the comparison available to others. The shared picture gives them something to question. The living world supplies resistance to the answer already on the paper.

A century and a half after Dürer's rhinoceros, another printed creature would invite readers to perform that encounter for themselves. It was common, tiny, and much less likely to be mistaken for a beast from a distant country.

It was a flea.

Sources and notes

09

Let the World Answer

Enlarged across a printed plate, the flea becomes formidable.

Its jointed legs, bristling body, and small armored surfaces demand an attention the unaided eye rarely gives it. In Robert Hooke's Micrographia, published in 1665, familiar small things arrive with structures many readers had never been able to inspect.

An instrument has changed the scale of the encounter. A printed image has made the encounter available to people who were not looking through that instrument.

But Hooke offers more than impressive pictures. He describes ways of observing, preparing specimens, and assessing magnification. In his preface, he explains that he examined objects under different lighting and from different positions before drawing them. Shadows can mislead. A hollow

can be confused with a projection. A striking view can require another view before the observer knows what it shows.

The picture is accompanied by an account of how a person might check it.

This changes the relationship between author and reader. The reader is invited to do something beyond accepting or rejecting the image on trust. They can attempt an encounter with the thing represented.

The difference between Dürer's rhinoceros and Hooke's flea is not a difference between one age that believed and another that suddenly learned to see.

People had tested claims against experience long before either book. Careful observation and practical knowledge have many histories. Nor does an instrument remove the need for interpretation; Hooke's attention to misleading illumination makes that plain.

What these objects let us notice is a particular arrangement of information. A representation travels together with enough of its method to invite further observation. Another person can ask whether the result depends on the original observ-

er, whether it persists under changed conditions, and whether a different explanation fits what happens.

The distant author need not be present for the investigation to continue.

Writing and printing help extend the encounter across people and time. Instruments help expose distinctions that ordinary senses miss. A community willing to compare methods and results can join these capacities into a practice of correction.

The world enters the argument as something more than a source of examples chosen to support it.

Hooke also describes a way to estimate how much his instrument enlarges a view. He looks through the microscope with one eye while looking at a divided ruler with the other. The two apparent sizes can be compared.

The magnificent flea depends on an operation almost comic in its bodily particularity: a person keeping two views available at once, using one to measure the other.

Without a scale, a large drawing can impress without telling the reader how large the object is. With a stated magnification, the image gains a relation to a measurement. Someone else can compare their result on more than the strength of an impression.

This is part of the work by which a private sight becomes a shareable observation. The observer makes the conditions of the sight available: the instrument, the preparation, the scale, the ways appearance changes when the light moves.

A later observer can then ask a more exact question. Does a difference between the pictures belong to the specimens, the instruments, the preparation, or the drawing? What could be changed to find out?

The published image begins another encounter with the thing it represents.

This gives error a different possible career.

An error can be copied until it looks authoritative. It can also be made specific enough to teach. A recorded prediction and a recorded outcome can remain side by side after the person who expected them to agree has changed their mind.

That pairing is precious. Memory alone may soften the discrepancy. A confident speaker may explain it away. But a public record can let another person see exactly what was expected and what happened instead.

The past becomes available as a constraint on the present account.

This is why the unglamorous parts of inquiry matter: identifying a specimen, retaining measurements, describing a procedure clearly, distinguishing what was observed from what was inferred. They help a future reader decide what the record permits and what it does not.

Without them, a result can arrive as a sealed assertion. With them, it may arrive as work another person can enter.

Sometimes the second look comes much later.

At White Sands in New Mexico, fossil human footprints were dated to a period around twenty-three thousand to twenty-one thousand years ago. The initial dating used seeds from aquatic plants. Critics raised a reasonable concern: old carbon dissolved in water can make aquatic material appear older than it is.

Researchers then used other evidence from the relevant layers. They dated pollen from terrestrial plants and examined quartz grains with a method sensitive to the time since exposure to light. The independent checks strengthened the case for the footprints' great age.

The objection had not made the footprints less real. It had identified a way the first interpretation might be wrong. The additional work addressed that possibility with evidence of a different kind.

This is what a productive disagreement can do. It tells an inquiry where to look next.

The people who made the prints are absent. The record cannot recover their whole lives. Yet more than one feature of the surviving ground can help constrain what we say about when they were there.

Shared inquiry is difficult because its participants are human.

They have ambitions, habits, loyalties, limited time, unequal access to instruments and audiences. A correct result does not announce itself with a physical glow. An institution can resist a better account. A fashionable method can conceal a common error.

The achievement is therefore not a community in which no one is biased. It is the development and maintenance of ways to make some errors discoverable despite the people making them.

Comparison matters. Independent evidence matters. So does the possibility that someone outside the original circle can obtain the work, inspect it, and offer a better account. The more consequential the claim, the more valuable it becomes to know how it could fail a test.

Information grows into knowledge through these activities. It does not acquire that status simply by accumulating.

Return to the flea on Hooke's page.

The creature is still the subject. The deeper invitation is an action: bring this account into contact with something you can examine. Change the light. Turn the specimen. Check the scale. Notice what the drawing leaves uncertain.

A printed page can recruit another observer into unfinished work.

That observer may live far away. For much of history, their response must travel by the old routes: a person, a horse, a ship. The thought can be quick; its journey cannot.

Then people begin laying a path across an ocean on which a message can move while the messenger stays home.

Sources and notes

10

The Ocean Between Two Words

In August 1858, a message from Queen Victoria to President James Buchanan took about sixteen hours to transmit across the Atlantic cable.

By the standards of a later age, the delivery was painfully slow. By the standards of the ocean around the wire, it was extraordinary. Words had crossed without waiting for a ship to carry their physical inscription from one shore to the other.

The cable had required ships, of course. It required manufacture, transport, laying, connection, instruments, operators, and all the work needed to keep a long, vulnerable physical system functioning. The message's apparent escape from transportation rested on a vast act of transportation already performed.

The first cable failed within weeks. A durable transatlantic connection followed in 1866.

The ocean remained. The delay it imposed on conversation had changed.

Before electrical telegraphy, a long-distance message commonly moved with a material carrier traveling the route. A letter could cross a sea because a ship crossed it. The recipient's answer had to make the journey back.

Decisions were made inside those intervals. A trader acted on prices already old. A family waited for news from someone who might by then be somewhere else. A question could travel outward while the circumstances that had prompted it disappeared.

Telegraph systems altered the relation between the speed of a message and the speed of the people concerned. Changes in an electrical system could be used to carry distinguishable signals. Operators could turn words into patterns, send them, and reconstruct words at the other end.

The route now joined two acts of attention much more closely in time.

People separated by an ocean could participate in events as those events were still developing. A distant reply could arrive soon enough to change the next decision. The interval between asking and acting could contract from the scale of a voyage toward the scale of an exchange.

That is more than faster delivery. It changes what can be coordinated at all.

The physical challenge was not to make a signal exist. It was to keep differences distinguishable after the journey.

A long cable changes the signals sent through it. Electrical effects spread and distort pulses; weaknesses in insulation and other faults can disrupt the system. The receiver must be able to tell which pattern the sender intended despite what the route does to it.

Simply forcing the system harder is not an unlimited remedy. Materials have limits. Equipment can be damaged. A useful message depends on a successful arrangement of the whole path, from encoding to recovery.

At the far end, a small distinguishable movement can stand for a decision made on the other side of the sea. The energy of the original voice is unnecessary. The speaker may never have spoken the message aloud. What must survive is a usable distinction among alternatives.

Was this the signal for one character or another? Did this pulse belong to the previous group or the next? Has something arrived that the agreed code allows a receiver to recognize?

These questions will eventually be gathered into a theory powerful enough to apply to cables, radio, disks, and many other media. First, people have to make them work in actual apparatus, through trial, measurement, and repair.

Faster messages also change the experience of absence.

A person far away can become reachable without becoming nearby. Their news can interrupt a room in which they are not standing. Their request can alter an afternoon. Their reassurance can arrive while reassurance still matters.

Later, telephony will carry the changing shape of a voice, and recording will let a performance wait. The two capacities are different: crossing distance quickly and crossing time patiently. Together they allow a person to encounter a voice that belongs neither to the same room nor to the same moment.

Scott's soot-marked paper belongs to this second adventure. His trace waits while other messages race. Both depend on arranging matter so that one event can help produce a related event elsewhere or later.

The inventions enlarge the range of human presence without abolishing the difference between a person and their message.

On April 15, 1912, Honolulu's Evening Bulletin carried a headline announcing: "All Titanic Passengers Saved."

The statement was false.

The report belonged to a rapidly changing stream of news after the ship's sinking. It carried an assurance attributed to a shipping-line official; later coverage would tell a different story. The surviving newspaper lets us see an account before its correction arrived.

The headline describes people as alive who were not. A message can cross a vast distance correctly enough to reproduce a claim while failing to describe what happened.

The transmission problem and the knowledge problem have parted company.

A receiver might obtain every character the sender meant to send. That accomplishment cannot establish whether the sender's account is true. Another observation, another witness, another inquiry is needed.

The speed of arrival can even make the distinction harder to notice. News appears while events still feel immediate. The distance crossed is impressive. The channel's success lends the statement an authority the channel itself cannot justify.

The better the channel becomes, the more clearly its particular task can be separated from all the other tasks surrounding it.

Suppose the sender has chosen a message. Can a system deliver that choice reliably through a route that sometimes damages it? How much can the route carry? How should the signal be arranged so that damage can be noticed, perhaps even repaired?

A mathematics of these questions will help build the world in which almost any kind of recorded media can become a pattern of bits.

It begins by putting the meaning of the message to one side long enough to understand how to get the message through.

Sources and notes

11

How to Keep a Promise to a Bit

Imagine that we agree on two possible replies to an invitation: yes and no. We also agree to send them as 1 and 0.

You send a 1. Something along the route changes it. I receive a 0.

The error is physically small and socially complete. I believe you are not coming.

Now suppose we agree to send each choice three times. A yes becomes 111; a no becomes 000. If the route changes only one position, I can still recover the intended choice. Receiving 101, I use the majority and recover 1.

We have spent extra signals to make the message resistant to a particular amount of damage.

If two positions change, the same rule can lead me astray. The protection has conditions. Yet under those conditions, it does something striking: the damaged message contains enough structure to help repair itself.

Claude Shannon's 1948 theory of communication gave such problems a general mathematical framework.

He considered sources that choose among possible messages and channels that carry signals subject to constraints and noise. Information, in this framework, concerns the alternatives and their probabilities. Learning an outcome reduces uncertainty about which possibility occurred.

If two possibilities are equally likely, learning which occurred supplies one bit of information. The word *bit* names a binary unit, a distinction between two alternatives. A physical device can represent that distinction through two states it can reliably tell apart.

Those states may be voltages, magnetic arrangements, marks, or other physical conditions. The abstraction allows engineers to reason about the distinction without confusing it with any one material used to carry it.

But the distinction still needs a material realization whenever an actual message is stored or sent. A bit in a working device is never rescued from physics by having a mathematical name.

One bit can matter enormously to a person.

If you are waiting for the answer to a question on which your future depends, the difference between two replies may change your life. If you are waiting for the outcome of an unimportant coin toss, the same amount of uncertainty can vanish with almost no personal consequence.

Shannon's measure does not confuse these situations. It deliberately measures a different aspect of them. The engineer needs to know what must be distinguished and how reliably it can be conveyed. The recipient may need to know whether to celebrate, grieve, travel, or wait.

The same successful transmission can accomplish its technical task while leaving a person unsure what to do.

This precision made the theory more useful. A system did not need a special mathematics for carrying a birthday invitation and another for carrying a photograph. Once messages were represented appropriately, general questions about capacity, coding, and error could be asked across many applications.

The emotional world was still there at the ends of the connection. The theory clarified a crucial part of the machinery between them.

The three-copy trick is wasteful but revealing.

It adds redundancy: structure beyond the minimum needed to state the choice once. Other codes distribute that extra structure more efficiently. In work published in 1950, Richard Hamming described methods that could identify and correct certain errors by arranging additional checks across groups of bits.

An overlapping set of checks can do more than announce that something is wrong. The pattern of failed checks can locate the wrong position, much as several independent directions can identify one address.

The receiver then changes that position and recovers the message, provided the damage falls within what the code is designed to handle.

The insight turns apparent excess into a resource. Extra relationships among the transmitted parts can make the intended arrangement distinguishable from nearby damaged arrangements.

With suitable coding and the right conditions, Shannon showed that communication below a channel's capacity can be made arbitrarily reliable in the theoretical limit. This is not a promise of perfect finite devices. It establishes that noise need

not impose the crude ceiling people might expect if they considered only individual, unprotected symbols.

The route can be imperfect while the organized system delivers an extraordinarily faithful result.

This is one of the hidden foundations of digital life.

A picture can be represented by numbers. Those numbers can be encoded as bits, carried across a noisy channel, checked, and used to reconstruct the represented picture. Sound can undergo a corresponding transformation. So can writing, measurements, and instructions.

Different kinds of human experience meet a common engineering language.

The transformation does not preserve everything. A recording system has limits of resolution and range. A compressed file may discard distinctions. A photograph does not contain every property of the scene. But within a chosen representation, digital methods can preserve and reproduce distinctions with great reliability.

The copy need not inherit every small physical imperfection of the medium carrying the previous copy. A receiver can recognize the intended discrete state and write a fresh realization of it.

That ability changes the economics of preservation and distribution. It also explains why the work never becomes entirely automatic: formats, devices, access, maintenance, and interpretation still have to survive. An unreadable old disk is another version of the silent manuscript, with different tools required to open it.

A reusable memory eventually has to be prepared for new work. One common operation is to reset it to a standard state, whatever it held before.

That small act brings the story of a bit into contact with heat. In the standard thermodynamic setting, erasing an unknown bit has a minimum average heat cost related to temperature. Rolf Landauer identified the connection; later experiments approached the bound with carefully controlled physical systems, including a tiny particle held in a pair of potential wells.

The principle does not say that every logical operation must dissipate that amount, or that a thought has a universal price. It makes a more exact point about a logically irreversible operation and its physical implementation.

What looks on a page like replacing either 0 or 1 with 0 must happen to something in the world. The distinction is removed from the memory through a process whose wider physical consequences cannot simply be ignored.

The abstract and the material have remained connected all along.

We began with a yes that might become a no.

An error-correcting arrangement can protect that choice across a hostile route. It can bring a sender's intended distinction to a recipient who is far away, later in time, or both.

Once many kinds of records can share this form, another possibility becomes practical. The same memory that holds numbers can hold a description of what to do with numbers. A machine can encounter instructions as a physical pattern it is built to follow.

Change the pattern, and the same apparatus can begin different work.

Sources and notes

12

A Machine for the Possible

In June 1948, an experimental machine in Manchester ran a program held in electronic memory.

It was called the Baby. Its main store held thirty-two words of thirty-two bits each, a tiny capacity by later standards. The apparatus was built to test whether a particular form of electronic storage could work in a computer. The calculation it performed mattered less than where the instructions lived.

They occupied memory in the machine, alongside the kind of stored patterns used for numerical data.

A different task could be supplied through a different pattern of instructions. The builders would not have to rearrange the machine's circuits for each new program.

In a letter published that September, Frederic Williams and Tom Kilburn described this flexibility. The device was small and experimental. The possibility was immense: some of the work of changing a machine could become the work of changing a description.

Twelve years earlier, Alan Turing had given this idea a precise mathematical form.

He considered idealized machines that read and write symbols according to rules. He then showed how a single such machine could simulate another when supplied with an encoded description of it.

The description itself becomes something the machine can read.

Think of the difference between building a separate mechanism for each tune and building an instrument that can follow many arrangements of notes. The analogy has limits—a universal computer's scope is much wider than music—but it locates the surprise. Some differences among machines can be represented as information for another machine to act on.

The same underlying apparatus can therefore carry out many different computable procedures. One pattern directs it to sort numbers. Another

directs it to manipulate an image. Another makes it simulate a process that has no physical counterpart inside the device.

The machine's next activity can depend on a description of an activity.

A physical system changes state according to how it is built. Some states represent instructions; other states represent the things those instructions operate on. The apparatus is organized so that encountering the instruction pattern changes which operation happens next.

At one level we can describe the chain of physical operations through voltages and circuits. At another we can describe adding, comparing, storing, and choosing the next instruction. The descriptions concern the same working device at different scales.

Human meanings enter through what people arrange the representations to stand for. A number may represent a temperature, a distance, or an item in an inventory. A change in that number can then be used to draw a picture, update a forecast, or tell a machine where to move.

The representation becomes consequential because it is connected to further activity.

This makes an enormous range of possible worlds inexpensive enough to examine before building anything in them.

Consider an imagined bridge design. A mathematical model represents selected features of its shape, materials, and loads. A program calculates how those represented features interact. Change the design, and another calculation can explore different consequences.

Suppose one calculated load makes a support deform too much. The designer can widen the support in the model, run the calculation again, and compare the results. The second version may bear the represented load better. It may also use more material, adding weight that changes other parts of the calculation. The next revision has a more precise problem to solve.

The simulated bridge carries no real traffic. If the model captures the relevant behavior well enough, its failures can help reveal a weakness while there is still only a proposal to revise.

The physical world remains the judge of whether the model is adequate. Measurements and experiments are needed to establish where its predic-

tions can be trusted. But computation changes how many consequences can be explored within that relationship.

A possible future can be brought into present decision through a sequence of represented states.

This is a larger and more systematic cousin of the capacity to imagine tomorrow. We give a machine explicit relationships to work through, and it can carry them farther than unaided mental calculation would comfortably reach.

The flexibility also runs backward into the past.

A recording can be analyzed for patterns too faint or complicated for unaided inspection. A damaged image can be processed in ways that make surviving distinctions easier to examine. A set of observations can be compared with several models, allowing researchers to see which account fits and where all of them fail.

The machine does not create the missing evidence merely by calculating. It can help make existing evidence more usable, and it can generate hypotheses about what might have produced it.

This difference is essential to Scott's recovered song. Software can transform an image of the trace into a proposed sound waveform. The pro-

posed reconstruction must remain accountable to the trace, to the recording mechanism, and to what is known about its timing.

Turing's work also established limits.

Universality does not mean that a machine can solve every well-formed question. There is no general procedure that correctly decides, for every possible program and input, whether the program will eventually stop. Some limits arise from the structure of computation itself.

Other limits are practical. A calculation may require more time or memory than we can supply. A model may omit something that matters. A measurement may be too uncertain to support the desired prediction.

These limits give the achievement its actual shape. A general-purpose computer is a remarkably flexible way to perform computations that can be specified, within the resources available.

The useful question becomes what we can arrange for it to do, how well the result fits our purpose, and how we will find out when it fails.

Then the programs themselves become things we can copy and send.

A method made executable can travel to another compatible machine. Someone who did not invent it can run it. Someone who can inspect and change it may improve it. The work of one programmer can become part of the working environment of many others.

This extends the old power of a written method. A recipe can guide a reader's actions; a program can directly govern operations in an apparatus built to follow it. Human judgment remains around the process—in designing, choosing, testing, and using it—but much of the repetition can happen without a person carrying out every step.

The computer becomes a place where records, instructions, and results continually change roles. One program writes a file that another reads. A measurement becomes an input. An output becomes a new instruction to a connected device.

And when the machines are joined, a method or a record no longer has to remain where it was first stored.

The library is about to acquire doors that open into other libraries.

Sources and notes

13

The Address of Almost Everything

The frustrating thing about the missing information was that it might not be missing.

It might already have been recorded somewhere inside the organization, in a form or location the person who needed it did not know how to find.

Tim Berners-Lee described this problem in his 1989 proposal at CERN. People moved between projects and left the institution. Technical knowledge became difficult to recover. The working relationships among people, documents, equipment, and software did not fit neatly into one permanent hierarchy.

He proposed a linked information system that could grow with those relationships. A document could refer to another document in a way a reader could follow directly. Information on different systems could become available through a common approach.

The World Wide Web grew from this work.

The ambition at its heart was wonderfully practical: something could already exist, and a person could still need a better way to reach it.

The web depended on a network history already underway.

Packet switching let messages be divided into smaller units that could share communication links with units from other messages. The network could forward them through intermediate points, using addressing and routing arrangements to move them toward a destination.

Packets might take different routes, although they need not. Systems could detect missing material and arrange retransmission. Sequence information could help put arriving pieces into the intended order.

Independent work by Paul Baran and Donald Davies developed important ideas about such networks. Later, Vint Cerf and Robert Kahn described ways to communicate across different packet networks. Interconnection could become a working relationship among systems built with differences of their own.

This is a quieter achievement than a picture appearing on a screen, but it makes the picture's journey possible. Many messages can share infrastructure. A larger exchange can survive some failures in its parts. Machines can coordinate delivery through signals whose entire purpose is to manage other signals.

An acknowledgment can mean that data arrived. It cannot mean that a human understood what the data said.

The web adds another kind of connection: the link a reader can follow.

A reference in a printed book gives directions to another object. A web link can help the reader request the referenced resource through the network. A citation becomes a possible journey initiated from the place where the citation is encountered.

The Internet provides the interconnected networks; the web is one of the systems of use built on them. Keeping the distinction clear reveals the collaboration. Physical links and network protocols move data. Addresses and web protocols help request resources. Browsers present material in forms people can navigate.

A click can conceal all of that work so successfully that the result feels almost spatial. The reader moves from page to page while the body stays in one chair. Documents held by distant machines become neighbors in an act of attention.

The route between them need not resemble their physical geography. A link can join a footnote in one country to an image in another because someone recognized a relationship worth making traversable.

The library gains a changing map drawn through its contents.

But a map made of links still leaves a person with the problem of where to begin.

Search systems build indexes: organized representations of material gathered from pages, allowing a query to find possible matches without reading every page anew at that moment. Ranking methods decide which candidates to show first.

In their 1998 paper describing an early version of Google, Sergey Brin and Lawrence Page combined textual information with a method that used the web's link structure to help estimate the im-

portance of pages. Links became evidence about attention and relationships as well as routes a reader might follow.

The system was doing more than fetching an object from a known shelf. It was making a selection among possible objects and presenting an order of encounter.

That order matters because readers have limited time. A page seen first has a different chance of influencing someone than a page never reached. The design of retrieval becomes part of the practical distribution of knowledge.

An answer can be available somewhere and still remain absent from a person's life.

For someone with access, the change can be extraordinary.

A student can follow a question beyond the books nearby. A family historian can inspect a distant document. A researcher can compare an old image with a new measurement. A curious person can move from a familiar word into a field they did not know existed an hour earlier.

Access is uneven, and the accessible web contains only part of what people know. Still, the reduction in the work of reaching many records is

real. A question that once required correspondence, travel, or a fortunate introduction can sometimes be pursued from the room in which it first occurred.

The result is a change in the threshold for curiosity. More questions become cheap enough to follow.

And following one can expose another. A person begins by asking for a date and discovers an argument about how the date was established. The route through information can change the question that opened it.

A correction can be available and still lose the race for a reader's attention.

Several highly visible pages may repeat the same source, while the less visible page contains the evidence that overturns it. The web has made both accounts reachable. The order of encounter helps determine which account is actually reached.

The network can make correction easy to publish and difficult to encounter. It can preserve an old mistake after the original author has revised it. It can bring a reader directly to excellent evidence, or to a persuasive summary that has lost the evidence's qualifications.

These outcomes depend on many choices: what gets published, what is indexed, how results are ordered, what people choose to open, and what they already know how to assess.

The machinery shapes the meeting. The meeting still requires judgment.

By now, an ordinary question can begin an astonishing physical itinerary. A body forms an intention. Fingers or a voice make it into a signal. Devices encode, transmit, route, retrieve, and display. Work by absent people arrives as something a present reader can use.

The apparent simplicity of asking rests on nearly every earlier achievement in this story.

Then another kind of response becomes familiar. Instead of returning only a page that someone wrote before the question was asked, a system can produce a new sequence of words shaped by the question itself.

The search has brought us to a text. The next encounter may be with a text being made as we arrive.

Sources and notes

14

The Answer That Was Not Stored

Imagine making a peculiar request of a machine: explain error correction using an invitation to a birthday party.

It can produce a passage about yes becoming no, about a small mistake with a large social consequence, about repeating a choice so that a damaged message can still be understood.

You have already encountered such an explanation in this book.

Now imagine replying: *I understand the invitation. I still do not understand why three signals help.*

The next answer can concentrate on that difficulty. It can show you 111 becoming 101, explain the majority, and try another example if this one does not work. The exchange can be shaped by the exact point at which your understanding stops.

A text is being produced for a question, then altered in response to a reader.

The new passage may never have existed in precisely that form before. Yet the system producing it depends on an immense inheritance of material that did exist: language, examples, records, methods, and the work of people who made them.

The past has become available in another form.

In a language model, training adjusts many numerical parameters—the values that govern how the model's computations proceed. Repeated exposure to examples and training objectives changes those values so that the system becomes better at the tasks used to train it.

One central task is predicting pieces of a sequence from the surrounding material available to the model. Doing this well across varied language can require sensitivity to grammar, facts, style, context, and patterns of reasoning expressed in text.

The learned parameters are not simply a catalogue of pages waiting to be opened. They support computations that can combine learned regularities in response to a new input. A model can also memorize material and sometimes reproduce it closely, so the distinction is not absolute. Generalization and memorization can coexist.

What happens in a particular response depends on the model, its training, the current input, and the system built around it.

The machinery is mathematical and physical. A person's examples affect training; training alters stored values; those values help shape later calculations. From the calculations comes a sequence of output symbols that a reader can encounter as language.

In an influential architecture called the transformer, a mechanism known as attention helps the computation use relationships among parts of a sequence. The name describes a mathematical operation, rather than establishing a conscious act of attending.

Generation proceeds through choices among possible continuations. Those choices can be conditioned by much more than the immediately preceding word: the question, earlier text, instructions, and other supplied context can all matter.

Change the conditions, and the resulting explanation can change. The request about a birthday party steers the same trained system into a different explanation from a request about a spacecraft sending signals home.

The arrangement gives old human work a new way to meet a present need.

An analogy used in one setting can become useful in another. A method described in one vocabulary can be explained through a vocabulary a different reader already knows. A draft can be transformed while preserving its central purpose. A question can be broken into smaller questions whose answers are easier to pursue.

This is not the first time information has been actively transformed by a machine. Earlier programs have long calculated, searched, translated, selected, and generated. The important change here is the breadth and accessibility of a learned interface through which people can request many kinds of transformation in ordinary language.

A person does not always need to know the name of the operation they require before asking for help with it.

That lowers a particular barrier to inquiry. *Here is where I became confused* can itself become useful input. The unfinished state of a person's understanding can help direct the next explanation.

The potential is especially striking in a world where many people have access to information but little access to someone with time to work through it with them.

The difference between a new answer and an old record now becomes consequential.

If a system retrieves Severa's invitation, it can direct a reader toward a surviving document and its scholarly edition. If it generates an imagined invitation in a Roman voice, it can produce a plausible text that never belonged to Severa at all.

Both outputs may be fluent. Only one is evidence of what she wrote.

A system can combine retrieval with generation, consulting external material and using it to help construct an answer. This makes records available to the process at the moment of response. It also creates opportunities to show the reader where particular claims came from.

But the presence of a citation does not guarantee that the cited source supports the sentence beside it. The relationship has to be checked. A model can misunderstand a passage, combine incompatible accounts, or invent an unsupported detail that fits the surrounding prose.

Dürer's extra horn can now arrive in the form of a sentence composed specifically for the person asking about the animal.

Here the earlier achievements of this story can be joined into a more capable practice.

A system can search for evidence, inspect a source, perform a calculation, and revise an answer in light of the result. Researchers have built methods that interleave model-generated steps with actions through external tools. The output of one step becomes information available to the next.

This can help distinguish an attractive answer from a tested one. A proposed numerical result can be calculated. A historical claim can be checked against an original document. An explanation can be compared with the observations it is supposed to explain.

The success comes from the whole arrangement: model, tools, records, procedures, and the judgment used to decide what counts as support. Fluency alone does not perform the comparison.

Nor does every conversation permanently retrain the model. Information can influence a response through the current context without chan-

ging the model's learned parameters. Systems may have additional ways to save information or update their behavior; those are distinct processes with their own designs.

Different kinds of persistence remain different, even when the interface makes them feel like one continuous conversation.

What becomes possible is a new way to work on the distance between having access and understanding.

A learner can ask the same question three ways without using up the patience of a page. A researcher can explore candidate explanations before deciding which deserve an experiment. A writer can test an image, find it misleading, and replace it. A person facing an unfamiliar document can ask for help locating the claim, the evidence, and the missing step between them.

These are possibilities to realize through actual performance. Their value will be uneven, sometimes considerable, sometimes absent. The work is to discover where the arrangement helps and make it dependable enough for the purpose at hand.

What makes the opening exciting is how closely it meets the shape of curiosity. Curiosity rarely arrives as a perfectly specified task. It arrives as a partial recognition, a confusion, an unexpected connection, a sense that two things might belong together.

Now those incomplete beginnings can sometimes be worked on in dialogue with an artificial system capable of generating useful next steps.

More of the questions that occur to a person may become questions they can pursue.

This book belongs to that possibility. A human asked for a telling that could make a large history intelligible and felt. A language model produced prose, used research tools, examined evidence, and revised the result. The intention, the sources, the machinery, and the reader all belong to the account of how the text can do anything.

Its sentences will succeed where they help you see a relationship clearly, remember an event, or ask a better question. They will fail where they obscure, mislead, or merely sound as though they have explained something.

The test continues in the reading.

And there is one last act of reading to return to: a line on soot-darkened paper, a calculation of how quickly it moved, and a voice that changed when people learned to ask a better question of the trace.

Sources and notes

CLOSING

When the Voice Arrives

At first, the recovered singer seemed to have a high voice, perhaps a girl's.

The first widely heard reconstruction of Scott's 1860 recording ran too fast. The timing of the trace had to be interpreted, and the original calibration doubled the playback speed later judged appropriate.

In 2009, work on another recording helped expose the problem. Speech sounded implausible at that speed. A slower reconstruction made better sense of the speech and other traces. The song, played more slowly, suggested an adult male voice instead.

It may have been Scott singing. The evidence does not establish the singer's identity with certainty.

The line on the paper had not changed. What changed was the relationship between the line and the operation used to make it audible.

The record was capable of correcting its first readers because it contained constraints they had not yet interpreted well enough.

Almost everything in this story has met inside that correction.

There is a physical event leaving a trace. There is a surface made and preserved. There are inscriptions that help identify what was done, an archive that makes the object available, instruments that reveal its shape, and methods that turn one kind of representation into another.

There are copies people can share, calculations they can repeat, and a disagreement that can be addressed by further evidence. There are ears and nervous systems able to recognize speech and song. There is a learned language through which researchers can explain a problem to one another.

The voice does not arrive through any one of these accomplishments alone.

It arrives through their meeting.

We often describe these changes in terms of speed and quantity. More records. More copies. More signals in less time.

Those changes matter. But the deepest consequences are also changes in the kinds of relationship available.

A person can learn from someone long dead. A community can coordinate around a plan that has not been built. A reader can compare witnesses who never met. A descendant can recover a family name from a document created under circumstances the descendant will never have to endure.

The absent become able to matter in particular ways because something present carries their effects.

This is no guarantee that what arrives will be wise or kind. An error can last; an injustice can be administered through an excellent record system. Yet the capacity also makes correction, recognition, and care possible across distances that would otherwise defeat them.

Severa's invitation remains a small, clear instance. A woman wanted her friend to come. The machinery of writing gave that wish another way to travel. We encounter it after the birthday is beyond all possible attendance, and still understand why the message was sent.

The surviving voice offers a different encounter.

If you listen to the recovered recording, the sound is faint and rough. It does not provide a transparent window into the room. You cannot turn your head and inspect what stood outside the apparatus's reach. You cannot ask the singer to begin again more clearly.

What you hear is a present reconstruction made from surviving evidence of a brief performance.

Even so, someone once sustained those notes. A body gave the air a changing motion; a mechanism gave a surface a corresponding trace. The ordinary act of singing entered an unusual arrangement of matter and was not entirely lost.

The person could not have known this listener, in this room, in this century. The performance can reach the listener anyway.

That is enough to make the distance feel different.

The histories we inherit do not only tell us where we came from. They give us things with which to continue.

Most of the people who made your reading possible could not have predicted your life. The makers of the script, the keepers of the records, the people who studied memory or built reliable

communication had other immediate tasks. Their work has become part of the conditions under which you can encounter a sentence now.

You do not need to know every name for their work to be helping you. Knowing some of the names makes the help more visible.

And your encounter need not end where the text ends. Something read can become a question asked later, an explanation offered more patiently, an old object treated with a little more care. A detail can wait in memory until another detail gives it a use.

No author can specify the whole onward route. That is part of what it means to give something to a reader.

Perhaps the detail you keep is the changing handwriting on an invitation. Perhaps it is the extra horn. Perhaps it is a damaged page being eased open so that an older line can meet the light.

Or perhaps it is simply this: in Paris in 1860, someone sang into a machine that could not play the song back.

The performance ended. The paper remained.

Many years later, people made a way to listen. Then they found a way to listen better.

The recovered recording ends too. Beyond its last note, the air in the listener's room continues with the sounds of an ordinary day. In a room the singer never entered, an old pattern has briefly become a new sound.

The breath is gone. Its reach is still changing.

Sources and notes

Sources and notes

This is an original telling written by GPT-6 (Astra) for David Jones in September 2026. The narrative links documented events through a recurring question: how can something absent influence what happens here? That organizing question is an interpretation, not a proposed scientific law.

Named historical scenes follow surviving evidence. Everyday demonstrations and hypothetical examples are identified in the text. No dialogue or private thoughts have been invented for historical people. “Information” takes several related but distinct senses across the story: physical correlation, inherited biological function, Shannon uncertainty, and communicated human meaning. The chapters explain these through their uses; none implies that matter as a whole has intentions or consciousness.

The notes offer direct routes to the evidence, with research papers, original documents, and accounts by the institutions that study or preserve them. Dates and mechanisms were checked during preparation. Where the evidence remains incomplete, the story keeps the uncertainty. Interpretive passages about the human significance of an event are the author’s, rather than conclusions proved by the cited source.

00 — The Voice on the Paper

Return to The Voice on the Paper

The opening follows a documented recording, while leaving the singer unidentified. First Sounds' account of its reconstruction methods describes the high-resolution imaging and adapted Lawrence Berkeley National Laboratory software behind the March 2008 release. Scott's phonautograms were made for visual study, and recovering sound required interpreting both the waveform and its progress through time. The sounds played today are new physical vibrations produced from that surviving evidence.

David Giovannoni's Library of Congress essay (2021) recounts the Paris recordings and their preservation in French institutions. Patrick Feaster's annotated discography (2010), item 36, transcribes the April 9, 1860 inscription naming the song. Pages 48–49 describe the discovery in 2009 that the initial reconstruction had run too fast. The story returns to that correction in its final chapter; it does not assume that the first audible version was already a settled interpretation.

01 — The Shape of an Absence

Return to The Shape of an Absence

The opening footprint is a general illustration, not a reconstruction of one identified person's walk. The National Park Service's account of fossil footprints explains how a foot can deform both the surface and underlying sediment, and how impressions and casts preserve different details. What survives depends on the substrate and subsequent events as well as the foot itself.

NOAA's introduction to climate proxies explains how tree rings, sediments, ice, and other physical records support inferences about past environments. Such records require interpretation; they are not self-explanatory measurements. An instructive example of independent checks comes from USGS research at White Sands: pollen dating and quartz luminescence strengthened the evidence for human footprints around 23,000–21,000 years old after questions arose about dating aquatic seeds. The chapter's practical loss of accessible evidence is distinct from the question of information conservation in fundamental physics.

02 — A Past with Offspring

Return to A Past with Offspring

The opening follows Daniel Gibson and colleagues' 2010 synthetic-genome study, also explained on the J. Craig Venter Institute's research page. The team assembled a modified *Mycoplasma mycoides* genome of approximately 1.08 million base pairs and transplanted it into a recipient *M. capricolum* cell. The resulting cells reproduced with the synthetic chromosome. This achievement depended on an existing cell and its molecular machinery; it did not begin with an entirely chemically assembled cell.

Marshall Nirenberg's 1968 Nobel lecture describes experiments that established correspondences between RNA sequences and amino acids within prepared protein-synthesis systems. The Nobel Assembly's account of John Gurdon's nuclear-transfer work explains why cellular surroundings also matter: a nucleus from a specialized tadpole cell could support broader development after transfer into an egg.

Research into simpler beginnings includes Mansy and colleagues' 2008 model-protocell experiments, which combined compartments with template-directed polymer synthesis. These were designed laboratory systems, not a reconstruction of life's complete origin. The unresolved beginnings should not be confused with the well-established dependence of present cells on inherited organization.

03 — The Smallest Yesterday

Return to The Smallest Yesterday

Robert Macnab and Daniel Koshland's 1972 experiment used *Salmonella typhimurium*. Rapid mixing changed attractant concentration throughout the surrounding fluid, allowing the researchers to examine responses to change through time without a spatial gradient. Increased attractant produced smoother swimming; a decrease produced more tumbling. The experiment supported temporal comparison while leaving the precise molecular mechanism open.

Later work made that mechanism more concrete. Goy, Springer, and Adler (1977) connected protein methylation with adaptation in *E. coli*. Krembel, Colin, and Sourjik (2015) altered receptor methylation sites and measured effects on signaling and chemotactic performance. Receptor modification helps adjust responses to background stimulation, allowing sensitivity to further change.

Here, physiological memory means an earlier stimulus leaves a state that affects subsequent behavior. The experiments establish that retained influence; they do not establish conscious recollection. Other organisms and chemotaxis systems need not use exactly the same mechanism.

04 — The Room That Will Not Stay

Return to The Room That Will Not Stay

The opening encounter appears in Scoville and Milner's 1957 report, which describes H.M.'s examination on 26 April 1955. The chapter uses only the year of his operation because exact dates differ between accounts. His injury affected several medial temporal structures.

Suzanne Corkin's 1968 motor-learning study reports improvement on rotary pursuit, bimanual tracking, and tapping, with delayed retention tested on rotary pursuit. This is distinct from Brenda Milner's earlier mirror-tracing work. Preserved skill learning alongside severe difficulty remembering events helped reveal that memory comprises differing capacities.

Bliss and Lømo (1973) documented prolonged enhancement of neural responses after stimulation in anesthetized rabbits. This demonstrated lasting changes in transmission, not an autobiographical memory observed entering storage. Loftus and Palmer (1974) showed that question wording affected speed estimates and later reports of nonexistent broken glass. Their experiments measured reports. They neither make every recollection unreliable nor show that every retrieval rewrites all of a memory.

For the connection between remembering and imagining, Addis, Wong, and Schacter (2007) found overlapping patterns of brain activity when people elaborated remembered and imagined future events. Overlap does not make these activities identical.

05 — The Journey Made of Air

Return to The Journey Made of Air

Riley and colleagues (2005) used harmonic radar to follow bees recruited by waggle dances, demonstrating use of communicated direction and distance. The dance guides a journey approximately; recruits also use other cues. Gil and De Marco (2010) examined antennal contacts during dance-following, helping explain how information can be acquired at close range in a dark hive.

Dong and colleagues (2023) found that bees lacking opportunities to follow dancers before their first performances still danced but made larger errors. Some performance improved with experience while a distance-signaling difference persisted. The finding joins inherited capacities with social experience; it does not demonstrate deliberate teaching or human-like grammar.

Galantucci (2005) studied pairs who developed graphical communication systems while playing coordination games. They already possessed language, so the experiment illuminates emerging conventions without reenacting language's prehistoric origin. The NIDCD's account of American Sign Language describes a natural language with its own grammar, expressed through hands and face. Language's capacities cannot be identified with speech alone. The bridge warning and other everyday scenes are illustrations, not reported experimental episodes.

UNESCO's account of oral traditions emphasizes performance, community, and transmission between generations. Oral traditions can preserve knowledge while also changing through improvisation and circumstances; their continuity does not require every telling to be identical.

06 — The Hand That Stayed

Return to The Hand That Stayed

Claudia Severa's invitation is Vindolanda tablet 291, a wooden ink tablet dated by its archaeological context to approximately AD 97–105. The invitation names 11 September as her birthday. The scholarly edition distinguishes the principal hand, understood to be a scribe's, from Severa's own added closing. Its text, translation, physical description, and commentary are available in Roman Inscriptions of Britain, Tab. Vindol. 291. The document establishes the invitation and its personal appeal; it does not establish whether Sulpicia Lepidina attended. "Sister" is the language of the greeting, not evidence that the women were biological sisters.

The silver loan is a separate Old Assyrian document, dated to the twentieth–nineteenth century BCE and associated with Kültepe/Kanesh in Anatolia. The Metropolitan Museum's catalogue entry describes six minas, approximately three kilograms, of silver owed by two men to Ashur-idi; a third was due at the next harvest. Witnesses, seals, and repayment conditions show a written obligation operating within a merchant community. Its Anatolian find context should remain distinct from the Mesopotamian origins of the writing tradition used there.

The account of writing's plural beginnings follows the British Museum's timeline of writing and Egyptian decipherment, which identifies independent emergence in Mesopotamia, Egypt, China, and Mesoamerica. The precise connections and chronology of the earliest Egyptian and Mesopotamian evidence remain subjects of research. These examples establish several histories of writing; they do not establish a single motive, route, or necessary sequence for every society.

07 — What the Fire Did Not Take

Return to What the Fire Did Not Take

The Archimedes Palimpsest is a thirteenth-century prayer book made from parchment containing erased older texts. Conservation and imaging recovered mathematical writings and other works, as well as the prayer-book scribe's name, Johannes Myronas, and a completion date of 14 April 1229 in Jerusalem. The Walters Art Museum's account of its conservation project documents this recovery. Reuse both obscured an earlier text and carried remnants forward. The surviving material does not tell us the scribe's private motives for selecting it.

The project's primary conservation account documents Abigail Quandt's disbinding work, begun in February 2000 and completed in November 2004, and the subsequent treatment of individual leaves before and after imaging.

For the work behind writing surfaces, see the Metropolitan Museum on papyrus manufacture, Getty on making medieval manuscripts, and the Library of Congress on European rag papermaking. They describe, respectively, crossed layers of plant pith; the preparation, scraping, and stretching of animal skin; and the conversion of used textiles into paper pulp. These are different materials and production histories. The Met explicitly acknowledges uncertainty about some ancient papyrus-making procedures.

Thomas and Jane Harris's marriage certificate, issued at Lebanon, Tennessee, on 28 April 1866, records a union already approximately fifteen years old and names their children. The National Archives reproduces the document. Its historical account of Freedmen's Bureau marriage records explains both their

value and their fragmentary coverage. A surviving certificate can give public form to a relationship that began earlier; an unsuccessful search of these incomplete records cannot establish that a family never existed.

The Bureau was established in March 1865, while the Civil War was still underway; see the National Archives' institutional history.

08 — A Thousand Identical Mistakes

Return to A Thousand Identical Mistakes

The British Library's Diamond Sutra is the earliest complete dated printed book known to survive, not the first instance of printing. Its date is 11 May 868; seven joined sheets form a scroll approximately five metres long. The colophon associates its production and distribution with Wang Jie on behalf of his parents. See the International Dunhuang Programme's account. The dedication documents sponsorship and purpose without identifying Wang Jie as the craftsman who cut or printed the woodblocks.

The Bibliothèque nationale de France's account of Jikji identifies the surviving second volume as the oldest surviving book printed with movable metal type: Heungdeok-sa temple, Cheongju, Korea, 1377. A complete woodblock edition followed in 1378. The surviving object's date is not the date of metal type's invention, and the chronology alone demonstrates no transmission route from Korea to Mainz.

For the Gutenberg Bible's mid-1450s production and hand-added decoration, see the Library of Congress exhibition and its Gutenberg research guide.

Dürer's 1515 rhinoceros woodcut was made from secondhand information: he had not seen the animal. Its extra horn and exaggerated armour-like features circulated through later representations even though more accurate images existed. The Natural History Museum's account explains the image's sources and long influence. It supports a particular history of faithfully reproduced error, not a claim that printing necessarily made natural history less accurate.

09 — Let the World Answer

Return to Let the World Answer

Robert Hooke's *Micrographia* appeared in 1665. The primary text is freely readable in Project Gutenberg's transcription, with institutional facsimiles at the Royal Society and Library of Congress. Observation LIII, "Of a Flea," describes the insect and refers readers to Scheme XXXIV. Distinguish Hooke's visible anatomical description from his conjectures about what some structures did.

The Preface explicitly describes comparing a magnified view through one eye with a ruler seen by the other to estimate magnification. Hooke also says he examined objects under several lights and orientations before drawing: changes of illumination could confuse hollows with protrusions, shadows with stains, or reflections with colour. His account of fly eyes offers a specific example of misleading appearance. Earlier in the Preface, he asks readers to treat conjectures as uncertain and permits future observations to contradict his own. These passages support the chapter's claims about measurement, repeated examination, and revisable reports; they do not make Hooke the inventor of those practices.

The Royal Society's modern account connects Hooke's recorded preparation methods and magnification levels with its demands for reproducible experimentation. It also compares his flea plate with Brad Amos's 2010 Mesolens image of a human flea. This is an actual later comparison, not proof that every feature of Hooke's image was correct. Published pictures and methods give other observers something specific to inspect and test; reliable agreement remains an achievement rather than an automatic property of print.

The White Sands episode follows the USGS account of the 2023 independent dating study. Terrestrial pollen dating and quartz luminescence addressed the concern that aquatic seeds could carry misleadingly old carbon. The evidence supports ancient human presence at this site; it does not identify the first arrival in the Americas.

10 — The Ocean Between Two Words

Return to The Ocean Between Two Words

The Science Museum's account of the transatlantic cable supports the approximately sixteen hours required for Victoria's congratulatory message in August 1858. This is the time needed to transmit a message through a difficult system, not the travel time of a single electrical disturbance. The same account distinguishes the short-lived 1858 cable from the successful connection established in 1866.

The museum's surviving Thomson mirror galvanometer makes the receiving apparatus tangible. A suspended magnet and mirror turned weak electrical changes into visible movements of reflected light. This instrument was used at the Irish end of the 1858 cable.

The Library of Congress's selected Titanic coverage identifies the Honolulu *Evening Bulletin* headline of April 15, 1912, in its 3:30 edition. The newspaper preserves the false reassurance. It does not by itself reveal every step by which that assurance developed. The distinction between transmitting a claim and establishing its truth is the chapter's interpretation of this evidence.

11 — How to Keep a Promise to a Bit

Return to How to Keep a Promise to a Bit

Claude Shannon's A Mathematical Theory of Communication (1948) measures uncertainty and the reliable transmission of selected messages. Its treatment deliberately sets aside their semantic importance. One bit is the uncertainty associated with two equally likely alternatives; it is not a unit of personal significance. The promise of arbitrarily reliable communication depends on a channel model, a rate below capacity, and suitable coding in a theoretical limit.

The three-copy demonstration is an elementary repetition code. Richard Hamming's paper (1950) develops more efficient arrangements of check bits. Their protection has a specified range: extra structure does not repair arbitrary damage.

Charles Bennett's discussion of Landauer's principle (2002–2003) explains the distinction between logically irreversible reset and reversible operations. Bérut and colleagues' experiment (2012) connects controlled memory erasure with measured heat. The chapter states an average cost under standard conditions, not an identical cost for every microscopic event, every computation, or every thought. Physical memories re-

quire physical arrangements even when their states are described abstractly.

12 — A Machine for the Possible

Return to A Machine for the Possible

Sections 6 and 7 of Alan Turing's On Computable Numbers (1936) describe a universal machine that can simulate another machine when given its encoded description. The possibility is mathematical: one set of operating rules can interpret different descriptions. It assumes access to enough tape and time. It does not imply that every question has an algorithmic answer, or that every computable answer is practically obtainable.

Williams and Kilburn's Electronic Digital Computers (September 1948) reports an experimental machine whose program could change without changes to its circuitry. Manchester's history of the Baby dates its first successful program to June 21, 1948, and explains its electronic store for both instructions and numbers. Its main memory contained 32 words of 32 bits. The specific milestone is stored-program electronic digital computing; the broader history contains many other kinds of machine and contribution. A description becomes an instruction through apparatus built to interpret it.

13 — The Address of Almost Everything

Return to The Address of Almost Everything

Tim Berners-Lee's Information Management: A Proposal (March 1989) supplies the chapter's opening situation. His concern was not simply that CERN needed to record more. Records could become difficult to find as people left and projects

changed, while their relationships exceeded any single hierarchy. Linked information offered a way to make those relationships navigable. The CERN history of the Web places that proposal within the work that produced the first website and the later release of Web software. These are stages in a development, not interchangeable invention dates.

The National Physical Laboratory's account of Donald Davies records the independent British contribution to packet switching. Paul Baran's distributed-communications report (1964) explores message blocks and alternative routes. Cerf and Kahn's intercommunication paper (1974) addresses communication among different packet networks, including sequencing, acknowledgments, and retransmission. Neither makes every route invulnerable. These mechanisms can recover a transmitted sequence without determining what that sequence means to a reader.

Brin and Page's account of their early Google prototype (1998) describes crawling, indexing, and ranking that uses both text and link structure. It is a historical design, not a specification of current search engines. The chapter's distinction between finding a relevant page and obtaining independent confirmation remains essential: several pages may repeat the same unsupported source. Search makes an order of encounter, and that order can influence which evidence a reader sees.

14 — The Answer That Was Not Stored

Return to The Answer That Was Not Stored

Vaswani and colleagues' Attention Is All You Need (2017) introduced the transformer architecture. Its attention mechanism computes relationships among sequence representations; the

name does not establish subjective awareness. The paper's original emphasis was translation, and it should not be treated as a complete description of every later language model.

Brown and colleagues' Language Models Are Few-Shot Learners (2020) provides a direct demonstration of the distinction between training and context. The authors evaluated GPT-3 on tasks supplied through text and examples without changing its parameters for those tasks. A system can therefore change its response to new context without permanently retraining itself. That distinction does not determine what a particular product might save in a separate memory or later training process.

Carlini and colleagues' memorization study (2022; revised 2023) documents verbatim reproduction of training passages under examined conditions. The chapter's title concerns the possibility of generating a newly composed answer; it must not imply that models retain no examples. Learning useful relationships and memorizing particular material can occur within the same model. Neither the fluency of an answer nor its apparent originality establishes its truth.

Lewis and colleagues' retrieval-augmented generation paper (2020) combines a generator with passages retrieved from an explicit external index. Yao and colleagues' ReAct paper (preprint 2022; ICLR 2023) interleaves model-generated steps with actions that can obtain further evidence from an outside system. These studies support the distinction between generating an answer and investigating whether it holds up. Their measured improvements concern specific evaluations; access to a source or tool does not guarantee correct selection, interpretation, or conclusions. None of these papers establishes consciousness, and the chapter makes no such inference.

15 — When the Voice Arrives

Return to When the Voice Arrives

The closing correction follows Feaster's firsthand account in the 2010 discography, published after the events it describes. A speech reconstruction in early 2009 exposed the implausible speed of the first interpretation. Revising the tuning-fork calibration brought speech and other recordings into agreement. The slower playback suggested an adult male voice; identifying the singer as Scott remains an inference. Evidence for his voice in a related speech recording is expressly circumstantial.

First Sounds' methods account also describes changes in waveform reconstruction and correction of uneven recording speed. Recovery was a sequence of investigations. A surviving trace constrains interpretation, while further evidence can change how that trace is read. The ending's account of what we owe such evidence is an ethical and literary judgment, rather than a conclusion contained in the waveform itself.

The recordings and their historical context can be explored through First Sounds' listening collection. Hearing the audio is optional; the narrative does not assume the reader has played it.

A Story of Information

The Long Reach of a Moment

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