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PRACTICE

The Neuroscience and Architecture of Time

This is a good time to talk about time. It is the beginning of a new era in the history of AIArchitect, it's time for another school year, it's about time for you to come home mentally from your vacation, and it's time to stop and reflect on what neuroscience can tell us about how and why the brain responds to time. Time, of course, is crucial to planning, designing, and creating the built environment. It is so much a part of our lives from our first memories on that we implicitly think of time as a thing. It is not. It is a concept that we have used our conceptual brains to define and measure. It is also a part of our hard-wired brains, and we find manifestations of that biological clock in organisms as simple as the fruit fly. Join John Eberhard, FAIA, as he explains time as a function of neuroscience.

by John P. Eberhard, FAIA
Founding president, Academy of Neuroscience for Architecture

> *"The time has come," the Walrus said,*
> *"To talk of many things:*
> *Of shoes—and ships—and sealing wax—*
> *Of cabbages—and kings—*
> *And why the sea is boiling hot—*
> *And whether pigs have wings."*
> *—Alice Through the Looking Glass by Lewis Carroll (1872)*

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In this article, we will explore different ways that time impacts architects and architecture and we will explore how our brains and minds make this possible.

Time is something we all believe we understand, but as St. Augustine tells us, when we try to explain "time" in words, we find our understanding is limited.

> *Time has no divisions to mark its passage; there is never a thunderstorm or blare of trumpets to announce the beginning of a new month or year. Even when a new century begins, it is only we mortals who ring bells and fire off pistols into the air.*
> —The Magic Mountain, *by Thomas Mann*

Time exists only in the human mind

Time is a product of the human mind. It does not exist in a physical sense, except in the devices humans have developed to keep track of "intervals." We have a sense of there being a continuous stream of experiences in which one event is followed by another.

Our minds and memories provide us with the ability to recall past events, so that we have awareness at each instant that there was some previous experience of an event we remember. For example, if you are sitting in your office reading this, you are able to remember getting up this morning, having breakfast, traveling to work, and entering your office a "little while ago." But, what does a "little while ago" mean? It implies that one or more intervals have passed.

We can't measure this until we agree on what to call an interval and describe it in physical terms. So, we can talk about an hour (24 of them in a day), or a minute (1/60 of an hour), or a second (1/60 of a minute). If we have a clock we can measure "a little while ago" with some accuracy (e.g., 29 minutes and 30 seconds). However, most of us can also guess close enough for everyday purposes (e.g., it was about half-an-hour ago). Two different places in the brain are used to understand what time it is and to estimate how much time has passed.

Our minds and working memories can also provide us with the ability to contemplate an event in the future. For example, if you are going to have a birthday next month, you can think about the date on which it will fall, because we have a large-scale measurement of time intervals called weeks, months and years. Future events can only be conjectures by our minds of events that we hope will happen (or sometimes not happen). We obviously have no way to know with certainty that they will happen; we can observe that they are likely to hap-

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pen, In nature, for instance, the sun will rise tomorrow morning, based on past experiences. However, there is no ability to confirm a future event like the sun rising until the "time" for the event actually arrives.

How we know time

Here are some things we might say about time. Each phrase uses the term in a slightly different way, but your brain "knows" what each one means:

"*Time* waits for no one, it passes you by. It rolls on forever, like the clouds in the sky."
"Once upon a *time,* there was a magic kingdom called Camelot."
"That firm seems to produce designs that are behind the *times.*"
"I expect you to be on *time* when you come to work tomorrow."
"Students in architecture school are required to produce a project against a time constraint. It's called a *charrette.*"
"Four *times* five equals twenty."
"Architects cannot spare *time* to read long articles in magazines (they say)."
"For most people. the significance of *time* lies in the way it shapes our behavior, rather than the fundamental role it plays in physics and philosophy."
"Biological rhythms control when we wake up and when we go to bed … most of the *time.*"

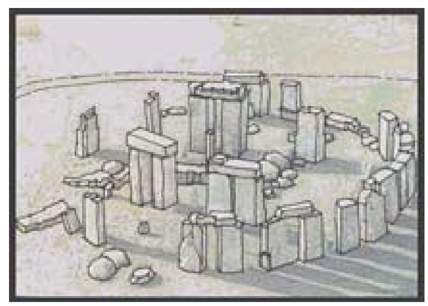
Knowing anything about time depends on the neurons—the 10 billion cells—of the brain. More precisely what the brain "knows" about the meaning of time depends on the specific arrangement of the networks of connections between neurons, and the way that neurotransmitters are released and absorbed to communicate between networks.

Calendars mark a larger scale measures

In 1582, Pope Gregory XIII established the calendar now in use everywhere in the world (with the exception of the Muslim, Jewish, and Chinese calendars, mostly related to religious observances). The Gregorian calendar was the successor to a long history of development by humans for dividing time over extended periods, such as days, months, or years and arranging such divisions in a definite order. It draws into one system the dating of religious festivals (for Christians) based on phases of the moon and seasonal activities determined by the movement of the sun.

This system is complex because the periods of the moon's phases and the sun's motion are incompatible; but by adopting regular cycles of days and simple rules for their application, the calendar provides a "rhythm" for the year with an error of less than half a minute. That slight error probably doesn't mean much to you, because your brain has enough trouble just remembering the date of your wedding anniversary, when you are next scheduled to visit the dentist, and whether today is Wednesday or Thursday. The fact that the mean solar day has a duration in sidereal time (related to the motion of the stars) of 24 hours 3 minutes and 56.55 seconds is more math than your brain wants to understand. And, if that were not bad enough, you would surely not want to know that the tropical year (used to keep the calendar year in step with the seasons) amounts to 365.242199 mean solar days. But there are people who do need to know this.

Our ancestors, who were trying to keep track of such things 3,000-5,000 years ago, used "architectural" structures of wood and stone to mark out points along the horizon to allow observations of when stars, the moon, and the sun moved across the sky. The most famous of these structures is Stonehenge in Wiltshire, England, where the original structure seems to have been erected about 2000 BC, with additions made at intervals over the next few centuries. As you probably know (see illustration) it is composed of a series of holes, stones, and archways arranged in circles around a large monolith called the heel stone. Observations were made by lining up the heel stone with one of the holes or other stones and watching for the appearance of the Sun or Moon against that point on the horizon that lay along the same straight line. There are more than 600 such structures that have been discovered in Britain, elsewhere in Europe, and in the Americas.



Mechanical clocks offer a smaller scale measure

A clock is a machine in which a device that performs regular movements in equal intervals of *time* is linked to a counting mechanism that records the number of movements. All man-made clocks, of whatever form, are made on this principle. Some are more accurate than others. Some are more handsome in appearance. And, many are clearly a key element in the architecture of the building where they are found.

The clock below was designed and built by my grandfather, John Eb-

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erhard. He had called himself an architect in his native Germany. But, when he came to America in 1880, he spoke very little English, so he became a cabinetmaker. We enjoy having his clock in our home to remind us of him. Every 15 minutes, it tells us in musical tones that another quarter-hour of our "time" here has past. And every hour, "grandfather" tells me in no uncertain terms that I need not ask "for whom the bell tolls; it tolls for thee."

The first mechanical clocks to which clear references exist were large, weight-driven machines, fitted into towers and known as turret clocks. These early devices did not strike the hour, nor did they have hands or a dial. The first public clock that struck the hours was made and erected in Milan in 1335. The oldest surviving clock in England is at Salisbury Cathedral and dates from 1386. A clock erected at Rouen, France, in 1389 is still extant, and one built for Wells Cathedral in England is preserved in the Science Museum, London. The Salisbury clock strikes the hours, and those of Rouen and Wells also have mechanisms for ringing chimes at the quarter hour.

The first domestic clocks were smaller versions of these large public clocks. They appeared late in the 14th century, and few examples have survived.

Atomic accuracy acquired

By the middle of the 20th century, when humankind began to travel into space, more and more accurate clocks were needed. The National Bureau of Standards in Washington, D.C, where I worked from 1964 to 1968, was responsible for keeping a record of time precise enough to be the U.S. standard for time. To do so, they built a "clock" based on the oscillation of a cesium atom—the most reliable counter in the universe.

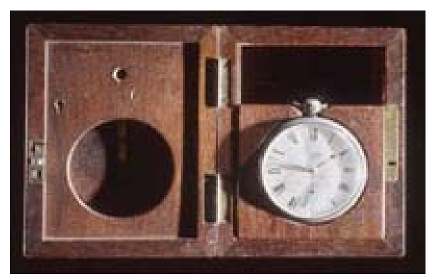
The merits of the cesium-beam atomic clock are
The fundamental frequency that governs its operation is invariant
Its fractional error is extremely small
It is convenient to use.

The unit of time, the second, was defined originally as the fraction "1/86,400 of the mean solar day." Considering that a very precise definition of the unit of time is indispensable for the International System, it was decided to replace the definition of the second with: "The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom." This is probably not easily understood by most people, but it works for setting the "atomic clock" [http://www.time.gov/index.html] kept by the National Institute of Science and Technology (NIST) in its Boulder laboratory. It is the standard for time measurement that we use in the United States.

Clocks illustrate "good" design

Although architects often design a building in which a clock is a prominent feature, they are not likely to design the mechanism used by a clock to keep track of time. But the design of the inner works of a clock is a classic design problem, used by Herbert Simon in his book *The Sciences of the Artificial* to illustrate what good design means:

"When an artifact (e.g., a clock) is designed, it has an inner environment (how it is organized and how it operates) and it is placed in an outer environment (the surroundings in which the clock operates). For example, if the clock is intended to serve as a chronometer on board a ship, it will not only have to have an inner design that records time, but it will have to operate in an environment in which the rocking of the ship is tolerated. It took many centuries after the invention of the first clocks, which used pendulums, before a 'chronometer' was designed, which used a metal spring, making it possible to keep time on board a ship."

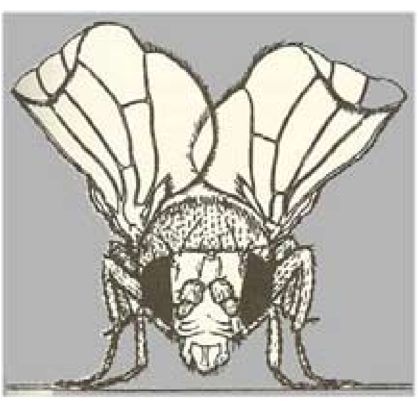


A biological clock gene resides in your brain

Now, let's look at a clock that works inside the brain. You probably go to bed and get up about the same time every day. If you are like me (and most other people) the "clock" inside your head tells you its time to get up, and if you stay up "past your bed time" you probably get sleepy. Neuroscientists now know that this happens because we have a "clock gene," inherited from previous generations, that sets a tiny region of our brains called the suprachiasmatic nucleus (SCN) used to produce a chain of chemical and nervous instructions that ripple through the body, controlling how each organ and tissue functions over the 24-hour day.

Time "flies" reveal clues in our genes

Human generations (each step in the history of development for the next set of parents) are approximately 10,000 days long, but the common fruit fly (scientific name *Drosophila*) has a generational time of 10 days. That's why when Dr. Seymour Benzer wanted to find a genetic basis for mammals' ability to keep time, he looked for an internal clock in the Drosophila. Through an amazing series of experiments, Benzer and his graduate students in 1967 discovered a gene that served as a natural clock for the fly. They discovered that there was a strain of flies with slow clocks that caused them to have 29- hour days, a strain with fast clocks that caused them to have 19-hour days, and a strain whose clocks seemed not to work at all—they were considered insomniacs.



Later experiments showed that the mating "song" of the Drosophila (that can only be heard by other Drosophila, but can be electronically amplified for humans to hear) has a rhythm established by the same clock gene. Each strain of Drosophila has a slightly different song, and females mate only with males who sing the song of their species.

Eventually experiments were also conducted to test the impact of the clock gene on the memory of Drosophila. Some flies could remember to avoid a dangerous smell (which they had been "taught" was dangerous using associated electric shocks) for an hour (which is equivalent to a few months in a human life). Others could remember for as long as twenty-four hours.

By 1983, with the development of methods for dissecting the chromosomes of genes, Benzer and his colleagues were able to discover which proteins the clock gene made. The clock gene of the Drosophila consists of 3,600 nucleotides (each represented by one of four letters A, C, T, and G). In a set of amazing experiments, they found that the fly with the slow clock had had the G nucleotide changed to an A in position 1766, and the fast clock fly had a T changed to an A in position 734. This small change did not break the clock but it accelerated or decelerated the "hands."

This and other research has established scientific evidence that the small clock in the Drosophilas' brains provides them with a sense of time and the rhythm of their song. It also influences the pace of their memories. It is likely, although not yet proven, that much the same thing happens in our brains, even though we have brains that are a million times as complex (we have 100 billion neurons in our brains and the Drosophila has only 100 thousand).

At the end of our time together today, here is some wisdom from Ecclesiastes Chapter III:

To every thing there is a season,
and a time to every purpose under the heaven.
A time to be born, and a time to die.
A time to weep, and a time to laugh; a time to mourn, and a time to dance.
A time to keep silence, and a time to speak.

Reference:
Visit the Academy of Neuroscience for Architecture Website.
[www.anfa.org]

Read the other seven articles in this series:
- You Need to Know What You Don't Know
[www.aia.org/aiarchitect/thisweek06/0127/0127eberhard.cfm]
- Thanks for the Memories
[www.aia.org/aiarchitect/thisweek06/0224/0224eberhard.cfm]
- See the Space and Hear the Sound of Music
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