Catching Unicorns

Bill Hurley and David Hurley

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The Exographic Revolution and the Rise of Techno-Literate Culture

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For Hayley, Deb, and Betty

We shape our tools, and thereafter our tools shape us.
John Culkin

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Preface

Over most of this project, our intent was to title this book ”Why Writing Matters.” We felt that writing was an important technology that was not receiving the recognition it deserved. Some scholars have taken an entirely different view, seeing it as unimportant. Others have viewed it as an instrument of colonial oppression. Given these stark differences, we decided to explore what precisely writing does for us, particularly when it comes to the discovery of ideas, such things as smartphones, mRNA vaccines, and Large Language Models. Is writing simply a way to record our thinking as we come to it, or does it do something more?

Our point of departure is the work of the cognitive neuroscientist Merlin Donald. Donald coined the term exographics, which he defined to be writing in its broadest sense, writing that not only included the representation of speech but also the symbolic systems of mathematics, music, science, engineering, and other areas of inquiry. He argued that exographics allows us to discover ideas we otherwise couldn't.

Here is an example. Imagine trying to get this sum: $84 + 1,045 + 693 + 719$. Think of this problem as a simple example of trying to discover an idea. Furthermore, you are not allowed to use paper and a pen to get an answer because we're interested in what you can do without recourse to writing. You simply have to sit with your hands neatly folded and work it out in your unaided mind.

Your authors would struggle to remember the numbers, never mind get a correct sum. But if we had a pencil and some paper, we could write down the numbers and then get an answer. Admittedly, this is a simple example, but it clarifies the existence of certain ideas that are only discoverable with exographics.

A more serious example comes from Einstein's work to discover special relativity. He was famous for his thought experiments. The one that led to special relativity had a one-car train with a passenger in the middle of the car traveling at high speed towards a station with an observer on the station's platform. At the point where the passenger is opposite the observer, the observer sees lightening strike the train at the front and back of the car simultaneously. Einstein wondered whether the passenger would see the same thing as the observer. It's at this point that he had to fall back to the mathematics of the experiment which he was able to work through with pen and paper. He freely admitted that his mathematics skills were poor, so there was no way that he could just sit and think the mathematics through in his mind and the complexity of the resulting mathematics bears this out. Einstein required exographics to discover special relativity.

The importance of writing to certain kinds of thinking was a revelation to us. We had thought that all thinking was done in our minds and that exographics was just a way to record the results of that thinking. But, as the arithmetic and Einstein examples illustrate, that's not the case. Furthermore, we were never taught this because our teachers were unaware of it. In fact, it was only discovered in the early 1990s by Donald and other psychologists. The result is still not widely understood, and this is one of our reasons for writing this book.

Once we establish the important role of exographics in the discovery of ideas, our next step will be to explain why the discovery of some ideas requires exographics but others don't. For example, the American R&B percussionists who invented the backbeat didn't need exographics to do so. Neither did Edmond Albius, the boy who, in 1841, discovered a method to hand–pollinate vanilla orchids, which allowed the cultivation of vanilla outside its native habitat and expanded the production of the spice considerably.

So why is exographics required for some ideas but not others? Our preferred sensory mode for discovering ideas is our visual field. Some 2.5 million years ago, our ancient ancestors were cracking stones together to produce a sharp edge, which would have been helpful in a variety of uses including the butchering of a carcass and the shaping of a wood blank into a spear. For these ancient craftsmen, all of the materials they used were in their visual fields, and the production process could be observed from start to finish. That is not true of the arithmetic problem above. There is no such thing as an "84" in the real world. Nor is there a "+" sign. These are abstract concepts we've invented. To use them to develop an argument, we had to get their representations into our visual fields, and we did this with exographics, symbols written on a physical medium like clay tablets or paper. In this way, these "unicorns" of our minds become as real as stone and wood. It's at this point that we can begin to combine them into ideas, ideas like $84 + 1,045 + 693 + 719 = 2,541$ and special relativity.

To summarize, when it comes to discovering ideas, we use exographics for two important purposes. First, it enables us to bring representations of abstract concepts into our visual fields (we term this the *reification purpose*). And second, it enables us to construct longer threads of reasoning involving these representations of abstract concepts (the *memory extension purpose*). With exographics, Einstein was able to catch the unicorns his mind produced.

From there, we'll look at the societal impacts of the exographics technology. We'll show that it's led to an astonishingly large class of ideas that we could not have discovered otherwise. We term this collection the e-Class and we'll argue that it's been increasing at an exponential rate for centuries. In fact, it's these e-Class ideas that have enabled the rise of techno-literate cultures. Our strong conclusion is that exographics is the most important technology we've created. It's enabled us to go from the hunter-gatherer existence our ancestors lived 10,000 years ago to today's advanced techno-literate cultures.

Bill Hurley, Kingston, Ontario
David Hurley, Stouville, Ontario
September 2025

Catching Unicorns

Introduction

Laws of nature are human inventions, like ghosts. Laws of logic, of mathematics are also human inventions, like ghosts. The whole blessed thing is a human invention . . .
Robert Pirsig, *Zen and the Art of Motorcycle Maintenance*

One of the defining traits of our species is the capacity to generate ideas, ideas as diverse as microchips, baseball, and quantum theory. The main contribution of this book is to argue that writing—this skill we have to make persistent visual marks on a medium—has been extraordinarily valuable to us in the discovery of ideas. We'll first explain why and then look at its role in the advance of techno-literate culture, these modern cultures we inhabit that have emerged in only the last 10,000 years, a few minutes of evolutionary time.

Evolutionary biologists tell us that some 7 million years ago our ancestors were sitting in trees with those of chimpanzees. Approximately 3 million years ago, they were bipedal and beginning a period of significant encephalization. *Homo sapiens* came into existence in Africa about 300,000 years ago and nearly went extinct 70,000 years ago.[1] About 60,000 years ago, we began a migration to Eurasia, eventually settling the globe. Throughout most of this history, we lived a hunter-gatherer existence with small groups moving to where food was more plentiful.

[1] Spencer Wells. *The Journey of Man: A Genetic Odyssey*. Princeton, NJ: Princeton University Press, 2002.

At the dawn of the Agricultural Revolution about 10,000-12,000 years ago, things started to change again in a significant way. In the Fertile Crescent, we began to live in fixed settlements to farm, domesticating various kinds of grains and animals. Eventually the Sumerians built walled cities within significant catchment areas, the first city-states. Importantly, they began to do some clever cultural things, such as making pottery on a large scale; building irrigation systems, constructing large temples and palaces; and inventing the plow, wheel, and lunar calendar. Many scholars mark Sumerian culture as the beginning of civilization.

But as it turns out, there was a revolution within the revolution.

About 5,000 years ago, to manage these fledgling city-states, Sumerian administrators began to make meaningful notations on wet clay tablets, like the one shown in Figure 0.1. For reasons we will explain, we refer to these notations as exographics. In effect, these tablets appear to have served as the equivalent of a modern shopping list, reminding administrators of who owed what in the settlement of palace and temple accounts. Unbeknownst to the Sumerians, this turned out to be a momentous discovery because we began to use this technology to discover important ideas that could not be discovered otherwise. In fact, we'll argue that these ideas constituted a whole new class of idea, one that would eventually give rise to the made world and lifeways of our modern techno-literate cultures. Merlin Donald has rightly termed this discovery of non-biological memory a revolution—the Exographic Revolution—primarily because it allowed us to think in a very different way.[2] With this technology, discovering Pirsig's "ghosts" was within our grasp.

[2] Merlin Donald. "The Exographic Revolution: Neuropsychological Sequelae". In *The New Brain Sciences: Perils and Prospects*, ed. by Dai Rees and Steven Rose, 157–178. Cambridge: Cambridge University Press, 2004. Donald lays the foundation for exographics in his 1991 classic, *The Evolution of the Modern Mind*. He distinguishes engrams (biological memory) from exograms (non-biological memory) and argues that exograms, unlike engrams, are durable, shareable, and revisable.

So, over the last 10,000 years—a few minutes of evolutionary time—we've gone from small hunter-gatherer societies to the large techno-literate cultures we inhabit today. Back then, we lived in 30-50 person extended family groups. Now, most of us live in very large cities. Tokyo has a population of 37 million.

What really sets us apart is our knack for culture. Relative to all other species, our cultural inventiveness has been astonishing. After all, cows don't barbecue or build smartphones, pigs can't make computer chips or do open-heart surgery, and whales can't play the guitar or make ice cream. The thesis of the book is that *the phenomenon of the rise of techno-literate culture is explained by our relentlessly curious, networked imaginations enabled by exographics.*

Figure 0.1: Precuneiform tablet. Photo by Rama, CC BY-SA 3.0 FR via Wikimedian Commons.

LET'S UNPACK this statement.

Exographics is the term we use to describe our inscription of meaningful symbols on a visual medium.[3] The key concept in this definition is the symbolic nature of exographics. By *symbolic* we mean the use of culturally-agreed symbols to represent the ideas and concepts our heads produce. For example, *writing*—the visual representations of the words we speak—is symbolic. If we write the word "apple" on a page, there is nothing about this symbol that connects it to the juicy red fruit. In fact, "apple" was spoken long before it was written, and back then our ancestors could just as easily have called it an "elppa." By the same reasoning, speech is also symbolic.

[3] Our plan is to italicize the important terms we define, usually at their first use.

Most importantly for our work, symbols can be used to represent abstract concepts. Take, for example, unicorns. We can write the word "unicorn," we can say it, and we can draw a picture of one. As we will see, this use of exographics to represent abstract concepts is the key to discovering a large class of ideas that we otherwise couldn't.

In addition to writing, exographics also includes the special representations we use in science, engineering, and mathematics, the representations of music and other objects (diagrams, tables, graphs, pictures, maps, signs, emojis).

With spoken and written symbols, we're able to deconstruct our experience into atomic words and phrases that we can sequence into sentences. For example, if you say "I have a dream" to a listener, you are pushing modulated sound at the listener and, fantastically, these arbitrary symbols have a culturally agreed meaning. The same is true of exographic symbols. Over time, we've been able to build sequences of exographic symbols that have very special meanings:

> We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty, and the pursuit of Happiness.

A few other species engage the symbolic to communicate but not with nearly the same complexity, precision, and creativity we do.

We don't know much about the origins of speech other than that, at some point in our distant past, we crossed the symbolic Rubicon. It's generally accepted that we communicated with gesture first, although some researchers have argued we began to speak and gesture concurrently.[4]

[4] David McNeill. *Hand and Mind: What Gestures Reveal About Thought*. Chicago: University of Chicago Press, 1992.

We know a lot more about the origins of exographics. The Sumerians were the first to use exographics about 5,000 years ago, but there is evidence we were capable of it long before that. For example, consider the cave art from Chauvet Cave in Figure 0.2. It's a picture of a group of rhinos and is about 30,000 years old. This ancient artist was representing what he or she saw and it's certainly symbolic.

WE LABEL OUR MODERN CULTURE a *techno-literate culture* and con-

Figure 0.2: Rhino drawings from the Chauvet Cave, c. 30000 BCE. Public domain image via Wikimedia Commons.

ceptualize it with four characteristics. First, most of the population has some minimal level of literacy including an ability to read, write, and do arithmetic. Second, it includes a relatively small set of individuals who are able to discover ideas that push our culture forward. Third, we've evolved socioeconomic structures and behavioral characteristics that enable large populations of strangers to coexist in relative harmony. These structures include cities, governments, laws, regulations, markets, media, prisons, corporations, and religions. And fourth, there is a substantial education system in place that teaches basic literacy and, for some, the advanced knowledge required to arrive at new ideas. Techno-literate culture is a tectonic shift from our lifeways as hunter-gatherers.

One of the things that fascinates us about modern techno-literate culture is that it seems to run well with very little central control. For example, how do those 37 million Tokyoites know what to do every day? Clearly, there is no central authority that issues instructions to each individual the night before, but the city functions well, day in and day out. The answer is that, over time, we've invented cultural norms, lifeways, and technologies to help us live together in a decentralized way. For example, at a crowded Tokyo intersection, we manage the movement of cars and pedestrians with traffic signals. The way Tokyoites manage their passage on a crowded bidirectional sidewalk with very few collisions is a marvel and relies on individuals following the "accepted rules of the road" and communicating movement intentions with subtle bodily signals. In a manufacturing facility, a worker knows when to go home simply by looking at her watch or a clock. If a Tokyoite wants to go to the theater, they can check the Internet for schedules and then buy a ticket for the show they want to see. A Tokyoite driving by a Starbucks with a craving for a Salted Caramel Mocha Frappucino can go through the drive-through, pay with his smartphone, and drive off with his beverage. To the casual observer, it may look like decentralized chaos, but it's not. Over millennia of living together in fixed settlements and cities, we've evolved rules and technologies that enable a decentralized coexistence.

Considering the phrase "relentlessly curious imaginations," we are a naturally inquisitive species. We want to know how things work and we like to solve problems and puzzles.

In the course of our evolution, we've evolved a neuro-psychological system that rewards problem solving. When you're solving a problem, the levels of a neurotransmitter called dopamine elevate as you anticipate getting to a solution. When you finally solve the problem, your dopamine levels virtually explode, triggering an intense feeling of satisfaction. fMRI scans show that successful problem solvers exhibit strong activation in areas of the brain rich in dopamine such as the ventral striatum, the prefrontal cortex, and the anterior cingulate cortex. Furthermore, there is evidence that some individuals are born with more active dopamine systems and tend to be better problem-solvers.

Curiosity is one of our most important biological traits. We'll look at some particularly good problem solvers—Isaac Newton for one—and we'll see that they appear to have been driven to solve problems almost to the exclusion of everything else including, at times, the basic necessities like food and sleep! This is why we've included the adjective "relentlessly."

All of us are aware of the powerful imaginations we have. On demand, we can start thinking about a problem and possible solutions. We certainly don't understand fully how our minds are able to do this. But they can, and we take it as a given.

That we can network our imaginations is critical. Individually, we are intelligent, but our most important trait might be our collaborative ability, as evidenced by some of our great cultural achievements. Neil Armstrong's trip to the Moon required 300,000 of us to work together for almost a decade. By some estimates, Apple's iPhone required 200 people working for 3 years. There is no other species that collaborates as ably as we do. Yes, bees cooperate but their culture hasn't changed for thousands of years.

What is not obvious is the cognitive glue that enables this collaboration, but Sarah Hrdy offers some insight with this thought experiment.[5] She first describes the typical things that happen when a group boards an airplane. As she explains, it's an orderly process where strangers go out of their way to cooperate and get along. She then wonders what would happen if it were chimps rather than hu-

[5] Sarah Hrdy. *Mothers and Others: The Evolutionary Origins of Mutual Understanding*. Cambridge MA: Harvard University Press, 2009.

mans getting on the plane with her:

> I cannot keep from wondering what would happen if my fellow human passengers suddenly morphed into another species of ape. What if I were traveling with a planeload of chimpanzees? Any one of us would be lucky to disembark with all ten fingers and toes still attached, ... Bloody earlobes and other appendages would litter the aisles. Compressing so many highly impulsive strangers into a tight space would be a recipe for mayhem.[6]

[6] Ibid., p. 3.

Evolutionary psychologists suggest that humans have undergone an evolutionary process similar to that of domesticated animals, in which traits promoting cooperation and reduced aggression were selected. In effect, they're suggesting we've *self-domesticated*.

One of the benefits of domestication is that it's easier for us to collaborate, live in large anonymous groups, form complex social structures, and, most importantly for this work, solve important problems that require a collective effort. We now have a very large exographic record of this problem solving in the world's libraries, archives, encyclopedias, books, journals, and other forms of exographic record. Furthermore, with the advance of modern information technologies like computers, the Internet, cloud storage, and search engines, we now have almost instantaneous access to information.

What is crucial for collaboration is our ability to learn from one another. Imagine two young children from different cultures: one from a developed culture; the other from an Indigenous culture. Unlike bees, whose culture is wired genetically, both human children will have to learn their cultures over time. For example, neither immediately speaks when born. But both have the capacity to learn their culture's language quickly. Furthermore, if these two were somehow switched at birth, both would easily learn the other culture. Social learning is crucial for a species that thrives on culture and cultural change.

PERHAPS THE MOST CONTENTIOUS PART of our statement of purpose is the phrase "imaginations enabled by exographics." Exographics is an important cultural skill but does it really play a significant role in our cultural advance? Aren't exographics just a way of recording our thoughts once our imaginations come to them? The implicit premise of this line of reasoning is that we can discover any idea without exographics.

To see that this argument is false, consider the arithmetic problem $8,497 \times 8,672$. You likely don't know the answer so you can think of this as an artificial exercise to discover an idea. But there is a catch. You're not allowed to use your hands. You simply have to sit with them neatly folded and do the required calculations in your head.

With this constraint, we're trying to understand what our minds are capable of without exographics.

Virtually all of us would find this "no-hands" problem impossible. That is, without exographics, it's impossible to discover the idea $8,497 \times 8,672 = 73,685,984$. But with exographics, it's easy. In fact, it's so easy that children learn to do it in grade school.

To take a more serious idea, consider Einstein's work to discover special relativity. He was famous for his thought experiments. For the one that led to special relativity, he imagined a one-car train with a passenger in the middle of the car traveling at high speed towards a station with an observer on the station's platform. At the point where the passenger is opposite the observer, the observer sees lightening strike the train at the front and back of the car simultaneously. Einstein wondered whether the passenger would see the same thing as the observer. It's at this point that he had to fall back to the mathematics of the experiment which he was able to work through with pen and paper. He freely admitted that his mathematics skills were poor, so there was no way that he could just sit and think through the mathematics of his cinema and the complexity of the resulting mathematics bears this out. Einstein required exographics to discover special relativity.

Before beginning this research, we both felt that exographics was no more than a convenient communication tool, one that helped us overcome the problems of space and time in a world where only oral communication was possible. No teacher or professor ever explained how exographics enabled idea discovery. After all, we think with the organ that sits within the confines of our heads—how could it be that an external technology like exographics could assist that internal process? It seemed entirely reasonable that exographics was the end result of thinking, and not its enabler! But for some ideas, that's not how it works, as the arithmetic and Einstein examples make clear.

But, there are ideas which do not require exographics to discover. For example, we didn't need it to discover the plow, surfboard, or yarn. So why is it that some ideas require exographics to discover but others don't?

We'll first argue that we do our best work in our visual field. We've been evolving this skill for at least 3 million years, dating to the time when our ancestors were chipping rocks to make tools. All of the material was before them, and they worked away until eventually a tool was produced. But there are some concepts we can imagine that do not have a real-world referent. An example is the number 23. Numbers exist only in our minds, but wood and hammers and nails are things we can reach out and touch. To make 23 real, we can use exographics to inscribe a representation of it on a visual medium, and in that way it comes into our visual field and is as real as a hammer. Once these products of our imaginations are reified on a visual medium, we can begin to use them to fashion new ideas just as our ancient ancestors chipped stone to make tools. As we see it, this is the crucial value of exographics that has been overlooked. Effectively, we're using exographics to make abstract objects real by bringing their exographic representations into our visual fields.

While our focus is the role of exographics in the discovery of ideas, we use many other external artifacts and technologies to help in the search. For example, on the way to a new song, a musician might use a device to record promising snippets for a melody. Gord Sinclair of the Tragically Hip uses his smartphone for this purpose. A chemist will experiment in her laboratory, one usually equipped with containers, machines, supplies, materials, and measuring devices. Computer scientists generally need a computer or a network of computers in their work. Cosmologists use telescopes to look at the heavens, and biologists use microscopes to view cells and microorganisms.

Another good example comes from the Spanish architect, Antoni Gaudí (1852–1926). He is famous for a number of structures, most notably the Sagrada Familia Basilica in Barcelona. Even though it's not yet complete, it's breathtakingly beautiful.

Basically, an architect has two problems. The proposed design has to be structurally sound and, at the same time, aesthetically pleasing. These days, most architects leave the structural aspect to engineers. But Gaudí was able to assess both with his "hanging chain" models. He began with a scaled floor plan on a board that he attached to a ceiling. He then suspended weights from strings hanging down from the board. A picture of one of his models is shown in Figure 0.3. Once the model was constructed, he took pictures of it and then turned the pictures upside down to judge the aesthetics of his design. This technique had a number of advantages. First, for the designs of churches, the arches and domes of the model took the catenary shape, well known to have significant structural advantages over spherical and parabolic shapes. And second, relative to a standard 3D presentation model, the hanging chain model allowed him to see the effects of design changes quickly. Subsequently, architects continued to use Gaudí's approach particularly in the design of churches, museums, and civic buildings.

We term such artifacts that help our imaginations discover ideas *ideation technics* or just *technics*. Lewis Mumford first used the word in his book *Technics and Civilization*.[7] Mumford focused on the role of technology in society and emphasized that technology should not be

[7] Lewis Mumford. *Technics and Civilization*. New York: Harcourt, Brace and Company, 1934.

Figure 0.3: One of Gaudí's hanging chain models. Photo by Canaan, CC BY-SA 4.0, via Wikimedia Commons.

viewed in isolation, but rather as an integral part of the society from whence it came. He viewed exographics not merely as a mechanical tool, but rather as one that extended the capabilities of individuals and societies. Certainly that is the way we see it and we'll be extending his arguments in this book.

In the same way that mathematics is viewed as the queen of the sciences, we view exographics as the queen of the technics. There is a strong sense in which exographics is fundamental to the origination of other technics. For example, exographics was required to invent the smartphone, the device Sinclair uses to help him compose.

OUR BASIC UNIT OF ANALYSIS is the *idea*, the engine of our cultural advance. The word comes from the ancient Greek word for "form" or "pattern," and another word meaning "to see." This etymological origin recognizes that ideas are strongly grounded in vision.

More generally, our *made world* (smartphones, hammers, clothes, TVs, computers, cars, . . .) and *lifeways* (economic systems, social institutions, societal norms, language, exographics, . . .) are a set of *cultural objects*, each arising as a result of our minds capitalizing on ideas.

Consider this example. About 2,000 years ago, the Inuit invented sun goggles made from wood, bone, or ivory. These had narrow slits to reduce the glare of reflected sunlight that caused snow blindness. A picture of a pair is shown in Figure 0.4. These sun goggles are a part of our made world and we have no doubt that it required considerable ingenuity, thought, and experiment to make the first pair.

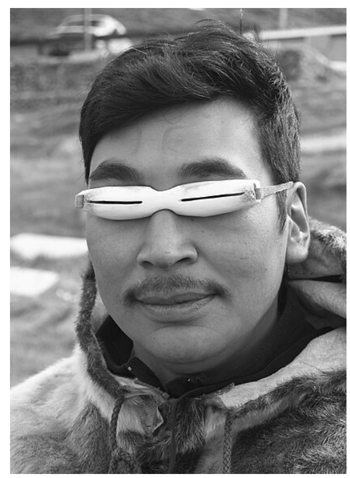


Figure 0.4: An Inuk wearing sun goggles made from caribou antler and caribou sinew. Photo by Julian Adrobo, CC BY-SA 2.0 via Wikimedia Commons.

We define the *Ideasphere* to be the set of all cultural objects we've innovated since the dawn of human consciousness over all cultures. It's a variation of Wade Davis's concept of the ethnosphere which he defines to be the "sum total of all thoughts, beliefs, myths, and institutions made manifest today by the myriad cultures of the world."[8] The Ideasphere is a large set.

[8] Wade Davis. *Light at the Edge of the World: A Journey Through the Realm of Vanishing Cultures*. Vancouver: Douglas & McIntyre, 2001, p. 8.

We propose an equivalence between a cultural object and the collection of ideas that led to the object's discovery. For example, if we consider the cultural object to be the aircraft, there have been many good ideas. Early on, the Wright brothers discovered how to control a powered aircraft's flight. The shape of their aircraft's wings had a significant effect on lift. The "warping" of the aircraft's wings allowed them to turn the aircraft in the horizontal plane. Subsequently, they determined that the upright rudder should be movable rather than rigid. We've seen many advances in design since: jet engines; swept and supercritical wing designs; turbofan engines; electric and hybrid-electric propulsion; lightweight composite construction materials including carbon fiber reinforced plastics; digital fly-by-wire systems; the inclusion of AI assists in navigation, air traffic control, and predictive maintenance; sustainable aviation fuels; and so on. Hence, the cultural object we've labeled "aircraft" is the confluence of a large number of ideas over a long period of time. In other words, ideas lead to our first pass at a cultural object, and over time we improve the cultural object with additional ideas.

There is nothing stopping us from thinking about a specific aircraft, say the Airbus A380, as a cultural object too. It required 10,000 engineers working over 10 years to design. The design was done using the code CATIA (Computer Aided Three Dimensional Interactive Application). This allowed engineers to design, visualize, and test components virtually before manufacturing. In total, there were over 4 million components. The design was entirely digital so there are no traditional paper blueprints. It's been estimated that, if printed, the CAD drawings would have required more than 100,000 pages. A large number of ideas were required to discover the Airbus A380.

Hence, the two cultural objects, the aircraft and the Airbus A380, are each equivalent to a large aggregation of ideas. Going forward, we will speak of the Ideasphere as including either a cultural object or, equivalently, its associated ideas.

We now come to an important definition. The *e-Class* is a subset of the Ideasphere defined to include any cultural object that required its innovators to use exographics to discover one or more of its associated ideas. Figure 0.5 contains a Venn-type diagram of the relationship of the Ideasphere and e-Class. Note that the e-Class is a proper subset of the Ideasphere. The "e" in e-Class is short for "exographics." Both the aircraft and the Airbus A380 are in the e-Class whereas Inuit sun goggles are not.

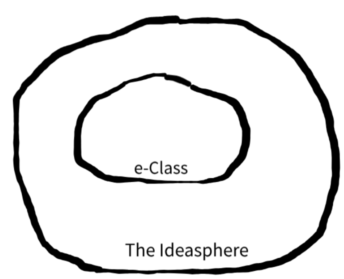


Figure 0.5: The e-Class as a proper subset of the Ideasphere.

Sometimes it's not clear whether a particular cultural object is in the e-Class. As the definition above makes clear, to include a cultural object in the e-Class, we need to know whether its innovators used exographics to discover one or more of the object's associated ideas. For example, did Samuel Barber use exographics to compose *Adagio for Strings*? We know he used staff notation to compose his *String Quartet, Opus 11* including its famous second movement, *Adagio*. He later arranged *Adagio* for a full string orchestra using staff notation. Consequently, Barber required exographics to compose *Adagio for Strings*, so it's in the e-Class.

We know that Keith Richards didn't need exographics to put together the 3-note up-and-back riff at the heart of the Rolling Stones' hit *Satisfaction*.[9] Consequently, the cultural object "*Satisfaction*/3-note riff" is not an e-Class object. However, Mick Jagger, the lyricist for the Stones, is on record that he used a pen and paper to work

[9] Richards discusses the origins of the riff in his autobiography *Life*. He was in the habit of noodling before going to bed, and, one night, after partying, he noodled with his tape recorder on. The next morning he listened to the tape and some of the recorded noodling led him to the riff in *Satisfaction*. So he needed a technic but not exographics.

through the lyrics of a song. Consequently "*Satisfaction*/lyrics" is in the e-Class. And since "*Satisfaction*/lyrics" is in the e-Class, so too is the cultural object "*Satisfaction*."

The saying "Float like a butterfly, sting like a bee" (Bundini Brown and Muhammad Ali) probably does not belong to the e-Class.

Wordsworth is said to have composed his poem *Tintern Abbey* entirely in his mind before writing it down. If he did, then it's not in the e-Class.

Special Relativity and Evolution by Natural Selection are in the e-Class.

Later in the book we'll argue the following points about the e-Class. First, we'll present empirical evidence that the growth in the e-Class has been exponential for centuries. Second, from a theoretical perspective, if the number of cultural objects generated over the next short period of time is assumed to be proportional to the stock of cultural objects at a given point in time, then it follows that the number of cultural objects will increase exponentially over time. This is a standard result in growth theory particularly in models of technology innovation. Third, we'll look at the growth in the e-Class after a society innovates an exographic system. As you might expect, substantial e-Class ideas soon begin to emerge. Fourth, we'll argue that this growth in the e-Class correlates directly with the rise of techno-literate culture.

Finally, as mentioned above, we want to emphasize that not all modern cultural objects require exographics to discover. New cooking recipes are generally improvised before being written down (sourdough bread, risotto, Peking duck). Much of modern dance is innovated without exographics (tango, break-dancing, shuffle-dancing, capoeira). Many of the tools and techniques of modern woodworking and metalworking have been innovated without the use of exographics. Language is learned without exographics. Much of modern music is composed without exographics including country, folk, rock, and jazz. Some modern fitness routines and remedies (intermittent fasting, cold plunges, herbal teas, massage, acupuncture) have roots in non-exographic wisdom. In short, that part of the Ideasphere outside the e-Class is also a large set and we continue to add to it.

An important contribution of our work is an embodied model of ideation. In cognitive science, "embodied" means that cognition is an integrated process requiring the brain and the body with its physical connection to the world.

It's important to distinguish *thought* and *ideation*. We conceive *ideation* as the process a person or group will go through to arrive at an idea. For serious ideas, such processes usually take a considerable period of time. It took Michelangelo 4 years to paint the ceiling of the Sistine Chapel in fresco. On the other hand, we might define *thought* to be the mental process that allows us to perceive, reason, imagine, remember, and decide—sometimes without sensory input. The essential difference is that ideation tends to require bodily movement as we will see in moment.

We propose the ideation process to be a sequence of generic iterations, each with two steps:

> *Logos step* (thinking): Observe the present state of the idea. If a finished idea has been achieved, stop. Otherwise, think about an action that, if executed, is likely to result in progress towards a finished idea.
>
> *Praxis step* (action): Execute the action decided in the logos step and then begin the next logos step.

We term this process *the diaconatic*. It's not a term you'll find in any dictionary as it's one of our invention. The etymology is based on the Latin "dia" for "through" and "conatus" for "attempt or struggle." The literal translation, then, is "through attempt or struggle." It's a variation of the term dialectic which is loosely translated "through speaking." This name emphasizes the notion that serious ideation is hard and that a discoverer must have the resilience to deal with intermittent failure, that not all diaconatic iterations will move the thinker closer to the objective. In fact, whole strings of iterations may fail to produce progress.

We like this model for two reasons. First, it's a simple descriptive model that seems to apply to all ideation including in the arts, the humanities, the sciences, engineering, the professions, and the trades. Essentially, it has mathematicians and artists using similar processes to discover ideas. Second, there is an explicit action step (praxis step) where the thinker has to engage physically with the environment. She may have to write a sentence, or execute a lab procedure, or make a few brushstrokes on a painting.

Some feel that Auguste Rodin's *The Thinker* (see Figure 0.6) is the epitome of ideation and discovery. But it's not the whole story. The other step, the step involving body movement, can be seen in Eduardo Paolozzi's bronze sculpture *Newton* located in the courtyard of the British Library (see Figure 0.7). Paolozzi has his scientist using a compass, and hence he is executing a praxis step. The discovery of ideas is a whole-body experience. It requires a mind and muscle movement.

In most cases, thinkers cannot predict precisely the results of the actions they decide to execute. We refer to this characteristic of a thinker's cognition as *opaque foresight*. Based on expertise, he or she has an inkling of what will happen, but there is usually not certainty.

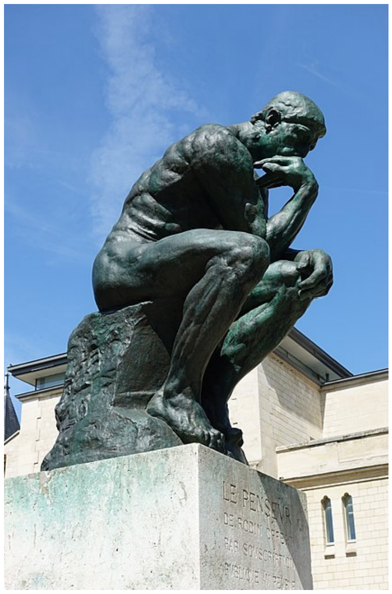


Figure 0.6: Auguste Rodin's *The Thinker*. Photo by CrisNYCa, CC BY-SA 4.0 via Wikimedia Commons.

This uncertainty begets the experimental nature of the diaconatic.

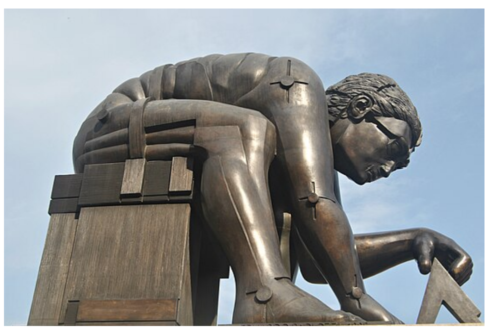


Figure 0.7: Eduardo Paolozzi's *Newton*. Photo by Loco Steve, CC BY-SA 4.0 via Wikimedia Commons.

Implicit in the diaconatic is the flow of information from the environment to the thinker. For example, an artist doing a painting might decide to do some brushstrokes at the logos step and then execute those steps at the praxis step. At the next logos step, he or she will assess the strokes just completed and then decide what to do next. Essentially, the environment provides the discoverer *feedback*, or equivalently, a *message*.

Those who chase ideas seem to be relentless tinkerers. They try something and if it doesn't work, they try something else. Think of a novelist. She might write a sentence, not like the way it turned out, and then rewrite it. We originally thought of this as trial and error but we prefer *trial and learn* because even if a trial fails, it usually provides the discoverer clues about what will work.

MOST OF US BELIEVE that our futures are determined biologically by genetics and natural selection. But we're now learning that culture can have a significant effect on our evolutionary path.

The essential characteristic of evolution is that we have a built-in biological mechanism that helps us cope with changes in the environment. In reproduction, slight changes in our genetic material (mutations) can lead to changes (adaptations) in our bodies and/or minds and/or behavior that make us a better match for the environment we find ourselves in. For example, millions of years ago, we were an arboreal ape and walked on all fours. But some change in the environment—probably climate change—led to food shortages and required us to go greater distances on average to get food. This may have resulted in our bipedal adaptation. Going to bipedal locomotion requires much less energy (and therefore less food to power our movement). We weren't as quick as most quadrupeds, but the savings in energy and other advantages must have been worth it.

The bipedal adaptation was crucial because it freed our hands to do other things like work with tools, carry food back to camp, and butcher a carcass. Modern humans have evolved very dexterous hands, including opposable thumbs that allow us to work with tools including writing devices such as pens, pencils, and computer keyboards. The evolution of our bipedal locomotion and hands follows the standard story of changes in the environment leading to favorable adaptations.

But it's also true that some of our cultural advances have induced significant biological adaptations. For example, in the deep past, our mouth, teeth, and jaw musculature were quite large, similar to those of a modern chimpanzee. But once we discovered cooking, we didn't need these large physical features to eat our food. The mastication and digestion of a cooked potato requires much less effort than a raw potato. The adaptive response to cooking was to evolve a much smaller mouth, teeth, and jaw. Hence, culture can affect our evolutionary path.[10] Evolutionary biologists refer to these dual effects as *gene-culture co-evolution*.

[10] Marc W. Feldman and Kevin N. Laland. "Gene-Culture Coevolutionary Theory". *Trends in Ecology & Evolution* 11, no. 11 (1996): 453–457.

One of the reasons we wrote this book is to contribute to the debate on the value of exographics.

Currently, there is no consensus among scholars. Some believe that their unaided minds are all they need to discover ideas. A few years ago, Bill had the following conversation with his sister, Joanne, a lawyer. She had asked him to tell her something interesting about the research he was doing for this book. He thought for a moment and replied, "When you do serious legal thinking, you always use your hands." She looked at him like he had five heads and responded categorically that she used her head to think. He then asked her how she prepared for an important cross-examination, knowing that she would tell him that she wrote it out on a legal pad with her favorite fountain pen. When she did, he came back with "So you use your hands to think." She looked at him, thought for a moment, and said "I might use my hands, but my mind is telling my hands what to do. My head is driving the whole process."

"OK," he said, "but what if I took away the pad and pen? Could you put together a cross-examination?" At this point, a light bulb appeared to go on and she conceded his claim, remarking that she'd never really thought about it that way.

The point of the anecdote is that Joanne needed a pen and paper to think through the long series of questions she would ask a witness. As she explains, she first determines a set of key questions that she wants the witness to answer in a way that helps her make her case. Once she establishes what those key questions are, she then has to think through a set of questions that precede each key question, leading the witness to answer the key question in the way she wants. The exercise of constructing the next question sometimes requires her to refer to questions she's already written. She'd have trouble remembering these questions if she didn't write them down. Hence, exographics is a crucial element of her thinking process. Yes, her mind is doing the heavy lifting, but it would be impossible for her to plan the complete cross-examination without exographics.

Until the end of the conversation, Joanne was convinced that her head was the only thing she needed to assemble her cross-examination. To her, she was using the pen and paper as a recording device to produce a plan she would use in the actual cross-examination. It was only when Bill threatened to take away the pen and paper that she realized she couldn't build the cross-examination without pen and paper.

As for Joanne's strong initial belief that she only required her head to do the cross-examination, many of us have this bias. Neurocentrism is a deep-seated cultural belief that we've all grown up with.

Another example is the well-known exchange between Nobel Laureate Richard Feynman and historian Charles Weiner. Weiner had suggested to Feynman that Feynman's notes served as "a record of the day-to-day work." But Feynman objected:

"I actually did the work on paper," he said.

"Well," Weiner said, "the work was done in your head, but the record of it is still here."

"No, it's not a record, not really. It's working. You have to work on paper, and this is the paper. Okay?"[11]

Feynman is emphasizing how writing was a necessary part of his thinking process. He doesn't explain it very well, likely because he

[11] James Gleick. *Genius: The Life and Science of Richard Feynman*. New York: Vintage Books, 1993, p. 409.

hadn't yet thought about how to. In contrast, Weiner is a neurocentrist.

Or consider the views of the eminent anthropologist Claude Lévi-Strauss:

> Writing is a strange thing. It would seem as if its appearance could not have failed to wreak profound changes in the living conditions of our race, and that the transformations must have been above all intellectual in character. ... Yet nothing of what we know of writing, or of its role in evolution, can be said to justify the conception.[12]

[12] Claude Lévi-Strauss. *Tristes Tropiques*. New York: Atheneum, 1961, p. 291.

Lévi-Strauss is wrong but, in fairness, he made this statement before cognitive scientists had identified the important role of exographics in enabling thought.

The negative views of writing go back to Plato. At that time, the ancient Greeks believed in oral discourse (the dialectic) as the only path to discovery. One of Plato's criticisms of exographics was that words on a page could not defend themselves or clarify their meaning. He also felt that writing would weaken a thinker's memory.

In contrast, there are scholars who see exographics as an essential support for thought. For example, the classical scholar Barry Powell wrote this:

> It is not hard to see that writing is the single most important technology in human life ...[13]

[13] Barry Powell. *Writing: Theory and History of the Technology of Civilization*. New York: John Wiley and Sons, 2012

Others also have strong views on the salutary value of literacy. These include Jack Goody, Walter Ong, Jacques Derrida, Merlin Donald, Donald Schön ("thinking on paper"), Lev Vygotsky, Roland Barthes, and Marshall McLuhan.

Finally, there is a third group who see exographics in a decidedly negative light. For example, Patricia Greenfield wrote this in her review of some empirical work questioning the importance of literacy:

> [Their work] should rid us once and for all of the ethnocentric and arrogant view that a single technology [exographics] suffices to create in its users a distinct, let alone superior, set of cognitive processes.[14]

[14] Patricia Greenfield. "Book Review of 'The Psychology of Literacy'". *Harvard Educational Review* 53, no. 2 (1983): 216–220

Greenfield is not the only one to react in this way to those scholars who have preached the advantages of exographics and the organizations that have promoted literacy with missionary zeal. Certainly, such promotion has resulted in some unfortunate outcomes. An example is the Residential Schools Program in Canada, a program that was designed to force literacy on oral Indigenous peoples. We now know that the effort, perhaps begun with the best intentions, was an act of cultural genocide, one in which unspeakable violence was committed against Indigenous children.

Hence, there are significant differences of opinion among scholars about the value of exographics. Some believe exographics is one of the great technologies we've invented. Others are skeptical, and among these, there is a group that is downright hostile to any assertion of the value of exographics, particularly when it's been imposed on other cultures.

In this book, we'll attempt a synthesis. As we've indicated, we believe that exographics and literacy have played a significant role in our cultural advance. But we will not argue that exographics has given us a superior set of internal cognitive processes. Rather it has simply given us a way to extend our working memorys. More particularly, it's enabled us to bring representations of abstract concepts (Pirsig's ghosts) into our visual fields where we've been able to fashion them into advanced cultural objects.

IT REMAINS TO CONSIDER the relative importance of education and literacy on our cultural advance. We take the position that the two are symbiotically linked. In our modern world, they are both necessary to prepare individuals to work on the frontiers of the Ideasphere.

But there is a sense in which literacy *precedes* education. In ancient Mesopotamia, when the administrative class determined that exographics was beneficial, schools were set up to train the next generation of scribes. At these scribal schools, young men would learn the exographic system as well as the system of city-state administration. This formal education outside the family has continued to this day. There were education systems in ancient Greece, ancient Rome and then in Europe, Asia, and North America. These systems all had two purposes. One was to teach the skill of literacy. The other was to prepare students for life as an adult. We now have massive techno-literate education systems across the developed world and, to a lesser extent, in various parts of the developing world.

The interesting question is whether these systems of education would exist had we not invented exographics. We think the answer is no. In this sense, we argue that our modern system of literate education is an artifact of the exographics technology.

WE HAVE ONE LAST POINT TO MAKE. Although the book is about the important role of exographics in discovery, the real engine of our ideation efforts has been our imaginations, and more particularly our *networked imaginations*. The role of exographics, then, is as a tool to help connect these imaginations and then to allow our imaginations to discover ideas we otherwise would not be able to. As we will argue, the proof is in the pudding: the Ideasphere has grown exponentially since the invention of exographics, allowing us to build the astonishing techno-literate cultures we now inhabit.

THE BOOK IS IN TWO PARTS. In the first, ”Capturing the Unicorns of the Mind,” we’ll explain in detail how exographics enables us to discover a large class of cultural objects (e-Class) that would otherwise not be discoverable. In the second, ”The Rise of Techno-Literate Culture,” we’ll look at the societal implications of the invention of exographics and the growth in the e-Class. Basically, we’ll trace the rise of techno-literate culture arguing that it’s gotten increasingly literate, increasingly technical, and increasingly global. Effectively our theory is a variant of globalization applied to ideas, one that focuses on the role of networked imaginations, curiosity, and exographics in the evolution of culture.

Part I

Capturing the Unicorns of the Mind

1
The Role of Exographics in the Discovery of Ideas

I know no other way out of what is both the maze of the eternal present and the prison of the self except with a string of words.
Lewis Lapham

LINGUISTS generally define writing as the representation of the words we speak on a visual medium like the words on this page. It's called *glottographic writing*.

But they also recognize another kind—*semasiographic writing*—that includes non-speech representations like those in mathematics and music. This equation,

$$e^{i\pi} + 1 = 0,$$

is an example of semasiographic writing. The picture in Figure 1.1, taken from one of Leonardo da Vinci's notebooks, is also semasiographic writing.

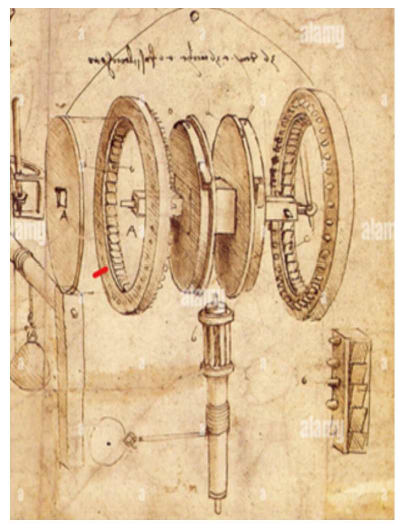


Figure 1.1: Da Vinci's exploded view of a design for a machine. Public domain image via Wikipedia Commons.

To avoid confusion, we've decided to term both types of writing *exographics* and define it to be the inscription of persistent symbols on a visible medium. Basically it's our ability to write symbols on a page (or any other medium). Merlin Donald was the first to use the term in the context of cognitive science.[1]

The inscription can be on any medium. William Stukeley related this about Isaac Newton while on walks at Cambridge:

> ... when he took a turn in the fellows gardens, if some new gravel happen'd to be laid on the walks, it was sure to be drawn over, & over, with a bit of stick, in Sir Isaac's diagrams;[2]

Apparently, Newton was not averse to exographing in the mud to explore an idea.

The picture in Figure 1.2 is of a young man wearing a virtual reality headset. He has a large number of screens open in front of him, to his right, and to his rear. Each screen exhibits exographic content, much of it semasiographic. He can interact with each of these screens with the keyboard and mouse, and if he is wearing VR

[1] Merlin Donald. "The Exographic Revolution: Neuropsychological Sequelae". In *The New Brain Sciences: Perils and Prospects*, ed. by Dai Rees and Steven Rose, 157–178. Cambridge: Cambridge University Press, 2004.

[2] William Stukeley. *The Memoirs of Sir Isaac Newton's Life*. London: The Royal Society, 1752.

controllers (special hand devices), he can "touch" a screen. None of these screens exist in the sense that there are no physical screens that people without the headset could see. Those screens are all virtual, and the young man can interact with each of them. Virtual reality gives new meaning to our notion of a "medium."

Figure 1.2: A man wearing a virtual reality headset. Image generated by OpenAI's DALL·E.

We make a distinction between *finished exographics*, the exographics you would see in a formal document like a paper, report, book, and *rough exographics*, the informal exographics done otherwise. Rough exographics includes the writing done in the moment-to-moment process of trying to bring an idea to the surface like sketching an engineering design, recording the observations of a chemistry experiment in a lab book, drawing the flowchart for a computer code, outlining a history essay in point form, or writing the staff notation for a snippet of music.

Rough exographics, by volume, tends to dwarf the volume of the finished exographics required to communicate the idea. Charles Darwin outlined the idea of evolution by natural selection in his book *On the Origin of Species by Means of Natural Selection*. The edition published by D. Appleton and Company in 1859 is 440 pages. To discover that idea, there were many years of field work, study, thinking, and rough exographics. Cambridge University Library holds the *Charles Darwin Papers*, a collection comprising over 30,000 digitized handwritten pages. *Part I Creation of the Origin of Species* covers the period 1837–1859 and includes notebooks and papers going back to the voyage of the *HMS Beagle*. For Darwin's idea of evolution, the ratio of rough to finished exographics was high.

THE INDUSTRIALIST LELAND STANFORD[3] had a keen interest in horses and gait analysis. In his time, it was not known whether all of a horse's feet were ever off the ground when running. A man took photographic pictures of one of Stanford's horses and some of them clearly showed that all of the horse's feet were off the ground. The human eye cannot discern this because the horse's legs move too quickly. But with the camera, reality freezes and we're able to see.

[3] He and his wife founded Stanford University.

Exographics has a similar property. In our definition of exographics, we suggested that it has to be *persistent* which means that the exographics must be stationary on the medium, over time.[4] That is, the symbols are motionless and you can look at them for as long as you require. Whereas the cognitive content of speech "disappears" almost as quickly as it is spoken, exographics is persistent.

[4] Roman Jakobson. "On the Relation between Visual and Auditory Sign". In *Selected Writings II*, 338–344. The Hague: Mouton, 1971.

Not all the text we write is persistent. For example, consider the subtitles in a movie. They seem to be consistent with our definition of exographics because we see the words and can read them. But if we can't stop the video, these words are as fleeting as the corresponding speech uttered by the movie characters. As soon as a line is given by an actor, its corresponding script at the bottom of the screen disappears to make room for the next line. In other words, movie subtitles are not persistent. Hence, not all text can be classed as exographics.

Another example is sign language. When someone signs, they are forming symbols with their hands which travel as light waves to an observer's eyes. Hence, sign language "text" is visual and symbolic. But, just as with movie subtitles, the signed words disappear cognitively in the same way that spoken words do.

Non-persistent text is generally not useful to us in the development of an idea because it's not stationary on the medium. Persistence is important because it allows us to sit and stare at the idea as we think about it and develop it.

WE SOMETIMES FORGET how tedious exographics was to learn. Skylar is a Grade 1 student in Canada. At the end of every week, she and her classmates write a short summary of the week's highlights. One of Skylar's summaries is shown in Figure 1.3. It translates

> We wrote in our journals. We balanced on benches. We talked about helping each other in our community. We learned about dairy farmers. We used scooters.

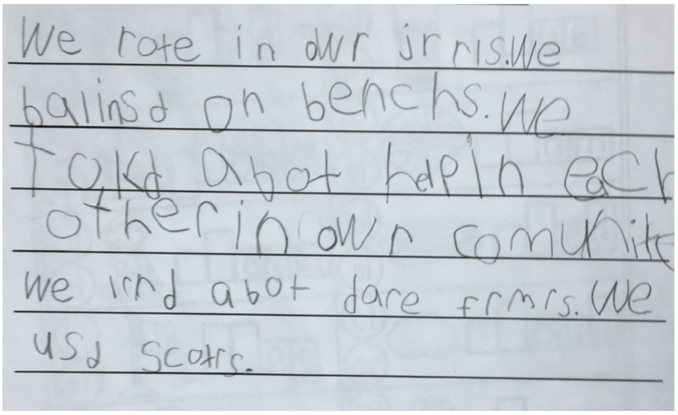


Figure 1.3: One of Skylar's weekly summaries. Picture is courtesy of Skylar's mom, Erin.

Let's have a look at some of her spellings. She is being taught phonetically so she knows the sounds of the letters and is able to put together pretty decent spellings. For example, in her first line, "rote" is pretty close to "wrote" and there is an argument that "rote" is the better spelling when you consider the silent "w" in the usual spelling. In the second last line, she spells "learned" with "lrnd" and in the last line, "used" with "usd." These words without vowels bring to mind the Phoenician abjad (a set of phonetic letters without vowel sounds). The ancient Greeks borrowed this abjad and then supplemented it with vowels to form the Greek alphabet. Again, are "learned" and "used" improvements? Not really. It's interesting to note that we used abjad-type spellings when we first started to text on smartphones. But now smartphones come with a predictive text feature that gives you correctly spelled guesses for the word you are trying to type.

In short, Skylar is embarking on a long journey that will take her to full literacy (with words and numbers). She will spend at least the next 12 years learning how to read and write and in so doing, learn a lot of the knowledge required to participate fully in our techno-literate society. We spend an enormous amount of money educating the next generation.

But here's the thing. Although it takes considerable effort to become literate, almost all children will become literate adults.

Furthermore, these writing skills and the simplest knowledge we learn through writing can be very useful at times. During the Apollo 13 mission to the Moon in 1970, an explosion caused a significant loss in battery power in the Command and Service Module (CSM). The decision was made to shut down the CSM and have the crew move into the Lunar Module (LM). This required that the guidance data from the CSM system be transferred to the LM system. To do this, the commander, James Lovell, had to make an arithmetic calculation by hand. We have a record of that calculation. Lovell used a pencil to transcribe CSM guidance data to a page of one of his manuals. He then followed the page's algorithm to get the new navigation settings to input into the LM. This exographic calculation had to be done correctly. Any error would have had catastrophic consequences. Lovell realized that and so asked Mission Control to check his calculations. Here is the conversation between Lovell and Mission Control:

> *058:04:03 CDR (LOVELL)*: Houston. Okay. I want you to double check my arithmetic to make sure we got a good course align. The roll CAL angle was minus 2 degrees. The command module angles were 355.57, 167.78, 351.87.
>
> *058:04:36 CC (CAPCOM)*: Okay, Jim. We copy the roll CAL at minus 2.0. The command module is 355.57, 167.78, 351.87.
>
> [. . . three minues later]
>
> *058:07:11 CC (CAPCOM)*: . . . And, Aquarius, your arithmetic looks good on the course align, there.

Let's put this in perspective. Quite a lot had to go right for the three astronauts to return safely to Earth. One requirement was that Lovell be able to do grade school arithmetic using exographics.

We'll now get into a detailed explanation for how exographics enables us to discover ideas we otherwise couldn't.

We'll begin by considering our ability to remember symbolic information. Imagine someone speaking the sequence "k 9 L z t 10 b 23 t R" and you are required to remember the symbols in the order given. We'd find this difficult, and our guess is that most readers would also. It's because our memories are not designed to remember unrelated symbols easily. It would be much easier to remember the gist of a joke ten times longer.

Psychologists have proposed models of the way we remember and process information. One useful for our purposes is the Modal Model.[5] It suggests that human memory comprises two main components: Working Memory (WM) and Long-Term Memory (LTM). WM is where we do all our thinking with LTM serving as a store of method, knowledge, and experience.[6] WM has the property of having low storage capacity. You can use it to recall a low volume of unrelated information (e.g. "k 9 L") but sequences like "k 9 L z t 10 b 23 t R" are simply too large.[7] Unfortunately LTM is not much help because it's difficult to store symbol sequences quickly.

In sum, our memory architectures are such that we have difficulty storing long strings of unrelated symbolic information quickly. But if we have an exographics capability, we can write a symbolic string down and in so doing store it externally for easy recall later if required.

[5] Richard Atkinson and Richard Shiffrin. "Human Memory: A Proposed System and Its Control Processes". *Psychology of Learning and Motivation* 23 (1989): 89–195.

[6] For more on the structure of WM, readers are referred to: Alan Baddeley. *Working Memory, Thought, and Action*. Oxford: Oxford University Press, 2007.

[7] See Miller's classic paper: George Miller. "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information". *Psychological Review* 63, no. 2 (1956): 81–97.

It's worth noting that there are special individuals, mnemonists, who are capable of prodigious feats of memory. Zerah Colburn, an 8-year-old American boy, was able to get the 16th power of 8 (281,474,976,710,656) in front of an audience in London.[8] Alexander Luria, in his book *The Mind of the Mnemonist*, describes the remarkable mind of S.[9] Whether S heard or read information, there seemed to be no limit to what he could recall. Lists of 70 random syllables could be recalled perfectly 15 years later. But Colburn and S are the exceptions, not the rule. Most of us have a poor memory when it comes to storing symbolic information.

[8] Frank Mitchell. "Mathematical Prodigies". *The American Journal of Psychology* 18, no. 1 (1907): 61–143, p. 65.

[9] Alexander Luria. *The Mind of the Mnemonist*. Cambridge MA: Harvard University Press, 1987.

Let's now revisit arithmetic problems. Consider calculating 847×86 without using your hands. One way to do it would be as follows.

> Calculate 847×6 (getting $5,082$)
>
> Calculate 847×80 (getting $67,760$)
>
> Add these two to get $5,082 + 67,769 = 72,842$.

When executing this arithmetic in your head, the difficulty arises when you have to execute a step while at the same time remembering the result of a previous step. We were able to get the first and second products, but once we got the second product, we had forgotten the first and therefore could not do the addition required in the third step. Hence, to do this calculation, you must be able to recall intermediate results for use later in the calculation. One of us tried a different product (another 3-digit integer by 2-digit integer) and committed the first product to LTM using lots of rehearsal. This enabled him to get an answer, but it took a long time and he expended a lot of mental effort. If we made the problem larger (say, the product of two 4-digit numbers), neither of us could do it.

These arithmetic examples are important because they enable us to prove this statement is false:

> All ideas discoverable by the human mind can be discovered without the use of external artifacts (such as exographics).

We term this the *neurocentrism fallacy* because some of the ideas we discover require us to use tools we operate with our hands. For most people, the arithmetic idea can only be discovered if they use tools like exographics, a calculator, an abacus, or a computer. This, then, is the advantage of exographics. Rather than trying to store the information in our biological memory systems, we can store it as exographics on a medium. Exographics makes 847×86 a simple problem. As we've explained, we term this the memory extension purpose of exographics.

WE ARE CERTAINLY CAPABLE of making longer arguments without exographics. Based on the work of the Harvard classicist Milman

Parry and others, we know that the Homeric epics (*The Iliad* and *The Odyssey*) were composed by Homer without exographics and then recited orally by poets for many centuries before they were eventually written down.[10] *The Odyssey* is over 12,000 lines, so to compose it orally is a significant feat of memory. To perform it, poets would travel from settlement to settlement reciting it at religious festivals and other kinds of community celebrations. However, they did not recite a word-for-word rendition but rather an improvisation, much like a jazz musician would improvise a solo. Parry argued that the structure of the poems is oral-formulaic. That is, the poet delivering the epic had a stock collection of words and phrases that he selected from under the constraint that he had to keep within the poem's fixed meter (dactylic hexameter). For instance, if he had to refer to Achilles, he might say "swift-footed Achilles" or "divine Achilles" or just "Achilles" depending on how much metrical room he had left in a line. Parry believed the poets had vast repertoires of stock words and phrases they could call upon when improvising the poems.

[10] Milman Parry. *The Making of Homeric Verse: The Collected Papers of Milman Parry*. Ed. by Adam Parry. Oxford: Oxford University Press, 1987.

The work of Homer makes it clear that the human mind is capable of composing significant stories without exographics. But being able to write down a story as you compose it makes it much easier to assemble. Once the ancient Greeks were in possession of their alphabetic exographic system post-Homer, the work of storytellers got a lot easier and, not surprisingly, the volume of their poetry and drama exploded over the course of the Greek classical period. In addition to literature and drama, the work of historians (Herodotus, Thucydides, and others), philosophers (Plato, Aristotle), and mathematicians (Euclid) begins to appear. Clearly exographics is a significant part of the explanation for "the Greek Miracle," their stunning contributions to the intellectual foundations of the West.

The same thing appears to be true in ancient Sumer. Any review of Sumerian literature should begin with a reading of Samuel Noah Kramer's exposition of their work.[11] They wrote myths, epic poems, hymns, lamentations, essays, and even texts of disputations. We know that proto-cuneiform was in place by about 3000 BCE and that their literature did not begin to appear until about 2500 BCE. One could imagine that, as the scribal schools began to take on a more important role, some professional scribes might have been inclined to write stories. The Electronic Text Corpus of Sumerian Literature is an online library providing some 400 works in translation, including the well-known narrative poem *Gilgamesh*, written about 2100 BCE.

[11] Samuel Noah Kramer. *The Sumerians: Their History, Culture, and Character*. Chicago: University of Chicago Press, 1963.

The role of exographics in the composition of much larger arguments extends to the modern era. For example, consider Edward Gibbon's *The History of the Decline and Fall of the Roman Empire*, published over the period 1776–1789. It's a 6-volume work of over 1.5 million words, an extended argument of tens of thousands of statements that would have been impossible to construct using only biological memory.

Another is Andrew Wiles' proof of Fermat's Last Theorem, generally regarded to be one of the great achievements of 20th century mathematics. Here is the first sentence of his paper giving the proof:

> An elliptic curve over $\mathbf{Q}$ is said to be modular if it has a finite covering by a modular curve of the form $X_0(N)$.[12]

The rest of the proof is 108 pages of sentences like that. It's a deductive argument that took Wiles years to produce. As he has explained, some statement transitions required him to come up with new mathematics, and others were just very difficult. But eventually he put the complete proof together, statement by statement. Doing this proof without exographics would have been impossible.

[12] Andrew Wiles. "Modular Elliptic Curves and Fermat's Last Theorem". *Annals of Mathematics* 141 (1995): 443–551, p. 443.

In an influential work, Eugene Ferguson examined the historical use of visualization and sketching in engineering and technology.[13] He suggested that a technologist/engineer has a vision, a complete picture in his mind of what the gadget will look like, and then reproduces that vision on paper.

[13] Eugene Ferguson. "The Mind's Eye: Nonverbal Thought in Technology". *Science* 197, no. 4306 (1977): 827–836.

Let's re-examine Leonardo da Vinci's exploded diagram of a machine as shown in Figure 1.1. Would it have been possible for Leonardo to have this complete sketch in his mind before putting pen to paper? We don't think so because his WM, despite its likely large size, would not have been able to hold all of this sketch's detail. Almost certainly, da Vinci engaged in a dynamic process, a back and forth with the page until he got to what he judged to be a suitable sketch.

If there is a group of us that might be able to generate a one-time vision of something, surely it's artists, and among them, Picasso was one of the best. But we don't think he had these complete visions either. Artists do studies in their preparation to do a painting. They do a number of sketches of the complete composition as well as various possibilities for the characters making up the composition. Picasso worked for a month and a half producing compositional and character studies for his mural *Guernica*. We have a record of these studies and they reveal how his thinking changed over his preparation to do the mural.[14] It's unlikely that Picasso had a one-time complete vision of *Guernica*.

[14] Robert Weisberg. "On Structure in the Creative Process: A Quantitative Case-Study of the Creation of Picasso's Guernica". *Empirical Studies of the Arts* 22, no. 1 (2004): 23–54.

Many scholars have observed that it's difficult to make arguments aurally because speech, unlike exographics, has the cognitive property that it disappears almost as quickly as it's spoken. But is this logic correct?

Suppose we had to solve this equation:

$$14x - 16 + 3x - 4x = 27 + 3x + 14 - 2x - 31 - 15x + 1. \tag{1.1}$$

Consider first solving it in our visual field with exographics. We would first look at it and recognize that it's linear in x. From this observation, we'd write a new equation moving all terms in x to the left-hand side and all of the constant terms to the right-hand side:

$$14x + 3x - 4x - 3x + 2x + 15x = 27 + 14 - 31 + 1 + 16. \tag{1.2}$$

To make the arithmetic more transparent, suppose we rewrite it like this:

$$[14 + 3 - 4 - 3 + 2 + 15]x = 27 + 14 - 31 + 1 + 16. \tag{1.3}$$

To avoid arithmetic errors, let's do each sum (the one on the left and the one on the right) three terms at a time to arrive at:

$$[13 + 14]x = 10 + 17 \tag{1.4}$$

and, in turn, this simplifies to

$$27x = 27. \tag{1.5}$$

The answer, then, is

$$x = 1. \tag{1.6}$$

With exographics, solving such equations is not difficult.

Let's now consider the difficulty solving it if there were no such thing as exographics and the equation was given to us aurally. If your authors just had to rely on our unaided minds, we couldn't remember it, much less manipulate it and solve it.

But suppose that we had the aural equivalent of exographics, say a tape recorder, to record the statement above and play it back as much as we required. In fact, suppose we have two tape recorders: one to record the question and the other to record our answer as we build it. Both tape recorders would allow us to rewind and listen to anything we'd already recorded.

Let's look at the details of how this system would work. You could repeat the following steps for each term in the equation:

1. Listen to the *new term* and the *current running solution*.

2. Add the *new term* to the *current running solution* to get the *new running solution*.

If these steps are executed, the following sequence of running solutions result:

Step 1: Term 1 is 14x. So, it becomes the running solution, or $RS_1 = 14x$.

Step 2: Term 2 is -16. So $RS_2 = 14x - 16$.

Step 3: Term 3 is $3x$. Hence, $RS_3 = 17x - 16$.

Step 4: Term 4 is $-4x$. So $RS_4 = 13x - 16$.

Step 5: The next symbol is the equality sign. So, there is no change to the RS: $RS_5 = 13x - 16$. But all the signs of the terms after the equality will be reversed.

Step 6: The next term is 27. So $RS_6 = 13x - 43$.

Step 7: The next term is $3x$. Hence $RS_7 = 10x - 43$.

Step 8: The next term is 14. So $RS_8 = 10x - 57$.

Step 9: The next term is $-2x$. Hence $RS_9 = 12x - 57$.

Step 10: The next term is -31. So $RS_{10} = 12x - 26$.

Step 11: The next term is $-15x$. Hence $RS_{11} = 27x - 26$.

Step 12: The final term is $+1$. So $RS_{12} = 27x - 27$.

We can now get the solution by setting $RS_{12} = 0$ or $27x - 27 = 0$ and $x = 1$.

For each new term, we only have to adjust the running solution's variable term or constant term. If we forget what the existing running solution is, we could simply replay it from the recorder. Hence, this is an easy argument to make in our aural field *if we have the right technology*. Just as we need exographics in the visual mode, we need voice recording equipment in the aural mode. We use the term *exophonics* to refer to such a technology. Effectively, exophonics has the property that it makes sound persistent. With the technology, we can repeat the sound as much as required to update our working memory registers.

This line of reasoning makes it clear that the real problem exographics helps us overcome is our weak memory systems (low capacity WM and hard-to-write LTM). It also makes clear that we need our hands to operate a technology (either exographics or exophonics) to deal with our limited memory. Finally, it renders false the conventional wisdom that we can't make complex arguments in our aural mode.

That said, our visual field is generally advantageous for making arguments for a number of reasons. First, relative to auditory input, visual input leads to better recall and problem solving.[15] Second, the brain tends to process visual information in parallel (seeing multiple elements at once) but processes auditory information sequentially. To see this, consider Leonardo's sketch presented earlier in the chapter. It would be impossible to design Leonardo's machine in our aural

[15] Alan Paivio. *Mental Representations: A Dual-Coding Approach*. Oxford: Oxford University Press, 1986.

field with spoken words even with access to exophonics. To say that pictures are worth a thousand words is a gross underestimate of the number of words.[16] Third, we know that visual-spatial processing in the occipital lobe is highly developed for problem-solving, while auditory processing in the temporal lobe is more specialized for speech.[17] Most likely there are evolutionary reasons. Our ancestors relied heavily on vision for hunting, navigation, identifying threats, and tool-making, all crucial for survival whereas speech and auditory processing evolved later and are primarily optimized for communication, not problem-solving.

[16] Anne Treisman and Garry Gelade. "A Feature-Integration Theory of Attention". *Cognitive Psychology* 12, no. 1 (1980): 97–136.

[17] Alexander Luria. *Higher Cortical Functions in Man*. New York: Springer, 1966.

Given the importance of exographics to e-Class idea discovery, how is it that some blind mathematicians can still do mathematics? Leonhard Euler (1707–1783), arguably the best mathematician of all time, was blind for the last 17 years of his life. Historians of mathematics have suggested that this period of blindness was his most productive. An important aspect of Euler's work during this period of blindness was that he dictated to knowledgeable secretarial assistants. As long as Euler could keep the current line or equation in his WM, with his secretaries providing other parts of what he had written as required, we don't think he'd have any trouble and he clearly didn't. Basically, Euler and his assistants constituted a "coupled system."

EXOGRAPHICS IS VALUABLE for idea discovery in another important way. As we suggested in the introductory chapter, it enables us to bring concepts without a real-world referent into our visual fields, and this enables us to manipulate, combine, and recombine such concepts into new ideas. We'll try to clarify what we mean.

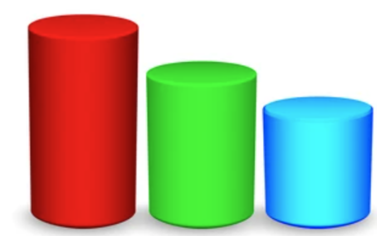


Figure 1.4: 3 cylinders with different characteristics.

Consider the graphic in Figure 1.4. If you were asked what you notice about these cylinders, you might say they're different sizes or there are 3 of them. If you were asked which is largest, you'd say the one on the left.

The concepts we used in the previous paragraph—"size," "largest," "left," "different," and "3"—do not have corresponding referents in the real world. There is no such thing as a "3" in the real world. We could think about 3 pianos, 3 French hens, or 3 cylinders but there is nothing we can point to in the real world that is a "3." The same is true of the concepts "size," "largest," "left," and "different." We will take some philosophical liberties and label them abstract concepts and distinguish them from concrete concepts like "apples" and "banjos" which do have real-world referents.[18]

[18] We are aware of the long history of philosophical thought on abstract and concrete entities. Our use of these concepts in this book is purely utilitarian in the sense that fewer words are required to write "abstract concept" than "concept without a real-world referent."

As we argued in Chapter 1, we're especially good at working with materials in our visual fields to fashion cultural objects and the evidence for this goes back millions of years. In contrast, for certain ideas, the “raw materials” of those ideas are not naturally present in our visual fields. For example, as we noted above, there is no such thing as the number “3” in the real world. But we were able to invent this abstract concept and then bring a representation of it into our visual field by inscribing “3” on a medium. Once inscribed, this representation is as concrete as a tree or a stone. We can then combine it with representations of other abstract concepts in an argument to discover ideas. Hence, exographics allows us to bring representations of abstract concepts into our visual fields where we can then manipulate them into ideas and cultural objects. We term this purpose of exographics its reification purpose.

Exographics is the key to unlocking Pirsig’s ghosts. By using exographics to get abstract concepts into our visual fields, we can start to make extended arguments with them. This is very apparent in mathematics, an imagined abstract discipline. You can’t find a function, or derivative, or matrix in the real world. They are all abstract concepts that come from our imaginations, and are reified with exographics over centuries. Without exographics, mathematics would not exist.

WHEN WE DO MATHEMATICS, sometimes reifications of reifications are useful. For example, suppose that we had to find three consecutive integers whose sum is 186. We could solve this problem by first letting the unknown numbers be x, $x+1$, and $x+2$ and then solving the equation $x+(x+1)+(x+2)=186$.

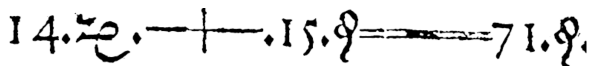
This is an example of a higher-order reification. At one level, numbers such as 3 and 186 are themselves reifications. The use of x to represent a number is a higher-order reification. It’s a reification of a reification.

The step of representing an unknown number by a symbol (algebra) was a difficult cognitive step. It dates at least to the work of the Persian mathematician al-Khwarizmi whose book on the solution of linear and quadratic equations contained the word “al-jabr” in its title. There is some debate about what ”al-jabr” means but the most reasonable interpretation is “restoration.” In the context of algebra and modeling, this makes sense because an unknown number is carried through a problem as a symbol (x for the consecutive integer problem above) and the value of the symbol is only revealed or “restored” at the end of the procedure.

Algebra reached Europe in the 12th century with the work of the mathematician Fibonacci and his book *Liber Abaci* (*Book of Calculation*, 1202). The Italians used the term “cosa” to represent the unknown in a problem and, later, English mathematicians referred to these as ”Cossike numbers.”

The representation of equations and algebraic quantities as we know them today in English begins with the work of Welsh mathematician Robert Recorde who details his approach in his book *The Whetstone of Witte* (1557). This is a remarkable development of arithmetic and algebra given as a Socratic dialogue between a master (teacher) and a scholar (student). In it, he invented the equals sign ("I will sette as I doe .. a paire of paralleles .. because noe .2. thynges, can be moare equalle") as well as introduced the "$+$" and "$-$" signs.

The first equation Record solved was this:



This is the equation $14x + 15 = 71$. Note the oversized plus sign and the long equals sign. On the nature of the unknown, x, Recorde writes

> . . . it mai bee thoughte to bee a rule of wonderful invention that teacheth a manne at the firste worde to name a true nomber before he knoweth resolutely what he hath named.

This would not have been an easy idea to discover. You begin by representing some number by a name, say x. But then you have to write down an equation that enables you to find x. Not only that, you have to figure out how to solve the equation. Today we know the rules for manipulating equations. But Recorde had to figure out how those manipulations worked. All of that couldn't have been easy. But he figured it out and now algebra and modeling are a big part of mathematics.

Let's summarize. The techno-literate culture we've advanced is a testament to our curiosity and our ability to imagine. But as we've demonstrated, to get the most out of our imaginations, we need external technologies—exographics is one—to help us. The reason for needing these external technologies is our poor ability to remember symbolic information: our WMs have only a small capacity to remember such information and our LTMs require us to use considerable mental effort to store it.

When we work through an argument leading to the discovery of an idea, we have to be able to recall parts of the argument for use later in the argument. As these intra-argument memory requirements build, there is less WM capacity with which to push the argument forward. That precise difficulty arises when we do arithmetic problems like getting the product of two multi-digit numbers. However, if we have an exographics capability, we can expand our WMs almost without limit and do these products easily. We've termed this the memory extension purpose of exographics.

Not all of our ideas require exographics to be discovered. Think of all the cultural objects we innovated before the appearance of exographics, objects like pottery, yarn, and bread.

But there is another class of ideas that requires exographics. These are the ideas we've been able to conjure by bringing representations of abstract concepts into our visual fields with exographics. Once in our visual fields, we've been able to mold them into an enormously large class of ideas we term the e-Class. We term this characteristic of exographics that enables us to bring abstract concepts to our visual fields its reification purpose. It's also why we've titled the book *Catching Unicorns*. In some myths, unicorns were conceived as fast, fierce, and difficult to catch. In the case of the e-Class, we argue that exographics is the key to capturing these unicorn-like ideas from the depths of our imaginations.

To summarize, exographics enables us to get representations of abstract concepts into our visual fields (reification purpose) and, once there, it extends our WMs to be able to make longer, more complex arguments (memory extension purpose).

There is an important third purpose we'll explore more fully later in the book. With exographics, we've been able to record our ideas and store them (in libraries, the Internet, archives) across time and space. We term these stored exographics the e-Library. Given that the great strength of our species is collaboration and culture, this is an enormously important resource for those who would contribute to the e-Class.

We'll conclude with a brief discussion of the possibility of an exographic mind. We and our ancestors have now been embedded in exographics for centuries. A key question is whether exographics has been around long enough for it to have begun to leave subtle evolutionary advantages to those of us born into it. We are not aware of any evidence that children in oral Indigenous societies have innate difficulty with literacy when introduced to it. Biologically, they seem to be just as capable as any other child, suggesting that children are universally capable of learning exographics and contributing to the e-Class. Hence, our simple assumption going forward is that exographics enhances what our imaginations produce by extending our WMs. But beyond that, we're not prepared to assume it offers any other enhanced cognitive powers.

2

The Growth of the Ideasphere and the e-Class

Technology builds itself out of itself. It creates itself from itself.
Brian Arthur

RECALL that the Ideasphere is the collection of cultural objects we've discovered since the dawn of human consciousness. Alternatively, we could think of it as all the ideas that gave rise to these cultural objects. The e-Class is the subset of the Ideasphere which has required exographics to discover.

One of Max Roser's graphics is presented in Figure 2.1.[1] It's a cleverly structured timeline showing major additions to the Ideasphere over time ranging from the distant past to *Now* and into the distant future. Roughly, the slope of this timeline over its smooth sections corresponds to the frequency of additions—the higher the slope, the higher the frequency of additions. Note that time begins in the circular spiral on the bottom left of the graphic with the first stone tools used by our ancestor species 3.4 million years ago. Over the spiral period there are just a few inventions, among them the control of fire and cooking 1 million years go and the first use of a musical instrument (the flute) 43,000 years ago. Above the dashed spiral, the folded smooth lines—each a millennium—begin at the Agricultural Revolution and proceed roughly to 1800. Basically, the lines over the last three millennia before 1800 have a bit of slope suggesting that technological advance is beginning to quicken. This advance explodes as the 19th century opens. In fact, this is true for all graphics that show how technology increases over time. It is an exponential increase (as in Roser's) and it "elbows" (i.e. it really starts to increase) around 1800.

[1] See his website *Our World in Data* (https://ourworldindata.org/technology-long-run).

Brian Arthur has suggested a theory to explain how technology advances.[2] He argues that a technology is just an assembly of components each of which may be an existing technology. Take, for example, a smartphone. It's a collection of antecedent technologies

[2] Brian Arthur. *The Nature of Technology: What It Is and How It Evolves*. New York: Free Press, 2009.

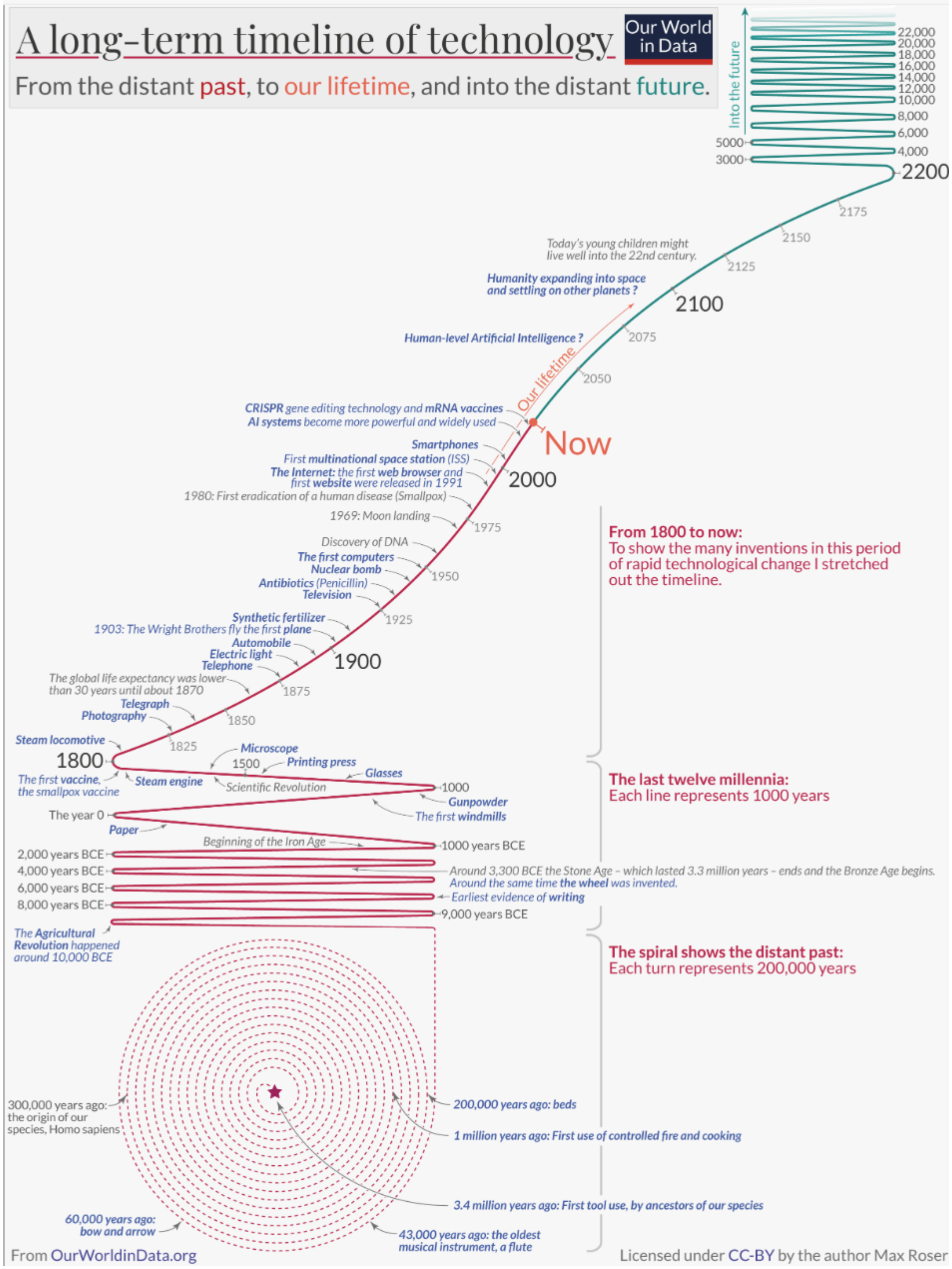


Figure 2.1: Technology growth over the last 3.4 million years. Courtesy of Max Roser, under license CC-BY.

including a high-quality digital camera, a GPS system, a high-speed data modem to connect to the Internet, a touchscreen interface, SIM cards that give each phone a unique identity, and a host of other technologies including a large supply of apps. In turn, each of these technologies depends on its own prior technologies. For example, the digital camera has a relatively long history dating back to the 1950s when engineers started to think about recording pictures digitally with a large array of semiconductor sensors. Since then, there have been many technological breakthroughs, including algorithms for compressing picture data for storage and transfer. Interestingly, all these technologies have required exographics to discover and have enabled the smartphone cameras of today. Software developers needed exographics to write the miles of code for the many apps available on smartphones. Hence, the smartphone is in the e-Class.

The exponential growth of the Ideasphere can be argued mathematically if one is willing to assume that the *growth* in ideas at a particular time is proportional to the *stock* of ideas at that time.[3] This assumption is consistent with Arthur's theory, and not surprisingly, Roser's curve is exponential.

[3] Let the instantaneous growth in the stock of ideas at time t be proportional to the stock of ideas at time t, $A(t)$. We can operationalize this assumption with this differential equation

$$dA/dt = kA(t),$$

where k is a positive constant. It has a solution

$$A(t) = ce^{kt},$$

where c is a positive constant. Note that $A(t)$ is an exponential function.

LET'S NOW TURN to the growth in the e-Class. Almost all of the ideas generated in traditional university disciplines are in the e-Class because they require exographics to discover. This is especially true for mathematics and the other disciplines in the sciences.

Harvey Leyman has done some remarkable work to document e-Class growth over long periods of time.[4] He looked at a number of disciplines, among them philosophy, genetics, mathematics, chemistry, medicine and hygiene, and economy and political science. For each subject over periods measured in centuries, Leyman consulted a variety of sources, including chronologies and encyclopedias, and in each year counted the number of inventions and discoveries. A plot of the number of discoveries over time for a subset of these disciplines is shown in Figure 2.2. The curves are consistent with an exponential increase in contributions over time. Note also that the curves appear to elbow about 1800.

[4] Harvey Leyman. "The Exponential Increase in Man's Cultural Output". *Social Forces* 25, no. 3 (1947): 281–290.

Another way to assess the growth of the e-Class is to look at the expansion in the number of university disciplines and the growth within these disciplines over time. At the formation of universities in medieval Europe, a very simple curriculum was taught. It consisted of the *Trivium* (grammar, logic, and rhetoric) followed by the *Quadrivium* (arithmetic, geometry, music, and astronomy). Some professional arts were taught, such as medicine, law, and architecture, but the primary programs were the preparatory work of the *Trivium* followed by the *Quadrivium*. Contrast that with the substantial number of disci-

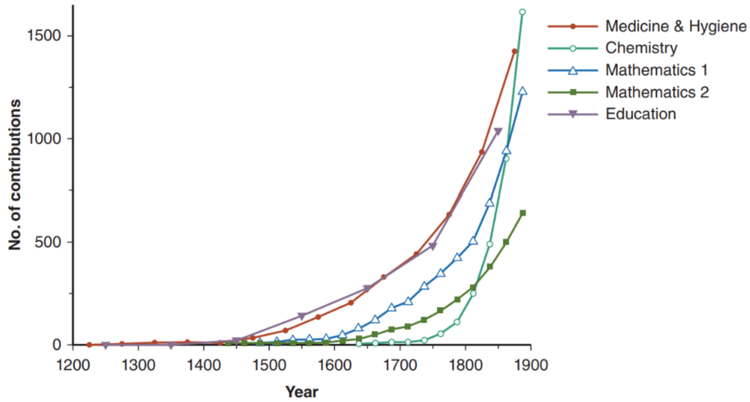


Figure 2.2: A plot of the number of discoveries over time in selected disciplines based on Leyman's data.

plines available at a university today. The difference is stunning and reflects Leyman's finding of exponential growth in e-Class ideas.

As for depth in any particular discipline, consider mathematics. It is usually divided into pure mathematics and applied mathematics. Fields in pure mathematics would include algebra, analysis, probability theory, geometry and topology, number theory, and logic and foundations. Applied mathematics includes approximation theory, computational mathematics, numerical analysis, operational research, dynamical systems, mathematical physics, information theory, cryptography, steganography, combinatorics, graph theory, and game theory. Each of these fields includes several subject areas. For example, algebra includes group theory, ring theory, commutative algebra, field theory, linear algebra, universal algebra, homological algebra, differential algebra, lattice theory, representation theory, K theory, and category theory. For each of these subjects, introductory and advanced textbooks have been written. In addition, there is ongoing research in each of these areas published in specialized journals. Suffice it to say that mathematics is a broad discipline, and a modern mathematics scholar would usually specialize in an area.

There is also significant e-Class work done in the private sector. At this writing, the "Magnificent Seven" includes these AI firms: Apple, Amazon, Alphabet, Meta, Microsoft, Nvidia, Tesla (electric cars but heavily invested in robotics and AI). The market value of these firms constitutes 35% of the value of the S&P 500. As a group, they've made the world a much smaller place. They provide us with an amazing communication and thinking scaffolding that we will continue to learn how to use. What's more, if the past has taught us anything, it's that this technological growth will continue.

Another way to show the increase in e-Class ideas is with patent data. Figure 2.3 shows the number of patents granted each year in the US over the period 1963–2019. Patents granted have gone from less than 50,000 in 1963 to almost 400,000 in 2019. Admittedly, not all of these would be in the e-Class but a majority of them would.

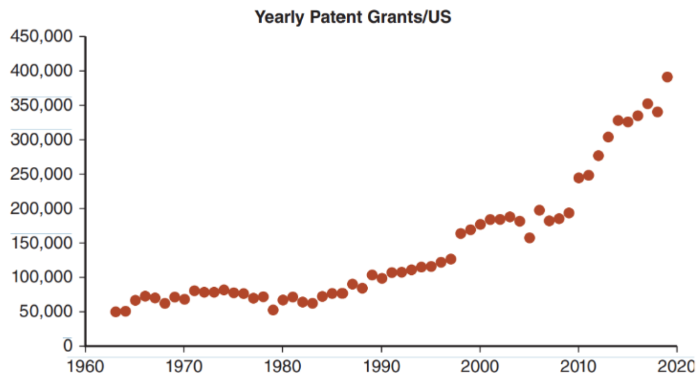


Figure 2.3: The number of patents granted yearly over the period 1963-2019.

THROUGHOUT THE HISTORY OF IDEAS, we've had some pretty special breakthrough ideas. Think of Copernicus suggesting that it was the Earth that revolved around the Sun and not the other way around (the heliocentric model). Or Darwin arguing that our deep ancestor species and those of chimpanzees were once the same species (evolution). Or Alexander Graham Bell's discovery of the telephone—how crazy it is that two people thousands of miles apart could converse over the tiny wire running between them. This spirit of discovery is also apparent in the arts. Think of Elvis Presley and The Beatles bringing light to a new genre of music called rock and roll. The list of disruptive ideas is long and impressive.

But is our science and technology becoming less disruptive? There are some who think so. The Founders Fund, a San Francisco-based venture capital firm, published a document, "What Happened to the Future?" and Peter Thiel famously noted his suspicions with "We wanted flying cars, instead we got 140 characters."

Serious scholars have studied the problem and they've concluded that, lately, technology has been less disruptive.[5] Michael Park, Erin Leahey, and Russell Funk (PLF) examined a large number of published scientific papers and approved patents over a significant period of time and published their findings in the prestigious journal *Nature*. We've looked at their work closely and it's our judgment that their data justifies their conclusions. But we still have some lingering concerns. First, the Leyman data span a period of centuries, and growth in all disciplines has been exponential over the period. Why would that growth suddenly stop now during a period when the casual evidence seems to suggest we've been making great strides,

[5] Michael Park, Erin Leahey, and Russell Funk. "Papers and Patents Are Becoming Less Disruptive Over Time". *Nature* 613 (2023): 138–144.

particularly in AI and biotechnology? It will be interesting to see what an update of the PLF data says in 25 years.

3
The Diaconatic: A Theory of Embodied Ideation

Mathematics is not a deductive science—that's a cliché. . . . What you do is trial and error, experimentation, guesswork.
Paul Halmos

In our description of the diaconatic in the opening chapter, we proposed that ideation occurs over a sequence of generic iterations, each with two steps:

> *Logos step* (thinking): Observe the present state of the idea. If a finished idea has been achieved, stop. Otherwise, think about an action that, if executed, is likely to result in progress towards a finished idea.
>
> *Praxis step* (action): Execute the action decided on in the logos step and begin the next logos step.

Effectively our thinker does this sequence of steps: think, act, think, act, think, act, and so on. In each praxis step (act), the thinker engages physically with the environment. In this way, it's clear that the discovery of ideas is an embodied process, one that requires neural activity (think) *and muscle movement* (act).

Sometimes it's useful to differentiate long sequences of similar diaconatic iterations. For example, Graham Wallas thought that there were four stages: preparation, incubation, illumination, and verification.[1] We'll suggest only two: preparation and execution. The preparation phase is where a thinker executes a sequence of diaconatic iterations to come up with a general plan of attack. After having roughed out a general plan, he or she then enters the execution phase where the plan is executed.

[1] Graham Wallas. *The Art of Thought*. Kent: Solis Press, 1926.

A good example is the painting process of the artist Alex Colville. He spent a lot of time preparing to do each of his paintings. Martin Kemp described Colville's approach for his painting *The Surveyor*.[2] Before his first brush stroke, it involved making 30 drawings over 14 months, most using an engineer's drafting tools.

[2] Martin Kemp. "A Measured Approach: Alex Colville's Exhaustive Search for Mathematical Probity". *Nature* 430 (2004): 969.

Picasso went through a similar process to prepare to paint his masterpiece, *Les Demoiselles d'Avignon*. Over a nine-month period, he filled 16 sketchbooks with drawings, sketches, and color studies. This great work of art was a diaconatic exercise with clear preparation and execution stages.

To be clear, the preparation and execution stages each require diaconatic iterations. The labels "preparation stage" and "execution stage" are simply a way to partition the complete sequence of diaconatic iterations into those required to complete the preparation stage and those required to complete the execution state.

The gestation period to discover serious ideas is usually measured in years. In 1899, the Wright brothers were experienced technologists when they decided to tackle powered fixed-wing flight. Four years later, they took their historic flight at Kitty Hawk. Darwin worked his adult life on ideas that led to the theory of evolution by natural selection. He published *The Origin of Species* at age 50.[3] It took Neil Simon three years and 22 rewrites before his first play, *Come Blow Your Horn*, was performed on Broadway.[4] In the late 1930s, John Steinbeck wrote *The Grapes of Wrath*, a novel for which he won the Pulitzer Prize. After writing the first 70,000 words, he destroyed them and started over.[5] The Israeli novelist Amos Oz described it this way:

> It is like reconstructing the whole of Paris from Lego bricks. It's about three quarters-of-a-million small decisions.[6]

Some logos steps are long. Charles Dickens reported this while working on *Barnaby Rudge*:

> I didn't stir out yesterday, but sat and thought all day; not writing a line; not so much as the cross of a t or dot of an i. I imaged forth a good deal of Barnaby by keeping my mind steadily upon him.[7]

This accords with Newton's characterization of his process:

> I keep the subject constantly before me, and wait 'till the first dawnings open gradually, by little and little, into a full and clear light.

There is a loose bilevel control of the diaconatic iterations. The discoverer usually has a high-level plan that guides the sequence of logos steps. For example, in the planning of *David*, Michelangelo undertook sketches and then produced small-scale wax and clay models of what he had in mind. These then guided him when he focused on the details of the plan. So, while carving the middle toe of the left foot, he could focus on that detail to the exclusion of everything else. Basically, decisions at the logos step are only loosely constrained by the high-level plan. Neil Simon didn't ever have a complete high-level plan. He began writing his plays with only sketches for the characters and the start of the plot but had no inkling of how the plot

[3] James Costa. "The Darwinian Revelation: Tracing the Origin and Evolution of an Idea". *BioScience* 59, no. 10 (2009): 886–894.

[4] Neil Simon. *Memoirs*. New York: Simon and Schuster, 2017.

[5] John Steinbeck. *Working Days: The Journals of {The Grapes of Wrath}, 1938-1941*. New York: Viking Press, 1989.

[6] Roger Cohen. "A Time for Traitors". *New York Times* (Jan. 2015): 17.

[7] Harry Stone. *Dickens' Working Notes for His Novels*. Chicago: Univeristy of Chicago Press, 1987, p. xii.

would progress or end. He is on record that his plays ended when he centered "Curtain" on a line.

It turns out that we have cognitive skills that help our high-level control. For example, we have the ability to track the gist of an idea. When a reader has just finished a novel, they can usually give you an overview of the plot and describe the characters, but they can't recall the exact contents of the second paragraph on page 107.

Visually, we do something similar. We tend to see the gestalt (the whole) before the parts that make up the whole. One interpretation of the graphic in Figure 3.1 is that it's a three-dimensional spiked ball. Another is that it's a two-dimensional drawing of a set of triangles with different bottoms. Most of us would see the spiked ball first.

Figure 3.1: A spiked ball or a set of triangles with round bases? Courtesy of Mabit1, CC BY-SA 4.0 via Wikimedia Commons.

Implicit in the diaconatic is the willingness of the discoverer to persevere. The novelist William Faulkner said this:

> At one time I thought the most important thing was talent. I think now that—the young man or the young woman must possess or teach himself, train himself, in infinite patience, which is to try and to try and to try until it comes right. He must train himself in ruthless intolerance. That is, to throw away anything that is false no matter how much he might love that page or that paragraph. The most important thing is insight, that is . . . curiosity to wonder, to mull, and to muse why it is that man does what he does. And if you have that, then I don't think the talent makes much difference, whether you've got that or not.[8]

[8] William Faulkner. "Press Conference, May 20, 1957". In *Faulkner in the University*, ed. by Joseph Blotner and Frederick Gwynn. Press Conferences, Univerity of Virginia. Jackson: University Press of Mississippi, 1959, p. 191.

He lays out two qualities that all great discoverers appear to share. First, there is the hard work of the diaconatic, the willingness to stay at it until it's right. The second is the determination to figure out what is driving the phenomenon under consideration. This comes back to our belief that curiosity is a fundamental human trait that drives ideation. In this way, idea discovery is also driven by emotion and not just rational thought.

We have some good examples of the diaconatic from music. Gord Sinclair is the bassist for The Tragically Hip, one of Canada's finest rock bands. We asked him to describe how he comes up with ideas for songs. This was his response:

> I almost always compose on guitar. I don't ever have a set agenda—I have never been able to punch a clock, go down to my studio and start writing. The first inspiration is the most elusive and satisfying part, which you can't predict or control. Some of my best stuff has come during baseball or golf on TV. I will sit and watch with my guitar in hand. I'm not really paying any attention to either, just noodling away and without fail the heavens open and new ideas fall out. My writing always starts with an instrumental riff or chord progression. There is something in the distraction (sports on TV) that frees up the creativity. Once I get the germ of an idea, I develop it into a song with more

> structure and then Gord [Gord Downie, the deceased frontman and lyricist of the Hip] would fill in the words from there to suit his taste.

This is a trial-and-learn approach where a song's chord progression is built over a number of trials. Sinclair's significant background in music informs these trials: he grew up in a musical family, studied conservatory piano, and plays a number of instruments including the bagpipes.

MOZART DID A LOT in his short life. He left us with some of the finest music the human race has created. His early biographers left the impression that he was a savant, basically composing in his head and then writing it down. Here is the so-called Rochlitz letter, purportedly written by Mozart:

> All this fires my soul, and provided I am not disturbed, my subject enlarges itself, becomes methodized and defined, and the whole, though it be long, stands almost finished and complete in my mind, so that I can survey it, like a fine picture or a beautiful statue, at a glance. Nor do I hear in my imagination the parts successively, but I hear them, as it were, all at once . . . When I proceed to write down my ideas, I take out of the bag of my memory, if I may use that phrase, what has previously been collected into it, in the way I have mentioned. For this reason, the committing to paper is done quickly enough, for everything is, as I said before, already finished; and it rarely differs on paper from what it was in my imagination.[9]

[9] See *Allgemeine musikalische Zeitung*, 1815, 17, 561–566.

Are we to believe that Mozart worked through *Eine Kleine Nachtmusik* in his head sitting in a chair or lying in bed, only writing it down when it was complete? Evidence from his private papers suggests otherwise. His basic approach was "to sketch" by composing small snippets daily. When he had enough of these, he would meld selected snippets together into a larger piece. Upon his death, there were a large number of unused snippets. The magnitude of this unused inventory would suggest that his composition was not a matter of transcribing a complete piece from his head to paper.

In addition, he had trouble putting together string quartet compositions. In other work, he would first write the melody (say, the first violin), and then the bass lines before adding the rest of the orchestration. But for string quartet pieces, he wrote all parts bar by bar. In the dedication of his string quartets to Hayden, he remarked that they were "the fruit of a long and laborious effort."[10] It sure doesn't sound like these flowed from his mind to the page once the thinking was done. We think it's safe to say that Mozart's process was diaconatic, a recurring search for the next note employing quill, paper, and a harpsichord.

[10] Marius Flothuis. "A Close Reading of the Autograph of Mozart's Ten Late Quartets". In *The String Quartets of Haydn, Mozart, and Beethoven: Studies of the Autograph Manuscripts*, ed. by Christoph Wolff. Cambridge MA: Harvard University Press, 1980.

IN LATE 1966, The Beatles had made the decision not to tour and went into the studio to make an album different from what they had done. They had been influenced by the sounds the Beach Boys had produced on their album *Pet Sounds*. These were sounds that could only be reproduced by playing back the recordings; they could not be reproduced in concert. The Beatles attempted the same thing with *Sgt Pepper*.[11]

[11] Kenneth Womack. *Sound Pictures: The Life of Beatles Producer George Martin, The Later Years, 1966–2016*. Chicago: Chicago Review Press, 2018.

Today, the individual sounds you hear in a piece of music are generally recorded digitally, each on a separate track. These tracks can be manipulated in any number of ways and then mixed to produce a final piece.

At the time *Sgt Pepper* was made, this digital mixing technology was unavailable. What they had was a 4-track analog tape recorder. With it, you could record guitar, bass, and drums individually on tracks 1, 2, and 3, and then mix or "bounce" them to track 4. Then you could record voice on track 1 with the instrumental mix you had previously done playing on track 3. Then these two could be bounced to track 4. If you wished to include another voice for harmony purposes, you could have it recorded on track 1 with the instrumentals and lead voice mix playing on track 3. You could continue to mix in this way until you got to the finished song.

The whole exercise took 700 hours of recording time, something unheard of at the time. *Sgt Pepper* and *Pet Sounds* were large diaconatic experiments that produced what many music critics consider to be masterpieces.

THE ENGINE THAT DRIVES THE DIACONATIC is the imagination we apply at the logos step. It's what we use to first assess what happened on the previous praxis step and then think about what action to take next.

Magically, we can imagine different worlds pretty much on demand and then communicate the details of those worlds to others. Newton imagined gravity, his concept for the glue that holds the universe together, a concept that is no more real than Dickens's *Ebeneezer Scrooge*. Shakespeare imagined the tragic story of *Hamlet*. Our ancient ancestors imagined that a useful tool could be had by chipping one stone with another. The human imagination is extraordinary, and it drives our cultural progress.

As we have indicated, we will not have much to say about how our brains generate thought. Certainly, our notion of how our bodies are involved in thinking has changed dramatically over time. Aristotle believed that we thought with our hearts. Plato thought that, apart from our bodies, we had an eternal spirit. Close in spirit to Plato, René Descartes saw the mind as not made of matter, but in the body and able to control matter. Descartes's conception is termed

Cartesian duality. Over time, as we discovered more about how the brain worked and was structured, we came to view the physical brain and its associated electro-chemical neuronal network as the seat of all thought. The philosopher Gilbert Ryle signaled the end of duality with his famous characterization of Cartesian duality as "the Ghost in the Machine."[12]

[12] Gilbert Ryle. *The Concept of Mind*. Chicago: Univeristy of Chicago Press (Kessinger Reprint), 1949, p. 15.

Some believe that all cognitive activity resides in our heads. As we've noted, this position is sometimes called *neurocentrism* (or *internalism*). On the other hand, there are the *cognitive integrationists* who believe that our cognition also requires bodily processes and artifacts in the environment.

There are many examples of us using artifacts in the environment to help us think. For example, consider our use of maps. We first locate our position on the map and then look at our surroundings to orient these surroundings with the representation on the map. Once we do these two things, we can begin to make decisions about how to get to the place we want to go. The map, an exographic, is crucial to navigation. There are some famous examples. One is Harry Beck's map of the London Tube System. It in no way reflects the actual distances between stops but it's excellent for navigating the system.

For thousands of years, Micronesians were able to sail between islands thousands of miles apart without instruments. This astounding skill has been described this way:

> The navigational practices of Oceanians present somewhat of a puzzle to the student of the history of cartography. Here were superb navigators who sailed their canoes from island to island, spending days or sometimes many weeks out of sight of land, and who found their way without consulting any instruments or charts at sea. Instead, they carried in their head images of the spread of islands over the ocean and envisioned in the mind's eye the bearings from one to the other in terms of a conceptual compass whose points were typically delineated according to the rising and setting of key stars and constellations or the directions from which named winds blow. Within this mental framework of islands and bearings, to guide their canoes to destinations lying over the horizon these navigators applied vital information obtained by watching with the naked eye the stars, ocean swells, steady winds, island-influenced cloud formations, land-nesting birds fishing out at sea, and other cues provided by nature.[13]

[13] Ben Finney. "Nautical Cartography and Traditional Navigation in Oceania". In *The History of Cartography, Volume Two, Book Three: Cartography in the Traditional African, American, Arctic, Australian, and Pacific Societies*, ed. by David Woodward and G. Malcolm Lewis, Chapter 13. Chicago: University of Chicago Press, 2011, p. 443.

This is a remarkable achievement. These indigenous sailors used the night sky and other artifacts to navigate for days over vast distances between small islands.

To prepare a dish, professional chefs will assemble its ingredients ahead of time and then put them in the order they go into the pot. This saves them having to check all aspects of the written recipe as they cook.[14]

[14] David Kirsh. "The Intelligent Use of Space". *Artificial Intelligence* 72, nos. 1–2 (1995): 31–68.

To teach arithmetic, a primary school teacher often has students use manipulatives. For example, to learn how to do simple subtraction problems, say $5 - 2$, a child will begin with 5 counters (a uniform object like disks or chips) and then remove 2 counters to arrive at the answer, 3. Eventually they will internalize this arithmetic and manipulatives are no longer required.

Bartenders, upon receiving an order, will immediately place the various types of glasses required on the bar-rail. In part, these glasses serve as a mnemonic for the bartender to fill the order. As the drinks are mixed, the liquid in the glasses also serves as mnemonic. Interestingly, very experienced bartenders outgrow these mnemonics. When they get to this point, they can focus on conversations with patrons, something that leads to higher tips, on average.[15]

[15] King Beach. "Becoming a Bartender: The Role of External Memory Cues in a Work-directed Educational Activity". *Applied Cognitive Psychology* 7, no. 3 (1993): 191–204.

This is probably as good a spot as any to summarize the integrationist literature.

In the last thirty years, we've come around to the view that our cognition depends upon neural processes, bodily processes, and artifacts in the environment. We have a number of terms for this including embodied thought, cognitive integration, the extended mind, material engagement theory, and cognitive offloading. All of these are terms which indicate that our thinking is sometimes enhanced by artifacts in the environment.

We've already mentioned the work of Merlin Donald. Donald Norman also recognized the power of exographics in ideation:

> The power of the unaided mind is highly overrated. Without external aids, memory, thought, and reasoning are all constrained. But human intelligence is highly flexible and adaptive, superb at inventing procedures and objects that overcome its own limits. The real powers come from devising external aids that enhance cognitive abilities. How have we increased memory, thought, and reasoning? By the invention of external aids: It is things that make us smart. Some assistance comes through cooperative social behavior; some arises through exploitation of the information present in the environment; and some comes through the development of tools of thought—cognitive artifacts—that complement abilities and strengthen mental powers. ... Probably the most important of our external aids are paper, pencil, and the corresponding skills of reading and writing. But because we tend to notice the unique, not the commonplace, few recognize them for the powerful tools that they are, nor does the average person realize what breakthroughs in reasoning and technology were required to invent writing, numerical representations, portable and reliable pens and pencils, and inexpensive, functional writing paper.[16]

[16] Donald Norman. *Things That Make Us Smart*. New York: Basic Books, 1993, p. 43.

This paragraph is a clear statement of embodied thinking. He is also suggesting that we don't appreciate the power of exographics because it's endemic. He begins by noting that our thinking minds have some pretty serious limitations. But happily, we were smart enough to invent technologies like exographics that enabled us to overcome some of those weaknesses.

Edwin Hutchins looked at distributed cognition, how individuals formed cognitive systems where the individuals within such a system generally engaged in embodied cognition. In his book *Cognition in the Wild*, he presents a detailed study of the cognitive systems used aboard a Navy ship.[17] A good modern example are the systems large ships use to berth. Such berthing requires the coordination of many individuals including those on the ship's bridge, those in tugboats, and those who will engage the ship's mooring system to secure the vessel to its berth. This system is distributed and many cognitive artifacts are used. We think Hutchins's work was critical because it got us to recognize the importance of the embodied mind in a network of imaginations which, to us, is the signature accomplishment of our species. His title, *Cognition in the Wild*, is a remarkable turn of phrase. At the time he wrote the book, neurocentric computational theories of the mind were in vogue: cognitive scientists saw the mind as a computer that worked on symbolically coded information stored in the mind. Hutchins's observations of how we actually thought (i.e., cognition in the wild) argued that there was more to the nature of our thinking processes than in-mind symbolic computation.

[17] Edwin Hutchins. *Cognition in the Wild*. Cambridge MA: MIT Press, 1995.

David Kirsh asks why we have a tendency to build an external representation of something we are trying to understand.[18] Just as Newton drew in the mud, some of us pick up a pencil and paper to try and figure something out. Kirsh asks "... why do people do more than just think in their heads?"[19]

[18] David Kirsh. "Thinking with External Representations". *AI and Society* 25, no. 4 (2010): 441–454.

[19] Ibid., p. 441.

David Chalmers and Andy Clark begin with this question: "Where does the mind stop and the rest of the world begin?"[20] They suggest that some "accept the demarcations of skin and skull, and say that what is outside the body is outside the mind." They disagree and argue that "cognitive processes ain't (all) in the head!" Chalmers and Clark refer to the system of the human, the pencil and paper as a "coupled system." Clark subsequently presents a more complete description of his ideas in his books *Supersize the Mind* and *Natural-Born Cyborgs*, and a number of other publications.[21] He argues that we are cyborgs by nature and the human mind has never been "bound and restricted by the biological skin-bag ... the ancient fortress of skin and skull."[22]

[20] David Chalmers and Andy Clark. "The Extended Mind". *Analysis* 58, no. 1 (1998): 7–19, p. 7.

[21] See Andy Clark. *Supersizing the Mind: Embodiment, Action, and Cognitive Extension*. Oxford: Oxford University Press, 2011 and Andy Clark. *Natural-Born Cyborgs: Minds, Technologies, and the Future of Human Intelligence*. Oxford: Oxford University Press, 2003.

[22] Clark, *Natural-Born Cyborgs*, 4–5.

There have been other important contributors. As a result of the early failures of Artificial Intelligence (AI), Rodney Brooks suggested that

> ... we should build complete intelligent systems that we let loose in the real world with real sensing and real actions.[23]

[23] Rodney Brooks. "Intelligence Without Representation". *Artificial Intelligence* 47, nos. 1–3 (1991): 139–159, p. 139.

He is advocating machines whose thought is embodied. Francisco Varela, Eleanor Rosch, and Evan Thompson wrote an important early book grounding the embodied mind in human experience.[24] Lambros Malafouris has proposed his version of embodied thinking: Material Engagement Theory.[25] Karenleigh Overmann has done important work on the embodied thinking related to the origins of numbers.[26] Richard Menary has offered an excellent synthesis of the implications of cognitive integration for writing and thinking.[27] Other important contributions are the connectionist theories of David Rumelhart, James McClelland, and the PDP Research Group. As we remarked above, the dominant view of the working mind in the 1980s was symbolic computation, the mind functioning as a computer would. In contrast, Rumelhart et al. thought of the mind as having a massively parallel structure based on neural networks.[28] Our mimicking of this structure in mathematical models has led to significant breakthroughs in the computer science field of deep learning. Another useful construct for our argument is cognitive offloading as described by Evan Risko and Sam Gilbert.[29] They define it to be the use of bodily action to reduce the cognitive demands of an information processing requirement.

[24] Francisco Varela, Eleanor Rosch, and Evan Thompson. *Francisco Varela, Eleanor Rosch, and Evan Thompson, The Embodied Mind: Cognitive Science and Human Experience (Cambridge: MIT Press, 1991)*. Cambridge MA: MIT Press, 1991.

[25] Lambros Malafouris. *How Things Shape the Mind: A Theory of Material Engagement*. Cambridge MA: MIT Press, 2013.

[26] Karenleigh Overmann. *The Material Origins of Numbers: Insights from the Archaeology of the Ancient Near East*. Piscataway NJ: Gorgias Press, 2019.

[27] Richard Menary. "Writing as Thinking". *Language Sciences* 29, no. 5 (2007): 621–632.

[28] David Rumelhart, James McClelland, and PDP Research Group. *Parallel Distributed Processing, Volume 1, Explorations in the Microstructure of Cognition: Foundations*. Cambridge MA: MIT Press, 1986.

[29] Evan Risko and Sam Gilbert. "Cognitive Offloading". *Trends in Cognitive Science* 20, no. 9 (2016): 676–688.

Despite this significant literature on the role of external artifacts (including exographics) in ideation, there are pockets of scholars who do not seem to recognize it. For example, there is not a single paper covering it in *The Cambridge Handbook of Thinking and Reasoning*.[30]

[30] Keith Holyoak and Robert Morrison. *The Cambridge Handbook of Thinking and Reasoning*. Cambridge: Cambridge University Press, 2005.

In his book *Thinking, Fast and Slow*, Daniel Kahneman offers a dual process theory of thought.[31] He argues that we engage in two kinds of thinking. *System 1* is the quick, intuitive thinking we use to make relatively unimportant decisions like what to wear, what to have for dinner, or what movie to see. *System 2* is slow, deliberate, hard thinking, the kind of thinking required to discover cultural objects.

[31] Daniel Kahneman. *Thinking, Fast and Slow*. New York: Farrar, Straus and Giroux, 2011.

Let's differentiate the two types with an example. Consider this problem:

> A ball and bat cost $1.10. The bat costs $1 more than the ball. What does the ball cost?

Without thinking much about it, you might estimate that the bat costs $1 and the ball costs $0.10 This seems to make sense, because they sum to $1.10. But it's wrong. With these costs, the bat costs $0.90 more than the ball, violating the condition that it costs $1 more. If you came to this solution, you were using system 1 thinking, and your answer matches those of a large number of Harvard and MIT undergrads.

Here is another example:

> Suppose there are 50 people at a cocktail party. We are interested in the chance that two or more people have a birthday on the same calendar date. If one person is born on 14 May 1959 and another on 14 May 1964, then it's true that there are at least two people with the same calendar date. Assume there are 365 days in a year. Is this chance (a) less than 15%, (b) somewhere between 15% and 85%, or (c) greater than 85%?

Most answer (a) with a few choosing (b). However, the correct answer is (c). With 50 people in a room, the probability that at least two people have the same calendar birthdate is 97%. Hence, it's almost a sure bet that you would find at least two people with the same birthday. This is known as the Birthday Problem. It's a good example of a problem for which our intuitions (system 1) don't work very well.

The cognitive psychologist Peter Wason gave experimental subjects the sequence 2, 4, 6 as an example of a rule he had in mind.[32] He then gave subjects the chance to test any triplet they wanted before finalizing their guess at the rule. Most of them tested sequences consistent with the rule "consecutive even numbers," sequences like "12, 14, 16" and "6, 8, 10." Of course, these sequences are poor tests if the rule is "consecutive integers separated by 2" (in which case 3, 5, 7 fits) or "increasing integers" (2, 5, 12). Wason's conclusion was that subjects came very quickly to the rule "consecutive even integers" and then tested a sequence of consecutive even triplets to confirm this rule. This tendency, to look for evidence that confirms a belief, is called the *confirmation bias* and many experimental studies since have replicated Wason's results.

[32] Peter Wason. "On the Failure to Eliminate Hypotheses in a Conceptual Task". *Quarterly Journal of Experimental Psychology* 12, no. 3 (1960): 129–140.

Kahneman and Amos Tversky were the first to look at a series of these reasoning flaws and biases.[33] Their early work provided the basis for much follow-on research by other scholars.

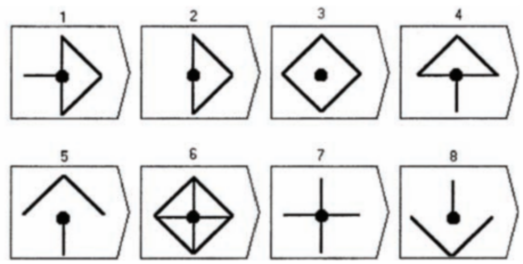
[33] Amos Tversky and Daniel Kahneman. "Judgment under Uncertainty: Heuristics and Biases". *Science* 185, no. 4157 (1974): 1124–1131.

But let's put these reasoning flaws in perspective. They arise largely because we apply system 1 rather than system 2 to a problem. But, as the history of ideas suggests, we've done some pretty amazing thinking when our system 2 process takes the lead. We've determined that the world is not flat, that we're not at the center of the universe, and that we've descended from a common ancestor with chimpanzees. If we eventually kick in our system 2 and think seriously, we're a pretty capable ape.

WHAT WE'RE REALLY GOOD AT is finding patterns that are not immediately apparent. To see this, we'll look at *Raven's progressive matrices tests*. There are 8 dot-stick figures in Figure 3.2 in the margin: 3 in the first row, 3 in the second, and 2 in the third.[34] The 3rd dot-stick figure in each of the first 2 rows is the result of applying a rule to the first 2 figures in each row. The problem is to determine what the rule

[34] Tom Verguts and Paul De Boeck. "The Induction of Solution Rules in Raven's Progressive Matrices Test". *European Journal of Cognitive Psychology* 14, no. 4 (2002): 521–547.

is and then apply it to the 2 dot-stick figures in the 3rd row to determine which of the 8 dot-stick figures below should fill out the third row in Figure 3.2.



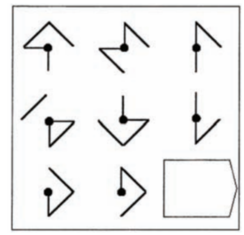


Figure 3.2: A Raven's Progressive Matrices Test.

Let's look at how we could explore a solution with a system 2 search. We'll use a diaconatic approach by hypothesizing a rule (once we see one) and then check it to see if it works. If it doesn't, we'll discard it and search for another.

We might start by observing that there is a dot in the center of every dot-stick figure including the 8 possible solutions. So, a dot is part of the rule.

What else can we try? Let's first classify the line types. This may or may not help but we have to start somewhere. Let's partition them into horizontal, vertical, and 45-degree lines. Now, let's look at the horizontal lines in the first row. There is a single horizontal line in each of the first two dot-stick diagrams but no horizontal line in the third. That is consistent with this rule: if a horizontal line is common to the first two dot-stick diagrams, do not include it in the third dot-stick diagram. Let's see if it works for the second line. It does! Hence, this appears to be a good rule. Unfortunately, there are no horizontal lines in the third row, so it's not much use to us.

Let's now look at vertical lines. There appear to be two types: those pointing south and those pointing north (with direction determined from the reference point of the dot). So, let's refer to "south vertical lines" and "north vertical lines." In the first row, the first dot-stick diagram has a south vertical line, the second has a north vertical line, and the third has both a north and south vertical line. Hence, we might hypothesize this rule: if a dot-stick diagram has either a north or south vertical line, then put that line in the third dot-stick diagram. Let's see if this rule works for line 2 . . . Yes, it works in line 2. Now we have a rule we can apply in the third line because its dot-stick figures have vertical lines.

You would keep going in this fashion, working up good rules. This is as far as we'll go with this problem. If you decide to try and complete the set of rules, check the sidenote for the correct answer.[35]

[35] The correct answer is 2.

The correct rule for a Raven's progressive matrix test is initially hidden from us. It's invisible until we discover it. Finding these rules is a matter of diaconatic experimentation. You look at the input pictures and, with your imagination, generate a rule. This rule is provisional until you can verify that it works for the first two lines and that there is an answer solution for its application on the third.

Charles Darwin studied botany and natural history his entire life. He spent five of those years on a sea voyage collecting new data. He filled many notebooks with observations, musings, and ideas. Eventually, his imagination led him to evolution by natural selection. We'll never know exactly what went on in his head. By his admission, he was influenced by the economist Thomas Malthus's thinking on human population behavior when resources are scarce. Malthus was aware of the role of famine and disease in limiting population growth. In *An Essay on the Principle of Population* (1798), he offered the idea that a population facing scarce resources (say through famine) would compete for those scarce resources, resulting in the stronger individuals surviving. Darwin admitted that this idea got him thinking about a similar competition in nature, one in which only the fittest animals and plants would survive to reproduce. This is an example of analogical thinking where the key attributes driving one situation are applied to those in another. Analogy is similar to pattern recognition.

Another example comes from the Wright brothers and their decision to warp the wings of their glider to affect a change in direction. We know they read James Pettigrew's book on animal locomotion.[36] In Wilbur's notebook dated September-October 1900, he made the following observation about a gliding pigeon:

> The bird certainly twists its wing tips so that the wind strikes one wing on top and the other on its lower side, thus by force changing the bird's lateral position. [37]

The bird's movement of its wingtips in the opposite directions (one up, the other down) led to wing warping and modern ailerons.

[36] James Pettigrew. *Animal Locomotion or Walking, Swimming, and Flying With a Dissertation on Aëronautics*. New York: D. Appleton & Company, 1874.

[37] Marvin McFarland. *The Papers of Wilbur and Orville Wright*. New York: McGraw-Hill, 1953, p. 35.

Relational Match-to-Sample Problems work like this. Consider the graphic in Figure 3.3. It shows two apples on the top row and then two pictures on the second row: the one on the left is two identical pictures of cherries; the one on the right is a picture of a banana and a lemon. The first row is termed the "sample"; the second constitutes the "objects." The test requires the subject to pick the object in the second row that best matches the sample in the first row.

The correct answer in this case is the left object, the cherries. It's correct because it's a picture of two things the same whereas the picture on the right is two different things. Consequently, this is a test of the subject's ability to see the abstract idea of "sameness."

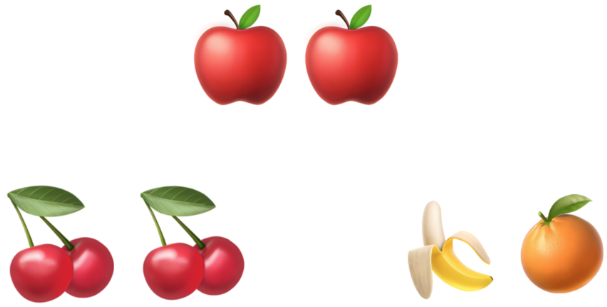


Figure 3.3: A Relational Match-to-Sample Problem to test sameness.

These tests have been used extensively with chimpanzees to test how well they can deal with abstract concepts. Think about this problem from the point of view of a chimpanzee. A direct comparison suggests there is nothing about the observable characteristics of the objects in the second row that is close to those of the two apples. To do this problem successfully, a chimpanzee has to be able to recognize abstract relations like ”sameness.”

Let’s consider the problem shown in Figure 3.4. Note that the two objects making up the sample are different (the sponge and lemon). In this case, the correct answer is the object on the right, the banana and the broom.

Figure 3.4: A Relational Match-to-Sample Problem to test the abstract concept ”different.”

Here’s where it gets interesting with chimpanzees. Chimpanzees in the wild cannot do these Relational Match-to-Sample problems. However, if they learn to process symbolic information, they can. To do so, they go through what is termed *token training*. They are first taught that certain tokens are associated with certain rewards. For example, it could be that a blue disk corresponds to a grape and a red disk corresponds to an M&M candy. Once they learn these associations, they are taught to take the token to a dispenser to get the reward the token represents. Eventually, when chimpanzees are given a choice among tokens, they will pick tokens whose reward they like and proceed to the dispenser. Clearly, chimpanzees are learning to associate tokens with rewards and hence the tokens serve as a symbolic representations of the rewards.

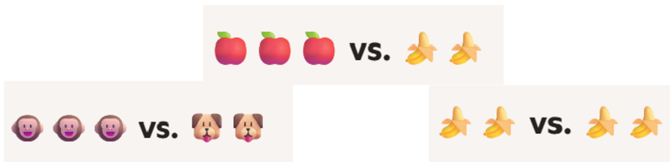


Figure 3.5: A Relational Match-to-Sample Problem to test numerosity.

Now suppose we give a token-trained chimpanzee the Relational Match-to-Sample test shown in Figure 3.5. Here the sample suggests 3 items vs. 2 items and the correct answer on the second row is the picture on the left of 3 monkees and 2 dogs. As it turns out, if a chimpanzee has been token-trained, they can generally do this problem *even if it's the first time they've seen it*.[38]

What appears to be happening is that, once chimpanzees are brought into the symbolic world with token training, they develop a cognitive scaffolding for recognizing new abstract relations among objects. Interestingly, research has shown that a child is only capable of Relational Match-to-Sample problems when a sufficiently high educational threshold has been reached.[39] Thompson et al. summarize this way:

> The present results, taken in the context of previous studies with language-naive chimpanzees ... also support the theoretical assumption that symbols are "in the world" first and only later "in the head." Furthermore, the chimpanzee's "upgraded mind," like that of a child, is the product of a historical process involving the external organization of symbolic experiences by other beings and, in the chimpanzee's case, another species.[40]

This evidence from chimpanzees suggests that our symbolic skills and abstract thinking may have deep evolutionary origins. The interesting question is how we—*Homo sapiens*—were able to bootstrap these skills.

But the important point is that we did and are now capable of the reasoning required to invent abstract concepts and mold them into models, theories, and ideas.

THERE IS EVIDENCE that our subconscious is active in the discovery of ideas. Most of us can recall instances where we suddenly become aware of something important. Maybe it was an imminent meeting or something we'd forgotten to do. What we are most certain about is that we have help from our subconscious when we are focused on solving a problem. Very often we'll set the problem aside, come back to it and see the solution easily. This happens frequently enough

[38] Roger Thompson, David Oden, and Sarah Boysen. "Language-Naive Chimpanzees (Pan Troglodytes) Judge Relations Between Relations in a Conceptual Matching-to-Sample Task". *Journal of Experimental Psychology: Animal Behavior Processes* 23, no. 1 (1997): 31–43.

[39] Dedre Gentner and Mary Jo Ratterman. *Language and the Career of Similarity*. Technical Report 533. The Center for the Study of Reading: University of Illinois at Urbana-Champaign, 1991.

[40] Thompson et al., "Language-Naive Chimpanzees," p. 42.

for us to think that our subconscious minds continue to work on the problem while our conscious minds are otherwise occupied. It sure worked for Einstein. In his biography of Einstein, Walter Isaacson wrote this:

> Music was no mere diversion. On the contrary, it helped him think. 'Whenever he felt that he had come to the end of the road or faced a difficult challenge in his work,' wrote his son Hans Albert, 'he would take refuge in music and that would solve all his difficulties.' The violin thus proved useful during the years he lived alone in Berlin, wrestling with general relativity. 'He would often play his violin in his kitchen late at night, improvising melodies while he pondered complicated problems,' a friend recalled. 'Then, suddenly, in the middle of playing, he would announce excitedly, "I've got it!" As if by inspiration, the answer to the problem would have come to him in the midst of music.'[41]

[41] Walter Isaacson. *Einstein: His Life and Universe*. NewYork: Simon and Schuster, 2007, p. 14.

Clearly, Einstein was engaging in an undemanding activity that helped him come to a way to move forward.

Asael Sklar and her research group have used the relatively recent experimental technique of continuous flash suppression (CFS) to test whether we can do arithmetic subconsciously.[42] The technique works like this. Two distinct video feeds are sent to each of an experimental subject's eyes. One feed is a sequence of Mondrian patterns (a Mondrian pattern, after the artist Piet Mondrian, is a collage of variously colored and shaped rectangles in a tiled grouping) that change quickly from pattern to pattern. The other begins with a blank white screen. When subjects face such input, their focus is drawn to the Mondrian side to the exclusion of the other side. At a random time after the experiment begins, the blank screen shows an arithmetic question, something like "$9 - 2 - 3 =$," for 2 seconds. The video feeds are then turned off and the subject is presented with an arithmetic problem, and it was either the same one they had seen in the stimulus part of the experiment or a different one, say "$8 - 3 - 1 =$." The *compatible regime* consisted of all the experimental subjects who got the same equation, and the *incompatible regime* were those who got a different equation. For each subject, the experimenters measured the time to give a correct answer. As it turned out, the average time to give a correct answer for the *compatible* regime was significantly shorter than it was for the *incompatible* regime.

[42] Asael Sklar et al. "Reading and Doing Arithmetic Nonconsciously". *PNAS* 109, no. 48 (2012): 19614–19619.

We have not explained the complete experimental protocol here, but the experimenters did a number of other tests to make sure, as best they could, that there were no other explanations for this difference in average solution times. This is a striking result. No experimental subject admitted to being aware of the equation shown to them in the stimulus part of the experiment. Yet the average solution time for the *compatible* group is significantly lower. This evidence is consistent with the explanation that the equation registered with a subject's subconscious mind. Obviously, we can't tell what sort of processing was performed by the subconscious, but, whatever it was, it allowed the subject to solve it more quickly when he or she saw it consciously. It was once thought that symbolic processing required the conscious mind. This experiment suggests otherwise. Regardless, our subconscious minds appear to be at work solving problems we are not consciously working on.

OUR FOCUS HAS BEEN on individual minds. But sometimes we employ more than one mind at the logos step.

We've already mentioned the dialectic as the process in which two or more thinkers come together to engage in an oral discussion about an issue. It's an ancient technique that dates at least to Classical Greece. The Greeks viewed the dialectic as the key to the discovery of ideas, a belief that dominated the universities of the West until the beginning of the Scientific Revolution. In the early days of the University of Paris, there was a period when writing was banned during lectures. Blackboards did not appear until the turn of the 18th century.

Today we understand why the dialectic is useful. When we think, we sometimes get into a sort of loop. For example, you might be trying to remember the name of the president of France (Emmanuel Macron), and all you can come up with is "macaroon" every time you try. You get stuck because we all have a memory with an associative structure. When English speakers are asked what word comes to mind in response to the stimulus "cat," most respond "dog." The great advantage of the dialectic is that, when you engage in a discussion, what another participant says sometimes causes you to think a thought you otherwise might not have. Effectively, the dialectic creates a "network stir" of ideas and is sometimes why we conclude that two heads are better than one.

Certainly, there are some famous pairs that together appeared to be better than they were individually. For example, in modern music, the names Lennon/McCartney, David/Bacharach, and Rogers/Hammerstein come to mind. Larry David and Jerry Seinfeld co-wrote *Seinfeld*. Francis Crick and James Watson discovered the shape of DNA molecules.[43] Einstein suggested that a key insight on his way to the discovery of special relativity came from a conversation he had with his good friend Michel Besso.

[43] It's generally agreed that Rosalind Franklin's contribution to this discovery has been overlooked. For an account see Brenda Maddox. *Rosalind Franklin: The Dark Lady of DNA*. HarperCollins, 2002.

A FINAL POINT has to do with the importance of the praxis (action) step in the diaconatic and our ideation efforts.

In the first sentence of their classic *Cognition and Tool Use: the Black-*

smith at Work, Charles and Janet Dixon write this:

> Our concern in this volume is to understand how people do things. How do individuals with a goal in mind go about accomplishing the end that they see as worthwhile, desirable, or necessary? This question requires examining the workings of the mind in thought and the workings of the body in the physical world.[44]

[44] Charles Keller and Janet Keller. *Cognition and Tool Use: The Blacksmith at Work*. Cambridge: Cambridge University Press, 1996, p. 14.

Of course, if you study blacksmiths, it's not surprising that you would include "the workings of the body" because blacksmith work requires the physical interaction of skilled craftsmen with the tools and materials they are working with. But, as we have seen, scholars who work at the frontiers of the e-Class also require physical movement. At a minimum, their work requires the use of exographics and exographics requires body movement. In this way, scholars and blacksmiths need the praxis step of the diaconatic.

But there is more to it. Some e-Class scholars require body movement because they need to understand how the world works as it pertains to their idea. Just as the Wright brothers had to figure out how their flying machine would interact with the air, Jack Kilby had to go into the lab to see if he could build a circuit that did not require individual components—transistors, resistors, capacitors, and wires—to be manually installed on a circuit board. Yes, they had thoughts about how their ideas might work, but they didn't know for sure those ideas would work until they actually tried them. Most of our great inventions have required this physical contact with the world. Hence, praxis/action is crucial to any serious ideation. Thought alone is not sufficient for success. But thought and action can be.

This brings us to the current hype on AI and our efforts to get to Artificial General Intelligence (AGI), generally defined as a non-human intelligence that can perform any intellectual task a human can with equal or greater proficiency. In the chase to get to sentient machines, AI firms like OpenAI offer that their approach of good guesses at the next symbol in a string is going to get us close, if not to AGI. The most recent step is a massive computer running a large generative AI model whose parameters have been estimated with the help of a massive data set. We have found this technology to be quite useful in our work but *it sure isn't AGI and it's unlikely to be any time soon*. And why? It's because a machine sitting in a corner massaging 1s and 0s has no capability to figure out how the physical world works. There is no way that such machines could produce the same quality of ideation that the Wright brothers and Jack Kilby were able to. At a minimum our sentient machines will have to be able to explore how the physical world works.

LET'S SUMMARIZE. Again, we'd like to emphasize that what drives human ideation is our curiosity and imagination, and most especially, our ability to network these imaginations. But as we argued in the previous chapter, to get the most out of these imaginations, we need technologies to overcome the weakness our memory architectures have for storing symbolic information. One of these technologies is exographics. As we've shown, it enables us to discover a large class of ideas that we could not otherwise discover.

We've suggested a process for ideation, the diaconatic. If you observed an individual in the act of ideation, you would see them going back and forth between thinking and acting. The diaconatic process explicitly incorporates that behavior. We suggest that the diaconatic is a sequence of steps, each consisting of some thinking (the logos step) and then some sort of action (the praxis step) to try what the logos step thinking suggested. Once again, the important step is the logos step where our imaginations are fully engaged. We characterize the process as a "trial and learn" process because after each praxis step, we assess whether the step was successful and, regardless of whether it was successful, we learn something about our problem.

Our focus over the remainder of the chapter is largely on this human ability we have to "see" the invisible. Our primary examples were Raven's progressive matrices tests and match-to-sample problems. For example, for Raven's progressive matrices tests, we're able to hypothesize rules seemingly out of thin air to try to figure out what the actual rule is. It is a distinctly human trait to observe a phenomenon and then think deeply about what could be driving it. An example has been our quest to figure out how to harness the power of electricity. Over centuries we figured it out, and today we can use the power of a flowing river to toast a bagel. Our efforts have now focused on trying to reproduce the temperatures at the heart of our Sun to be able to power whole cities for a year with a glass of water. There don't appear to be limits to what our imaginations will tackle.

4
The Exographic Revolution

The notion of representing a sound by a graphic symbol is itself so stupefying a leap of the imagination that what is remarkable is not so much that it happened relatively late in human history, but rather that it ever happened at all.
Jack Goody and Ian Watt

SCHOLARS of the history of writing generally agree that it was invented independently five times.[1] The first of these was in ancient Mesopotamia towards the end of the Uruk period (4000–3000 BCE)[2] and well into the Agricultural Revolution. We don't know the details, but the general outline goes something like this.

At that time, the alluvium of the Tigris and Euphrates rivers and their surrounding areas was a veritable Garden of Eden, with fertile land for growing, marshland habitats where waterfowl, fish and small ungulates were plentiful, and, beyond the borders of the alluvium, rich grazing lands for goats, sheep, and cattle.

The first larger settlements were formed during the Ubaid period (approximately 5500–4000 BCE). Clay-brick houses were built and the first temples appeared. The use of decorated pottery was extensive. There is evidence of farm tools, including plows and sickles. The vast majority of the population were farmers, agricultural laborers, and pastoralists. But there was some labor specialization in the settlements. This included labor associated with textiles, pottery, jewelry, boat building, and irrigation systems. A healthy economy was developing based primarily on agriculture.

Urbanization continued into the Uruk period. The population of the walled city of Uruk has been estimated to be between 50,000 and 100,000 by the end of the 4th millennium (3000 BCE). Cultural development also continued. Extensive irrigation systems were built and maintained. Wool largely replaced flax fiber in textile production. A pottery industry developed that included pottery wheels and advances in kiln technology. There were developments in metallurgy

[1] Stephen Chrisomalis. "The Origins and Co-evolution of Literacy and Numeracy". In *The Cambridge Handbook of Literacy*, ed. by David Olson and Nancy Torrance, 59–74. Cambridge: Cambridge University Press, 2009.

[2] We will denote all years and periods before the Common Era with BCE. Otherwise we will usually leave the era unspecified. So the old 1521 AD or 1521 CE will be denoted 1521.

and especially in architecture: new materials (sandstone, limestone, gypsum, and standardized clay bricks) were used to build massive public structures like the temple and palace in the Eannu district. These large structures included elongated hallways replete with pillars and creative artwork. There is evidence of the appearance of the wheel for the first time based on reliefs of chariots and transport vehicles carved in limestone.

Hence, by 3500 BCE, there had been a massive urbanization and a significant economic expansion. There were large public and religious sector bureaucracies. In fact, several scholars have argued that Uruk was an empire with significant influence upstream from the alluvium and to the east into what is now Iran.[3]

[3] Guillermo Algaze. *The Uruk World System: The Dynamics of Expansion of Early Mesopotamian Civilization*. Chicago: University of Chicago Press, 2005.

This civilization with its associated ruling hierarchy required support through taxation. There is clear evidence of storage systems where those taxed could bring their goods to settle their assessments. For the most part, this would have been farmers delivering cereals, grains, and other agricultural products. Grain was the perfect good to tax.[4] In the absence of a system of money, it's easy to transport, easy to measure, and will store just about indefinitely.

[4] James Scott. *Against the Grain: A Deep History of the Earliest States*. New Haven: Yale University Press, 2017.

But this taxation system presented a problem. Bureaucrats had to keep track of who owed what, track the settlement of these accounts, and manage the bureaucracy. As Uruk grew larger, it would have been impossible for one person or a few people to administer these obligations with only biological memory. What bureaucrats needed was an information system, one that relied on some kind of external technology to store information.

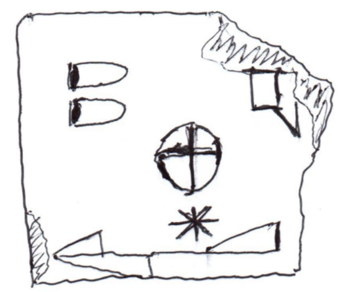


Figure 4.1: Example of a Sumerian clay tablet with exographics.

So they invented exographics by making notations on wet clay tablets with a reed stylus. An example is shown in Figure 4.1. Each of the two identical objects on the top left represents a count of 1 so the total count is 2. The symbol in the middle is for "small cattle" and the other symbols denote the temple and the god Ianna. We're not sure what precise purpose this tablet served but it was surely administrative. Maybe it was the tax assessment for a small farm, or a receipt to indicate that a farmer had settled his account. It dates to about 3300 BCE and the script is proto-cuneiform. In effect, this is the start of exographics. About 500,000 such tablets have been recovered and the vast majority are administrative in nature.

Figure 4.2: A proto-cuneiform tablet showing an allocation of beer. Photo by Jim Kuhn, CC BY 2.0 via Wikimedia Commons.

Proto-cuneiform became more complicated quickly. The tablet shown in Figure 4.2 is one that records an allocation of beer. Note that the tablet is divided into frames with inscriptions within each frame. The deeper inscriptions are numbers.

Eventually, this early exographics morphed into the cuneiform writing used to represent Sumerian language. Figure 4.3 shows the development of cuneiform symbols over time beginning with Sumerian logographic symbols. The last column is Assyrian cuneiform. You can see that the symbols look less logographic over time. As with most representation systems, symbols transition to less iconic forms over time.

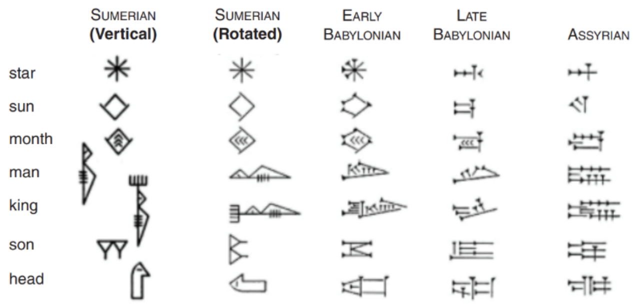


Figure 4.3: A table of cuneiform signs for various words from Sumerian to Assyrian. Public domain image by William Albert Mason, via Wikimedia Commons.

PRIOR TO EXOGRAPHICS ON WET CLAY and going as far back as 7500 BCE, small clay tokens were used to track amounts. These took various shapes. Three of these (spheriod, disc, and tetrahedron) are shown in Figure 4.4. The consensus among archaeologists is that each shape stood for a good. So, for instance, a spheroid could have been 1 measure of oil. Hence, 2 spheroids were for 2 measures, 3 were for 3 measures, and so on.

Figure 4.4: Examples of early token shapes used in ancient Mesopotamia.

In time, these tokens were sometimes packed into clay bullae or envelopes. Basically, a fresh clay ball was formed and then cut in half. Hardened tokens would then be packed into both halves of the soft clay. Subsequently, the two halves would be rejoined, shaped back into a ball, and left in the sun to bake and harden. It is likely that a bullae represented some kind of account.

At Nuzi, Leo Oppenheim discovered a hollow egg-shaped clay bullae with cuneiform writing on the outside.[5] The writing translated to a list of 49 items: 21 ewes that lamb; 6 female lambs; 8 full grown male sheep; 4 male lambs; 6 she-goats that kid; 1 he-goat; and 3 female kids. When this bulla was opened, a total of 49 tokens of various shapes were found. But other researchers are skeptical. Kristina Sauer reports that, of the 200 hollow envelopes discovered to date, only 18 have exographics on the outside and the contents of only 14 of these are known.[6] Significantly, not all have a correspondence between what's inside and what's recorded on the outside surface.

[5] Leo Oppenheim. "On an Operational Device in Mesopotamian Bureaucracy". *Journal of Near Eastern Studies* 18 (1959): 121–128.

[6] Kristina Sauer. "From Counting to Writing: The Innovative Potential of Bookkeeping in Uruk Period Mesopotamia". In *Appropriating Innovations: Engtangled Knowledge in Eurasia, 5000–1500 BCE*, ed. by Philipp Stockhammer and Joseph Maran, 12–28. Oxford: Oxbow, 2017.

Denise Schmandt-Besserat reports that, in the same place, Oppenheim found other cuneiform tablets that had accounting notes like these:

> These sheep are with PN; the stones have not been deposited

> Three lambs, two young he-goats, the share of PN, they are charged to his account ... [but] not deposited among the stones
>
> One ewe belonging to PN, its stone has not been removed.[7]

This is strong evidence of an advanced administrative system based on exographics.

Notwithstanding this conflicting evidence, we reckon it was just a short cognitive step to go from these token/bulla systems, with their two-dimensional inscriptions on the outside, to proto-cuneiform tablets.

John Halloran has suggested that the token/bulla systems have their origin in the idiosyncratic tally stick systems that individual Sumerian pastoralists and farmers would have used beginning in the Ubaid period and possibly before.[8] In a cuneiform piece entitled *The Debate Between Sheep and Grain*, likely written in the third millennium, we find this passage:

> Every night your count is made and your tally-stick put into the ground, so your herdsman can tell people how many ewes there are and how many young lambs, and how many goats and how many young kids.[9]

Halloran is a Sumerian lexicographer and he suggests that the Sumerian word "sudum," which means "to count," derives from the Sumerian words for "portion" and "post or stake." He goes on to quote from Karl Menninger's chapter on tally sticks:

> But the farmer ... also had to keep track of his crops and livestock and harvests. ... Where did he get the numerals to reckon with? From no one but himself! He developed his own number signs, which were adequate for his own ordinary dealings, and which no one but himself could read and understand.[10]

Halloran suggests that the idiosyncratic systems farmers used for counting were the precursors of the token/bulla systems.

IN SUMMARY, exographics had a long gestation period in Sumer, beginning with the tally sticks of pastoralists as far back as 7500 BCE. Shortly after this, it appears these peoples developed some kind of token system to track measures of various kinds of goods. Eventually, Sumerians went to proto-cuneiform notations on clay tablets to administer resource exchange. All of these artifacts—tally sticks, tokens, and proto-cuneiform tablets—were reliable substitutes for LTM.

It's clear that the notations on clay tablets served as an *aide-mémoire*, basically a shopping list to help these early administrators remember important resource management information. Unbeknownst to these early scribes, they had laid the important groundwork that would eventually lead to the e-Class.

[7] Denise Schmandt-Besserat. *Before Writing: From Counting to Cuneiform*. Austin: University of Texas Press, 1992, p. 9.

[8] John Halloran. *Early Numeration - Tally Sticks, Counting Boards, and Sumerian Proto-Writing*. https://www.sumerian.org/tallysticks.pdf, Aug. 2009. Visited on 08/12/2024.

[9] https://etcsl.orinst.ox.ac.uk/

[10] Karl Menninger. *Number Words and Number Symbols: A Cultural History of Numbers*. Cambridge MA: MIT Press, 1969, p. 223.

More broadly, with the invention of exographics, we see the co-invention of literacy and measurement. Administrators saw measurement and literacy as crucial to the progress of their city-states. As we'll see, this same story would be repeated in other civilizations where exographics came into use. Basically, administrators needed exographic data and measurement to be able to manage their agriculturally-based exchange economies.

Most would agree that the Information Age began in earnest in the mid-20th century with American technological breakthroughs that led to today's advanced computer technologies. But there is an argument that it started with the city-states of ancient Mesopotamia. As their economies grew, it became too much for palace and temple administrators to manage with just their heads. So to help with the crucial aspect of administrative record-keeping, they invented exographics. The first information system was not driven by modern digital technology but rather by ancient administrators inscribing clay tablets.

5
Exographics and the Prepared Mind

I put down the cup and examine my own mind. It alone can discover the truth. But how: What an abyss of uncertainty, whenever the mind feels overtaken by itself; when it, the seeker, is at the same time the dark region through which it must go seeking and where all its equipment will avail to nothing. Seek? More than that: create. It is face to face with something which does not yet exist, to which it alone can give reality and substance, which it alone can bring into the light of day.
Marcel Proust, from *Remembrance of Things Past*

The Greeks and Romans believed in oral discourse (the dialectic) as an effective way to discover new ideas. Hence, one of the critical subjects in their education was rhetoric, the ability to craft speech or writing that convinces, informs, or moves people that an argument is correct.

The ancients felt that the most important components of rhetoric were *memoria* (memory) and *inventio* (imagination). In Greek mythology, Mnemosyne was the Greek goddess of memory and was mother of the Muses who presided over the arts and sciences (e.g., history, music, tragedy, astronomy). That is, Mnemosyne is associated with *memoria*, and the Muses, with *inventio*. Effectively, a good rhetorician had to have a good imagination and a significant store of knowledge to be able to think and argue contemporaneously with others.

Over the years, our assessment of the relative importance of memory and imagination has changed. In the opening of *The Book of Memory*, Mary Carruthers contrasts a medieval view with one from the present.[1] The medieval assessment is based on Bernardo Gui's biography of Thomas Aquinas written shortly after Aquinas died:

[1] Mary Carruthers. *The Book of Memory: A Study of Memory in Medieval Culture*. Cambridge: Cambridge University Press, 2008.

> Of the subtlety and brilliance of his intellect and the soundness of his judgment, sufficient proof of his vast literary output, his many original discoveries, his deep understanding of the Scriptures. His memory was extremely rich and retentive: whatever he had once read and grasped he never forgot; it was as if his knowledge were ever increasing in

> his soul as page is added to page in the writing of a book. Consider, for example, that admirable compilation of Patristic texts on the four gospels which he made for Pope Urban [the *Catena aurea* or "Golden Chain"] and which, for the most part, he seems to have put together from texts that he had read and committed to memory from time to time while staying in various religious houses. Still stronger is the testimony of Reginald his *socius* and of his pupils and of those who wrote to his dictation, who all declare that he was used to dictate in his cell to three secretaries, and even occasionally to four, on different subjects at the same time ... No one could dictate simultaneously so much various material without a special grace. Nor did he seem to be searching for things as yet unknown to him; he seemed simply to let his memory pour out its treasures ... [2]

[2] Ibid., p. 3.

Contrast that with this description of Einstein by Leopold Infeld, a colleague of Einstein's at the Institute for Advanced Study:

> I was very much impressed by the ingenuity of Einstein's most recent paper. It was an intricate, most skillfully arranged chain of reasoning, leading to the conclusion that gravitational waves do not exist. If true, the result would be of great importance to relativty theory ...
>
> The greatness of Einstein lies in his tremendous imagination, in the unbelievable obstinacy with which he pursues his problems. Orginality is the most essential factor in important scientific work. It is intution which leads to unexplored regions, intuition as difficult to explore rationally as that by which the oil diviner locates the wealth hidden in the earth. ... The most amazing thing about Einstein was his tremendous vital force directed toward one and only one channel: that of original thinking, of doing research.[3]

[3] Ibid., p. 2.

These descriptions clearly emphasize different components of ideation. In the case of Aquinas, it was his memory. For Einstein, it was imagination. But are they thinking differently? Carruthers argues they are not:

> My point in setting these two description up in this way is simply this: the nature of creative activity itself—what the brain does, and the social and psychic conditions needed for its nurture—has remained essentially the same between Thomas's time and our own. Human beings did not suddenly acquire imagination with Coleridge, having previously been poor clods. The difference is that whereas now geniuses are said to have creative imagination which they express in intricate reasoning and original discovery, in earlier times they were said to have richly retentive memories, which they expressed in intricate reasoning and original discovery.[4]

[4] Ibid., p. 4.

In other words, thinking is thinking. It requires an internalized knowledge (memory) and an imagination with which to stir that knowledge.

Since the discovery of exographics, we've been developing an external storage of knowledge that, today, is significant. We can now use tools like Google and ChatGPT to search a very large external store of digital knowledge. Of course, this raises an obvious question: in the face of this quick access to external knowledge, *what knowledge should be stored internally*? How much internalized knowledge is enough?

WE'VE BEEN ADDING to the exographics record since we invented it. It's now large and houses the e-Class. We'll define the *exographics library* or *e-Library* as the worldwide repository of exographics. At present, it includes brick-and-mortar libraries, archives, as well as the store of digital exographics across the Internet. It also includes the store of exographic files in professional, corporate, and government offices. The e-Library is a critical component in the discovery of ideas, primarily to get researchers to the edges of knowledge on the problem they have chosen to study.

We don't have an answer for what a scholar needs to store internally but there have certainly been critiques of these new digital media for storage and query. In his book *The Shallows*, Nicholas Carr has suggested that the Internet, with its many distractions, has eroded our ability to read and think deeply.[5] As he sees it, the very thing that was to help us (external store of information) has eroded our ability to apply imagination to information to ideate new knowledge. Carr's argument is close in spirit to Neil Postman's earlier critique of electronic media like television.[6] Postman argues that the image-driven nature of television has transformed public discourse into entertainment, which, in turn, undermined serious thought.[7] More recently, there have been critiques of search technologies like ChatGPT. Of course, the acid test will be what happens to the growth in the Ideasphere and e-Class over time.

[5] Nicholas Carr. *The Shallows: What the Internet Is Doing to Our Brains*. New York: W W Norton, 2010.

[6] Neil Postman. *Amusing Ourselves to Death: Public Discourse in the Age of Show Business*. New York: Viking Penguin, 1985.

[7] Postman knew Marshall McLuhan well and was no doubt influenced by McLuhan's ideas about "hot" and "cool" media.

We have already covered aspects of thought at the logos step of the diaconatic. In the remainder of this chapter, we'll focus on the preparation of our minds/imaginations for thinking at the logos step. We'll begin with some short descriptions of skill generation and expertise.

CHESS

Adriaan de Groot was the first to look at the question of what separates great chess players from merely good ones.[8] He studied three classes of player: grandmaster/master; experts; and amateurs. His general finding was that the search strategies used by these classes—as measured by the number of moves examined, the depth of the search, and the speed of the search—were indistinguishable. The only difference he could observe was that the grandmas-

[8] Adriaan de Groot. *Thought and Choice in Chess*. The Hague: Mouton and Company, 1965.

ters/masters made better moves.

In another experiment, he assessed the recall of the three classes in the following way. He showed a player actual chess positions (taken from grandmaster matches). These positions averaged 25 pieces on the board. After showing a position for a duration that varied between 2 and 10 seconds, he asked the player to recreate the position from memory. Table 5.1 gives the percentages of pieces that each of the three classes was able to recall correctly. These results make sense. Better players have better recollection of actual positions.

Class	Recall
Grandmaster	93
Experts	72
Amateurs	50

Table 5.1: Recall percentages by class.

Subsequently, researchers repeated de Groot's experiment except that subjects were asked to recall randomly generated positions rather than actual match positions. This made quite a difference. The recall of all classes was about the same and very poor. Subjects were only able to place about 15% of the pieces correctly. This suggests that chess experts have a highly specialized LTM geared to actual play.

London Cabbies

Researchers have studied the brains of London cabbies.[9] These cabbies take about two years of training to learn thousands of destinations and how to navigate between them. The research focused on the hippocampus, the region of the brain responsible for spatial memory and navigation. They compared the structure of the hippocampi of cabbies to those of a control group using structural MRI and found that those of the cabbies were significantly larger with a different structure (the part of the hippocampus believed to be associated with storing spatial knowledge was larger for the cabbies). In addition, the variation in the size of the hippocampus was positively correlated with driver experience. Hence, experience appears to rewire the brain's circuitry, an effect called brain plasticity.

[9] Eleanor Maguire et al. "Navigation-Related Structural Change in the Hippocampi of Taxi Drivers". *PNAS* 97, no. 8 (2000): 4398–4403.

Perfect Pitch

In a recent book, Anders Ericsson describes the example of people who have a musical talent called "perfect pitch."[10] An individual with perfect pitch can identify a musical note when they hear it. If C is played, the individual can identify C; if a B flat is played, the individual can identify B flat, and so on. The frequency of this skill in the general population is thought to be 1 in 10,000.

[10] Anders Ericsson. *Peak: Secrets from the New Science of Expertise*. London: The Bodley-Head, 2016.

The conventional wisdom was that perfect pitch was a skill that people were born with. An interesting experiment changed that thinking. A psychologist recruited 24 children between the ages of 2 and 6 and put them through a rigorous training program. Each child worked 4–5 sessions a day, with each session lasting a couple of minutes. The task was to try to learn to identify 14 chords. The time for the children to learn these chords varied between 12 and 18 months. In total, 22 of the 24 children who began the study completed it, with 2 having to leave the experiment because they had moved away. Once training was complete, the children were tested for perfect pitch. All 22 children who completed the training had perfect pitch. This is strong evidence that perfect pitch can be learned. With enough practice and dedication, humans can learn to "see" heavily disguised environmental cues.

Jack Kilby

Jack Kilby was a co-inventor of the integrated circuit, an invention critically important to digital technology. The integrated circuit is a very large electronic circuit etched on a small amount of silicone material, an idea Kilby came to in 1958 after finishing graduate studies in electrical engineering. Here is a description of Kilby's reading:

> Kilby himself reads, not skims but reads, two or three newspapers every day and a dozen magazines or so each week. In addition he devours books; his office looks like a publisher's warehouse where the books have staged a coup. For years, Kilby took the time to read every new patent issued by the U. S. government.[11]

[11] T. R. Reid. *The Chip: How Two Americans Invented the Microchip and Launched a Revolution*. New York: Random House, 1985, p. 65.

Regarding his reading, Kilby said this: "You read everything—that's part of the job. You accumulate all of this trivia, and you hope that someday maybe a millionth of it will be useful." Kilby's education and reading brought him to the point where he was able to make one of the most important inventions of the 20th century.

Thomas Edison

Edison was not a good student according to his teachers, one of whom found him mentally slow. After only a couple of months at school, his mother decided to homeschool him. She started with the basics: reading, writing, and arithmetic. But over time, she let him study what he was interested in, largely science and technology. He read voraciously including Michael Faraday's *Experimental Researches in Electricity*. It is likely that Faraday's emphasis on experimentation with different materials and devices was a great influence. Edison was a tireless experimenter. For his incandescent light bulb, he and "the Muckers" (his lab assistants) tried over 1,600 different materials in over 6,000 trials, eventually settling on a carbonized bamboo filament that lasted 1,200 hours.

During his career, Edison filled more than 3,500 notebooks detailing his ideas and experiments. It's been suggested that the exographics therein were crucial to his thinking process:

> Rather, Edison reveled in his notebook drawings as sheer process, the life of his mind in full gear. He wrote literally to find out what he was

thinking.[12]

Exographics were a critical part of Edison's discovery process.

[12] Neil Baldwin. "The Laboratory Notebooks of Thomas Edison". *Scientific American* 273, no. 4 (1995): 160–163, p. 160.

Copernicus

We know that Copernicus had a vast collection of books and manuscripts. He possessed four incunabula:[13] Euclid's *Elementa Geometriae* (1482); Albohazen Haly's *In Iudiciis Astrorum* (*The Judgments of the Stars*, 1485); Alfonso X's *Tabula Astronomicae* (1490); and Regiomontanus's *Tabulae Directionum et Profectionum* (1490). He also had copies of Regiomontanus's *Epitoma in Almagestum Ptolemei* (1496) and Aratus's *Soli Phenomena* (1499). Copernicus was in possession of all of the texts in astronomy available at the time. He also had a copy of Euclid's *Elements* which would have prepared him to read the astronomical texts and do his own calculations. These two activities put him in a position to work on his heliocentric model. He published his treatise *On the Revolutions of the Celestial Spheres* detailing the heliocentric model in the year of his death, 1543. Once again, exographics played a key role in bringing a great discoverer to a ground-breaking idea.

[13] "Incunabula" is the name given to printed books produced before 1501.

A person who only knows arithmetic is not likely to make a significant original contribution to mathematics. Similarly, a person visiting London for the first time is not likely to be a good London cabbie and a person just learning chess is not likely to beat a grandmaster. What is clear is that a person doing serious ideation must internalize some of the knowledge, skills, and methods of their area of inquiry. And very often, this involves education and learning beyond that education. Certainly, education involves a significant consumption of exographics, as does learning beyond formal schooling. We term the knowledge, skills, and methods that have been internalized the *memory load* and we conceive it as the minimum required to put an individual in a position to mine the e-Class. We also refer to a mind with these characteristics as a *prepared mind*. We think the prepared mind is best understood in what it is not. In our view, the "next big idea" is unlikely to come from a Google search or ChatGPT query by amateurs.

One path to the frontiers of the e-Class is the university and its graduate programs. In doctoral programs, students take courses designed to bring them to the edge of knowledge in the particular discipline they study. Students typically write field exams to demonstrate their knowledge and then, under the guidance of an adviser, undertake research that leads to a thesis that is supposed to be an original contribution. Throughout, the student tends to consume and produce exographics, the main medium of exchange. While it used to be that theses were defended orally, now the medium of choice for the thesis is the written document. Once students graduate, they will continue to learn and think, with the research output generally summarized with exographics. In sum, the prepared mind of a doctoral graduate is usually formed with a healthy dose of exographics.

GIVEN THE IMPORTANCE of exographics to this process of prepared mind formation, we'll look briefly at the evolution of the e-Library.

The earliest library goes back to Nippur in Mesopotamia about 2000 BCE. In that collection of tablets, there is one with a list of 62 titles, suggesting that it might be a catalog. The library of Ashurbanipal (the Assyrian king) came into existence in 668 BCE at the insistence of the king. It lasted for about 70 years until the end of the Neo-Assyrian Empire. It held about 30,000 tablets. Many of these have significant bibliographic information including a title (usually the first few words of the tablet), the original writer, the scribe if it was a copy of an original, and the stamp of the king. However, no catalog of its holdings has ever been found. Regarding the great Greek library at Alexandria, there are only references to the catalog that Callimachus supposedly produced in about 250 BCE (his so-called *Pinakes*).

The science of library organization did not advance much until the 16th century. In about 1560, Florian Trefler, a Benedictine monk, published his ideas on how to organize a catalog. He was the first to use call numbers, a system that allows users to find a volume quickly. It was a clever idea, one that we still use today.

In 1545, the physician and naturalist Conrad Gessner published *Bibliotheca Universalis*, a catalog of all known works of Latin, Greek, and Hebrew writers. It was in alphabetical order by author. For each of about three thousand authors, there was an entry for each book that included the title of the book and a brief annotation. Twelve thousand titles were listed. Gessner was known as the "father of bibliography." From here, it was a short jump to think about a single library containing all that had been written, the so-called Universal Library.

The modern counterpart would be a digital universal library. With the invention of high-speed computing, high-speed mobile computing, the Internet, and modern search engines like Google and ChatGPT, such a high-tech library could give everyone access and be easily searched. It would be accessible from anywhere at any time.

One of the notable attempts at a digital universal library was Google's in the early 2000s. Larry Page and Sergey Brin, the cofounders of Google, had always entertained the notion of a digital, searchable library and set about the task in 2002. They first approached the University of Michigan which agreed to let Project

Ocean digitize 7 million books. In return, the university would have unlimited access to the database. Google developed the technology to do the digitization, but it still required a human in the loop to turn pages. Each book took about 40 minutes to copy. Google made the same deal with a number of other universities including Stanford, Harvard, and Oxford. Of the 125 million books available at the time, Google managed to digitize 25 million of them at a cost of $400 million.

The project hit a snag when authors objected because they believed their copyrights were being infringed. The class action lawsuit brought by authors and publishers against Google was successful, and the project died. The database now sits unused in Google offices.

Let's consider a few issues with the concept of a universal library. There is a difference between information and knowledge. For example, for a considerable period of time, Charles Darwin collected information about various species trying to explain the variation he observed. In the Galapagos, he documented finches with quite different beak shapes and structure. Later, he reasoned that the different beaks were an adaptation to the type of food the finches were eating depending on their location. In one location, where seeds were abundant, the finches developed much larger beaks capable of breaking the seeds to begin the digestion process. At other locations, finches had smaller beaks because their diet was insects that did not require a large beak to break apart. These observations of beak size and location were some of the data (information) that Darwin used to arrive at his theory of evolution by natural selection (knowledge).

Reasoning with information leads to knowledge. The story (knowledge) at any point in time is always provisional. It's the conventional wisdom until a better theory comes along.

There does not appear to be a consensus on the possibility of a universal library. There are those who feel that technology will eventually solve the problem. Others see it as a problem mainly because the avalanche of information in such a library would get in the way of producing new knowledge. We don't see a problem with lots of information. As a species, we have a great record of producing knowledge and we don't see that progress slowing as a result of too much information.

We think it's safe to say that, over time, the competition in Internet search will refine search technologies. We may or may not get to the universal library. But what we now have, the e-Library, is a wonderful resource for those working on the frontiers of e-Class discovery.

IT'S CLEAR that scholars interact with the e-Library in important ways. We use it as a sort of visual dialectic that we conceive as follows. The e-Library gives us the ability to read what others think about a topic of interest. When we read what others think, it stimulates our thinking and sometimes causes us to think differently. Hence, we can think of the extent of what's been written on a topic as roughly the equivalent of speakers in a dialectic conversation. We read what they write, and this sometimes triggers changes in our thinking about the problem we're working on. The words of the Spanish poet Francisco de Quevedo come to mind:

> Withdrawn into the peace of this desert,
> along with some books, few but wise,
> I live in conversation with the deceased,
> and listen to the dead with my eyes.[14]

[14] Francisco de Quevedo (1580–1645), from his poem *From the Tower*.

We are going to refer to these "conversations" we have with silent interlocutors as *the diagraphic* (translated "through writing"). Effectively, the diagraphic is a slow, asynchronous, visual dialectic. Most importantly, we propose it as a massive extension of the dialectic. It doesn't replace the dialectic but rather supplements it. It's a recognition that our advance on the Ideasphere is a social endeavor through two modalities, speech and exographics.

6
Collaboration and Networked Imaginations

If I have seen further, it is by standing on the shoulders of giants.
Isaac Newton

HAVE a look at the exographic in Figure 6.1. It's an MRI showing a cross-section of a human brain. It's astonishingly detailed. You could imagine how useful such pictures would be to doctors treating a person with a brain injury or disease. MRI machines are not cheap. A "3 Tesla MRI" will cost you almost $6 million.[1]

[1] A Tesla is a measure of the magnetic field strength of the machine's magnet.

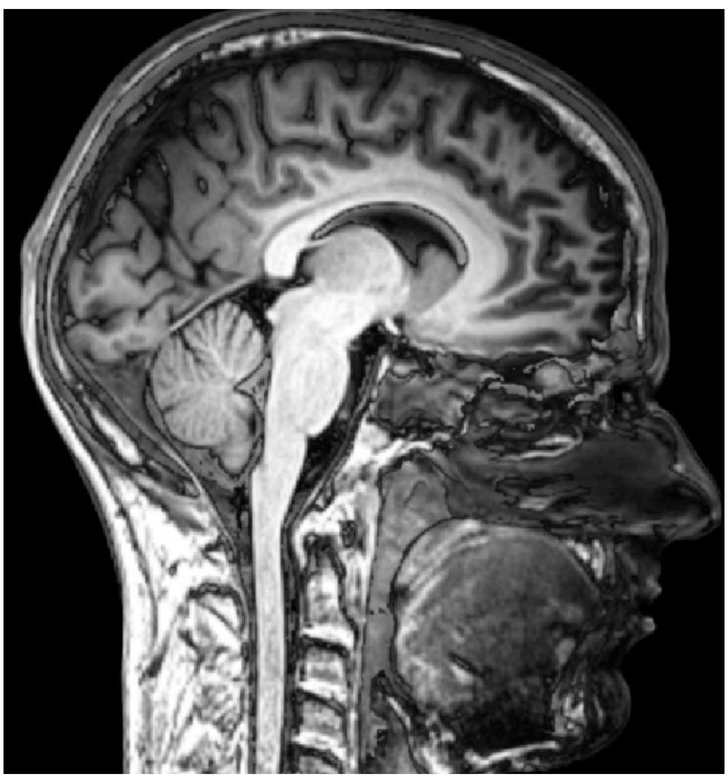


Figure 6.1: MRI sagittal section of the human brain, approximately midline. Image retrieved from Wikimedia Commons, licensed under CC BY-SA 2.0.

The story of the development of these machines is interesting. Like so many other good ideas, it began with some detective work on how nature actually works. In this case, a researcher subjected different materials to two magnetic forces, one very strong, the other weaker and oscillating. This resulted in the materials emitting electromagnetic radiation that could be recorded. Ultimately, the researchers found that different materials gave different electromagnetic signatures, an effect known as nuclear magnetic resonance (NMR). It was an interesting discovery, but thirty years passed before a couple of other researchers began to think about using NMR to try to build images like the one above. NMR was discovered in the 1930s, but using it to take pictures didn't begin in earnest until the early 1970s. Over time, we eventually built MRI machines. Of course, the MRI machines we build now will not be the end of the story. We'll continue MRI development to get increasingly accurate pictures.

Isador Rabi was the researcher who discovered NMR in 1938, a discovery that won him the Nobel Prize for Physics in 1944. We suspect Rabi lived in a house with running water so that when he was thirsty he could go to a tap and get a glass of water. We're guessing that he didn't know anything about how to design and build a water system for a city, much less how to plumb a house to be able to get water from the city supply lines to the taps in his house. But this wasn't just true for the water he drank. He likely didn't grow the food he ate or manufacture the car he drove or build the house he lived in or tailor the clothes he wore. All of that was done by other people. What he did know was physics at the cutting edge which enabled him to teach students and discover NMR.

What is our point? We've emphasized how a few scholars discover ideas and add to the Ideasphere, which is essentially equivalent to our culture (our made world and lifeways), which has expanded considerably over time. But, as the previous paragraphs suggest, we've had to work together to do all of this. We collaborate like no other species. To explain our species, we have to look at how this collaboration could have evolved. What is clear is that we've evolved minds that are highly attuned to the group we are with. From an early age, we learn our culture and how to participate in it. In this chapter, we examine some of the special cognitive and cultural skills we've evolved to function in a highly collaborative society.

FOR COLLABORATION, it's important to have some awareness of what another person is thinking. Psychologists label this skill theory of mind (ToM), or "mentalizing" or "other-mind awareness."

Consider the one-on-one interaction between a mathematics student and teacher working at the blackboard. Let's suppose that the teacher writes something on the board, perhaps an equation, and then looks at the student's face. The teacher is trying to get some indication that the student understands what he has written. If the student fixes her gaze at the exographics and maintains that gaze, she is signaling that she hasn't understood. Had she understood, she would have indicated so immediately, perhaps by nodding her head or saying "yes." In the case where a pregnant pause is long enough, the teacher might say "See that?" which is the teacher's invitation to the student to explain what she thinks the issue is that she doesn't understand. At that point the student will continue to look at the board, perhaps pointing at various parts, to explain, as best she can, what she doesn't understand. When she's finished, she looks at the teacher's face to get some indication from the teacher's expression whether he has understood her issue. It goes back and forth like this until the student either understands or gives up. We tend to think of communication as just language but it's a lot more.[2]

[2] Edward Hall. *The Silent Language*. New York: Doubleday, 1959.

Another indication of our other-mind awareness is the so-called false belief test. Imagine the following experimental situation involving three children. Alice and Evelyn are each playing with a toy, while Matt is sitting quietly apart from them watching. All are three years old. Box A is near Alice, and box E is near Evelyn. Alice takes the toy she is playing with, puts it in box A, and then leaves the room. While Alice is out of the room, Evelyn takes Alice's toy from box A and puts it in box E. Now suppose that an experimenter tells Matt that Alice is going to come back into the room and get her toy. The experimenter then asks Matt where Alice is going to look first. If Matt is a typical 3-year-old, he will answer box E. But if he were 5-years-old, he would answer box A.

Psychologists attribute this difference to the development of Matt's ToM. As a 3-year-old, he believes others have the same knowledge he does. This is why he thinks that Alice would go to box E when she gets back to the room. However, at age 5, his ToM abilities would have developed to the point where he would realize that Alice couldn't possibly know that Evelyn had moved the toy and would answer that Alice would first look in box A. In this way, Matt is aware that other people can have false beliefs, which is why this test is called the false belief test.

When it comes to our mind-sharing skills, an important source of evidence comes from individuals who have autism, a condition that generally presents as some form of social cognitive impairment. These range from those who are quite severely affected (the child who rocks back and forth, does not make eye contact, is prone to outbursts, and has difficulty speaking) to those with Asperger's Syndrome (AS) or judged to be high-functioning autistic (HFA). AS and HFA individuals tend to be socially awkward, sometimes difficult to get along with, and have obsessive interests. For whatever reason, people with autism do not have the same social "glue" that non-autistic people have.

But some with autism are highly creative. There is evidence that Newton, Michelangelo, Mozart, Darwin, and Einstein were all "on the spectrum," a phrase indicating that an individual suffers some level of social cognitive impairment.[3]

[3] Michael Fitzgerald. *Autism and Creativity*. New York: Bruner-Routledge, 2004.

YOU CAN LEARN a lot about our collaborative skills from one remarkable experiment. We've seen versions of it in YouTube videos and in print. One version opens with a 15-month-old boy minding his business, holding his mother's hand. Next, you see an adult experimenter carrying a pile of magazines walk by the boy and his mother. The boy observes him walk to a bookcase, place the magazines on one of the bookcase's shelves, and then close the doors of the bookcase. The experimenter then goes back to the entrance of the room and picks up another pile of magazines, carrying them with both hands under the pile. He walks back to the bookcase (recall the doors are closed), just stands there for a second, and then takes a step back. The child sees this, immediately lets go of his mother's hand, walks to the bookcase, and opens the doors. The experimenter then steps forward, places the pile in the bookcase, and then closes the bookcase doors again. Once more, the experimenter goes back to the entrance of the room, picks up another pile of magazines in the same way, and begins to walk back towards the bookcase. The child sees this, immediately goes to the bookcase and opens the doors so that the experimenter can deposit this third pile of magazines into the bookcase as soon as he gets there.

The key to appreciating the behavior of the little boy is to understand what would happen if a chimpanzee were placed in the same situation. Primatologists tell us that a chimpanzee wouldn't be the least bit interested in helping. At best, it would just glance at the experimenter as he stood in front of the closed bookshelf. Is it because chimpanzees are lazy or stupid? Hardly. It's just that they don't possess some of the important social skills that enable humans to collaborate in ways that no other species can.

Michael Tomasello has referred to this ability in the little boy as *shared intentionality*.[4] It comprises two components. First, it's a suite of skills that enables the boy to understand the intentions of others, and second, it includes the boy's intrinsic desire to collaborate.

[4] Michael Tomasello et al. "Understanding and Sharing Intentions: The Origins of Cultural Cognition". *Behavioral and Brain Sciences* 28, no. 5 (2005): 691–735.

Shared intentionality certainly governs some of our simplest interactions. Suppose a person says to you "Do you have the time?" N. J. Enfield argues that this creates an obligation in you to respond. You have to at least say "No, I don't," and more probably, you'd say "No I don't. Sorry."[5]

We've mentioned that humans have *self-domesticated*.[6] The notion is that we've gone through a natural evolutionary process similar to those that dogs, domesticated farm animals, and other animals have experienced. Traits like reduced aggression, increased social tolerance, and increased social intelligence have been selected for.

One of the benefits of self-domestication is that we're able to cooperate and work together. It also enables us to form complex social structures and live in large groups. Large cities are an example. As we will see in Part II of the book, cities are critical to the expansion of the Ideasphere. Furthermore, self-domestication accelerated the appearance of speech and exographics, two skills that have been crucial to our cultural advance.

[5] N. J. Enfield. *How We Talk: The Inner Workings of Conversation*. New York: Basic Books, 2017, p. 17.

[6] Richard Wrangham. *The Goodness Paradox: The Strange Relationship Between Virtue and Violence in Human Evolution*. New York: Pantheon Books, 2019.

Our *mimetic faculty* refers to the ability we have to recognize and produce similarity. We are great mimics, and this skill is critical to social learning.

In *Poetics*, Aristotle argues that it's instinctual. He also felt that our reasoning ability derived from our ability to see an object as the imitation of another (as in analogical reasoning). The German philosopher Walter Benjamin wrote this:

> Nature produces similarities; one need only think of mimicry. The highest capacity for producing similarities, however, is man's. His gift for seeing similarity is nothing but a rudiment of the once powerful compulsion to become similar and to behave mimetically. There is perhaps not a single one of his higher functions in which his mimetic faculty does not play a decisive role.[7]

Subsequently, he argued that the mimetic faculty is the ability to produce and recognize similarities or sameness.

[7] Walter Benjamin. "On the Mimetic Faculty". In *Selected Writings, 1926–1934*, ed. by Michael Jennings, Howard Eiland, and Gary Smith. Cambridge: Cambridge Belknap Press, 1999.

In his book *Mimesis and Alterity*, the anthropologist Michael Taussig expands on Benjamin's definition:

> ... the faculty to copy, imitate, make models, explore difference, yield into and become Other. The wonder of mimesis lies in the copy drawing on the character of the original ...[8]

Taussig suggested that this mimetic faculty is a sixth sense.

[8] Michael Taussig. *Mimesis and Alterity: A Particular History of the Senses*. New York: Routledge, 1993, p. xiii.

As these scholars have suggested, our mimetic faculty includes our ability not only to imitate but also to see the similarity or sameness in a collection of objects. A good example of this is the assessment of relational match-to-sample problems discussed earlier in the book.

The ancient Greeks thought of mimesis as the imitation or representation of reality, usually in the context of literature and art. This dates at least to the *Homeric Hymns* (approximately 700 BCE). Both

Plato (in *The Republic*) and Aristotle (in *Poetics*) argue that the artist (in sculpture, wall paintings, mosaics) and poet (in drama) attempt to represent real-world phenomena.

Mime is a form of theater in which the story is acted out with only body gesture and facial expression. It dates to ancient Greece. Silent films of the early 20th century are good examples. The opening scene of *A Dog's Life* (1918) has Charlie Chaplin playing one of his classic characters—The Tramp. He is sleeping in a fenced dirt yard and the fence has quite a few gaps and holes. He suddenly wakes up and mimes that he is cold. To "solve" the problem, he pulls out a handkerchief, folds it up, and then stuffs it into a small hole in a fence board close to the ground. He then gets back on his side and goes back to sleep, content that the problem has been solved.

We certainly enjoy stories and fantasies. Whether novels, plays, movies, video games, daydreams, we spend an unusually large percentage of our time consuming or generating fantasy.[9] Our storytelling impulse can also be found in our ability to generate scientific theory. To explain planetary motion, Newton hypothesized an invisible force called gravity. When an actor plays a part, it's a mimetic act (acting) within a mimetic creation (the drama). Acting extends to everyday life. In *As You Like It*, Shakespeare has Jacques say this:

> All the world's a stage,
> And all the men and women merely players;
> They have their exits and their entrances;
> And one man in his time plays many parts.

[9] Jonathan Gottschell. *The Storytelling Animal: How Stories Make Us Human*. New York: Mariner Books, 2012.

The sociologist Erving Goffman explored Shakespeare's insight in his book *The Presentation of Self in Everyday Life*.[10] He saw us wearing different dramatic masks depending on the social situation. For example, on a public transit bus, suppose that you sit facing a stranger with a shopping bag between his feet. Would you look at him and say "What's in the bag?" Probably not. You wouldn't because it's not consistent with the social script you have to follow in that situation. It's not just actors who act. We all act. Life is mimetic.

[10] Erving Goffman. *The Presentation of Self in Everyday Life*. Garden City: Doubleday, 1959.

There are interesting historical accounts of primitive peoples having a significant mimetic faculty. Here is one from Claude Lévi-Strauss's *Tristes Tropiques*:

> That the Nambikwara [an Indigenous people of Brazil living in the Amazon Basin] could not write goes without saying. But they were also unable to draw, except for a few dots and zig zags on their calabashes [gourd made from the hard shell of a tropical fruit]. I distributed pencils and paper among them, none the less, as I had done with the Caduveo. At first they made no use of them. Then, one day, I saw that they were all busy drawing wavy horizontal lines on the paper. What were they trying to do? I could only conclude that they were writing or, more exactly, that they were trying to do as I did with my

> pencils. As I had never tried to amuse them with drawings, they could not conceive of any other use for this implement.[11]

[11] Claude Lévi-Strauss. *Tristes Tropiques*. New York: Atheneum, 1961, p. 288.

The willingness of the Nambikwara to mimic Lévi-Strauss's writing is fascinating. Except for the chief, they had no inkling of the purpose of writing but were quite prepared to imitate and take part, likely because they felt it was powerful magic.

Children's play often involves significant exercise of their mimetic faculty.[12] A little boy might grab a small block, hold it above his head, and run around a room making what he thinks is an airplane sound. The block has suddenly become an airplane. A little girl will play with dolls in the same way.

[12] Vivian Paley. *A Child's Work: The Importance of Fantasy Play*. Chicago: University of Chicago Press, 2004.

It turns out that we all have a *mirror neuron system*. Neurophysiologists discovered these neurons while studying the control of hand and mouth movements in macaque monkeys. The neurons of these systems were activated when the monkeys executed a particular movement or when they *watched* another monkey execute the same movement! It was as if these monkey brains were "silently" mimicking the action another was doing. There is now substantial evidence that humans also have these systems. But there is much less certainty about how these systems actually work in humans.[13]

[13] Cecilia Heyes and Caroline Catmur. "What Happened to Mirror Neurons". *Perspectives on Psychological Science* 17, no. 1 (2022): 153–168.

Infants seem to develop a mimetic capacity almost immediately. Andrew Meltzoff and Keith Moore write this:

> The newborns' first response to seeing a particular facial gesture is activation of the corresponding body part. For example, when they see tongue protrusion, there is often a quieting of the movements of other body parts and an activation of tongue. They do not necessarily protrude the tongue during this initial phase, but may elevate it, wiggle it, or move it slightly in the oral cavity. Likewise, when shown lip protrusion, they produce a marked tension of the lips and even press them together before there is imitation of the movement. It is as if young infants isolate what part of their body to move before how to move it. We call this 'organ identification.'[14]

[14] Andrew Meltzoff and Keith Moore. "Explaining Facial Imitation: A Theoretical Model". *Early Development and Parenting* 6, nos. 3–4 (1997): 179–192, p. 183.

They also have some remarkable photographs in which an infant mimics the facial expression of a parent. Infant chimpanzees also develop this facial mimicking skill quite quickly, suggesting that our mirror neuron system has been evolving for a while. Babies also simulate conversation with an adult by responding to an adult's baby talk with their own meaningless babble when it's their turn. The resulting conversation is very close to a real human conversation in both rhythm and exchange, but, of course, it's semantically meaningless. Think about the staggeringly complex achievement of an infant mimicking an adult. How does it know to stick out its tongue in response to a mother sticking out her tongue or to smile when a mother smiles? Mirror neurons perhaps?

Children usually imitate adults to a fault. There have now been a number of studies which roughly follow the same experimental methodology.[15] A reward is put into a box that can be retrieved by simply pulling down on the knob of a spring door and holding the door open while reaching into the box with the other hand to retrieve the prize. An experimental subject is given some time to examine the box and door to see how it works. Subsequently, the experimenter executes the following demonstration steps:

[15] See Victoria Horner and Andrew Whiten. "Causal Knowledge and Imitation/Emulation Switching in Chimpanzees (Pan Troglodytes) and Children (Homo Sapiens)". *Animal Cognition* 8, no. 3 (2010): 164–181; and Mark Nielen and Keyan Tomaselli. "Overimitation in Kalahari Bushman Children and the Origins of Human Cultural Cognition". *Psychological Science* 21, no. 5 (2010): 729–736.

Step 1. She takes a stick and with it traces two circles on top of the box.

Step 2. Then, she places the stick on top of the knob and pushes it down to open the door.

Step 3. Finally, holding the door open with the stick, she reaches in with her other hand to claim the prize.

After this demonstration, the subject is given some time (usually a minute) to get the prize. No instructions are given as to how to do this and the subject is free to choose any method to get the prize. There are two aspects of the steps to get the prize that are irrelevant to getting the prize: there is no need to trace two circles with the stick on top of the box; and there is no need to use the stick to hold open the door. Yet, when children do this experiment, almost all follow the exact method the experimenter demonstrates, including the irrelevant actions. This phenomenon, in which human children tend to follow a sequence of instructions that include irrelevant actions to achieve a goal, is termed *overimitation*.

Chimpanzees have been subjected to the same experiment and they tend not to overimitate. Generally, they engage in a set of actions that gets to the same goal without exactly reproducing the actions of the demonstrator.[16] Relative to human children, chimpanzees are poor imitators.

[16] Francys Subiaul. "What's Special about Human Imitation? A Comparison with Enculturated Apes". *Behavioral Sciences* 6, no. 3 (2016): 13

Researchers have tested our unconscious tendency to mimic in the following way.[17] In an experiment, two people are brought into a room. One is a subject. Unknown to the subject, the other is a confederate of the experimenters. They take turns describing a series of photographs. This subject-confederate pair is under the supervision of an experimenter sitting behind a desk. The subject and confederate sit in chairs on the other side of the desk from the experimenter. The subject has a clear view of the confederate as they take turns describing the photographs. Each subject does 2 10-minute sessions, each with a different confederate. In one of the sessions, the confederate rubs his or her face frequently; in the other, he or she shakes a foot, again frequently. The experimenters record the number of times the subject rubs his or her face in the particular session where the confederate does the same. Similarly, the experimenters record the

[17] Tanya Chartrand and John Bargh. "The Chameleon Effect: The Perception-Behavior Link and Social Interaction". *Journal of Personality and Social Psychology* 76, no. 6 (1999): 893–910.

number of times the subject shakes his or her foot in the particular session where the confederate does the same. Sure enough, subjects did more face rubbing in the presence of the face rubbing confederate and more foot shaking in the presence of the foot shaking confederate. Furthermore, in a debriefing after the experiment, each of the 35 subjects is asked if they noticed anything peculiar about the mannerisms of the confederate. One subject mentions a particular confederate's hand gestures; two mention that confederates slouched when they sat. But no subject mentions face rubbing or foot shaking. This experiment demonstrates that we mimic the mannerisms and behaviors of people we are with and we do this unconsciously. This is evidence of an innate mimetic faculty.

If we aim to imitate—and this could mean copy exactly or approximately—we need to be able to see or discover the essence of what we are to imitate. For example, a child will see other children kicking a ball and then they will try it. If a calculus student wants to understand the Fundamental Theorem of Calculus, they will look at some examples to see how it works. A lawyer's work in the common law requires assessing how the facts of the case are the same as precedent cases. Hence, our mimetic faculty is critical to cultural learning, particularly in school. Even when we finish our formal education, learning continues because if we're mining a vein of the e-Class, we need to understand the most recent ideas.

In all societies, there must be a transmission of the society's culture from one generation to the next. Hence, there must be learning and this depends crucially on our mimetic faculty.

One way to learn more about our intelligence is to look at non-human primate intelligence. An excellent study in this regard is one by Esther Herrmann and her colleagues.[18] To assess the relative importance of general intelligence (GI) and social intelligence (SI), they looked at the performances of 30-month-old children and chimpanzees on a battery of tests. We know that our culture is significantly different from chimpanzee culture. Does our general intelligence explain this difference in cultures or is it our social intelligence?

[18] Esther Herrmann et al. "Humans Have Evolved Specialized Skills of Social Cognition: The Cultural Intelligence Hypothesis". *Science* 317, no. 5843 (2007): 1360–1366.

We've examined all the tests in each class (GI and SI) and we judge them to be sensible instruments to measure their respective intelligence.

So, what did the study find? Statistically, there were no differences between the chimpanzees and the children in GI scores. But on the battery of SI tests, the children outperformed the chimpanzees. More particularly, the children were better on the social learning tests. This is powerful evidence supporting the position that human social learning may be our most important cognitive skill.

7
Collaboration and Communication

Words are but pictures of our thoughts.
John Dryden

One of our key strengths is collaboration and we've evolved pretty sophisticated ways to communicate with one another to enhance this collaboration. Let's have a closer look at the nature of language and communication.

To say the word "cat," you first open your mouth wide and move your tongue to the bottom of your mouth to say the "ca" sound. To say the "t," you then touch your tongue to the top of your mouth and then quickly release it as you say "t." Fortunately, when we compose what we want to say, we don't have to think about these movements to make the sound. We just make them. Interestingly, we learn to speak very early in life before attending school. In contrast, learning the exographics technology requires years of education.

The atomic sounds of speech are called phonemes. For example, the word "team" comprises the phonemes "t," "E" (the long "e," pronounced as the "ee" in "teeth"), and "m." Each of these is meaningless. Yet when they're said in the sequence, they constitute a word with a meaning we've agreed on.

There is a further combinatorial aspect of speech. We use words to form sentences. These sentences are constructed according to rules that linguists refer to as syntax. The number of sentences each of us can form is limitless. With just 42 phonemes, we can produce an unlimited number of sound sequences, each with an associated meaning.

One remarkable thing about speech is our ability to translate high-velocity speech to meaning. The normal rate for the velocity of speech delivery is about 12 phonemes per second. The sentence "In hell, I'll be in good company" totals 21 phonemes which means it could be said in under 2 seconds. This sentence is easy to understand when someone speaks it at this normal rate. It turns out that we can understand speech delivered at 5 times this rate with a bit of practice. This is surprising when you consider that a discrete "beep" played at 20 times per second (or higher) sounds like an uninterrupted sound.[1]

[1] Michael Eysenck. *Psychology: An International Perspective*. New York: Psychology Press (Taylor and Francis Group), 2004.

There are a number of explanations for how we assign meaning to language. One is *embodied simulation*, the notion that, when we read (or hear) a passage, we sometimes do a mental simulation of what the passage describes.

Here is the first paragraph of Benjamin Bergen's book *Louder Than Words*:

> Polar bears have a taste for seal meat, and they like it fresh. So if you're a polar bear, you're going to have to figure out how to catch a seal. When hunting on land, the polar bear will often stalk its prey almost like a cat would, scooting along its belly to get right up close, and then pounce, claws first, jaws agape. The polar bear mostly blends in with its icy snowy surrounding, so it's already at an advantage over the seal, which has a relatively poor sense of vision. But seals are quick. Sailors who encountered polar bears in the nineteenth century reported seeing polar bears do something quite clever to increase their chances of a hot meal. According to these early reports, as the bear sneaks up on its prey, it sometimes covers its muzzle with its paw, which allows it to go more or less undetected. Apparently the polar bear hides its nose.[2]

[2] Benjamin Bergen. *Louder Than Words: The New Science of How the Mind Makes Meaning*. New York: Basic Books, 2012, p. 1.

Bergen finds this behavior fascinating, as did the sailors who reported it while visiting the Arctic in the 19th century.[3] Then Bergen begins an interesting description of how a reader would attach meaning to this passage eventually suggesting that their mind's eye might produce a scene with the bear engaging in this action. Eventually he explains that a reader would find the bear's behavior fascinating because it's covering up the only thing that is black in the seal's field of vision which is, for the most part, all white. He then writes this:

[3] *The Spectator*, 1901, p. 984.

> [But] I actually never mentioned anything about color.[4]

[4] Ibid., p. 2.

If you reread the passage, you'll see that he doesn't. He goes on to explain that a reader, in their efforts to attach meaning to the paragraph, fills in a lot of detail that is not explicitly mentioned. This is what is meant by embodied simulation. It's the idea that we understand language by mentally simulating the action the words describe.

But there is another way to think about it. Each of us has an understanding of the way the world works and how we function in it. Cognitive scientists have used various terms for this skill including mental model, schema, conceptual framework, and so on. We are going to call it *The Model* and it's the idiosyncratic knowledge that each of us has that enables us to function sensibly in the world. For some of us, it includes knowledge that the moon is round, an important ingredient to make bread is yeast, Maurice ”Rocket” Richard had a younger brother Henri ”The Pocket Rocket” Richard, and 10 is more than 2. For most of us, The Model would include the fact that polar bears have a black nose and that most of the rest of the objects in the Arctic are white. We have no doubt that we simulate mentally the action Bergen's passage describes. But we also know that when we run that simulation, each of us brings the knowledge of The Model to bear.

An old problem in AI is speech recognition, the assignment of a meaning to speech and text. To test quality, Hector Levesque has suggested questions similar to this one.[5] Suppose we give a machine these two sentences:

> The city councilmen refused the demonstrators a permit because *they* advocated violence.

> The city councilmen refused the demonstrators a permit because *they* feared violence.

[5] Hector Levesque. "On Our Best Behaviour". *Communications of the ACM* 57, no. 9 (2014): 86–95.

The problem is to identify who the italicized "they" refers to in each sentence. To answer, a machine needs to have some way of understanding what the rest of the words in the sentences mean, and, more particularly, it has to distinguish the verbs ”advocate” and ”fear.” Humans do this problem easily: given what we know about city councils, demonstrators, and the meanings of the verbs, we'd quickly determine that the "they" in the first sentence referred to the demonstrators.

As it turns out, ChatGPT is able to specify who ”they” is in each sentence but there are many simple problems which give ChatGPT difficulty. For example, consider this query:

> I went to a party. I arrived before John. David arrived after Joe. Joe arrived before me. John arrived after David. Who arrived first?[6]

[6] This is taken from Ali Borji's ”A Categorical Archive of ChatGPT Failures” posted Feb 6, 2023 to *Medium*.

ChatGPT responded that it was impossible to answer based on the information given. But with some elementary logic you can deduce that Joe arrived first. We input the same question in 2025 except that we asked who arrived last. ChatGPT answered John which is correct.[7]

[7] It's well known that AI firms have large departments which use human raters and labelers to improve the quality of generative AI responses. One aspect of this has to be looking at instances of hallucination and making sure that an app does not repeat the error for a specific question and its close variants.

Where we have trouble interpreting speech is with deeply recursive sentences like this:

> At that time, John was aware that Mary believed that Phil understood John knew that Harry had two girlfriends.

You have to think about what was in John's mind at the same time you take into account what the others knew.[8]

[8] R. D. Laing, a Scottish psychiatrist, made these puzzles famous with his poetry: R. D. Laing. *Knots*. New York: Vintage Press, 1972.

LET'S NOW HAVE A LOOK at gesture. Merlin Donald has written extensively on language evolution and offers this:

> The output of any nervous system is muscle movement. Therefore, the only way a nervous system can publicly display and transmit its perceptions of the world to another nervous system is to translate its perceptions into patterns of muscle movements. A mimetic act is basically a motor performance that reflects the perceived structure of the world, and its motoric aspect makes its content a public, that is, a potentially cultural, expression.[9]

[9] Merlin Donald. "Imitation and Mimesis". In *Neuroscience to Social Science, Volume 2: Imitation, Human Development, and Culture*, ed. by Susan Hurley and Nick Chater. Cambridge MA: MIT Press, 2005, p. 283.

Donald is emphasizing that communication requires muscle movement. Whether it's the movements of the musculature in our vocal tracts to speak, or the movement of our bodies in agreed ways to communicate an idea with gesture, or the movement of our hands, fingers, arms, eyes, and head to inscribe exographics on a medium, we must employ muscle movement. In fact, gesture remains a big part of our suite of communication skills. To name a few, we wave a hand to greet or say goodbye, we shake our heads from side to side to indicate "no" and up and down to say "yes," we can shrug our shoulders to indicate uncertainty or indifference, and we can raise our eyebrows to suggest surprise.

It's interesting to speculate about the origins of gesture and speech. We know that, at some point, our ancestors began to communicate in novel ways along the lines Donald is suggesting. It's certainly possible that we began with gesture and signing. The mode we currently use for speaking—voice and gesture—requires the brain to operate our hands, arms, and voice box. As we'll see, most of us have difficulty producing speech if we are not able to gesture. Congenitally blind people make significant use of gesture when they speak to each other on the telephone. This suggests that gesture may have deep evolutionary origins. If gesture did precede speech, imagine one of our ancient ancestors getting back to camp and explaining that a member of the hunting party had been attacked by the prey. He might hold up the index finger on his left hand and then, with his right hand, sweep in and grab the extended index finger. That sequence of gestures is effectively a sentence. The literature on the role of gesture in language is large. There are many papers and some excellent books.[10]

[10] See: Susan Goldin-Meadow. *Hearing Gesture: How Our Hands Help Us Think*. Cambridge MA: Belknap Press, 2003; Adam Kendon. *Gesture: Visible Action as Utterance*. Cambridge: Cambridge University Press, 2004; and David McNeill. *Hand and Mind: What Gestures Reveal About Thought*. Chicago: University of Chicago Press, 1992.

Let's now look at experimental evidence that suggests that gesture plays an important role in the production of speech. In an interesting experiment, Susan Goldin-Meadow and her colleagues had children and adults solve math problems on a blackboard individually.[11] Children solved equations like this: $3 + 6 + 5 = x + 6$. Adults solved factoring problems: $x^2 - 7x + 10 = (x - a)(x - b)$. After getting a solution, children were given a list of words to remember and adults

[11] Susan Goldin-Meadow et al. "Explaining Math: Gesturing Lightens the Load". *Psychological Science* 12, no. 5 (2001): 516–522.

were given a list of letters to remember (letters are harder to remember than words). Then both groups were asked to stand at the board and explain how they got their answers. Once these explanations were provided, they were asked to reproduce what they had been assigned to remember. The experimenters looked at two conditions. In one, subjects were allowed the use of gesture in their solution explanations; in the other, they were not. The experimenters expected to see that subjects in the gesture condition could remember more words and letters and this is what they found. Gesture appears to lighten the cognitive load, allowing subjects to remember more words and letters. This and other experimental evidence suggest that gesture is important in language production.

LET'S NOW CONSIDER the idea that, when it comes to language, our minds function like computers. That is, they are *closed* symbolic processing systems. With this model, there are meanings stored for each word in our minds, and ways (grammars) of stringing these words together into meaningful sentences. Most importantly, we don't need our perceptual and motor systems to interpret a sentence once our central processor receives it.

There is a simple thought experiment that points to the difficulty with this theory. It's known as the *Symbol Grounding Problem*.[12] Imagine trying to learn a foreign language with only the language's dictionary. This would be impossible because every word would be defined in terms of others you don't know. With only the dictionary, you need a way to "bootstrap" your knowledge of the language. That is, you need to learn the meaning of a sufficient number of words so that you could then take the dictionary and learn the language. To do that, there has to be something like an exchanges a mother has with a child for a child to acquire an initial set of word meanings. The child is sensitive to the social intent of the mother. This involves, for example, the mother pointing at an apple, repeating the word "apple," and then doing this enough for the child to finally make the association between the word and the fruit. The mother engages the child *mimetically* until the word is learned. The key here is the word "closed" in the description of the symbolic processing system. It can't be closed. There has to be a way for a learner to pick up some words through the sort of mother–child mimetic exchange described above. The implication is that learning a language is embodied.

[12] Stevan Harnad. "The Symbol Grounding Problem". *Physica D: Nonlinear Phenomena* 42, nos. 1–3 (1990): 335–346.

LANGUAGES CHANGE over time and, over enough time, they change a lot. To see this, consider the first few lines of *The Canterbury Tales* written by Geoffrey Chaucer in the 14th century:

> When that April with his showers soote

The drought of March hath piercèd to the root
And bathèd every vein in such liquor
Of which virtúe engendered is the flower;
When Zephyrus eke with his sweetè breath
Inspirèd hath in every holt and heath
The tender croppès, and the youngè sun
Hath in the Ram his halfè course y-run,
And smallè fowlès maken melody

This certainly isn't modern English, but there are hints. Stangely, the English have occupied the same geographic territory for centuries and, over the last 7 centuries, they've invented a new language! Why?

The answer has a lot to do with metaphor as we'll now explain. Consider this sentence:

It's been a rollercoaster of emotions.

A rollercoaster is a ride at a carnival and, as such, has little to do with human emotion. Yet in the context of emotion, it indicates the speaker has experienced some emotional ups and downs. So, the idea of changes in emotion over time is being compared to a ride on a rollercoaster. Effectively *a metaphor is an attempt to understand one concept in terms of another*. The two objects are not the same but there's a sense in which they are. To understand a metaphor, we put our mimetic faculty to work.

Most words have literal and metaphorical meanings. An example is the word "cool." The literal meaning for "cool" has to do with temperature. When I say "That's cool!" I sometimes mean that it's colder than I expected. But cool has metaphorical meanings and one of these dates to Shakespeare:

Lovers and madmen have such seething brains,
Such shaping fantasies, that apprehend
More than cool reason ever comprehends.[13]

[13] *A Midsummer's Night Dream* (Act 5, Scene 1).

Here he uses it to describe reason which has nothing to do with temperature. In the 20th century, the word began to be used as a hip sign of approval. "That's cool!" or just "Cool!" indicate high praise.

Our simplest words sometimes can be used to convey a number of different meanings. For example, think about the word "apple," and try and generate as many idioms as you can. Here are a few:

An apple doesn't fall far from the tree.
How about them apples?
You're comparing apples and oranges.
She's the apple of my eye.
He's a good (bad) apple.
She's apples.
He upset the apple cart.

Take the first sentence and imagine a person trying to learn English who has never seen this sentence and doesn't have the same idiom in their native language. They would have great difficulty figuring out that sentence's meaning.

George Lakoff and Mark Johnson are two of the pioneers of embodied cognition. In their book, *Metaphors We Live By*, they argue that our conceptual systems are largely metaphorical.[14] One of their examples concerns the concept ARGUMENT and the conceptual metaphor that ARGUMENT is WAR. On its face, argument has a lot in common with war and this is reflected in the language we use:

[14] George Lakoff and Mark Johnson. *Metaphors We Live By*. Chicago: University of Chicago Press, 1980.

> Your claims are *indefensible*.
> He *attacked* every *weak point* in my argument.
> His criticisms were *right on target*.
> I *demolished* his argument.
> I've never *won* an argument with him.
> You disagree? OK, *shoot*!
> If you use that *strategy*, he'll *wipe you out*.
> He *shot down* all of my arguments.

For each sentence, note the italicized words and phrases could be used just as easily in sentences about war.

Here's another: HAPPY is UP; SAD is DOWN. They offer the following sentences by way of example:

> I'm feeling *up*.
> That *boosted* my spirits.
> My spirits *rose*.
> You're in *high* spirits.
> Thinking about her always gives me a *lift*.
> I'm feeling *down*.
> I'm *depressed*.
> He's really *low* these days.
> I fell into a *depression*.
> My spirits *sank*.

Again, the relevant up/down words are in italics. It's clear from these that "up" and related words are associated with feeling good and "down" words with feeling bad.

One of the main points that Lakoff and Johnson make is the enormity of the number of conceptual metaphors and their book details an impressively long list. The interesting question is why there is so much metaphor.

The best explanation we've seen is one Guy Deutscher offers in his book, *The Unfolding of Language*.[15] We'll sketch his basic argument.

[15] Guy Deutscher. *The Unfolding of Language*. New York: Picador, 2005.

Consider a chair with four legs and let's get in the Wayback Machine and go to the point where the first chair was built. Let's also suppose that folks at that time were trying to come up with a name for what we call the legs of the chair. You overhear one of the woodworkers suggest "Stams. Let's call them stams." Let's suppose that, at this time, folks already use the word "leg" for each of the two human extremities that run from our torsos to the ground; they also use it to describe the same extremities for animals. You might argue that there are other possibilities for the four supports for the table. For example, what about "slegs" (short for "support legs") or "clegs" (short for "chair legs")? You can see where this is going. Setting our wisdom about hindsight aside, why not just "legs"? That would certainly be a little easier on your memory because there would be no need to deal with a new word. If you went the new word route, more than a few people would be asking "What'd we call those four chair support thingies?" Using words metaphorically makes sense because, generally, it eases the cognitive burden of remembering the word we assign to a new object. There is more to Deutscher's argument but his main point is that using words metaphorically is cognitively easier than inventing a new word for every concept/notion we've brought forth.

Eventually a metaphorical use will fall out of favor. Grammarians and style guides all share the same opinion of clichés and that's not to use them. To show how "tired" some of these can be, Steven Pinker has offered this sentence:

> We needed to think outside the box in our search for the holy grail, but found that it was neither a magic bullet nor a slam dunk so we rolled with the punches and let the chips fall where they may while seeing the glass as half-full—it's a no-brainer.[16]

[16] See https://youtu.be/OV5J6BfToSw?t=1054 at 17:20

Good writers would make it a point not to use any of these.

Metaphor goes a long way to explain how languages change. Old tired metaphors die and new ones are hatched.

WE LEARN a lot of language by analogy using rules. However, in English, there are lots of exceptions to the rules. There are the irregular verbs, i.e "I went to the store" instead of "I goed to the store." For plural nouns, most of the time it's enough to add an "s" as in "clocks" or "monsters" but there are many irregular nouns (e.g., mouse/mice, foot/feet, child/children). These irregularities make it difficult to learn English because it's easier to follow a general rule than internalize a long list of exceptions. For that matter, what is so wrong with "Yesterday I seed three mouses!"

Well, it's complicated. The French have an organization, the *Académie Française*, which governs all aspects of the French language. For English, there is no such organization. English changes in a decentralized, organic way. Words, grammar, and syntax only change if the vast expanse of English users decide that they should be changed and specific changes tend to occur over a long period of time, much like the way the meaning of the word "cool" changed. Yes, there are books on style, but these do not come with an imprimatur. Changing what is acceptable English is a democratic exercise that plays out over a significant period of time.

A PIDGIN IS a rudimentary language formed when two peoples with different native languages share the same geographic location usually for some common purpose such as trade. Pidgins typically have a very simple grammatical structure with words borrowed from both parent languages. Generally, a creole arises when a pidgin becomes the native tongue of the progeny of those who initiated the pidgin. Over a number of generations, the children can modify the pidgin to arrive at a full vocabulary and complex grammar. In effect, the creole is a sophisticated language that develops from the pidgin.

Here are sentences in Tok Pisin, a creole serving as the national language of Papua New Guinea (the translations are underneath each example):

> Sapos yu kaikai planti pinat, bai yu kamap strong olsem phantom.
> (If you eat plenty of peanuts, you will come up strong like the phantom.)
>
> Fantom, yu pren tru bilong mi. Inap yu ken helpim mi nau?
> (Phantom, you are my true friend. Are you able to help me now?)
>
> Fantom, em i go we?
> (Phantom, Where did he go?)

You can see that there are elements of English in Tok Pisin.

Pidgins and creoles are strong evidence of shared intentionality and our mimetic faculties at work. When two linguistic groups meet to work towards a common goal, communication will facilitate their efforts. Over time, a simple common language comes to life and serves to enhance collaboration. This is another good example of shared intentionality.

LET'S SUMMARIZE by relating communication and collaboration. No other species can match our extraordinary ability to ideate cultural objects. Think of the smartphone. It's a recent invention but its design and manufacture depended on centuries of science and technology. In other words, the human network of minds, over time and space, was able to put these devices in our hands. Without collaboration, there would be no smartphone. So we've managed to leverage this group effort into a stunning cultural object.

Given that collaboration and cultural advance have been at the center of the human experience, is it any wonder that we've figured out a very efficient way to share the contents of our minds with each other? Language, gesture, and exographics are extraordinary achievements that make for an efficient sharing of ideas. As we've already remarked, it's simply staggering that we can communicate the contents of our minds with arbitrary sounds, squiggles on a page, and meaningful body movements.

As research with chimpanzees indicates, it would not have been easy to come to symbolic communication. Chimpanzees can ideate and use tools in the wild but there is only limited evidence that they can communicate symbolically, and hence it is unlikely that they will be engaging in abstract thought any time soon. In contrast, captive chimpanzees can be trained to recognize and use symbols. In turn, this enables them to engage in limited abstract thought. Captive chimpanzees have access to Pirsig's ghosts, but only with the help of another species—us.

8
The Evolution of Exographic Technologies

Give me twenty-six soldiers of lead and I will conquer the world.
Johannes Gutenberg

EXOGRAPHIC technologies include the hardware (the medium and means of inscription) and software (the representation system). In this chapter, we'll consider how its hardware has improved. Then we'll look at software changes that have allowed our imaginations to expand the e-Class significantly.

THE MATERIALS OF THE MEDIUM have changed considerably. The Mesopotamians used wet clay. The Romans used papyrus sheets and other media. Today we use a variety of materials, ranging from paper to the materials of a computer screen, to the "thin air" of virtual reality headsets.

Inscribing tools have also changed. The Mesopotamians used a stylus shaped from reeds. The Romans used a variety of inscribing tools. There was one to mark wax tablets. Another was a calumus, a pen fashioned from a reed; the reed was cut at an angle so that one end came to a sharp point which could then be dipped in ink. Today, we use pens, pencils, and even specialized pens to inscribe a computer screen.

An important aspect of exographics is the physical organization of longer documents. The Mesopotamians used as many clay tablets as required. The Romans used papyrus sheets glued together to form a scroll. The next innovative configuration was the codex (the book as we know it). Its pages are piled on top of each other and then bound on the left.

Religion played a key role in the creation of the codex. One of the great works in literature is Virgil's *Aeneid*, written in Latin between 29 and 19 BCE. The *Vergilius Vaticanus*, a manuscript held in the Vatican Library, contains a 50-page fragment of the *Aeneid* and was written about 400, long after Virgil wrote the original which was likely a scroll. What gets the attention of a modern reader is that there are no spaces between the words. This is termed *scriptio continua* and it was standard practice until Irish monks began to insert spaces between words in the 7th century.[1] Also, there are no small letters, just capital letters. There are no punctuation marks or paragraph indents and no page numbers. Even if we knew Latin, this would be difficult to read. It would be like trying to read this English:

THEPENISMIGHTIERTHANTHESWORD

It's much easier to read if spaces are inserted between the words:

THE PEN IS MIGHTIER THAN THE SWORD

Despite our cognitive familiarity with spaces between words, it's still startling to see how a small change like this can make reading much easier.

The *Vergilius Vaticanus* is a codex, not a scroll. At that time, we know that the Roman standard for manuscripts was the scroll. Yet in 400, well before the collapse of the Empire, the codex had become the dominant technology for manuscripts. Normally, if a technology like the codex is going to displace a well-established technology like the scroll, it has to have some significant advantages. What were these advantages?

First, a codex would be cheaper to produce because you can write on both sides of the page and therefore less material is required. Second, because a codex requires less page material, it would store more compactly. Third, it would be easier to find specific points in a codex because you can flip a large number of pages easily, whereas, with a scroll, you have to roll your way through the intervening pages. There has been a substantial debate about whether these advantages would have been sufficient to cause manuscript producers to switch to the codex form. Most scholars feel they wouldn't have been. So what induced the change?

As it turns out, the early Christians were among the first to use the codex. Research has suggested that there are 42 known gospel fragments dating from the 2nd to the 6th century and every one is a codex.[2] This is certainly surprising because the first couple of centuries of that period would have been dominated by scrolls. The argument is that given the volume of words on a papyrus page in a scroll, it would take a 30-meter-long scroll to include all four gospels. Such a scroll would be completely unmanageable. But a codex could easily contain all four gospels.[3] Over time, the expansion of Christianity and the Empire's declaration of it as its official religion would have given considerable impetus to the codex.

LET'S NOW MOVE to the Carolingian improvements to Latin. Charle-

[1] Paul Saenger. *Space Between Words: The Origins of Silent Reading*. Redwood City: Stanford University Press, 1997.

[2] T.C. Skeat. "The Origin of the Christian Codex". In *The Collected Biblical Writings of T.C. Skeat*, ed. by Keith Elliot, 113:79–87. Novum Testamentum, Supplements. 2004.

[3] We're not certain whether these early codices contained all four gospels. But we know the *Codex Sinaiticus*, housed at the British Library, was written in the 4th century and contains all four.

magne invited the great medieval scholar, Alcuin, to teach in his palace school in 782. Over time, Alcuin introduced improvements to Latin writing. He required that every written letter be pronounced, a change that made Latin much easier to learn. The Carolingians were the first on the continent to put spaces between words and were likely influenced by the scripts of the Irish monks. Capital letters were used to begin sentences, and periods were used to end them. Large capital letters were used to start a new paragraph, and question marks were used at the end of sentences where required. Finally, they developed a script, Carolingian minuscule, which made text much easier to copy.

The Latin the Carolingians defined became the standard across Western Europe and some have argued that this standardization was a significant part of the reason for the increase in population and wealth over the period 1000–1300.[4] This argument is based on a number of econometric analyses that find that relatively obvious changes, like enhanced communal defense against invaders, the increase in long-distance trade, and the introduction of the feudal system, are not enough to explain the tremendous growth in per-capita income over that period. Harold Innis and then Blum and Dudley argue that an increasingly literate population and the introduction of standardized exographics (Carolingian miniscule) facilitated the use of written contracts to govern decentralized exchange. As we now know from modern economics, enforceable contracts facilitate trust (among other salutary benefits) and make a much higher volume of exchange possible.[5] Hence, as Blum and Dudley argue, it was this change, the growth in literacy, exographics and contracting that is the likely explanation for the growth in per-capita income.

[4] Ulrich Blum and Leonard Dudley. "Standardized Latin and Medieval Economic Growth". *European Review of Economic History* 7, no. 2 (2003): 213–238.

[5] There is now an extensive literature on the economics of contracting. For the present context, interested readers are referred to: Oliver Williamson. *Markets and Hierarchies: Analysis and Antitrust Implications*. New York: The Free Press, 1975.

LET'S NOW LOOK more closely at exographics media and inscription technologies. Clay and papyrus were the media of choice for millennia. Over time, as the papyrus plant became scarcer, we began to use parchment, a material made from sheep and calfskin.[6] To make a sheet of parchment, the skin (with the hair attached) was soaked in a lime solution for a period of three to ten days depending on temperature, and then washed with water. At this point, it was easy to remove the hair, but both surfaces would still have been too rough for inscribing once dry. Hence, the skin was stretched on a frame, and, while still wet, both sides were scraped with a crescent-shaped knife called a lunellarium. The skin was then dried. Once dry, both sides were slightly wetted again and then sanded or "pounced" with a pumice stone. This was sometimes done twice. Finally, both surfaces were rubbed with chalk to whiten and smooth the surface.

[6] Sometimes the paper made with calfskin is called vellum.

The Chinese were the first to make paper from rags. The technique diffused through trade to the Middle East about the 8th century, and then made its way to western Europe about the 12th century.

The paper we write on today is made in a highly mechanized, complex two-stage process where pulp is manufactured from wood chips and then goes through a long procedure to produce paper.

In terms of inscription technologies, quill pens were used for centuries. They were made from goose, swan, or turkey feathers by first stripping away the attached feather material and then letting the naked quill dry for a few months. Once dry, the greasy outer skin could be scraped off and the pith inside the quill removed. A penknife was used to shape the nib of the quill. Two angled cuts were made at the end of the quill, the second at a sharper angle. Next, the end of the quill was snipped to make a sharp edge at the desired thickness. Finally, the end of the nib was split. This split enabled the smooth flow of ink from pen to parchment.

A scribe might use up to 60 quills in the course of a day's work and these needed to be maintained. As writing progressed with the same quill, the end of the nib would wear and ultimately it would have to be cut to restore a working business end. As the 19th century opened, there were 27 firms selling quill pens in London. Annual sales in England were in the hundreds of thousands.

It wasn't until quills were replaced by pens with steel nibs that this maintenance requirement was relaxed. But it was a long time, towards the end of the 19th century, before steel-nibbed pens were accepted as better. Maygene Daniels documents the history of steel-nibbed pens and other writing instruments (including fountain pens, the pencil, ball point pens, and typewriter).[7] What is fascinating is the nature of the development. It's a long story of many incremental improvements interspersed with a number of technological breakthroughs. Of course, the breakthroughs continue. Today, the electronic word processor on a computer has replaced the typewriter. We can also inscribe text on a computer screen with voice.

[7] Maygene Daniels. "The Ingenious Pen: American Writing Implements from the Eighteenth Century to the Twentieth". *The American Archivist* 43, no. 3 (1980): 312–324.

A SIGNIFICANT CHANGE in inscription technologies in Europe was Gutenberg's movable type and printing press developed about 1450. The Chinese were the first to invent the printing press in about 250 BCE. Basically, they inscribed wooden blocks. They were also the first to invent a movable type in about 1045.

Gutenberg's contribution was to produce a small rectangular piece of metal with a particular letter raised on the surface of one end. He did this by pouring a molten alloy of lead, tin, and antimony into a specialized mold. When the alloy had cooled enough, he snapped out the piece of type. He was a goldsmith by training so had the expertise to come up with such a process. His method yielded a large number of identical pieces of type for each letter. Once these pieces were made, they could be moved around very quickly in a form depending on what was being printed. The form was inked, and, with the press, a blank page and the form were brought together to produce a page of text. A replica of a Gutenberg press is shown in Figure 8.1.

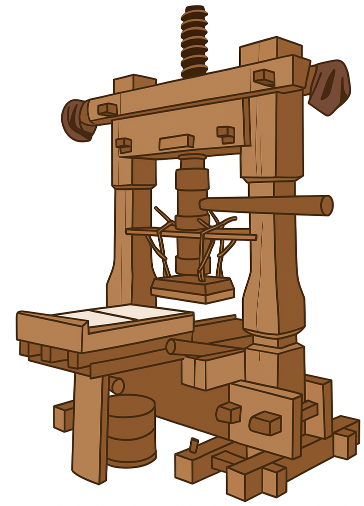


Figure 8.1: A replica of the Gutenberg printing press.

Before this, presses had a woodblock form: basically, the block was inked, and then paper was pressed against it to obtain a printed page. The problem was that the blocks were difficult to make and not easy to change. Gutenberg's contribution was the development of *moveable type*, a process to produce type that was assembled into forms. Once work was finished with the form for a particular page, the same pieces could be used to assemble another form for the next page. With Gutenberg's system, mistakes could be fixed easily. If a word was misspelled, a printer could readily make the correction. With blocks, a misspelled word required a whole new block.

Gutenberg's first printing was the so-called Gutenberg Bible. A picture of one of its pages is shown in Figure 8.2. Each letter on this page corresponds to one piece of type. Note the artwork midway down the second column. Artists called rubricators did this work by hand. The typeface is based on Textura, a style of Gothic script popular in Europe at the time and sometimes called Blackletter.

In Gutenberg's time, most inks were water-based. These didn't work well with Gutenberg's press so he developed a special ink with high metallic content and better adherence.

LET'S NOW CONSIDER the larger societal effects of Gutenberg's innovation.

Before Gutenberg, manuscripts were handwritten in scriptoria, usually in monasteries. The scriptorium was a large room where monks sat at elevated desks with quills in hand. Compared to the printing press, there were two problems. First, there were transcription errors, and these would compound as successive copies of the manuscript were produced. Second, producing copies by hand is expensive relative to the printing press. Econometric research suggests that the cost of printed books fell by two-thirds shortly after the printing press was invented.[8]

[8] Jeremiah Dittmar. "Information, Technology, and Economic Change: The Impact of the Printing Press". *The Quarterly Journal of Economics* 126, no. 3 (2011): 1133–1172.

Regarding the production of manuscripts in western Europe before the arrival of the printing press, Table 8.1 presents the number of manuscripts produced each century over the 10th to 15th centuries. Note that the number of manuscripts grows steadily but jumps to about 5 million in the 15th century, the century when the printing press arrived. This data suggests that whatever the underlying social process driving the production of text (in scriptoria or printing

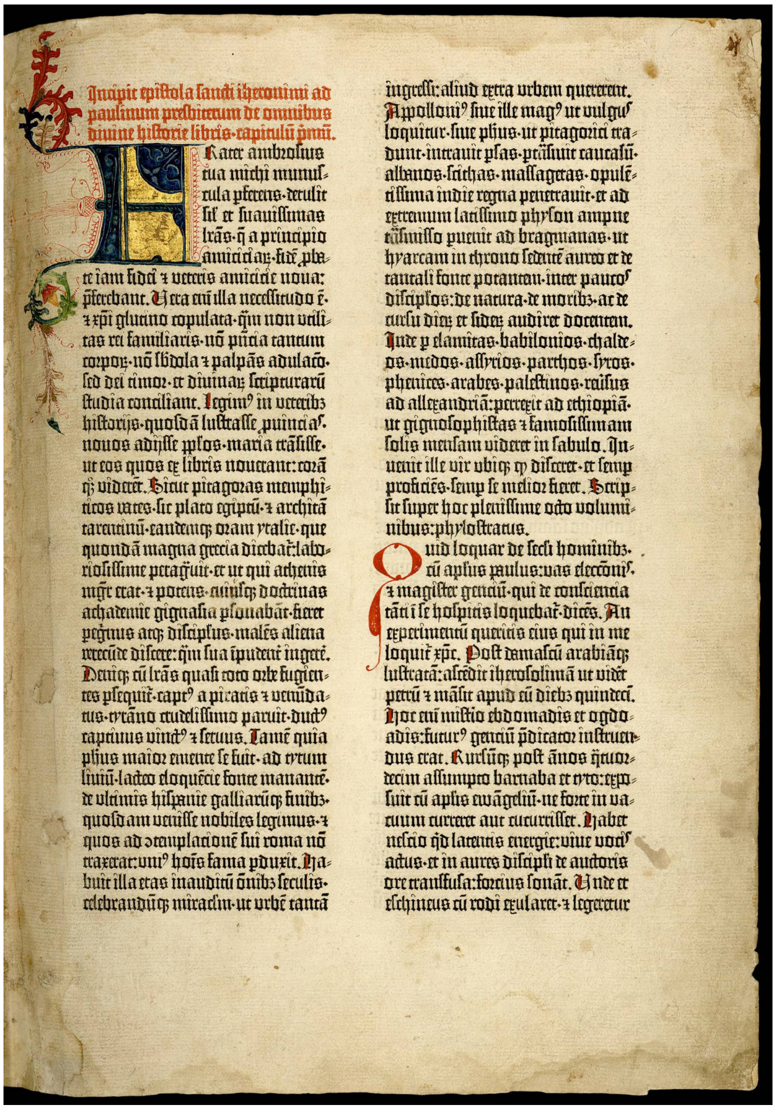


Figure 8.2: A page from the Gutenberg Bible. Public domain image via Wikimedia Commons.

shops), it had begun well before the arrival of the printing press.

Century	Number of Manuscripts
10	135,637
11	212,030
12	768,721
13	1,761,951
14	2,746,951
15	4,999,161

Table 8.1: The number of manuscripts produced by century. This table is adapted from Table 1 in Eltjo Buringh and Jan Luiten van Zanden. "Charting the 'Rise of the West': Manuscripts and Printed Books in Europe, A Long-Term Perspective from the Sixth through Eighteenth Centuries". *The Journal of Economic History* 69, no. 2 (2009): 409–445.

Table 8.2 presents estimates of the number of printed books produced in each half century from 1451 to 1800. Note that just in the last half of the 15th century alone, 12.6 million printed books were produced, which is double the number of manuscripts copied in the previous 5 centuries. In the first half of the 16th century, the period the Reformation began, 78 million printed books were produced. That is an astonishingly high increase in the number of books. Thereafter, the growth is not as rapid, but it's a steady exponential growth. This data strongly suggests that Gutenberg's printing technology diffused rapidly and that there was a significant demand for books, and as we will see, a demand strongly influenced by the Reformation.

Half Century	Number of Printed Books (1,000s)
1451 to 1500	12,589
1501 to 1550	78,017
1551 to 1600	138,427
1601 to 1650	200,906
1651 to 1700	331,035
1701 to 1750	355,073
1751 to 1800	628,801

Table 8.2: The number of printed books by half century, 1451–1800.

Elizabeth Eisenstein is an authority on the effects of the printing press and has summarized her findings in two major works.[9] Her position is this:

> The impact of printing, experienced first by literate groups in early modern Europe, changed the character of the Italian Renaissance and ought to be considered among the causes of both the Protestant Reformation and the rise of modern science.[10]

We think it safe to say that the printing press was not the cause of the Reformation. Luther's commitment to his positions was not

[9] Elizabeth Eisenstein. *The Printing Press as an Agent of Change*. Cambridge: Cambridge University Press, 1979; and Elizabeth Eisenstein. *Divine Art, Infernal Machine: The Reception of Printing in the West from First Impressions to the Sense of an Ending*. Philadelphia: University of Pennsylvania Press, 2011.

[10] Elizabeth Eisenstein. "The Emergence of Print Culture in the West". *Journal of Communication* 30, no. 1 (1980): 99–106, p. 99.

influenced by the existence of the printing press. However, it was fortunate that the printing press had come along just before Luther launched his mission to enhance literacy among his followers. Bibles and other related printed materials were cheaper and in good supply, which gave Luther's Reformation, one based on literacy, significant momentum.

Gutenberg's innovation of the printing press and the Reformation increased the literate population, and there can be little doubt that this give e-Class discovery a significant boost. It's not surprising that soon after we observe that the Renaissance continues, the Scientific Revolution begins with Copernicus in 1643, and about the same time, the Enlightenment (about 1600–1800) begins. Shortly thereafter, the Industrial Revolution also begins.

We've refined our exographic symbol systems considerably. We'll begin by looking at the evolution of exographic number representation.

The Sumerians used the symbol

to represent the number 23. Each of the sideways cuneiform wedges (the first two symbols on the left) is a 10 and each of the three upright cuneiform wedges, a 1. This is clearly a more efficient representation than if twenty-three individual tally marks were used:

IIIII IIIII IIIII IIIII III

The Romans used

XXIII

and today we use the Hindu-Arabic symbol

23

Our modern system uses fewer symbols to represent the same idea.

When it comes to a change in a representation system, the incumbent system has the advantage that people are familiar with it and, for this reason, are resistant to change. Yet our representation systems have changed in significant ways over the centuries. Up to about 1000, the only number system used in Europe was the Roman system. But by the late 16th century, Hindu-Arabic numbers had taken over. For centuries, the representation for 23 was "XXIII." Then it switched to "23." Why?

The basic Roman numbers and their Hindu-Arabic equivalents are as follows:

I = 1, V = 5, X = 10, L = 50, C = 100, D = 500, and M = 1000.

The Roman system is additive. For example, to determine what number LXVII is, we simply add the values: 50 + 10 + 5 + 1 + 1 = 67. To add two Roman numbers, say LXVII + CLXXXVI, we would first concatenate the two strings by symbol-type:

LXVII (67) + CLXXXVI (186) = CLLXXXXVVIII (253).

Then we would simplify the resulting string by symbol type going from right to left. In this case, there is nothing to be done with the three I's on the right. But VV is an X so we could rewrite it to CLLXXXXXIII. But the 5 X's are an L, so we would have CLLLIII. Then two Ls make a C and we end up with CCLIII which is 253.

The Romans used an interesting way to multiply, which they likely picked up from the Egyptians via the Greeks. For clarity, we'll illustrate with a Hindu-Arabic example:

$$16 \times 132 = 8 \times 264 = 4 \times 528 = 2 \times 1056 = 1 \times 2112.$$

You can see what's happening. At each step, the smaller number is halved and the larger is doubled. Eventually, this brings you to the final answer, 2,112. These numbers are contrived but the same principle can be applied if either or both numbers are odd. An advantage of this approach is that the Romans didn't have to memorize single-digit multiplications (e.g., 7 × 8 = 56) to do higher order products as we do. They only had to know how to halve and double numbers, and that was easy in their system.

Researchers have compared the cognitive work required to perform a representative set of arithmetic operations in both the Roman and Hindu-Arabic systems.[11] This research accounted for all the cognitive work it takes to do an operation for a large set of sample problems. Here is an example. Let's look at the cognitive work to do 54 + 68 in our system. We would first fix our attention on the digit 8 in 68 and store it in working memory. Then we would attend to the digit 4 in 54 and store it. Then we would search for the answer to 8 + 4 in our LTM and this gives 12. The cognition audit continues in this way with the recording of all reads, attention changes, and LTM searches for 1,000,000 additions of the form $x + y + z$ for x, y, z between 1 and 100. We won't go over all of their experimental results because three measures tell most of the story: the total number of symbols used, the total reads (you look at a symbol and store it), and the total attention shifts (you change your attention from one symbol to another). These measures are presented in Table 8.3. The table numbers are in units of 1,000 (the element 5,760 is actually 5,760,000).

[11] Dirk Schlimm and Hansjörg Neth. "Modeling Ancient and Modern Arithmetic Practices: Addition and Multiplication with Arabic and Roman Numerals". In *Proceedings of the 30th Annual Conference of the Cognitive Science Society*, ed. by B. C. Love, K. McRae, and V. M. Sloutsky. Austin: Cognitive Science Society, 2008.

	Hindu-Arabic	Roman
Total Number of Symbols	5,760	15,032
Total Reads	8,116	244,166
Total Attention Shifts	16,625	336,413

Table 8.3: Cognitive effort measures for the arithmetic experiment.

Looking first at the total number of symbols, the Roman measure is almost three times as large. It's easy to see why by looking at some simple additions. Here is the one we looked at above:

LXVII (67) + CLXXXVI (186) = CCLIII (253).

There are 18 individual Roman symbols but only 8 Hindu-Arabic symbols.

For the next two measures (total reads and total attention shifts), the Roman measures are staggeringly larger. These are partly explained by the higher number of symbols that the Roman system requires, but the nature of the additive Roman system is also a factor.

Based solely on these three measures, the Hindu-Arabic system is better, however it requires more effort to learn. To learn the addition and multiplication operations, users need to store a set of single-digit additions (e.g., 6 + 8 = 14) in their LTMs whereas with Roman addition, they don't.

The other important thing about arithmetic in any sophisticated number system is that, to do it, we generally need to engage our hands and some sort of external cognitive resource. For example, to calculate 386 × 459 in the Hindu-Arabic system, you need a pencil and paper, or a calculator, or a computer. In medieval Europe, the equivalent Roman calculation would require a counting board or an abacus, and both were easy to learn. In fact, the counting board and abacus can be used to do Hindu-Arabic arithmetic and were used extensively once the Hindu-Arabic system replaced the Roman system.

The important takeaway from this experiment is that a human armed with an abacus or counting board is able to do arithmetic calculations more quickly using the Hindu-Arabic system. The same computation is possible using the Roman system, but it's just not as efficient cognitively. However, the Roman system was in Europe first and that's an advantage, as we have already noted.

John Durham confirms the lead taken by the academic sector:

> There is little doubt that 'Arabic' numerals were well known in academic circles by the 11th century.[12]

The evidence we were able to find is consistent with this assessment. We checked *The Doomsday Book*, the colossal demographic and

[12] John Durham. "The Introduction of 'Arabic' Numerals in European Accounting". *The Accounting Historians Journal* 19, no. 2 (1992): Article 2. See footnote 2 on p. 2.

economic survey of England and Wales completed by the court officials of William the Conqueror in 1086. It's written in Latin and all the numbers are Roman numerals. We then looked at the published work of a number of the early scientists in the coming Scientific Revolution, including Tycho Brahe (1546–1601), Johannes Kepler (1571–1630), Copernicus (1473–1543), and William Gilbert (1544–1603). All used Hindu-Arabic numerals. There is some evidence that Gerbert of Aurillac (946–1003) was the first to introduce Hindu-Arabic numerals to European education. However, the real push came from Leonardo of Pisa ("Fibonacci") and the publication of his *Liber Abaci* (*Book of Calculation*) in 1202. He begins with this:

> The nine Indian figures are:
>
> 9, 8, 7, 6, 5, 4, 3, 2, 1.
>
> With these nine figures and with the sign 0 which the Arabs call zephir, any number whatsoever is written, as is demonstrated below.

Once the numbers are introduced, he then demonstrates how Hindu-Arabic arithmetic worked.

Durham goes on to suggest that the use of Hindu-Arabic numbers commercially was an Italian innovation of the 14th century. However, within this commercial sector, Roman numerals persisted well into the 16th century. So, the switch to Hindu-Arabic numbers did not occur overnight. It was a slow process that took centuries.

We know that Europe underwent a considerable economic and social transformation between 1000 and 1500. Through the early Middle Ages, Europe was basically an agrarian society assembled around small villages. Exchange was largely barter. After 1000, agricultural production expanded considerably due to climate change and a number of innovations that made agriculture more productive.

As this agricultural expansion continued, towns and cities grew in population and trade among them and Arab cities in the eastern Mediterranean increased significantly. This expansion of trade encouraged the rise of a merchant class and a movement away from barter to a price system. Economic activity expanded considerably, and this led to a substantial increase in the computation required to support exchange.

As the merchant class grew, there was a need for apprentices to learn commercial arithmetic. They were taught by masters at reckoning schools, located in the cities along the trade routes. By 1338, there were 6 reckoning schools in Florence alone. The curricula at these schools were based on the Hindu-Arabic system including the representation of numbers, the arithmetic operations on these numbers, and the commercial application of arithmetic. One of the standard arithmetic texts of the 15th century was the *Treviso Arithmetic*, published in 1478 by an anonymous author. It is based on the Hindu-Arabic system with lots of commercial applications. Here is one:

> If 100 pounds of ginger are worth 16 ducats, 18 grossi, 14 pizoli and ½, what will 8564 pounds and 1/3 be worth.[13]

[13] Frank Swetz. *Capitalism and Arithmetic: The New Math of the 15th Century*. La Salle, Illinois: Open Court Publishing Company, 1987, p. 115.

Here is another:

> A merchant has 10 marks and 6 ounces and ½ of silver of a fineness of 5 ounces and ½ per mark. He has 12 marks of another kind which contains 6 ounces and ½ per mark. He has 15 marks of another kind which has fineness of 7 ounces and ¼ per mark. And from all of this silver, he wishes to coin money which shall contain 4 ounces and ¾ of fineness per mark. Required is to know the amount in the mixture, and how much brass must be added.[14]

[14] Ibid., p. 157.

These problems are a clear indication that commercial transactions and calculations were not trivial (especially if you were just learning the Hindu-Arabic system). Additionally, trade among the cities was complicated by the fact that each city had its own currency, so exchange calculations were involved in all transactions among merchants of different cities.

Over the first centuries of the Renaissance, pressure was building to move to the Hindu-Arabic system. One advantage was that detailed commercial calculations could be recorded in pen and ink, whereas it was only possible to record the final answer when a counting board was used for a Roman system calculation. Another advantage of the Hindu-Arabic system was that it was easier to deal with fractions, and these came up frequently in currency exchange calculations. In addition to these advantages, the Schlimm-Neth experimental work described above makes it clear that any calculation could be done more quickly using the Hindu-Arabic system on a counting board or abacus.

Other explanations have been offered. Some have suggested that the innovation of double-entry bookkeeping facilitated the transition to Hindu-Arabic numbers. However, several researchers have argued that Roman numerals persisted long after the emergence of double-entry bookkeeping.[15]

[15] Alan Sangster. "The Genesis of Double Entry Bookkeeping". *The Accounting Review* 91, no. 1 (2016): 299–315.

In some recent research, Raffaele Dana examined 1,200 arithmetic texts published in Europe over the period 1400–1600.[16] He looks at where these texts were published every 25 years. His results show a clear geographical diffusion pattern. Beginning in 1400 there are only a few texts and these were published in central/northern Italy. By 1500, there was a clear pattern northward into France and Germany, helped by the recent invention of the printing press (1450). By

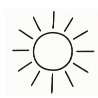
[16] Raffaele Dana. "Figuring Out: The Spread of Hindu-Arabic Numerals in the European Tradition of Practical Mathematics (13th-16th Centuries)". *Nuncius* (2021): 1–44. `https://doi.org/10.1163/18253911-bja10004`.

1600, the texts had been published throughout continental Europe and had a toehold in Britain. He goes on to suggest that the primary push was the commercial revolution and the corresponding increase in economic activity. Dana makes a convincing case and we conclude that it was largely the commercial sector in Europe that drove the change to the Hindu-Arabic system. The education system, scientific sector, and cognitive efficiency of the Hindu-Arabic system contributed to the system getting a toehold in Europe, but the commercial sector was the driving force that led eventually to wholesale change.

A final note. The Roman and Hindu-Arabic systems are equivalent in the sense that 23 is the same concept regardless of the symbols you use to represent it. But the Hindu-Arabic system, although harder to learn, requires much less cognitive effort to use.

LET'S NOW TURN to one of our biggest breakthroughs in representational improvement: phonetic writing systems.

Suppose that we were charged with designing a writing system. An obvious place to start would be to draw pictures of a concept. For example, for the concept of the Sun we might choose a symbol that looks like it:



This approach is termed a pictographic system and many early writing systems followed this principle.

A fundamentally different approach is a phonetic system where the atomic speaking sounds are represented with visual symbols. The main advantage of a phonetic system is that, if a novice reader does not recognize a word, they can stitch the sounds of the word's letters together and have a good chance of decoding it. Keep in mind that readers already recognize the word when it's spoken.

Novice readers can also get a clue about what the next word is from the context defined by the words that precede it. For example, suppose you're reading these words:

> Many years later, as he faced the firing -----, . . .

What do you think the word after "firing" is? Surely it's "squad" which is what Gabriel Garcia Marquez chose in the first sentence of his novel, *One Hundred Years of Solitude*.

When we become mature readers, we can read so quickly that we don't even look at all the letters in a word. Try reading this passage:

> Aoccdrnig to a rscheearch at Cmabrigde Uinervtisy, it deosn't mttaer in waht oredr the ltteers in a wrod are, the olny iprmoetnt tihng is taht

> the frist and lsat ltteer be at the rghit pclae. The rset can be a toatl mses and you can sitll raed it wouthit porbelm. Tihs is bcuseae the huamn mnid deos not raed ervey lteter by istlef, but the wrod as a wlohe.

The words in this paragraph have the characteristic that their first and last letters are correct, but all the letters in their interiors are garbled. This passage is easily read even though there are some significant misspellings. Clearly our minds are doing some pretty significant gymnastics to decode this passage.

Once readers mature, there is no difference in the speed of their reading regardless of the type of writing system they learn. Hence, the advantage of a phonetic system is that it is learned more quickly.

Let's now consider the evolution of music notation and its effects. In the 8th century, European composers began to work through their creations on paper. The music historian Richard Taruskin writes about the importance of this change:

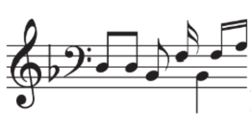
> Something over a thousand years ago music in the West stopped being (with negligible exceptions) an exclusively oral tradition and became a partly literate one. This was, from our perspective, an enormously important change. . . . The development of music literacy also made possible all kinds of new ideas about music. Music became visual as well as aural. It could occupy space as well as time. All of this had a decisive impact on the styles and forms music would later assume. It would be hard for us to imagine a greater watershed in musical development.[17]

[17] Richard Taruskin. *Music from the Earliest Notations to the Sixteenth Century*. Vol. 1. The Oxford History of Western Music. Oxford: Oxford University Press, 2005, p. 1.

Taruskin suggests that using exographics to represent music "made possible all kinds of new ideas." How so?

Certainly, written music has become more complex since the 10th century. A snippet of exographics for an early Gregorian chant is shown in Figure 8.3. The stenographic marks above the words (called neumes) indicate how the lyrics are to be sung.

Contrast that with the notation of modern music as shown in Figure 8.4. This modern notation allows composers to construct polyphony (multiple melodies), a step up from the monophony (one melody) of Gregorian chant.

To understand polyphony, we first need to understand the general structure of staff notation. Here is a short snippet of modern music:

The notes and other symbols are drawn on a set of 5 horizontal parallel lines and the 4 spaces between these lines. The set of lines and spaces is termed the staff or stave. This notation captures several dimensions of the music. There is a vertical dimension: notes placed

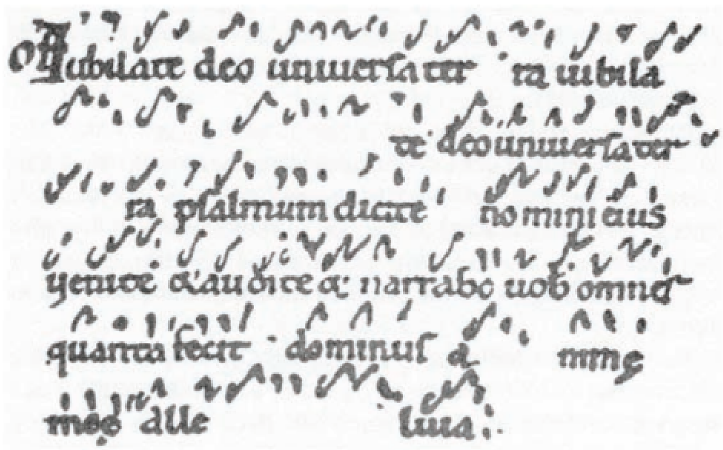


Figure 8.3: The exographics for an early Gregorian chant. Public domain image via Wikimedia Commons.

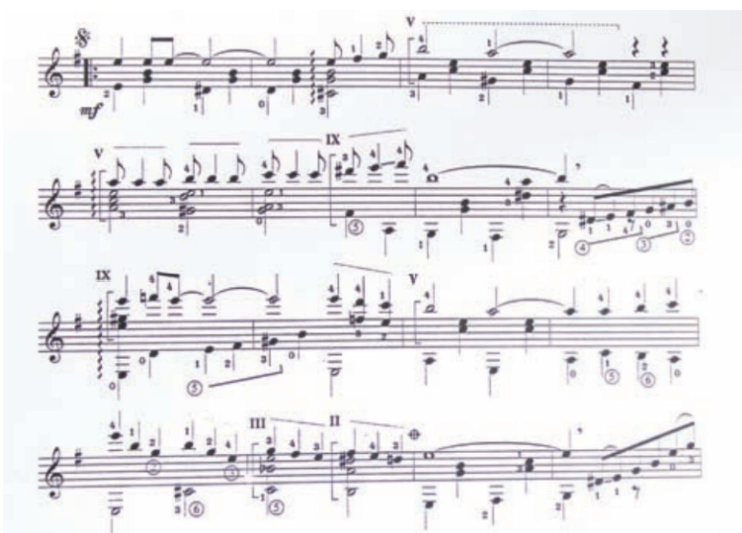



Figure 8.4: An example of modern staff notation.

higher on the staff have higher tones or pitches. The second dimension is horizontal, and it specifies the order in which the notes are to be played over time. A third dimension is the shape of the notes, which indicates how long the notes should be held. Effectively, we have a three-dimensional reality (pitch, time, and melody) captured with two-dimensional exographics. That's clever and a significant e-Class advance.

A much loved classical piece is Johann Pachebel's *Canon in D Major*. In Figure 8.5, we've shown a few bars of its oldest surviving manuscript. There are three violin parts and a *basso continuo* part normally played by a cello. The first four lines of staff notation in the diagram are played simultaneously. Each is a different melody and the blending of these four parts into a whole constitutes the resulting polyphonic music.

Here you can see the value of exographics. It would have been impossible for Pachebel to put this together sitting at a keyboard without paper and a quill pen. At the time, staff notation on paper was the primary technic available to composers and looking at the overall complexity of the composition, he could not possibly have done this without exographics to record it as he went.

In contrast, jazz composers have little need for pen and paper as they rely on a lot of improvisation. When Miles Davis went into the studio to make *Kind of Blue*, he only had a rough outline of what he wanted to do. This appears in live performances of, for example, *So What*, the signature song on the album. You never hear the same improvised melody twice, but the accompaniment is always the same.

TECHNICS WHICH EXTEND our vision (eyeglasses, telescopes, microscopes) have been extraordinarily useful to us to expand what we can observe. We are now extending this important cognitive skill using exographics. To see this, consider the picture in Figure 8.6. It's of the center of our galaxy, the Milky Way, about 25,000 light-years away. If we were to go to the center of the Milky Way and travel from the left edge of this picture to the right edge at the speed of light, it would take about 1,000 years. To put this in perspective, if you were traveling at the speed of light, you could go around the Earth 7.5 times in one second. The volume of real space this picture covers is incomprehensibly large. As for what's in it, one of the researchers who helped produce the picture, Ian Heywood, described it this way:

> The complex, cirrus-like emission from the Galactic center super bubble dominates this image. This is traversed by the Radio Arc, a complex of many parallel radio filaments. The radio bubble nestles against the diffuse Sagittarius A region in the lower centre of the image. The

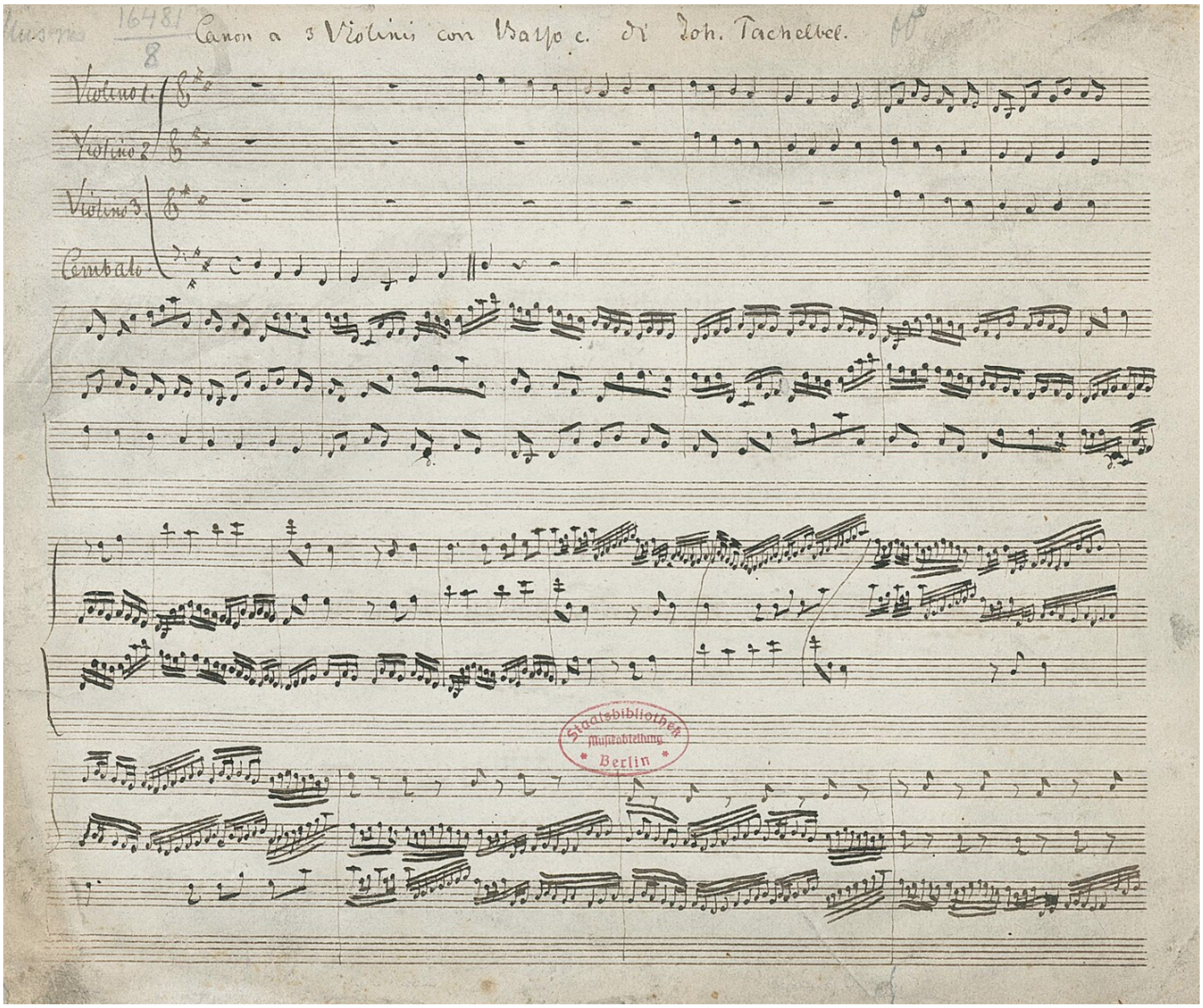


Figure 8.5: A few bars from the oldest manuscript of Johann Pachebel's *Canon in D Major*. Public domain via Wikimedia Commons.

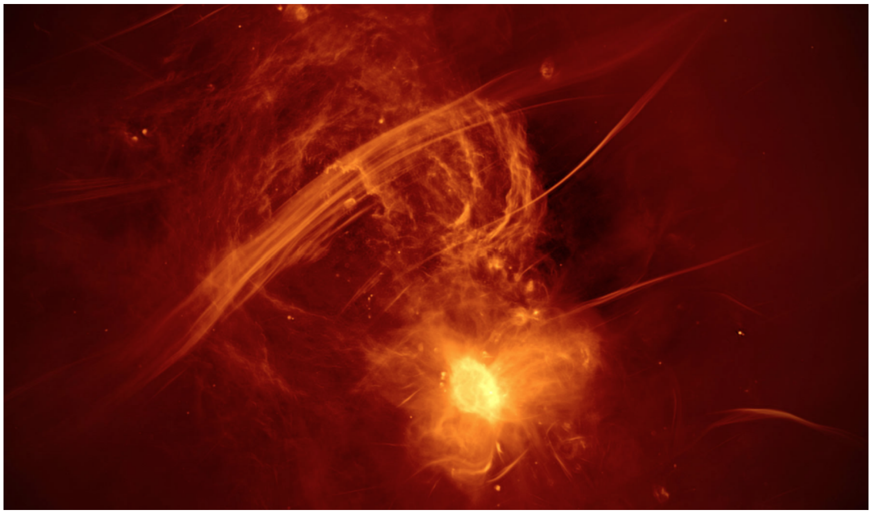


Figure 8.6: A picture of the black hole at the center of the Milky Way galaxy. Photo © Dr Ian Haywood. Used with permission.

> bright dot near the centre of this region is Sagittarius A*, a 4 million solar mass black hole. This image captures the chaotic complexity of the very heart of our Galaxy.[18]

Most galaxies have a black hole at their centers and these tend to be quite large. In the case of the Milky Way, it's 4 million times larger than our Sun. What you see in this picture are galactic events that occurred 25,000 years ago. In effect this is archaeological light. It's 25,000-year-old light captured by the MeerKAT radio telescope. What is happening at the center of the galaxy at this moment won't be known for 25,000 years.

The MeerKAT radio telescope, located in South Africa and completed in 2017, is currently the most advanced radio telescope of its kind in the world and comprises 64 linked receptors spread over a circular area of diameter 8 kms. A receptor is shown in Figure 8.7. Each of these, with its dish and housing, is about 20 meters tall and weighs 42 tons. When in operation, receptors receive cosmic radiation which is then converted to a numerical data signal and forwarded to a main hub for further processing and storage. The data from this receptor array is then analyzed to produce pictures like the one shown above. For that single picture, 200 hours of telescope time were used to collect 70 terabytes of data. To give you an idea of how much data that is, a single book (60,000 words) is about a megabyte. So, 70 terabytes would be 70 million books. If you could read one of these books in an hour and never sleep, it would take you just under 8,000 years to read all of them. Seventy terabytes is a lot of data!

More importantly, it's clearly impossible to survey the raw numerical data as it sits to get some idea of what you're seeing. What's

Figure 8.7: A MeerKAT receptor. Photo by Morgan Shell, CC BY-SA 4.0 via Wikimedia Commons.

[18] Dr. Ian Heywood, taken from the press release at https://www.sarao.ac.za/media-releases/new-meerkat-radio-image reveals-complex-heart-of-the-milky-way/?fbclid=IwAR1I$_aL4j-5b5a6pna1Bq5iJTJK-e-DeO4uYT49_EBGEyG2hiGYOsdgtQ8k$.

required is an algorithm and two supercomputers to transform the raw exographic data into the picture above (another exographic). The picture is meaningful. It tells us a little more about ourselves and our place in the universe. But to get it is no small feat. It requires that you throw $330 million at thousands of qualified imaginations.

TO SUMMARIZE THE CHAPTER, our efforts to discover and improve cultural objects also apply to exographics. One of the reasons we substituted the Hindu-Arabic number system for the Roman system was that it took less cognitive effort to use. The phonetic reading systems of the ancient Phoenicians and Greeks were easier to learn than logographic systems, and they survive in various forms to this day. English, the *lingua franca* of the world, is a phonetic system and much easier to learn than Chinese, a largely logographic system. We discovered polyphony in music soon after enhancing the exographic system with staff notation.

All in, the symbolic systems of representation evolve and are subject to the same cultural forces that improve any cultural object.

Part II

The Rise of Techno-Literate Culture

9
The Globalization of Ideas

The internet has revolutionized globalization by connecting people from different corners of the world, enabling the exchange of ideas and knowledge.
Sir Tim Berners-Lee

A depiction of a group of hunter-gatherers on the move is shown in Figure 9.1. Notice the group's material engagement (weapons, tailored clothing, carrying devices). Throughout our history, man has continually searched for artifacts and tools to make survival more likely and life more livable. No doubt, the culture depicted here passed from generation to generation with social learning. For example, once a generation learns how to tailor clothing, the technique does not have to be reinvented by subsequent generations.

Figure 9.1: A depiction of early hunter-gatherers. Image generated by OpenAI's DALL·E.

In Figure 9.2, we've shown a small section of the Large Hadron Collider, the machine built to study subatomic particles by looking at what happens when two beams of protons traveling in opposite directions at very high speed smash into each other. The machine is basically a 27 km ring (torus) constructed in a tunnel about 23 meters below ground. It took a decade and $7 billion to build. To appreciate the size of the machine, look at the two men in the center of this picture. The machine comprises millions of parts, including kilometers of wire, and was extraordinarily complex to design and build. As with the contents of the picture of the hunter-gatherers, it is a testament to man's willingness to embrace the material world. Furthermore, it says a lot about us that we would build this monstrously complex and expensive machine just to explore the subatomic nature of matter.

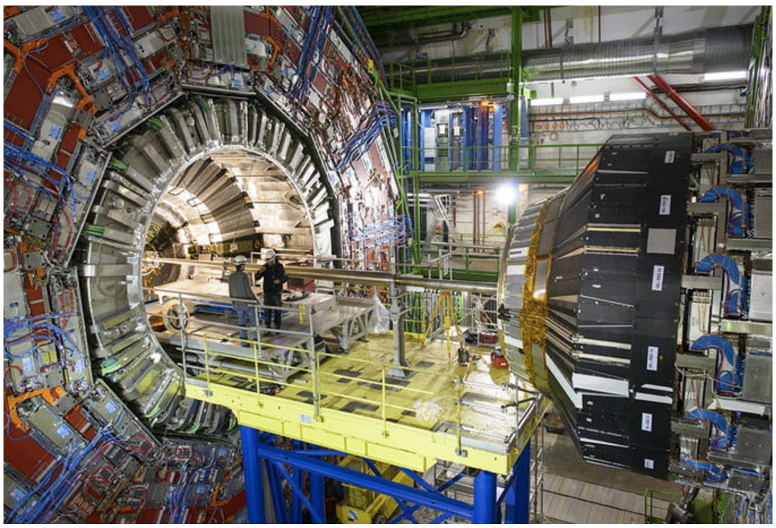


Figure 9.2: A section of the center of the Large Hadron Collider. (Image courtesy of CERN, CC BY 4.0)

It is these two pictures we wish to reconcile in the second half of the book. The archaeological evidence suggests that we lived as hunter-gatherers for hundreds of thousands of years prior to the Agricultural Revolution. How did our species go from the hunter-gatherer world of spears and animal-skin clothing to our modern material cultures that include such technologies as the Large Hadron Collider *in just 10,000 years*?

We'll argue that the reason is our relentlessly curious imaginations, aided by exographics and other technics. These imaginations, networked across space and time, gave rise to techno-literate culture, a culture deeply embedded in literacy and measurement.

FOR SOCIETIES in the developed world, "literacy is the water we swim in." Most attribute this analogy to David Foster Wallace in his 2005 commencement address at Kenyon College:

> There are these two young fish swimming along, and they happen to meet an older fish swimming the other way, who nods at them and

> says, "Morning, boys. How's the water?" And the two young fish swim on for a bit, and then eventually one of them looks over at the other and goes, "What the hell is water?"

Foster Wallace may have been familiar with this observation usually attributed to Marshall McLuhan:

> We don't know who discovered water, but it wasn't a fish.

McLuhan was interested in the effects of media, so his comment emphasizes the notion that pervasive, ubiquitous elements of our environment, such as exographics, often go unexamined because they are so integral to our daily lives.

To see that we are immersed in literacy, consider the following sketch. A quick glance at a watch or clock tells us whether we are likely to arrive at a meeting on time or whether there is enough time for our team to score the winning touchdown. Or, at an airport, we make our way to the correct gate by observing the large numbered signs overhead; our boarding pass for the aircraft specifies our row (a number) and seat (a letter). Road signs and maps help us get to our destinations. Or we might have to press the number 7 in an elevator to make sure we get to the 7th floor of the hospital. And once we are on the 7th floor, we can read the signs on the doors and in the hallways to navigate to the right place. Or take the simple signs "pull" and "push" on most glass doors that tell us what to do once we grip the horizontal door handle. Or what about all the occasions when you've had to print your name and other biographical information on the forms you've filled out. Even our cars have identifiers like the model type, license plate, and serial number. Most professional athletes have a number for identification purposes when they are playing. Everyone knows who 99 is. Or when we go to the grocery store, we sometimes want to check the receipt to make sure that we got what we paid for and were charged the sale price instead of the full price. Or what about the directions on how to use a parking pass dispenser? Or we might have to follow the directions of a recipe to cook a nice meal. And we certainly need to be able to read labels to make sure we get the right bottle of wine. Or what about the bank of user-names and passwords we use to get into our computer apps. For that matter, what about navigating something like a smartphone or tablet? Or what about the labels we put on Christmas and birthday gifts. Or what about reading and recording the digital output of devices that measure important health indicators like pulse and blood pressure. The list seems endless.

More generally, exographics is used extensively in our professions and institutions. Doctors rely heavily on exographics in their work including: taking patient histories, writing letters and notes to other doctors, writing prescriptions, reading machine and device output, studying journals, and reading notes from other doctors. They keep a written file, sometimes large, on each patient. The same is true for lawyers and the justice system. Large corporations and governments keep extensive written records. The economy generates an extraordinary paper trail (think of the receipts you get after just about every transaction you make). Educational institutions rely heavily on exographics. Many of us get the news of the day from various sources in the print media. The Internet now contains an extraordinarily large quantity of exographics.

The point is that exographics is endemic in our modern techno-literate lives. Most of the world—by some estimates 85%—is now literate. Indeed, exographics is the water we swim in.

HAND-IN-HAND WITH LITERACY, measurement is also ubiquitous.

What don't we measure? There's the economy (prices, quantities, GDP, income, inequality, tax, sales, costs, demand, supply ... the list is huge). There's science (time, distance, speed, acceleration, density, volume, and again the list is just about limitless). There's engineering (engineers measure everything ... their list might be the largest). There's sport (scores, heights, weights, goals, assists, touchdown passes, interceptions, times of possession, ERAs, batting averages, and so on). There's medicine (temperature, blood pressure, heart rhythm, concentrations of compounds in the blood, risk of a heart attack and stroke, life expectancy, body-mass index). There's politics (number of votes, demographic measures, poll results, and so on). There's war (number of casualties, number of troops available, number of tanks, fighter aircraft, warheads, submarines, etc.). Measurement even extends to the arts: it's used extensively in music; the structure of a poem is sometimes measured; some sculptors and artists measure; and architectural design—at the nexus of the arts, science, and engineering—depends heavily on measurement.

Performing a single measurement sometimes requires a significant effort. Canada's Gross Domestic Product (GDP) was US $2.14 trillion in 2022. This is an important number because it's a measure, albeit imperfect, of how well the Canadian economy did in 2022. To make it, Statistics Canada conducts thousands of surveys of Canadian businesses, government departments, and households. One such survey is the Annual Survey of Manufacturing Industries which is administered to a sample of hundreds of manufacturing firms selected from the Statistics Canada Business Register. Each of these companies receives a 31-page questionnaire designed to extract the financial data that Statistics Canada requires. But this is just one sector of companies. There are many other sectors. Once Statistics Canada is in possession of all survey responses from all sectors, the data are checked and then aggregated across sectors to produce the estimate of GDP. That's a lot of effort to produce a single measurement, one that is impossible without exographics.

We've given a sketch of the importance of literacy and measurement to the cultures of the developed world. Now let's give something similar for the globalization of ideas. Here, we'll interpret globalization as the increased sharing of ideas worldwide. This phenomenon of the spread of ideas is driven by advances in technology, trade, communication, and transportation, which make it easier for people, goods, services, information, and, most especially, ideas to move across borders.

Consider the picture of US President Joseph Biden and Chairman Xi Jinping of China in Figure 9.3. They are both wearing a blue suit, which seems to be the preferred uniform of male leaders worldwide.

Figure 9.3: President Joseph Biden and Chairman Xi Jinping. Public domain image via the White House.

Figure 9.4 contains a picture of two great hockey players, Wayne Gretzky of Canada and Igor Larionov of Russia. Hockey was invented in Canada. It's now spread to a large number of countries including fledgling programs in China, Japan, the UAE, Australia, India, Mexico, and South Africa. Currently, 83 countries belong to the International Ice Hockey Federation.

Figure 9.4: Wayne Gretzky and Igor Larionov

A picture of a hamburger as served in a Moscow bar is shown in Figure 9.5. The hamburg patty, essentially chopped steak, first appeared in Hamburg, Germany in the 19th century and was brought to the US by German immigrants. Around the turn of the 20th century, the patty was placed between two pieces of bread and became the sandwich we know today. Hamburgers are eaten across the developed world.

Figure 9.5: A hamburg as served in Garage Bar Anton in Moscow.

Figure 9.6 is a picture of Anna Tikhomirova of the Bolshoi Ballet performing in Delhi, India. Ballet had its beginnings in Italy during the Renaissance and is now performed in almost every country of the developed world.

Universities have been in existence for centuries, and in the West, since the 12th century.[1] Today, there are roughly 40,000 universities worldwide. They are modern knowledge factories and crucial to the advance of the e-Class.

[1] The University of Constantinople, established in 425 CE, is generally regarded to be the first university.

There is plenty of evidence that the Sumerians consumed a lot of beer. It was a staple of laborers for a number of reasons. Most importantly it was safer than water to drink. The Hymn to Ninkasi (approximately 1800 BCE) is the earliest known written recipe for beer. Ninkasi was the Sumerian goddess of beer and brewing, and the hymn serves both as a prayer and as an instructional guide for brewing beer. Recently, scholars have argued that beer had a signif-

Figure 9.6: Anny Tikhomirova performing with the Bolshoi Ballet in Delhi, India. Photo by Ramesh Lalwani, CC Attribution 2.0 Generic.

icant role in launching the Agricultural Revolution.[2] About 13,000 years ago, the Natufian cultures appear to have carved out limestone mortars in Raqefet Cave (Israel) and other locations.[3] These mortars contained microscopic traces of a beer-like substance made from wild grains and cereals. Hayden et al. argue that feasting was a part of these early cultures and such celebrations included alcoholic beverages like beer:

> Given all these characteristics, initial grain cultivation does not make sense as an adaptation to meet basic subsistence needs; however, it *does* make good sense as a strategy to produce some valued foods (beer, bread, and gruels) as a surplus supplement for special events. In poor years, only the feasting would be foregone. In good years, hosts with surpluses for feasts could benefit handsomely.[4]

Hence, beer has a deep history. It's now consumed in over 180 countries and it's the most popular alcoholic beverage.

Stop into a coffee shop anywhere on the globe and you will see the majority of patrons glued to their smartphones. It's been estimated that, by 2025, 89% of the world's population will use a smartphone. Design and production of these devices is global in nature. By some estimates, Apple's supply chain draws from over 40 countries world wide. Originally invented in North America (Blackberry and Apple), the smartphone is now a global phenomenon, one that requires a substantial global network infrastructure to operate. There are estimates that mobile network operators have averaged a total infrastructure investment of $110 billion in each of the last 5 years.

A picture of a modern Inuit hunter is shown in Figure 9.7. Note the snowmobile rather than a sled and dogs, the non-traditional clothing, and the rifle, a 19th century addition that came from contact with European explorers. The rifle replaced the traditional weapons of bows, arrows, harpoons, and spears.

[2] Brian Hayden, Neil Canuel, and Jennifer Shanse. "What Was Brewing in the Natufian? An Archaeological Assessment of Brewing Technology in the Epipaleolithic". *Journal of Archaeological Method and Theory* 10, no. 1 (2013): 102–150.

[3] The Natufians were semi-sedentary peoples who inhabited the Levant (largely modern Israel, Jordan, Lebanon, Palestine, and Syria) over the period 12500-9500 BCE. There is evidence that they deliberately cultivated rye, one of the first evidences of farming.

[4] Ibid., p. 141.

Figure 9.7: A modern Inuit hunter. (Photograph by Dr John Tyman. Copyright held by the photographer; reproduced here with his kind permission.)

A picture of an F1 motorcar is shown in Figure 9.8. The first motorcar, a three-wheeler and steam-powered, was built and driven by Nicolas-Joseph Cugnot in 1769. The F1 car pictured was being driven by Red Bull's Max Verstappen, the winner of the Formula 1 Championship in 2024. The car is valued at over $20 million and is capable of a top-end speed of 370 kms/hr. Verstappen's salary in 2024 was $65 million, about 5 times what Connor McDavid makes for playing in the National Hockey League.[5] Worldwide F1 revenues in 2024 were $3.6 billion. F1 races are run in 21 countries and the drivers come from 15 different countries. F1 is now a global enterprise that transcends borders. It runs on ideas that require exographics to work out, particularly the aerodynamics of the cars to maximize down forces.

[5] McDavid is generally considered to be the best hockey player in the world today.

What these pictures and descriptions make clear is that the world shares ideas. A cultural object invented in one society soon makes its way to other cultures. Trading has a long history. The first trading routes were along the Silk Road, which eventually linked East and West. Chinese silk made its way to the West beginning about 2000 BCE. In 2022, the World Trade Organization estimated the total value of trade in goods and services to be US $32 trillion, which is about a five times what it was in 2000. Global trade is not slowing down, and neither is the diffusion of ideas.

Let's come back to the thesis of the book. In Part I, we argued that our networked imaginations enabled by exographics were at the heart of our cultural advance. What remains is to trace the rise of

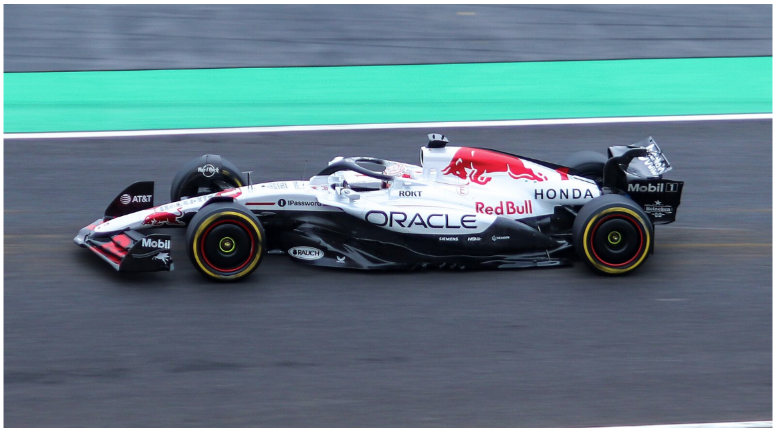


Figure 9.8: The Red Bull RB21 F1 motorcar driven by Max Verstappen in the 2025 Japan Grand Prix. Photo by Morio, CC BY-SA 4.0.

techno-literate culture beginning with the ancient Sumerians. We'll sketch the transmission of the Sumerian culture to ancient Greece and Rome, then to the East and Western Europe, and then to the rest of the developed world including the US. Over the course of this transmission, the evidence will show that the e-Class expanded at every turn ultimately giving rise to the lifeways and made world of the techno-literate cultures we observe today.

10

The River Civilizations and Their e-Class Forays

What's past is prologue.
Shakespeare, from *The Tempest*

In this chapter, we'll look at the five societies where exographics was independently invented: Mesopotamia, Egypt, Mesoamerica (the Maya), the Indus (the Harappan cities), and China. We'll also look at a significant ancient civilization—the Trypillia Megasites—that did not develop a writing system despite large fixed settlements with significant populations. For those civilizations that developed an exographic system, it's certainly possible to discover e-Class ideas. There is no guarantee this will happen, but we'd not be surprised to see it. As we'll document, the evidence shows that these civilizations made significant e-Class contributions, particularly in mathematics.

Sumer/Mesopotamia

The Sumerian culture flourished in Mesopotamia (Mesopotamia means "the land between the rivers") from roughly 4100 BCE to 2000 BCE. When their influence waned, other civilizations came to the fore at various times including the Akkadians, Assyrians, and Babylonians. The following discussion of mathematics covers the collective set of advances made by all of these cultures. Hence we'll generally use the adjective "Mesopotamian" unless there is a good reason not to.

One of the major contributions of Mesopotamian mathematics is the positional number system. Our modern system is a base-10 positional number system. For example, our number 423 is

$$423 = 4 \times 10^2 + 2 \times 10^1 + 3 \times 10^0.$$

It has the characteristic that the value of a digit will depend on its position in the sequence of digits making up the number. A place-holder system has two advantages. First, it gives users the flexibility to produce as large a number as required and this was important as the economic activity of the Mesopotamian city-states grew. And second, it's easy to do arithmetic with a place-holder system.

The Sumerians eventually devised a one-size-fits-all base-60 system sometime toward the end of the third millennium.[1] Before that, there were a number of placeholder systems in use depending on what commodity was being measured.[2]

[1] Eleanor Robson. "The Uses of Mathematics in Ancient Iraq, 6000–600 BC". In *Mathematics Across Cultures: The History of Non-Western Mathematics*, ed. by Helaine Selin, 93–113. Dordrecht: Kluwer Academic Publishers, 2000.

[2] Hans Nissen, Peter Damerow, and Robert Englund. *Archaic Bookkeeping: Early Writing and Techniques of Economic Administration in the Ancient Near East*. Trans. by P Larson. Chicago: University of Chicago Press, 1993.

One number these early Mesopotamian systems did not have was 0. This leads to some difficulty because it's hard to distinguish, say, 308 and 38.

The Mesopotamians were able to do all four arithmetic operations in sophisticated ways. In our system, to get, say, 13×29, we'd use the standard multiplication algorithm we learned in school. But to use it, we'd have to know the simpler products such as 3×2 and 3×9. The Mesopotamians computed products using a table of squares. They took advantage of the fact that

$$(a+b)^2 = a^2 + b^2 + 2ab$$

to obtain the product ab:

$$ab = [(a+b)^2 - a^2 - b^2]/2.$$

For example, to get 13×29, they would look up the squares of 41, 13, and 29 and then use the formula above to get the answer:

$$13 \times 29 = [(13+29)^2 - 13^2 - 29^2]/2 = 377.$$

In addition to whole numbers, they knew fractions and could do fractional arithmetic.

They were also able to use a crude form of algebra to solve problems like this: "The product of two numbers is 60 and their difference is 7. What are the numbers?" Using modern mathematics, the two numbers can be found by solving a quadratic equation. The cuneiform tablet that presents the problem also provides its solution. There are no equations in the solution, but rather a sequence of arithmetic calculations that demonstrate the Mesopotamians knew how to solve general quadratics.

The Mesopotamians were able to calculate the exact areas of basic geometric shapes, including rectangles, right triangles, and trapezoids. They approximated the area of a circle and could calculate the approximate areas and volumes of irregular shapes.

Pythagorean triplets are integer values of a, b, and c which satisfy $a^2 + b^2 = c^2$. An example is $a = 3$, $b = 4$, and $c = 5$. Some historians have attributed their discovery to the ancient Greek philosopher Pythagoras. However, one of the most famous Mesopotamian artifacts, the tablet Plimpton 322, suggests the Mesopotamians knew about them as early as 1800 BCE, long before the time of Pythagoras.[3]

[3] Eleanor Robson. "Words and Pictures: New Light on Plimpton 322". *The American Mathematical Monthly* 109, no. 2 (2002): 105–120.

Hence, with exographics, the Mesopotamian civilizations were able to make significant inroads in mathematics beyond arithmetic, a set of ideas squarely in the e-Class. Of interest is where they applied their mathematics.

As we have already remarked, the vast preponderance of Mesopotamian tablets deals with the ongoing administration of their societies. They certainly demonstrate the willingness of these peoples to measure just about everything. The early temple complexes in Uruk and Susa were at the heart of developing urban centers. With close management, temple administrators were able to generate substantial wealth and power for their princes and priests.[4]

[4] Nissen et al., *Archaic Bookkeeping*, 1993, Chapter 14

Land management was crucial to the success of these societies. They needed to be able to survey field sizes so they could forecast harvest amounts. The fields were usually long rectangles with the short side bordering an irrigation canal. Sometimes they were irregular shapes and the area would have to be approximated. Their knowledge of geometry and area measurement for regular shapes helped them make these approximations. Agricultural labor was closely scrutinized including harvest activities (reaping and threshing), field preparation (plowing and harrowing), and maintenance (hoeing and weeding). Estimates of the required annual labor would be made, and, at year end, these would be compared to the actual resource expended, a cost accounting practice that is called variance analysis today. Construction labor was managed in the same way. Interestingly, these cultures were the first to plan construction with architectural diagrams drawn to scale. Estimates of the bricks required were based on volume calculations. All of this constitutes a significant e-Class advance.

We have already described Sumerian literature. As the Homeric epics make clear, exographics is not required to compose long stories. But exographics makes it much easier and this is why we see an explosion of literature in ancient Sumer once they arrived at cuneiform writing.

FROM THE BEGINNINGS of the Agricultural Revolution, we began to live in increasingly larger groups. To do that, we had to invent and refine institutions that helped to maintain some sort of social order. One is a justice system.

Figure 10.1: The stele housing the Code of Hammurabi at the Louvre. Photo by Mbzt, CC BY 3.0 via Wikimedia Commons.

Hammurabi ruled Babylonia from 1792 to 1750 BCE, and under his reign, was able to bring most of Mesopotamia under his control. About thirty years into his rule, he decided to write a set of rules to govern individual behavior. The *Code of Hammurabi* was originally etched into a four-ton piece of diorite (called a stele) that stands 2.4 meters tall. A picture of it is shown in Figure 10.1.

Item 142 of the Code deals with family law:

> If a woman decides she does not like her husband anymore, she must give her reasons. If she is not at fault, but he leaves and neglects her, he shall give her back the dowry. Then she can go back to her father's house.

Item 22 concerns criminal behavior:

> If a man is a brigand (member of a gang of robbers) and attacks people who are traveling, he shall be put to death.

Item 2 is an interesting law that requires trial by ordeal:

> If a man accuses a man of sorcery and cannot prove it, the accused shall go to the river and shall throw himself in. If he drowns, he is a sorcerer, and his accuser shall take his house and property. If he is unharmed, the accuser shall be charged with sorcery and be put to death. The innocent man shall also take the house and property of his accuser.

The reasoning for this law is based on the Babylonian belief in the gods and their divine will. If the accused survived the ordeal, then it was surely the case that the gods were looking out for an innocent man.

Items 196 and 197 are "eye for an eye" laws:

> If a man destroys the eye of another man, his eye shall be destroyed. If one man breaks another man's bone, they shall break his bone.

Item 229 deals with professional practice in construction:

> If a builder builds a house and it collapses and kills the owner, the builder shall be put to death.

Aggrieved parties could ask for a trial. Evidence would be presented, the judge would determine the facts and then make a decision, usually in exographics.

The idea of justice, codes of law, and their interpretation by court systems, are all e-Class ideas. Due to the complexity of these societies, it's difficult to see how a system of justice could run purely in an oral mode.

BABYLONIAN SCIENCE MADE CONTRIBUTIONS in a number of areas. One was astronomy. To understand how they thought about astronomy, the Babylonian belief in the influence of the gods must be taken into account. Samuel Kramer wrote this about Sumerian beliefs:

> Operating, directing, and supervising this universe, the Sumerian theologian assumed, was a pantheon consisting of a group of living beings, manlike in form but superhuman and immortal, who, though invisible to the mortal eye, guided and controlled the cosmos in accordance with well-laid plans and duly prescribed laws. The great realms

> of heaven, earth, sea, and air; the major astral bodies, sun, moon, and planets; such atmospheric forces as wind, storm, and tempest; and finally, on earth, such natural entities as river, mountain, and plain, such cultural entities as city and state, dike and ditch, field and farm, and even such implements as the pickax, brick mold, and plow—each was deemed to be under the charge of one or another anthropomorphic, but superhuman, being who guided its activities in accordance with established rules and regulations.[5]

Kramer called this paragraph "axiomatic."

With the gods controlling the movement of celestial bodies, a natural thing to do would be to look for celestial omens. Otto Neugebauer reports a series of texts called *Enuma Anu Enlil*.[6] It consisted of 70 tablets and about 7,000 omens. Neugebauer has estimated that this text developed over a number of centuries and reached its final form about 1000 BCE.

Neugebauer reports that the formative stages of Babylonian astronomy occurred over the period 1800 to 400 BCE. After 400 BCE, its study really picked up speed. They mapped the heavens, plotted the movements of the Sun, Moon, and planets, predicted celestial events like eclipses, and formulated a 12-month calendar based on these celestial movements. Many of our numerical measures of time are based on their base 60 measures (60 minutes in an hour, 60 seconds in a minute).

Interestingly, Neugebauer thought that our understanding of Babylonian astronomy was still in its infancy. He felt there were more tablets on the topic and that these needed to be studied by mathematicians. Recently, a British Museum tablet from has been translated which suggests that the Babylonians were getting Jupiter's position from the area under a time-velocity graph, a step very close to the calculus.[7] It's a sophisticated development that could't have been done without exographics and measurement.

Regarding medicine, there are tablets that listed diagnoses, argued the importance of taking a patient's medical history, recommended medicines to deal with illnesses, and explained surgical techniques including how to set broken bones. In preparation for surgery, doctors would wash their hands.

Sumerian metallurgy was well developed by the end of the 4th millennium. They were able to extract basic metals from ore through smelting. They used the copper-rich mineral malachite to extract copper. The malachite was first crushed into smaller pieces, usually with a stone hammer and anvil, and then heated to over a 1,000 degrees Centigrade in furnaces made of clay. With the help of charcoal and bellows (usually animal hide over a wooden frame), they were able to generate sufficiently hot fires. Eventually, the copper would melt and go to the bottom of a stone melting pot. Then the impu-

[5] Samuel Noah Kramer. *The Sumerians: Their History, Culture, and Character*. Chicago: University of Chicago Press, 1963, p. 113.

[6] Otto Neugebauer. *The Exact Sciences in Antiquity*. New York: Dover Publications, 1969.

[7] Mathieu Ossendrijner. "Ancient Babylonian Astronomers Calculated Jupiter's Position from the Area under a Time-Velocity Graph". *Science* 351, no. 6272 (2016): 482–484.

rities would be skimmed off the top with stone ladles using tongs. The relatively pure copper would then be poured into ingot molds and stored for later use. Copper was used to make weapons, farming tools, and other tools like axes and hammers. Eventually they made bronze by mixing copper (90%) and tin (10%). Relative to copper, bronze is harder and holds an edge better, making it superior for tools, weapons, and agricultural implements.

Exographics played a key role in metalworking administration and production. For example, scribes documented detailed recipes and techniques for making and using bronze. They also recorded ratios, weights, and temperatures (using the change in material color as it heated) to ensure consistency in metal production. Masters tracked materials such as ores, charcoal, and finished goods, preventing theft and ensuring supply control. Supervisors used tablets to delegate tasks and record progress. Often, contracts were recorded with exographics. Metalworkers, like other tradespeople, owed a portion of their production to palaces and temples, and these obligations were recorded. Archaeologists have found cuneiform tablets listing metal quantities in workshops, such as: "5 talents of copper received from Dilmun; 2 talents used for making tools; remainder stored in the temple treasury."

There is a famous Babylonian document called the *Kikkuli Text* that explains how to train horses for use in war. Dating to about 1300 BCE, it's a total of 1,080 lines on four tablets written in Hittite cuneiform. It begins "Thus [speaks] Kikkuli, the horse trainer from the land Mittani." The document is a detailed training program that runs over 184 days. Instructions are given on a horse's diet, its training program (an interval training program of running and cantering) and special treatments in the stables (massages and blankets). Each day is mapped from morning to night. Interestingly, Dr Ann Nyland trained some Arabian horses over a seven-month period between 1991 and 1992 following exactly the regime Kikkuli prescribed. She found that his methods were, in certain respects, superior to modern methods. Here is a case where exographics is used to pass on a complex process to others. The text is silent on how Kikkuli arrived at his program. It might have been that he did careful experiments to arrive at this method. This would have required him to track with exographics exactly what he did with each set of horses to determine what was best.

Egypt

About 5,000 years ago, the geographic conditions along the Nile were remarkably similar to those in Mesopotamia. Not surprisingly, we observe the same sort of fixed settlements based primarily on agriculture. However, one of the difficulties with research on ancient Egypt is that the archaeological record is not nearly as detailed as it is for Mesopotamia. In Mesopotamia, a large number of clay-fired tablets have survived, whereas the ancient Egyptians wrote with ink on papyrus, a form of paper made from the stem of the papyrus plant. Unfortunately, papyrus inscribed with text needs to stay dry to keep. With the regular flooding along the Nile, many papyrus documents have likely been lost forever.

The earliest evidence of exographics appears about 3250 BCE.[8] These are inscriptions found in tombs at Umm el-Qa'ab/Abydos and at Saqqara and tend to be of an administrative nature. Full sentences do not appear until 2690 BCE, about 5 centuries later. What is clear is that the initial exographics did not represent spoken language. This is remarkably similar to the story in Mesopotamia where the early exographics in Uruk was proto-cuneiform of an administrative nature.

[8] Ilona Regulski. "The Origins and Early Development of Writing in Egypt". In *The Oxford Handbook of Topics in Archaeology*. Oxford Academic, Oct. 2015.

Some scholars have argued that Mesopotamian exographics diffused to Egypt. However, the current thinking is that, at best, the Egyptians may have been influenced by the idea and then went ahead and created their own system.

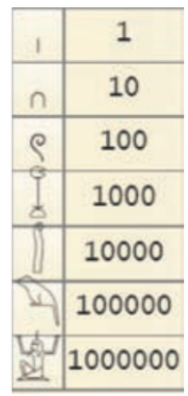


Figure 10.2: Egyptian number representations.

Regarding numbers, they used a symbol for each power of 10 as shown in Figure 10.2. That is, 1 is simply a vertical line, 10 is the sign $\cap$, 100 is a coiled rope, and so on. The Egyptian number for 465 is:

Note that, from right to left, we have the five 1s, then six 10s, and finally four 100s. Their number for 280 is:

Starting on the right, it's eight 10s and then two 100s.

This system is clearly not a placeholder system. In fact it's a lot like Roman numerals, a nonpositional additive system. Nevertheless, it's easy to represent numbers and do the four arithmetic operations. But relative to a placeholder system, it's symbol intense.

Two of the more famous sources of Egyptian mathematics are the Rhind Papyrus (about 1650 BCE) and the Moscow (Golenishchev) Papyrus (about 1700 BCE). Each lists a set of problems. Here is an example from the Rhind:

Problem 24. Find the heep if the heep and a seventh of the heep is 19.

The Rhind Papyrus gives solutions with a sequence of arithmetic calculations, but the underlying reasoning is not given. It could be that scribes taught their students these general solutions but they're not mentioned on the Rhind itself.

In the Moscow Papyrus, one of the problems is to get the volume of a frustum (a pyramid with the top cut off; the cut is parallel to the floor of the pyramid).

The Egyptians could also do fractions and fractional arithmetic. Here is a problem, again from the Rhind Papyrus:

> *Problem 31.* A quantity, 2/3 of it, 1/2 of it, and 1/7 of it added together are 33. What is the quantity?

The scribe writes an extensive solution procedure, eventually giving this solution:

$$14 + 1/4 + 1/56 + 1/97 + 1/194 + 1/388 + 1/679 + 1/776.$$

This equates to 1386/97 which is the correct solution. Clearly, this scribe would have required exographics to get this solution. There is simply no way a normal human being could work this out with their unaided mind.[9]

[9] Marshall Clagett. *Ancient Egyptian Science: A Source Book*. Vol. III Ancient Egyptian Mathematics. Philadelphia: American Philosophical Society, 1999.

THE EGYPTIANS MADE CONTRIBUTIONS to astronomy, metallurgy, and medicine, as described by George Sarton.[10] One of their notable accomplishments was the design and use of the first solar calendar which appeared over the period 3000-2800 BCE. Interestingly, Egyptian exographics appeared shortly before, about 3100 BCE. There is evidence that Egyptian scribes and priests inscribed astronomical records on temple walls, and it was the study of these records that led to a calendar based on the solar cycle rather than lunar cycles. Their solar calendar was 365 days and was based on the heliacal rising of Sirius, which is the first visible appearance of the star Sirius in the eastern sky just before sunrise after a period of being hidden by the Sun's glare. This appearance coincided with the annual Nile flooding and was made the start of their solar year.

[10] George Sarton. *Ancient Science Through the Golden Age of Greece*. New YORK: Dover Publications, 1952. See pp. 144-145.

There is a significant volume of Egyptian literature as documented by Miriam Lichtheim in her 3-volume anthology.[11] As for the education of scribes, Ronald Williams begins his paper on the ancient Egyptian scribal system with this abstract:

[11] See Miriam Lichtheim. *Ancient Egyptian Literature, Volume I: The Old and Middle Kingdoms*. Ancient Egyptian Literature. Oakland: University of California Press, 1973; Miriam Lichtheim. *Ancient Egyptian Literature, Volume II: The New Kingdom*. Oakland: University of California Press, 1976; and Miriam Lichtheim. *Ancient Egyptian Literature, Volume III: The Late Period*. Oakland: University of California Press, 1980.

> ... The requirements of a highly complex governmental administration in Egypt led to the development in the mid-third millennium of methods of training young scribes to enter the civil service. In addition to the much later Greek descriptions of the educational system in ancient Egypt, there are scattered references to it in Egyptian biographical and literary texts. These are few in number in the early periods, but soon become more plentiful. The didactic treatises beginning in the Old Kingdom and the compositions specially designed for scribal use, together with the innumerable school texts written mostly on ostraca,

> afford valuable evidence for the content of the young scribe's curriculum. The nature of the elementary instruction during the first four years may be deduced, as well as the advanced training which was of a more specialized nature. The "text books" employed in the instruction of students are also known to us. Finally, the Egyptian attitude towards the efficacy of educational methods finds expression in their literature.[12]

[12] Ronald WIlliams. "Scribal Training in Ancient Egypt". *Journal of the American Oriental Society* 92, no. 2 (1972): 214–221, p. 214.

and then this in the first paragraph:

> But the role of the scribe became vital with the development of a complex state at the beginning of the Old Kingdom [2700–2200]. The calculation and recording of taxes, the preparation of census lists for military and labour corvées, and the calculations required for the massive building projects, all called for a large and well-trained civil service.[13]

[13] Ronald Williams, "Scribal Training," 1972, p. 214

Clearly, there was a school system in which scribes learned both how to write and their administrative roles in the society, which included managing the taxation system, recruiting soldiers for the army, and designing and executing large public projects.

To SUMMARIZE, in ancient Egypt we have a fixed-settlement population situated within a differentiated agricultural economy managed by administrators. Again, exographics was invented to serve as a memory aide for these administrators. But over the centuries, Egyptian scribes made a substantial e-Class contribution just as the scribes in Mesopotamia had.

The Maya

The Maya settled in Central America about 2600 BCE and their Classical Period ran from 250–950 CE. They lived in large city-states, some with as many as 100,000 inhabitants (Palenque). As with the other early civilizations, their economies were centered around agriculture. The primary crops were maize, beans, and squash. Travel between settlements was either by canoe or carefully constructed roadways. Maya architecture and art are exceptional. They built many stone temples with some reaching a height of 30 meters.

The decipherment of the Maya script is an interesting story that stretches over centuries.[14] This work was difficult because, in the 16th century, their Spanish conquerors burned most of their documents since the clergy had declared them to be "the work of the devil." Hence, there wasn't much to go on. The decipherment to date has been based on only 4 codices and script engravings on buildings, monuments, walls, and pottery. Despite this limited data, linguists reckon that about 90% of the script has been decoded.

[14] Michael Coe. *Breaking the Maya Code*. New York: Thames and Hudson, 1992.

When linguists try to figure out how a script works, one of the first things they do is count the number of unique symbols. If a script has

20-30 symbols, it is likely a phonetic script where an atomic sound is represented by a unique symbol. If there are 80-100 symbols, it is likely that it's a syllabary, where a single symbol represents two atomic sounds. For example, what we in English represent with "ka" will have one symbol in a syllabary. Finally, if there are a large number of signs, it is likely that the script is logographic where each symbol represents a word or phrase. For example, Chinese has over 100,000 symbols.

With the Maya script, there were approximately 800 symbols and linguists deduced that the script was a combination of syllabary and logography, or a *logosyllabic script*. This gives rise to the possibility of representing a spoken word in a number of ways. Two representations of the Maya word for jaguar are shown in Figure 10.3.

Figure 10.3: Logographic (left) and syllabic (right) representations of the Maya word for jaguar (*b'alam*).

What makes study of the Maya culture difficult, then, is not that we haven't deciphered their language. It's because there is such a limited amount of writing to learn about the culture. That said, we have learned a lot, particularly about e-Class ideas and we turn to that discussion now.

For their number system, the Maya used a base-20 placeholder system similar in function to the Mesopotamian base-60 system. Each of the first 19 numbers was represented with dots (each worth 1) and horizontal lines (each worth 5). The symbol for 13 is

To represent the number 413, they used:

The lower number is 13. The middle number, a picture of a shell, is 0 and the top number is 1. Hence, in our decimal system, it's

$$1 \times 20^2 + 0 \times 20^1 + 13 \times 20^0 = 400 + 0 + 13 = 413$$

We know that the Maya did addition and subtraction. However, there is no evidence they did multiplication or division, but these two operations are certainly possible.[15]

[15] Joseph Lambert, Barbara Ownbey-McLaughlin, and Charles McLaughlin. "Maya Arithmetic". *American Scientist* 68 (1980): 249–255.

Almost certainly the Maya used their number system for administrative purposes. What we know with more certainty is that they used this number system extensively in the three calendar systems they used. They also did a lot of astronomical calculations, including the prediction of lunar and solar eclipses and the cycles of Venus. Their estimate of the length of a year was 365.2420 days whereas in our modern Gregorian calendar, the length is 365.2425.

It's unfortunate we don't have more of the Maya exographics corpus. We do know they had a complex fixed-settlement society based on agriculture and they invented an exographics system to help them manage it. This then led to e-Class contributions, some of which are described above. We judge this to be enough evidence to conclude the beginnings of a techno-literate culture.

The Indus Valley Civilization

The ancient Indus Valley (or Harappan) civilization flourished about the same time (3300–1300 BCE) as the ancient Mesopotamian and Egyptian cultures. Geographically, it was the largest of the five river cultures, eventually including most of Pakistan and parts of Afghanistan and India. The Indus story reads the same as the others, with urbanized fixed settlements based on agriculture.

Excavations at Mehrgarh suggest that its inhabitants were farming (mainly sheep, goats, wheat, and barley) as early as 7000 BCE. By 5500 BCE, they started making pottery, figurines, and other crafts and by 3500 BCE, they were trading with other settlements. About this time the settlement at Harappa began to become prominent and eventually it developed into a large urban center. At the height of its prominence, Harappa exhibited a differentiated economy based on agriculture.

Mysteriously, the only source of Harappan exographics discovered is an inscriptional corpus of perhaps several thousand entries, many of which are repeated. There are no longer-form texts as were found in Mesopotamia and ancient Egypt. Hence, we have the same difficulty studying the Harappans as we do the Maya. There is so little information that it's difficult to translate despite many attempts.[16] Over 400 script elements have been identified. Here is a representative inscription:[17]

The linguist Steven Bonta has recently published a partial decipherment of Indus inscriptions.[18] He concludes that inscription writing is largely of two kinds. One is for appellation purposes and includes names (including those for gods), positions, and caste names. The other is for measurement and is likely some sort of receipt for a donation or required contribution to the temple.

[16] Nisha Yadav and M. N. Vahia. "Indus Script: A Study of Its Sign Design". *SCRIPTA* 3, no. June (2011): 1–36.

[17] This is the so-called Dholavira Signboard.

[18] Steven Bonta. *A Partial Decipherment of the Indus Valley Script: Proposed Phonetic and Logographic Values for Selected Indus Signs and Readings of Indus Texts*. Tech. rep. www.academia.edu, 2023.

What is striking about Harappan cities is their design and architecture. Their cities were laid out in a grid-like street structure with main streets and side streets of uniform width. Structures were built of bricks uniform in size. Most cities had sophisticated water supply systems, particularly in Dholavira, where there were several large storage pools within the city walls. These supplied water in sufficient quantities that some inhabitants were able to shower. They also had sewer systems that carried excess water and sewage away.

There is much evidence that the Harappans used uniform weights and measures with two scales. These scales and written seals marked with symbols and weights suggest that Harappans almost surely were at the stage of starting to track goods and obligations with some sort of archaic accounting system, much the same as was used in ancient Mesopotamia.

Archeologists have discovered some sophisticated devices to measure length. One is the so-called Mohenjodaro Ruler whose subdivisions were 1.32 inches (the "Indus inch").

There is no evidence of education, much less a literate education. But given the quality of their urban and architectural design over time, it had to be that successive generations were learning these skills, but whether it was in scribal schools or an apprenticeship-type program is unknown.

It's difficult to say much more about the Harappans. Nonetheless, despite minimal evidence of exographics and education, we feel it's sufficient evidence to warrant the conclusion that the Harappan civilization was a budding techno-literate culture.

China

The Shang Dynasty flourished along the banks of the Yellow River in Northern China over the period 1600–1050 BCE. Like the other river civilizations, their economy was based on agriculture. They grew primarily millet with some rice, wheat, barley, soybeans (for food, animal feed, and soil enrichment), hemp (for fiber used in textile and rope production) and fruits and vegetables (apricots, plums, pears, chestnuts, and cucumbers). Domesticated animals included pigs, cattle, sheep, and chickens for meat, horses for transport and chariot warfare, and silkworms for silk.

Eventually, there was a strong governing hierarchy headed by emperors. Large palaces were built, public projects like irrigation systems and city walls were also constructed, and armies were raised. One inscription suggests that an army of 13,000 men was sent on a campaign. Another speaks of bringing back 30,000 prisoners of war who would then be used for slave labor and sacrifice.

The Shang were highly skilled in bronze metallurgy. With it, they produced farming tools, decorative vessels, weapons (swords, daggers, spears, and battle axes), and chariot fittings. They were experts with jade, particularly as it was used in the sculpture of art objects. Ceramics and pottery were also manufactured.

There is evidence that the Shang innovated a logographic exographics system around 1200 BCE, a year that roughly corresponds with the beginning of the Late Shang period. It was important to them for a number of reasons. One use was in administration. Scribes had to record tax assessments and payments and other important aspects of their resource exchange. The Shang engaged in military operations frequently, so another use would have been in the organization and day-to-day operation of large armies. Exographics may also have been used to record royal decrees, treaties, and laws, although we have no direct evidence of this.

One of the difficulties in determining precisely how they used exographics is that there is not much left of their record. They wrote on strips of bamboo and silk with ink, and these would never have survived to the present.

However, we have a lot of information about their exographics from their divination activities.[19] The Shang believed in divination and it was done in the following way. A "charge" was carved into a bone (usually an animal shoulder blade) or a turtle shell. Often a charge consisted of two related statements, for example "We will receive a millet harvest this year" and "We may not receive a millet harvest this year." One such divination is shown in Figure 10.4. Once the charge was inscribed, the shell or bone was subjected to heat and cracks would then form (as shown in the figure). The diviner would then interpret these cracks and suggest which forecast was the most likely, recording his finding on the bone or shell. Interestingly, there are many similarities between this ancient exographics and modern Chinese exographics, suggesting that modern Chinese exographics is a direct descendant of the Shang script.

[19] David Keightley. "Shang Divination and Metaphysics". *Philosophy East and West* 38, no. 4 (1988): 367–397.

There is no direct evidence that the Shang had schools to educate their administrators in exographics and bureaucratic system function. But they did have a large bureaucracy and a well-developed exographics system. Some scholars have suggested that it's likely that novice scribes may have apprenticed under experienced scribes in the royal courts.

There is certainly evidence of large fixed settlements. Anjang had a population estimated to be almost 100,000 and was about 25 square kilometers in area. It had a large palace-temple complex that included the Emperor's residence and government buildings. The second largest city was Zhengzhou, an earlier capital city, with a population of 40,000 people at its height.

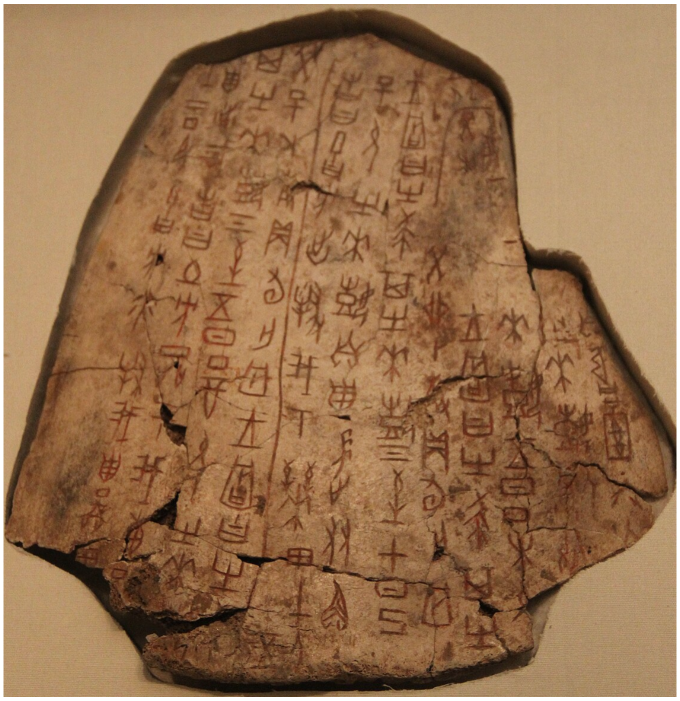


Figure 10.4: An ox scapula bone showing a divination charge in Shang Dynasty writing. Photo by Dr Gary Lee Todd, CC 1.0 Universal Public Domain.

The Shang had enormous influence on succeeding Chinese civilizations. The Shang scholar Dallas McCurley comments:

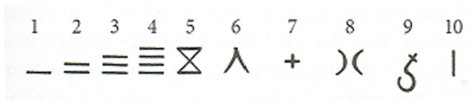
> The fall of the Shang at the hands of one of their enfeoffed polities, the Zhou, did not cut short their influence on subsequent mainstream Chinese developments. The Zhou (1045–256 BCE) and successive dynasties perpetuated the legacy of the Shang (which was, to a degree, the legacy of Erlitou) through continuing practices of ancestor worship, a patrimonial system of inheriting political status, elaborate burial ritual, the calendar based on Earthly branches and Heavenly stems, divination as a means of state advisement, writing, and a layout of the capital's administrative and ritual center, found even today in such structures as Beijing's Forbidden City.[20]

[20] Dallas McCurley. "Shang Dynasty". In *Berkshire Encyclopedia of China: Modern and Historic Views of the World's Newest and Oldest Global Power*, ed. by Haiwang Yuan and Linsun Cheng, 4:1941–1944. Great Barrington: Berkshire Publishing Group, 2009, p. 1944.

The city of Erlitou was the capital of the Xia civilization (1766-1045 BCE), the civilization that preceded the Shang. McCurley is arguing that the strong family culture across generations was a bridge to succeeding cultures and eventually modern Chinese culture.

The Shang did not have any contact with the other river civilizations, particularly those in Mesopotamia and Egypt, so it is unlikely that they got their inspiration for numbers and arithmetic from these cultures. Furthermore, the Silk Road did not open up until about 200 BCE. Consequently, the Shang work on a number system, arithmetic, and other mathematics was their own invention.

We'll not look at the details of the Shang number system or arithmetic here. But suffice it to say that they did arrive at a base-10 positional number system based on these digit symbols:



and this allowed them to use as large a number as they needed for administration purposes. In addition, they were able to do arithmetic, something we've seen to be critical to administering a resource-based economy. As we've already argued, a positional number system and arithmetic would require exographics both to invent and use.

Subsequent Chinese civilizations made extraordinary contributions to mathematics long before mathematicians in the West came to these ideas. An example is matrix algebra. Suppose you had to solve this system:

$$\begin{aligned} 3x + 2y &= 8 \\ 2x + y &= 5. \end{aligned}$$

The Chinese did it like this:

$$\begin{bmatrix} 3 & 2 \\ 2 & 1 \\ 8 & 5 \end{bmatrix} = \begin{bmatrix} 1 & 2 \\ 1 & 1 \\ 3 & 4 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 0 \\ 3 & 1 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 2 & 1 \end{bmatrix}$$

Note that the equations are stated as columns. The manipulation is just as we would do it today, giving the solution $x = 1$ and $y = 2$ (bottom row). The West did not get to matrices until the 19th century.

THE STORY OF THE SHANG is remarkably similar to those of the other river cultures. They developed a differentiated economy based on agriculture. They built and settled large cities. Their government was a massive bureaucracy and, as with all bureaucracies, it relied on exographics to keep track of things. Eventually, the Shang made great progress in the e-Class particularly with mathematics. We don't have any evidence on the extent of a literate population or public schools to train this population. But there had to have been an education system of some kind and the more likely explanation is that it was done with future scribes apprenticing with working scribes. We think it safe to conclude that the Shang exhibited all the characteristics of a techno-literate culture.

The Trypillia Megasites

The Trypillia societies originated in the forest-steppe area north of the Black Sea in what is now Ukraine and Moldova. They centered in the region famous for the rich Ukrainian "black earth" (*chornozem*) that gives this area its current label: the "breadbasket of Europe." It has its origin during the Pleistocene glaciations, which ground up rock further north and deposited massive amounts of loess (windblown silt) south of the ice front. These fine mineral particles settled across the Ukrainian steppe, creating a nutrient-rich, easy-to-work base layer.

There appear to have been three important Trypillia epochs: an early stage (4800–4200 BCE), the megasite formation stage (4200–3650 BCE), and the dispersal phase (3650–3000 BCE). During the megasite formation stage, settlements of 10,000 to 15,000 inhabitants formed, rivaling the sizes of the large settlements in ancient Mesopotamia. Archaeologists have discovered 38 of these megasites with some sitting on as many as 320 hectares.[21]

[21] By comparison, the Mesopotamian city of Uruk was about 400 hectares if you included the suburbs and industrial areas outside the city walls.

The megasites consisted of concentric rings of two-story houses around a large central area of perhaps 100 meters in diameter. The modern equivalent would be the current organization of the urban space at the Burning Man festivals in Black Rock City, built each year for the festival and then taken down immediately afterward. The city consists of dwellings located on circular and radial roads built around a central area containing the effigy to be burned at the end of the festival.

What is remarkable about these Trypillia sites is how different they were culturally from the other river civilizations. The focus was on agriculture, with very little specialization in other goods except pottery and figurines. That we know of, these cultures were not literate and there is no evidence of a central authority or religion, other than the larger halls located close to the central communal area.

Research suggests that the inhabitants of these megasites were exceptional farmers. They raised cattle, pigs, sheep, and goats, and planted grains, cereals, legumes, and especially pulses (lentils, dry peas, and chickpeas). Their diet consisted of 10% meat and the rest grains, cereals, and legumes. These diets were high in calories and IAA levels.[22]

[22] IAA stands for Indispensable Amino Acids. These are amino acids that cannot be synthesized by the body and therefore must be obtained through diet.

It appears that farmers had fenced fields where they kept animals that they fed household scraps, the vegetation in a field, and hay harvested from the rich grasses of the steppe. The animal dung served to fertilize the fields and prepare them for growing crops which were rotated regularly to freshly fertilized fields. So, in essence, animals were not kept to provide meat, but rather to play a crucial role in the nutrient maintenance of the fields. These conclusions are based on strong archaeological evidence including chemical analysis of various isotopes that appear in the bones of humans, animals, and charred crops.[23]

[23] Frank Sculutz et al. "Isotopes Prove Advanced, Integral Crop Production, and Stockbreeding Strategies Nourished Trypillia Mega-populations". *PNAS* 120, no. 52 (2023): e2312962120.

In their recent sweeping history of humanity, David Graeber and

David Wengrow offer the Trypillia culture as one that originated and sustained itself without a central authority.[24] There were no princes, priests, or any sort of hierarchical structure to keep the masses in line. This perhaps explains why the Trypillia cultures were nonliterate: There was simply no need for writing to help a central authority manage economic exchange. Basically, the megasite economies ran themselves with individual farmers making decentralized decisions in a land of abundance.

[24] David Graeber and David Wengrow. *The Dawn of Everything: A New History of Humanity*. Farrar, Straus and Giroux, 2021.

Summary

The story among these early civilizations that employed exographics is remarkably similar. Agriculture gets a toehold with a percentage of the hunter-gatherer population domesticating plants and animals and beginning to live in fixed settlements. An economic surplus is generated, and the settlements grow into cities with differentiated economies and religious and civil hierarchies. This results in "taxation" where the ruling authority extracts some of the economic surplus to provide for the costs of administration, protection (the army), and public projects like irrigation systems and temple/palace construction. Eventually, the administrative requirements become too much for biological memory and an exographic system is invented to help administer the settlement.

Let's put this into perspective. We've argued that exographics allows us to access a set of ideas that would otherwise not be discoverable. Consequently, we would expect to see that civilizations that had come to exographics might also contribute to the e-Class. In fact, all of the civilizations that came to exographics independently appear to have generated e-Class ideas primarily in mathematics, science, engineering, the law, and literature. Importantly, exographics and the measurement it enabled seem to be the first e-Class ideas in all of these cultures.

In sum, these early cultures constitute early examples of the emergence of techno-literate culture, albeit with only a small percentage of the population being literate.

But the confounding evidence to this narrative comes from the Trypillia megasites. These civilizations were comparable in size to those that developed in Mesopotamia, originated about the same time, and flourished for centuries. Yet there is no sign of hierarchy or a central ruling authority. The culture's need to develop communal resources like armies and administration appears to have been minimal. Hence, there was no need to develop an exographic system which, in turn, explains why they made no e-Class contribution and why a techno-literate culture did not emerge.

As Graeber and Wengrow point out, the Trypillia megasites are evidence that the standard narrative of "hunter-gatherer to agriculture to hierarchy" was not true of all ancient development.[25] Based on the work of anthropologists, particularly Marshall Sahlins, we know that hunter-gatherer societies were generally egalitarian with little or no hierarchy.[26] This was largely a characteristic of such societies where food could not be stored. The Hazda of Tanzania survive on diets of tubers, berries, honey, and game. Due to its perishability, most food is consumed shortly after collection. Their societal norms frown on hoarding. On the other hand and in the recent past, the Haida of the Pacific northwest (Queen Charlotte Islands) were surrounded by plentiful supplies of food consisting of fish, shellfish, tubers, berries, and game (deer and waterfowl). Most importantly, they stored some of these food sources with smoking and drying for use in the harsh winter months. Unlike the Hazda, the Haida had a strong class-based society with nobility, commoners, and slaves, a society that was reinforced with cultural institutions like potlatch. The interesting question is whether the nature of the Haida subsistence—storeable, abundant food resources—gave rise to their hierarchy. Graeber and Wengrow argue that it would not. It's their position that hierarchy isn't a natural outcome of agriculture or surplus. Rather, they see it as a social invention, one that humans have often resisted.

[25] Graeber and Wengrow, *The Dawn of Everything*.

[26] Marshall Sahlins. "The Original Affluent Society". In *Man the Hunter*, ed. by Richard Lee and Irven DeVore, 85–89. Chicago: Aldine Publishing Company, 1968.

If Graeber and Wengrow are are correct, it's certainly understandable that a megasite could have been egalitarian with minimal hierarchy. But, at the same time, the rise of hierarchy is understandable when there is an essential requirement for strong communal resources like armies, temples, palaces, irrigation systems, and administration.

But the Trypillia megasites aside, the ancient river cultures were nascent techno-literate cultures where an exographics technology was crucial to their ongoing development and our first forays into the e-Class.

11
The Greek Miracle

Man is the measure of all things.
Protagoras

HISTORIES of the West usually begin with the ancient Greeks and Romans and then move on to medieval and modern Europe. But, as we have already indicated, the story starts with the Mesopotamian and Egyptian river civilizations each of which had a substantial influence on the Greeks.

Another was the Phoenicians (roughly 1100–300 BCE) who settled the eastern Mediterranean coast in what is now Lebanon, with major city-states at Tyre, Sidon, and Byblos. They were expert shipbuilders and navigators, and this led them to be extraordinary seafaring traders, building colonies and trading outposts—Carthage among them—all along the northern and southern coasts of the Mediterranean to the Iberian Peninsula and on to Britain. Since they had few natural resources, they relied on manufacturing and trade to support their expansion. They traded wood (largely cedar with pine and oak) and a variety of manufactured goods, including ships, glassware, pottery, wine, crafts, and a very popular purple dye (Tyrian purple) made from a species of snail abundant in the waters of the eastern Mediterranean.[1] The Phoenicians were exceptional innovators.

[1] In *Odyssey*, Homer refers to the Phoenicians with the word *Phoinikes* which is based on the Greek word *phoinix* meaning purple or crimson. Hence one interpretation is that Phoenician means "purple people" or "the purple ones."

They had an exographics system including a number system. Their number system was a simple precursor of the Roman and Greek systems. At the lower end of their system, they built numbers with 4 symbols: a symbol for 1 (𐤖), for 10 (𐤗), for 20 (𐤘), and one for a 100 (𐤙). The Phoenician number

is read from right to left. The first three symbols ("100s") give 300, the next two ("20s") make 40 and the last two symbols ("1"s) make 2. So the number is 342.

One of the difficulties with this additive system is that it's symbol-intensive. Our number 999 would require 23 of their symbols. The Roman numeral system was also additive, but the Romans defined a subtractive representation that required fewer symbols, so for our symbol 4, they used IV rather than IIII.

The Phoenicians were one of the first civilizations to use a phonetic exographics system. Their "alphabet,"[2] comprising 22 symbols, was an abjad, meaning that it was phonetic, but it only had letters representing consonant sounds. Such exographics systems are easy to learn and, for this reason, were adapted by many of their trading partners including the Greeks, who recognized a good idea when they saw one. The Greeks adopted the Phoenician abjad about 800 BCE and then added vowel symbols to get to their alphabet.[3] In this way, the Phoenicians were crucial to the development of the West because they introduced the Greeks to a phonetic exographics system.

[2] We've put the word in quotation marks to account for the fact that the word alphabet is generally reserved for the collection of symbols the ancient Greeks used for writing.

[3] Barry Powell. *Homer and the Origin of the Greek Alphabet*. Cambridge: Cambridge University Press, 1991.

Carolina López-Ruiz suggests that there was a Phoenician literature.[4] She argues persuasively and mentions the Phoenicians making use of exographics to come to original ideas in science and to support their system of courts and laws.

[4] Carolina López-Ruiz. "Phoenician Literature". In *The Oxford Handbook of the Phoenician and Punic Mediterranean*, ed. by Brian Doak and Carolina López-Ruiz, 256–269. Oxford: Oxford University Press, 2019.

In the assessment of Phoenician e-Class contributions, we run into the archaeological difficulty of scant evidence. They wrote largely on papyrus and much of their exographics either has not survived or we've yet to discover it. What we know comes from their inscriptions, what other civilizations have written about them, and a few written documents.

But given what the Phoenicians were able to do, we find it hard to believe that they would not have made substantial e-Class contributions in addition to those we have already described. First, they were traders and would have needed a number system and arithmetic for transactions, accounting, and inventories. Second, they were skilled navigators and almost surely would have required significant measurement skills to build their ships and sail them based on astronomical measurement. Third, they were excellent engineers, building cities, palaces, temples, and harbors. Such construction would have required a number system, arithmetic, and measurement.

AS FOR ANCIENT GREECE, it's generally agreed there were three epochs which preceded the Greek Classical Period (500–300 BCE).

The Mycenaean Period (1600–1100 BCE), was centered at Mycenae, some 90 miles southwest of Athens. Mycenae was similar in structure to the city-states in Mesopotamia in that it had a redistributive economy, a political structure headed by a king, and an administrative system complete with an exographics system and scribes. The Mycenaean writing system, Linear B, was partly logographic but mostly a syllabary. Not surprisingly, literacy was restricted to a small scribal class.

The Dark Age covered the period 1100–800 BCE. With the collapse of the Mycenaean economy, there was no longer a need for administration, and Linear B disappeared.

It was during the Archaic Period (800–500 BCE) in Athens that ancient Greece began to take on the structure that marked the Classical Period. There were developments in politics (the city-states including Athens and Sparta would eventually emerge), economics and trade, and especially culture. During this period, highly democratic educational systems emerged with a focus on literacy. David Harvey has written a comprehensive assessment of the extent of Athenian literacy. He considers a multitude of evidentiary sources and concludes this:

> The great majority of Athenian citizens were, I believe, literate; the average Athenian could read and write with greater facility than the average Spartiate. This is clear from all sorts of evidence. Much of this is conjecture and deduction; but all these conjectures and deductions point in the same direction, and thus confirm one another in a convincing manner.[5]

[5] David Harvey. "Literacy in the Athenian Democracy". *Revue des Études Grecques* 79, no. 1 (1966): 585–635, p. 628.

Harvey concludes that a significant percentage of the Athenian population was literate and, further on in that volume, offers that an education system was in place to teach young students. Hence, Plato was not proposing something new when, in his *Laws*, he set aside four years for children (ages 10–13) to learn literacy skills.

In sum, the ground for Greek e-Class discovery was made fertile by an easily learned exographics system and a democratic education system. The combination of these two led to a relatively large number of individuals working on e-Class ideas, and it laid the foundation for the achievements that would come in the Classical Period.

The Classical Period (500–322 BCE) was one of unparalleled e-Class expansion. What the Greeks did was incredible. It's not our intention to document in detail what historians of ideas have already laid out. The Greek advances in art (particularly sculpture), architecture, philosophy (especially logic), mathematics (especially geometry), science, literature, poetry, drama, history, and politics (especially the idea of democracy) were stunning.

Nonetheless, we can make some important points related to our argument. The civilizations we've studied to this point contributing to the e-Class were driven to do so primarily to solve practical problems. But the Greeks took abstraction to another level. For example, consider the following passage from Aristotle's *Prior Analytics*:

> If it is necessary that no B is A, it is necessary also that no A is B. For if

> it is possible that some A is B, it would be possible also that some B is A. If all or some B is A of necessity, it is necessary also that some A is B.

This is typical of the arguments Aristotle presents as he develops his theory of categorical logic. In particular, note the abstract nature of the argument. He doesn't spell out what A and B are. They could be anything.

Or consider the treatment of geometry by Euclid. He begins with definitions (lines, points, etc.) and then makes assumptions (premises). From these he derives theorems. For example, consider the diagram in Figure 11.1. It's of a triangle with a line drawn from each vertex to the midpoint of the opposite side. It appears that these three opposite side bisectors intersect at a common point called a centroid (point G). Euclid wondered why this was the case and eventually proved that it would always happen for every possible triangle he could draw. We do mathematics in the same way today. Effectively it's a formal method for justifying the patterns that mathematicians discover.

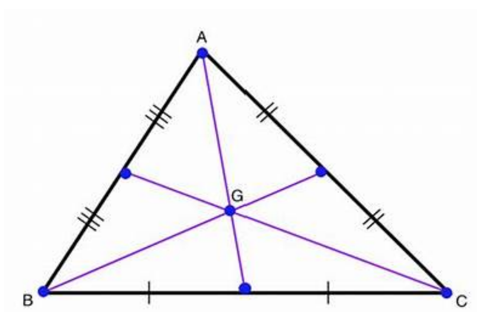


Figure 11.1: A triangle with opposite side bisectors.

When it comes to Greek e-Class discovery, there is an archaeological find—the Antikythera mechanism—that is beginning to change our understanding of the ancient Greeks. The mechanism is an ancient bronze device, dating to about 150 BCE. It was discovered in the ruins of a shipwreck in 50 meters of water off the island of Antikythera in 1901. Based on research since 1901, it has been called the first analog computer, since it used a complex system of 30+ interlocking gears to model the movements of the Sun, Moon, and the planets, and predict eclipses. The inscriptions on its casing reveal that it was a scientific instrument, embodying the advanced astronomical knowledge of the Hellenistic period. A modern replica of the device is shown in Figure 11.2.

We don't know where it came from or who designed and built it. But it was almost certainly made by Greek craftsmen, probably on the island of Rhodes. At that time, Rhodes was a major center of astronomical learning and home to Hipparchus, one of the greatest ancient astronomers, who worked on lunar theory and eclipse prediction—both functions encoded in the mechanism. Later analysis of the inscriptions suggests astronomical terminology associated with Rhodes.

To our knowledge, there is no machine that preceded this or followed it until astrolabes appeared in the Middle Ages. Of course, it could be that we have yet to discover similar mechanisms built at the same time.

Figure 11.2: A modern replica of the Antikythera mechanism built by Mogi Vicentini. Photo by Mogi Vicentini, CC BY-SA 3.0.

The design of this device required mathematics, the construction of numeric scales, and an intimate knowledge of how the bodies in the heavens moved. Clearly it would have been impossible without exographics. Consequently, the Antikythera mechanism is an e-Class cultural object.

How does one explain this Greek e-Class expansion, the so-called "Greek Miracle"?

Some scholars have suggested it's the Greek temperament and genius, but we find that hard to believe. As we have seen, our cognitive abilities and those of our ancestors have developed over millions of years. To think the Greek advance was the result of a mutation or two leading to enhanced cognitive ability is a stretch, since even a favorable mutation would take generations to spread through the population. We feel there is a more direct explanation.

As the Greek Classical Period begins, the Mesopotamian and Egyptian scripts (cuneiform and hieroglyphics respectively) were well established and used by relatively small scribal classes. One of the reasons for a small scribal class was that this class derived real power from these skills and was not about to share them or modify the exographics system to make it easier to learn. Hence, if a phonetic system was going to be invented, it would have to be done off the beaten track and Greece and Phoenicia, at that time, were definitely off the beaten track.

This status quo effect has a parallel today. Think of some of the crazy spellings we have in English: colonel, thought, bright. Why aren't these kernl, thot, and brite? Then think about how difficult it would be to change these. The leaders of today's scribal class (writers, editors, teachers, professors) have a vested interest in maintaining the status quo. Change would be difficult.

As the Archaic Age progressed, increasingly more of the population was becoming literate. By the beginning of the Classical Period, a significant fraction of the Greek male population was educated and literate. A part of the ascendance of education and literacy is explained by the ease with which a phonetic system is learned relative to a logographic system.

It stands to reason then, if you end up with a higher percentage of literate educated citizens, then we should see more e-Class ideas. Elizabeth Eisenstein has suggested a group effect she characterizes with the phrase "combinatorial intellectual activity."[6] This is similar to the point we made earlier in the book that, if the increase in the stock of ideas over time is proportional to the current stock of ideas, then the stock of ideas will increase exponentially over time.

[6] Elizabeth Eisenstein. *The Printing Press as an Agent of Change*. Cambridge: Cambridge University Press, 1979.

The story of the ancient Greek contribution to the e-Class can be summarized as follows. The ancient Greeks borrowed a phonetic system and improved it by adding vowels. This made their exographics system easy to learn and, combined with their democratic education system, it resulted in a high literacy rate that, in turn, enabled their stunning e-Class expansion.

LET'S NOW PUT the story of ancient Greece in the context of a techno-literate culture.

There have been estimates that, over the Greek Classical Period, there were 100+ city-states. Athens was the largest and had a population of 250,000 at its peak. Urbanization had taken hold in a significant way.

The economies in these city-states were certainly differentiated.

They depended much more on finished goods and trade than did the more ancient river economies of Mesopotamia and Egypt. Edward Harris has compiled a comprehensive list of some 170 occupations in classical Athens (500–250 BCE).[7] A short sample included statue-maker, seamstress, sausage-seller, money-changer, silver-smith, dyer, needle-maker, flute-player, bookseller, tanner, and spear-maker.

[7] Edward Harris. "Workshop, Marketplace and Household: The Nature of Technical Specialization in Classical Athens and Its Influence on Economy and Society". In *Money, Labour and Land: Approaches to the Economics of Ancient Greece*, ed. by Paul Cartledge, Edward Cohen, and Lin Foxhall, 67–99. London: Routledge, 2001.

Harris goes on to suggest that Plato (in his *The Republic*) was aware of basic economic principles. Plato argued that wants/demands led to specialization and the division of labor which in turn led to the invention of the polis (city) to facilitate this specialization and production, and the invention of money to facilitate exchange. He understood that there had to be institutional support for markets, including protection (from theft and violence), and a system of justice to settle the disputes that naturally arise in the exchange of goods and services. Importantly, Plato's work was done some two millennia before the work of Adam Smith and about 2,500 years before Douglass North, Ronald Coase, and Oliver Williamson offered their observations on the importance of institutional support for market exchange.[8]

[8] We are referring to Smith's *The Wealth of Nations*, North's *The Rise of the Western World: A New Economic History,* Coase's *The Nature of the Firm*, and Williamson's *Markets and Hierarchies.*

One use of exographics was that it allowed urban administrators to manage the increased volume of exchange and the production of public assets (city walls, temples, palaces, a standing army, weapons). As we have seen, once exographics is introduced, it soon gives rise to e-Class ideas, particularly in measurement, mathematics, the sciences, law, and literature. Certainly, the ancient Greeks made substantial e-Class discoveries.

With the introduction of exographics, schools were established to train the next generation of scribes. The Greeks believed in education and literacy, perhaps achieving the highest rate of literacy among these ancient civilizations due to the ease with which their phonetic exographics system was learned.

Overall, the ancient Greeks developed a substantial techno-literate culture, one that eventually provided the intellectual foundation for the advance of the West.

12
The Roman Contribution

A room without books is like a body without a soul.
Cicero

THE diffusion of exographics to the West begins in Mesopotamia and the Fertile Crescent, runs through Greece to Rome and the East, and then to Western Europe. All of the civilizations on this path contributed to the e-Class, and it's hard not to be impressed with what the Romans were able to do. Although they borrowed heavily from the Greeks, they made notable contributions to law, literature, and especially to engineering, technology, and architecture.

THE ROMAN EXOGRAPHICS SYSTEM was phonetic and largely derived from those of the Greeks and Etruscans. Our alphabet today is basically the Roman alphabet with a few modifications over time to take into account the new languages it was representing.

Latin, the language of the Romans, had a very long run. It was the *lingua franca* of scholarship and learning in European universities well into the 18th century. The Latin Quarter on the Left Bank of Paris is where the Sorbonne and most of the University of Paris are now located. The name goes back to Medieval times when students had to speak Latin at all times, including at the local bars and eateries.

The Romans produced a substantial literature including essays, letters, histories, epic poems, poems, and plays. Notable authors include Cicero, Virgil, Ovid, Horace, Catullus, Virgil, Lucretius, and Boethius. Despite the existence of a large literate population, the Romans did not extend e-Class ideas in science and mathematics significantly. Exceptions include the work of Pliny the Elder on the natural world, Ptolemy on various topics but most especially his geocentric model of the universe as described in his book *The Almagest* (he was also one of the first to use diagrams and models of the phenomena he studied), Galen in medical science, and Hero in engineering and experimental science. What the Romans are most noted for are their e-Class contributions to engineering, machinery, and especially architecture.

THE GENIUS OF ROMAN ENGINEERING is evident in what remains of their roads, aqueducts, monuments, and amphitheaters. We'll look at a representative case: the design and construction of the Colosseum, which still stands in Rome.

Imagine you're the finest Roman architect and you've just been given the job of designing and constructing an amphitheater—a big amphitheater—for the emperor Vespasian. How would you start?

Your first problem is that the Emperor wants it built where a lake now sits, so the lake needs to be drained.

Then it's going to need a pretty significant foundation to support the stunning superstructure the Emperor wants. As it turns out, the foundation you eventually build is 31 meters wide, 6 meters deep, and is filled with Roman concrete. In addition, you decided to extend this foundation above the ground by another 6 meters by pouring concrete into an area defined by 3-meter-wide forms of reinforced brick. Eventually, this foundational ring you will build has a perimeter of 530 meters. Like other Roman architects, you believe in a good foundation.

The superstructure will be about 15 stories high at its highest point. To build it, you make extensive use of the arch, as shown in Figure 12.1. You've decided on three levels of arches, with 80 arch sections on each level for a total of 240 arch sections. An Etruscan invention, arches were perfected by the Romans. The weight of the structure above the arch is distributed by the keystone (middle stone at the top of the arch) to the two side columns that support the arch. The structural advantage is that the "hole" in the arch reduces the weight that the structure below must support.

The amphitheater's floor is to be made of wood. The wild animals used in some events are to be kept in the cellar below the floor and, when required, are to be winched up to the trapdoors at field level. Today, there is no record of how these lifts worked but, several years ago, a team of archaeologists and engineers built a lift based on the space available using materials readily available at the time. It was a difficult undertaking and complex to build.

You have access to Vitruvius's manual of architectural practice *De Architectura* (*On Architecture*). In it, he's set out out three architectural principles—utility, strength, and beauty—which architects still use today. Utility refers to the usefulness of the space. In the context of a stadium, this principle would consider such things as the experience of spectators, including sight-lines, ease of access and egress,

Figure 12.1: The Colosseum. Public domain image by Kevin Brintnall.

washrooms, and water supply. Your plan calls for the Colosseum to be supplied by three of the main aqueducts that feed Rome. It also calls for washrooms throughout with the waste to be carried away by the running water supplied by the aqueducts. For access and egress, you plan on 80 gates. Food and trinket vendors located just outside the Colosseum will provide the concessions.

One type of event the Emperor wants to stage is the recreation of famous sea battles. For these, you plan to flood the Colosseum with water that will be 2 meters deep. Model ships 3-5 meters in length will reenact historic naval battles.[1]

A modern cross-sectional view of the amphitheater structure is shown in Figure 12.2. It's an intricate plan.

Now for the key question: Would it have been possible for you, your team, and engineers to gather on the site of the Colosseum on the first day of construction and improvise this complex structure? The answer is clearly no. But, unfortunately, we have very little information on the drafting procedures used by these ancient architects. Vitruvius refers to eight diagrams (presumably floor plans) in his text, but these diagrams have been lost. However he does make indirect references to drawing in *De Architectura*. Antonio Corso has listed a number of these. In Vitruvius's paragraph 1.1.3, he suggests that an architect must be "a skilful draughtsman." Further on, in paragraph 1.1.13, he states that the architect must be "not unskilled with his pencil."[2] On the basis of these statements and other evidence, Corso concludes that the Romans used detailed drawings.

This evidence suggests that the Colosseum would have been impossible to plan and build without exographics. Consequently we conclude that the Colosseum is an e-Class object.

[1] The Romans actually built these lakes but how they did it remains a mystery.

[2] Antonio Corso. *Drawings in Greek and Roman Architecture*. Oxford: Archaeopress, 2016, p. 15.

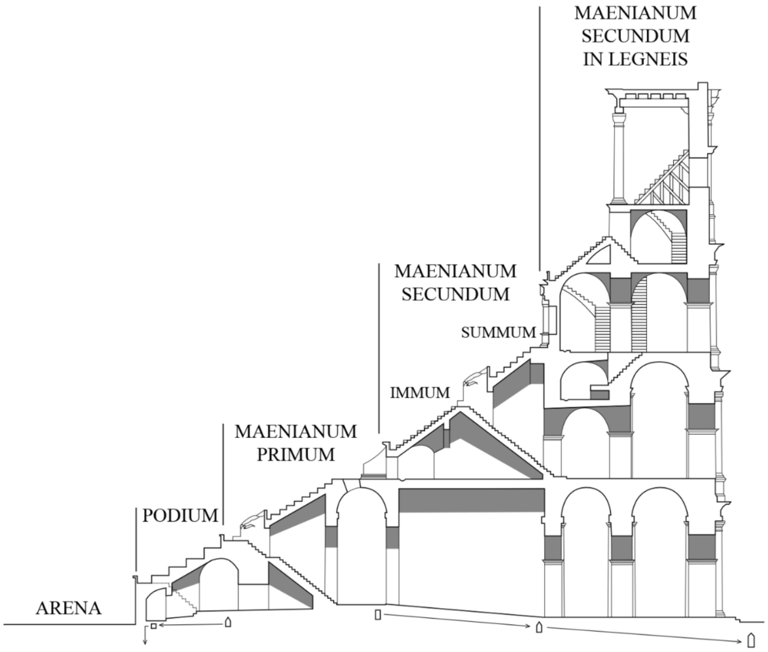


Figure 12.2: The Colosseum in cross-section. Public domain via Wikimedia Commons.

There is evidence that the Romans used complex machines. An example is a Roman treadwheel crane, one that can be seen in the detail of the Haterii Relief, a marble carving circa the 1st century and shown in Figure 12.3. The relief is quite detailed. The crane is on the left side of the relief and appears to be about 15 meters tall (based on the height of the men who are operating it). Note that, at the bottom of the treadmill, there are 5 men inside (there are likely more in the part of the wheel not showing in the relief) who power it. Note also the very heavy pulley systems attached towards the top of the crane. Although not shown in the relief, the other ends of these pulley systems would have been fixed at ground level and used to lift the heavy wooden crane arm (and tread wheel) off the ground and into place. You can see the heavy pulley system that runs straight down from the top of the crane arm. At the bottom of this would have been the apparatus connecting the crane to the object being lifted. It was likely that a Lewis Iron (or Lewisson) was used for this purpose. A Lewis Iron is a heavy metal contraption that is inserted into a "seating" (specially prepared hole) carved into the top of the object being lifted. When lift pressure is applied to the Lewis Iron, it becomes firmly set into the seating. There are estimates that such a crane, with multiple pulleys, could lift 12 to 15 metric tons with only a few men manning the treadmill.

An interesting question related to these ancient cranes is how Roman engineers erected Trajan's Column. The column is 40 me-

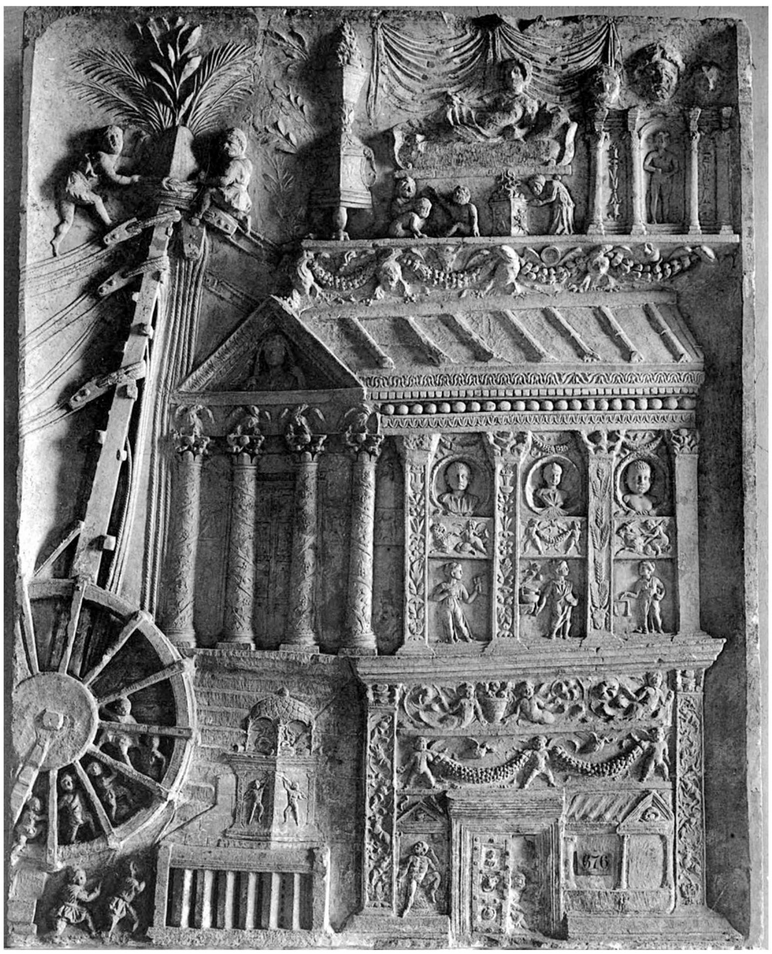


Figure 12.3: The Haterii Relief showing a massive crane. Public domain image by Pierre Gusman.

ters high comprising 29 blocks of marble (these blocks are called ”drums”) each weighing 25-75 tons. The platform piece at the top is 59 tons. We don’t know exactly how the Romans raised this column, but Lynne Lancaster has an interesting take.[3] She proposes that engineers built a dual-shaft scaffolding large enough to enclose two columns.[4] With a massive pulley system, likely driven by human and animal power, each column drum was lifted in the space beside the actual column until its bottom was at a height just greater than where it would sit. A horizontal platform sitting at a height above the actual column would move horizontally until it was under the drum just raised and then the drum would be lowered onto the platform. Once lowered on the platform, the pulleys were removed and the platform with the drum sitting on it was moved horizontally to position the piece above where it would sit. The pulleys were then repositioned and reattached to the piece, and the piece was subsequently lifted off the platform. Then the platform was moved out of the way and the piece was lowered to where it would sit.

[3] Lynne Lancaster. “Building Trajan’s Column”. *American Journal of Archaeology* 103, no. 3 (1999): 419–439.

[4] For Lancaster’s depiction of the scaffolding, see her Figure 9, p. 431.

What should be clear is that this construction was the product of an engineering design process using exographics. It is one thing to sit and make a spear out of a blank of wood. Exographics wouldn’t have been required by the first spear designer. But if you’re erecting Trajan’s Column, you need exographics.

In most of the societies we’ve looked at, there has been a familiar story. As a society grows larger, it becomes hierarchical with a central administration serving as part of the control mechanism. When the society reaches a certain level of complexity, administrators will need something other than their heads to keep track of things. Typically, they used exographics for this purpose.

Rome was the same. The Roman Empire had a population of millions spread over a great area on both sides of the Mediterranean that stretched from Spain and Britain in the west to the Euphrates in the east. What cultural institutions are required to build and maintain such empires? Rome used a well-organized army combined with some very effective diplomacy with the peoples in the conquered territories.

The Roman army was highly trained, organized, and rigidly disciplined. To complement their technical prowess, they equipped their forces with the finest kit, including highly protective armor, and a well-designed sword. Above all, they relied on overwhelming force—Rome had by far the largest standing army in the ancient world. But the real strength of their military was its logistical system, which supported their presence in Rome and a system of garrisons and outposts across their empire.

With a large complex organization like the Roman army, hierarchical in nature, we're not surprised to find that exographics was a significant managerial tool. Sara Phang writes this:

> The army clerks produced documentation concerning recruitment, daily tasks and long-term missions, the giving and confirmation of orders, furlough, and annual reports on the composition of units. These records show a high degree of uniformity over space and time.[5]

[5] Sara Phang. "Military Documents, Languages, and Literacy". In *A Companion to the Roman Army*, ed. by Paul Erdkamp. Oxford: Blackwell Publishing, 2007, p. 286.

At its height, the army had 400,000 personnel, so it would have been very difficult to administer without exographics.

Another Roman institution that relied on exographics was its system of justice. Early in the history of Rome, there were two classes of people: plebeians (the lower class) and patricians. Laws were based on traditional practices and adjudicated by members of the patrician class called pontiffs who sometimes favored their fellow patricians when disputes involved a patrician and a plebeian. This led to a fair amount of acrimony and social unrest. As a result, the patricians produced a document in 449 BCE called *The Twelve Tables* that formed the basis of Roman law as we know it today.

As the Republic grew, so did the frequency of disputes. These were not only among Roman citizens, but also among Romans and citizens of conquered territories. By the 3rd century BCE, the need for additional laws was recognized, and the new profession of jurist was instituted. Basically, jurists were the equivalent of a modern lawyer. They wrote a lot about the law. Their corpus became Roman law and eventually morphed into the Justinian Code published in the 6th century CE, at the direction of the Emperor Justinian (482–565 CE).

We've examined trial procedures. Generally, scribes were used to record what happened. It is clear that all professional parties to a trial wrote. Exographics was a big part of the Roman system of justice.

The Roman literacy rate has been estimated to be 10-20%. Basically 100% of the upper class (bureaucrats, senators) was educated, 20-30% of the middle class (merchants, craftsmen, military officers, clerks), and about 5-10% of the lower classes (farmers, laborers, soldiers, and slaves).

Wealthy Romans first sent their children to primary school (ages 7-11) where they would be taught reading, writing, arithmetic, and poetry. These students then attended a secondary school (ages 12-15) where they were taught Latin and Greek literature, poetry (e.g., Homer, Virgil), history, mythology, and rhetoric. Then there was a higher education for students 16 and older. They were taught public speaking, law, philosophy, and debate, the arts critical to the upper classes who often pursued political or legal careers. The focus was on persuasive argumentation.

To SUMMARIZE, THE ROMANS made significant e-Class contributions in literature, science and mathematics, and most especially, in engineering and architecture. Their engineering achievements in the construction of roads, aqueducts, bridges, buildings, and monuments were extraordinary.

What seems universal is that, when we observe a hierarchy (like a city-state, nation-state, or bureaucracy like an army), we also observe exographics to help administer the hierarchy and this was certainly true in Rome.

In effect, Roman culture was a continuation and expansion of ancient Greek culture. Given its substantial urbanization and outreach, its literacy rate and education system, we conclude that Rome formed a substantial techno-literate culture.

13
The East Through the Middle Ages

Ideas cross frontiers more easily than armies.
Victor Hugo

Through the Middle Ages, roughly 500 to 1500, the intellectual center for cultural expansion was squarely in the East. In this chapter, we look at some of the cultural achievements in the East including how and when these were disseminated to the West.

It's not surprising that the East dominated after the collapse of the western Roman Empire. Certainly, the axis of scholarship before the collapse ran between Rome in the west and the Tigris and Euphrates to the east. At that time, western Europe was no more than a collection of agrarian peoples federated with the Empire as well as the barbarian peoples including the Visigoths, Franks, Burgundians, Anglo-Saxons, Celts, and others. In contrast, the East was more urbanized (Constantinople, Alexandria, Antioch) and intellectual. The trade routes, the main thoroughfares for cultural dissemination, headed east to China through India.

The education system in the Christian East was well developed. An educated man was expected to know Greco-Roman classical literature, Christian doctrine, and rhetoric. The Roman *Trivium* and *Quadrivium* framed much of higher-level learning.

The jewel of higher learning was the University of Constantinople, founded in 425. Students were trained in law, philosophy, medicine, mathematics, astronomy, and rhetoric. It remained a center of elite education throughout the Middle Ages, roughly equivalent in prestige to the madrasa system in the Islamic world and the universities of Bologna, Paris, and Oxford which appeared later.

The graphic in Figure 13.1 shows a small collection of cultural objects that originated in the East and eventually made their way to the West. The time characteristics of each object's dissemination are described by a horizontal line. The left end of each line corresponds to the approximate year of invention, and the right end, to the approximate year the object appeared in the West. Most of these objects are in the e-Class and required substantial ingenuity to discover as we will now describe.

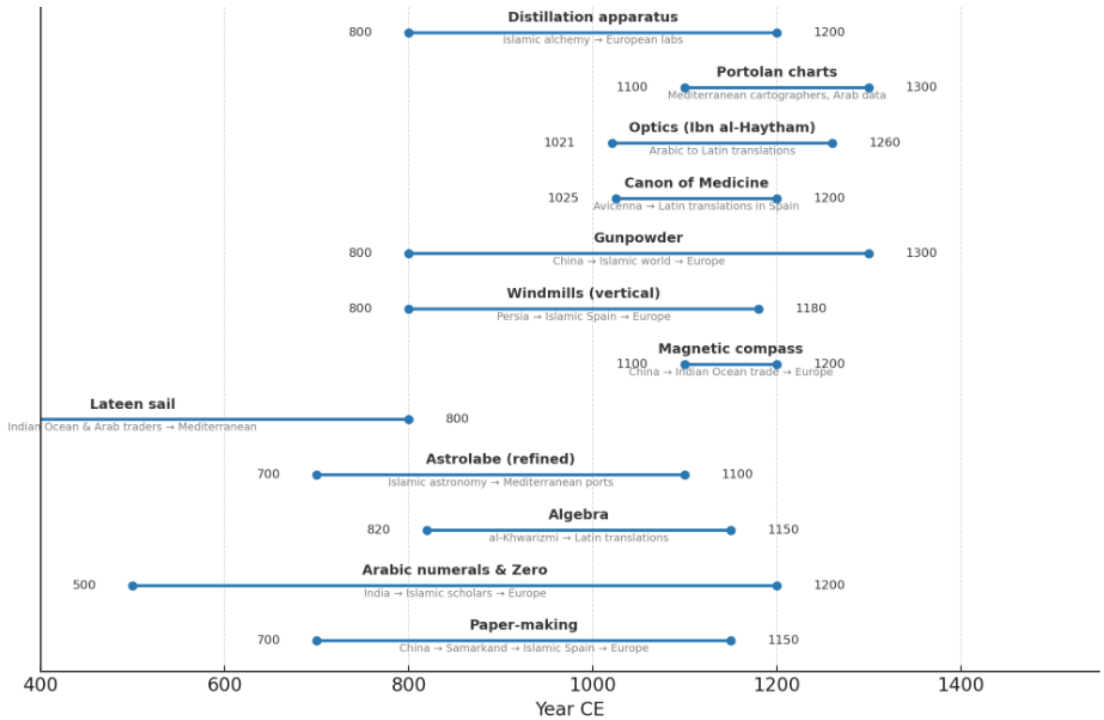


Figure 13.1: Major inventions or improvements of inventions that made their way from the East to the West.

Distillation Apparatus

When heat is applied to a liquid mixture, the component of the mixture with the lowest boiling point turns to vapour first. This vapour is then cooled in a coil or tube and the resulting liquid is collected in a separate container. This separated liquid, then, has a higher concentration of the liquid with the lower boiling point in the original mixture.

Distillation has been part of chemistry since antiquity where it was used to extract perfumes, essential oils, and medicines. It's also important when making spirits. Let's consider the modern example of Scotch whiskey. Before distillation, the Scotch fermentation mixture is basically a kind of beer, about 6–8% alcohol by volume. Alcohol has a lower boiling point than water, so after the first distillation, the resulting liquid has a much higher concentration of alcohol, 20-25% by volume. A second distillation raises this concentration to 65-70% and it's at this point that the distillate is aged in oak barrels to give it a smoother taste.

Although ancient in origin, the process made its way to Islamic labs in about 800. These chemists took these crude versions and radically improved the technique, turning it into a reliable chemical process. Four centuries later, it made its way to the West where more improvements were made including the invention and use of a hydrometer that enabled chemists to measure the composition of a liquid mixture accurately.

Portolan Charts

A Portolan chart is a very accurate map used primarily for sea navigation. One of the Mediterranean is shown in Figure 13.2. Note the boot of Italy in the map's upper left quadrant. Also note the compass "roses" at various points on the map. Lines of constant bearing called "rhumb" lines emanate from these points. These accurate maps made navigation much safer and more efficient in that rhumb lines and a magnetic compass allowed navigators to plan more direct routes. They were also very valuable for "coasting" where a ship travels between ports with the land always visible. The oldest Portolan map is the *Carta Pisana*. It originated in Italy and dates to the late 13th century.

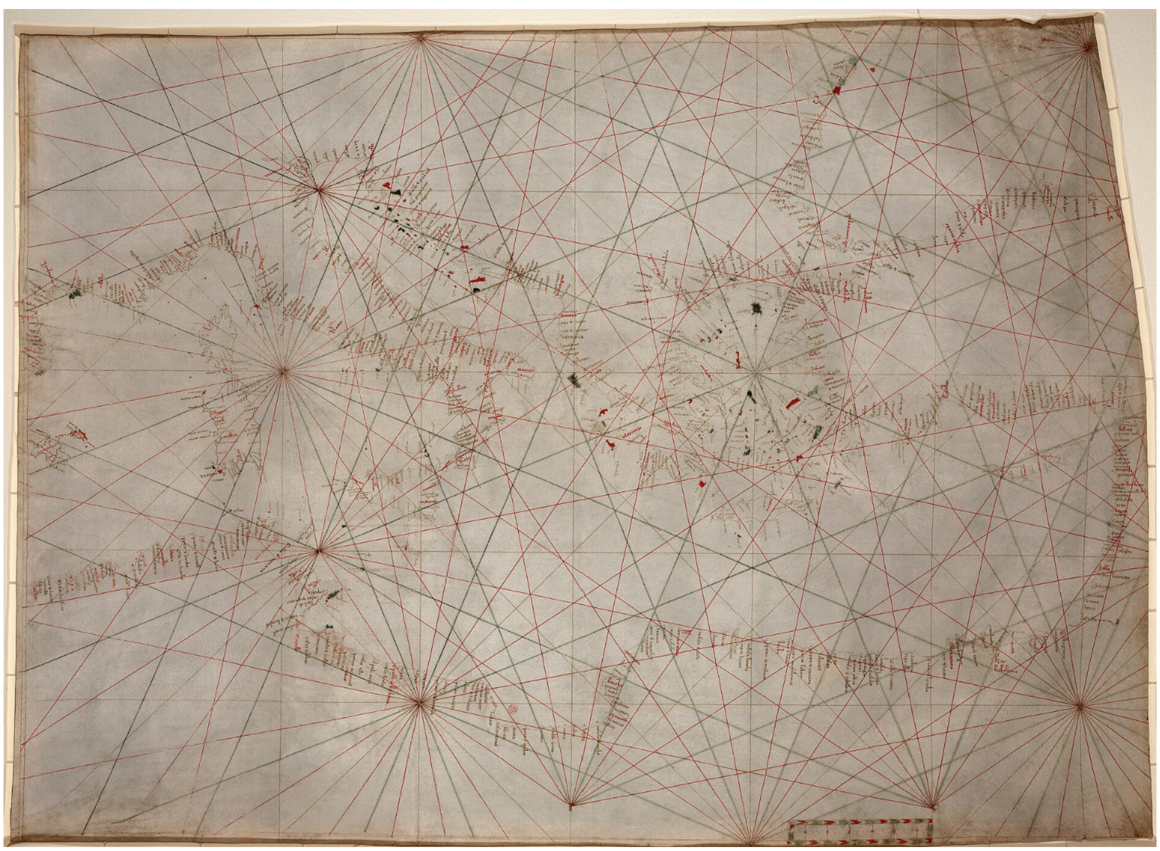


Figure 13.2: Portolan chart of the Mediterranean, c. the 14th century. Public domain image via the Library of Congress, Geography and Map Division.

The geodesist Roel Nicolai has questioned the origin of these early maps.[1] In part, his argument is based on the fact that these maps appear to be based on a Mercator projection, a cartographic advance that was not invented in the West until the late 16th century.[2] Given the geodesic measurement techniques available at the time the Portolan maps appeared, it would have been impossible for Italian cartographers to construct such maps. Consequently, Nicolai's firm conclusion is that the Portolan maps made in Italy must have been based on maps that originated elsewhere. His best guess is that these originated in Greece or Byzantium where there was extensive knowledge of geometry and measurement.

[1] Roel Nicolai. "The Premedieval Origin of Portolan Charts: New Geodetic Evidence". *Isis* 106, no. 3 (2015): 517–543.

[2] The difficulty with making a two-dimensional map is that the earth is spherical. So, the cartographer has to have a way of projecting points on a three-dimensional surface to a two-dimensional surface

The Canon of Medicine

The Canon of Medicine is a large encyclopedia (5 books in all) compiled by the Islamic scholar Avicenna in 1025. It was based on the knowledge of medicine in the Islamic world which, in turn, was based on Greco-Roman medicine (including Galen), Persian medicine, Chinese medicine and Indian medicine. The Arabic manuscript runs about 1,200 pages.

In the 12th century, it was translated to Latin in Toledo (Spain). Subsequently, it became the standard textbook for teaching in European universities through the 18th century. The printed Latin version over the 15th-17th centuries ran to over 1,000 pages.

The Canon of Medicine is an important e-Class object.

The human effort to improve health and survival has been ongoing for a long period of time. In Figure 13.3, we've shown the changes in life expectancy over the period 500-2024 CE. There are two things to note about this graph. First, life expectancy has more than doubled over this period largely because of advances in medical and health science, particularly in the area of infant mortality. Second, the curve increases exponentially after 1800, about the time the Industrial Revolution was beginning. So *The Canon of Medicine* is only one small part of an effort that has now run for millennia. Nonetheless, it was an important because it summarized our knowledge of medicine and health at the time and was widely disseminated. In turn, this enabled more minds to continue to work on health issues.

The Astrolabe

The astrolabe is a portable multifunctional astronomical calculator. A 9th century version of one is shown in Figure 13.4. These were developed in the Islamic world but there is written evidence that there may have been precursors to it developed by the Greeks about the 4th century.

To build an astrolabe, a technologist has to use the mathematical technique of stereographic projection of a celestial sphere onto

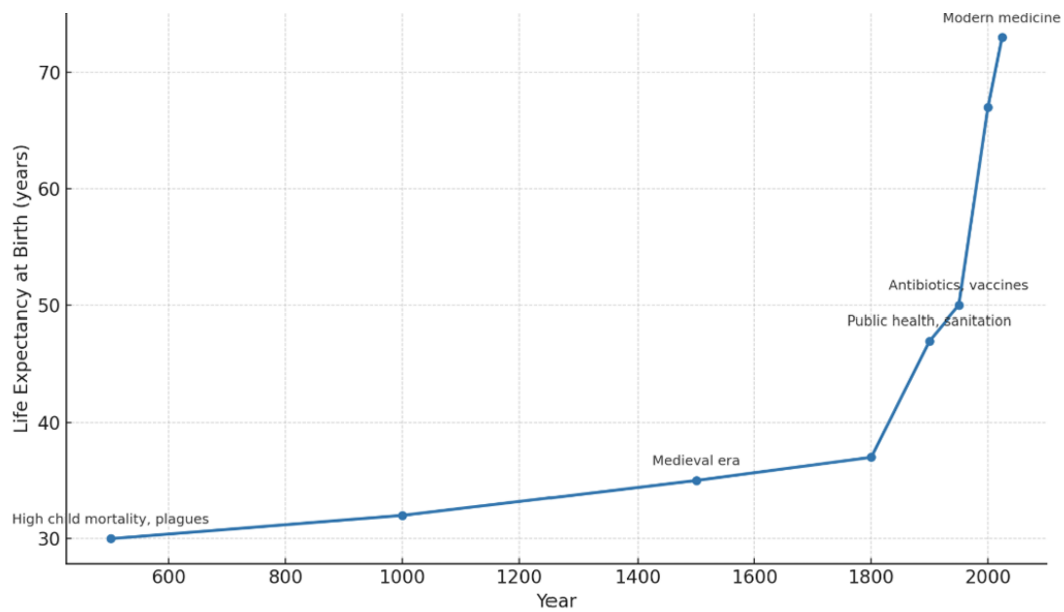


Figure 13.3: Global life expectancy over time, 500-2024 CE. Data to construct the graph was taken from Internet sources.

a two-dimensional surface, a technique developed by Hipparchus of Rhodes about 150 BCE. Theon of Alexandria (4th century CE) described the astrolabe directly and hence the suggestion above that the Greeks may have been the first to build one.

With the astrolabe, users could determine local time (day or night); find latitude or the current position relative to the stars; and identify celestial bodies and predict their positions.[3] Based on this multifunction capability, Seb Falk has referred to it as the medieval equivalent of a modern smartphone.[4]

[3] These were the main uses but there were others.

[4] Seb Falk. *The Light Ages: The Surprising Story of Medieval Science*. New York: W W Norton, 2020.

Before the invention of the astrolabe, telling the local time relied on methods that were approximate, at best. These included sundials, water clocks, and observing shadow lengths. But with the astrolabe, you could tell local time quickly and with a high degree of accuracy.

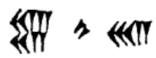
Learning how to use an astrolabe is relatively easy, and it was a major part of the curriculum for the *Quadrivium* over the late Middle Ages. Young students would learn how to use it as modern students would learn how to use a calculator or a computer.

What is striking is the ingenuity required to design this device. Imagine the technologist who set out to build a gizmo that would, say, tell the local time accurately based on the gizmo's interaction with bodies in the heavens. Over time, we ended up with a device with a number of moving parts and numeric/verbal scales etched into a number of them. There is no question that the originating technologist (or more likely technologists) would have made extensive use of exographics. The astrolabe was a remarkable addition to the e-Class.

Figure 13.4: Planispheric astrolabe, North Africa, 9th century. Photo from the Khalili Collections, CC BY-SA 3.0 IGO

The Number 0

We've already talked about positional numbers where the value of a digit in a multi-digit number like 542 depends on where the digit is. The Sumerians were the first to use positional numbers. But they had no placeholder symbol, so they used additional space between digits as a placeholder. This could be confusing. For example, in our modern number system, how would we write 100 if there weren't placeholder symbols? About 1800 BCE, the Babylonians began to use two wedges on their side as the symbol for a placeholder. So the number



stood for $45(60)^2 + 0(60)^1 + 32(60)^0$. Here, the two smaller wedges in the middle serve as the placeholder symbol.

But a placeholder is not the number 0. In 628 CE, the Indian mathematician and astronomer Brahmagupta wrote a treatise, *On the Opening of the Universe*, wherein he argued that there is a number 0, and then he outlined its properties. For example, if a is an integer, then $a + 0 = a$, and $a - a = 0$. These are two of the standard properties you'd see in a modern algebra text. Some of his properties were not correct. For example, he did not define a division by 0 as indeterminate as we would today.

The number 0 was a crucially important invention. Without it, there is no algebra, no equation solving, and for that matter, no modern science or engineering. While the placeholder has been invented many times, the number 0 was only invented once and it happened in India about the 7th century CE.

al-Khwarizmi's book, *Book on Calculation with Hindu Numerals*, introduced the idea of 0 to Islamic scholars. Eventually, the book's Latin translation made its way to Europe around the 13th century. As we have seen, Fibonacci's *Liber Abaci* was instrumental in bringing al-Khwarizmi's work, including the Hindu-Arabic number system and the number 0, to Italy and the rest of Europe.

Synthesis

What the history of ideas makes clear is that the East was much more advanced than the West until about 1500 CE. One of the great puzzles of intellectual history is how the West was able to overcome the East's substantial lead, ultimately dominating the world of ideas.

That issue aside, this chapter makes it clear that the spread of ideas is not usually affected by cultural and ideological differences. Sometimes their dissemination takes time, and sometimes a long time. But eventually good ideas spread.

It also makes clear that science was not an invention of the West. Science had been going on in the East a long time before the West got to it.

14
The Rise of Western Europe

How, between the ninth and the sixteenth centuries, had these bumpkins managed all that?
Alfred Crosby on the rise of Europe, from his book, *The Measure of Reality*.

After Rome fell to the barbarians in 476, Europe entered the Middle Ages, where e-Class discovery slowed significantly. In fact, some have argued that European civilization suffered a near-death experience shortly after the fall of Rome.[1]

[1] Kenneth Clark. *Civilisation: A Personal View*. London: BBC and John Murray, 1969.

Let's fast forward to 1543. The Protestant Reformation, begun in 1517, is starting to catch on. The Renaissance is well underway and Filippo Brunelleschi has discovered linear perspective in art. Johannes Gutenberg innovated his printing press and it was diffusing quickly across Europe. The New World has been discovered. Amid this awakening, a Catholic cleric working in the obscurity of what is now northern Poland published a short monograph entitled *On the Revolutions of the Celestial Spheres* wherein he proposed the crazy idea that the planets, including the Earth, revolve around the Sun! The cleric was Copernicus, and his work represented the opening salvo of the Scientific Revolution, soon to be followed by the Enlightenment and then the Industrial Revolution. Humanity has not looked back. There has been a sustained exponential growth in e-Class ideas over the last five centuries, and particularly since 1800.

What happened? How did we manage to go from the darkness of the early Middle Ages to the intense light of the last five hundred years? We'll argue that religion played a significant role, as did education, changes in exographics technology, and most importantly, a change in *mentalité*—a realization that there was more to knowledge than the wisdom of the ancients, that new knowledge could be discovered and exploited.

There have been some notable books on the history of medieval literacy. One is Michael Clanchy's *From Memory to Written Record*. He explains his thesis in his first paragraph:

> Printing succeeded because a literate public already existed; . . . Writing was not new in 1066, of course, either in England or elsewhere. In the royal monasteries of Anglo-Saxon England, as in other parts of Europe, an original literate culture had been created which was distinguished especially by its illuminated manuscripts of parchment. From these royal and monastic roots, new uses and forms of writing proliferated in the twelfth and thirteenth centuries and took shapes that would last for generations.[2]

[2] Michael Clanchy. *From Memory to Written Record: England 1066–1307*. 2nd. Oxford: Wiley-Blackwell, 1993, p. 1.

The first word in the quotation—printing—refers to Gutenberg's printing press and movable type (c. 1450). What he is arguing is that literacy was in use by the lay population in England in the 12th and 13th centuries, well before the appearance of the printing press.

Brian Stock argues essentially the same thing in *The Implications of Literacy*. Only he goes further. His first sentence is:

> This book is a study of the rebirth of literacy and of its effects upon the cultural life of the eleventh and twelfth centuries.[3]

[3] Brian Stock. *The Implications of Literacy: Written Language and Models of Interpretation in the Eleventh and Twelfth Centuries*. Princeton: Princeton University Press, 1983, p. 3.

Rosamond McKitterick takes exception to both Stock and Clanchy in the first paragraph of her book, *The Carolingians and the Written Word*:

> Literacy and the use of the written word in the early Middle Ages have hitherto been thought to have been confined to a clerical elite, while society at large conducted its affairs orally. Many, indeed, have seen that beginning of 'good things' at the millennium, with a 'rebirth' of literacy in the eleventh and twelfth centuries, as if brand new awakenings and skills appeared in the wake of Halley's Comet to an awed Europe. But if such great changes were taking place in the 11th century, from what were they a change?[4]

[4] Rosamond McKitterick. *The Carolingians and the Written Word*. Cambridge: Cambridge University Press, 1989, p. 1.

She then goes on to describe the uses of literacy over the Carolingian Renaissance of the late 8th and 9th centuries under Charlemagne, which included much more than the exographics of a clerical elite. In fact, McKitterick documents that the Carolingians were doing the same remarkable things with exographics as were done in Clanchy's Norman England—exographics in support of commercial transactions. Private property had been in existence stretching back to antiquity. As we will see, Europe was characterized by increasing commercialization over time. It is clear that, from about 800, an urban mercantile class arose apart from the agrarian class. What were once settlements soon became bustling commercial towns. With this increasing commercialization, the frequency of exchange accelerated. Once again, when we see towns and cities develop, it is mainly to take advantage of specialization, the division of labor, and exchange.

In early medieval times, exchange transactions were largely oral. In addition to the two individuals who executed the exchange, there were witnesses and various forms of ritualistic behavior. For instance, in feudal times, there was a ceremony of homage and fealty when a vassal was recognized by his lord and awarded a fief. One of the rituals in such ceremonies was the lord kissing the vassal on the lips and then saying that the vassal "was his man."[5] Another ritualistic behavior was witness identification by pulling the witness's ear. The rationale for this practice was that touching the ear would jog the witness's memory since, at that time, memory was thought to reside in the ear.[6] Research suggests that this practice has its origin in the *Twelve Tables* of the ancient Roman legal system (5th century). Although it's not explicitly mentioned in the *Twelve Tables*, there are referenced to it in Roman literature, including in Horace's *Satires* and Virgil's *Eclogues*.[7]

[5] Russell Major. ""Bastard Feudalism" and the Kiss: Changing Social Mores in Late Medieval and Early Modern France". *The Journal of Interdisciplinary History* 17, no. 3 (1987): 509–535, p. 510.

[6] This belief came from the oral nature of medieval learning and scholarship. Students learned by listening, not by looking at what a professor or instructor wrote.

[7] Nella Lonza. "Pulling the Witness by the Ear: A Riddle from Medieval Ragusan Sources". *Dubrovnik Annals* 13 (2009): 25–35, p. 31.

Exographics also played a role in social arrangements. Here is an example, "Freising no. 61," a charter executed in the Duchy of Bavaria in 773:

> In the name of God, I have been contemplating and considering my soul and the future life, so that I might deserve to receive great favour before the pious Lord. I, Raholf, had been able to gain my very own property as a gift from the divine giver, which my father left to me as an inheritance. It is pleasing to profit for eternity from the transitory life and to give to Him in this life, He who is able to give back in perpetuity and from whom patrimonies are granted and all the changeable things are distributed. Therefore, as we already expressed in writing above, I was able to bring together whatever I acquired in and whatever I shall add to the place called Jesenwang. I hand over and transfer the buildings, enclosures, unfree persons, livestock, territory, meadows, pastures, and whatever I seem to possess there, to the church of the blessed and always pure Virgin Mary, founded at the episcopal house of Freising, and to Christ's confessor Corbinian. And not only do I give these resources, but I also subject my own body to the service of the church. If anyone tries to go against this charter of donation or wishes to break it, let there be no doubt that he will receive the anger of the divine judge, and when he incurs the wrath of Mary, the mother of God, let him remain condemned under the bonds of excommunication in the displeasure of those saints whose relics are praised there. Let this donation nevertheless remain firm and secure with the subjoined stipulation. Enacted in the episcopal city of Freising in the 26th year of the reign of the lord and most illustrious duke Tassilo on the 18th of the Kalends of September in the presence of Bishop Arbeo and all his clerics. These are the names of the witnesses who were pulled by their ears, as the custom of the Bavarians requires: in the first place, Bishop Arbeo, into whose hands this thing was given. Wulfbert, Magolf, Horskeo priests. Arn, Leudfrid deacons. Chuno. Sullo. Petto. Hitto. Radwald. Arbeo. Wulfleoz. Wicrat and many others. I, Sundarhar, wrote this from the mouth of Bishop Arbeo, subscribed it, and confirmed the witnesses.[8]

[8] This charter is taken from a collection of the charters issued by the first five bishops of Freising, written sometime between 824 and 835. It's available at: https://charlemagneseurope.ac.uk/charter-basics/.

Effectively, a charter is an agreement or declaration around an exchange of property, goods, or rights. Here, an individual, Raholf, is bequeathing all of his property to the Church. There were many of these types of receipt that appeared before Charlemagne, suggesting that the writing associated with exchange predated the Carolingian Renaissance. The point is that commercial writing was present in Europe long before its supposed post-millennium "rediscovery."

THE ORIGINS OF THE CHRISTIAN RELIGION are well known. It was an attractive religion based on some important features, including a forgiving, loving God and eternal salvation. After some very difficult times at the hands of the Romans, things turned around. In 313, the emperor Constantine made Christianity one of the Empire's official religions and in 380, the emperor Theodosius made it the Empire's official religion.

At the fall of Rome in 476, the Christian population was expanding quickly across Europe. Over this expansion, another force was at work: monasticism. Christian men and women interested in a more spiritual life settled in monasteries, abbeys, and convents to lead a disciplined life of work and prayer. St Augustine wrote one of the first guides for monastic life, *The Rule of Augustine*, about 400. Other famous guides include the anonymously written *Rule of the Master* and Benedict's variant of it, *The Rule of Benedict*. These manuals describe Christian organizations where the abbot had strict authority. As one scholar has suggested, this authority could be specific:

> It contains the pleasing provision that the abbot has a right to make a monk blow his nose in a manner likely to give least offence to the attendant angels.[9]

[9] Peter Levi. *The Frontiers of Paradise: A Study of Monks and Monasteries*. New York: Weidenfeld and Nicolson, 1987, p. 51.

One of the more important monastic communities was Cassiodorus's (487–580), a Roman nobleman who built a monastery on his estate at Vivarium. His focus was on education and book production primarily because he saw the need to preserve Roman and Greek culture, and particularly the literate aspect of those cultures. His manuscript, *Institutiones*, set out an educational curriculum centered on scripture. The Benedictines moved to Rome, where they were directed by Pope Gregory the Great to focus on book reproduction and preservation.

One of the important concepts Stock presents in *The Implications of Literacy* is the notion of a textual community. Roughly, a textual community is one in which the thinking, values, self-image, and relations with others outside the community are guided by an authoritative, foundational text. It's a literate way of life in which those in authority teach and interpret the text. The rest undergo a literate education and socialization process with their peers. A good example of a textual community is a monastery where the literate senior monks teach novices. The authoritative text is the Bible, and supporting texts seek to interpret and educate.

Almost all medieval monasteries had a scriptorium where monks would work copying manuscripts. As monasteries spread through Europe, so did literacy and the supply of books. The growth in the number of monasteries over time in various regions of Europe is shown in Table 14.1. Note the tremendous growth up to the 13th century.

	Century					
	10	11	12	13	14	15
Britain	437	526	1325	1530	1447	1333
France	2091	5051	8104	8564	8189	7554
Germany	1129	1652	2873	3110	2967	2752
Italy	995	2072	2990	3405	3416	3333
All Others	1691	3184	4833	5339	5251	5397
Total	6343	12485	20125	21948	21270	20369

Table 14.1: The number of monasteries in selected regions of Europe. This table is adapted from Table 5 in: Eltjo Buringh and Jan Luiten van Zanden. "Charting the 'Rise of the West': Manuscripts and Printed Books in Europe, A Long-Term Perspective from the Sixth through Eighteenth Centuries". *The Journal of Economic History* 69, no. 2 (2009): 409–445.

Europe underwent significant political, social, and economic change over the period 500–1700. The following sketch suggests that Christianity's dependence on literacy eventually had a lot to do with the explosion of human imagination and ideas in Western Europe.

The Church dominated early European medieval politics. Christianity was attractive because it offered the reward of heaven for the faithful who led a virtuous life. Another lever the Church had was excommunication. Any soul excommunicated could not go to heaven. This included kings and those in secular authority. In effect, there was a partnership between the Church and secular authority with the Church as senior partner.

It was important for the Church to defend its teachings. Hence, it had procedures to deal with heretics, those who were accused of taking positions contrary to Church teaching. An individual accused of heresy had a grace period in which they could repent and withdraw their positions. Those who refused could be stripped of their property, excommunicated, and, in egregious cases, put to death, usually by burning at the stake. What's more, the secular authority was put in charge of meting out any penalty the Church imposed, and any wavering on the part of a king could result in his excommunication. If nothing else, this demonstrates the power of an idea: you promise the masses a rapturous eternal life in heaven and then give yourself the authority to take it away with a stroke of a quill. As long as people believed the Church had this power, it gave the Church a vice-like hold on the populace.

During the same period, there was substantial economic change.

Western Europe went from a mainly agrarian rural society to the initial stages of a commercial urban one. There was a significant expansion of mercantilism post-millennium and this fueled population migration to the towns. Education was becoming increasingly important. The monasterial and chancery school systems were expanding.

ANOTHER CRUCIAL DEVELOPMENT was the Protestant Reformation for which there is a massive literature. Our intention is not to review this complete literature but rather we will focus on that part of the Reformation story that is relevant to the expansion of the e-Class.

The first significant challenge to the Church's authority came on October 31, 1517, when the Augustinian monk and professor, Martin Luther, pinned his 95 Theses to the front door of All Saints' Church in Wittenberg, thus beginning the Protestant Reformation.

At that time, Luther was professor of the Bible at the University of Wittenberg. In medieval times, a primary vehicle for the evaluation of university students was the disputation: where a student, under strict procedural rules, was charged with defending an assigned question. In effect, they were debates in which participants tried to find the truth. Professors also gave public disputations so it was not uncommon for a professor to post theses announcing that he would defend them in a public disputation. Hence, there was nothing unusual about Luther posting his theses. What really got things started was Luther appending them in a letter to the archbishop.

Luther's main complaint concerned the Church's sale of indulgences. An indulgence was a benefit that was supposed to reduce the time a sinner would spend in purgatory after death, and they were sold for substantial amounts of money. Sellers often sold forgeries and kept the revenues for themselves. Sometimes they went as far as promising that souls already in hell could go to heaven.[10] Luther questioned the theology justifying indulgences by arguing that salvation could not be purchased.

[10] Alberto Cassone and Carla Marchese. "The Economics of Religious Indulgences". *Journal of Institutional and Theoretical Economics* 15, no. 3 (1999): 429–442.

Another of Luther's difficulties was the Church's position that it alone had the authority to rule on matters of faith and morals. Luther felt that each of the faithful had a right to interpret the Bible as they saw fit, a teaching known as *sola scriptura* ("by scripture alone"). At the heart of the teaching was the notion that the Bible is the sole infallible authority for Christian faith and practice, and not the ecclesiastical leaders of the Church. This was a strong position that demanded a response from the Church.

Luther's positions made a lot of sense to the people of Saxony and his support grew steadily to the point where Frederick the Wise, the Elector of Saxony, decided to protect Luther largely because Saxony was off the beaten track, and Frederick liked the notoriety that

Luther was drawing. Eventually, Luther was called to a special Diet at Worms in 1521 and was challenged to defend his teaching.[11] He responded:

> Since your most serene majesty and your high mightinesses require of me a simple, clear and direct answer, I will give one, and it is this: I can not submit my faith either to the pope or to the council, because it is as clear as noonday that they have fallen into error and even into glaring inconsistency with themselves. If, then, I am not convinced by proof from Holy Scripture, or by cogent reasons, if I am not satisfied by the very text I have cited, and if my judgment is not in this way brought into subjection to God's word, I neither can nor will retract anything; for it cannot be right for a Christian to speak against his conscience. I stand here and can say no more. God help me. Amen.[12]

[11] A Diet was the name given to a deliberative body of the Holy Roman Empire.

[12] Taken from: https://www.bartleby.com/268/7/8.html.

It is startling to read the strength of Luther's conviction in this passage given before the Emperor of the Holy Roman Empire. Luther was asked twice more whether he wished to change his statement, and each time he declined. Keep in mind that this was a heretical position and the Church was not averse to burning heretics at the stake. The trial ended with the Edict of Worms, which branded Luther a heretic. However, he was not arrested because Frederick had negotiated his safe passage to and from the Diet.

Protestantism continued to grow in popularity. Given that the authority for interpreting the Bible on the Protestant side now rested with individuals, it was no surprise to see a number of Protestant sects come into existence, including Lutherans, Calvinists, Hutterites, and many others. Less surprising was that all of these denominations would have serious disagreements about authority. Over the next 130 years, a number of religious wars broke out, ending with the Thirty Years War (1618–1648). Exhausted from conflict, a group of kingdoms, including representatives of the Church, sat down to discuss a new way to resolve disagreements. These talks resulted in the Peace of Westphalia in 1648. This agreement made religious authority an individual responsibility. It would no longer be determined or enforced by the state. Citizens were free to choose one of three denominations (Roman Catholicism, Lutheranism, and Calvinist) without the state's interference.[13] Thus, we have the beginnings of the idea of separation of church and state. An important implication is that the Church could no longer constrain e-Class ideas.

[13] The exception was the Netherlands which practiced wider tolerance.

Returning to the doctrine of *sola scriptura*, Luther argued that if Scripture was to be the sole authority, then the faithful needed to be able to read Scripture. Consequently, Luther was a strong proponent of literacy and urged the princes of Saxony to open schools so that more children could be taught to read the Bible. To make things easier, he translated the Bible from Latin to German and these vernacular editions were extremely popular. Surprisingly, Luther insisted that women be educated. As a result, literacy soared in western Europe. The important implication is that a high literacy rate translated to more e-Class explorers and hence an expansion of the e-Class.

AFTER THE FALL of the Roman Empire, there was still a need to manage bureaucracies and economic exchange, although on a much smaller scale and certainly there was a more local element to this work. If bureaucracies needed to be managed, then there was a concomitant requirement for literacy. So, by necessity, even the "barbarian" peoples that overran Rome needed a literate class to manage the affairs of trade and governance. By the 4th–5th centuries CE, Rome's allies and mercenary forces often included Goths, Vandals, Franks, and others. Apparently, these armies learned to use Roman Latin for contracts, troop rosters, correspondence, and diplomatic communication.

As we have already indicated, what made the difference in Europe was Christianity's deep reach into society. The Church was Europe's largest political entity. It had a large bureaucracy, and whenever you have bureaucracy, you have a requirement for literacy. Moreover, the Church was the quintessential textual community based on the Bible. The need for literate clergy to manage the Church drove the establishment of monastic and chancery schools across Europe.

In the period before 1000, the European population was largely rural and uneducated. However, there were pockets of education and enlightenment. As we have already suggested, one of these was the Carolingian Franks who went through their Renaissance in the 8th and 9th centuries.

Charlemagne (742–814) ruled over much of Western Europe from 768 to 814. He was a wise leader who placed great value on literacy and education and is largely responsible for initiating the Carolingian Renaissance. Charlemagne's principal architect of this awakening was the English scholar and cleric Alcuin (735–804). We know a lot about Alcuin because much of his extensive correspondence survives. He was educated at the cathedral school in York where he later became headmaster. In 781, he met Charlemagne who invited him to his court in Aachen. Charlemagne wanted to bring together the best teachers and scholars in Europe and Alcuin was one of them. He arrived in Aachen in 782.

Soon after, in 787, Charlemagne issued the *Charter of Modern Thought*, a declaration that his program of reform would include the establishment of a school system to bring literacy to as many as possible. It began in the palace school where the program of instruction moved from one of military arts and court protocols to one of general learning and literacy. Subsequently, he instructed the monastery and cathedral schools across his empire to take in lay students in addition to those students who were training for permanent positions within these institutions.

We know that Europe underwent a considerable economic and social transformation between 800 and 1500. Throughout the early Middle Ages, Europe was basically an agrarian society assembled around small villages. Exchange was largely by barter. After 1000, agricultural production expanded considerably due to climate change and a number of technological innovations, including wind and hydro-power to run grain mills and other processes, the wheeled carruca plow pulled by shoed horses rather than oxen, and a shift from a two-field to three-field rotation of crops. All of these innovations helped make agriculture more productive.

As this agricultural expansion continued, towns and cities grew in population and trade with Arab urban centers in the East increased significantly. Some estimates have the population of Europe doubling between 1000 and 1300 and there are estimates that the per capita GDP almost doubled over the period 1000 to 1500.[14] This expansion of trade gave rise to a merchant class, a significant growth in money supply and investment capital, and the movement away from barter to an exchange economy based on money and credit. It also brought with it a significant requirement for education.

[14] Angus Maddison. "The West and the Rest in the World Economy: 1000–2030". *World Economics* 9, no. 4 (2008): 75–100.

Post millennium, we start to see some interesting things happening. The historian Charles Homer Haskins was the first to note the renaissance of the 12th century:

> This century [the 12th century] was in many respects an age of fresh and vigorous life. The epoch of the Crusades, of the rise of towns and of the earliest bureaucratic states of the West saw the culmination of Romanesque art and the beginnings of Gothic; the emergence of the vernacular literatures; the revival of the Latin classics and of Latin poetry and Roman law; the recovery of Greek science, with its Arabic additions, and of much of Greek philosophy; and the origin of the first European universities. The 12th century left its signature on higher education, on scholastic philosophy, on European systems of law, on architecture and sculpture, on the liturgical drama, on Latin and vernacular poetry.[15]

[15] Charles Homer Haskins. *The Renaissance of the Twelfth Century*. Cambridge MA: Harvard University Press, 1927, p. vi.

The monastic and chancery schools did not have sufficient capacity to educate all who wanted it, so a great many private schools came into existence.

Importantly, universities first appeared: Bologna (1088), Salamanca (1134), Oxford (1096–1167), Paris (1160–1250), and Cambridge (1209). Over time, many more were added. Table 14.2 shows the number of universities added each century from the 12th to 17th centuries. Note the high rate of growth over time. Also note the stunning increase in the 15th century, the century Gutenberg innovated his printing press.

Century	Change in the Number of Universities
12	7
13	20
14	44
15	118
16	150
17	182

Table 14.2: The number of universities added each century in Europe. This table is adapted from Table 7 in: Eltjo Buringh and Jan Luiten van Zanden. "Charting the 'Rise of the West': Manuscripts and Printed Books in Europe, A Long-Term Perspective from the Sixth through Eighteenth Centuries". *The Journal of Economic History* 69, no. 2 (2009): 409–445.

In the context of e-Class discovery, universities are interesting in that they are a microcosm of the difficulties that exographics has had breaking into oral cultures. As we've documented, this problem goes back to Plato's negative views on exographics. In the pursuit of truth, Plato saw exographics as inferior to two minds working dialectically. We now know a lot more about the good things exographics can do for us, but in the early days of universities, scholars were influenced by the scholars of antiquity. Guided by Plato's ideas, some of the early universities had regulations that prohibited students from taking notes in class. They also outlawed lecturing in which teaching masters spoke slowly enough to enable student note-taking. This prohibition of note-taking was based on the belief that students' minds were strengthened if they didn't take notes. Note-taking, as their argument went, would undermine and weaken the strength and quickness of mind developed by purely oral learning.

In 1452, Cardinal d'Estouteville eliminated the strict rules banning note-taking at the University of Paris. He also argued that teaching masters had to lecture at a pace which allowed students to take notes, although it appears that he left the choice open to individual lecturers, permitting both types of lecturing.[16]

[16] Robert Rait. *Life in the Medieval University*. London: Cambridge University Press, 1918.

As already noted, when the first universities came into existence, the main vehicle used to test a student's knowledge and ability to reason was the disputation, an oral dialectical argument. At modern universities, the main vehicle of examination for the PhD is a written dissertation, a practice that only began in the 18th century. Although the written dissertation is the main vehicle of examination today, we still ask students to defend their ideas orally. The fact that orality was the primary medium of thesis examination for centuries speaks to the difficulty of exographics becoming the medium of choice at universities.

So, orality was firmly the medium of choice in early university pedagogy. But over time, the dominant medium became visual because we discovered that writing could enhance learning outcomes.

One of the longer-term trends in human thought has been our gradual acceptance of the idea that we can explain the world without recourse to myth and the gods. Some of our ancient ancestors saw solar eclipses as an omen or message from their gods. But now we're able to explain eclipses as as a consequence of the movements of the Earth and Moon around the Sun in the same way that your shadow moving along the ground is an artifact of you walking on a sunny day.

This change in *mentalité* has had a long gestation but generally begins with the Mesopotamians and the discovery of their e-Class ideas, although all of the Mesopotamian civilizations had a healthy respect for their gods. In Europe, after the fall of Rome, the Church held a firm grip. For example, Church teaching was that Earth was at the center of the universe as in Ptolemy's geocentric model of the heavens. But then things started to change as we began to learn more about how nature worked. Copernicus entertained a model of the heavens in which the Earth revolved around the Sun. Galileo came within an inch of his life for being Copernicus's cheerleader. Newton saw things the way Copernicus and Galileo did while contributing with a set of fundamental laws that governed the movements of heavenly bodies.

Notwithstanding these initial steps to understand how the world really worked, the average person, in 1600, believed in much we don't today. The following picture is painted by David Wootton:

> In order to grasp the scale of the Revolution, let us take for a moment a typical well-educated European in 1600—we will take someone from England, but it would make no significant difference if it were someone from any other European country as, in 1600, they all share the same intellectual culture. He believes in witchcraft and has perhaps read the *Daemonologie* (1571) by James VI of Scotland, the future James I of England, which paints an alarming and credulous picture of the threat posed by the devil's agents. He believes witches can summon up storms that sink ships at sea . . . He believes in werewolves . . . He believes Circe really did turn Odysseus's crew into pigs. He believes mice are spontaneously generated in piles of straw. He believes in contemporary magicians . . . He has seen a unicorn's horn, but not a unicorn.
>
> He believes that a murdered body will bleed in the presence of the murderer. He believes that there is an ointment which, if rubbed on a dagger which has caused a wound, will cure the wound. . . . He believes that is is possible to turn base metal into gold, although he doubts that anyone knows how to do it. . . . He believes the rainbow is a sign from God and that comets portend evil. He believes that dreams predict the future, if we know how to interpret them. He believes, of

> course, that the Earth stands still and the Sun and stars turn around the Earth once every twenty-four hours—he has heard mention of Copernicus, but he does not imagine that he intended his Sun-centered model of the cosmos to be taken literally. ... He owns a couple of dozen books.[17]

[17] David Wootton. *The Invention of Science: A New History of the Scientific Revolution*. New York: HarperCollins, 2016, p. 16.

But this belief in magic, folk wisdom, and the wisdom of the ancients was giving way to a view that the force of reason and empiricism could enable us to understand how nature actually worked. This was no more evident than in a realization by the Jesuit Jose de Acosta (1539–1600):

> I will describe what happened to me when I passed to the Indies. Having read what poets and philosophers write of the Torrid Zone, I persuaded myself that when I came to the Equator, I would not be able to endure the violent heat, but it turned out otherwise. For when I passed [the Equator], which was when the sun was at its zenith there, having entered the zodiacal sign of Aires, in March, I felt so cold that I was forced to go into the sun to warm myself. What could I do then but laugh at Aristotle's Meteorology and his philosophy? For in that place and that season, where everything, by his rules, should have been scorched by the heat, I and my companions were cold.[18]

[18] Taken from: Anthony Grafton. *New Worlds, Ancient Texts*. Cambridge MA: The Belknap Press of Harvard University Press, 1992. Grafton's bibliographic entry is: J. de Acosta, *The Natural and Moral History of the Indies*, 1590, translated by E. Grimston, New York.

Acosta now had direct evidence that the ancients, in this case Aristotle, didn't have a corner on all knowledge, and sometimes were just plain wrong. Others had the same realization, and not long after this, we have the Enlightenment and Kant's famous dictum *Sapere aude* or "Dare to know." There is still a healthy respect for the ancient wisdom, but the outlook is forward with new ideas rather than backward to the old ideas. Some intellectual historians have termed this new period of forward-looking rationality and empiricism *Modernity* and its beginning is generally associated with the Scientific Revolution and the Enlightenment.

ONE OF THE GREAT ACCOMPLISHMENTS of Europe was the adoption of the standardized measures of the Metric system and the Imperial System. We'll summarize a few points about them here. But before that, we'll relate a relevant modern incident.

On July 23, 1986, Air Canada Flight 143, a brand new Boeing 767, was headed to Edmonton from Montreal when it ran out of fuel at 41,000 feet. At the time, Air Canada was transitioning to the Metric system from the Imperial system. As a result of some nonroutine events prior to Flight 143 departing, the ground crew had to measure the volume of fuel in the aircraft's tanks manually and then convert it to kilograms, a measure required by the aircraft's onboard computer. The ground crew used a dipstick to measure the metric volume (liters) in the tanks but then used the wrong factor to convert it to kilograms. They used the Imperial conversion factor

1.77 pounds/liter when they should have used the Metric factor of 0.8 kilograms/liter. As a result, the aircraft had only half the fuel it required for the flight. Previously, maintenance had disabled the aircraft's fuel gauges, so the aircrew had no way of knowing what was actually in the tanks before takeoff. In retrospect, it seems that what could go wrong was going wrong.

Despite the grim circumstances of a 132-ton aircraft at cruising altitude running on empty, the landing went surprisingly well. The pilot happened to be an experienced glider and the First Officer was a retired Canadian Air Force pilot. When they realized they couldn't make Winnipeg, the First Officer suggested they try for Gimli where he knew there was a decommissioned Canadian Armed Forces air base with a runway. To make a longer story shorter, the aircrew were able to land in Gimli. All souls on board walked away from the "Gimli Glider."

This almost tragic set of events serves to point out the importance of the standardization of measurement. Had Canada been on only one measurement system, there would be no Gimli Glider. Needless to say, there are many other examples where measurement error has resulted in significant loss.[19]

At the end of the 18th century, the French were the first to attempt establishing a national system of weights and measures with their Metric system. Before that, the system of standards was a mess and new standards were proliferating at a high rate. Ronald Zupko has written a wonderful history detailing the chaos.[20] In his first chapter, Zupko goes into great detail on hundreds of measurements and these, he argues, are only a small fraction of the measurement units in existence at the time. Here is one of his first paragraphs:

> Central governments contributed substantially to weights and measures proliferation by promulgating several national standards for individual units that had widespread usage throughout their respective domains. In France, for example, the arpent was the principal treasure of area for land, but there were three official standards. The "arpent de Paris" contained 100 square perches, each perche of 18 pieds in length. It was a square whose four sides were 180 linear pieds each, totaling 32,400 square pieds (34.189 a). The "arpent des eaux et forêts" contained 100 square perches, each perche of 22 pieds in length; its four sides were 200 linear pieds each, totaling 48,400 square pieds (51.072 a). The "arpent de commun"—authorized for use in the provinces—was 100 square perches, each perche of 20 pieds. This square had sides of 200 linear pieds each, totaling 40,000 square pieds (42.208 a). The corde, a measure of volume for firewood, also had three national standards: the "corde des eaux et forêts" was a pile 8 pieds long, 4 pieds high, each billet being 3 pieds, 6 pouces in length, or 112 cubic pieds (3.839 cu m) in all; the "oorde de port" was a pile 8 pieds long, 5 pieds high, each billet being 3 pieds, 6 pouces in length, or 140 cu-

[19] For NASA's Mars Climate Orbiter Project, the $327 million spacecraft arrived at Mars in 1999 but was lost because, to calculate thrust, Lockheed Martin used imperial units (pounds) and NASA used metric units (newtons). As a result, the spacecraft entered the Martian atmosphere at the wrong angle and disintegrated.

[20] Ronald Zupko. *Revolution in Measurement: Western European Weights and Measures Since the Age of Science*. Philadelphia: American Philosophical Society, 1990.

> bic pieds (4.799 cu m) in all; and the "oorde de grand bois" was a pile 8 pieds long, 4 pieds high, each billet being 4 pieds in length, or 128 cubic pieds (4.387 cu m) in all. In the late eighth century the perche was fixed under Charlemagne at 6 aunes or 24 Roman pieds (ca. 7.09 m) and this remained the national standard until the end of the Middle Ages when it was replaced by three other perches: the "perche de Paris" of 3 toises or 18 pieds (5.847 m); the "perche de l'arpent cannon" of 20 pieds (6.497 m); and the "perche des eaux et forêts" of 3 2/3 toises or 22 pieds (7.146 m).[21]

[21] Ibid., p. 4-5.

This description and others like it begin on page 4 and run to page 24, and as mentioned above, these pages are only a small sample of the standard measures available at the time. Regarding this proliferation, Zupko writes:

> Tens of thousands of new units were introduced and hundreds of thousands of local variations emerged from the Atlantic coast to central and eastern Europe.[22]

[22] Ibid., p. 4.

Hence, these measurement standards varied from region to region within a country and across countries.

Some of the standards chosen were odd. For example, many weight measures in Scotland were based on the standard of the "weight content of river water poured into certain vessels":

> The boll, first standardized under David I at 12 gallons or the capacity of a vessel 9 inches deep and 72 inches in circumference, was commonly regarded throughout the Middle Ages as any vessel capable of holding 164 pounds of the clear water of Tay [longest river in Scotland]. By 1600 it was fixed at 4 firlots or 8789.34 cubic inches (1.441 hi) and equal to 4.087 Winchester bushels for wheat, peas, beans, rye, and white salt, and 12,822.096 cubic inches (2.101 hi) and equal to 5.963 Winchester bushels for oats, barley, and malt. Both bolls were equal to 16 pecks or 64 lippies. The firlot of Edinburgh was the standard after 1600 for wheat, peas, beans, rye, and white salt, 21 1/4 pints (3.612 dkl) or 103.404 cubic inches each or 2197.335 cubic inches in all and equal to 1.0218 Winchester bushels, while the Linlithgow firlot was the standard after 1600 for barley, oats, and malt, 31 pints (5.270 dkl) or 3205.524 cubic inches and equal to 1.4906 Winchester bushels. Prior to 1600 the firlot was defined as a vessel holding 41 pounds of the clear water of Tay. The Scots gallon for liquids and dry products contained 827.232 cubic inches (ca. 13.60 l) or 4 quarts, 8 pints, 16 choppins, 32 mutchkins, or 128 gills. Throughout the Middle Ages it was defined as a vessel capable of holding 20 pounds and 8 ounces of the clear water of Tay. Finally, the pint of post-1600 vintage of 103.404 cubic inches (ca. 1.70 l) was defined in medieval Scottish legislation and in several acts thereafter either as 2 pounds and 9 ounces of the clear water of Tay, or as 2 pounds and 9 ounces troy weight of clear water, or as 3 pounds and 7 ounces troy weight of water from the river of Leith. The daily or yearly water purity of the two rivers must have caused medieval Scotsmen untold problems.[23]

[23] Ibid., p. 6-7

Further on, he describes an even stranger standard:

> In France the houpée was the distance recorded between one man who remained stationary and shouted ″houp″ or ″hop″ and another man who walked down the road and stopped at that point where he could no longer hear the shouts.

It's been suggested that this measure may have had some use in vineyards.

As Zupko indicates, this proliferation of local standards made trade and commerce difficult. As we understand today (and as central authorities back then realized), there are great advantages to a uniform system of weights and measures based on objective standards. But it was difficult to impose such a standard on regional centers of trade because local governments had a clear monetary incentive to maintain their local systems of weights and measures.

Let's take the example of grain. In many medieval towns, grain was sold by the bushel (or whatever the local unit happened to be). But the size of a bushel (the physical container) could vary significantly from town to town. Local government officials (grain measurers, inspectors, market clerks, etc.) were responsible for certifying that the containers used in the local marketplace satisfied the local measurement standards and charged a fee to do so. If a higher authority (say, the crown or a distant parliament) tried to impose a uniform bushel size across the kingdom, these officials would become less relevant and fee revenues would be lower. Hence, all local governments had a strong incentive to resist the central authority.

As we now know, these local governments, while powerful, were overcome. But it took the better part of 50 years to do so. It wasn't until the 1840s that the Metric system was widely accepted in France. By the 1820s, Britain imposed their Imperial system which they then took to the world as the British Empire expanded. After that, European countries, one by one, began to adopt the Metric system. Due to the strong support of the Metric system by scientists and industrialists, Britain eventually relented and allowed its use alongside the Imperial system in 1890.

As for working to science-based standards, let's consider the definition of the meter. The Metric system's first definition was this:

> One ten-millionth of the distance from the North Pole to the Equator, measured along the meridian that passes through Paris.

The story of how this was done is fascinating. But for our purposes, note that this approach defines a meter with the measurement of another distance. Somehow you have to get an accurate estimate of the distance along the meridian that passes through Paris and then estimate the distance of the North Pole to the Equator. Eventually, the French arrived at a length, scientifically determined, that was embodied in a platinum bar—the *Mètre des Archives* held in Paris.[24]

The current definition of a meter is:

> The distance light travels in $1/299,792,458$ of a second where a second is defined to be the time it takes a cesium-133 atom to do $9,192,631,770$ oscillations.

[24] Some readers might wonder why the French went through this complex scientific procedure to arrive at their definition of 1 meter. So did we and we've yet to find a reasonable explanation.

Apparently, this definition results in a standard meter length that does not vary much. It's approximately 10^{-9} or 1 part in a billion. But it can be much more accurately measured if required. In some labs, the error can be as low as 10^{-18}.

So why do we have to be this accurate? What would be so wrong with deciding on an arbitrary length for a meter by taking a rod, cutting it to an arbitrary length, and then declaring that to be your meter. You could distribute copies of this rod so that people making measuring sticks and tape measures could replicate the length of the original.

This approach is certainly reasonable for some uses, but there are many modern applications that require a very accurate meter measurement. These include GPS systems, nano-manufacturing applications, chip manufacturing, quantum devices, and many other applications. The modern definition of a meter seems odd but it's required.

Several points to summarize. First, we note the key requirement for exographics if you are going to measure. Any measurement involves a physical comparison of two things: the object to be measured and the standard that you are using to measure that object. It generally requires the body and hands, the operation of a measuring device (the standard), and the reading of the measurement which requires exographics. Hence exographics are required both in the marking of the measuring device and in the recording of the measurements themselves. Even though our desire to measure led us to discover exographics originally, it's now the case that *we can't measure without exographics*. We conclude that measurement and, in particular, the establishment of standard measures were important e-Class ideas.

LET'S SUMMARIZE the chapter. Some historians see the Middle Ages in Europe as a period when civilization hung in the balance. Almost overnight Europe went from the high culture of the Roman Empire to a patchwork of warring tribes. The view from outside Europe at the time was not hopeful. Here is what the Muslim geographer al-Masudi wrote about Europeans around the turn of the millennium:

> As regards the people of the northern quadrant, they are the ones for whom the sun is distant from the zenith, as they penetrate to the

> north, such as the Slavs, the Franks, and those nations that are their neighbors. . . . The warm humor is lacking among them; their bodies are large, their natures gross, their manners harsh, their understanding dull, and their tongues heavy. . . The farther they are to the north the more stupid, gross, and brutish they are.[25]

[25] Bernard Lewis. *The Muslim Discovery of Europe*. New York: Norton, 2001, p. 139.

From what we've been able to glean from the history of ideas, Europe made phenomenal progress over the Middle Ages. We arrived at Modernity, and as the 17th century opened, our mining of e-Class ideas began to quicken considerably. In our view, the history of the Middle Ages is one of great intellectual progress.

It begins with Christianity and the Church. Christianity became the religion of the Roman Empire and was attractive enough that it quickly spread across Europe. It was a textual community centered on the Bible and, therefore, literacy was important. Literacy was also important in the management of the Church. The Church was the largest political organization in Europe over the Middle Ages and, as we've seen, any large bureaucracy requires literacy to run.

The Church was all powerful as the 16th century opened. But cracks were beginning to form. As the 16th century progressed, the Reformation increased in popularity and this weakened the authority of the Church. As we've seen, the nature of Luther's Protestantism encouraged literacy. After the Peace of Westphalia, the Church's authority in the world of ideas virtually disappeared. Basically, no idea was off limits. Copernicus was concerned about publishing his idea of a heliocentric universe. Galileo got into terrible difficulty, almost paying with his life. But when Darwin suggested that humans and monkeys shared a common ancestor, the reception given to the idea was much easier by comparison. Religion had less influence over ideas.

As we pointed out earlier, we also made progress in the technology of exographics, going from stylus, papyrus, and rolls to quills, parchment, paper, and the codex. However, at the top of this list was Gutenberg's innovation of movable type and the printing press. Even though the Chinese had invented both long before, Gutenberg was able to innovate a technology that was perfect for taking a phonetic language like Latin and the various vernaculars and bringing them to the printed page. The printing press diffused quickly, and with it, book production soared. In 1450, Europe was ready for the book.

An essential input for the mining of e-Class ideas is education. Very early in medieval Europe, monastic and chancery schools carried the load in literacy education. After the turn of the millennium, private schools were also added. The most important development in medieval education was the university. There were only a few in the 12th century but 182 at the close of the 17th century. Higher education had arrived. The early universities were dominated by oral exchange between teaching masters and students, but around the time of the Protestant Reformation, there was a gradual switch to a visual medium, and today universities are producing a large quantity of e-Class ideas, particularly after 1800.

The explosive growth in e-Class ideas began in the late medieval period. With the arrival of Modernity, we see in quick succession the Scientific Revolution, the Enlightenment, and the Industrial Revolution. We made great advances in music and mathematics. In music, beginning with the innovation of staff notation, composers were able to arrange polyphony of stunning complexity and beauty. In mathematics, Hindu-Arabic numbers supplanted the Roman system, and eventually algebra and modeling diffused across Europe and particularly the universities.

It's hard not to be impressed with the growth of the e-Class in Europe. We were doing all the right things. Exographics technologies improved. The education systems were sufficient to produce scholars who would generate significant new e-Class ideas. In summary, educated, socially constructed imaginations employed exographics to mine a substantial increase in e-Class ideas.

Certainly, Western Europe could be characterized as having a techno-literate culture. There was much e-Class discovery, a substantial education system, and substantial social institutions (including the new form we now call a nation-state) based on literacy and measurement. In sum, techno-literate culture took a big step forward with the progress of Western Europe.

15
The US and Digital Exographics

The new electronic independence re-creates the world in the image of a global village.
Marshall McLuhan

Since settling North America in the 17th century, the Americans have managed to build one of the most innovative techno-literate cultures. Here is a short list of the e-Class contributions they've given the world:

Travel: air (the Wright Brothers), space (the Saturn V rocket, the Apollo Program, the Space Shuttle), road systems, and Ford's idea of an assembly line to produce cars.

Entertainment: the camera, the video camera (Edison), movies, animation, video games, television, phonograph (Edison), music (folk, rock, and jazz).

Power: modern power networks, the light-bulb (Edison), nuclear energy (the Manhattan Project, fission).

Science and engineering: electro-magnetism, chloroform, commercialization of the telephone, nanotechnology, biotechnology including mRNA vaccines and protein folding, mapping the human genome, gene-editing techniques, the MRI, the great telescopes including the Hubble and James Webb.

We could extend this science and engineering list considerably, but there is one class of such ideas that has really propelled the world into a different age and that is the digitization of the exographics record.

The Information Age began in ancient Sumer when we invented exographics and then started to build an exographics store of information we've termed the e-Library. For millennia, we've built great libraries to store the exographics record. An example is Trinity College Dublin's Old Library, shown in Figure 15.1. By some estimates, there are 2.5 million libraries world-wide and that doesn't include the libraries of individuals. There are approximately 12 million university professors across the world and each of these would have a small library of books in their field. Each year, buyers shell out approximately $76 billion for the 2.2 billion books they purchase. The "bricks and mortar" e-Library is large and growing.

Figure 15.1: The Long Room of the Old Library at Trinity College, Dublin. Photo by David Iliff, CC BY-SA 4.0.

Over the last fifty years, we've made considerable progress in the digitization of the e-Library through digital technology including the Internet and its expansion. At this writing, the Internet is estimated to be 149 zettabytes of information. By our rough calculation, that's equivalent to over 2 million British Libraries. The Internet is wired with over 2 million kilometers of cable including underwater cable. That's about 5 times the distance from the Earth to the Moon. Suffice it to say that the Internet is now large and a considerable proportion of it is exographics. With apologies to British computer scientist Sir Tim Berners-Lee, the invention and expansion of the Internet is largely the result of American e-Class ideation.

It's worth taking a moment to think about what this vast exographic store represents. Think of the effort that goes into producing just a small piece of this expanse. For example, a single article in a reputable journal like *Nature* or *Science* is about 6 pages long. The work by the author—more likely authors—to produce that paper is usually measured in years. Hence, there is an extraordinary amount of e-Class thinking that sits behind many entries in the exographic record, ranging from working papers to journal articles to books.

Our ancestors could certainly process numbers with their exographics technology and the number systems they used. However, over time, there was a push to innovate technologies that would speed up the arithmetic associated with measurement. One such device was the abacus, and there is some evidence that it was used by the Sumerians 5,000 years ago. The ancient Greeks used it, and the Romans used a variation of it called a counting board. These counting boards were in general use in Europe even after Europe moved to the Hindu-Arabic number system.

In the 17th and 18th centuries, innovation of computing machines continued with Blaise Pascal's "Pascaline" and Gottfried Leibniz's mechanical calculator. Charles Babbage proposed to build a massive mechanical calculator having some of the characteristics of a modern computer, but he was never able to complete one of his designs, probably because they were far too large and complex.

Things really started to change once the Americans began to work on the problem in the 1940s. The story starts with John Atanasoff and Clifford Berry's ABC computer, the first digital computer and much faster than the analog machines designed by Vannevar Bush and others. It used electric switches to store numbers: if a switch was on, it was a 1, and if it was off, it was 0.

In 1944, Harvard mathematician Howard Aitken built a digital computer about 17 meters in length based on electric relays. This machine had the disadvantage that the relays were large, slow, and used a lot of power.

The ENIAC, the first general-purpose digital computer, was built in 1946 by two scientists at the University of Pennsylvania, John Mauchly and J. Presper Eckart. It used 18,000 vacuum tubes and, like the electric relays, each vacuum tube could go on and off to store 1s and 0s. It was over 26 meters long and weighed over 30 tons. But Mauchly and Eckart did not stop there. They teamed up with mathematician John von Neumann to build more advanced machines. Von Neumann was the first to suggest the notion of a stored program, an important principle we still use today. The three teamed up to build the UNIVAC 1, the first digital computer to work on commercial problems (the US census).

There were some problems with these early electric digital machines. They were large, susceptible to breakdown, and extremely expensive to build. To solve these problems, the first step forward was the invention of the transistor by William Shockley, John Bardeen, and Walter Brattain. Transistors were like vacuum tubes in that they were on or off, but they had some significant advantages. They were much smaller, used very little power, and were much more reliable.

Schockley decided to leave Bell Labs and start his own company, Shockley Transistor, to pursue his work on the transistor. There, he hired some exceptional engineering talent including Robert Noyce and Gordon Moore who, upon disagreements with Schockley, decided to start their own company, Fairchild Semiconductor.

It was at this time that Jack Kilby, working at Texas Instruments in 1958, managed to build the first integrated circuit. His prototype worked, but his design had the major disadvantage that it required thousands of transistors to be externally wired. About a year later, Robert Noyce invented the monolithic integrated circuit, a large circuit, complete with transistors and other necessary components, etched on silicon with no massive requirement for external wiring. This "chip" was the real breakthrough in modern digital technology. It enabled us to build bigger and faster computers simply by designing more complex chips. The most recent computer chips have billions of transistors compressed into a very small space.[1] The average smartphone runs on a chip with 10 billion transistors and is about the size of a fingernail.

[1] At this writing, Cerebas Systems has manufactured its Wafer Scale Engine 3 (WSE-3) which has over 4 trillion transistors.

Among the many contributions that enabled modern digital technology, the work of Kilby and Noyce was crucial. The integrated circuit is small, requires very little human work to integrate into a computer, and is very reliable. It was a breakthrough that built on the large array of inventions that preceded it.

IT'S ONE THING to build an electronic corpus of exographics. It's quite another for individual users to be able to search and access the information. To this end, there have been a number of important major trends since the invention of the integrated circuit: the development of personal computers, the introduction and development of network computing and the Internet, the development of Internet search engines, the development of mobile wireless computing, and the development of AI. All have an associated history of innovation much like the one for the development of the chip we've just described. Furthermore, there does not appear to be any let-up in sight. Researchers will continue to refine existing technologies and develop new ones.

Personal computing devices include desktop and notebook computers, tablets, and smartphones. The development of network computing, the Internet, and search engines enables us to access the exographic record for the information we need. And finally, mobile computing enables us to search and access from just about the four corners of the Earth. When it comes to information search, there are search engines like Google. But, more recently, AI has provided some excellent tools. The Large Language Models now being produced enable users to quickly get to the information they need, albeit care must be taken to make sure the information accessed is correct.

The development of digital technology has moved the world considerably along the path to McLuhan's global village. We are now getting close to what is essentially instantaneous access to information, which clearly bodes well for our mining of the e-Class. Despite the obstacles of nation-states, information technology appears to be moving us closer to a shared global techno-literate culture.

Finally, we note the unintended benefits of technologies. Our ancient ancestors invented exographics to store important information in the management of their resources. But subsequently, it was used to develop e-Class ideas, a benefit those ancient scribes would never have predicted.[2] In the same way, we began to pursue computer technology for the purpose of being able to do arithmetic quickly. But we now use it to do so many other important things. We bank and pay our bills online, we pay for our groceries with a debit or credit card, we check when an event is scheduled, we can call or text a friend with a smartphone, and we can write a novel on a computer. So much of what we do now is done in a digital exographics world.

[2] This use of a technology for another purpose is sometimes called "functional re-purposing." The equivalent term for re-purposing adaptations in biological evolution is "exaptation."

THE US MIGHT BE the quintessential modern techno-literate culture. The country is literate, has strong socio-economic institutions to support innovation, and has probably the best system of elite education in the world. This shows up in an examination of the list of Nobel Prize winners by country. The US ranks first with 420 awards; the United Kingdom is a distant second with 142 awards.

16
Does Exographics Explain "The Great Divide"?

These words ... called into existence an entirely new train of thought. ... I now understood what had been to me a most perplexing difficulty—to wit, the white man's power to enslave the black man.
Frederick Douglass (1818–1895), upon realizing the power of writing. Born a slave, Douglass became a free man, a friend of Abraham Lincoln, and one of the leading public intellectuals of 19th century America.

There are many oral cultures in the world today and, generally, these have substantially different lifeways than those of techno-literate cultures.[1] The Sentinelese inhabit North Sentinel Island in the Bay of Bengal to the east of India. Not much is known about their culture. They survive on the island's flora and fauna as well as what they can harvest from the sea. There are reports that they are not yet able to control fire.

[1] An oral culture is generally defined to be one where the culture's language has yet to be codified in a written script.

The anthropologist Jack Goody has labeled the difference between these two types of society The Great Divide, and he and others have attributed the difference to exographics.[2] The claim was met by a sizable reaction based largely on the empirical results of Sylvia Scribner and Michael Cole.[3] Today, the conventional wisdom is that exographics is, at best, a contributing factor. But we intend to argue that exographics is the explanation.

[2] Jack Goody and Ian Watt. "The Consequences of Literacy". *Comparative Studies in Society and History* 5, no. 3 (1963): 304–345.

[3] Sylvia Scribner and Michael Cole. *The Psychology of Literacy*. Cambridge MA: Harvard University Press, 1981.

Initially, we'll look at cognition and innovation in oral societies. The evidence suggests that, while there may be a cultural divide, *there is no cognitive divide*. Thereafter, we'll argue that exographics plays a significant role in explaining The Great Divide. Our position is that it amounts to the e-Class which, in turn, would not exist without exographics.

I. J. Gelb, in his book *A Study of Writing*, wrote the following:

> To this statement might be added the opinions of many other great men—among them Carlyle, Kant, Mirabeau, and Renan—who believed

> that the invention of writing formed the real beginning of civilization. These opinions are well supported by the statement so frequently quoted in anthropology: As language distinguishes man from animal, so writing distinguishes civilized man from barbarian.[4]

[4] I. J. Gelb. *A Study of Writing*. Chicago: University of Chicago Press, 1952, p. 221.

As Gelb suggests, the early anthropologists felt the same way. Among them, Lewis Henry Morgan was most influential. In his book *Ancient Society* (1877), he argued that European civilization was the apex of human evolutionary achievement. He felt that there were stages of civilization along the way and that oral Indigenous societies, with their simple and sometimes barbaric lifeways, were going through the necessary stages that would eventually lead them to enlightened, literate cultures.

We now know that Morgan's notion of all cultures following a single evolutionary path which eventually leads to a techno-literate culture is nonsense. In our view, the lifeways of oral cultures demonstrate that these "barbarians" have a remarkable ability to innovate, suggesting that "the savage mind" is made of the same Promethean clay as those of us inhabiting techno-literate cultures. Let's now look at the evidence.

Alexander Luria, the eminent Russian psychologist, did important work in a number of areas. One of these was research on the cognition of illiterate Russian peasants in the 1940s.[5] He and his team interviewed a sample of these peasants to gain some insight into how they thought. He asked straightforward questions based on Western logic, things like categorization and the interpretation of syllogisms. His results constitute an extraordinary window into how nonliterate people think.

[5] Alexander Luria. *Cognitive Development: Its Cultural and Social Foundations*. Cambridge MA: Harvard University Press, 1976.

We will describe only one of Luria's interviews, the one with Nazir-Said, age 27 and illiterate. He was first asked this:

> There are no camels in Germany. The city of B is in Germany. Are there camels in B?

Effectively, he is being asked to complete a syllogism. The first two sentences constitute the premises and, based on these, Nazir-Said is asked a question about the syllogism's conclusion. The interviewer then repeats the question: "So are there camels in Germany?" and Nazir-Said responds "I don't know, I've never seen German villages." At this point the interviewer repeats the question: "Are there camels in Germany?" This time Nazir-Said responds "There are no camels in Germany, are there camels in B or not? So probably there are. If it's a large city, there should be camels there." The interviewer then asks "But what do my words suggest?" and Nazir-Said replies "Probably there are. Since there are large cities, there should be camels." The interviewer then suggests "But if there aren't any in all of Germany?" and Nazir-Said's response is "If it's a large city, there will be Kazakhs or Kirghiz there." Again, the interviewer takes exception: "But I'm saying that there are no camels in Germany and this city is in Germany" and Nazir-Said responds "If this village is in a large city, there is probably no room for camels." Nazir-Said clearly does not understand the syllogism and so can't generate the conclusion. All other nonliterate interviewees gave essentially the same response.[6]

[6] Luria, *Cognitive Development*, p. 112.

In addition to nonliterates, Luria also interviewed some of the younger people who had been to the local schools for one or two years. All were asked the same kind of problems the nonliterate persons were asked. Table 16.1 summarizes the overall results for the question put to Nazir-Said. Note that all of the educated young people were able to answer correctly. Luria attributed this difference to literacy and the education the younger people had received.

Group	Number of Subjects	Correct Categorization
Nonliterate Persons	26	1
Educated young people	12	12

Table 16.1: The performance of nonliterates and educated young people on the categorization problem.

Luria's work is important in helping us understand the effects of literacy and education on thought. It should be clear that people untouched by literacy and education think in a much different way. They think in the here, the now, the practical, what they know. It's what Claude Lévi-Strauss called "the science of the concrete," which he described this way:

> ... it is neither the mind of savages nor that of primitive or archaic humanity, but rather mind in its untamed state as distinct from mind cultivated or domesticated for the purpose of yielding a return.[7]

[7] Claude Lévi-Strauss. *The Savage Mind*. Chicago: University of Chicago Press, 1962, p. 219.

That they think differently doesn't mean they think poorly.

Approximately the time that Luria's work was published in the US, Sylvia Scribner and Michael Cole presented data they suggested enabled them to weigh in on the relative importance of education and literacy.[8] Their subjects were the Vai people of Liberia, who exhibited various levels of literacy. A substantial number of them were nonliterate and the rest were literate in one or more of three languages: a native Vai script, Arabic (widely learned in Qur'anic schools), and English (learned at Western-style educational institutions). Scribner and Cole realized that they had an opportunity to do a direct test of the effects of literacy by comparing the nonliterate group with those who understood only the Vai script and had not yet experienced a literate education.[9] If literacy mattered, they

[8] Scriber and Cole, *The Psychology of Literacy*.

[9] Scriber and Cole saw it as an opportunity to disentangle the joint effects of literacy and education. That is, with Luria's data on the educated young people, was it the education or literacy or both which explained their superior performance?

argued, then it ought to show up in the superior performance of the uneducated group familiar only with the Vai script relative to the nonliterate group. They used the same sort of cognitive testing that Luria did including classifications and syllogistic reasoning.

Their main finding was that the group familiar only with the Vai script performed no better than the nonliterate group. They also found that those who had experienced a literate education had a better performance relative to the other groups, much as Luria had. Based on these results, Scribner and Cole argued that education, not literacy, was the key.

But let's take a closer look. Consider Luria's interview with Nazir-Said described above. This interview is reflective of all the Scribner-Cole interviews. From Nazir-Said's response, it is clear that he is not able to restrict himself to the stand-alone facts of the syllogism. Rather, he turns to his experience, what he knows, to answer. In contrast, students in literate education systems learn quickly that they must confine themselves to the fictional premises of the syllogism to answer questions about it.

The responses of nonliterate persons to syllogistic reasoning questions make it clear that education is important if a student is going to learn how to deal with the restricted intellectual space of syllogisms and other general forms of reasoning like modeling and theory building. This is an absolutely essential skill if they are to advance to the frontiers of e-Class thinking and discover new knowledge. Furthermore, Scribner and Cole's work certainly does not allow the conclusion that nonliterate persons are inferior thinkers. After all, based on Luria's work, it's evident that the progeny of these nonliterates are quite capable of this kind of thinking with minimal education.

But what is also true is that the Scribner-Cole empirical findings in no way negate the necessity of exographics to discover important ideas. As we made clear in the early chapters of this book, exographics is essential if our imaginations are going to continue to push abstract reasoning in the pursuit of e-Class ideas.

ROBERT BOYD, PETER RICHERSON, AND JOSEPH HENRICH (BRH) have done important work on culture in oral societies. We'll begin with their discussion of Inuit ideation.[10]

Average temperatures during Arctic winters range between $-25°C$ and $-35°C$, so it's important that the Inuit wear warm clothing. Here is BRH's description of the Inuit tailoring of parkas and footwear:

> The best [parkas] were made from caribou skins harvested in the fall. Caribou skins insulate better than seal or polar bear fur because the individual hairs have an unusual air-filled structure, something like bubble wrap. Caribou skins harvested in autumn have fur that

[10] Robert Boyd, Peter Richerson, and Joseph Henrich. "The Cultural Niche: Why Social Learning Is Essential for Human Adaptation". *PNAS* 108(Supp 2) (2011): 10918–10925.

> is just the right thickness. Hides were repeatedly stretched, scraped, moistened, and then stretched again to yield pliable skins. Parkas were assembled from multiple pieces to create a bell shape that captures heat, while also allowing moisture to dissipate when the hood is thrown back. Hoods were ruffed with a strip of fur taken from a wolverine's shoulders because its variable length makes it easier to clear the hoarfrost. Winter footwear was constructed with many layers: first the alirsiik, fur-lined caribou stockings, then the ilupirquk, short lightweight stockings with the fur outside, then a pair of pinirait, heavier stockings with the fur to the outside, then kamiik, boots with the fur outside, and finally tuqtuqutiq, short heavy double-soled boots of caribou skin. Clothing was stitched together with fine thread made from sinew taken from around the vertebrae of caribou. The sinew had to be cleaned, scraped, shredded, and twisted to make thread. Several different kinds of stitches were used for different kinds of seams. A complicated double stitch was used to make footwear waterproof. To make these stitches, Central Inuit women used fine bone needles that made holes that were smaller in diameter than the thread.[11]

[11] Ibid., p. 10919.

All of that is sophisticated ideation. For example, how would they have discovered that the alteration of caribou sinew made for the best thread?

Another example is the Inuit bow and arrow for hunting (before they had access to European rifles). One of the challenges in making them is that there are no trees in the Arctic. So, they had to be made from driftwood and antlers. Here is the description from BRH:

> . . . they made short bows and used every bowyer's trick to increase their power. A bow can be made more powerful by adding wood to the limbs. However, making the bow thicker increases the stress within the bow, leading to catastrophic and dangerous failure. This problem is exacerbated in short bows because the curvature is greater. Instead, the Inuit made bows that were thin front to back, wide near the center, and tapering toward the tips. These bows were also recurved, meaning that the unbraced bow formed a backward "C" shape. Bracing the bow leads to a compound curve, a geometry that stores more potential energy. Finally, the Inuit constructed a unique form of composite bow. When a bow is bent, the back (the side away from the archer) is stretched, whereas the belly (the side closer to the archer) is compressed. Wood, horn, and antler are stronger in compression than tension, so the ability of a bow to sustain strong bending forces can be enhanced by adding a material that is strong in tension to the back of the bow. In central Asia and western North America, sinew was glued to the back of the bow to strengthen short bows for use on horseback. The Inuit lashed a woven web of sinew to the backs of their bows, probably because they had no glues that would work in the moist, cold conditions of the arctic.[12]

[12] Ibid., p. 10920.

Again, this is sophisticated ideation.

A final example comes from the book *Hunters of the Northern Ice* by anthropologist Richard Nelson.[13] The Inuit depend on their seal har-

[13] Richard Nelson. *Hunters of the Northern Ice*. Chicago: Univeristy of Chicago Press, 1969.

vest for food, clothing (skins), heating (the blubber), and for making traditional tools (from bone and sinew). For this reason, they need to understand the environment close to the sea. Nelson explains it this way:

> Kayak hunting and ice hunting share the fact that the hunter is operating on a moving surface. Unlike solid land it is a permeable surface through which he may pass rapidly and disastrously. Not only is the surface on which the Eskimo may spend some one-fourth of his life constantly moving, it also lacks the gross complexity of most other geographic zones. The visual cues are small, consisting of subtle changes in the color of the ice, of small patches of snow which reveal wind direction and force, of water texture and slight indications of tidal changes and currents. Even these minimal cues may be obscured by fog, snow, wind, rain, glare, darkness, and the low level contrasts that camouflage the animal as well.[14]

[14] Ibid., p. xiv.

Nelson spends the first five chapters of his book (132 pages) describing the intricacies of the dangers this environment presents. With changing sea currents, wind, and weather, Inuit hunters must be good meteorologists and understand the implications of that weather for the changing condition of the sea ice. This is clearly a knowledge that has built up over centuries and all hunters must understand it.

Another interesting aspect of BRH's work is their "lost European explorer" examples. One of these was the Franklin expedition, which departed England in 1845 to discover the Northwest Passage. Eventually, the two ships of the expedition froze in the ice near King William Island. All expedition members perished. Yet, at the time, the Netsilik Inuit people had flourished in this inhospitable landscape for at least a millennium. How could the Netsilik survive, but the Franklin expedition members could not? The answer is culture. The Netsilik knew how to survive in that climate. But the Europeans, even with access to the Netsilik, did not.

Another example in this genre is the ill-fated 19th century Burke-Wills expedition across Australia. Some of the leaders of this expedition were separated from the main group and ended up near Cooper's Creek in desperate need of food. The local tribe shared their method for making a flour called nardoo from a local plant in good supply. The nardoo could be used in various kinds of baking and provided plenty of calories. But unfortunately, the explorers didn't follow the exact preparation instructions which basically required them to first make a watery paste of crushed seeds. As a result, they did not rid the plant of a toxin that eventually worked on their nervous systems to immobilize them. All but one died.

Indigenous oral peoples have an extensive knowledge of their surroundings. An example comes from the work of Louis Leibenberg on persistence hunting.[15] Persistence hunting requires bushmen to chase

[15] Louis Leibenberg. "Tracking Science: The Origin of Scientific Thinking in Our Paleolithic Ancestors". *Skeptic Magazine* 18, no. 3 (2013): 18–23.

a large game animal such as a kudu until the animal overheats and cannot move. The bushmen are then able to kill the animal easily. This kind of hunting is possible because humans, when running, are able to cool themselves with their sweat gland system. In contrast, animals are only able to cool themselves by breathing through their mouths, and this system is not nearly as efficient as ours.

Leibenberg recounts a specific endurance run he undertook alongside Ju/'hoansi bushmen. During that run, he had become dangerously dehydrated and didn't have any water. He soon appealed to his fellow hunters:

> I asked if I could drink the stomach water of the kudu to quench my thirst. I had drunk the stomach water of gemsbok on a previous hunt and although it tasted like rotting grass soup, it was not too bad. At this stage I was so thirsty that taste was not much of a concern. But !Nate said that I would die if I drank it, because the kudu was feeding on a leaf that is poisonous to humans.[16]

[16] Louis Leibenberg. *The Origin of Science: The Evolutionary Roots of Scientific Reasoning and Its Implications for Citizen Science*. Capetown: CyberTracker, 2013, p. 20.

Eventually, one of the Ju/'hoansi ran back to the village and came back with enough water to restore Liebenberg. The point is that the Ju/'hoansi have an encyclopedic knowledge of the ecosystem they inhabit.

To summarize, this evidence supports two key conclusions regarding nonliterate societies. First, these people are hardly savages. They are capable of extraordinary ideation, an indication that their imaginations function in the same way as ours. This position is certainly justified in an evolutionary context. *Homo sapiens* and its ancestor species have been evolving for millions of years. It stands to reason that intra-species differences between modern nonliterate and literate societies are likely to be small or nonexistent since exographics has only been around for about five millennia.

Second, as Luria's work has shown, the educated progeny of nonliterates were able to answer his survey questions perfectly, suggesting that their literate parents would also be capable of easily sliding into techno-literate lifeways had they been immersed in it early enough in their development.

Both points support the conclusion that those in oral societies and literate societies are born with the same cognitive potential, something philosopher Bruno Latour has noted:

> No "new man" suddenly emerged sometime in the 16th century, and there are no mutants with larger brains working inside modern laboratories who can think differently from the rest of us.[17]

[17] Bruno Latour. "Visualisation and Cognition: Drawing Things Together". In *Knowledge and Society - Studies in the Sociology of Culture Past and Present*, ed. by E. Long and H. Kuklick, 6:1–40. Stamford: Jai Press, 1986.

In other words, *there is a Great Divide, but no great cognitive divide*.

Let's now turn to the argument that exographics explains The

Great Divide.

The notion that the ability to read and write (literacy) induced salutary internal cognitive effects was supported by a number of mid-20th century scholars, including Jack Goody, Walter Ong, Eric Havelock, and Marshall McLuhan.[18] For example, Eric Havelock wrote this:

> The alphabet, making available a visualized record which was complete, in place of an acoustic one, abolished the need for memorization and hence for rhythm. . . . The mental energies thus released, by this economy of memory, have probably been extensive, contributing to an immense expansion of knowledge available to the human mind.[19]

[18] See: Walter Ong. *Orality and Literacy: The Technologizing of the Word*. New York: Routledge, 1982; Eric Havelock. *Preface to Plato*. Cambridge MA: Harvard University Press, 1953; and Marshall McLuhan. *The Gutenberg Galaxy: The Making of Typographic Man*. Toronto: University of Toronto Press, 1962.

[19] Eric Havelock. *The Literate Revolution in Greece and Its Cultural Consequences*. Princeton: Princeton University Press, 1982, p. 87.

By "alphabet," he meant exographics, the visual record of what the mind produced on a medium. This visual storage rather than "an acoustic one" economizes on memory but he doesn't specify exactly how memory is affected. His use of the word "probably" is revealing. When Havelock wrote this, we did not understand how artifacts like exographics help us to think. But he sure sensed it.

In the early 1980s, Walter Ong offered this:

> . . . without writing, human consciousness cannot achieve its fuller potentials, cannot produce other beautiful and powerful creations. In this sense, orality needs to produce and is destined to produce writing. Literacy, as will be seen, is absolutely necessary for the development not only of science but also of history, philosophy, interpretive understanding of literature and of any art, and indeed for the explanation of language (including oral speech) itself. There is hardly an oral culture or a predominantly oral culture left in the world today that is not somehow aware of the vast complex of powers forever inaccessible without literacy.[20]

[20] Ong, *Orality and Literacy*, pp. 14-15.

He hints that he will explain why literacy is necessary for science, philosophy, etc. (as the phrase "as will be seen" indicates) but his arguments in the remainder of the book are at best superficial in this regard. As far as we can see, he offers no detailed explanation for how literacy achieves these salutary ends. Note, also, that he is suggesting that there are powerful forces that move oral societies to writing ("orality needs to produce and is destined to produce writing"). Ong wrote this at a time when many scholars felt strongly that all societies would eventually achieve literacy, a notion that has led to untold hardship for many oral peoples.

Ong wrote that "writing restructures thought" and "writing restructures consciousness." In other words, the very acts of reading and writing enhance our higher-order cognitive function. Somehow, our heads reach a higher level of intellectual potential.

This effect of literacy that enhances our cognition is termed the *literacy thesis*. Seen through the lens of what we know today, there is simply no support for it. But it's easy to understand how these scholars arrived at it. After all, something had to explain The Great Divide. And since they didn't understand how exographics enhances our thinking, they assumed that it had to be exographics that were transforming our internal wiring and cognition, allowing us to get to these new ideas and substantially enhanced lifeways. Effectively their conclusion was correct (writing enhances ideation) but their reasoning was faulty.

A vigorous counterargument to the literacy thesis began to take shape during the 1980s. This occurred on two fronts. One originated with the work of Harvey Graff, detailed in his book *The Literacy Myth*.[21]

[21] Harvey Graff. *The Literacy Myth: Cultural Integration and Social Structure in the Nineteenth Century*. New York: Academic Press, 1979.

There are significant "literacy missionary" groups within technoliterate cultures who feel that literacy must be preached and delivered to all oral societies. In the words of UNESCO (United Nations Educational, Scientific, and Cultural Organization):

> Literacy empowers and liberates people. Beyond its importance as part of the right to education, literacy improves lives by expanding capabilities which in turn reduces poverty, increases participation in the labor market and has positive effects on health and sustainable development. Women empowered by literacy have a positive ripple effect on all aspects of development. They have greater life choices for themselves and an immediate impact on the health and education of their families, and in particular, the education of girl children.[22]

[22] The quote is reproduced from the UNESCO site: https://www.unesco.org/en/literacy/need-know.

The implicit logic in this statement (and those of governments, boards of education, other NGOs) is essentially this:

> First literacy. Then economic, social, and moral progress *for all individuals who become literate*.

It is the part in italics that Graff objects to. He presents evidence, primarily from the 19th century, that there is no such relation between literacy and progress *for all individuals*. One aspect of his evidence was his observation that many illiterates did well and many literates did not.

Graff does not take the position that literacy is unimportant. Clearly, we have societal structures that depend heavily on individuals having at least a basic level of literacy. He is simply questioning the proposition that literacy leads to progress for all individuals.

The second and more serious assault on the literacy thesis begins with the work of Sylvia Scribner and Michael Cole described earlier. To some extent, the claims of the literacy thesis scholars stirred recollections of the ethnocentric views of the early anthropologists who variously described Indigenous cognition as "pre-logical," "pre-rational," and "pre-literate." For an article entitled "Goody and the Implosion of the Literacy Thesis," John Halvorsen wrote this abstract:

> In a series of influential books, articles and lectures over the past quarter-century, Jack Goody has probably been the foremost advocate of the 'literacy thesis', the principal claim of which is that the development of logical thought ('syllogistic reasoning', 'formal operations', 'higher psychological processes') is dependent on writing, both in theory and in historical fact. The aim of the present critique is to show that there is no inherent relationship between literacy and logic: that the possibilities for such development supposedly afforded uniquely by literacy also exist in nonliterate discourse; that such possibilities, in any case, had no evident role in the historical beginnings of logic; that, in short, the 'cognitive' claims of the literacy thesis have no substance.[23]

[23] John Halverson. "Goody and the Implosion of the Literacy Thesis". *Man* 27, no. 2 (1992): 301–317, p. 301.

This is harsh criticism. But it's also clear that he's wrong because he doesn't understand that e-Class ideas are only discoverable with exographics.

David Olson labels this opposition to the effects of literacy on cognition the *literacy myth* movement. In his book, *The World on Paper*, he titles Chapter 1 "Demythologizing Literacy." He begins by describing six points of the received wisdom on literacy and then, one by one, documents research that casts doubt on them. We'll review just one, his fifth:

> Literacy as an instrument of cultural and scientific development. We take it as going without saying that writing and literacy are in large part responsible for the rise of distinctively modern modes of thought such as philosophy, science, justice, and medicine and conversely that literacy is the enemy of superstition, myth, and magic.[24]

[24] David Olson. *The World on Paper: The Conceptual and Cognitive Implications of Writing and Reading*. Cambridge: Cambridge University Press, 1994, p. 6.

To counter this straw man, he first argues that the miracle of ancient Greece was largely done with oral discourse. He cites evidence that literacy was quite limited in ancient Greece and then argues that oral cultures are more than capable of complex modes of thought. Eventually he writes: "Consequently, no direct causal links have been established between literacy and cultural development . . . "

Let's try to establish a few links. Consider the work of Euclid, who is generally thought to have recorded ancient Greek achievements in geometry in roughly 300 BCE. What we know of Euclid's *The Elements* is based on a long succession of manuscripts written by scholars through the ages including Cicero, Boethius, and eventually Thomas Heath's (1908) translation of Heiberg's text.[25]

[25] Thomas Heath. *The Thirteen Books of Euclid's Elements*. New York: Dover Publications, 1956. The book was originally published in 1908.

In Book I, Euclid proves the Pythagorean Theorem which states that the sum of the squares of the lengths of the shortest two sides of a right triangle is equal to the square of the length of the longest side. In the proof, Heath offers the diagram shown in Figure 16.1, presumably based on Euclid's original. The right triangle is ABC with the right angle at vertex A. The basic line of proof is to show that the area of the square ABFG (based on the side AB of the triangle) plus the area of the square ACKH (based on the side AC of the triangle) is equal to the area of square BCED (based on the side BC of the triangle). The proof is just under two pages and requires some intermediate constructions based on the additional lines in the diagram.

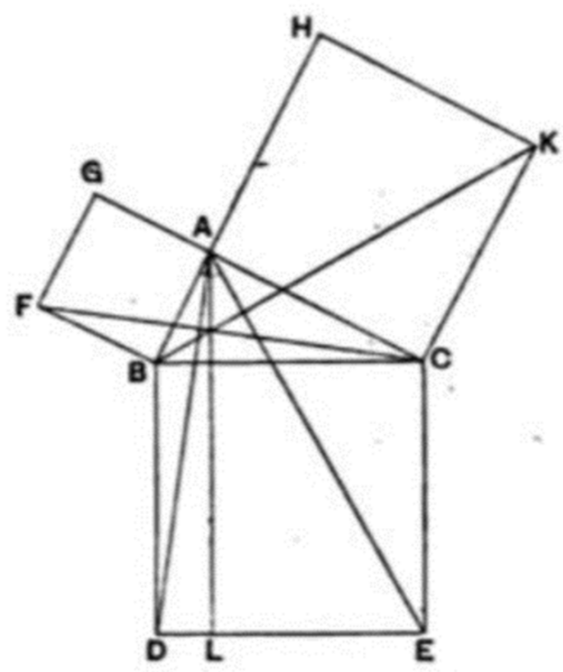


Figure 16.1: Our best guess of the diagram used by Euclid to prove the Pythagorean Theorem.

It would be impossible to do this proof without exographics. Just working up the diagram in your unaided mind would be a feat. Then you would have to think through the details of the proof, all in your unaided mind. Consequently, we submit that an oral people could not have discovered the mathematics of *The Elements*.

Earlier we argued that the work of Homer makes it clear that we can compose and recite an improvisation of significant stories without exographics. But being able to write down a story makes it much easier to compose. Once the Greeks were in possession of their alphabetic writing system post-Homer, the work of story-tellers got a lot easier and, not surprisingly, ancient Greek poetry and drama exploded in the course of their Classical Period. And not only literature and drama, but also the work of historians (Herodotus, Thucydides) and philosophers (Plato, Aristotle) begins to appear. Exographics was a real shot in the arm and, as we see it, a good part of the explanation for the Greek explosion in literature, history, philosophy, and mathematics.

Hence, contrary to Olson's claim, the ancient Greeks required exographics to make much of their substantial contribution to e-Class ideas.

In summary, a number of cognitive scientists made the argument in the early 1990s that, to take full advantage of our imaginations, we needed exographics. The e-Class is now large and is at the heart of our techno-literate civilizations. Essentially, e-Class ideas constitute the cultural difference between techno-literate societies and oral cultures like the Sentinelese.

Furthermore, no special genius is required to learn the exographics technology. As a matter of course, it's relatively easy for children and young adults to learn to read and write to be able to function in these advanced techno-literate societies.

In addition, there is strong evidence that children in nonliterate societies are perfectly capable of learning exographics. What's more, there is no sense in which those living in a nonliterate society are backward, or preliterate, or prelogical, or inferior to those in literate societies. Nonliterate peoples are extraordinary innovators who are simply living different lifeways.[26]

[26] If you have doubts about this, have a look at *Tuktu and the Big Kayak* a 1967 short made by the National Film Board of Canada and available on YouTube. It's about the construction of a kayak by Inuit craftsmen using driftwood, animal sinew and hides, and some very primitive tools. It's an extraordinary film.

The early literacy thesis scholars suggested that literacy explained The Great Divide. They offered their theories in the 1960s through the 1980s before the role of exographics in enabling the discovery of ideas was fully understood. In the face of the evidence of The Great Divide, their only way out was to conclude that the very act of reading and writing altered the way their minds functioned, and, in their view, it was this enhanced cognitive power that gave rise to The Great Divide. We now know that's not true.

Let's now move to the literacy myth scholars. Their position on the preeminence of education over literacy is largely based on the empirical findings of Scribner and Cole and, to a lesser extent, of Luria. We have no problem with the importance of education. The results of Scribner, Cole, and Luria make it clear that education is required to get individuals to be able to think in an abstract way, to be able to function in the e-Class world of concepts, models, and theory. With education, they move from Lévi-Strauss's "science of the concrete" to a *mentalité* that enables them to work at the frontiers of e-Class discovery. We believe that exographics and education are both crucial to developing thinkers capable of discovering e-Class ideas.

But let's examine the relationship between exographics and education more closely. All societies, whether nonliterate or literate, must ensure there is a transfer of cultural knowledge to the next generation. In oral societies, children and young adults learn the lifeways of their society largely through a learn-by-doing approach. For example, when old enough, a male begins to go on hunts to learn how it's done. In contrast, children in techno-literate societies go through a formal literate education program. In techno-literate societies, we've invested heavily in education. This enables our young people to function in a highly literate society and, for some, to discover new ideas on the frontiers of the e-Class.

Hence, whether it's a nonliterate culture or a techno-literate culture, there is a societal process in place to ensure that the next generation acquires the requisite cultural knowledge.

More particularly, the history of techno-literate education, going back to the scribal schools in Mesopotamia, makes it clear that one of the important purposes of these schools was to pass on the exographics technology to the next generation. Certainly, that argument applies today. Hence, had we not come to exographics, there would be no need for the massive techno-literate education system we have in place today. In this way, we argue that a literate education is an artifact of our adoption of the technology of exographics.

Hence, we submit that the vast collection of e-Class ideas is the essential difference between cultures on either side of The Great Divide, and therefore, human imagination, extended by exographics, explains The Great Divide.

17 The Rise of Techno-Literate Culture

My hero is Man the Discoverer.
The first sentence in Daniel Boorstin's *The Discoverers.*

HERE is our statement of the book's purpose from the introductory chapter:

> The phenomenon of the rise of techno-literate culture is explained by our relentlessly curious, networked imaginations enabled by exographics.

Let's now reconsider this statement, one piece at a time.

The Rise of Techno-Literate Culture

In just 10,000 years, a few seconds of evolutionary time, we've moved from small hunter-gatherer bands to these techno-literate cultures we inhabit today. That's an extraordinary change. What happened?

We've defined a techno-literate culture as having four important characteristics:

Literacy. The majority of the population has a minimal level of literacy, including the ability to read, write, and do arithmetic. Exographics was invented only 5,000 years ago and, at that time, the only literate people were the scribes who administered the various city states where exographics was important. In 2024, the world literacy rate was 86.3%.[1] As we have argued, literacy and measurement are endemic in the developed world. The first author (Bill) was in an orthopedic waiting room earlier this year (2025) with 11 other people, all senior citizens. Every person except Bill was interacting with a device (mostly smartphones but there were several tablets). Bill happened to be reading a magazine when he looked up to notice the others. All 12 people were consuming exographics. On that day, a preoperative day for patients scheduled for various joint replacements, many measurements would have been made. Bill's height, weight, pulse, blood pressure, and various measurements of

[1] See worldpopulationreview.com.

his blood chemistry were taken. X-rays of his hip joint to be replaced were also taken. The daily medications (type and amount) that each patient took were recorded and reviewed by the internist. So, at the end of the day, the file each patient carried was full of paper containing print and handwritten exographics and was handed over to an administrator before leaving. A health system would not be able to function without exographics.

Ideation. A techno-literate culture includes a relatively small set of individuals who are able to discover ideas that push our culture forward. As we documented in Part I, the Ideasphere and e-Class have grown exponentially for centuries and there is no indication that this growth is slowing. In Part II, we documented that the ancient river cultures, once in possession of their exographics systems, began to make e-Class contributions almost right away. Initially they developed number systems and arithmetic because of the exigencies of measurement. We documented the extensive growth in the e-Class in ancient Greece and suggested that their democratic education system led to more scholars contributing to the e-Class over the course of their Golden Age. The Romans borrowed much of the Greek culture, particularly aspects of their education system. However, their contribution to the e-Class was largely in engineering, architecture, the military and diplomatic arts, and the law. At the fall of Rome in 476, the Eastern Roman Empire, centered in Constantinople, continued to thrive for nearly a thousand more years. Its major centers and intellectual hubs (Constantinople, Antioch, Alexandria, Athens) were deeply rooted in the Greek-speaking East, and they played a pivotal role in preserving and transforming classical knowledge. As we have seen, there was much e-Class discovery in the East which eventually made its way to the West. At the same time, the Christian church was spreading across Europe, taking with it the exographics necessary to run a large bureaucracy. It was about this time that Europe started to transition from a largely agrarian society to one with a sizable urban commercial sector and this led to more e-Class ideation. Two events in Europe gave a considerable boost to literacy and the e-Class: Gutenberg's innovation of his printing press and the Protestant Reformation. Gutenberg's press brought down the price of books considerably and the volume of books sold went up exponentially from the late 15th century on. Luthor embraced *sola scriptura*, the theological principle that the Bible is the sole infallible authority for Christian faith and practice, unlike the Catholic Church which relied on the teachings of the pope and church councils. Luthor believed that Christians should read the Bible for themselves rather than depending on the Church hierarchy for authoritative interpretation. As a result, Luthor strongly supported the education of his followers. The effect of more people being educated brought more attention to the e-Class. Shortly thereafter, we see the Scientific Revolution, the Enlightenment, and the Industrial Revolution within a few centuries. The American experiment began in the 17th century, and continued the British revolution in the industrial arts. In the 20th century, the Americans built continually better electronic computers and this eventually led to the invention of the integrated circuit, microchips, personal computers, the Internet, mobile computing, and the beginnings of the field of AI. These technologies enhanced the availability of information, which is at the heart of e-Class progress.

Techno-Literate Lifeways. We've evolved socio-economic structures that enable large populations of strangers to coexist in relative harmony. These institutions include governments, laws, regulations, courts, media, prisons, corporations, religions, markets, money, security forces (police and armies), communication networks, transportation systems, power networks, and so on. But most importantly, we invented fixed settlements, and over the last 5,000 years, they have grown into great megacities distributed across the globe. There are two reasons for this great shift. First, working in close proximity allows for new ideas to take root. Second, working in close proximity enables us to take advantage of gains from trade.[2] In 1800, approximately 70% of the total labor force worked in agriculture. Today (2024), it's less than 4% despite a vast increase in agricultural output.

[2] Edward Glaeser. *Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier, and Happier*. New York: Penguin Press, 2011

Techno-Literate Education. Across the developed world, there is a substantial education system in place to teach basic literacy, techno-literate lifeways, and, for some, the advanced knowledge required to arrive at new ideas. The education of the young in hunter-gatherer societies occurs via a learn-by-doing approach. Post-Agricultural Revolution, as fixed settlements grew and differentiated goods and services were offered, the young would be taken in as apprentices and learn the special skills associated with a particular trade. In Sumer, after the discovery of exographics, scribal schools were set up to teach adolescents this technology, as well as various aspects of administering these early city-states. Remarkably, the education of these scribes took about 13 years. Students would start at age 5 and continue until age 18 at which point most started their professional life usually in the palace or temple bureaucracy. Much had to be learned, including exographics, arithmetic, and administrative procedures. The ancient Greeks had a similar system. Students went to school beginning at age 7 and continued to about age 18 with pretty much the same curriculum. The important difference was that some young Greek adults took an advanced education beyond age 18 for a few years. At institutions like Plato's Academy and Aristotle's Lyceum, they studied mostly philosophy and science. Roman education was remarkably similar to Greek education and also offered higher education beyond age 18 to a selected group, who typically studied philosophy and rhetoric. A key difference in Europe was that eventually the university was invented. The first universities required 3-4 years beyond secondary school and the curricula studied were initially the *Trivium* and *Quadrivium*. But eventually we see the appearance of new disciplines based on the expansion of the e-Class. In summary, the history of education beginning in Sumer and moving through Greece to Rome, to the East and Europe, and on to the US shows remarkably similar systems in all locales. These were systems designed to teach students the fundamentals of exographics and then how to function in a society that depended heavily on exographics and measurement. Gradually, higher education evolved to teach students the relevant knowledge required to be able to contribute to the e-Class.

In sum, nobody disputes that our modern techno-literate cultures are fundamentally different than the hunter-gatherer cultures our ancestors lived before the Agricultural Revolution. The contrast between the two is stunning. The example we use in Chapter 10 to emphasize the juxtaposition is the Large Hadron Collider, one of the most complex machines we've built. As we've described, it took thousands of us working for years to build it and it's an amalgam of technologies we've discovered over centuries.

It's been suggested to us that "techno-literate culture" is "civilization" by another name and hence why the need for the new name? Civilization is a fine name but, to us, it doesn't draw attention to the remarkable change that has occurred in human culture over a relatively short period of evolutionary time. Neither does it indicate the nature of the change. Our name was selected to do both. We want to draw attention to a societal sea change, but we also want to point out that exographics and measurement are at the heart of that change.

Culture

If extraplanetary observers were studying the natural life of this planet, what would jump out at them is human culture—what we've been able to do as a group with our hands and heads. No other species is even close.

Take, for example, the eyed needles we fashioned from animal bones about 40,000 years ago.[3] The significance of the eye was that

[3] Ian Gilligan et al. "Paleolithic Eyed Needles and the Evolution of Dress". *Science Advances* 10, no. eadp2887 (2024)

the needle could be used to thread skins together (with animal sinew serving as thread) to make closer-fitting multi-layered clothing that enabled us to settle colder climates. One of the interesting things about them was how the needle holes were made. One approach was to use a foramen (a natural hole in the bone that housed nerve and blood vessels). In this case, the craftsman would shape a blank, making sure to leave the foramen at one end to serve as the eye. The other approach was to use a stone drill. Drilling was a delicate operation given the amount of material available to house the eye.[4] The eyed needle was a clever idea.

[4] Francesco d'Errico et al. "The Origin and Evolution of Sewing Technologies in Eurasia and North America". *Journal of Human Evolution* 125 (2018): 71–86.

Another example is the Burj Khalifa shown in Figure 17.1. It's the tallest building in the world (9 football fields high) and took 6 years to build. At its peak, 12,000 workers were employed. What is obvious is that its design and construction took a network of minds. Networked imaginations and bodies allow us to build complex structures like the Burj.

We think of culture as the shared characteristics, beliefs, and practices of a group of people. It includes their lifeways (such things as customs, traditions, values, language, behaviors, social and economic institutions) as well as their made world (tools, technologies, machines, architecture, and so on). The hallmark of human culture is that it changes, usually through new ideas that are adopted widely. Our modern cultures are much different from those of our ancient ancestors. For example, there was a time when our ancestors didn't speak or do exographics or use electricity. But now we do. In contrast, chimpanzee culture has changed little over a long period of time.

As we have argued, culture and cultural change are driven by human imagination, our ability to network with other minds, and exploit technics like exographics. Ours is a mind built for mind-sharing and culture and it's why we're masters of the planet.

Social Learning

One aspect of this mind we have for culture is our ability to learn from others. As we suggested in Part I, our mimetic skill is crucial. For example, we learn a discipline by listening to teachers and seeing what they write on a blackboard, from doing homework exercises, from speaking with other students, and from reading textbooks. This mimetic learning goes right back to our earliest days at school learning to draw letters. We would practice making an "a" by drawing a small circle and a vertical line that connected to the right edge of the circle and then we'd repeat this exercise for the rest of the line, perhaps drawing 10-15 of them.

In Part I, we wrote about Michael Tomasello's notion of shared

Figure 17.1: The Burg Khalifa in Dubai. Photo by Donald Tong, CC BY-SA 3.0.

intentionality. Recall the experiment in which the little boy observes the adult who is successively piling magazines on shelves. The boy understands very quickly what the adult is trying to do and willingly helps with no promise of reward. A chimpanzee could never do what the boy does. Humans have an innate set of observational and other-mind reading skills that enable us to collaborate. Moreover, it's part of our nature to collaborate willingly without the promise of a reward.

Social learning is crucial to cultural progress because it saves us having to rediscover cultural knowledge. For example, we don't have to reinvent how to start a fire if one of us already knows how to do it.

Relentlessly Curious

We seem to have a biological need to know.[5] Psychologists have hypothesized that this curiosity is a drive much like hunger or thirst. Another explanation is the so-called "curiosity gap" effect, the effect that, when we sense a knowledge gap, our brain feels discomfort until we find a reasonable explanation. We hate not to know.

As we noted earlier, there is a neurochemical explanation for our curiosity. When we sense a gap in our knowledge, our brains release dopamine, a neuro-transmitter, and this release causes us to crave an answer. Multiple fMRI studies have shown that this need activates the brain's reward system, particularly in the caudate nucleus and ventral striatum regions, two key dopamine areas. Moreover, the anticipation of learning something new triggers dopamine release before we even get the answer. And when we finally get the answer, another spike in dopamine reinforces the behavior.

As you might expect, some people have stronger dopamine systems than others, and these people tend to be good at solving problems. Isaac Newton is an example. Here are two passages from a biography by Dunham:

> One striking thing about Newton's readings at this time was that he was not content to stick with the Greek classics. He devoured Descartes' geometry, but only with great effort. He later recalled beginning the work and reading a few pages until utterly stumped. Then he would return to page 1 and begin anew, this time penetrating a bit further before the writings became incomprehensible. Again he would start over, and by this gradual process he plowed his way through *La geometrie*, without the assistance of a single tutor or professor.[6]

and

> . . . Newton turned his attention elsewhere. He read voraciously and could be seen walking across the grounds in deep contemplation. When an idea had captured his interest, Newton could be impossibly

[5] George Loewenstein. "The Psychology of Curiosity: A Review and Reinterpretation". *Psychological Bulletin* 116, no. 1 (1994): 75–98.

[6] William Dunham. *Journey Through Genius: The Great Theorems of Mathematics*. New York: John Wiley and Sons, 1990, p. 163.

> single-minded and would often neglect to eat or sleep in favor of long bouts with an especially intriguing problem.[7]

[7] Dunham, *Journey Through Genius*, p. 162.

Newton didn't *want* to know how the world worked. He *needed* to know.

Networked Imaginations

Sometimes it appears that some of our most important ideas have come from a lone genius working through the details of a complex argument in a secluded location undisturbed by the outside world. When Cambridge closed because of the plague in 1665-1666, Newton returned to the family farm, Woolsthorpe Manor, where he continued to work on a number of important ideas, including the calculus. Seeing him as the "isolated genius" is one way to characterize how he worked. But there is another that paints quite a different picture.

Newton attended the King's School in Grantham from 1655 (age 13) to 1661 (age 19). In the fall of 1661, he began university work at Trinity College, Cambridge. There, he was greatly influenced by his mathematics professor, Isaac Barrow, the first Lucasian Professor of Mathematics (Newton was the second). In 1666, once the plague had passed, he returned to Cambridge and eventually became a professor.

As detailed by John Harrison, Newton had a significant library.[8] Harrison lists almost 1,800 entries. Among these, there were many crucial to his work, including Euclid's *Elements*, Galileo's works, and Descartes' *La Géométrie*, from which he learned coordinate systems and the algebraic representation of geometric shapes like lines and circles. Hence, the institutions of education, especially Cambridge and his library, were crucial to Newton's formation.

[8] John Harrison. *The Library of Isaac Newton*. Cambridge: Cambridge University Press, 1978.

We also know that Isaac Barrow taught Newton the most up-to-date method for getting the slope of a curve, the basic problem of the calculus. Barrow taught a geometric approach that took a long time to get a single slope. Newton's contribution was to get slopes algebraically (his "method of fluxions"), as we do today. His method took minutes and was a significant improvement on the geometric approach.

The point is that *Newton was socially constructed*. He was educated by other imaginations over many years. A part of that education was learning new ideas like Cartesian coordinates from books produced by other capable imaginations (Descartes). And finally, Newton learned directly from another imagination (Barrow) the existing technique for getting the slopes of tangents of curves, and it's here where his work on the calculus begins by exploring how to get those tangents algebraically. What is clear is that Newton's work was only possible because of the network of imaginations that contributed to his formation. Absolutely, he was a genius and worked alone to push mathematics and other ideas forward. But his formation to get him to the point of his path-breaking work was all via the network of imaginations he found himself in.

More generally, we've developed some very sophisticated communication skills (gesture, speaking, and exographics) to enable this network of imaginations to function.

With exographics, we've taken communication to another level. Exographics makes it possible for people separated by space and time to communicate. We can send emails and text messages to collaborating colleagues half a world away in a matter of seconds. Once again, it's difficult not to appreciate the prescience of McLuhan's global village.

Exographics and computing technologies have enabled us to set up the Internet, a vast compendium of information that is now searched fairly easily. Information is a few keystrokes away. With exographics, the mathematics of neural nets, and a large expanse of data, we've been able to build search engines like Google and ChatGPT. These are extraordinary technologies that would not exist without exographics. Most importantly, they're crucial to imagination networks at work.[9]

[9] At this writing, it is well known that all Large Language Models LLMs), including ChatGPT, suffer from the problems of hallucination (false, misleading, or completely fabricated information) and boneheadedness (errors that violate common sense, basic logic, or fundamental knowledge). Furthermore, these problems do not appear to have been solved by larger LLMs (more data and/or more parameters) such as Grok 3.

Imaginations Enabled by Exographics

Before the invention of exographics, there was plenty of evidence that we had powerful ideation skills: stone tools, the control of fire, cooking, settling the globe, tailored clothing, weapons (spear, bow and arrow, sword), cities, and, of course, agriculture. All of these innovations demonstrated our ability to think abstractly, to see *what could be* from manipulating *what is.* The Ideasphere was definitely expanding.

But it's only after the Exographic Revolution, about five thousand years ago, that we see the pace quickening with the remarkable expansion of the e-Class. Mathematics and measurement were among its first entries, and ideas from science and other disciplines soon followed. Take, for example, electricity. The ancient Greek philosopher Thales noticed that rubbing amber with animal fir caused small objects like feathers to be attracted to amber. The English physicist William Gilbert (1544–1603) made fundamental contributions to our understanding of magnetism, including the fact that the Earth is a large magnet. Benjamin Franklin (1706–1790) showed that lightning was electricity with his kite experiment. Alessandro Volta (1745–1827) invented a chemical battery capable of producing an electric current. Michael Faraday (1791–1867) discovered electromagnetic induction. James Clerk Maxwell (1831–1879) wrote the theory of electromagnetic radiation. Thomas Edison (1847–1931) and Nikola Tesla

(1856–1943) were instrumental in the commercialization of electricity. So, a small number of scientists and technologists have worked over a long period of time to further our understanding of electricity and then how to take advantage of it. Most of this work could not have been done without exographics.

Few would question the benefits of the ongoing rise of techno-literate cultures in the developed world. On average, our standard of living is higher, most of us have interesting work, infant mortality is lower, and we're living longer and healthier lives. But, unfortunately, techno-literate culture has brought with it a number of serious problems:

War on an Industrial Scale. We are primates and appear to be wired for tribal and violent behavior. Think about the 20th century alone. There were two great wars, many smaller bloody conflicts, and a significant number of genocides. The number of dead in World War II alone is estimated to be at least 70 million. We are now in possession of nuclear arsenals that could, in the words of Winston Churchill, "make the rubble bounce" many times over. What makes matters worse is the growing weakness of the international order. Despite this potential for massive bloodletting, the psychologist Steven Pinker has argued that, in relative terms, human violence is receding.[10]

[10] Steven Pinker. *The Better Angels of Our Nature: Why Violence Has Declined*. New York: Viking, 2011.

Poisoning the Climate. Scientists generally agree that we are doing damage to our climate and that without cooperative action among nations, we are headed into the abyss. On the matter of scientific evidence, the reader is referred to the seminal work of Michael Mann et al.[11] and a follow-on book by Mann.[12]

[11] Michael Mann, Raymond Bradley, and Malcolm Hughes. "Northern Hemisphere Temperatures During the Past Millennium: Inferences, Uncertainties, and Limitations". *Geophysical Research Letters* 26, no. 6 (1999): 759–762.

[12] Michael Mann. *Climate Wars: Dispatches from the Front Lines*. New York: Columbia University Press, 2012.

Biodiversity Loss. The global human population was 7.8 billion in 1970 and, with fertility rates still supporting growth, it's expected to be 9.9 billion by 2050 (prb.org). Over the last 10,000 years, the biomass of vegetation has been cut by 50%. There has been an approximately 25% loss of animal species over this same period. Biodiversity is important for many reasons, one of which is that our ecosystem acts as a "carbon sink," absorbing half of all carbon emissions.

Vast Inequities in Economic Wealth. There is significant evidence that the rich are getting richer.[13] The economist Thomas Piketty argues that capitalism has a systemic flaw which leads naturally to income inequality and his position is consistent with the evidence.[14] It's his

[13] Paul Collier. *The Bottom Billion: Why the Poorest Countries Are Failing and What Can Be Done About It*. New York: Oxford University Press, 2007.

[14] Thomas Piketty. *Capital in the Twenty-First Century*. Cambridge MA: Harvard University Press, 2014.

position that we are living in a second Gilded Age where the richest 1% in the US have the same relative wealth the comparable group had a century ago.

The Nuclear Risk. At the end of World War II, the US developed the atomic bomb, a significant e-Class feat. But now many nation-states have the technology and significant arsenals. The risk with nuclear weapons is not so much the direct devastation of a major exchange, but rather that an exchange might lead to a "nuclear winter" and the associated major food shortage, leading to a significant loss of life and possibly human extinction.

The Problem of Dependence. Before the Agricultural Revolution, we lived in hunter-gatherer societies where there was specialization but not nearly to the extent we have today. By some accounts, there are now thousands of occupations. The nature of our economic organization, with this imperative of specialization, means that each of us has a narrow set of specialized skills. Orthopedic surgeons don't build their homes, and carpenters don't do hip replacement surgery. In contrast, our hunter-gatherer ancestors led self-sufficient lives. Hence, with the rise of techno-literate culture, we now have societies where large numbers are dependent on the society's cultural system functioning as it should. We have constructed finely tuned decentralized societies in which each of us plays a specialized role. Unfortunately, this carries an attendant risk: if there is a disruption of any significance, there can be a significant loss.

HOW ARE WE TO SOLVE THESE PROBLEMS? One class of solution will rely on our ingenuity. We've shown ourselves to be highly innovative in the face of problems. For example, consider the problem of climate change and greenhouse gases. Our techno-literate cultures have a massive appetite for energy and currently fossil fuels provide a good deal of that requirement. Unfortunately, the use of fossil fuels produces a lot of CO_2, the primary gas that is now the primary cause of the greenhouse effect with its concomitant increase in global temperatures.

One solution is renewable energy and we're well down this road. This would include technologies based on wind power, hydroelectric power, and solar power. All of these have the benefit of no direct carbon footprint, but can they be scaled?

Another technology that is beginning to show promise is fusion, the nuclear reaction that powers the energy generation at the core of the Sun. The basic physics is that when two nuclei join in a fusion reaction, a large amount of relatively clean energy is produced.

The difficulty is that high temperatures are required to enable this reaction. At the core of the Sun, the temperature is about 10 million degrees Celsius, and this combined with high gravitational pressure enables the fusion reaction. On earth, we don't have the benefit of the Sun's high gravitational pressure. To obtain a fusion reaction, we need to heat hydrogen atoms to 100 million degrees Celsius. The technical difficulty is that we don't have materials that can withstand such high temperatures. One of the possible solutions is to put superheated hydrogen plasma (a gas consisting of two hydrogen isotopes) into a donut-shaped magnetic field. The gas circulates and the magnetic field keeps it away from the walls of the chamber. Recently, scientists have experimented with coverings of tungsten and beryllium on the walls of the chamber, and these have been able to withstand the heat generated by the fusion reaction. The beauty of fusion is that it produces radioactive materials with a half-life of only about 100 years, which is much less than the life of the radioactive waste produced by fission methods. The difficulty is that the technology needs to be scaled, and this is likely to take decades. Consequently, a commercially viable fusion reactor is not likely to be available until the second half of this century. Hence fusion looks like it could be a good solution, but not for a while.

THE OTHER APPROACH to our problems is to try and alter our behavior. But are we going to be able to cooperate enough, both within and among societies, to make progress on problems like climate change? With climate change, nation states have to cooperate and this raises the challenge of the "tragedy of the commons" which argues that farmers grazing their cattle on the commons (a common area) will all overgraze and in so doing, destroy it.[15] The solution of the problem requires farmers to cooperate, but each has an incentive to defect. Something like climate change requires cooperative action and political will at a global level but, so far, we haven't done this very well.

It's our feeling that we're on a path that is going to require our ingenuity and cooperation on a massive scale. We think that important technologies based on our ingenuity will come. The trick will be whether we can overcome our wiring and muster the required cooperation. The real stumbling block could be us.

WHAT CAN WE SAY ABOUT THE FUTURE? Let's go over our deep history once again. Somehow life began with single cells, and these sometimes formed colonies of genetically related cells. Eventually multicellular organisms formed from some of these colonies and, for this to happen, cells had to be able to adhere to and communicate with each other. In effect, the multi-cellular organism is fitter than a

[15] Garrett Hardin. "The Tragedy of the Commons". *Science* 162, no. 3859 (1968): 1243–1248.

colony of cells. Eventually these multicellular forms evolved to complex forms capable of significant function including movement. Most importantly, they evolved complex sensor systems of the environment. Eventually evolution produced *Homo sapiens*.

This story has evolution working on single cells, then colonies of cells, and eventually multicellular organisms. *Homo sapiens* is a product of this long macroevolutionary story of cooperation.

But there is more to it. What we are suggesting is that evolution has now blessed us with cognitive abilities to conjoin into mindsharing networks which are able to advance culturally. This is yet another level of cooperation over a very long evolutionary chain of cooperation. Our network of minds is able to coordinate individual thought and action to do things it otherwise couldn't. None of us, individually, is capable of going to the Moon. But, working together, some of us can make that trip.

We have a suite of cognitive skills that powers our creative network of minds. Yes, we are a set of individual minds formed by the network and capable of discovering ideas; but we also share those ideas willingly with the network. Like the little boy we described earlier helping the magazine transporter, we all take part enthusiastically. We see and understand. We learn and teach. We speak. We write. And in the end, the cognitive network of which we are all a part, supported by the technologies of exographics and measurement, invents and builds in an unprecedented way. Yes, individuals are crucial for cultural discovery. *But the key is we*.

One of our goals for this book is to clarify the role of exographics in the discovery of ideas. We believe we've done that and a synopsis of our argument goes like this.

The story begins with recognizing this rare ability we have to think and communicate symbolically. We've broken our experience into smaller, atomic parts that we call concepts. Fantastically, we began to associate different concepts with different sounds and this enabled us to share our thoughts with each other. Among all animal species, we are the only species that can do this in a sophisticated way.[16] Eventually we were able to translate our vocal symbols into visual symbols (exographics). Hence, we can now communicate our thoughts aurally and visually. It's an extraordinarily useful skill for a species that relies on a network of minds to push cultural progress forward.

[16] Parrots can speak but they don't seem to understand what they are saying.

From there, we showed how we use exographics to overcome the weaknesses we have in our memory systems to process symbolic information, and, in particular, to craft arguments that involve the manipulation of abstract concepts. We can't do these manipulations with our naked minds but we sure can with exographics. In fact, with exographics, we've been able to build this stunning collection of ideas in the e-Class, a collection that accounts for the cultural differences between hunter-gatherer societies and modern techno-literate societies. For this reason, we judge exographics to be the most important technology we've invented.

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