PUZZLES OF TIME

A Handbook For The New Millennium
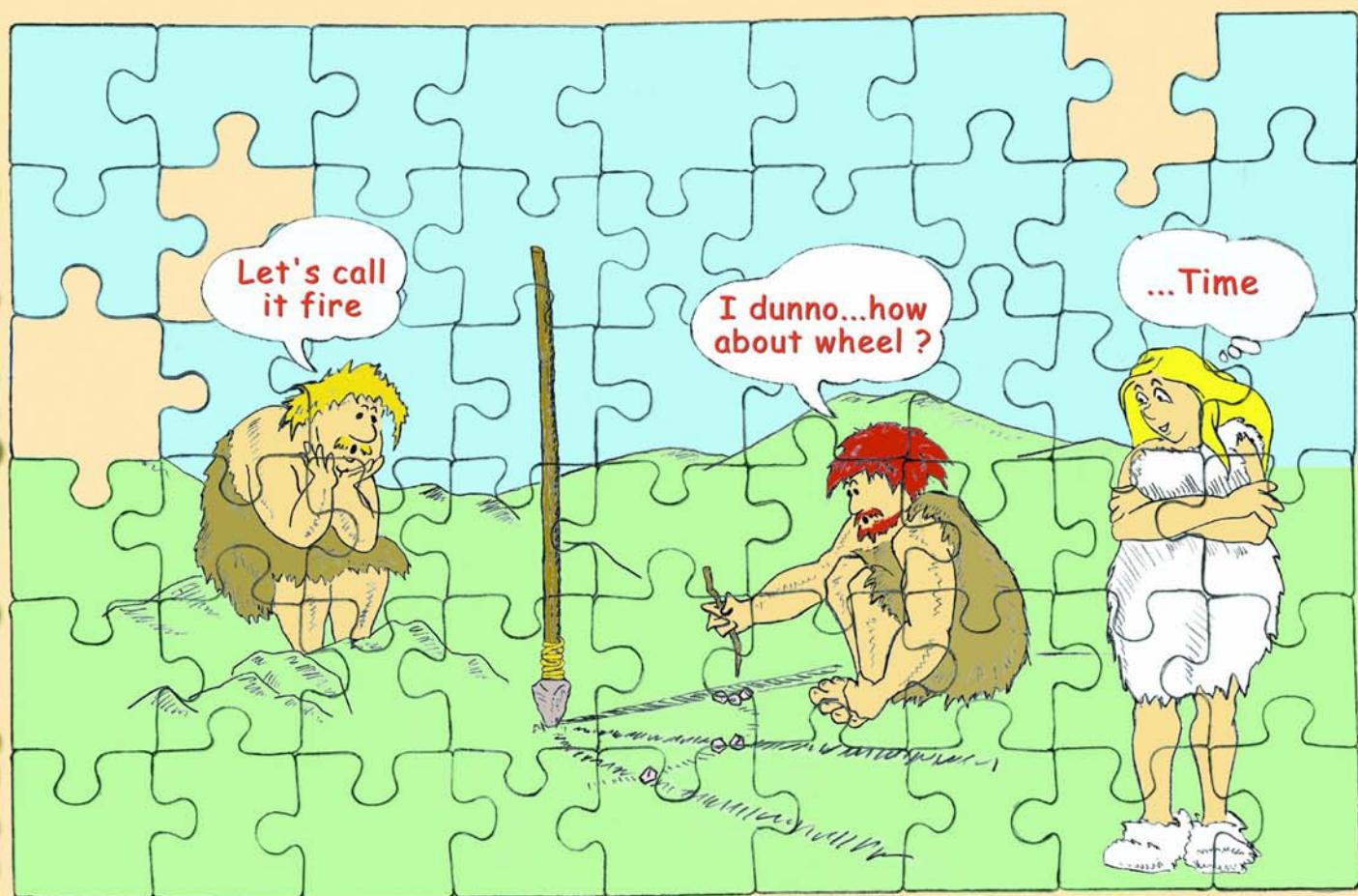
Dom Massaro and Don Rothman

Illustrations: Bill Rowe

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1850 --- 100 million years old

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Travelogue 1: The Wonder of Time

Filled with Wonder

It is easy to be filled with wonder, about our place in the world, the orderly nature of our surroundings, and the wonder of our own wonderment. One of these sources of wonder, time, is often taken for granted, but its study provides many challenges. We grapple with these challenges in this book, which contains puzzles, facts, and fun. Enjoy your travels through time and about time! We begin with our own *timely* fascination.

It's not known when humans first came
up with a name for the concept of time

Our Poetic Fascination with Time

Time is important because it persistently reminds us of our human nature and the stages of our life. All of us have thought about time, and some writers have captured its essence through poetry. Consider the poem by Henry Twells, which is fixed to the front of the clock-case in the north transept of Chester Cathedral in England.

When I was a child I laughed and wept,
Time crept.
When as a youth I waxed more bold,
Time strolled.
When I became a full-grown man,
Time ran.
When older still I daily grew,
Time flew.
Soon I shall find, in passing on,
Time gone.
O Christ! wilt Thou have saved me then?
Amen.

Of course Shakespeare, the world's best-known playwrite, often wrote about time. Notice how the meter, or rhythm of the lines, resembles the steady ticking of a clock or, even better, the swing of a pendulum.

The waves make toward the pebbled shore,
So do our minutes hasten to their end;
Each changing place with that which goes before,
In sequent toil all forward do contend.

Shakespeare's Sonnet 60

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You might also be familiar with the song whose lyrics were originally written in the Bible (Ecclesiastes 3:1-7).

To every thing there is a season and a time to every purpose under heaven:

> **A time to be born, and a time to die;**
> **A time to weep, and a time to laugh;**
> **A time to get, and a time to lose;**
> **A time to keep silence, and a time to speak.**

Or, as Shakespeare's Jacques tells us in *As You Like It*:

> **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,**
> **His acts being seven ages. At first the infant,**
> **Mewling and puking in the nurse's arms.**
> **Then the whining school-boy, with his satchel**
> **And shining morning face, creeping like snail**
> **Unwillingly to school. And then the lover,**
> **Sighing like furnace, with a woeful ballad**
> **Made to his mistress' eyebrow. Then a soldier,**
> **Full of strange oaths, and bearded like the pard,**
> **Jealous in honor, sudden and quick in quarrel,**
> **Seeking the bubble reputation**
> **Even in the cannon's mouth. And then the justice,**
> **In fair round belly with good capon lined,**
> **With eyes severe and beard of formal cut,**
> **Full of wise saws and modern instances;**
> **And so he plays his part. The sixth age shifts**
> **Into the lean and slippered pantaloon,**
> **With spectacles on nose and pouch on side,**
> **His youthful hose, well shaved, a world too wide**
> **For his shrunk shank; and his mighty manly voice,**
> **Turning again toward childish treble, pipes**
> **And whistles in his sound. Last scene of all,**
> **That ends this strange eventful history,**
> **Is second childishness and mere oblivion,**
> **Sans teeth, sans eyes, sans taste, sans everything.**

Metaphoric Time

A metaphor is an imaginative way to say something by saying it's something else that resembles it. For example, we say, "It's an oven outside" to describe a very hot day. We can gain some insights into time by analyzing how we talk about it. You've probably heard time used metaphorically in these ways.

Time as something that can be saved: "This shortcut will really save us time."

Time as something that can be lost: "I just don't know where the time has gone."

Metaphorical Meaning:	Example:
Time is something moving toward you:	When Tuesday comes.
Time is money:	She is wasting time.
Time is a pursuer:	Time will catch up with you.
Time is a container:	My school day was completely filled.
Time is a resource:	We are almost out of time.
Time is a landscape we move through:	Summer vacation is coming up.

Time as something moving toward you
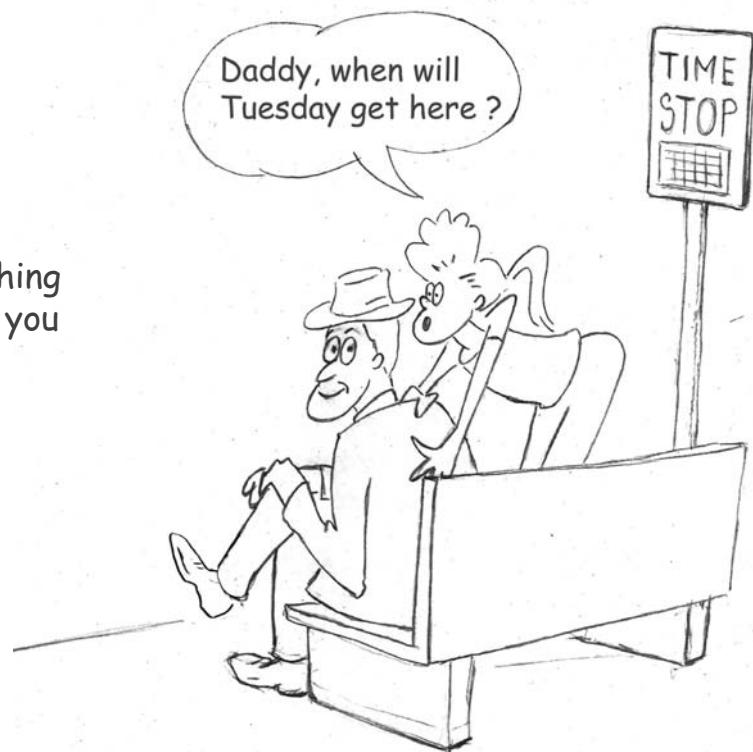
Time as a pursuer

An Early Thought About Time

   Aurelius Augustinus, a religious philosopher, lived about 1600 years ago in a period of political upheaval and war. Known today as Saint Augustine, a great thinker and writer, he made an important observation about time in his *Book Eleven* of *Confessions*:

> *"What, then, is time? If no one asks me,*
> *I know what it is. If I wish to explain it*
> *to him who asks me, I do not know.*
> *My soul is on fire to understand this*
> *great enigma."*

   It is human to want to put what we understand into words. And it is often a lifetime's work. We honor and share Augustine's curiosity, which is why we wrote this book.

St. Augustine, a famous Christian theologian and philosopher, lived from 354 to 430.

A Puzzle to Ponder: Is Time Like Sound?

Prompted by Augustine's philosophical confession, it's worth asking: is there even such a thing as time? Maybe it is only in our mind. Time might exist only as a relationship between us and our world. If so, time could be similar to sound. Most of us accept the idea that there is a real world apart from us. A tree can live in the forest whether or not we see it, but what about the sounds it might make? There is an old, well-known, puzzle:

> *If a tree falls in the middle of a forest and nobody is nearby, does the falling of the tree make a sound?*

Like many questions, this puzzle might be answered *yes* or *no*, or even *maybe*. Before we grapple with this question, a humorous variant is worth considering:

> *If a tree falls in the middle of a forest and nobody is nearby, will the other trees make fun of it?*

A Yes Answer

      Of course, there is a sound even though there are no witnesses to the falling tree. To support this answer, we can record the sound wave that is created by the falling tree.
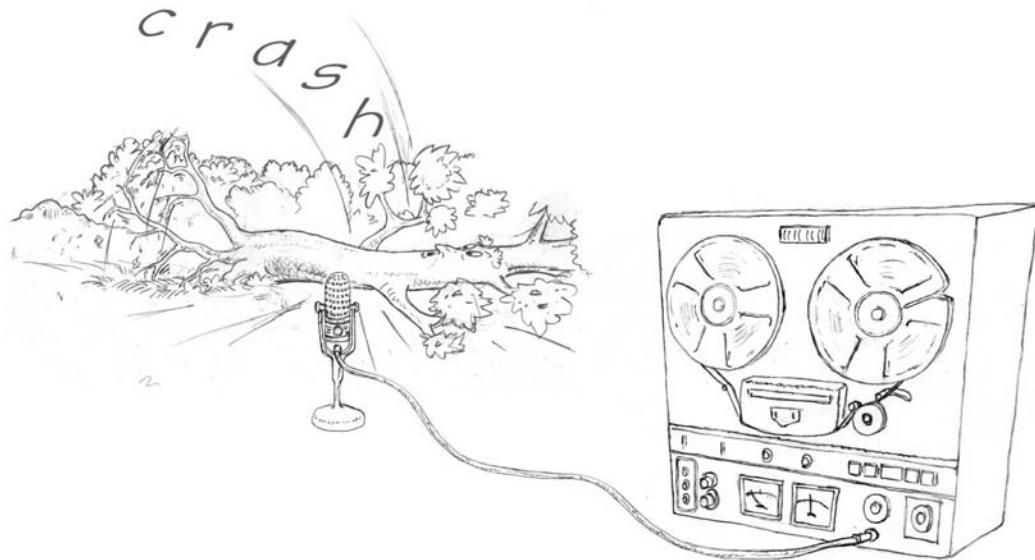
When we play back the tape we will hear the sound it made.
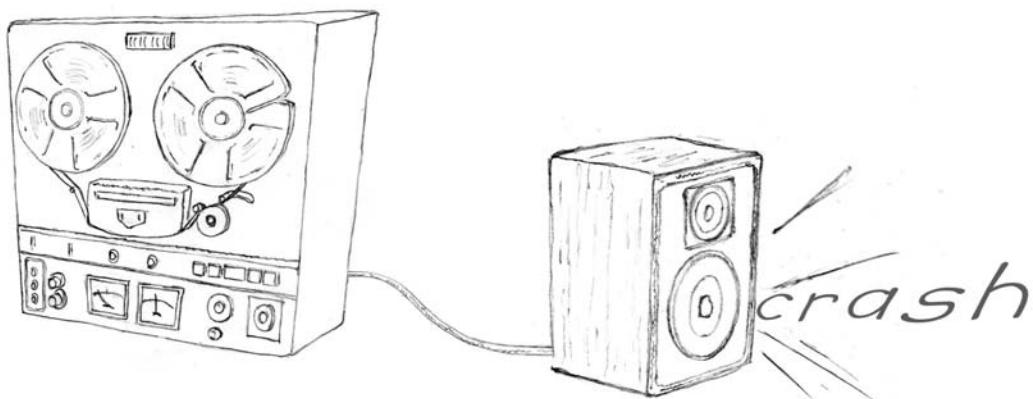
      A warning or *caveat* (kah vee aht), however, is that a sensing and thinking being is still necessary for the sound experience, if not during the original event, at some later time when the recorded version is replayed.

A No Answer

Although this answer might seem wrong, some thought should convince you that there is some truth to it. On the one hand, we believe that the earth, planets and stars exist independent of our thoughts about them. We are realists—people who believe in a material world. A sound, however, is not completely material; its existence requires someone to hear or experience it.

We have been talking about sound because it resembles time. Just as a sound must have someone to hear it, time must have someone, like you or me, to imagine it and to measure it.
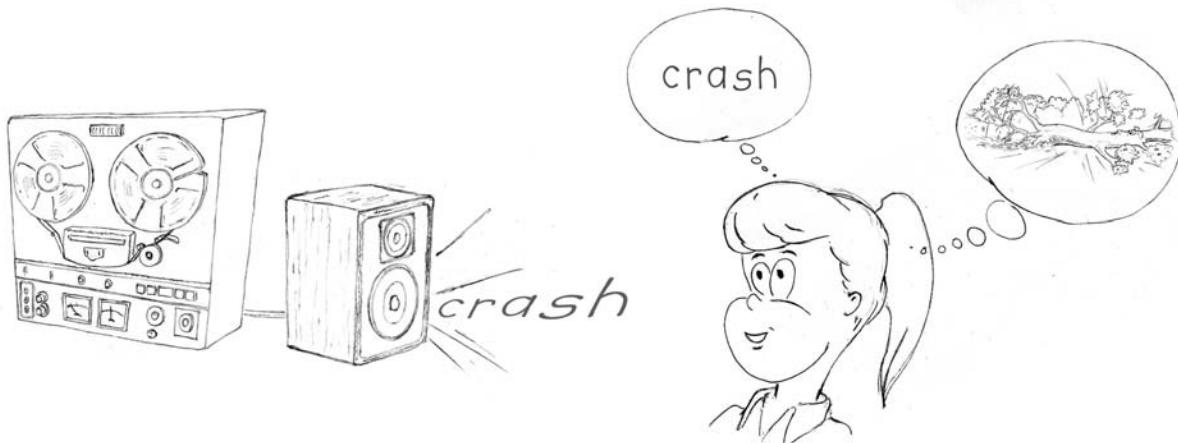
The experience of sound requires an experiencer. For the girl the sound waves from the speaker are transformed into the auditory experience of a crashing tree. This experience may acquire additional meaning by evoking familiar images of similar experiences she has had in her past.

The tape machine, on the other hand, only registers the physical aspects of the event and does not have the personal auditory experience of a crashing tree.
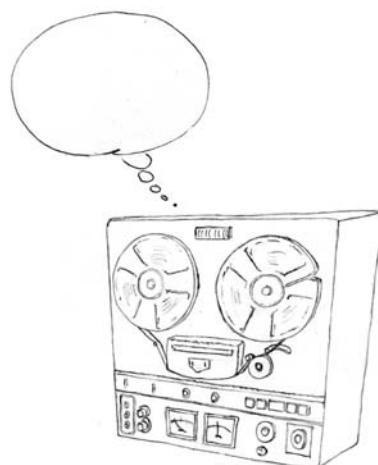
Therefore, if by "sound" we mean something more than the sound wave, then sound requires a hearer. Does time work this way too?

How We Learn About Time

Although we cannot say with certainty whether time exists independently of us, any conscious knowledge about time must be learned.

Time, initially, is no more intrinsic to our mind than it is to an hourglass.
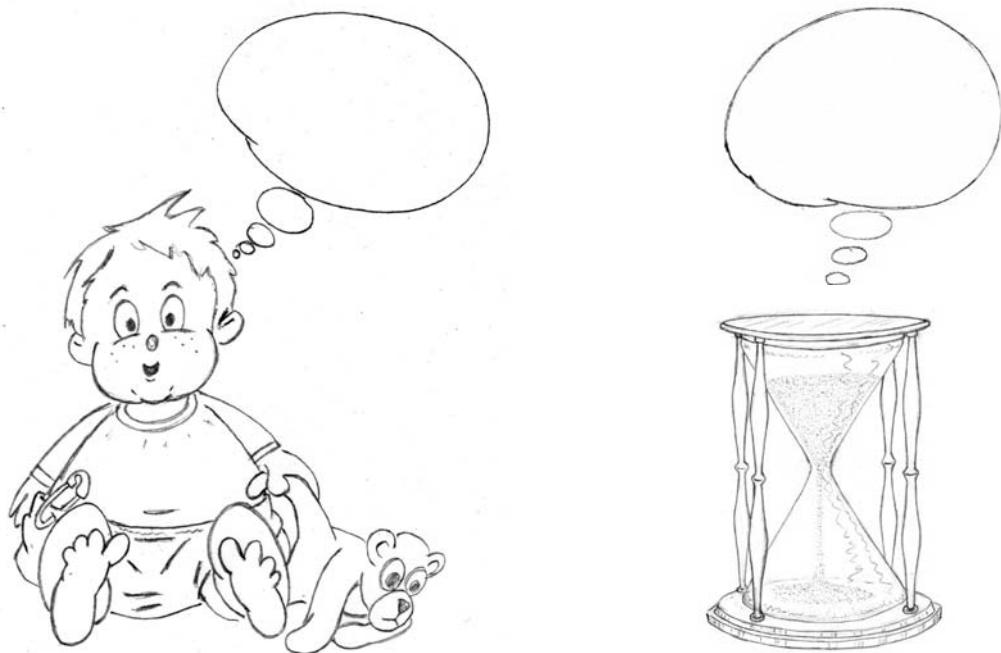
Time is an idea or concept that we (but not hourglasses) learn through experience.
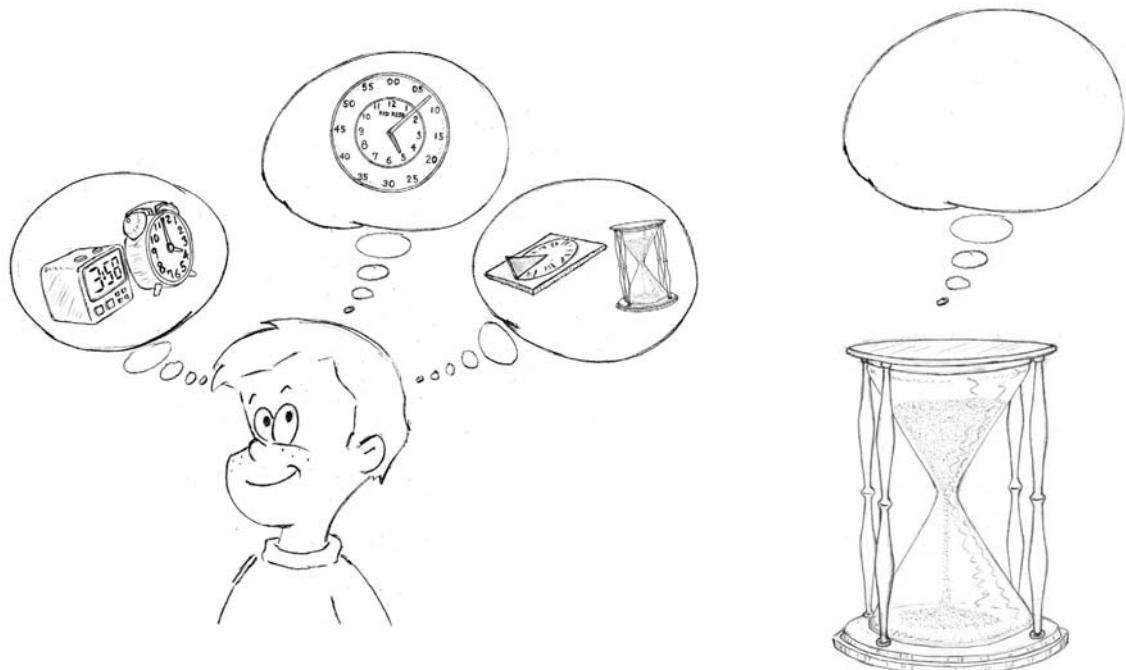
Resolution: The Paradox of Time

We feel most comfortable when we can think or reason in yes and no logic. Time, however, challenges this simple way of thinking. The famous Greek philosopher Heraclitus captured this when he said:

"Everything is and is not because everything is in flux.
We step and do not step in the same stream.
We are and are not."

Monday morning

The next day
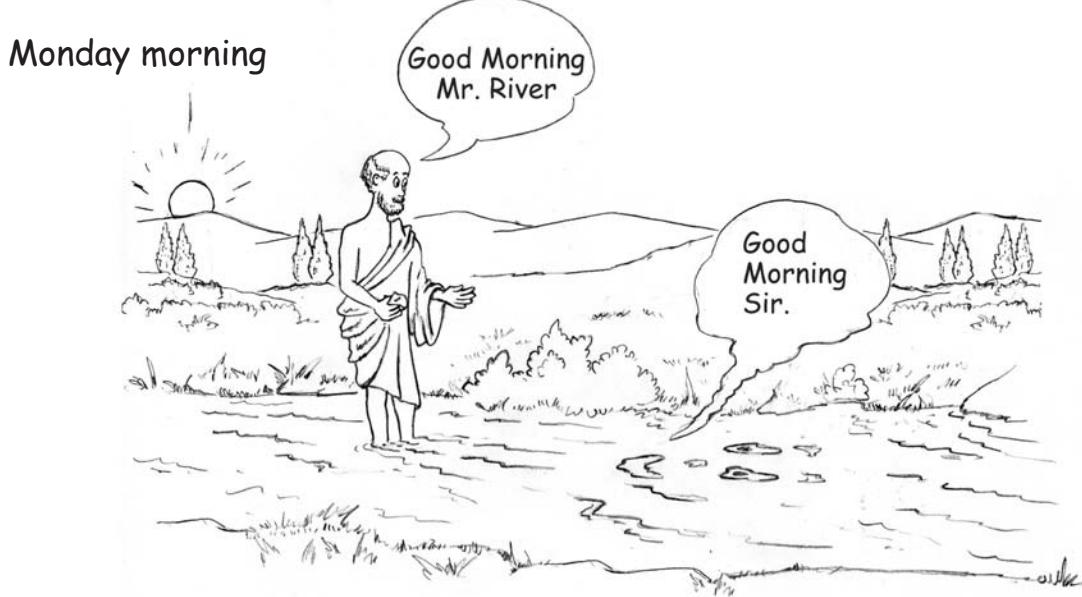
The contemporary Danish writer Peter Hoeg sums it up best when he states:

"Time refuses to be simplified and reduced. You cannot say that it is found only in the mind or only in the universe."

With this uncertainty, we cannot confidently conclude that time exists independent of our idea of it.

Knowing that a great deal of uncertainty may always surround our understanding of time, scientists still seek to deepen our knowledge about it. This often requires them to create hypotheses that may start like this: "Let's assume that time should be a measure of how things move", or "If we assume that the sunrise on Wednesday and the sunrise on Thursday have something related to time in common, then…" or "Even if one cannot step into the same river twice, something compels us to see the ever-changing river as having an identity, so…" In other words, scientists turn their curiosity and uncertainty into a method of inquiry.

Richard Feynman, renowned scientist, science teacher, bongo drum player, and science detective, also acknowledged the puzzle of time. He described how it could be studied scientifically, which requires measurement.

"Maybe it is just as well if we face the fact that time is one of the things we cannot define (in the dictionary sense), and just say that it is what we already know it to be: it is how long we wait! What really matters anyway is not how we define time, but how we measure it."

We will remember Feynman's advice throughout this book, although we cannot ignore the challenge to discover and define time accurately and imaginatively.

Following the lead of scientists before us we can explore how to measure time, expecting in the process to understand many other important aspects of our lives. It's tempting to assume we need a machine to do this. Surprisingly, however, *we* are living, breathing time-keeping machines. We can call this human timekeeping, the title of our next travelogue.

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Travelogue 2: Human Timekeeping

Brain Waves

When we learn about our body, we discover that we are natural recorders of time. Our brain activity produces electrical charges that can be measured and depicted in a graph.

We can plot the amplitude of the energy as a function of time, as shown in the accompanying figure. As we see in the graph, the waves made during an alert or even during a relaxed state are much different from those made in a drowsy or sleep period. If we somehow track these brain waves and other bodily functions, we discover that we have built-in measuring devices, or what psychologists have called an internal clock.

ALERT

RELAXED

DROWSY

ASLEEP

DEEP SLEEP

COMA

1 SEC
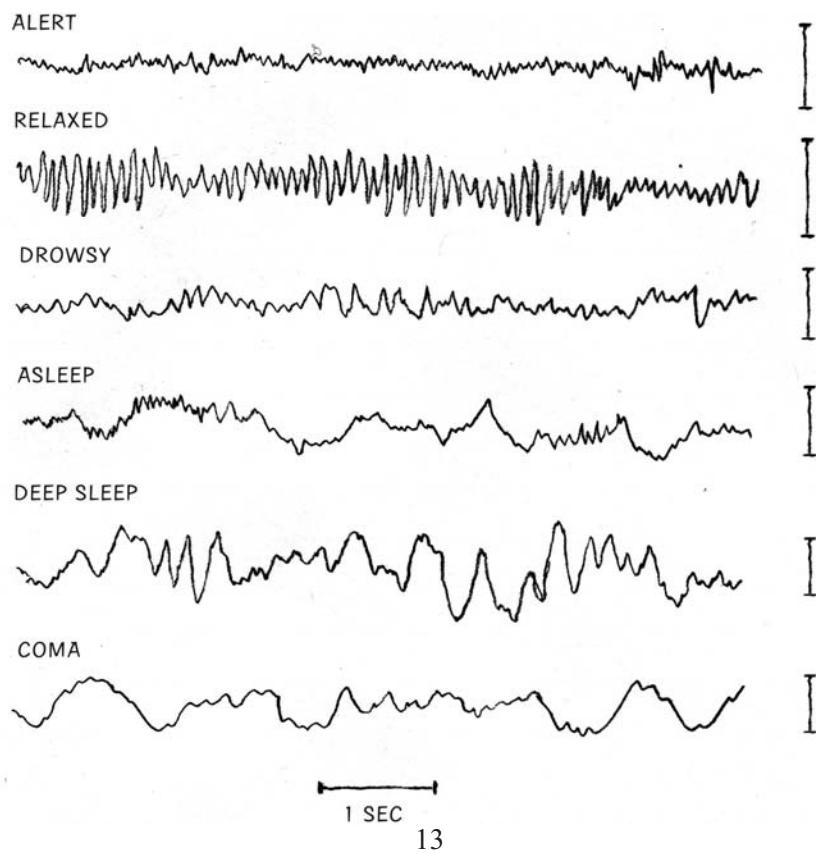
Counting Time

       We perceive and experience time. Some events seem to last forever. Other events go by much too quickly. We are fairly good at estimating time. We can tell the difference between two very similar time intervals. Have someone count silently to either 10 or 12, and have them tell you when they begin counting and stop counting. You should be able to tell the difference between these two counts. Counting is one method of measuring time. By counting in a regular fashion, we can time events fairly accurately. The famous physicist Richard Feynman observed that he could count accurately and read at the same time. His friend and colleague John Tukey was unable to count and read simultaneously.

       Feynman discovered that he and Tukey were counting in very different ways. Feynman was talking to himself, whereas Tukey was watching a tape with numbers go by in his mind's eye.

Counting while reading was easy for Feynman because he was using one system for counting and another for reading. Tukey, on the other hand, required the mind's eye for both counting and reading. Different people access their internal clocks in different ways. Feynman and Tukey monitor their clocks differently. Feynman talks to himself, while Tukey reads to himself.

This difference should alert us to the fact that different people might solve the same problem in different ways. Teachers who know this provide a variety of learning environments to support these individual differences.

With many different individuals with different clocks and methods of keeping time life could be chaotic (kay-ah-tick). In fact, there are impressive similarities in our experience of time, as we will learn in the next section.

Internal Clocks

       Some psychologists believe that our ability to perceive time and small differences in time is due to an internal clock that has the accuracy to record very short events. Such a fine level of accuracy would not be possible without some type of internal clock or pacemaker. This device ticks off short intervals that we can keep track of.

Perceiving Time

       We are very sensitive to small changes in time. Consider two time periods. How different do they have to be in order for us to perceive a difference? If a tone is played for 1 second, how much shorter or longer does a second tone have to be for you to notice the difference? What about a tone that lasts 10 seconds? Or a tone of 100 seconds? For a tone of 10 seconds, we can hear that a tone of 11 seconds is longer. For a tone of 100 seconds, a one-second change goes unnoticed. We require tones of 90 or 110 seconds to hear them as shorter or longer. We can notice about a 10% change, as illustrated by the graph.

The just noticeable difference as a function of duration.

16
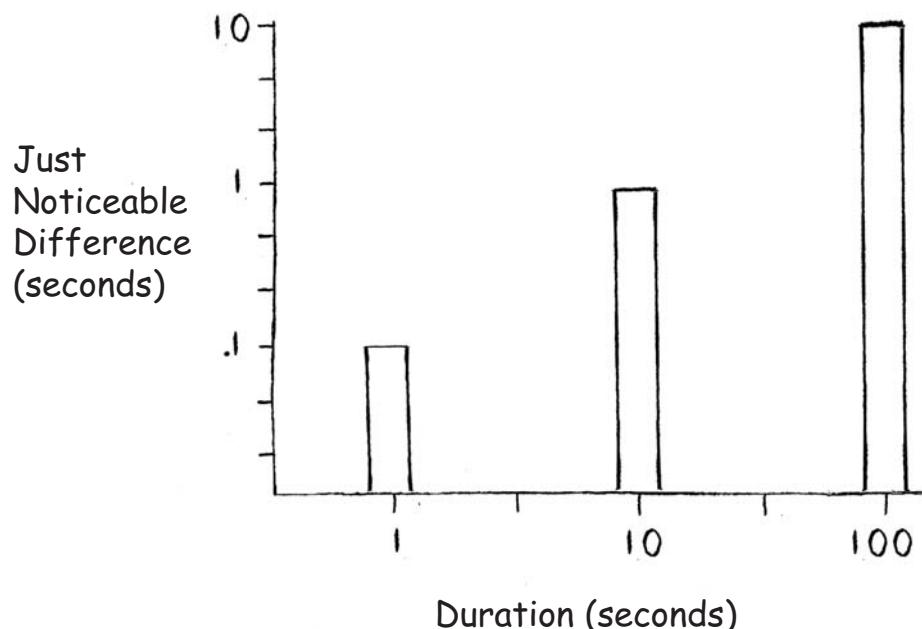
The so-called *just noticeable difference* is related to the overall duration of the tone. For shorter tones, we can notice smaller differences. For longer tones, we need larger differences. Our ability to notice a difference is *relative* to the duration of the tone. We will return to the relative nature of perception in our discussion of relativity theory.

The relativity of perceiving time illustrates a more general characteristic of our perception. Find a three-way light that gives three different brightnesses. Our light gives 50, 100, and 150 Watts, which is a measure of the intensity of the light. Now cycle through these three intensities, and pay attention to your perception of the light. Given that the change in intensity is the same from 100 to 150 as it is from 50 to 100, you would expect that your perception of the brightness change would be the same also. But what actually happened? Yes, the change from 50 to 100 was perceived to be much bigger than the change from 100 to 150. This is because 100 is twice as big as 50 whereas 150 is only 1 and 1/2 times bigger than 100. Our perception of a change is relative to what has been changed.

Just Noticeable Difference Curve

17
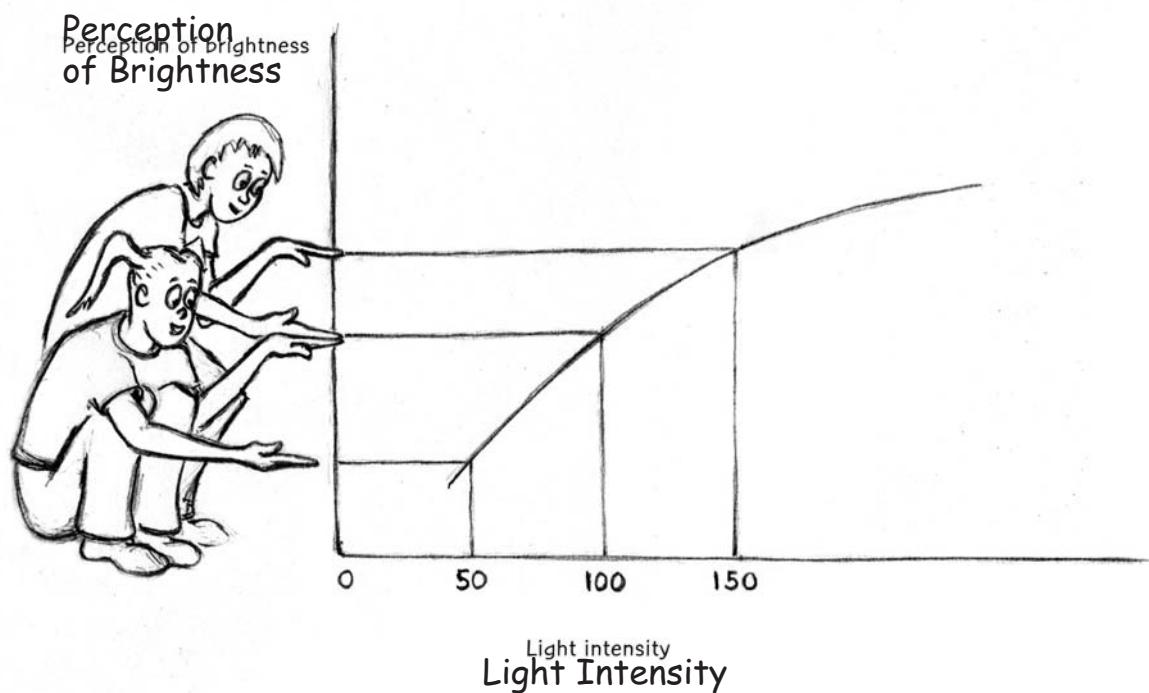
Timing and the Self

The timing of events in our lives is central to our experience and even to our sense of self. Entering a warm room or car, we experience the discomfort and choose to open a window. This choice leads to the action of actually opening the window. In more technical parlance, we form an intention to open the window and then execute the movement to achieve our goals. It is only natural to assume that we are in control of this action. Our feeling of control is at least partially based on our experience of the order of these two events. We form an intention to act and then carry out the action.

Scientific inquiry often challenges our intuitions. Benjamin Libet carried out some experiments that asked participants to report their impressions about the time when they decided to act and when they actually acted. As illustrated, the participants viewed a clock and introspectively reported the times shown on the clock corresponding to their choice and their action.
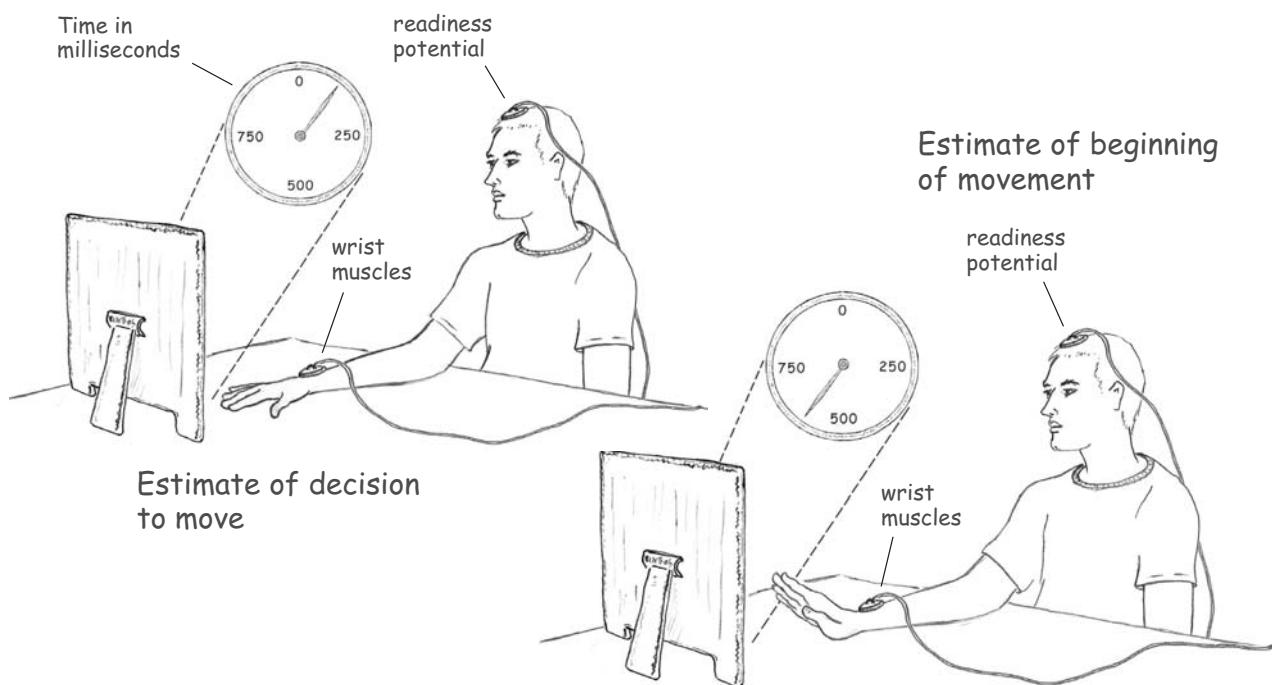
Simultaneous with these subjective measures, Libet recorded a change in the electrical activity of the brain called a readiness potential. Muscle activity was also recorded. The graph on the next page (from Obhi & Haggard, 2004) shows the results of this type of experiment. The participant thought that he decided to move at point (1) in the graph, which was about 350 milliseconds before he thought he started to move at point (2) in the graph. This agrees with our intuition.

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A — Significant change in readiness potential

1 — When the subject thinks he decided to move

2 — When the subject thinks he began moving

3 — When the subject actually began moving
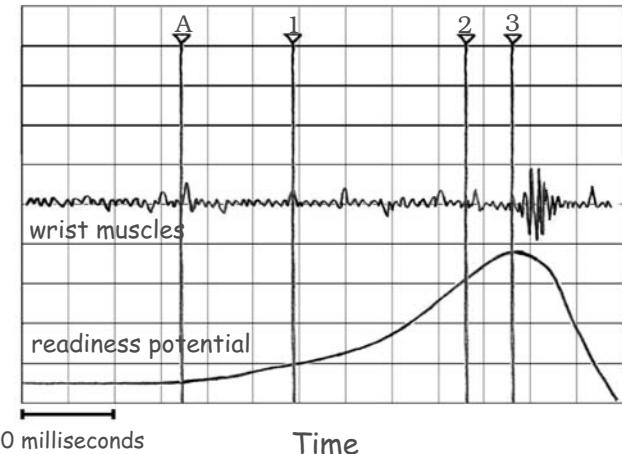
Surprisingly, however, as the graph also shows, the appropriate motor area of the brain actually produced electrical activity in the form of a readiness potential to move at point (A) about 250 milliseconds earlier than the time that the participant thought he made his decision to move at point (1).

This result is a sobering one indeed because it implies that our conscious experience of a decision has already been anticipated by preconscious brain activity. As cognitive scientists have learned, much of the brain's activity is not open to introspective report, and therefore is not conscious. This result should not be too surprising, however, because our conscious experience of the world around us necessarily follows a great deal of unconscious processing. For example, we can't describe how we recognized the redwood tree outside our window, only our experience of seeing it. This observation does not mean we are not in control of our actions. Our values, motivations, and goals contribute to our behavior. We must assume that we have control of our destinies. To quote I. B. Singer: "You have to believe in free will; you have no choice."

Anarchic Hands

There are some unusual experiences of time related to behavioral abnormalities. For instance, with "anarchic hand" syndrome, a person's hand will do things all on its own. People know that their hand is doing something that they did not will it to do. They say that something is simply wrong with their hand, or some other confabulation, and they may even try to stop it with their other hand. They have the sensory feedback letting them know that the movement is happening but it is not preceded by the normal sense of expectation of an upcoming action. This experience of a hand movement without expecting it creates an abnormal timing of events, which is so disturbing that some additional action, explanation, or justification is deemed necessary.

Our Pace of Life

Our use of time is reflected in our pace of life, which can be measured in various ways, such as how quickly we walk and talk, how quickly a clerk fills an order, or even the accuracy of our clocks. Not surprisingly, the pace of life differs across different regions, cities, and nations. People tend to be fast paced in the Northeast of the United States in such cities as Boston and New York. People are likely to be slower paced in the West in cities like Los Angeles and in the South in cities like Shreveport, Louisiana. A scientist and his students collected these indices of the pace of life in six different countries listed from fastest paced to slowest paced: Japan, United States, England, Taiwan, Italy, and Indonesia. We might expect that the pace of life would also be very different in different work and play settings. You would look foolish if you were in a hurry at the beach or took your old sweet time while working in a fast-food restraurant.

Don't Fool with God's Sense of Time

People are fairly good at perceiving, measuring, and counting time. Moreover, they do it in different ways. What about God? A wiseguy asked God the following: "God, you have so much, what is a billion dollars worth to you?" God answered, "Only about a dollar." "Hmm," said the wiseguy, "could I have just a dollar?" God replied, "Sure, in about a minute." For God, a minute was a billion minutes or about 1779 years.

Travelogue 3: Time and Experience

Timing Eyes and Ears in Astronomy

Astronomy involves the measurement of the position and motion of celestial bodies. About two centuries ago, most of the astronomical activity was at Greenwich, England. For this reason, the time of day was defined relative to this location, and we continue to refer to Greenwich mean time (GMT). A short boat ride down the Thames from London and a visit to the astronomy museum in the Royal Greenwich Observatory is a must on an English holiday.
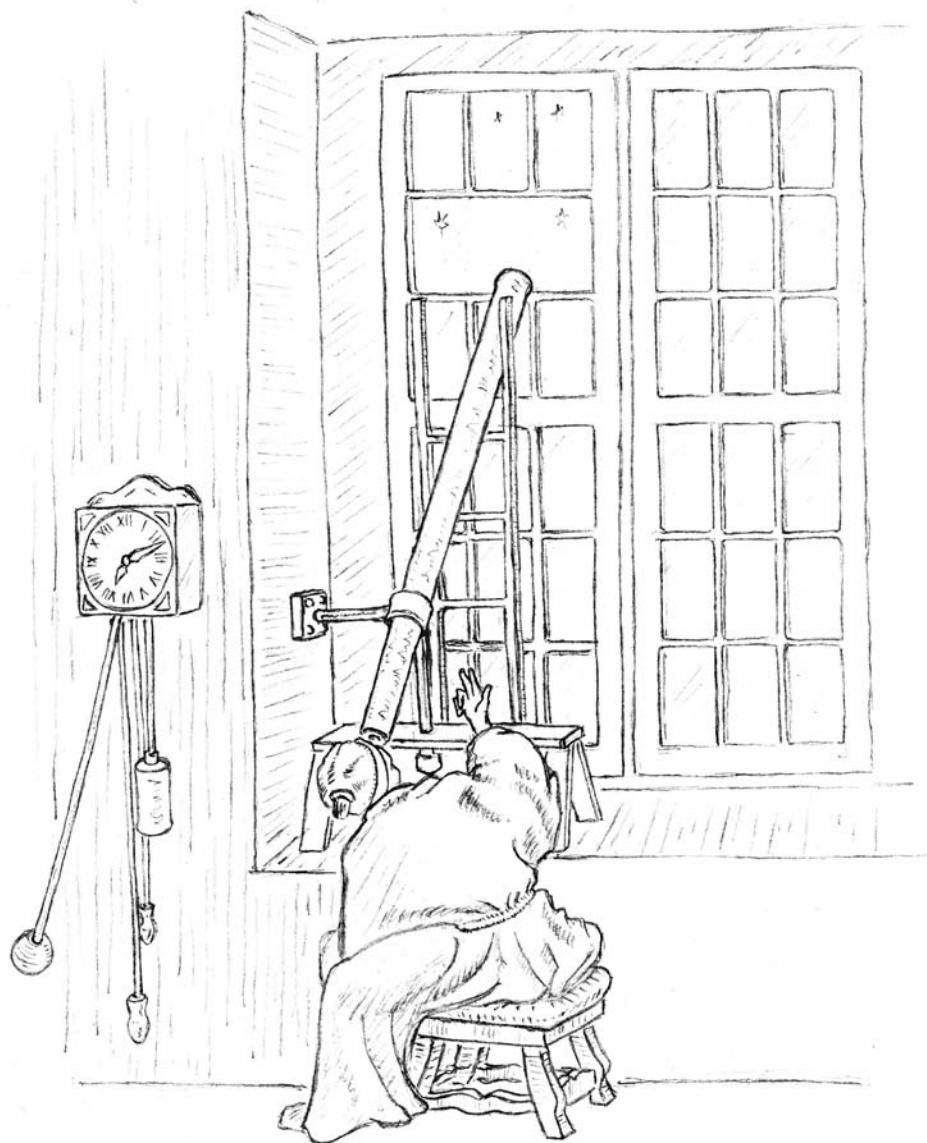
The 18th century astronomer's telescope had a vertical line representing the meridian. Viewing a star moving across the telescope, the astronomer had to measure exactly when the star passed the meridian. This was called the eye and ear method. First viewing a clock that ticked off seconds, the astronomer would find out what time it was, to the accuracy of seconds, and then count the ticks as he viewed the star moving across the telescope. By counting the ticks, it was possible to see where the star was at each second and estimate the time it crossed the meridian to the accuracy of .1 second. The time would then be recorded in the log book and so on for all of the stars.

Star approaching meridian

meridian

Tick — One thousand one

Tock — One thousand two

Tick — One thousand three
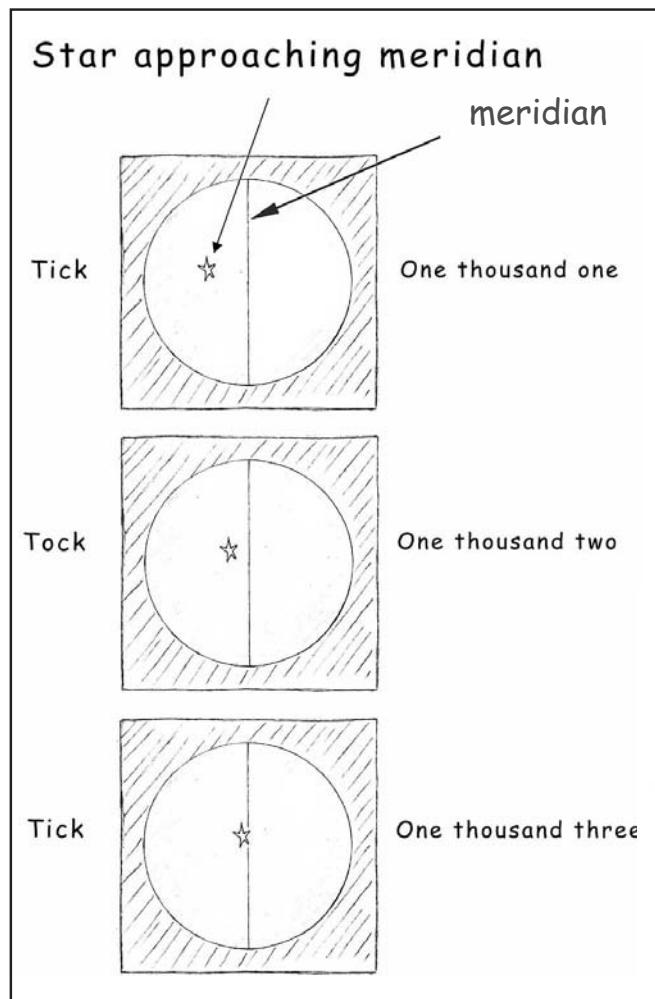
Astronomer's View
Through Telescope
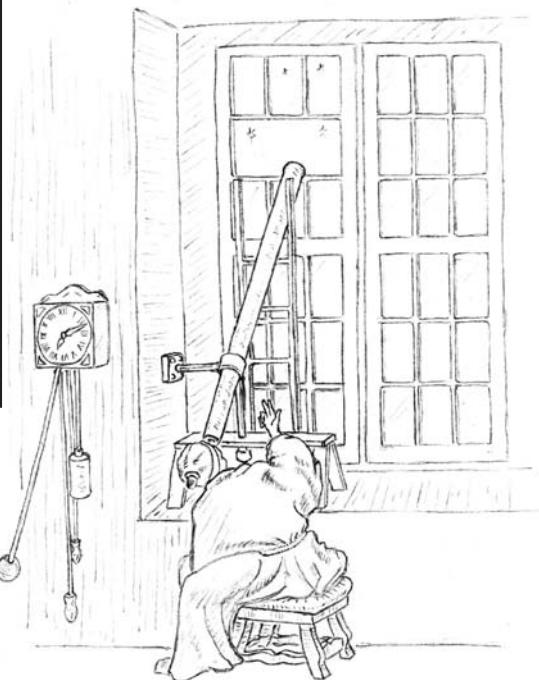
No Two Astronomers Look and Listen Alike

Different astronomers would work on different nights. It wasn't long before a crisis arose. It all started when the boss, Nevil Maskelyne, fired his assistant, David Kinnebrook, because Kinnebrook was recording different times from Maskelyne. Astronomers knew that some stars should cross the meridian at the same time on different days. What Maskelyne observed was that Kinnebrook's recording was about .8 second later than his own recordings. Since one of the two must have been in error, Kinnebrook, the assistant, took the blame.

This could have been the end of the story if it weren't for another astronomer, F. W. Bessel. He thought about this problem and went through the log books to evaluate the recordings of different astronomers. It wasn't just Maskelyne and Kinnebrook who disagreed, but, in fact, most astronomers did not agree with each other. Some astronomers always saw the stars later than others. Or to put it another way, some astronomers always saw the stars earlier than others.

Most importantly, Bessel saw order in all of this chaos. He was able to make sense of every astronomer's results. He could bring all of their recordings into agreement by developing a personal equation, which corrected each astronomer's time by subtracting or adding a constant. If a given astronomer was early, he was usually early for all the stars, and his time could be corrected and brought into agreement with another astronomer's time by adding a constant. The illustration on page 23 gives hypothetical results from two astronomers for two stars. As the tables show, all of the astronomers' data could be brought into good agreement by simply adding .4 seconds to the left astronomer's time and subtracting .4 seconds from the right astronomer's time.

Bessel also carried out experiments under controlled conditions to verify his observations. He found that two astronomers would not see a light cross a boundary at the same time; one would be consistently faster or slower than the other, which is exactly what he had noticed when he studied their log book.

$$T = t + .4$$

Maskelyne's personal equation.

$$T = t - .4$$

Kinnebrook's personal equation
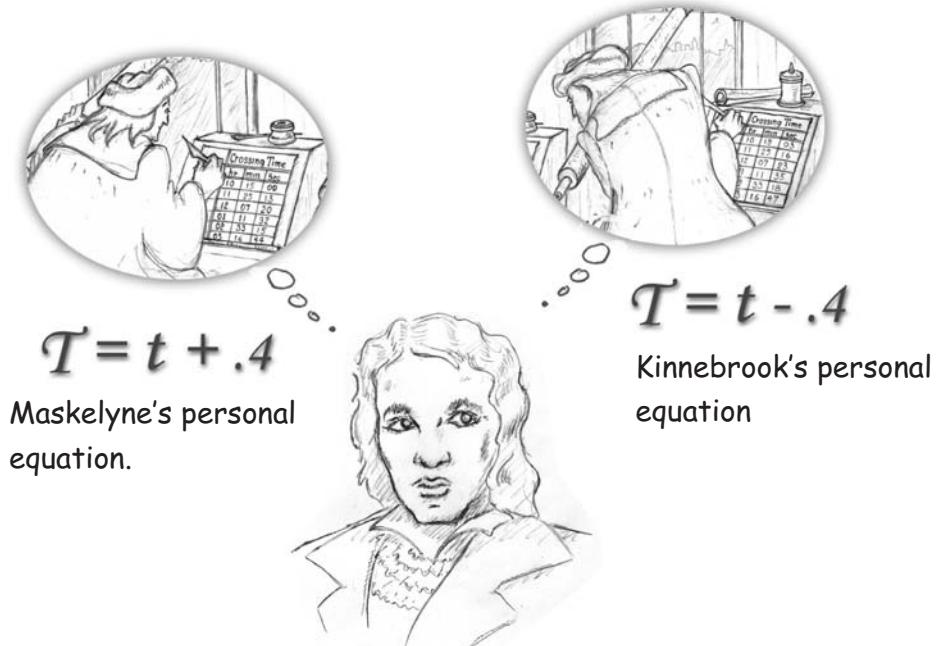
We landed on this planet with sensory systems, such as our eyes and ears, to perceive and act on the events taking place around us. It should not be surprising to find that different individuals, who already differ in so many noticeable ways, would also differ in the time it takes them to react to a given event. These minute differences among us can sometimes have fairly dramatic consequences. For example, children who are very insensitive to some signals, such as moving images or changing speech sounds, can have difficulty in learning to read. Highly sensitive people can become experts. As Yager, the famous pilot who was the first person to break the sound barrier, said, "I'm the best pilot because I see so well and because I've flown so much."

Pointers and Bells

One early experiment produced a puzzling result, which could only be understood by realizing that it takes time to see and hear. This study was carried out by a German scientist named W. von Tchisch. He asked a willing participant to monitor (watch carefully) a clock, with a pointer moving rapidly around the dial. The task was to indicate the position of the pointer when he heard a bell ring. The point of the investigation was to determine where the person would report seeing the pointer when the bell rang.

In one situation, the bell rang when the pointer was at 9. Most of us would think the person would report that the pointer was at 9 or 10 when the bell rang. But the person reported 8. How could a person see the pointer at a location before the bell even sounded? This could have been the beginning of the study of extrasensory perception (ESP), or knowing more than your senses tell you.

Auditory input from the bell to the ears

Visual input from clock face to the eyes
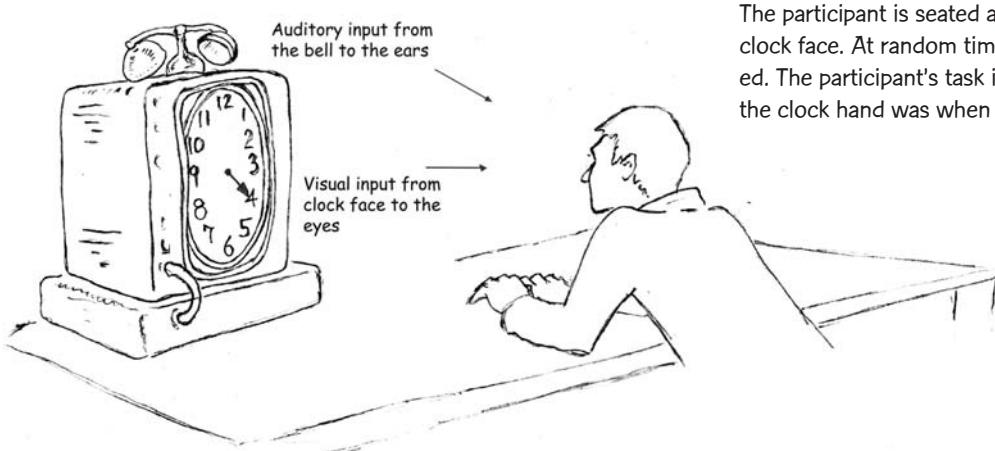
The participant is seated and watches the clock face. At random times the bell is sounded. The participant's task is to report where the clock hand was when the bell sounded.

Von Tchisch tested the following possible interpretation. The person might think that it takes some time to hear the bell and, therefore, report the location of the pointer earlier than when it was actually seen at the sound of the bell. This is a good interpretation, but even when von Tchisch tested himself in the situation, he would see the pointer at a number before the bell sounded. He experienced the pointer at 5 when he heard the bell, which actually rang at 6. How can we explain this foolishness?

Von Tchisch concluded that a person could anticipate the bell and actually hear it before it occurred. Like other direct realists, however, von Tchisch didn't consider the possibility that it takes time to see and time to hear. There is a lag between the time the physical event occurs and the time that we experience that event. How does this lag account for the fact that the subject reports a pointer at a place before the bell actually rang?

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To begin our answer, there is no reason that the time it takes to hear the bell is equivalent to the time it takes to see the pointer. It may have taken longer to see the pointer than to hear the bell. Consider the following possibility as an example. Assume that it takes two time units of the clock to see the pointer at a particular point. That is, you experience the hand at a location 2 units behind when it actually occurred. If the hand is pointing at 4, you see it at 2. Assume further that it takes one unit of the clock to hear the bell sound. If the bell rings at 4, you hear it when you see the pointer at 3.
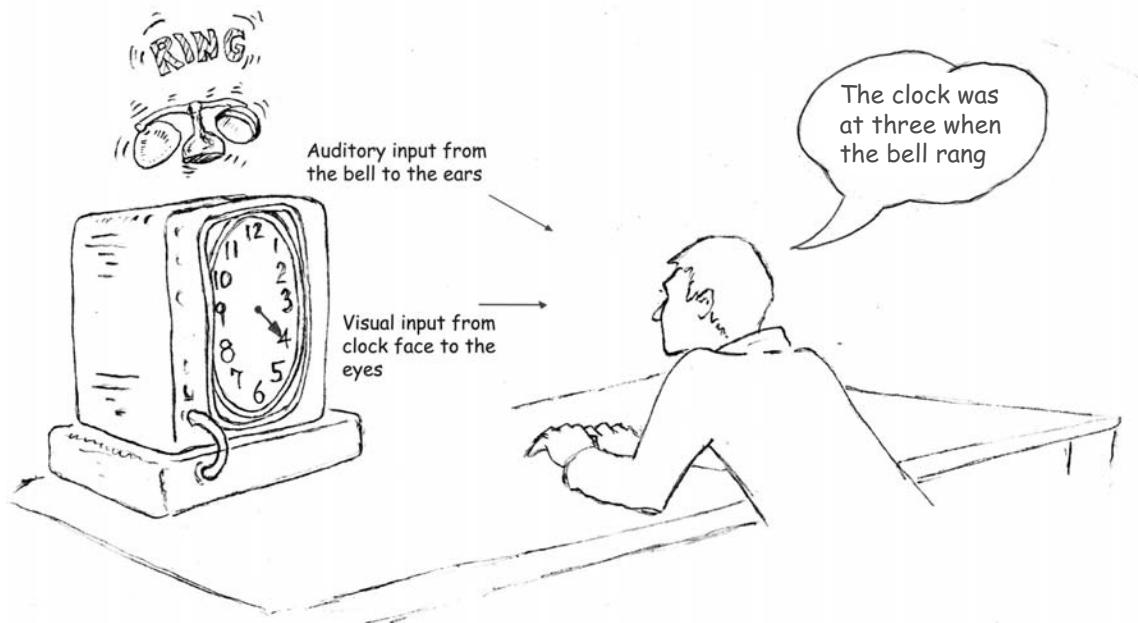
The bell rings at 4 but the participant reports it at 3.

In this example, perception lags behind the physical event two units in visual perception and one unit in auditory perception. If the bell is rung at 4, the pointer is objectively at 4 when the person hears the sound. However, it takes two units of time to see the pointer, and one unit to hear the bell. When the person hears the bell she sees the pointer at 3. The person did not hear the bell before it rang! It took one unit of time to hear the bell and two units of time to see the pointer. Von Tchisch's study makes it clear that it takes time to experience light and sound and that this time can be measured.

Clock Units	Physical Events		Visual Perception	Auditory Perception
	Clock	Bell		

Visual perception lags behind physical visual event by two clock units

Auditory perception lags behind auditory event by one clock unit
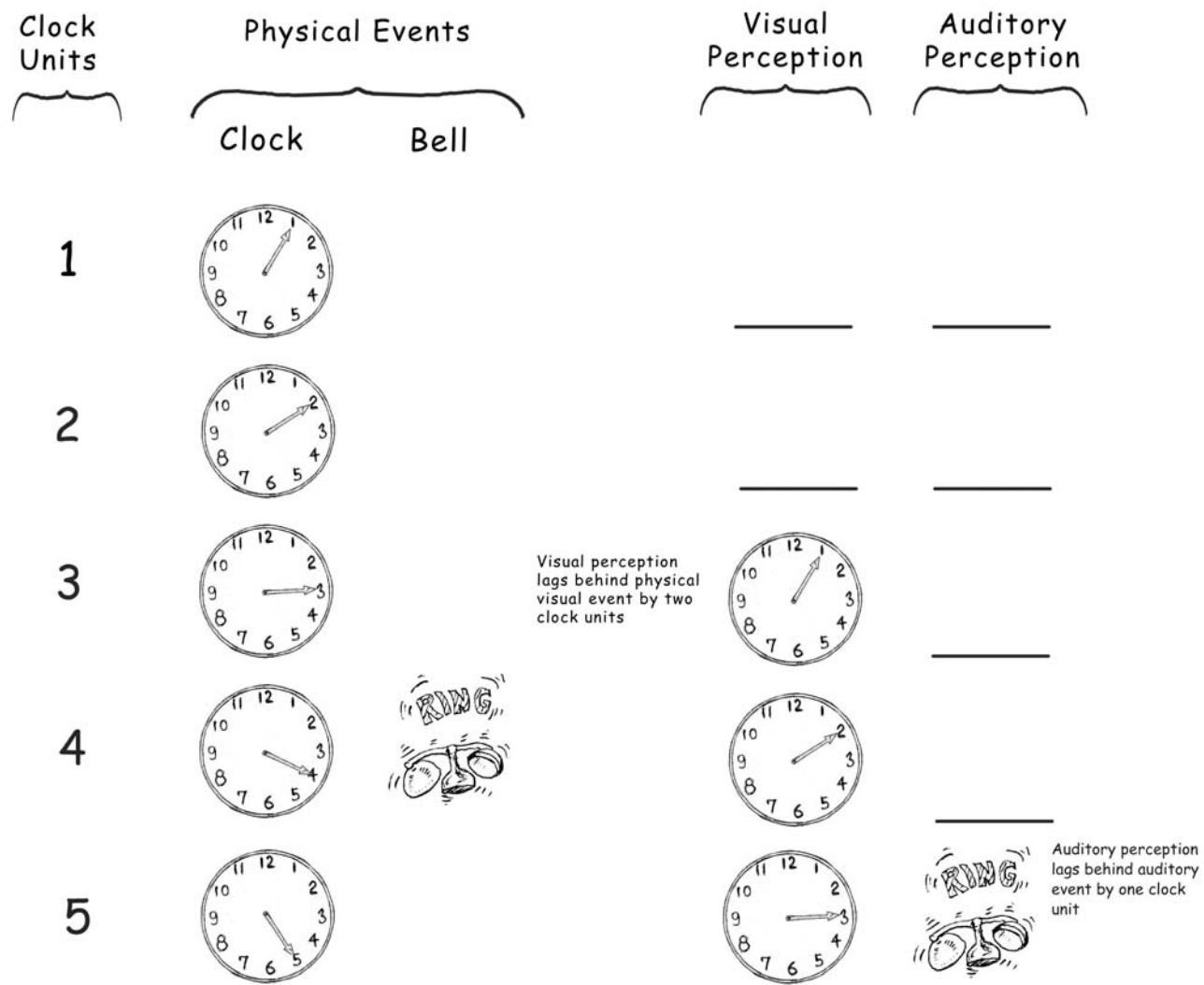
Participant perceives the bell as being simultaneous with clock position 3

The diagram above depicts the physical and perceptual course of events when there are different delay times for the visual and auditory sensory systems. In this case the participant perceived the bell as being coincident with clock position 3, when it actually occurred coincident with clock position 4.

Direct Realism

Bessel's resolution of the astronomers' differences made apparent that our experience of the world does not correspond exactly with the world. Previously, most scientists, at least implicitly, held a view of perception now called direct realism. Direct realists believe that our experience mirrors the environment exactly. Our experience of an event occurs at the exact time as the event (possibly allowing time for light and sound waves to travel).
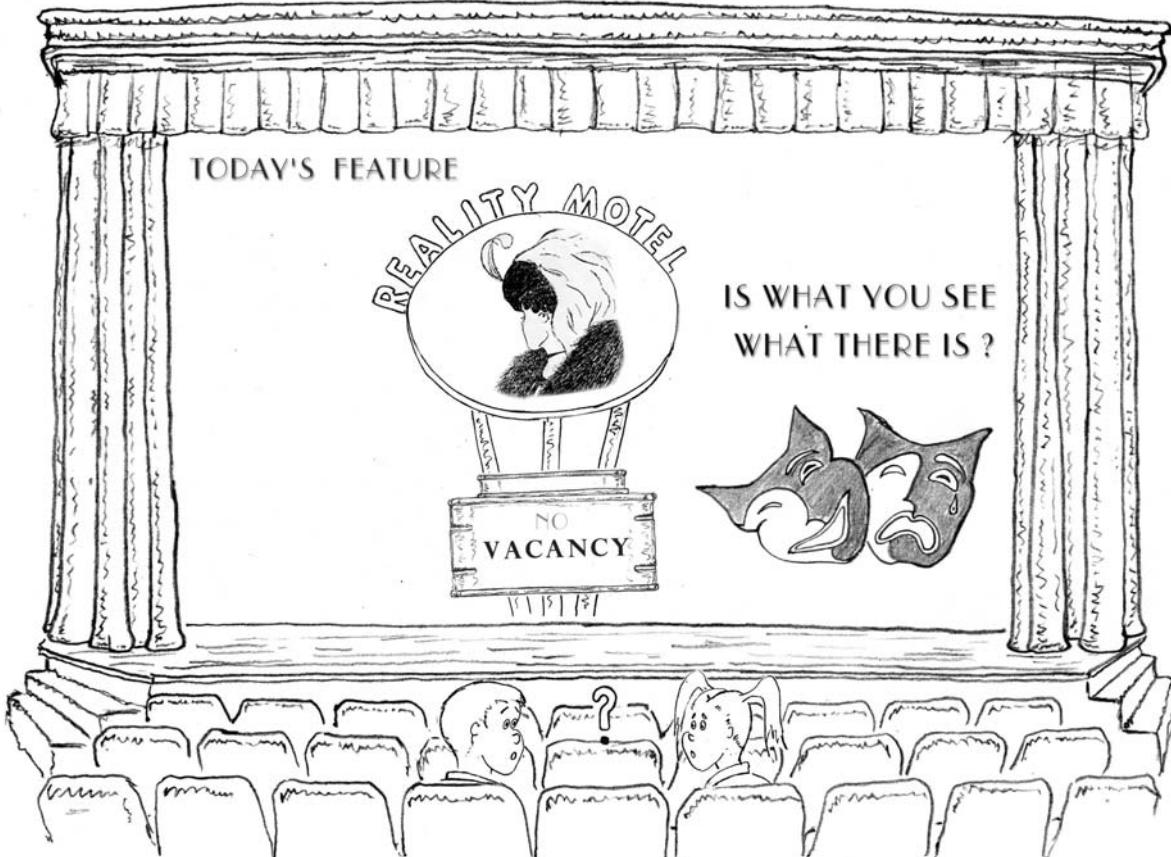
An alternative view assumes that there is some lag between the presentation of the events in the environment and our experience of those events. We don't experience immediately a change in the environment, and Bessel's personal equation told us that the time to react to a change differs for different people. As we saw with individual differences in counting strategies, people's reaction times can also differ. Unlike Maskelyne, we should embrace this diversity. But we must also recognize that the consequences of these differences can be significant.

We should think about how misleading direct realism is when we learn about afterimages and reversible figures in Travelogue 4. Direct realism also fails to explain our experience of pointers and bells, the early engaging puzzle about time we just witnessed.

Measuring Our Nerves

In science, it is foolish to say something cannot be done. Respected scientists once predicted that flight in machines heavier than air was impossible, and no use for the telephone or TV would be found. The famous physiologist Johannes Mueller believed that the time required for a stimulated nerve to carry its message to the brain and for the brain to activate the muscles was "infinitely short." Therefore the speed or velocity of nerve conduction could never be measured. At about the same time as Mueller's pronouncement, however, Hermann von Helmholtz, the famous German scientist, was doing exactly that.
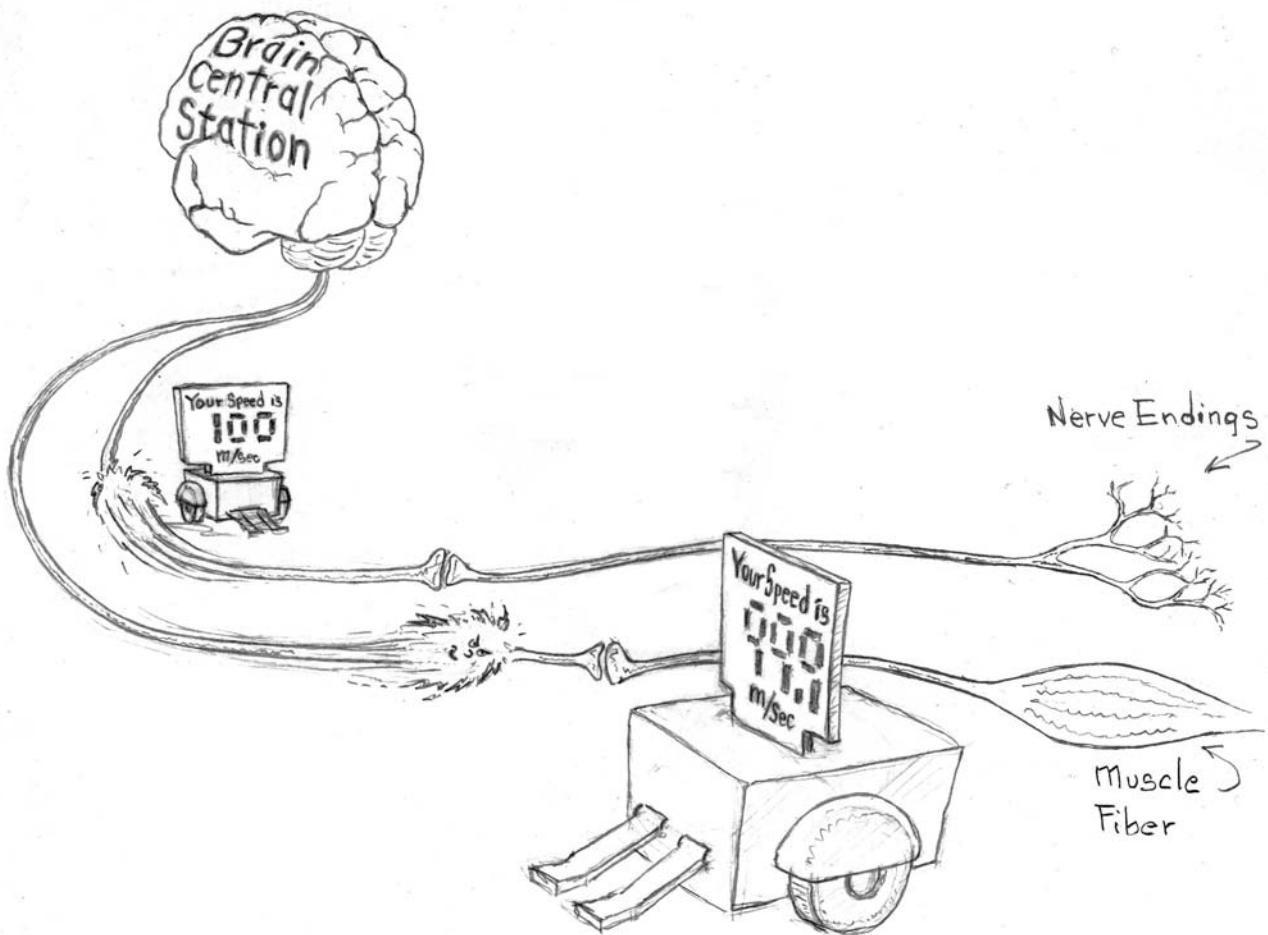
Helmholtz worked out a technique for measuring nerve conduction velocity in frogs, and subsequently applied the same principles to a series of experiments with humans. The experiment measured the time between the presentation of a stimulus on someone's skin and her response.

Helmholtz compared two conditions. In one, the muscles of the ball of the thumb were stimulated at a point on the wrist (the subject's hand and arm were immobilized). Reaction time was measured between the onset of this stimulus and the onset of the muscle contraction reflex of the thumb. In the other condition, the same muscles were stimulated at a point just above the fold of the elbow. The time required for muscle contraction to the stimulus at this point was also measured and was found to be more than in the first condition.

The logic of this experiment was founded on the belief that the two times should differ by a small amount. They should differ only by how much farther the nerve impulses had to travel in one condition than in the other. The basic task did not differ under the two conditions so that the time for all other processing between the stimulation and muscle reflex should be constant. Thus, all Helmholtz had to do was to measure the two times and then determine the extra time required for the longer distance. In order to compute the speed of nerve conduction, he divided this time by the difference between the two distances. In this way, Helmholtz was able to estimate human nerve conduction velocity at about an inch or two a millisecond or 100 ft/sec. How fast is this? It is about the same speed as cars driving on an open highway. This result was surprisingly accurate, given the speed of nerve conduction time and the short distance between the two points.

Helmholtz also employed his subtraction method with voluntary responses. He stimulated someone's skin at either of two different distances from the brain. The task was to respond to the stimulus as rapidly as possible with a movement of the hand. The two conditions, therefore, only differed with respect to how far the nerve impulses had to travel to the brain. All other components of the task were assumed to be constant in the two conditions. The estimate of nerve conduction velocity was the same as that estimated from involuntary responses.

T1=5 milliseconds

Time for stimulus to reach thumb muscle from point A

Elicit thumb reflex by stimulating at this point

A

T2=15 milliseconds

Time for stimulus to reach thumb muscle from point B

Elicit thumb reflex by stimulating at this point

B
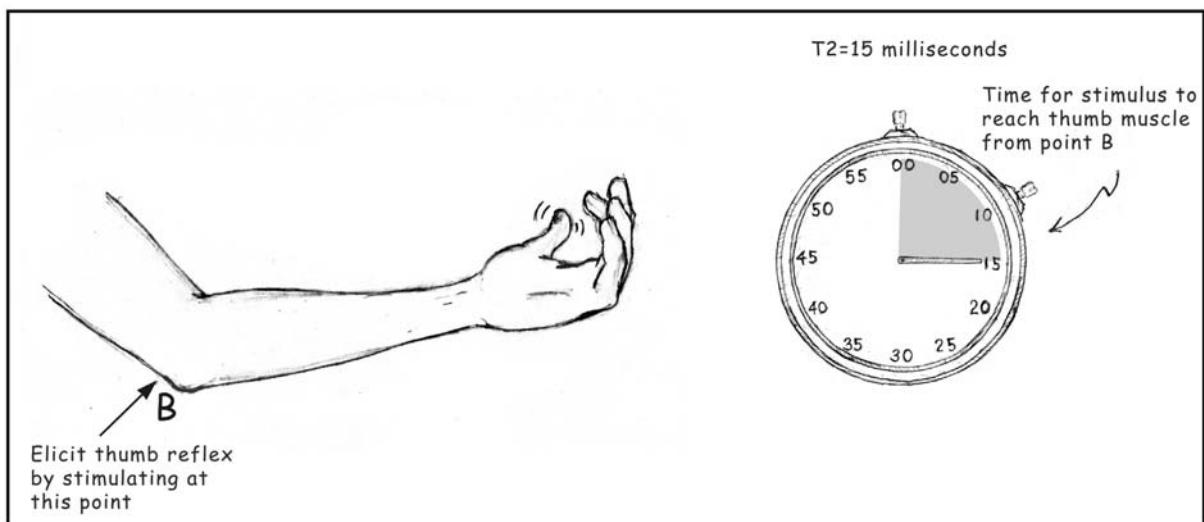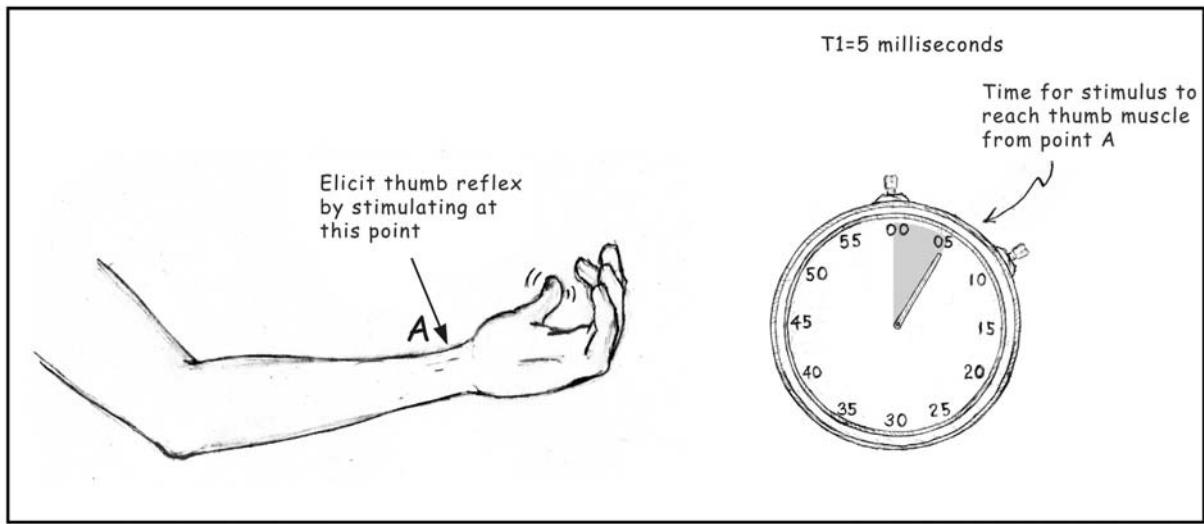
The difference between the time for response when stimulating from point B, and the time for response when stimulating from point A, gives the time it takes for a nerve impulse to travel the length the forearm.

T2-T1 = 10 milliseconds

1 millisecond = .001 second
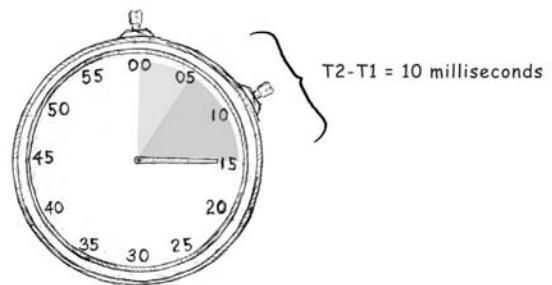
Reacting with Different Senses

Another scientist, French astronomer Adolph Hirsch, measured the time it took to respond (moving a hand) to stimuli presented to the eye or ear. Hirsch found that stimuli to the eye produced slower times than stimuli to the ear. A reaction to a visual stimulus took about 1/5 of a second, whereas a reaction to an auditory stimulus took only about 1/6 of a second. The longer time to perceive a visual than an auditory stimulus is consistent with our explanation of the Pointers and Bells paradox.

The fastest reactions he found were to a touch stimulus, which took about 1/7 of a second. It would be fun to do the pointer task with a touch instead of an auditory stimulus! Can you think of any reasons for these differences in terms of human survival and well-being?
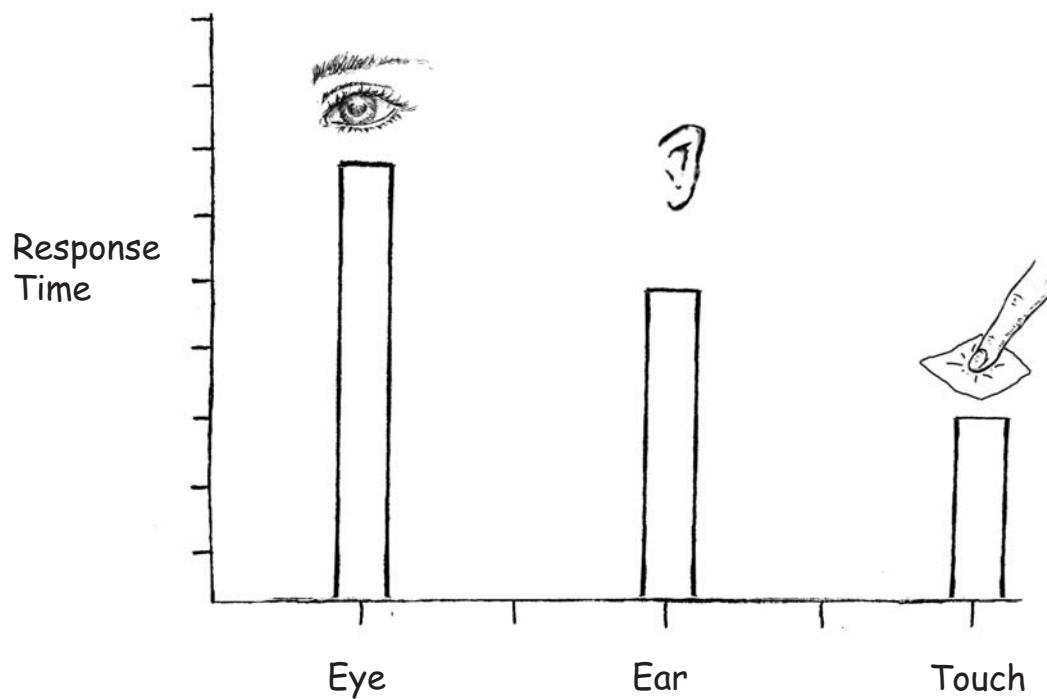
Intensity of a Stimulus

Many studies like those carried out by Hirsch have shown that the time it takes to respond to a stimulus decreases as the intensity of the stimulus increases. Thus, a person instructed to press a lever as soon as she hears a tone will respond sooner, as the loudness of the tone is increased.

This result is consistent with other studies, which have actually shown that nerve conduction time across the synapses on the way to the brain is inversely related to stimulus intensity. This means that as intensity increases, nerve conduction time decreases. Logically, this effect of intensity should influence the process of responding to the stimulus. We react more quickly to a car's horn than to the purr of its engine.
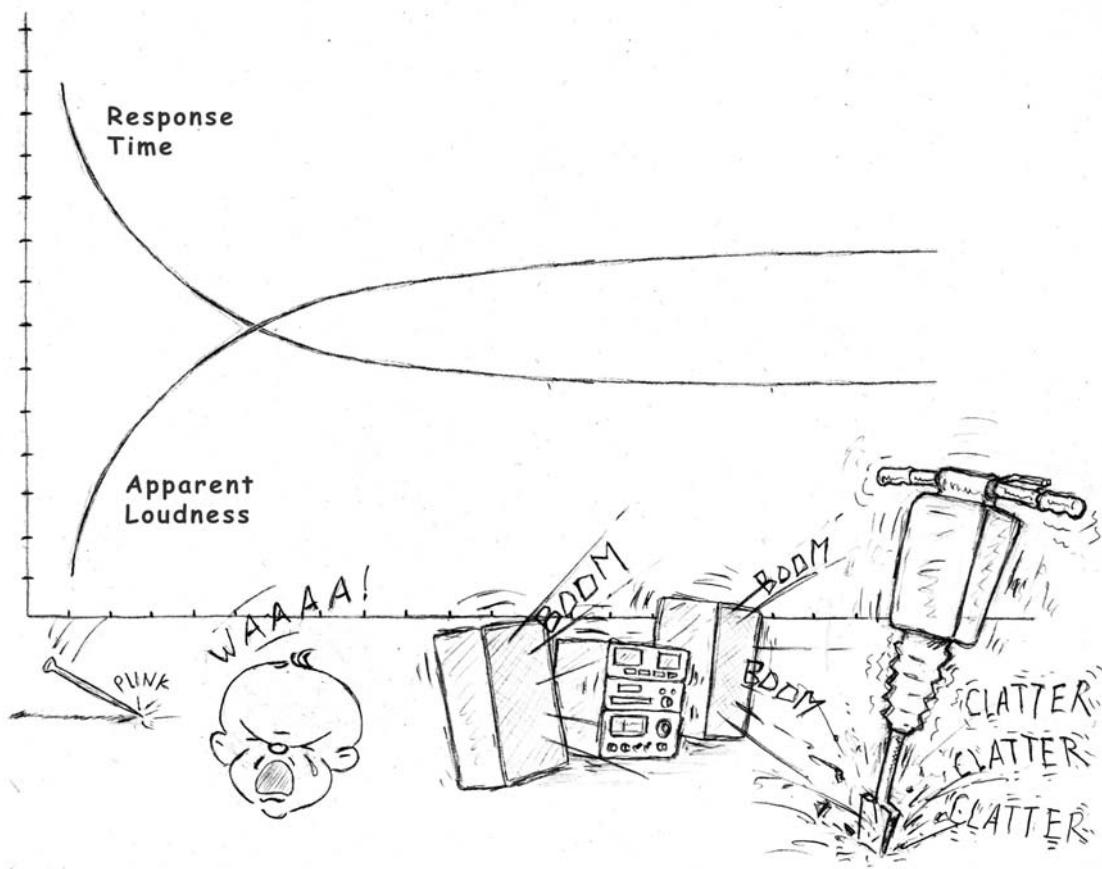
The time it takes us to respond can be influenced by the intensity of the stimulus. Given this possibility, the differences that were observed in the Pointers and Bells experiment and in Hirsch's study could have been due to modality, intensity, or both of these variables. Research on intensity provides new insights into old problems. Science develops incrementally, that is, in steps sometimes over long time periods.

Travelogue 4: Psychology of Time

We noted earlier that time seems to require someone to experience it. It is also true that experience requires the passage of time. No time means no experience, as in the well-known adage, "Time is what prevents everything from happening at once."

We now describe how time shapes our perception, experience, memory, and learning.

"Looking Time" Leaves Its Mark

Our future experience is influenced by our past. Looking at one color for a while makes us less sensitive to that color. After viewing one color, we will tend to see the opposite (complementary) color when a neutral surface is viewed. Each color is replaced by its complementary color. This is called a negative afterimage. Green replaces red and red replaces green. Yellow replaces blue as blue replaces yellow.

The artist Jasper Johns used color afterimages to allow the viewer of his painting to see an American flag in the traditional red, white, and blue even though he did not use any of these colors on the canvas. If his green black, and yellow flag is viewed for about a minute before fixating a white surface, we see Old Glory even though it is simply a negative afterimage.

Black and White Afterimage: Hold the page at arm's length and fixate on the black bulb for about 20 seconds, trying not to avert your gaze. Then look off to the white space on the right. You will see a glowing white bulb with a black filament.
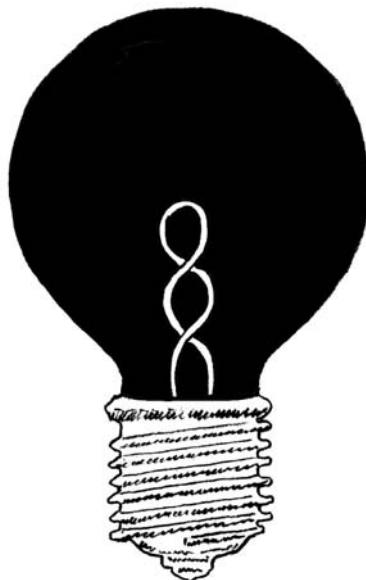
Seeing Two Things at One Time

      How many things can you do at the same time? We are at our best when we are doing only one thing. Although intuitively not true, a similar principle holds for our perception. We can see only one thing at a given time. What we see in a scene is called a figure-ground organization. We see some figure of interest against some background, such as a cyclist figure pedaling along the highway background. Although our figure-ground organization of a fixed scene can change from moment to moment, at any given moment we see only one thing. Psychologists have created reversible figures in which there are two possible scenes in the same picture. We see only one at a time and our perception reverses between the two possibilities. One of the best-known reversible figures is the Rubin figure, which fluctuates between two faces and a vase.

Can you see the two faces alternating with the maple leaf in the Canadian flag.?
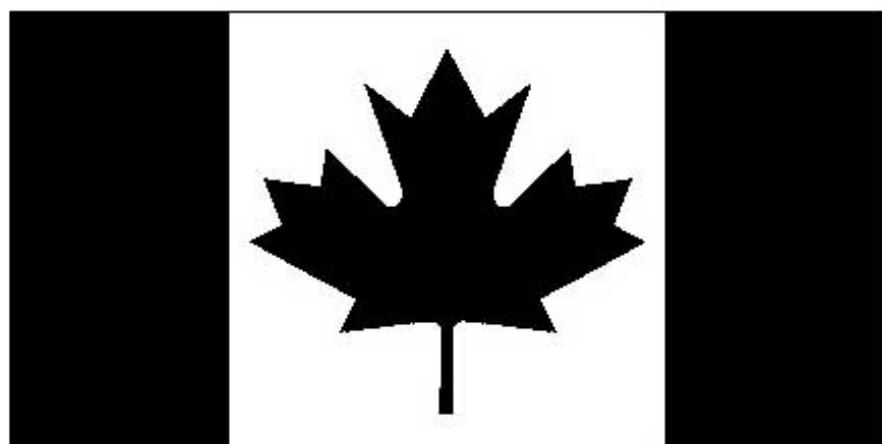
Boring

The next best-known reversible figure, created by the famous psychology historian E. G. Boring, is an ambiguous lady who can be seen as a young girl or as an old woman. Take a look at the lady. Some see an old woman with a long nose. Some see a young lady with a necklace. With some effort, everyone can see both. What is amazing, however, is that we can see only one of them at a time.

It is possible to control the picture that you get by focusing on different parts of the figure. To see the young girl, look at eye lashes. To see the old woman, look at her mouth. Point of view exerts a critical influence. No matter how skilled we become in seeing the two alternative figures, however, we experience only one at a time. This constraint eases our perceptual load.

To help you see both, here are modifications of the picture to show more clearly the two alternatives.

Young Woman   Old Woman

Reversible Cubes

Finally, we cannot leave this topic without showing the reversible cube. Take a moment and watch what happens as you look at this cube. Try to describe the process of becoming aware of how perception is transformed in time. Some say it resembles watching a film loop. What is important to remember in all of these cases is that we are able to see only one figure-ground organization at a given time. Therefore, an accurate description of our experience will have to account for the omnipresence of time in all that we are and do.
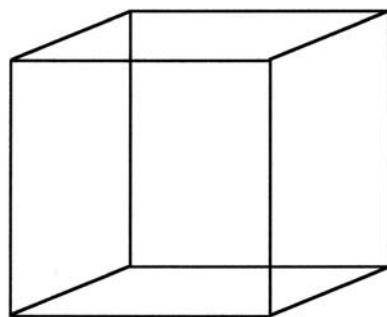
Perception And Metaphor

Recall how we described metaphor as an expression that honors, simultaneously, similarity and difference. These visual exercises may provide the same sort of pleasure that metaphor gives us.

Learning Nonsense

     We have seen that time is an important ingredient of our perception. It also plays an important role in our learning and memory, as scientists have observed for more than a century. In 1885, Hermann Ebbinghaus published the first experimental study of verbal learning, or the learning of words. Viewing psychology as a science, he was committed to the experimental method as the appropriate framework for its study. His goal was to assess the learning and retention of *new* words. To achieve this goal, he had to eliminate any influence of words a person might already know. Ebbinghaus realized that people would already have words in their vocabulary and, therefore, any study of learning and retention of words would not be free of this previous knowledge. Rather than using real words, he made up a new vocabulary of consonant-vowel-consonant nonsense syllables, which have claimed a role in psychology ever since. Some examples are DAF, BIX, REN, and GOM. Using only himself as subject, Ebbinghaus carried out a highly systematic series of experiments involving the learning and retention of nonsense syllables.

The Upside of Time on Task

      Ebbinghaus established two laws of how learning and memory depend on time. These laws still stand today, over 100 years later. The first law is that learning increases with the time spent on the memorization task. This law, called the total time function, can be summarized by the aphorism, "You get what you pay for."

      Ebbinghaus would read a list of 16 nonsense syllables, from the first to the last. He would repeat this practice for a given period of time. On the next day, he measured his memory by determining the number of additional repetitions required to relearn the list by heart. The idea is that the more that is learned, the less study time is needed on the next day to relearn the list. The amount of time it took Ebbinghaus to relearn the items was a function of the number of repetitions. As we might expect, the more time spent learning the less time it took to relearn the list. Furthermore, Ebbinghaus found a simple linear relation between the study time on day one and the amount learned. We can conclude that the more you practice the more you learn.

Study time to relearn list as a function of the number of repetitions in learning.
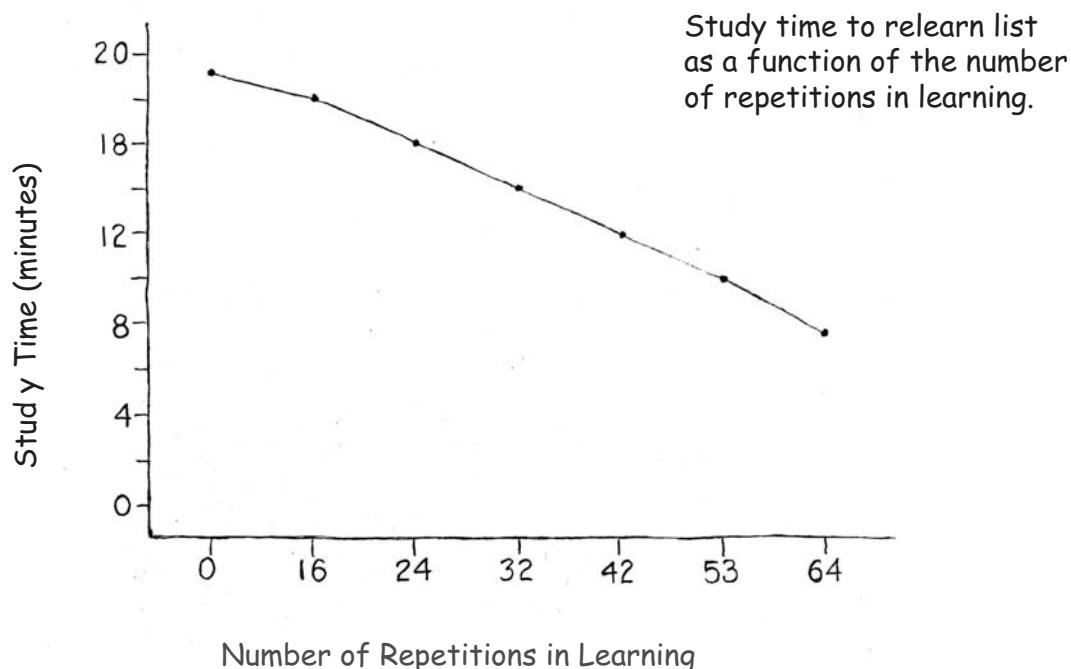
The Downside of Time Away from Task

       What God gives, she also takes away. The more time we spend learning a skill, the more expert we become. The flip side of this law is that the more time we spend doing something else, the more we forget that original skill. Ebbinghaus's classic study of forgetting involved an even more heroic effort. Ebbinghaus taught himself many different lists of nonsense syllables. A given list was relearned after a forgetting interval as short as 20 minutes or one as long as 31 days. Memory for the nonsense syllables decreases systematically with increases in the time between original learning and testing. The second law is that forgetting increases with increases in the time intervening between learning and testing. Forgetting is not linear, however, because the total amount forgotten per unit time decreases with longer times. This means that parents can still remember something about their school friends, even though it has been many years since they have seen them.

The percentage of nonsense syllables Ebbinghaus remembered after the different retention intervals.

Retention Interval (m = minutes, h = hours, d = days)
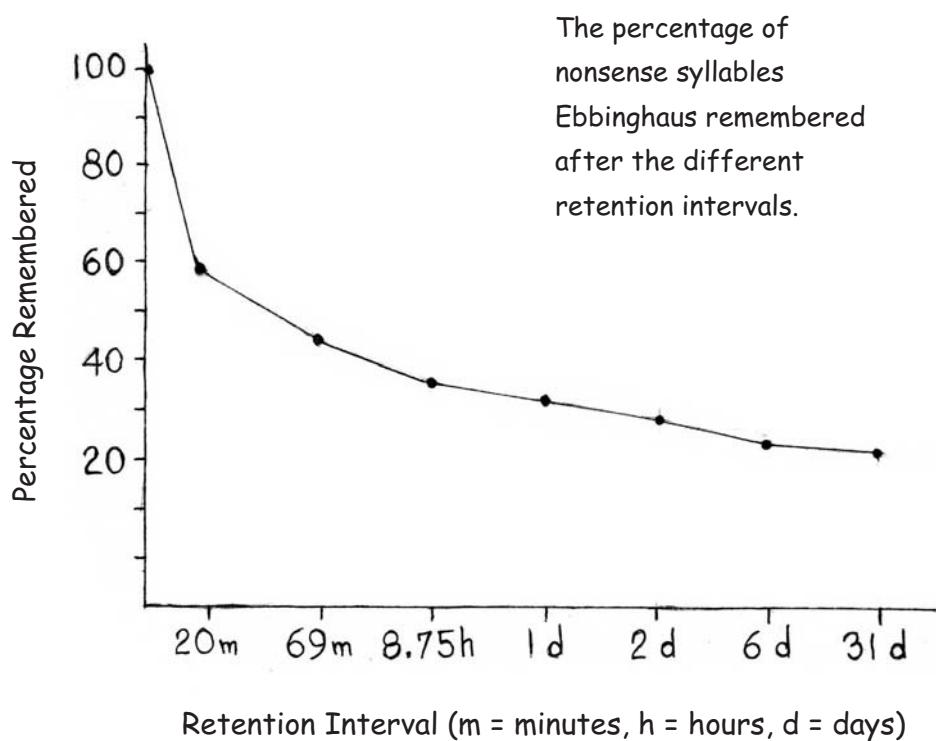
How to Practice with so Little Time

We are all pinched for time, and making the best of it is a constant concern. Let's say you have only a fixed amount of time to devote to learning some skill such as playing the piano, learning arithmetic facts, shooting baskets, or learning a new language. How do you optimize (make the best of) the limited amount of time you have? Research by psychologists has proven repeatedly that spacing your practice over a longer time leads to better learning than massing your practice within a shorter time. This finding is highly general and holds across an amazing variety of skills.

Young students learning to type practiced either an hour a day or two hours a day. The learning curves for the two groups shows there is a big advantage for practicing just an hour a day rather than two hours a day when the total time on task is the same.

Typing speed as a function
of total practice time.
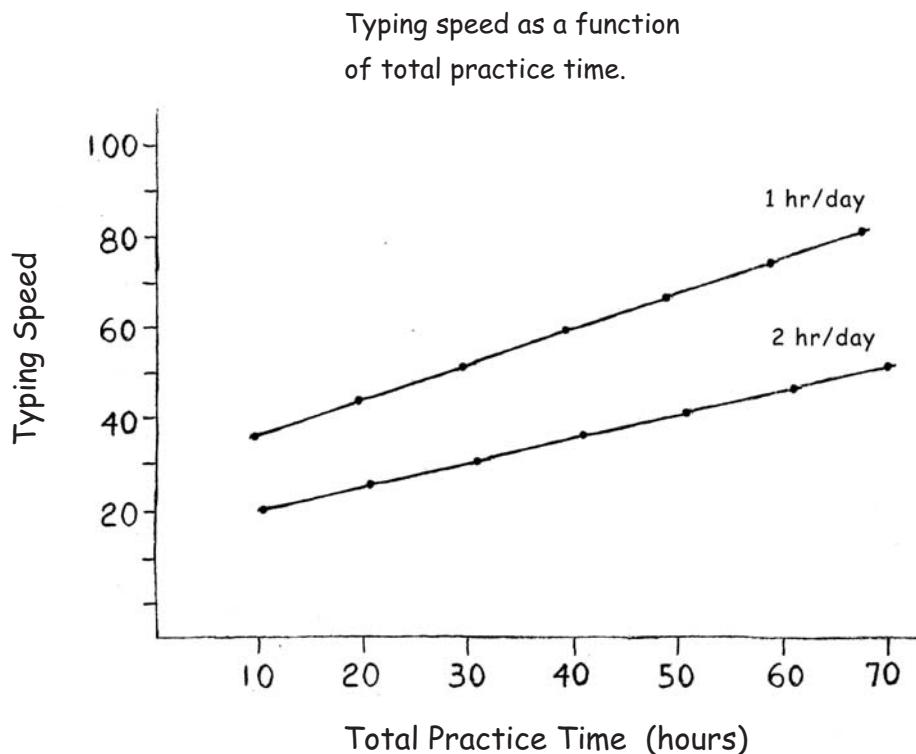
Maximizing Your Learning Power

We now know a little more about how to maximize learning and memory. One important variable, not surprisingly, is time on task. Or, to put it another way, "no pain, no gain." The time away from a task will make you rusty. To offset this forgetting, try to spend a little time on task even with skills not currently being used, such as baseball during soccer season.

Long-Lasting Memories

No matter how long ago we learned it, we are still blessed with a strong memory for the alphabet song which is a popular method to learn the alphabet. We know it was in place as early as 1834 when it was first copyrighted by C. Bradlee and titled "The Schoolmaster."
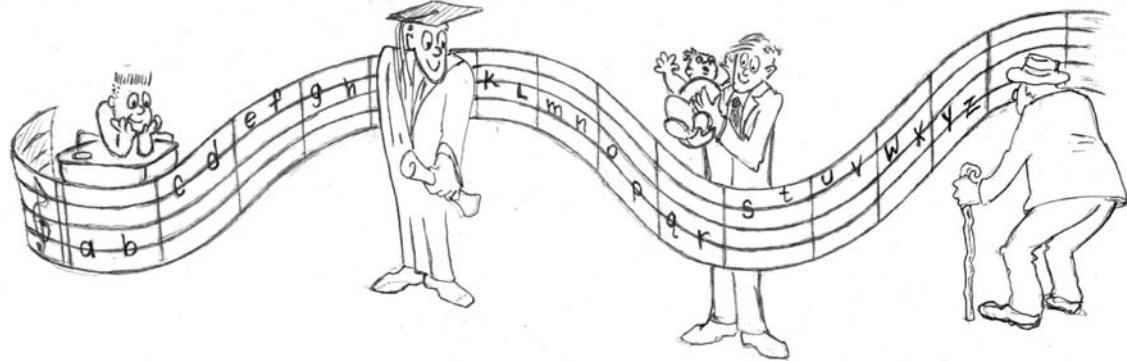
The melody is based on the well-known children's song, Twinkle, Twinkle, Little Star.

Twinkle twinkle little star,	a b c d: e f g
How I wonder what you are.	h i j k: l m n o p
Up above the world so high,	q r s
Like a diamond in the sky.	t u v
Twinkle twinkle little star,	w x
How I wonder what you are.	y and z
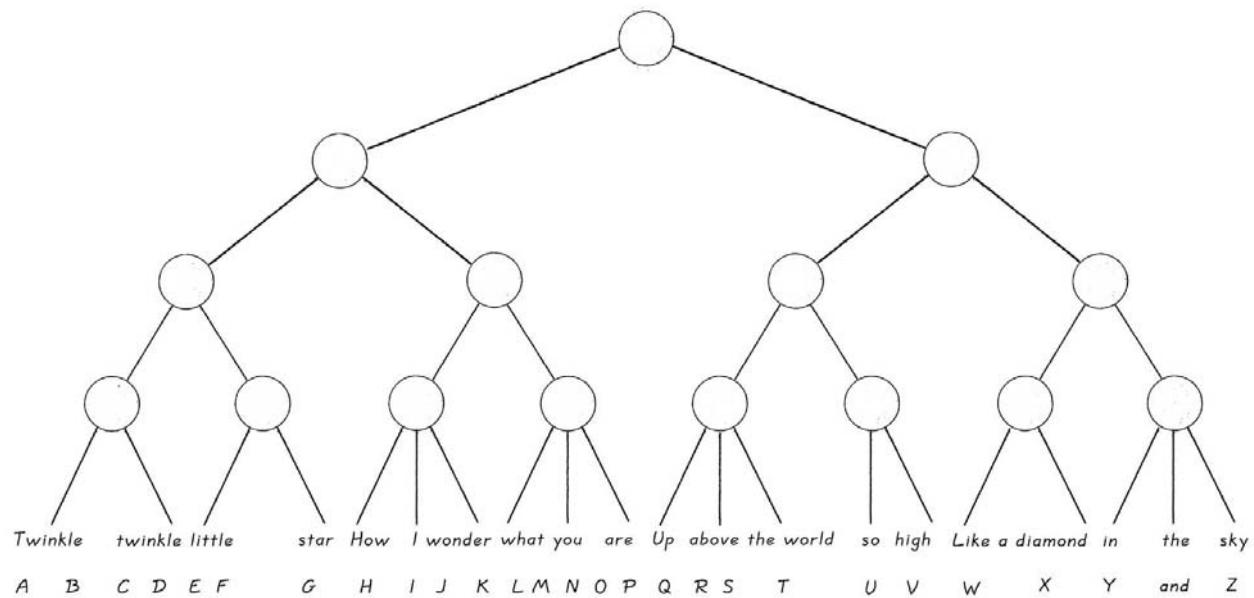
Believe it or not, this song still influences how quickly we can call up (retrieve) a letter from memory. If I ask you what letter follows G, it will take you much longer to say H than if I ask you to indicate what letter follows O. The ABC song groups the letters, and we still are prisoners of this grouping. It is easy to retrieve letters within a group and difficult to retrieve letters between adjacent groups.

The graph shows how quickly students were able to say the letter that followed the test letter. It takes much longer to say H given the test letter G than to say P given O. The letters G and H are in different phrases whereas O and P are in the same phrase of the melody.

Response time to say the letter that follows the test letter. In the figure the arrows give the onsets of phrases of the melody, which should give short response times when they are presented as test letters.
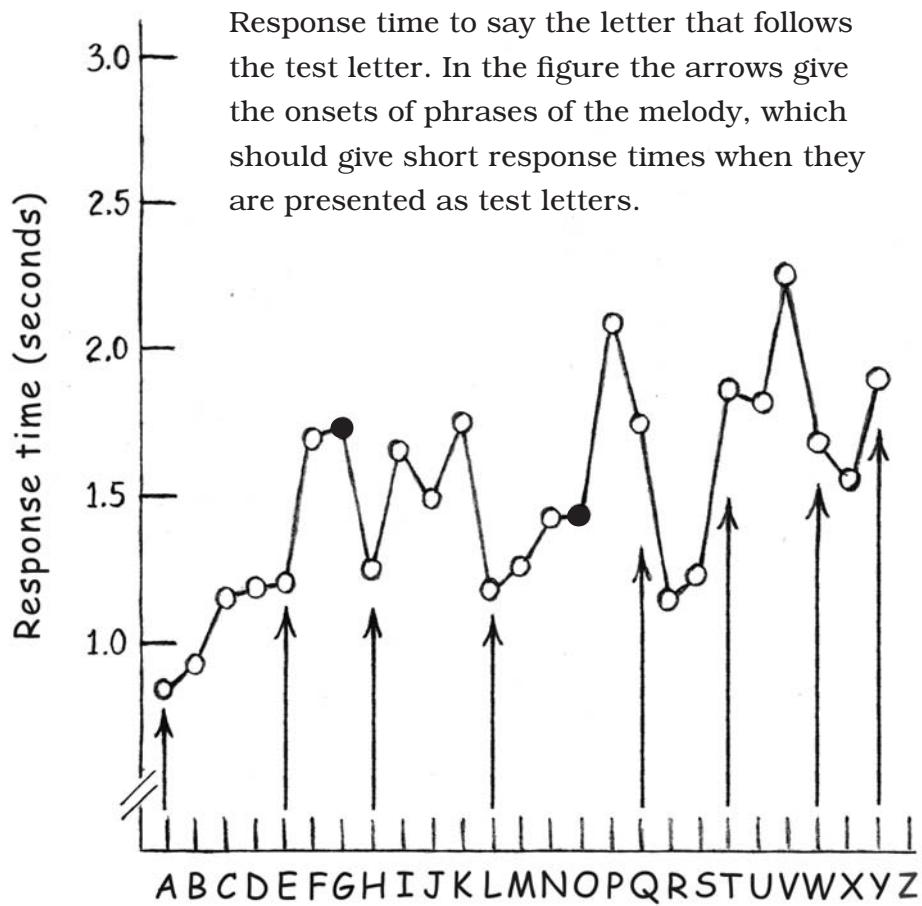
Baseball: Illusions from Time

We are fairly keen perceivers of changes in the speed of a moving object. However, sometimes we are tricked by an illusion. An illusion occurs when our experience contradicts what actually occurred.

In baseball games, a ball hit to an infielder appears to speed up after the ball bounces off the artificial turf. This is impossible because the bouncing can only slow the ball down. Why do we experience this speedup? It seems that we experience a speedup because this situation is so similar to another more common one in which a speedup actually occurs. When an object moves abruptly from standstill to some constant speed we, of course, see it speed up. Similarly, the bounce of the ball can be considered to be an abrupt start, and therefore, it will necessarily be seen as speeding up from the starting bounce. Our perception being relative to the context of the ball bouncing anticipates our discussion of Einstein's theory of relativity on page 48.
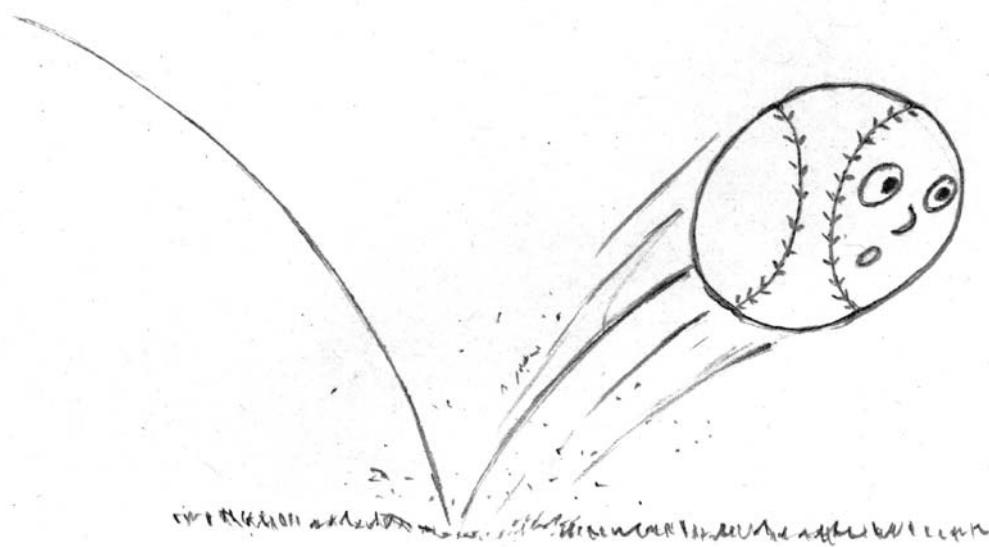
Catching Balls Using Time

How does a player catch fly balls so easily? The ball is coming toward the fielder, and she has to judge when and where it will land. As an object moves closer to us, the size of its image on our eye increases in a systematic way. The information in this expansion of the image is called "time to contact." If a baseball is heading toward us, we are faced with an expanding image. We are very sensitive to this type of increase in the image. An expanding image on our TV gives the impression that the object is moving towards us. Even babies will try to duck if they are shown this type of expanding image.
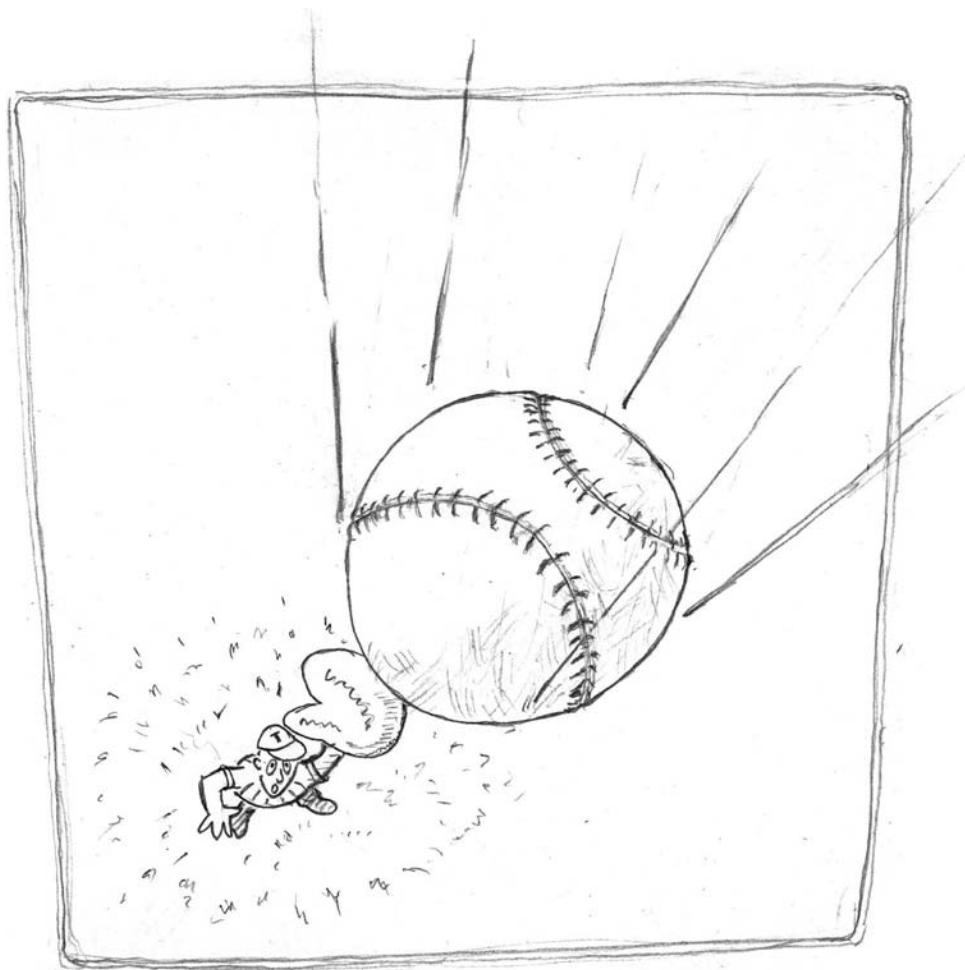
How quickly this image is changing in size is called the rate of expansion. It depends on the speed of the ball. The rate of expansion is a cue or signal to how soon the ball will arrive. A player only has to place her glove at the arrival location before the ball gets there.

Travelogue 5: Physics of Time

The Earth is Aging

Some people think they know more than they do. An archbishop of the Church of England, James Ussher, in 1640, pronounced that the Earth was created on October 4, 4004 B.C. This would make the earth about 6000 years old. About 100 years after Ussher, the science of the earth, called geology, was initiated. Geologists examined and measured the layers or strata of rocks on earth. Their estimates around just 100 years ago placed the earth at about 100 million years old. Today, with the knowledge of many different sciences, the earth is now estimated at between 4 and 5 billion years old. We can wonder what the next estimate might be. Just as we were going to press, scientists discovered that they might have overestimated the age by about one billion years.

1640 --- 6000 years old

HOLY BIBLE

1850 --- 100 million years old

2000 --- 4.5 Billion years old
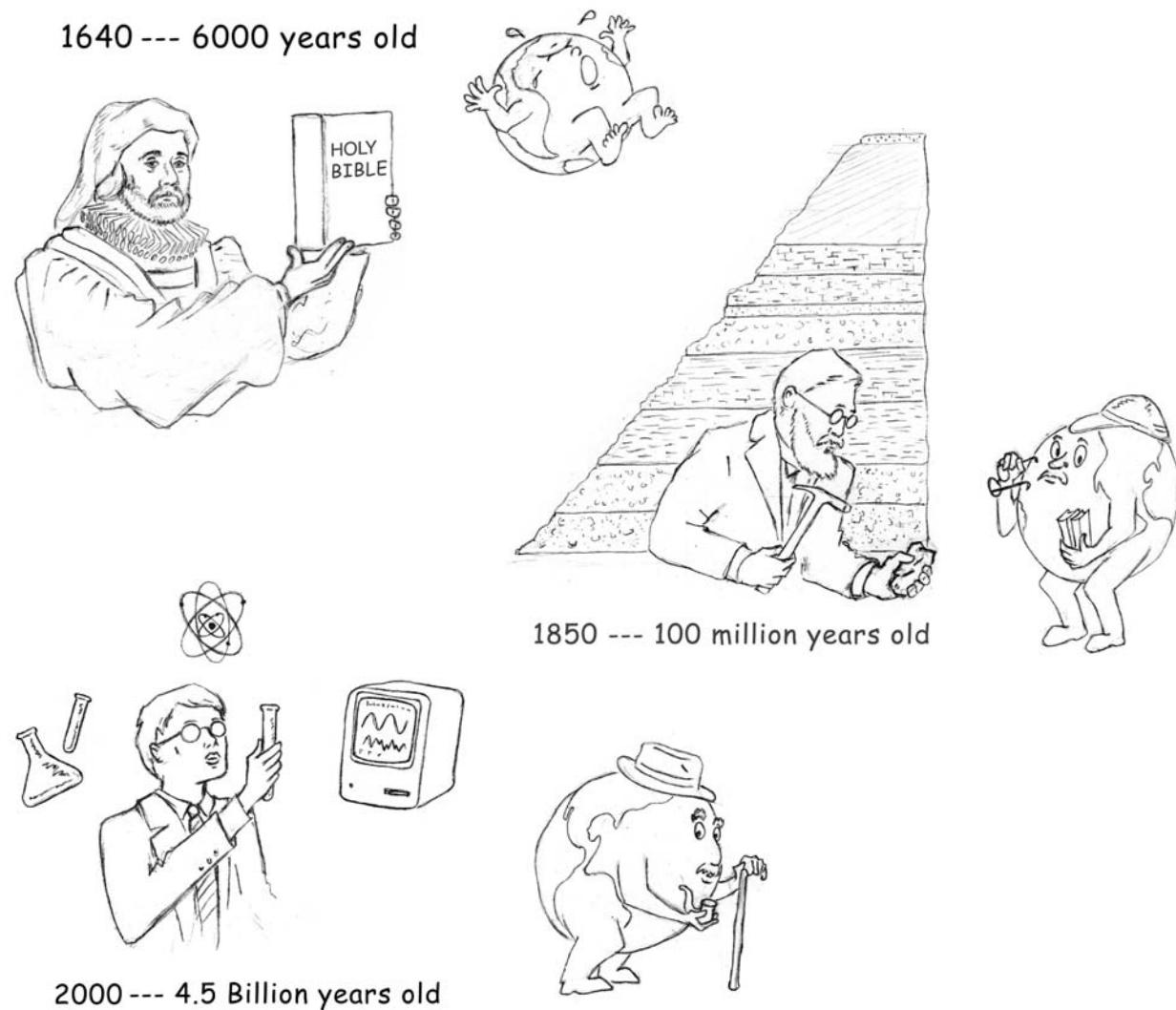
The Butterfly Effect

We can blame time for much of what we perceive around us. Peering over Natural Bridges State Beach, in our town, we remember the natural bridges that at one time connected the rock formations. Erosion over time has left only memories of the bridges.

Time also participates in the Butterfly effect of Chaos Theory. Small differences at one point in time have dramatic consequences at some later time. The idea is that a butterfly flapping its wings 500 miles north of here over the Pacific Ocean can influence the weather in Santa Cruz a few days later. OK! So maybe not a butterfly, but, at least, a 747.

Einstein's Relativity Theory

Everyone knows something about Einstein. You might have heard that he was a poor reader (dyslexic) and worked as a clerk in a patent office. We easily appreciate his observation that "time is like a departing guest, always going, but never gone!" On the other hand, very few of us really understand his relativity theory.

One of Einstein's greatest contributions was his insight that any measurement requires a frame of reference. For timekeepers, this is nothing new because we record time in terms of some physical event as the frame of reference. For example, a day corresponds to one complete rotation of the earth. That is, time is measured relative to a frame of reference. Thus, the name Einstein is synonymous with relativity. What is relativity?

Look at the center circle in the two groups of circles below. The center circle on the left appears to be so much larger than the center circle on the right. Actually, the two circles are the same size. Grab a measuring device and see for yourself. Why do we experience this perceptual illusion? It's analogous to Einstein's frame of reference. Our perceptual process leads us to see in relative rather than absolute terms, leading to a contrast effect. The center circle on the left appears large relative to the small surrounding circles, and the center circle on the right appears small relative to the large surrounding circles.
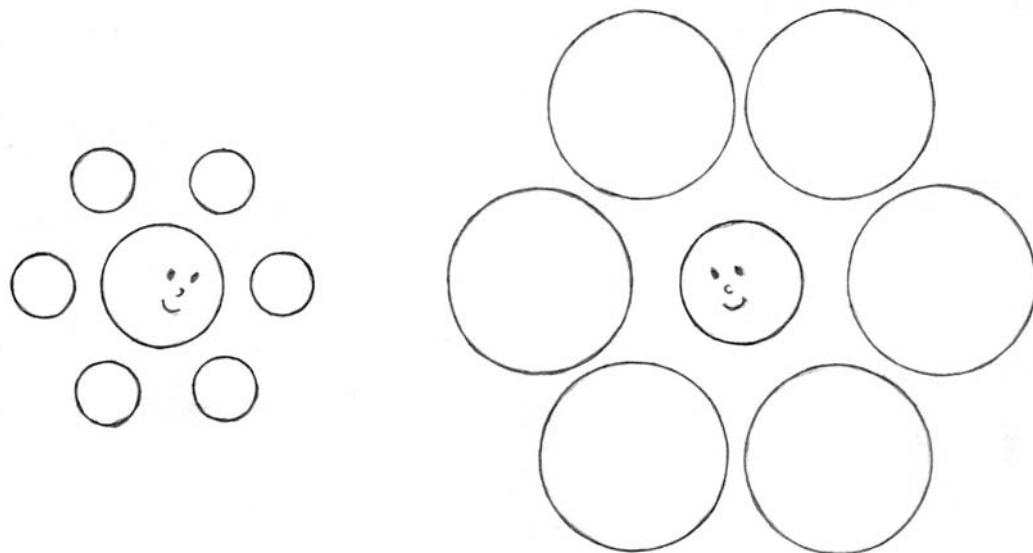
Remember we reached the same conclusion of relativity on pages 16 and 17 to explain our ability to tell the difference between two different durations or a change in the brightness of a light. This ability to tell the difference between two time periods depends on their difference relative to their total duration.

Sound experience also gives us another example of relativity. If a car is blowing its horn as it is traveling past you, you should hear it as an eee-ooo sound. The pitch of the sound is higher as the car is approaching you, and lower when the car is receding into the distance. This is known as the Doppler Effect named after Johan Effect (just kidding, Johan Doppler).

In the same way that our perception of the circle is relative and the frequency of the car tone reaching our ears is relative, the motion of objects is relative. A motion of an object must be judged relative to a motion or stillness of another one. There is no absolute resting state of an object. Similarly, time cannot be absolutely defined or measured.

Not everything is relative, however. Einstein also predicted correctly that light travels at a constant speed that is independent of the motion of the light's source. Einstein's legacy is filled with puzzles of time, which are captured by the poem in the famous magazine *Punch.*
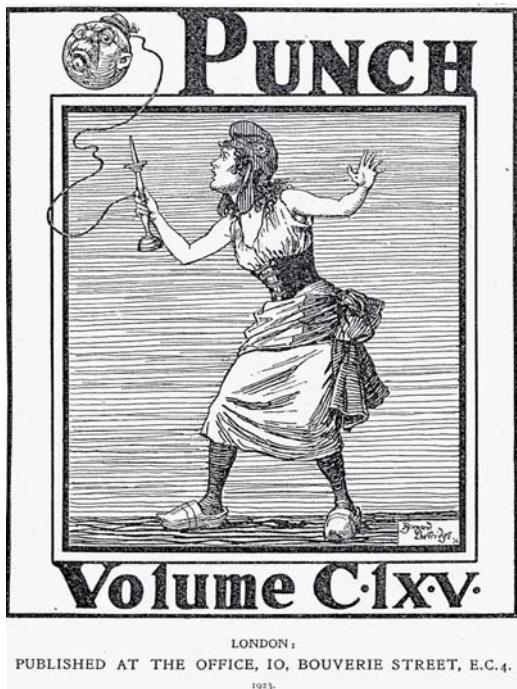
There was a young lady named Bright
Whose speed was faster than light;
She set out one day
In a relative way
And returned home the previous night.

(A. Buller, Punch, 19th December 1923)

Time Flies Like An Arrow

Stephen Hawking has puzzled about time more than any of us, and his insights were wonderfully communicated in his best-selling book, *A Brief History of Time.* This great scientist describes the three arrows of time—facts that make the past different from the future.

1) Disorder Increases with Time.

We all know what disorder is. It is the lack of order. We are told to put our room in order—"Please straighten up your room!" Believe it or not, things naturally become more disordered with the passing of time.
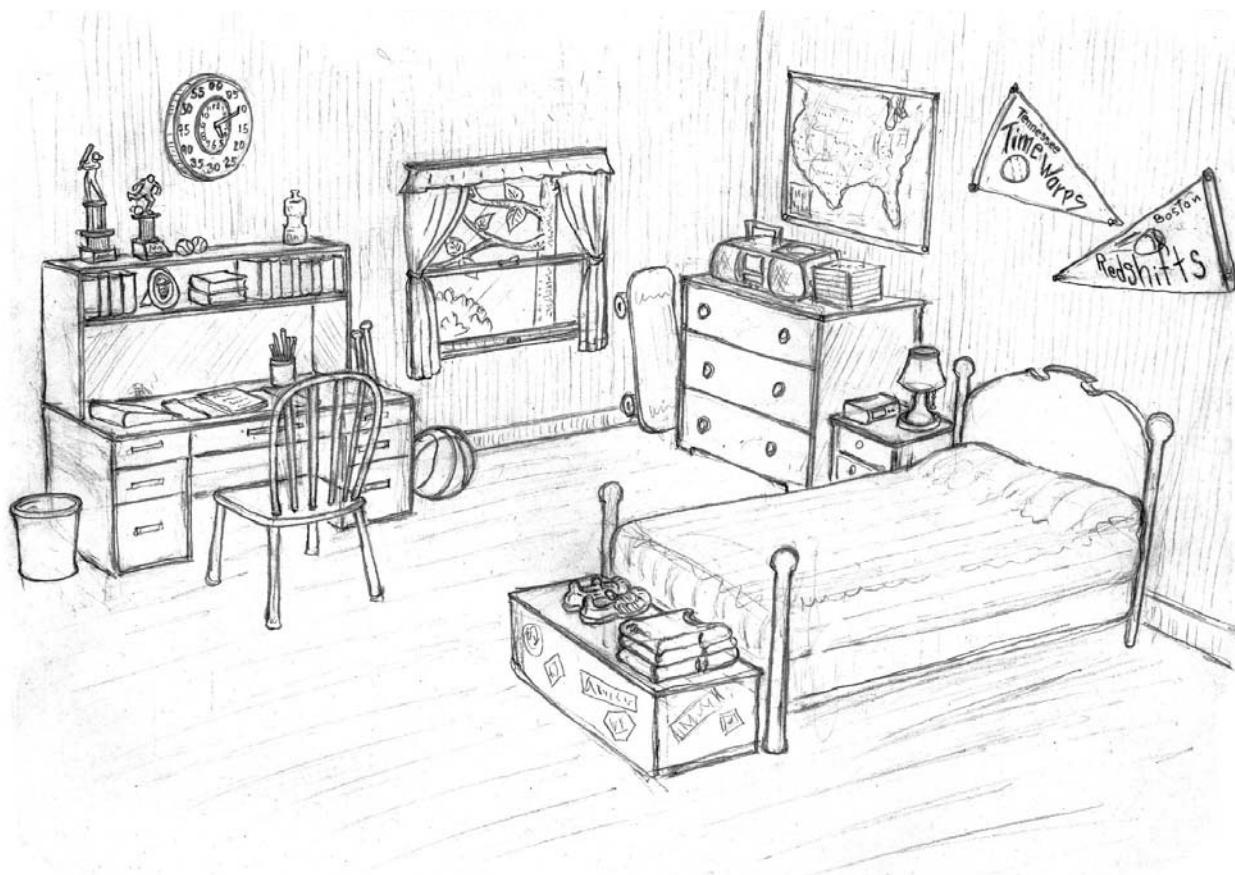
Your room would eventually get messy even if you didn't live in it. This printed page will someday be random marks. Your favorite tape or CD-ROM will eventually be nothing but noise. This first arrow of time refers to *entropy* (en-tro-pee). An isolated system will always head towards its most likely or random state. This idea is also know as the Second Law of Thermodynamics (ther-mo-dy-nam-ics), and has a vivid parallel in William Butler Yeats's poem *The Second Coming*.

Things fall apart; the center cannot hold;
Mere anarchy is loosed upon the world.
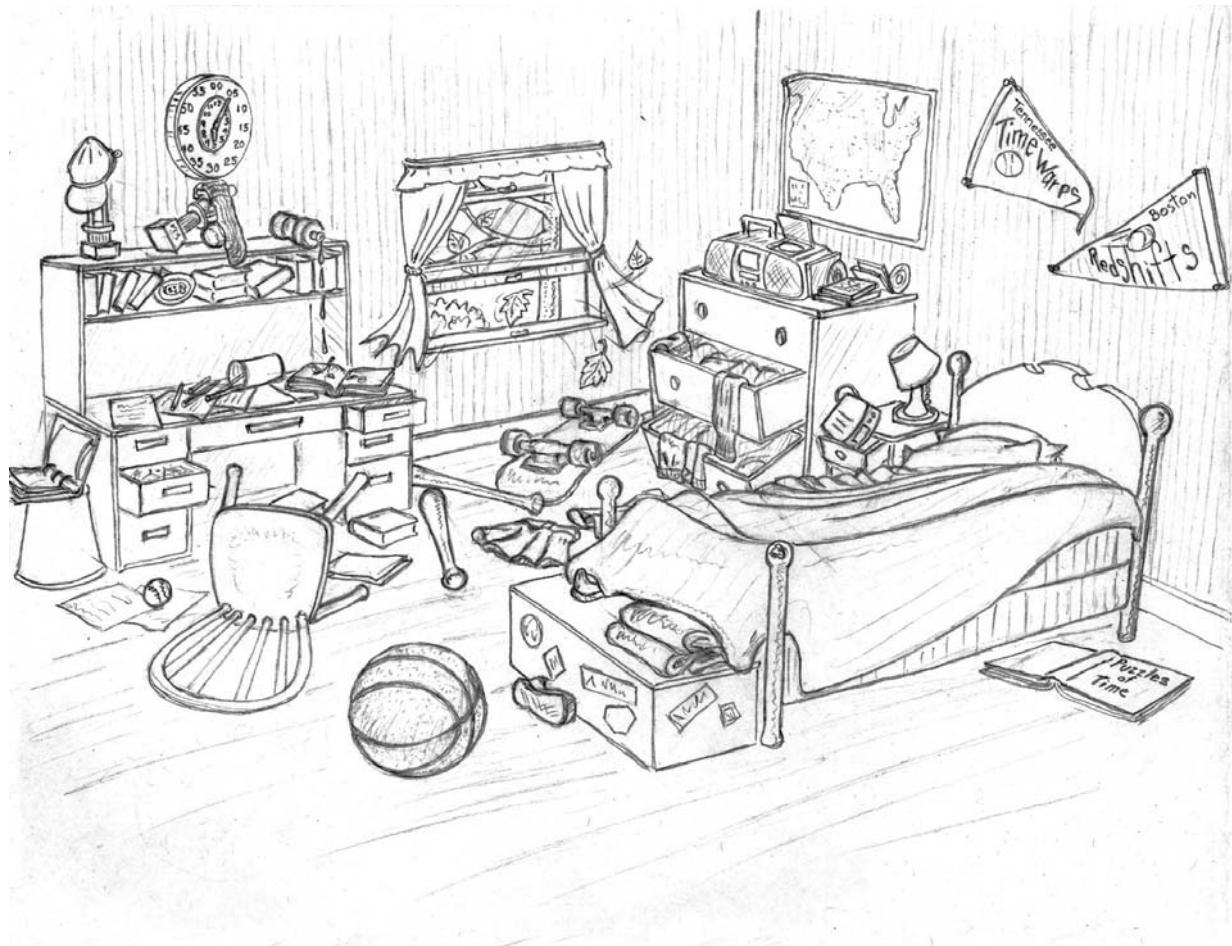
2) We Experience Time as Passing.

When you wake up in the morning, you know that time has passed. The newspaper confirms your belief by telling you what events have occurred since yesterday's news. The second arrow of time is that we perceive time as passing. Time does not stand still for us no matter what we do.

Many people have hoped to stop aging. The most famous attempt has been the many searches for the Fountain of Youth. Drinking the waters of this fountain would supposedly keep you forever young as time passes. Although we haven't been able to delay aging, people use a variety of products to keep looking youthful.

Father time guarding
the fountain of youth.

3) The Universe is Expanding with Time.

Isn't it hard to believe that it all began with a big bang? Scientists are convinced that it did, and they also believe that our universe has been getting bigger ever since. The third arrow of time is the constant expansion of our universe. It is continuously growing with the passage of time.
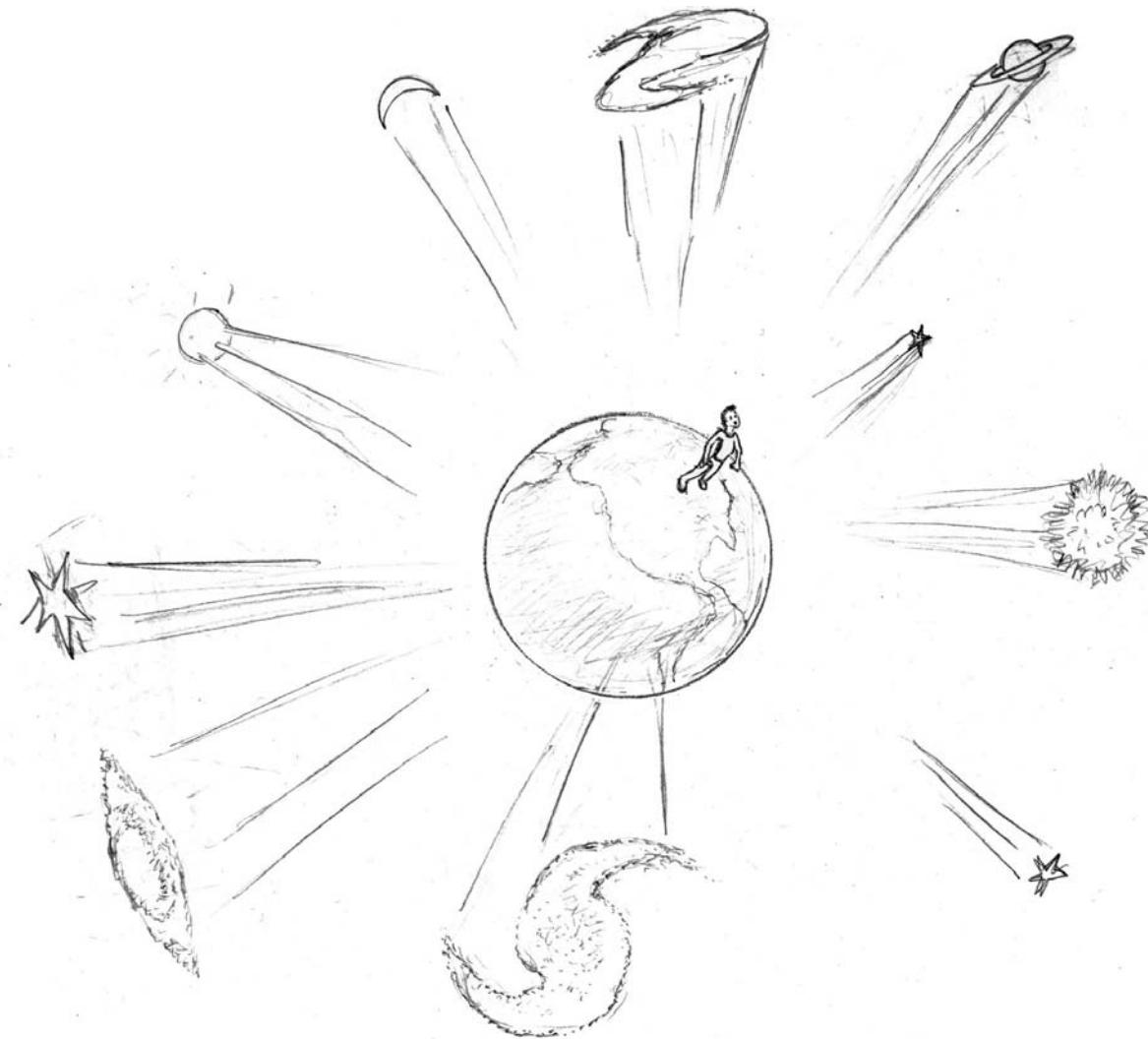
The universe is expanding uniformly. From our viewpoint it appears as though everything is receding from us.

Stopping Time for Everyone but You

Imagine having the ability to stop time for eveyone but you. The hero of the story *The Girl, the Gold Watch, and Everything* by John D. MacDonald inherits a gold watch from his grandfather. The appropriate setting on this watch brings the universe and its inhabitants to a standstill. During this period of suspension, only the hero can move about and create havoc. Oh, to have this watch! Imagine that you are guarding Michael Jordan. Normally, he would dribble, carry out a few fakes, and leave you behind as he goes to the basket. With the gold watch, you can stop time as soon as he begins to dribble. You slowly take the ball away—there is no need to hurry because time is stopped— and dribble to your own basket. When you are well out of range, you start the watch and everyone is flabbergasted by your excellent play. Only your imagination stands in the way of a wonderful life. Hey, maybe this was Jordan's secret.

Saving Time

One view of human history focuses on our ingenuity to employ time-saving devices. Perhaps the first one to come to mind is the computer, although we can point to many others. These include the printing press, the cotton gin, the bicycle, the steam engine, and electricity, to name a few. Charles Babbage is given credit for designing the first programmable computer. Some of the credit should also be given to Ada Augusta, Countess of Lovelace, who exchanged ideas with Babbage and proved the mathematical feasibility of such a thing. Lady Lovelace also puzzled over whether computers could ever become more intelligent than their programmers. She didn't think so, and so far no one has proved her wrong. Computers seem to be getting "smarter" at some things, such as IBM's Big Blue beating the famous chess champion Kasparov in a game of chess.
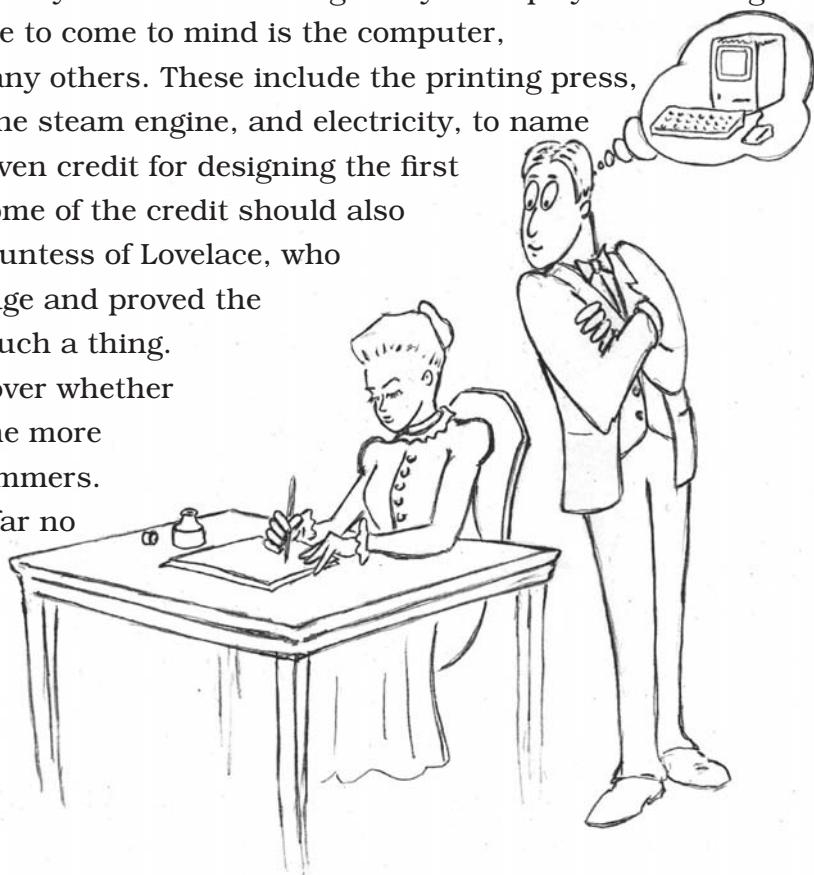
Travelogue 6: Time Problems

Test Your Sense of Time

1. What day follows the day before yesterday if two days from now will be Sunday?

2. Two train stations are 50 miles apart. At 1:00 P.M. on Sunday, a train pulls out from each of the stations, and the trains start toward one another. At the same time, a hawk flies into the air in front of the first train and flies ahead to the front of the second train. When the hawk reaches the second train, it turns around and flies toward the first train. The hawk goes back and forth between the two trains until the trains meet. Assume that both trains travel at a speed of 25 miles per hour and that the hawk flies at a constant speed of 100 miles per hour. How many miles will the hawk have flown when the trains meet?

3. The first soccer player can kick 5 balls in 5 seconds, and a second can kick 10 balls in 10 seconds. They start kicking at the same time. Which player can kick 3 balls in the shorter time?

4. A student decides that it is only necessary to attend school half the time. What days she attends she leaves to chance. The bus to her school leaves her bus stop every 20 minutes, as does the bus to the beach. To attend school half the time, her strategy is to simply take the first bus that arrives. She reasons that this is a fair strategy because her arrival at the bus station is totally random. Thus, half of the time the school bus will arrive first and half the time the beach bus will arrive first. Is the student correct in her reasoning?

5. A Buddhist monk walks up a mountain beginning at sunrise and gets there around sunset. (By the way, the aspirations of Buddhism were to reach Nirvana, a state where time ceased to exist.) She meditates for a few days and makes her way back down the mountain along exactly the same path. She also leaves at sunrise to go down the mountain. Prove that there is a place on the mountain trail that she visits at exactly the same time on both trips.

When you solve a problem, you can end your solution with QED (*Quod est Demonstratum*, in Latin), which means "This is Demonstrated."

Answers to Time Problems

1. The day that follows the day before yesterday is simply yesterday. Today is Friday so the answer is Thursday.

What day follows the day before yesterday
if two days from now will be Sunday?

Start with Sunday

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
1	2	3	4	5	6	7
Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003

Two days from NOW will be Sunday

That means NOW is Friday.

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
1	2	3	4	5	6	7
Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003

If NOW is Friday then
YESTERDAY is Thursday

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
1	2	3	4	5	6	7
Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003

That makes the day before yesterday Wednesday

And the day that follows Wednesday is Thursday

| MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
1	2	3	4	5	6	7
Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003	Sept. 2003

THURSDAY
4
Sept. 2003

So the day that follows the day before yesterday
if two days from now will be Sunday is Thursday

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2. All you need to know is how long the hawk flies. The trains meet in one hour so the hawk flies for one hour and covers a distance of 100 miles.

12:00 PM

100 mph

25 mph   25 mph

50 Miles
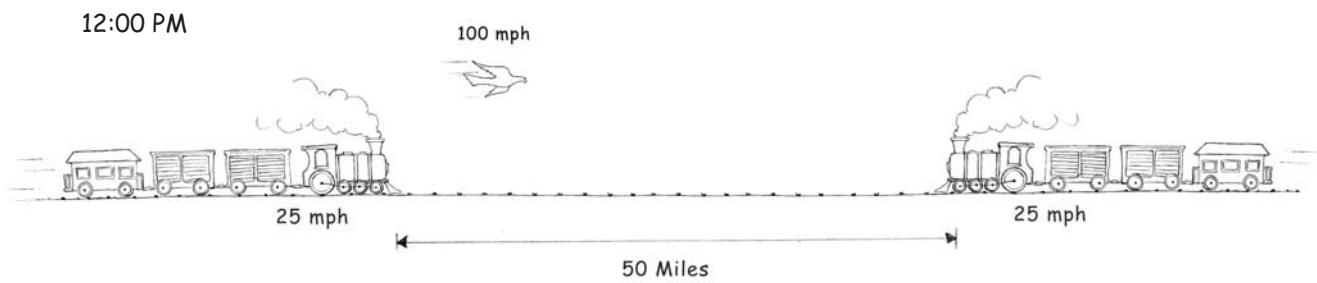
1:00 PM
One hour later
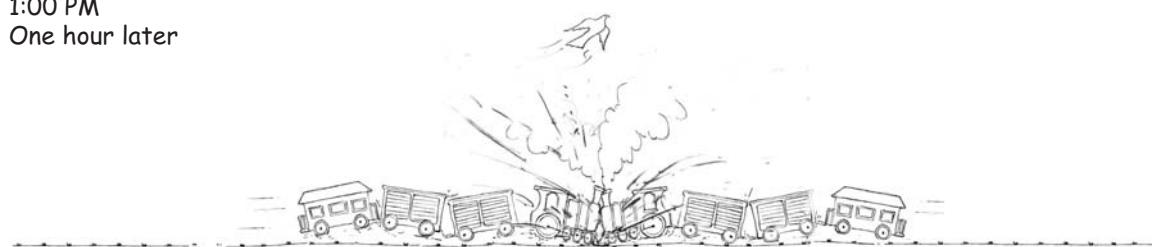
3. The first thought is that they kick at the same rate. But what is important is the time between kicks. At 5 kicks in 5 seconds, there are 1 1/4 seconds between kicks. At 10 kicks in 10 seconds, there are 1 1/9 seconds between kicks. Thus, the second player will get off 3 kicks before the first player.

First ball kicked here 5 seconds ago.

Time in seconds
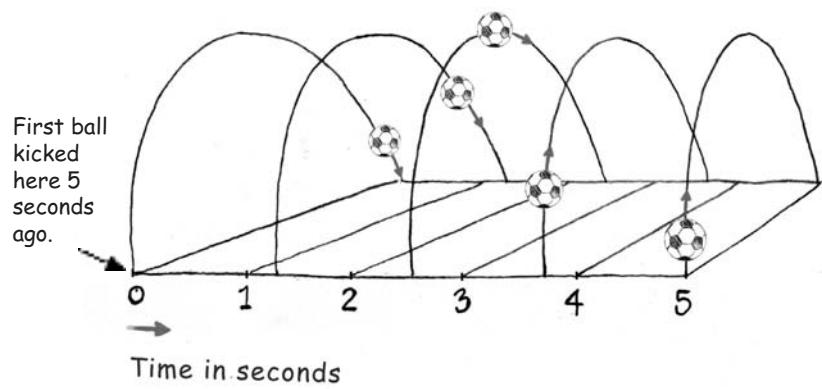
You can see from the diagram that in the time the second kicker has gotten off three kicks the first player has only delivered two.

First ball kicked here 10 seconds ago.

Time in seconds
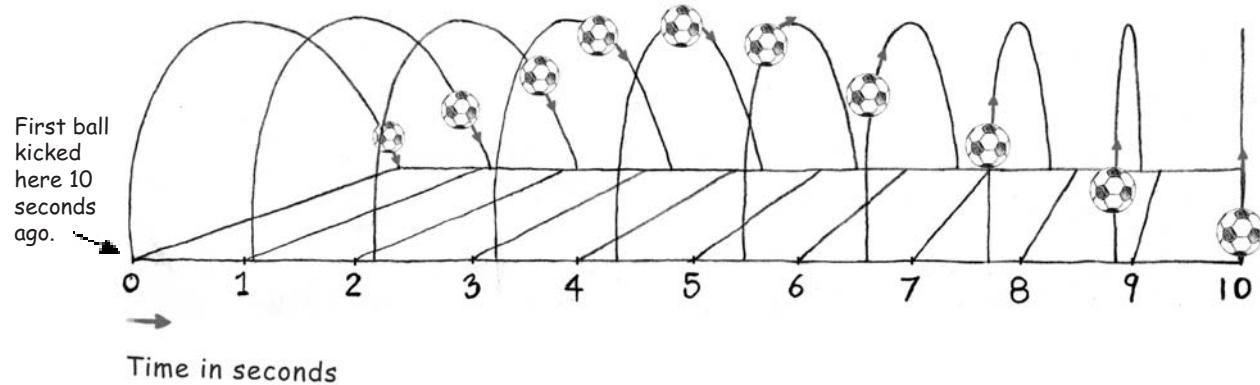
4. The student's strategy is not correct. She will not necessarily get to school on half of the days because the time between the two buses is not necessarily equal. Let's say that the beach bus always came one minute after the school bus. In this case, she would usually end up going to the beach. The more time between the two buses the more likely she will take the second bus to school.

Assume the bus to school comes at the hour and 20 minutes and 40 minutes past the hour. The bus to the beach can come within a 20 minute period. If it comes very soon after the bus to school, then she is much less likely to catch the bus to the beach. As the period between the two buses increases, then it becomes more likely that she will catch the bus to the beach.

Beach
School

20 min   40 min   60 min   80 min

20 min   40 min   60 min   80 min

20 min   40 min   60 min   80 min

20 min   40 min   60 min   80 min
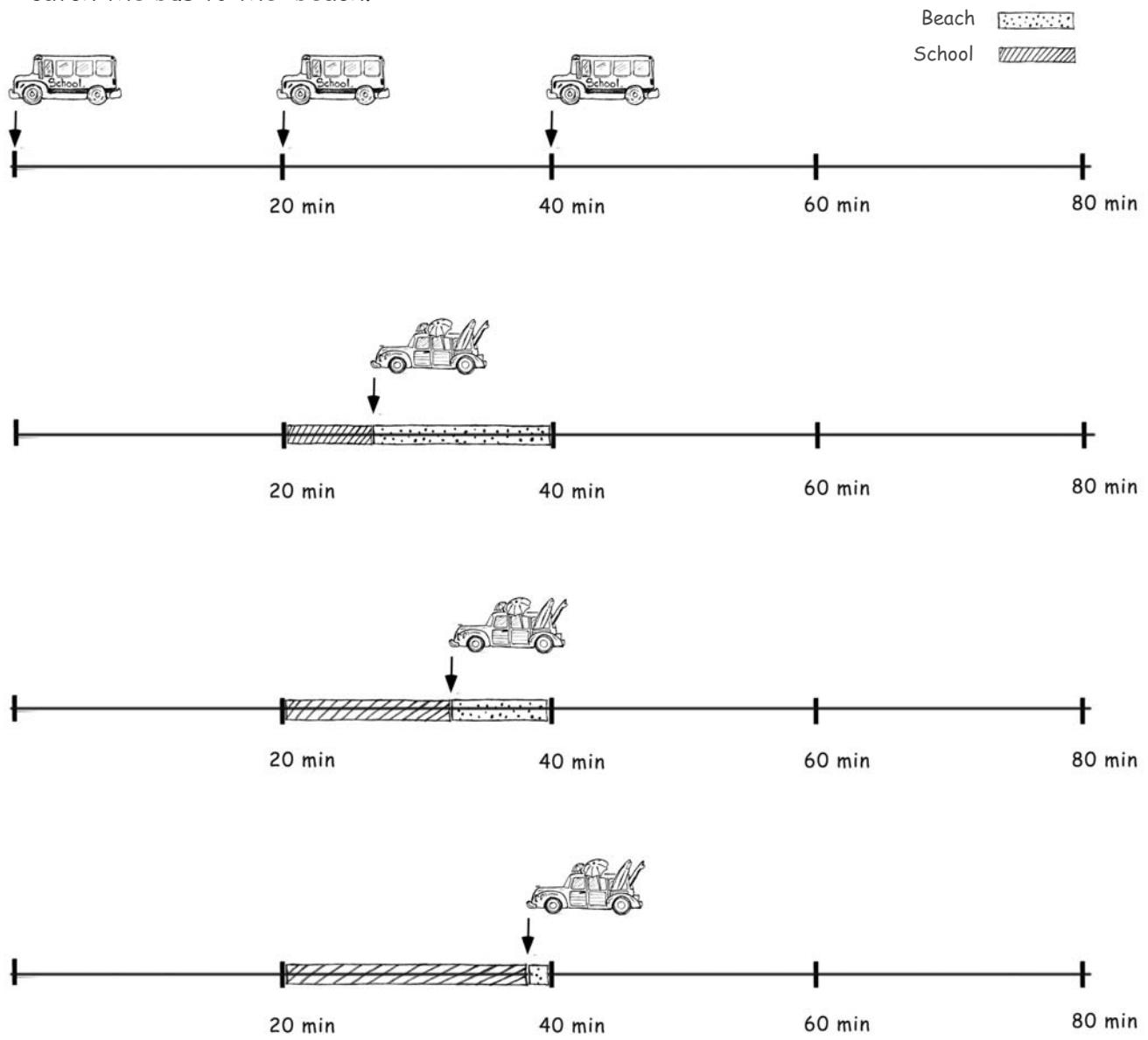
5. There is an intersection point even if the monk walks at very different rates up and down.

Conceptually this is the same as two different monks ascending and descending the mountain, both of them beginning their journey at sunrise.
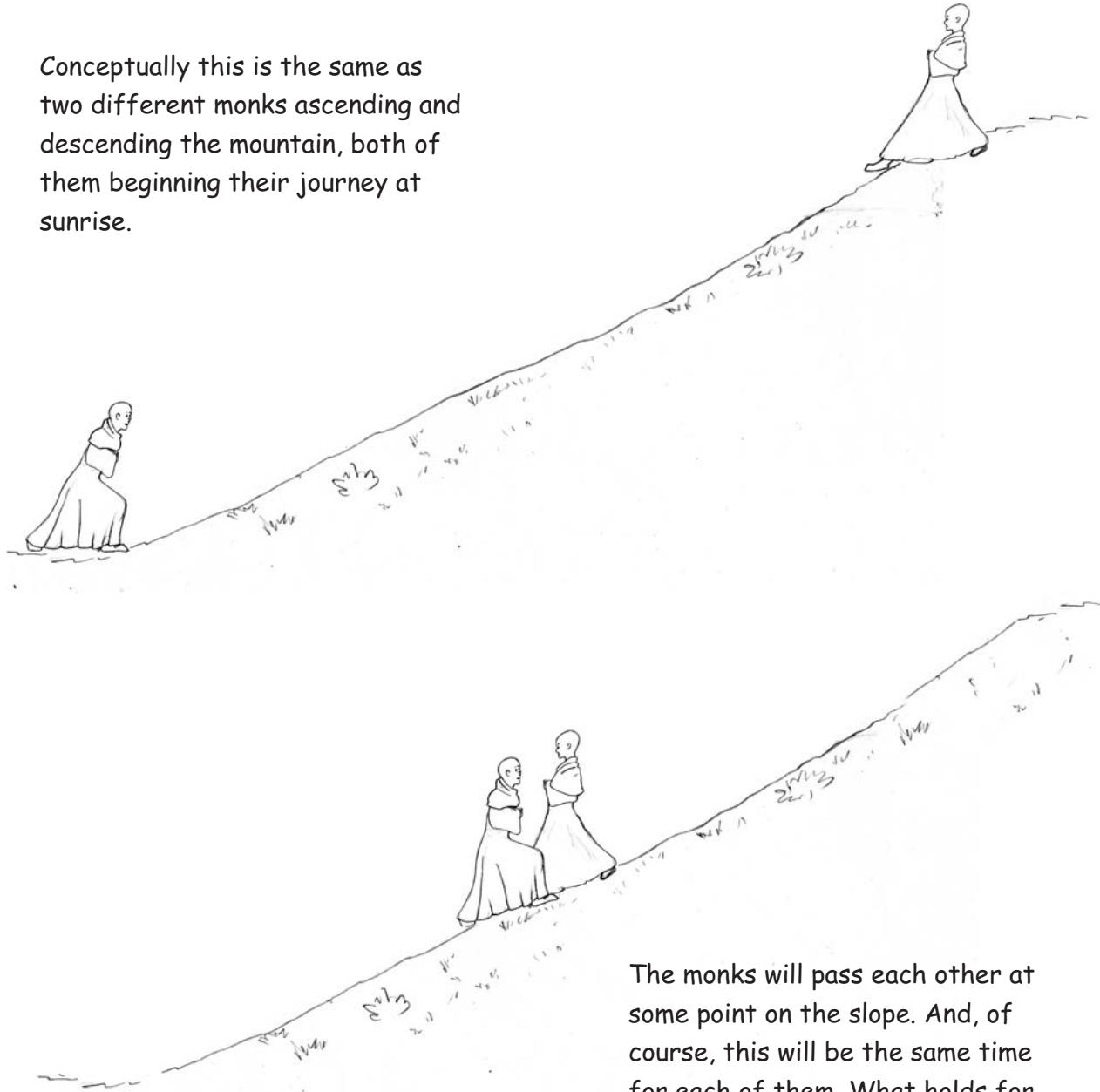
The monks will pass each other at some point on the slope. And, of course, this will be the same time for each of them. What holds for two monks holds for one.

Summary

We have explored many aspects of time in this book, and we hope that your curiosity has been awakened. While our story reveals that the scientific study of time is a difficult undertaking, requiring patience, ingenuity, and, occasionally, courage, the rewards for engaging in this inquiry are profound.

The history of research about time shows us that no matter how valuable intuition is, it is fallible and often misleads us. If we ask penetrating questions about time, carefully design strategies to test competing hypotheses, and engage in dialogue with other clear thinking people about our results, we will make progress in understanding the world.

Often, scientists have to stand up to pressure from others who want to inhibit deeper understanding. This sometimes requires courage, because old habits and privileges resist change. The history of time includes people who questioned authority, and who tried to challenge even their own assumptions on their journey to understanding.

We've also pointed out that we think in metaphors, and that studying language itself will deepen our understanding of time and lead us to greater precision in discussions with others about our findings. Smart people use what they learn to continue to learn; they pose questions all the time, and help others pose them too. They also celebrate mysteries—those almost impossible to explain events that call upon our imagination, intelligence and wisdom to figure out.

Finally, time offers us a window into just about all aspects of our lives. As you continue your exploration, you'll find that to be intrigued by this subject is also to be intrigued by the world.

Bibliography

Barnett, Jo Ellen (1998). Time's Pendulum. New York: Plenum Press.

Bennett, Paul (1999). The History of Time. UK: Ticktock Publishing Ltd.

Ben-Peretz, Miriam and Bromme, Rainer, Editors (1990). The Nature of Time in Schools. New York: Teacher's College Press.

Block, R. A. (1990). Cognitive Models of Psychological Time. Mahwah, NJ.: Lawrence Erlbaum Associates, Inc.

Burns, Marilyn (1978). This Book is About Time. Covelo, CA: Yolla Bolly Press.

Cipolla, C. M. (2003). Clocks and Culture: 1300-1700. New York: W. W. Norton & Company.

Davies, P. (2003). How to Build a Time Machine. New York, NY: Penguin.

Dolan, Graham (1999). The Greenwich Guide to Time and the New Millennium. Great Britain: Heinemann Library.

Duffy, Carol Ann, Ed. (1999). Time's Tidings. London: Anvil Press Poetry, Ltd.

Dunlap, J. C., Loros, J. J., & DeCoursey, P. J. (Eds) (2004). Chronobiology: Biological Timekeeping. Sunderland, MA: Sinauer Associates, Inc.

Feynman, R. P. (1988). What Do You Care What Other People Think? New York: W. W. Norton.

Flaherty, Michael G. (1999). A Watched Pot. New York: New York University Press.

Galison, P. (2003). Einstein's Clocks, Poincarè's Maps: Empires of Time. New York: W. W. Norton.

Harrison, Michael & Stuart-Clark, Christopher (1998). The Oxford Treasury of Time Poems. Oxford: Oxford University Press.

Helfrich, H. (1996). Time & Mind. Seattle: Hogrefe & Huber Publishers.

Hoeg, Peter (1994). BorderLiners. New York: Farrar, Straus and Giroux.

Jonsson, Bodil (2001). Unwinding the Clock. Ten Thoughts on Our Relationship to Time. Translator: Tiina Nunnally. New York: Harcourt.

Landes, David S. (1983). Revolution in Time. Cambridge: The Belknap Press.

Levine, Robert (1997). A Geography of Time. New York: Basic Books.

Lippencott, Kristen, et al (1999). The Story of Time. London: Merrell Holberton Publishers.

Macey, S. L. (1994). Encyclopedia of Time. New York: Garland Publishing, Inc.

Michon, J. A. & Jackson, J. L. (Eds.). Time, Mind, and Behavior.

Obhi, Sukhvinder S. & Haggard, Patrick (2004). Free Will and Free Won't. American Scientist July-August 2004, pp. 358-365.

Physics Today Special Issue: Richard Feynman. Physics Today, 1989, 42, No. 2.

Pickover, Clifford A. (1998). Time: A Traveler's Guide. New York: Oxford University Press.

Repcheck, J. (2003). The Man Who Found Time: James Hutton and the Discovery of the Earth's Antiquity. Cambridge, MA: Perseus Publishing.

Shook, Michael D., & Shook, Robert L. (1992). It's About Time. New York: Plume Books/Penguin USA.

Sobel, Dava (1995). Longitude. London: Fourth Estate.

Turner, A. J. (1984). The Time Museum: Volume I Part 3. Rockford IL: The Time Museum, Johnson Press.

Waugh, Alexander (1999). Time: Its Origin, Its Enigma, Its History. New York: Carroll & Graf Publishers, Inc.

Zubrowski, Bernie (1988). Clocks: Building and Experimenting with Model Timepieces. New York: Morrow Junior Books.

The three contributors to this book crossed paths in several endeavors, but their collaboration merged around and over time. Their first book, *Time to Learn About Time*, created a new set of wonders and puzzles that have compelled readers' attention.

At a formative age, Dom Massaro learned that it took him only 48 hours to drive his '57 Chevrolet Bel Air Convertible from Youngstown, Ohio to the end of Route 66 in Santa Monica, California. His seemingly timeless journey included UCLA, UCSD, and UCSC, where he is Professor of Psychology and Computer Engineering. Helping out in his children's classrooms, he was troubled by the errors the students made in their lesson on telling time. As a cognitive scientist, he was challenged to uncover the nature of the difficulty in reading traditional analog time and to design a better mousetrap. His invention, the Kid KlokTM, based on principles of psychology, cognitive engineering, observational, and experimental evidence, has proven to be an easy-to-read analog clock for children. Being an avid cyclist, he spends a considerable amount of time on his bicycle puzzling about time and associated puzzles.

Don Rothman grew up in Brooklyn, New York and witnessed a remarkable acceleration of time between the middle 1940s and the early 1960s. Old clothes dealers in horse-drawn wooden wagons, old men who appeared on the street a few times a year to sharpen knives, bakery and milk delivery trucks, and the Brooklyn Dodgers vanished just before he left for the University of Michigan to earn a high honors degree in English. He went on to earn a graduate degree in Renaissance literature at UC Berkeley, teaching at Merritt College in Oakland, CA before moving on to his current position as a Senior Lecturer in Writing and Director Emeritus of the Central California Writing Project at UC Santa Cruz. He is married to a brilliant retired kindergarten teacher, and their two children continue to ask wonderfully puzzling questions.

Bill Rowe is a former Research Associate of the University of California, Santa Cruz Institute for Particle Physics. He grew up in Jeffersonville, Indiana, a small town located on the banks of the Ohio River. His early interest was in art, but after graduating from high school he turned to music and played saxophone in various bands working out of Louisville, Kentucky, until entering the Air Force in 1966. After the military he entered the University of California Santa Cruz where he graduated with a degree in physics. His recent endeavors include the design and fabrication of electrodes for neuroscience research, and illustrating a 2004 book on the Standard Model in physics. He writes and performs music, and his plays have been performed in Chagrin Falls, Ohio. His intellectual endeavors include puzzles of the mind in his relentless quest to understand consciousness and to develop a coherent view of the embodiment of perception and action.
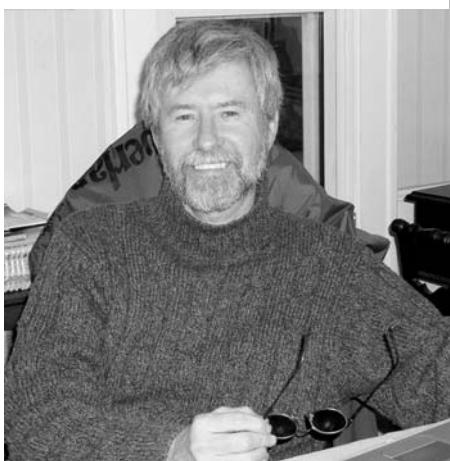
Is time nature's way of keeping

everything from happening all at once?

Is time in the mind of the beholder, as some say,

or is it a physical dimension like space?

What does it mean to say we can lose time,

or save it, or wait for it to come?

Can we understand time?

or

Is time a puzzle?

In this Handbook For The New Millennium

we are guided through the puzzles of time,

fitting together time pieces from

physics, biology, psychology, history, and literature.

Along the way we find an exciting pattern of

interlocking revelations as well as the equally exciting

and intriguing missing pieces.

A delightful journey of

discovery well worth the Time
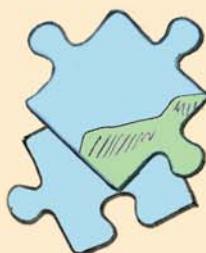
This book is recommended for adults
by young people ages 12 to 25