Chaotrons, Chaotic Motion and the Human Brain

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Chaotron kinetic sculptures and the human brain

The chaotic motion of a Chaotron kinetic sculpture is an example of how most machines are not constrained to a simple repetitive motion but rather wander through a range of motions. The more moving parts a machine has, the more dimensions this available range may have. If you are not familiar with Chaotron kinetic sculptures, please see several of the other pages of this web site and also watch the video at https://www.youtube.com/watch?v=I5PZshifH6g.

The human brain is a machine. It is not just a mechanical machine; it is primarily a chemical and electrical machine with some mechanical features. Chemical and electrical systems, however, run according to physical laws just as do mechanical devices, and they exhibit chaotic behavior in the same way as do purely mechanical devices. To encompass all devices that exhibit chaotic behavior, I use the term, *physical devices*.

Even though a human brain and a simple three-moving-part kinetic sculpture may not have a very obvious relation, they both are physical devices; their changes through time are governed by the same laws of physics, and they share an important characteristic of this motion—it is *chaotic*. In this context, chaotic does not mean it is random or uncontrolled. It means that over time it can wander over every configuration it can possibly have without repetition and it is exquisitely sensitive to its environment.

The first sections of this article explain some interesting aspects of chaotic motion using a Chaotron kinetic sculpture as an example. The latter sections discuss how these aspects of chaotic motion relate to the human brain.

Chaotic freedom of physical devices

First, consider an important aspect of chaotic motion that gives it the enormous freedom to go wherever it is not explicitly forbidden.

Isaac Newton's laws of mechanical motion and all the other laws of physics connect only the present moment, the immediate past, and the immediate future. These three times are separated only infinitesimally. Newton's $F=ma$, or in words, *a force on an object causes it to accelerate inversely to its mass*, relates the force applied at this moment to the acceleration of the object at this moment. The acceleration is defined as the position of the mass right now with respect to its positions at moments infinitesimally before and after. In

mathematical terms, the position of the object appears in the equation as its second derivative: the acceleration. Most significantly, the equation contains no mention of the more distant future or past.

Any longer-term physical connections in time must be provided by something other than the basic laws of physics. Consider that the earth has revolved around the sun for billions of years, but if somehow the gravity of the sun suddenly disappeared, the earth would instantly abandon its sun-centered orbit for a straight line into deep space without any constraint from its over 4.5 billion years of orbiting.

All complex physical devices exhibit chaotic behavior except those that are built with specific tight constraints that limit their behavior to one or a few options. Although a piston engine may have many moving parts, those parts are bolted together so that they all move together in a fixed pattern: the shafts rotate; the pistons and valves move up and down; and all the parts are synchronized to move together. A piston engine can speed up or slow down, but it can change its motion in no other way.

Other devices have multiple parts that are not so tightly constrained, and the parts can move independently as in a Chaotron sculpture. Such devices exhibit chaotic motion to the extent allowed by the constraining factors built into the device.

A Chaotron sculpture has loosely coupled parts that influence each other but do not constrain one part to exactly follow another. Nonetheless, each of the moving parts may be attached to another part so that the attachment point of each part must follow its attached part, but the opposite end of the part is not so constrained. The sculpture may be set in motion with a certain energy and be kept in motion by a sustained weak push that compensates for friction, air resistance and other energy-absorbing effects. In these conditions the sculpture is constrained to never perform any motion that requires more or less energy than is constantly present. Any physical device that exhibits chaotic motion has both its loosely coupled freedom and its constraints.

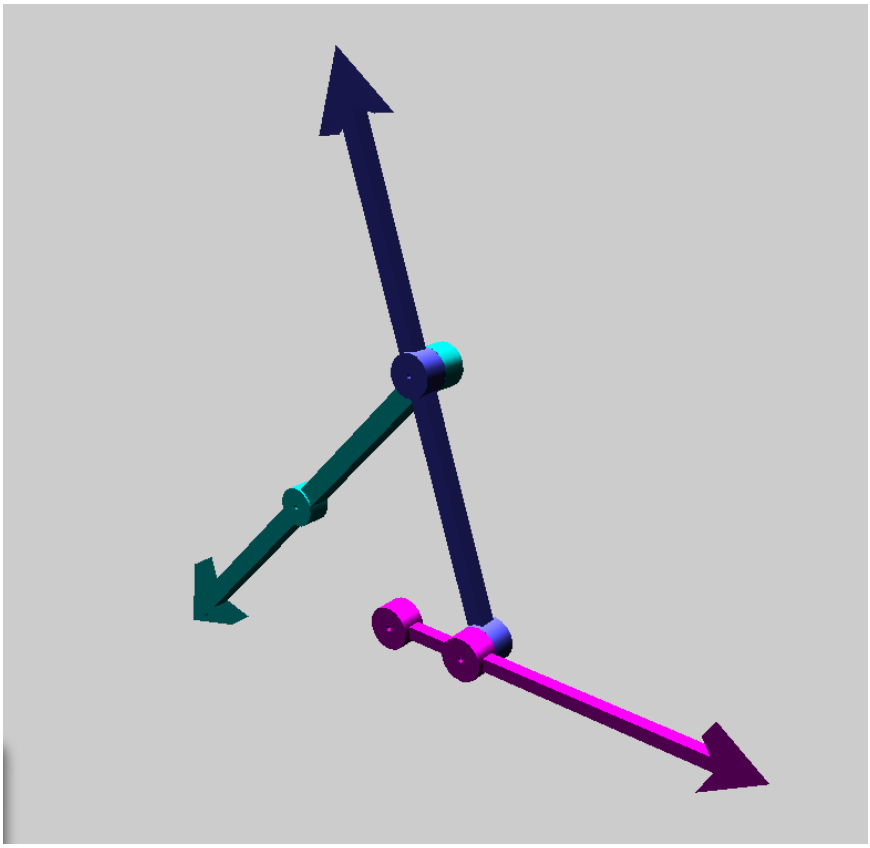

Figure 1: A graphical representation of a three-arm Chaotron kinetic sculpture

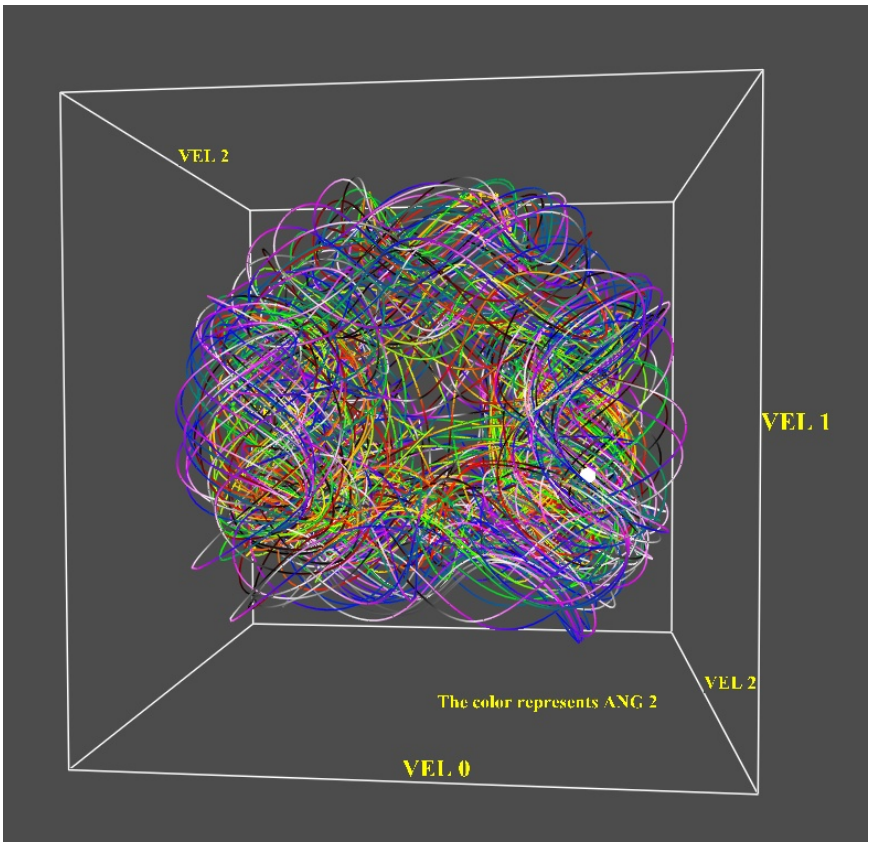

Figure 2: A 3D graph of the velocity of the three arms of the Chaotron sculpture shown in Figure 1.

Figure 1 shows a simple graphical representation of a three-arm Chaotron kinetic sculpture. The first arm (light blue) is mounted on a laterally fixed but freely rotating shaft. The second arm (dark blue) is mounted on a free shaft at one end of the first arm, and the third arm (magenta) is mounted on a free shaft at one end of the second arm. For a real view of such a sculpture, refer to the video mentioned in the first paragraph of this article.

Figure 2 shows a 45 minute history of a computer simulation of the sculpture shown in Figure 1. The velocity of each arm is plotted along one direction in a cube to give a 3D graph of its motion. The color of the line represents the angle of arm 2. While the path of the arms tangles so much that one cannot follow the motion in detail, the graph demonstrates that the motion is not simply repetitive. Eventually the graph would become an opaque mass of lines as the sculpture explored the spaces in between the earlier lines. Over time, the sculpture travels through every combination of the arm velocities allowed by its construction and the energy it is given. The character of this graph suggests that "chaotic" is an apt description of the motion.

The butterfly effect

A second characteristic of chaotic motion is that the future motion is exquisitely sensitive to the physical device's environment. This characteristic is called *The Butterfly Effect*. That name was given by Edward Lorenz who noticed it in computer simulations of the earth's weather and saw that a disturbance of the atmosphere as weak as the wind made by a butterfly's wings could affect the formation of a hurricane. (https://en.wikipedia.org/wiki/Butterfly_effect)

Because the equations of physics express instanteous connections among the parts of a physical device and

its connection to other devices, they dictate how one instant evolves into the next. At that next instant, however, if the external circumstances change, then the path of the physical device that would have gone along one path now goes along another. The tiniest push by an external force can cause a physical device to veer off into a radically different future. A Chaotron kinetic sculpture demonstrates this effect as follows.

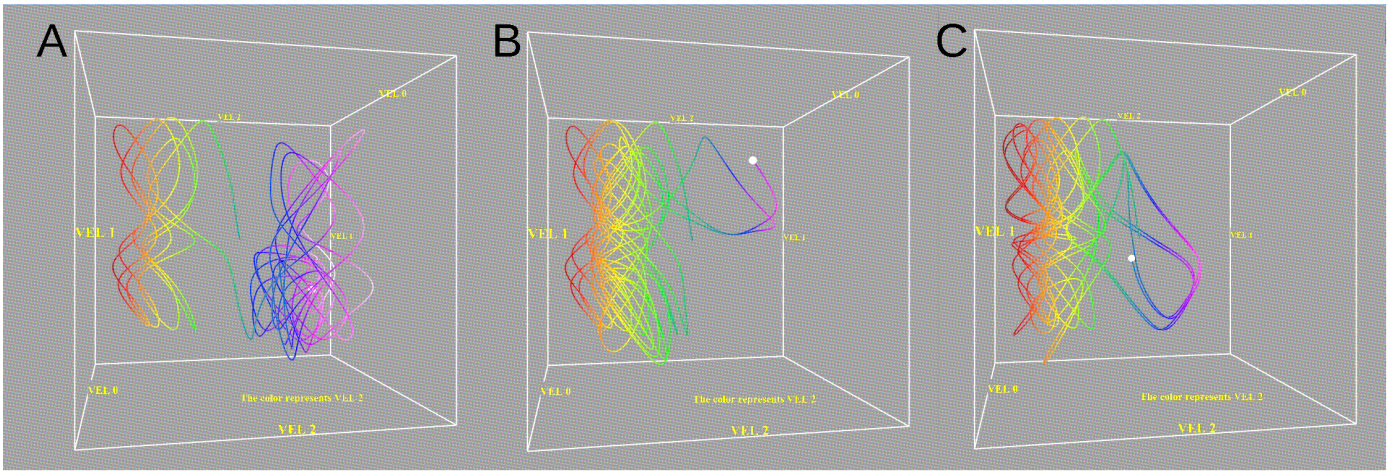

Figure 3: The 180-second history of the three-arm-Chaotron sculpture. The angular velocity of each of the three moving arms is plotted along one axis of a three axis graph. The starting point of the motion is at the center of the box and the initial motion on the left of each graph is approximately the same, but the motions diverge as time advances until the last part of the motion on the right of each graph where the third arm has reversed direction is very different for each case.

Figure 3 shows three simulations of a three-moving-arms Chaotron sculpture in which the starting condition of each simulation is different by a very small amount. Each simulation lasted 180 seconds. In simulation A, all three arms are motionless at the start. In simulation B, one arm has an initial rotation to the left of 0.0001 radians/sec (0.0057 deg/sec). In simulation C, the one arm has an initial rotation to the right of 0.0001 radians/sec.

The difference among the initial configurations is truly small. If the rotation simply continued for 180 seconds with the same difference in rotational speed as initially given, one would see about 1 degree difference in the final positions and negligible difference in the rotational velocities. The total energy in simulations B and C is the same and they have only about 4 parts per billion greater energy than simulation A. In fact, Figures 1A, 1B and 1C show that the resulting motions start out very close to the same, but they diverge dramatically by the end of the 180 second simulation.

The sensitivity of physical devices to very small external effects applies to almost all complex devices. The presence of friction or viscosity or electrical resistance in all real-world devices is sufficient to inject at least a small degree of chaos into the motion.

Creatures of our past

These examples of chaotic freedom and the Butterfly effect in a simple physical device shows that the laws of physics do not insist on a long-determined cause and effect relationship nor do they make the device immune to change by small external influences. The past does, however, have consequences for the present, even for a physical device as simple as a billiard ball. Suppose an eight ball is at some position on a felt-topped table at this moment. How it got to that place depends on a very complicated past. It began life as a synthetic polymer, was molded into a ball, polished and put into a cardboard carton. It was trucked to a store, carried home in an auto, dumped on a billiard table, and is now speeding across toward a corner

pocket. Most of those events have absolutely no effect on whether it goes into the pocket. Just how perfectly it was molded makes some difference. How the cue ball hit it makes the defining circumstance.

The billiard ball's past is not its irrevocable destiny. Up ahead on the table is a cookie crumb dropped there by an untidy player. The billiard ball hits the cookie crumb and its future is now different. It glances the corner of the pocket and recoils across the table until it hits the six ball.

Another characteristic of the eight ball that affects its course in life is its mass. It takes off very fast when the cue ball hits it if it is light, and it begins its roll more slowly if it is heavier. When the ball strikes the cookie crumb, it is deflected more if it is light and less if it is heavy.

In the Butterfly effect example, Newton's law propels the sculpture arms along a future path that depends on the past path, current external influences and the arms internal properties. The mass makes an arm resistant to but not completely immune to external forces. The initial change is small, but that small change propels the arm into a slightly different environment than it would have experienced. Over time the initial change and the new environment that change produced lead to a significant change.

Our past is encoded in our brains, but unlike the hard polymer of a billiard ball, our brains' encoding of the past is in a variety of ways, and that record of the past is constantly updated by our experiences.

Determinism

Many people think that if the brain is a purely physical device, then its behavior is strictly determined by physical laws; and it has no option to make free, original choices and has no *free will*. This is a misconception based on a lack of appreciation of the flexibility of complex physical devices like a Chaotron sculpture or the human brain. In the scientific and philosophical literature about free will, this viewpoint is called *determinism*.

Of course, free will can be explained by the intervention of supernatural forces. If a human is controlled by not only his physical brain but also a supernatural component, then he operates by methods and laws completely unknown to science and can do whatever the supernatural realm dictates. Because a long history of brain research has found no evidence for such a supernatural component and because that research has made great advances in explaining the functioning of the human brain without invoking supernatural mechanisms, this text deals only with the question of free will in a purely physical human brain.

If the human and particularly his brain is purely physical, does he have multiple possible futures, or is his future uniquely determined only by his past? The concept that given a past, only one future is possible is called *determinism*. It is defined in *The Stanford Encyclopedia of Philosophy* (http://plato.stanford.edu/entries/compatibilism/) as:

> "...we shall define determinism as the metaphysical thesis that *the facts of the past, in conjunction with the laws of nature, entail every truth about the future*. According to this characterization, if determinism is true, then, given the actual past, and holding fixed the laws of nature, only one future is possible at any moment in time."

A human brain certainly has many parts. Many of the cells that make up a human brain are neurons, and a brain has roughly 100,000,000,000 of them. They are coupled together by long arms (axons) that carry the chemicals making up the cell and carry electrical impulses. Any other neurons that touch these arms can be affected by the electrical impulses and by chemicals released at the tips of the arms. This coupling is not rigid, however, as is the coupling of pistons and valves, and the neuron acts under the influence of many neighbors and on its own internal state. Thus the brain overwhelmingly meets the requirements for demonstrating chaotic behavior.

Chaotic freedom and the human brain

The human brain has its billions of parts loosely coupled as in the three-part Chaotron kinetic sculpture example. Like the Chaotron kinetic sculpture example, the brain moves forward in time according to the immutable physical laws and is infinitely sensitive to external conditions that may steer it. It reacts to changes in its external conditions instead of just progressing on a predetermined course. Of course, those external conditions are also part of a larger physical system.

Given that a brain is a chaotically free physical device, it is not irrevocably bound to a single future by physical laws and its history. The question of just how the brain makes a decision at this moment: how the brain uses its past and its present-moment environment to constrain its motion into the future becomes the central issue. If the brain can make a decision based on the factors present at some moment in time, a decision not based solely on its past by some rote method, then that brain exercises free choice, free will, and moves into the future based on that decision.

Just as a billiard ball has its past built into it as its mass, its roundness and imperfections in the roundness, its balance and other manufacturing considerations, and it may have cracks developed over time from use and misuse, a brain has its past built in as memory, learning, development of preferences, loves, values, emotions, and other characteristics of an experienced brain. Does the accumulation of these features over time lock us into a fixed future?

Is human action locked in by the past and the laws of physics?

Exercising free will does not mean that we are free to act randomly. It means that we are free to act based on our beliefs, our values, our desires, our loves, our memories with one of an almost unlimited range of futures (chaotic freedom) decided on when all those internal constraints and forces and our current external situation (the butterfly effect) are weighed by our conscious and unconscious thought processes.

The butterfly effect acting in the context of our brains shows that a complex past does not lock us into a single future. Tiny present-day external influences can deflect us into a huge range of futures.

Our past is encoded in our brains by learning and remembering in many ways. Our ability to do arithmetic was learned in our earliest school or preschool learning. It resides somewhere in our higher intellectual faculties. Our love of certain people resides in perhaps a wider range of facilities including our rational and emotional faculties. All the ways in which our history is encoded into our brains, all the internal forces and constaints that our genetics and our experiences have built: *That's who we are*.

When faced with a decision, a moment when our external circumstances and our internal forces all bear down on our future, we lunge forward into the future based on the net result of all those influences. And each time we make a decision, that decision and its consequences are folded back into our history and influence our future at the next and every decision point to come. Our history influences our present moment decisions but does not dictate them and make them immune to current external forces: *That's what free will is.*

The fact that our brains are simply and purely physical devices is not at odds with the aspects of human brain function that we value most. No supernatural intervention is required to explain those functions. Yes, we can remember, learn, love and hate, laugh and cry and decide.

Finally and wonderfully, we each have an immense, unknown, not fully decided future toward which we are propelled by the chaotically free laws of physics but directed by our whole, complicated, chaotic human brains.