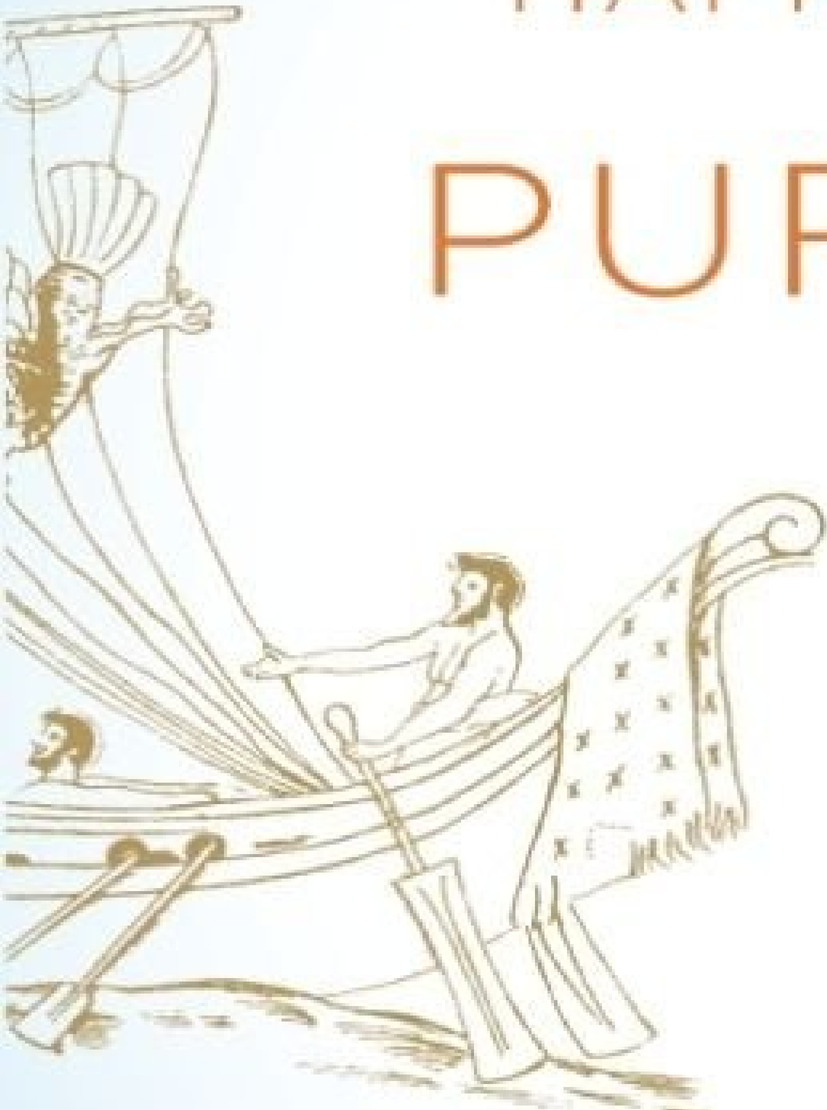
The HAPPINESS of PURSUIT



What **NEUROSCIENCE** *Can Teach Us About the* **GOOD LIFE**

SHIMON EDELMAN

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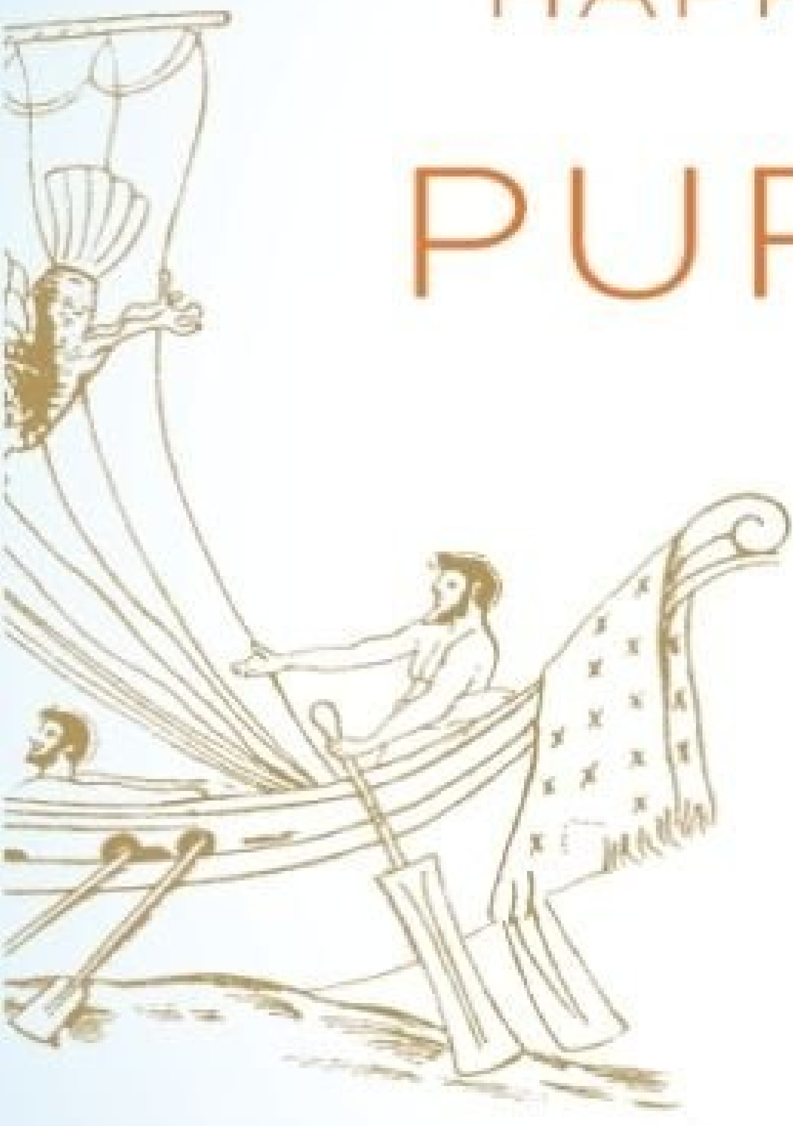

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The Happiness of Pursuit

What Neuroscience Can Teach Us about the Good Life

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BASIC BOOKS
A Member of the Perseus Books Group
New York

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AUTHOR’S NOTE

According to one popular conception of science that goes all the way back t
Francis Bacon’s invention of it in 1620, scientific endeavor is all about gettin
answers from nature. That said, given that the quality of answers one ge
depends conspicuously on the quality of the questions one asks, scientific inquirie
lacking in intrepidity, imagination, and insight are likely to yield little more tha
scientifically validated tedium.

In the science of human existence, one half expects things to be easier. A
someone who lives its subject matter, am I not in the best position to as
questions that go to the heart of it? And yet, it often seems to me that the real
important questions hover at right angles to reality, manifesting themselve
merely by a faint sense of unease or a premonition that I am about to miss th
point of what is happening.

By acting swiftly and decisively, it is sometimes possible to apprehend a fleetin
question and put it away for study. Here, I make a public example of four suc
questions, captured while stalking me on a hike through the canyon country c
southern Utah:

1. A juniper tree, hanging on to a gravelly mound in a bend of the canyo
until the next flash flood.
2. A set of lizard tracks in the drying mud.
3. A dusty drive toward a far trailhead, down a narrow wash bordered b
steep banks, arriving at length at an impassable sand trap.
4. A butterfly.

As you can see, such questions lose little of their cunning even in captivit
where they pretend that they are not questions at all, or that they are of n
concern to the busy scientist and should be released into the custody of poets c
philosophers. Such guile is best overcome by setting aside the convention
divisions between science and the humanities. This is why in this book my take c
the life of the mind and how to make the most of it, while decidedly scientific,
not entirely conventional.

1

Home Is Where the Mind Is

No justice, no peace.
A journey is mapped out.

> Allons! whoever you are, come travel with me!
> Traveling with me, you find what never tires.
>
> **—WALT WHITMAN,**
> Leaves of Grass: Song of the Open Road (1892, 82:9)

No Justice, No Peace

When I was eight years old, I read a book in which a few lines of a poem wer quoted. The book was Monday Starts on Saturday by Arkady and Bor Strugatsky. The poem was by Christopher Logue, in a Russian translation. (forgot to tell you that this was happening back in the USSR; the book's real titl was Понедельник начинается в субботу.) The book, subtitled very aptly "A Fair Tale for Younger Research Scientists," was about the daily life of applie magicians who work wonders by running experiments and solving equation Whether or not this book contributed to my own eventual choice of career, enjoyed it immensely. The poem, in contrast, must have gone right over my hea —I have no recollection of it from that reading. As I discovered much later, it wa an excerpt from Logue's "Epitaph":

You ask me:
What is the greatest happiness on earth? Two things:
changing my mind
as I change a penny for a shilling;
and
listening to the sound of a young girl
singing down the road
after she has asked me the way.

In subsequent rereadings of the book (once every few years ever since that firs time), I have found myself becoming more and more intrigued by the poen Maybe this is because happiness, with which it deals so deftly, is presented in th book as a challenge to the leading character, who works as the head of th

computing center at the National Research Institute for Miracles and Magic. (B
that time I was a computer scientist myself, albeit with very little magic and n
miracles at all to my credit.) The challenge is implicit in a complaint voiced by a
elderly graduate student, Magnus, who for decades now has been writing
dissertation for the Department of Linear Happiness and who offers Logue's poen
as an example of the difficulties he faces:

Magnus sighed.

> —Some say one thing, others—another.
> —Tough,—I said with sympathy.
> —Isn't it? How would you make sense of all this? To listen to the sound of girl singing. . . . And not just any singing, but the girl is supposed to b young, down the road from him, and that too only after having asked hi the way. . . . Is this any way to behave? As if such things could b algorithmized, huh?

For many years, I let those questions be. As a little boy, I was pretty happy no understanding algorithms, or girls. As a teenager, I was too busy trying to actuall get a live girl to ask me the way. (As this was still in the USSR, I was unaware tha the pursuit of happiness, along with life and liberty, is an inalienable human righ or I would have felt more relaxed about it.) As a computer scientist, I may hav been mildly intrigued by whether or not happiness could be captured by a algorithm, but by then I had my own dissertation to worry about. Then I became professor of psychology (a natural career move for a certain type of compute scientist . . . stick around and you'll see why), and things gradually took a unexpected turn.

I now had an excuse to think, on company time, about anything at all having t do with the human condition—a development that made me feel like a bear tha wakes from hibernation to learn that a natural foods store specializing in bul trail mix and artisanal honey has been built over its den. My research interest which for many years had been confined to just a couple of the mind's faculties mostly vision, then also language—began to broaden. Having discovered the sam principles at work in both, I became curious about the rest.

By then, I was teaching a big introductory course on cognition, which, I felt, ha to encompass everything that's known about how the mind works. Teaching, whe taken seriously, does wonders to one's capacity for critical thinking; I realize that although the existing psychology textbooks were up to the moment on fact they were decades behind on understanding. I ended up writing a text of my ow which I subtitled "How the Mind Really Works."[1]

For a while, the possibility of understanding things for myself with sufficien clarity to enable me to share my understanding with others made me vague happy. Then I perceived that the mandate that I claimed for myself came with rider. If I truly grasped how the mind works, I should be able also to transcend a the usual vague intuitions about when, why, and how a person feels happy an replace them with sound scientific insight.

To my dismay, I realized that I would have no peace until the possibility o happiness being amenable to a scientific—perhaps even algorithmic—treatmen ~~was given, if not a decisive resolution, then at least a fair hearing. This book~~ is m attempt at cajoling my conscience into letting me off that particular hook.

A Journey Is Mapped Out

To forestall the crushing skepticism that people tend to develop soon afte hearing about someone embarking on this kind of project, let me explain why think it is both timely and feasible. In the past several decades, tremendou progress has been made in understanding the mind/brain. It turns out that th principles that determine how the brain gives rise to the mind are very genera are statable in a pretty concise form, and have everything to do with computation Given that the brain is the organ with which people experience happines understanding the brain offers for the first time a real chance for understandin how and why happiness happens, and perhaps for developing some recipes- algorithms!—for pursuing it more effectively.[2]

The focus on the pursuit of happiness, endorsed by the Declaration o Independence, fits well with the idea of life as a journey—a bright thread tha runs through the literary canon of the collective human culture.[3] With the worl at your feet, the turns that you should take along the way depend on what you ar at the outset and on what you become as the journey lengthens. Accordingly, th present book is an attempt to understand, in a deeper sense than merel metaphorical, what it means to be human and how humans are shaped by th journey through this world, which the poet John Keats called "the vale of sou making"—in particular, how it puts within the soul's reach "a bliss peculiar t each one's individual existence."[4]

The fundamental insight that serves as the starting point for my story is that th mind is inherently and essentially a bundle of ongoing computations, the brai being one of many possible substrates that can support them. I make the case fo these claims by constructing, in plain sight and out of readily available material a conceptual toolbox that affords the reader a glimpse of the computation underlying the mind's faculties: perception, motivation and emotions, actio memory, thinking, social cognition, and language. This conceptual buildu culminates in an explanation that states, in plain language, the nature of th phenomenal self and of consciousness. Readers who are interested in the detai that I omit can follow the leads offered by the many notes at the end of the book.[5]

These conceptual tools prove to be useful in making new sense of the notion o the pursuit of happiness. Quite satisfyingly, it emerges that the framers of th Declaration of Independence presaged the findings of the scientific inquiry int happiness: the dynamics of the self and of happiness is such that the pursuit itse —the journey rather than the destination—is what really matters (hence the titl of the book). This insight, such as it is, informs the book's conclusion: the seeke after happiness returns home, only to grow restless and eventually succumb t the lure of a new journey. On the basis of the understanding develope throughout the book, the following practical advice is offered as a way of summin up its lessons in seven words: when fishing for happiness, catch and release.

2

Computing the Mind

A great metaphor that isn’t. Concerning computation. No cognition without representation. Three things everyone should know about life, the universe, and everything. Promethean probabilities and amazing Bayes. Minds within brains. Minds without brains.

And if the body were not the Soul, what is the Soul?

—WALT WHITMAN,
Leaves of Grass: I Sing the Body Electric (19:1)

A Great Metaphor That Isn’t

Let me tell you a short story about the brain. The brain is the most complex obje
known to science. Because scientists have been unable to explain exactly how th
brain gives rise to the mind, they keep resorting to technological metaphors o
complexity. The best metaphors are those that draw on concepts associated wit
newfangled technologies, which still exude a certain aura of mystery. In the pas
such metaphors came from mechanics (“the brain is an intricate clockwork”) an
electronics (“the brain is a vast telephone exchange”). For some time nov
everyone’s favorite source of metaphors has been computer engineering. Still, n
matter how much we like to compare brains (“meat computers”) and computer
(“electronic brains”), the computer metaphor is merely the latest installment in
long series of fads to which brain science periodically succumbs.

If you find yourself liking this story, you are in good company. The “compute
metaphor” view of how the mind works sounds sophisticated and modest at th
same time and is particularly intellectually appealing to progressive-minde
people who know their history of science and value openness toward the prospe
of continued replacement of good theories by better ones. It is also popular wit
science writers, including those practicing cognitive scientists who are eager t
share their findings and insights with anyone who is interested in how the min
works. For them, the computer metaphor offers a neat way to introduce an
explain the tremendous progress made by cognitive science in the three decade
since computational theorizing first started to prove uncannily effective. Bette

yet, they can do so without actually calling the reader a computing machine.

But what if you really are one?

In our daily lives we routinely encounter devices that can only be understood i terms of computation. Take grocery-store cash registers as an example. Thes come in different sizes and colors and may rely on diverse mechanical an electronic components, but they all have one inalienable, categorical, definin feature in common: they compute. Take away a cash register's ability to comput and you're left with a heap of junk, the machine equivalent of a dead body. In th deepest possible sense, computing is what cash registers are fundamental about. It would be intellectually irresponsible to insist that doing sums is only on among many equally valid ways of describing the function of a cash register or t argue that a cash register is only metaphorically a computing machine.

This observation sets the stage for the unveiling of what is undoubtedly both th most important and the least-kept secret of cognitive science. Although it ha entire books devoted to it, this secret has so far managed to elude the attention o most of the general public and even of some cognitive scientists. It has been abl to hide in plain sight because of its revolutionary implications. (We humans ofte blissfully ignore inconvenient truths, even as we stare them in the face.) Here the secret, then: computation is just as much a defining feature of brains as it is o cash registers. Moreover, in both cases it is the most important suc characteristic: a cash register's very existence (let alone its mechanics o electronics) can be really understood only by resorting to the concept o computation, and so can the brain's.[1]

Because it takes a while to do justice to the idea that cognition is computation let me offer you right away a few quick examples that illustrate it. My firs example is as simple as black on white—the black of the print against the white o the paper in front of you. Just as all cats are black in the dark, both the paper an the print would be equally invisible if it were not for the light that illuminates th page. Intuitively, the paper reflects more of the light that falls on it than the prin does, which is why the letters are seen as darker than their background. It woul seem, therefore, that telling apart the print and the paper boils down to gaugin the amount of light reflected from each. There is, however, a complication: th amount of light that enters your eye after hitting the page is determined by tw independent factors: the quantity of light that is available to begin with (th intensity of the illumination) and the fraction that is reflected from the page (i reflectance).

To fully appreciate the challenge faced (and met!) by your visual system, even a you are reading these lines, let's state it in concrete and precise terms. (It's oka to skip the numerical example that follows if you already saw the light.) Suppos your eye is registering 100 photons per second arriving from the region of th page that you are looking at. This measurement can result from variou combinations of illumination and page reflectance: for example, 10,000 photon (strong illumination) falling on it with only 1 percent of them being reflected bac (low-reflectance or "dark" surface), or 125 photons (weak illumination) falling, o which 80 percent are reflected (high-reflectance or "light" surface). A quic reflection (do try it at home!) reveals that there is an infinity of possible pairing of illumination and surface reflectance values that can give rise to the very sam number of photons reaching the eye. Which pairing is the right one?

To find that out, the brain must solve a problem that is fundamentall computational: given a product of two numbers (illumination and reflectance determine what they are individually. Your ability to perceive the ink as black and the paper as white in direct sunlight as well as in deep shade is clear evidenc that your brain indeed manages to solve this inherently arithmetical probler How it does that is beside the point for the moment.[2] Let's just admit, as we mus that at least one everyday perceptual task can only be solved throug computation, because this task cannot even be stated without resorting t numbers (which is why I had no choice but to mention numbers while introducin it just now).

My second example involves the task of thinking. Intuitively, thinking is wha follows perception (sizing up the situation you're in) and precedes action (doin something about it). Humans are pretty good at abstract thinking (witness th ability of some of us to stand up to chess-playing computers, sometimes for as lon as a couple dozen moves), but it would be more useful for us to focus here o more mundane challenges, such as figuring out which register line in supermarket checkout area to join. The simplest approach to this problem, whic I personally face much more often than I play chess, is to estimate the length o each line in person-units and then to join the shortest one. Those of us with som supermarket experience are likely to see the simple head-counting approach a unsatisfactory. We know that a better estimate of the amount of time one is likel to spend standing in a line depends not only on the number of people ahead o you, but also on the number of items each of them is buying and on the efficienc of the cashier, as measured by the number of items he or she can scan and ba per minute.

This example illustrates nicely the value of thinking before doing: a few seconc spent on observing a line and thinking about what you see can save you quite few minutes' worth of waiting time, which seems like a reasonable return o investment. During these seconds, your brain forms estimates of the number o people in line and the number of items each one has, multiplies these tw numbers together, and divides the product by an estimate of the cashier efficiency. Do it for each line you're considering, and you have the proper ground for making an informed choice about the most promising line. Thus, at least som problems that require thinking, just like perception, reduce to the manipulation o numbers according to certain rules, in this case multiplication, division, an comparison.

My third and for now last example has to do with a drinking problem, albeit no of the kind that necessarily involves alcohol. This particular problem arises in th planning of bodily movements. Imagine yourself sitting at a dining table, with you hand around a glass of water that rests in front of you. You are thirsty, but befor you can quench your thirst your brain must crunch some numbers. Because th incident that we are imagining is set in the three-dimensional space of the dinin room, it takes three numbers to specify the location of the hand that is holding th glass. If you single out one corner of the room and measure how far your hand from each of the three surfaces (two walls and the floor) that meet at that corne you can pinpoint its location precisely. As far as your brain is concerned, howeve many more than three numbers are needed. This is because the brain does n measure or control directly the distances between your hand and the walls.

What the brain controls is the angles of the various joints of the body, of whic there are many. Looking just at your upper extremities, you can count thre independently controllable angles at the shoulder (direction in the horizonta plane, direction in the vertical plane, and rotation), two at the elbow, and two a the wrist. So the very formulation of the problem of planning how to get you hand with the glass from its resting position on the table to your mouth involves whole series of pretty scary-sounding computations. First, the brain mus establish a correspondence between locations specified in the “room” format (a triplets of numbers) and the same locations specified in the “body” format (as lis of seven numbers). Second, it must use this correspondence to compute th seven-number setting that would bring your hand with the glass to your mouth.

Formidable as it is, this is merely a simplified version of the actual, full-blow problem of hand movement control, which requires more than bringing the glas to your mouth (rather than, say, to your ear). For one thing, you would probabl like to be able to do it without spilling the water along the way or smashing i your teeth at the end. Let me set these complications aside and reiterate instea the key point: in the three examples offered here, the problems that arise, which chose from the three main areas of cognition—perception, action, and what’s i between—are all inherently computational. These problems, which the brai encounters and solves as a matter of daily routine and usually outside of consciou deliberation, cannot even be stated without recourse to numbers, and the solution must therefore involve some kind of number crunching.

This realization spells a certain kind of doom for the venerable compute metaphor for the brain, with which I opened this chapter. In science, a metapho may wither away after being made irrelevant by new insights into th phenomenon that motivated it in the first place. Alternatively, it may crystalliz into an accepted explanation, if theoretical advances and empirical finding vindicate it. Such is the fate of the computer metaphor in brain science—a tru great metaphor that isn’t.

Concerning Computation

Given that the computer metaphor for the brain looks like it has the embarrassin (for a metaphor) quality of being literally true, we must make sure that w understand what computation is, if we ever want to be able to fully understan brains. Luckily, understanding the basic nature of computation does not require degree in computer science. Contrary to what one is inclined to believe, mos instances of computation in the universe happen without involving any kind o particularly complex, contrived, or specially engineered device. Computation is a around us; in fact, it is as common as anything can be, for the following simpl reason: every physical process that unfolds over time computes something.

Think about it. How would a pebble that you release from your grasp be able t strike the ground precisely at the correct instant if it could not figure out- compute—its trajectory, given the acceleration of gravity and its initial position How would a stove-top heating element be able to reach precisely the correc temperature if it could not figure out the current that flows through it, given th grid's voltage and its own resistance? In a very concrete sense, a falling pebbl computes its trajectory by following Newton's laws, just as a heating elemen computes the current that flows through it by following Ohm's law.

There is of course nothing mysterious about objects obeying the laws of physic on the contrary, it would be a mystery (in other words, a sign of a subtler law a work) if they did not, or if exceptions or exemptions were possible. This situatio seems to be not to everyone's liking: riding a ski chairlift one winter day, I saw o a pylon an ad that began: GRAVITY: IT'S MORE OF A NUISANCE THAN A LAW– a bizarre notion, given that not just skiing but actually getting down at all fror the mountain and seeing your loved ones ever again (rather than flying o screaming into space) would be impossible, were it not for gravity. Like it or no the implacability of the laws of physics is what makes the world go round, so t speak, and in doing so carry out a vast panoply of computations.

Most of these computations are very limited in the spatial and temporal reach o their effects. Such is the fate of the computation performed by the pebble that release and let fall to the ground. The law-abiding pebble faithfully computes it own trajectory and manages to arrive at its resting place at a precisely time moment, yet this computation is pretty inconsequential: a few grains of sand ma be kicked around, but once they settle the only readily discernible change in th state of affairs of the universe is that the pebble, which was previously in my hand is now on the ground. Who cares?

That particular computation was useless, but it could have been otherwise, only the fall of the pebble were to have some significant and endurin consequences or repercussions on other events. Here is how this could happen Imagine that you are defending a castle. Your assigned post is immediately abov the portcullis, and your duty is to drop an anvil onto the head of any attacker wh comes too close to it. Your store of ammunition is limited (the besiegers jus intercepted an inbound shipment of blacksmith supplies), and so you would like t time the release of each anvil so that it arrives at a certain small volume of spac simultaneously with the head of the intended target. This can be easily arrange through practice with some pebbles. All you need to do is mark the position of th knight who is charging at the gate as you release the pebble; if the pebble the strikes the charging knight's helmet (you'll hear it), you can be reasonably sur that the next time a knight's charge takes him through the marked position yo may drop the actual anvil instead of the practice pebble.

You may be surprised to realize that what I just described happens to be computer- controlled ballistic missile launch system. The missile is, of course, th anvil, which is ballistic by definition, because it has no onboard means c propulsion. And what about the launch-control computer? Since you are in charg of releasing and observing the pebble, you are one of its parts. Another part is th earth, whose gravity field so conveniently imparts an equal acceleration to anvi and to pebbles (as Galileo famously discovered four hundred years ago). Ye another part is the pebble that you use to simulate the anvil's projected descen Unlike the listless, lonely pebble from the earlier example, about whose fa nobody cares, this one is lovingly tracked and the computation it carries out (ju by being itself and acting naturally) is made use of. Its use lies in serving as stand-in for or a representation of the anvil: the actual fall of the pebble, as unfolds over time, represents the potential descent of the anvil.

Because the fall of the pebble is precisely analogous to the fall of the anvil that represents (their trajectories unfold at exactly the same rate), the anvil-aimin computer of which the pebble is part is an analog computer. The familiar digit computers differ from analog ones in one key respect: they deal i representations that are made to correspond to their objects through som arbitrary but consistent rules rather than through direct physical analogy. A goo example of a digital representation is the code agreed upon in April 1775 by Pau Revere and Robert Newman, the sexton of the Old North Church in Boston, fo representing the mode of the expected British assault: one if by land, two if b sea.

There is nothing inherent in assault by land that dictates that it should b represented by one lantern in the belfry as opposed to two. It is in this sense tha the Revere-Newman code is symbolic and arbitrary. Switching to a more moder example, consider how my notebook's battery meter represents the remainin charge. If I have worked for an hour since the last full charge and the meter no shows "75%," I conclude that the battery will last for three more hours. Th connection between the symbols "75%" and what I take them to represent entirely a matter of convention; the same information could have been equal well represented by the symbols "3/4." Alternatively, I can switch the batter meter from the digital representation mode to analog, in which case it would loo like a little "thermometer" whose mercury is three-quarters of the way up to th maximum mark.

What is common to all these examples of representation is that some physica symbol—an object, event, or process—stands in for some other object, event, c process for the benefit of a third party. Thus, some squiggles on my noteboo screen represent for me the battery level; the appearance of a lantern in a belfr conveys to Paul Revere a piece of battle intelligence; the fall of a pebble tells th castle defender how the fall of an anvil would proceed. Understandin representation gives us a crucially important conceptual handle on computatio The key insight is this: useful computation hinges on the possibility of som objects or processes representing others. Indeed, the reliance on representatio is the defining characteristic of useful computation, which distinguishes it fro computation that merely happens as the world goes on.

No Cognition Without Representation

Against the constant, pervasive background hum of the universe relentless computing its next state given its past history, the relationship of representation- two computations that always co-occur in a particular order or unfold over time i lockstep with one another—stands out as a great rarity. Merely drawing a paralle between some carefully chosen aspects of two events is not at all difficul especially if it is numerical or otherwise abstract; finding a repeated co occurrence or a parallel that persists over time is.

As I ponder this point, I observe nine ducks landing on a pond and am struck b the thought that their number is exactly the same as the number of months I hav left until the date on which I promised to deliver this book to the publisher. Wha am I to make of this observation? It is this kind of coincidence, invariably noted i retrospect, that inspires popular tales of successful auguries, such as the on found in the second book of The Iliad. The Greeks, weather-bound at Aulis on the way to Troy, witness an omen: a snake devours a mother sparrow and its eigh chicks in their nest, then turns into stone. They are told by Calchas, their chi soothsayer, that the omen means that the coming war with Troy will not b resolved until the tenth year. It is worth noting that this story betrays perfe hindsight on Homer's part: the prophesied tenth year happens to be the very yea during which the main events of The Iliad are set.[3]

The strange decision to count together the sparrows and the newly petrifie snake to reach the number ten would have ruined the career of a lesser augu than Calchas (who did not seem to have had any problem convincing the Greek at Aulis that King Agamemnon's daughter had to be sacrificed to Artemis to brea the spell of bad weather). Scholars believe that the sparrow omen stor confounded Aristotle, who was otherwise a great admirer of The Iliad.[4] Eve since, educated people's readiness to take such omens at face value has bee steadily on the wane. Indeed, some people viewed numerological divination wit great suspicion already in biblical times, as suggested by the injunction found i Leviticus: "Nor shall ye employ auguries, nor divine by inspection of birds." On likes to think that the Old Testament lawgivers sought to protect the people fro superstitiously perceiving false patterns in noise (rather than merely to prote their own monopoly on foretelling).

The more complex a set of observations, the more likely it is to give rise to gho "patterns," or correlations that arise by chance—an apparent signal in a sea o random noise. Skepticism toward such correlations is the only reasonable defau stance in science, and it can only be assuaged through the application of science single most powerful ghost-busting tool: statistical analysis of data. Patterns tha withstand statistical scrutiny are still suspect: they need to be explained, that i integrated into a wider framework or theory that makes sense of as much data a possible, in the simplest possible terms. This is how observations (themselve usually guided by informed guesses or hypotheses) get distilled into laws o nature.

Now that we are armed with the scientific method, let us return to the problem of telling apart reliable from unreliable representations—that is, true co occurrences between events from chance ones. The first hypothesis to be let go the one stating that a bunch of objects represents another bunch of differen objects simply because their number is the same. As if to prove this point, my nin ducks on a pond are joined by another; I rush home and open my mail to see if th deadline for my manuscript has receded by a month, only to find out that, alas, is still only nine months away. Apparently, the number of ducks on that particula pond does not, after all, represent the time frame of my contract with th publisher. More generally, attaching wide-ranging representational significanc to patterns of bird flocking is empirically unwarranted, as one can quickly learn b observing the efficacy of the hypothesized representations over time.

It would be even better if we could tell ahead of time, from first principle whether or not one thing—object, event, process—is going to be representative o another. Thanks to the understanding of the natural world that has already bee gained by science, it is possible to do so. What is it then that singles out vali instances of representation? There is just one principle that can ensure th validity of a representation: causation, as it is embodied in the various laws o nature.[5] The fall of a pebble and the fall of an anvil are caused and governe instant by instant by the same universal law—the law that Newton is said to hav discovered when he intuited that the motion of the celestial bodies is not an different from the motion of terrestrial ones. Because of that common causalit falling pebbles are representative of falling anvils (and apples and penguins, bu not ducks). We may think of the relation between processes that all obey the sam mathematical equation as representation by causally justified analogy.

There is another way in which causality can give rise to a valid representationa relation: one event may simply cause the other. This is how the lighting of lantern in the belfry of a church on the eve of the Battle of Lexington and Concor represented the redcoats' advance (through the mediation of one Rober Newman). Representation that is underwritten by causality in this direct manne is much more versatile than causal analogy: whereas falling objec representative of each other must all resemble each other in certain respec (heft, flightlessness), smoke represents fire by virtue of being caused by it, not b resembling it. Moreover, it does not matter how far from the represented even the causal chain leads before it reaches the representing event, as long as th chain is reliable; thus, a blaring fire alarm represents fire even if it is activated b smoke.

The principle of representation of one event by another through a causal chai whose reliability is guaranteed by the laws of nature is extremely powerful. Onc it is discovered by evolution [6] and unleashed into the biosphere, it becomes force that can change the face of the planet. Whereas computation as suc