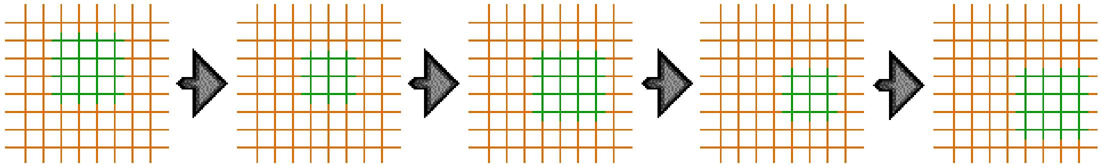
Thermal Model of Idealized Brains and Conceptual Devices That Embody Their Activities

Abstract: Physics researches into thermodynamic critical point phenomena suggest a thermal model of brains. The idealized conceptual unit is a distinct and compact body, called a Neuronal Group, made up of a large number of identical idealized units (Neurons) interacting through a uniform “nearest-neighbor” activation. The chief operating principle is Phasic Cycling where Virtual Energy in the body is alternatively stored (heating) and dissipated (cooling): at maximum storage, activity in the Neuronal Group is disordered and the Neuronal Group is in the Neuronal Critical State; upon dissipation, an ordered phase appears that may be one among several phases in an ordered phase structure and such emergence is interpreted psychologically as experiences of objects, including perceptions and purposeful intentions, and of acts, including muscular acts. The principle of Phasic Cycling is embodied in conceptual devices – Structural Engines – that operate in a cyclical fashion, pumping pulses of Virtual Energy through Assemblies of Neuronal Groups that cycle energy flows through cooling and heating waves and thus produce phases, corresponding psychologically to production of experiences of objects and acts. Development of Structural Engines imitates development of Heat Engines that occurred the nineteenth century and that is the basis of the modern concept of energy. The Idealized basic design can be made subject to various modifications and applications that yield many and various Structural Engines suggestive of diverse forms of personal experience.



Incremental reversible Phasic Cycling in a module of Idealized Brains

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(An example of the most refined and certain activity of the Thermal Model)

CONTENTS

I. Large-scale character and architecture of the Thermal Model.

1. In this formal presentation, general and vaguely-stated matters are presented first and there is progressive sharpening and narrowing through imposition of ***constraints*** that restrict application of the model to certain kinds of natural phenomena occurring under certain kinds of circumstances, chiefly activity that is highly repetitious with structured variations requiring selections by a person. The idea is simultaneously to both develop a tool and also employ it on tasks to which it is most suited. Clarification is achieved through progressively narrowing the focus of application. This approach avoids insurmountable problems encountered when the clearest matters are those that are first presented.

I begin by examining some large-scale, loosely-defined matters from various angles and using different conceptual systems. Examination begins with overall evaluation and taking a certain attitude with respect thereto. It's like picking up a complicated object, e.g., an insect, and turning it over, around and about while obtaining a general sense of the large parts and their relations.

2. In this new approach to describing activities of brains, there are three distinct but related domains: (1) a ***biological domain*** in which activities of biological neurons and neuronal groups, are stated in terms of physiology, anatomy, gestational development, etc. presumably reflecting natural laws stated by physics, chemistry, molecular biology, etc.; (2) a ***psychological domain*** in which an organism – e.g., a person – perceives and acts, often purposefully; and (3) a ***device domain*** containing designs for ***Structural Engines*** that relate the biological domain and the psychological domain.

Style notes. Capitalized words like "Structural Engines" refer to Idealized objects. Ideals are concepts, treated as if they were things in the world, that organize facts in a simple and useful way. The Ideal Gas Law is a familiar example but there are many other examples in physics, including the Vacuum, the Infinite Body discussed below and, of course, the Carnot Heat Engine imitated by Structural Engines. Ideals are a basis for device designs.

3. The biological domain is the suggested ground for the ***operation*** of Structural Engines while the psychological domain is the suggested ground for the ***products*** of Structural Engines. In other words, activity of Structural Engines involves two domains that are governed by different principles. The nature of experience produced by Structural Engines is ***different from*** the nature of biology that governs the operations. Productive principles are different from operational principles.

A similar distinction applies to computers and clarifies the distinction: in computers, the physical principles governing operations are those of hardware design, including the quantum theory of solids, technology of semiconductors and principles of circuitry; while the productive principles are those involving software, including binary numbers, data types, algorithms and recursion. These are very different conceptual domains notwithstanding their common involvement in the general domain of science and technology. Software is perfectly exact, based on general rules; while physics and engineering use approximations and exploit particular features of particular materials. The "binary" nature of computer products makes it difficult to use them to explore the quantum theory of solids, semiconductor technology and some circuitry questions where reality is described by continuous variables, e.g., those stating quantities that vary continuously in space and time. You learn more about the physical operations of a computer by taking it apart with a screwdriver than by observing its activities accessed through monitor, keyboard, mouse, etc.. The converse applies if you want to learn how to use a computer productively – then the screwdriver is useless and the monitor, keyboard etc. are the way to go.

On the biological side of Structural Engines, the operational side, I suggest that principles of physics govern activities of brains and these are the principles on which Structural Engines are based. That is, I suggest that certain physics principles discussed below are involved in activities of brains and I use them in a constructed or Idealized class of devices called Structural Engines. In other words, Structural Engines, conceptual devices, are designs for Idealized brains operating according to principles of physics that I suggest are operating, more or less, in biological brains. "Idealized" means that the design is in an easily-understood form, while real biology is much more complex. It is understood that, in important ways, the Idealized imitation is quite different from the biological original.

On the psychological side, Structural Engines are ***productive devices***; and the ***products*** of the Engines, ***structures of objects and acts***, imitate a person's experience and thus are used to interpret activity in the psychological domain. The class of activities imitated by Structural Engines is highly restricted and impoverished when compared to the full range of activities of a human being, but I suggest that Structural Engine can usefully work on "matters about which all persons agree." The current model is directed toward imitation of some mental activity of a human person developed before age 7, chiefly mental activity involving coordination of perceptive activity and muscular activity, following the description and analysis provided by developmental psychologist Jean Piaget (1896-1980).

Hence, the activities of Structural Engines are based in biology while the products of Structural Engines imitate psychology. This is the ***device approach*** to the "brain-mind" problem.

4. This approach to describing activities of brains is different from other approaches and the proposed devices are different from other devices, e.g., computers. The Structural Engines here proposed belong to a class of ***thermal control devices*** that includes cooks' ovens, metallurgists' furnaces and potters' kilns. In each device, physical material (Idealized brains in the case of Structural Engines) undergoes large-scale changes, called ***phase transitions***, that are controlled by variations in temperature ("virtual temperature" in the case of Structural Engines). I say that ***we cook up our experiences more than we calculate them***. (An important class of experiences is the same whether cooked up or calculated.)

Thermal devices are not machines and ***Structural Engines are not machines***. The physics is ***not*** the physics of mechanics that is said to support the belief that "brains are computers." Rather, the physics is ***thermodynamics***, a branch of physics that overlaps mechanics in some important ways but that also identifies and deals with activities of physical matter that are not within the reach of mechanics. An important class of activity that is partially within the reach of thermodynamics is ***irreversible phase transitions***, e.g., irreversible phase transitions in metal alloys like steel, called ***martensitic transformations***, that are driven by **<u>fast quenches</u>** and such

irreversible phase changes are not within the conceptual reach of mechanics or computers. Structural Engines, when called upon to do so, drive irreversible phase changes repetitively and productively; and I suggest that some products of Structural Engines, some structures of objects and acts, cannot be comprehended by any mechanical system of concepts.

5. A thermal approach suffers from ***systemic defects*** that would not be present in the achievements of a mechanical model, were a mechanical model to be achieved. The thermal approach ***aggregates detail*** and generates only ***static images*** of the activity being described. It is as if an action video on a computer monitor was turned into shades of gray with seriously lossy compression and presented as a series of "snapshots," detached from one another so action is no more than implied. That's better than nothing but by no means all that we would like to get.

6. Although the thermal model is based on images that show activity I ascribe to consciousness, the thermal model does not attempt to "explain consciousness," does not attempt to define causal relationships involved in mind-brain interactivity and does not attempt to state answers to "hard questions" about matching personal experience with external reality. Whether thermal devices can have consciousness like a person's is a question that is extraneous to the model, at least at this stage of development. The model allows for souls and selves – or for chance events and darwinistic evolution – as you prefer. The model is pervaded by systemic defects that compel abstinence as to such matters.

7. Matters where the principles of thermodynamics overlap those of mechanics are the simplest to develop and are of chief importance here. Chiefly, these matters are activities of an organism that can be modeled both by the thermal model and also by mechanical models. In the thermal model, such activities take place under ***constraints*** – restrictions that are part of the thermal model. Chief constraints are imposed by Idealizations that include perfect isolation of activity from outside influences and/or perfect environmental stability as expressed in the form of exact repetitions of experience. Structural Engines support clearly defined, repetitive activity with incremental modifications. Incremental modifications can be conceived in static forms ("variations") and/or active forms (classes of "processes on paths" constructed from classes of "objects," "acts" and/or "primal" operations or processes).

Important if crude classes of matters considered herein are: (1) ***comprehensible matters*** where good approximations are produced both by mechanical models and also by thermal models; (2) ***incomprehensible matters***, e.g., what is going on during a major catastrophe or a general theory of turbulence in physics, where no model works well; and (3) ***difficult matters*** where success requires specialized skills applied in a fashion I call ***exercise of freedom***. The tasks of courtroom judges are exemplary of difficult matters. The thermal model partially engages difficult matters that mechanical models fail to engage.

The chief distinction is that between (1) comprehensible matters where activities are approximately described by both mechanical models and thermal models and (3) difficult matters where mechanical models necessarily fail but where thermal models may have some success. The following words track across the three domains in distinguishing comprehensible matters from those that are difficult (may also apply to incomprehensible matters):

Parallel words describing comprehensible matters: continuous, reversible, incremental, repetitive, stable, congruent (parts fit together exactly and are organized by consistent overall principles)

Parallel words describing difficult or incomprehensible matters: discontinuous, irreversible, saltatory (jumpy), unique, unstable, incongruent (gaps or conflicts between parts; elements that are facially contradictory)

8. The results of the different approaches (mechanical vs. thermal) typically differ when there are time limitations for production in the nature of a "deadline," or when a given purpose cannot be achieved by incremental modifications of repetitive activity. The thermal model suggests that productive activity is sometimes still possible under such circumstances and that approximate success in description can sometimes be achieved when a mechanical approach fails. That is, activity of brains can sometimes be imaged, even if crudely and approximately, by the thermal device model as to matters where activity cannot be imaged at all by mechanical models. Some such activity imaged by the thermal model is ascribed to an exercise of freedom performed by a person. Even though the details of such activity are not predicted by the thermal model, such activity becomes conceivable by means of a thermal model. Understanding gained through studies of Idealized brains operating under Ideal conditions assists in conceiving of devices that imitate activity of real brains where conditions are not Ideal and where a person exercises freedom. The thermal model operating under mechanically Ideal circumstances does not exercise freedom but a possibility of freedom remains implicit. For purposes of this essay, this completes the comparison between the thermal model and mechanical models.

9. The thermal model involves the construction of three sets of relationships involved in the three domains (biological, psychological and device domains). First is the construction of a set of relationships between supposed activities of biological brains and activities of devices. The chief focus of presentation in this essay is on this ***biology-device*** set of relationships and, therefore, this set of relationships is treated herein as fundamental and other sets of relationships are based on the biology-device relationships.

10. The second set of relationships, based on the first, state ***how the devices do what they do***, namely, the devices are designed to generate, assemble, modify, navigate and organize ***structures*** of objects and acts. This set of relationships is stated herein in a general way, showing how such structural activity is possible without providing details of application. The general description of structural activity provided herein is to be reduced to technology ("structons") suitable for detailed application; and presentation of structon technology is planned for a separate publication.

11. The third set of relationships states relationships between products of devices and psychological structures. This set of relationships is grounded in the work of Piaget and his collaborators, especially their work involving "formal operations" that are sometimes expressed in terms of the mathematical theory of groups. Formal operations govern, e.g., a person's cognition of movements of objects in space and time and use of hierarchy, number, series, logic, etc. to organize experience. In this essay, group-theoretical principles are used to organize products of the Structural Engines. That is, Structural Engines show group-theoretic

correspondences between (a) sequenced phase transitions in Idealized brains and (b) sequenced acts of an Idealized organism or person stated in terms of objects in the organism's or person's experience. These correspondences make up the central core of the third set of relationships. Other relationships in the third set are assimilated thereto.

12. In this essay, the third set of relationships states correspondences between conceptual products of the devices and personal experience as applied to certain matters about which all persons agree ("objective matters"). From the psychological side of the correspondences, the chief focus herein is on a psychology that deals with matters about which all persons agree and that constructs space, time, movement of material objects, makeup of material objects, numbers, physical laws, organizations, juridical laws (enforced by the courts), political states, communications within organizations, the meanings of some words, etc. Important constructions include the acts or actions of persons. Such acts may be experienced through a primal "inner sense" of one's own acts and through observations of acts of other persons that are judged to be "the same" as one's own acts (e.g., when I imitate another person). In sum, I give the products of the devices a psychological interpretation ("structures of objects and acts") that is to be discussed in detail in a separate publication: Structural Engines Engaging Reality ("SEER") Model of Personal Intelligence and Freedom.

13. The three sets of relationships define a path with each set of relationships reduced to an arrow: (activities of biological brains) → (activities of devices) → (products of devices) → (structures of objects and acts). To recapitulate, the chief argument in this essay is that activities of the proposed devices resemble activities of brains. This device approach is designed to reach several goals simultaneously: to state useful and forward-looking resemblances between activities of devices and activities of biological brains; to express relationships through the model that appear through inner sense to describe activities of oneself or others; and to construct a conceptual system from germinal elements suitable for extensive development. These are the goals the thermal model sets out to attain, however much the actual achievement may fall short of satisfaction.

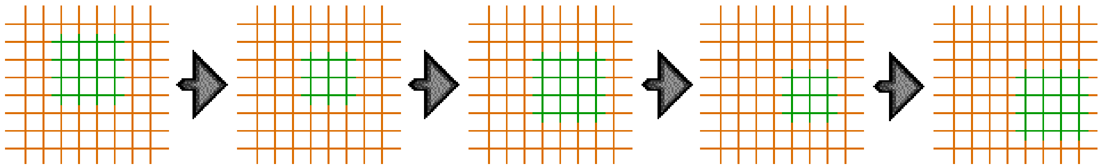
14. The device approach to modeling a brain as a thermal production system (i.e., a thermal device that produces structures) has an important precedent that originated in studies by Sadi Carnot (1796-1832) of conceptual devices he invented, Idealized Heat Engines. Carnot's Heat Engines constructed relationships, previously unknown, between heat and work that led to beneficial development of steam engines on which Carnot's studies had been based. (R. L. Hills, *Power from steam: A history of the stationary steam engine* (1989).) The modern concept of "energy" as a number that states a quantity of ***potentially obtainable*** work (an "amount of work" that is purely conceptual) did not exist and could not have existed prior to Carnot's inventions. (See Introduction, § 6: "Energy's not real, it's only Ideal.") Details of this "Thermal Model of Brains" incorporate features drawn from Carnot's approach and from work of other "pure thermodynamicists" [S. G. Brush *The Kind of Motion We Call Heat* (19??)], with special reliance on the work of Clifford A. Truesdell III (1919-2000), e.g., *The Concepts and Logic of Classical Thermodynamics as a Theory of Heat Engines etc.* (1977). The theory of Structural Engines follows paths laid down by the theory of Heat Engines.

15. The thermal model is centrally based on the ***thermodynamics of critical point***

phenomena and an orderly detailed presentation commences with discussion of that area of physics. The presentation uses conceptual images and diagrams with general explanations. There are no serious mathematical formulations. There is additional device-based conceptual imagery in the background (see Technology of Freedom on the website for an earlier stage of conceptual development) but there are no additional mathematical statements available for that background imagery. The stage of conceptualization is: "how are such things possible?" rather than "here's a manufacturing design."

16. "Critical point phenomena" studied in physics have often been suggested for models of brains but the approach here is different from other suggestions in that the focus here is on primal images of activity rather than on stating mathematical formulations or technical expressions in computerized or mechanical form.

17. Features drawn from known thermodynamic critical point activity of physical systems are identified and used in a new concept called ***Phasic Cycling***, that I suggest imitates some activity of real brains in Idealized models. In Phasic Cycling, a Neuronal Group alternatively enters into and leaves the Neuronal Critical State. When the Group enters into the Neuronal Critical State, ordered activity in the Group is disrupted. When the Group leaves the Neuronal Critical State, ordered activity in the Group is established that may be different from that prior to the disruption and that may incorporate adjustments to accommodate external influences. In the Thermal Model, it is upon re-establishment of ordered activity that a person may experience an object or act identified to that activity. Phasic Cycling is discussed below but a preview construct may provide guidance even though it is so crude as to distort some details:



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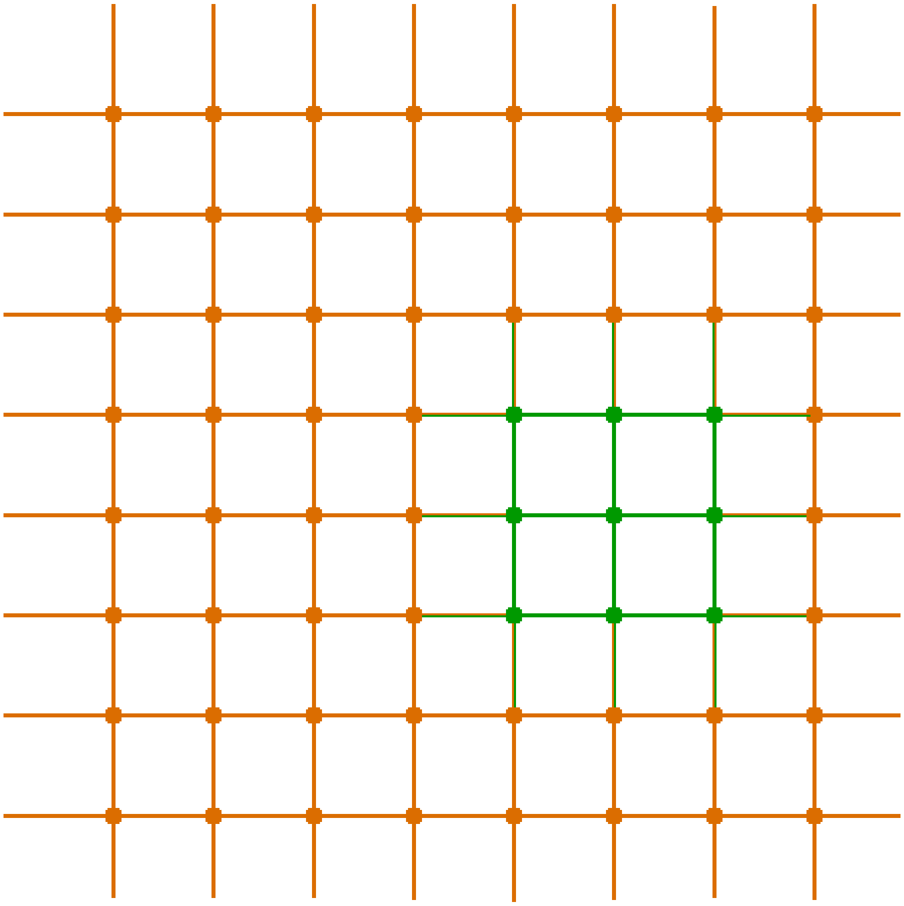
(An example of the most refined and certain activity of the Thermal Model)

In the construct there are five images that represent steps and each step succeeds or supersedes the prior step, with stepping at short intervals in time. These are like frames in an animation. (Conversely, the Thermal Model suggests that animated images succeed as illusions because they present material in a "natural" form, i.e., a form congruent with episodic and/or saltatory (jumpy) activities of brains that are concealed by the illusory quality of continuity.)



Each step-image shows the largest-scale view of a network of Neuronal Groups. The adjacent image is the "full-size" version of the fourth step-image in the construct above.

Treating the system as a node-and-link network, each node is a Neuronal Group and each link is two "semi-links," one running in each direction.

The next level of detail follows exactly the same form. Only now, each node is a Neuron and each link is a pair of Axons, one projecting in each direction. However, only a Neuronal Group can enter into the Neuronal Critical State. If two Neurons belong to the same Neuronal Group, they always enter into and detach from the Neuronal Critical State together.

In the diagrams, parts of the network at the Critical Virtual Temperature do not sustain identifiable activity. The part of the network below the Critical Virtual Temperature does sustain particular phasic activity.

In the Thermal Model, the organization of Neurons into Neuronal Groups generates hierarchies of "nearest-neighbor" relationships. The focus is on the existence of and interplay of the aggregated hierarchies rather than on the relationship between any two levels in any hierarchy.

The images show only activity on the plane of the image. I presume that activity on the plane of the image can drive or be driven by activity in a "third dimension." For example, I can imagine that the establishment of each of the larger steps in the construct of phasic activity (the first, third and fifth images) triggers the release of a particular finger of a pianist's hand from it's "ready" position so as to strike a piano key above which it is hovering; hence, the image might show a run of three notes on the piano performed with three fingers. It is sometimes convenient to imagine connections to sensing organs and/or muscles running off in the "third dimension."

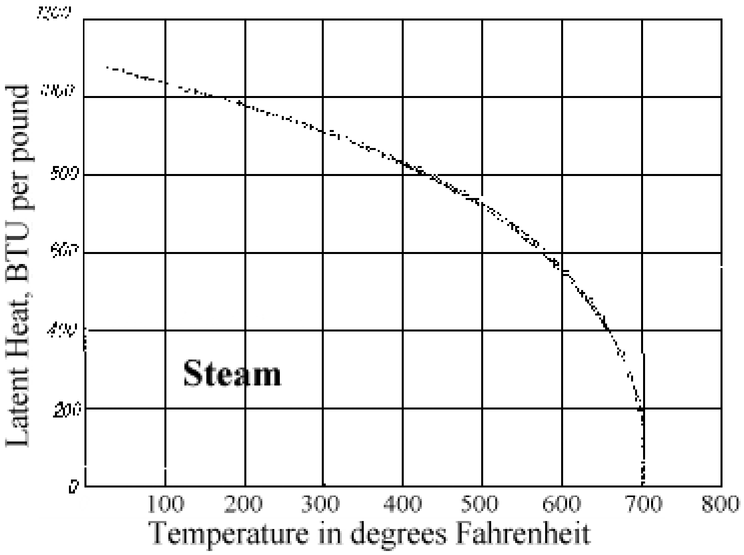
The imagery shows "reversible activity." The progression of phasic activity is so smooth and requires so little energy to drive it that it resembles a "frictionless" machine or reversible Heat Engine. This is activity that is best suited for clear presentation in the Thermal Model.

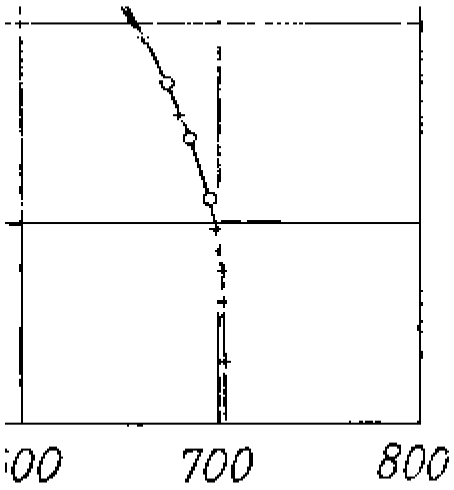
All reversible activity can be performed incrementally but not all incremental activity is reversible: irreversible dissipation that occurs when two bodies of different temperatures are joined can be achieved incrementally by limiting the relative size of the junction. As activity approaches mechanical Ideals, e.g., on a billiard table, there is activity that is reversible but not incremental . One advantage of incremental reversible activity is such activity can assemble other diverse and useful structured activities. As emphasized by Piaget in the psychological domain, reversibility enables a person to assemble, disassemble and reassemble structures of objects and acts in various ways.

A. Feature One: **Universality of Critical Point Phenomena**.

18. ***Universality*** in critical point phenomena means that a large number of diverse systems all show "the same" phenomena at a "critical point" specific to each system. In practice this means that graphs of certain kinds of activity all show "the same" shape. There is a large-scale shift that occurs at a critical temperature. Two examples are (1) steam and (2) an extremely simple (Idealized) mathematical model for magnets, the ***two-dimensional Ising model***.

The most important feature shared by both systems and by all critical points systems is that, just below the critical temperature, a shift of only ***a few degrees*** results in ***a massive change*** in activity. The shape of the curve is nearly vertical just below the critical temperature and identically 0 above the critical temperature. This is the physics basis of ***phasic cycling*** discussed below. The system ***switches*** when temperature varies "just a bit," but it is a special kind of switching.





The Critical Point
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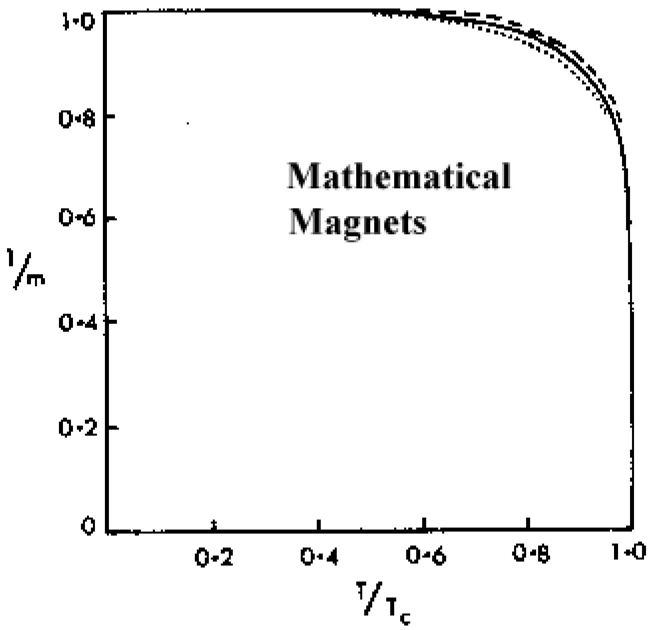


Steam graphs from Kearton, discussed below. Mathematical magnets graph adapted from Domb at .

Universal phenomena are a basis for the construction of ***classes*** of phenomena, that is, classes are based on the presence of “the same” features. When viewed from the physics of critical point phenomena, fluid-vapor systems, including steam, and some arrangements of “magnets” in a mathematical model constitute a single class.

In all forms of critical state phenomena, there is an important common feature (shown in the graphs): at the critical state there is a "steep decline" to 0 of a quantity that measures the kind of phasic activity that is present. It is said in critical point physics that there is a sharp transition of an ***order parameter*** from 0 at or above the critical point to another value just below the critical point.

Analysis in terms of physics shows that critical point phenomena are deeply rooted in simple geometry and other general space-type relations and it is the general space-type relations rather than the characteristics of the particular inter-particle interaction that governs activity near the critical point. Classes of phenomena governed by "the same" physics make it possible to compare systems of different forms and, more abstractly, for conceptual borrowing between domains. That is, the principle of universality supports taking concepts from one domain, e.g., a mathematical domain, and applying them to another domain, e.g., a biological domain, in an imitative way. Any such imitation should have additional supports but universality is the foundation.

19. Critical point phenomena appear to arise in ***any*** system constituted by the aggregation in an isolated space of a large number of identical units that affect one another via a "nearest-neighbor" interaction and that are otherwise subject only to large-scale influences that affect units "the same." As energy is incrementally supplied to any such system in a way specific to the system, the activity of the system will show universal critical point features. It appears that every system so constituted can be brought to a critical point.

20. The simplest example is constituted by liquid water and steam in a laboratory vessel and that example is the basis for discussion and development. The discussion commences with a review of fundamental thermodynamics concepts and proceeds toward the target.

21. **Definitions**. As a practical matter, thermodynamics or, more generally, thermal physics is a science that states mathematical formulations involving the ***temperature***, T, of one or more compact bodies of physical matter. Temperature measures activity of a body in the aggregate and the concept is applicable only if "the same" temperature pervades the entire body. It is presumed that temperatures between bodies can be compared and that a higher temperature measure higher activity. It is factual and universally observed that if two bodies have different initial temperatures and they are then put into contact, the activities of each will, if isolated from external influences, reciprocally adjust so that both bodies eventually reach a common, intermediate temperature. Temperature is a means of comparing activity in different bodies but only in a certain way that leaves many questions unanswered such as: how come the pizza burns your mouth when the metal pan on which the pizza cooked has long since cooled, since they both started off at the same temperature in the oven?

A compact body of physical matter is one that is set off or separated from all other bodies and that is dense in the volume of space occupied (that is, there's nothing else there that affects the thermal activity). In brains, compactness may be relative because bodies such as neuronal groups are interconnected; but we shall begin with Ideally compact bodies.

22. It is factual that compact bodies of physical matter take on different forms at different temperatures, e.g., H_20 that takes on the forms of ice, liquid water and steam. Such

different forms are called ***phases***. The concept of phase is also used to describe temperature-driven changes in metal alloys, such as steel; changes of field strength in magnets (magnets lose their strength in a furnace); and various laboratory-based and technological systems such as liquid crystal displays. (M. A. Anisimov, *Critical Phenomena in Liquids and Liquid Crystals* (1991).) An important feature of phases is the ***sharp transition*** from one form to another. An enclosed, still body of liquid water will completely freeze if the temperature is lowered to just slightly below 0 °C but will not freeze at all if the temperature remains just above that temperature. There is no temperature that sustains an intermediate state between liquid water and ice. "Singularly" sharp transitions in phase at the critical state are described by graphs that show a nearly vertical shape.

23. The concept of phase is also often used to describe behavior of organisms. See, e.g., J. A. S. Kelso, *Dynamic Patterns* (1996). I also use the concept of phase in this way. For example, it is possible to say that an adult human has two gaits, walking and running; and each of these gaits is a "phase" like ice and liquid water are phases of H_20.

Accordingly, in steady repetitive motion with the legs, there is either a time when both feet are on the ground (walking) or a time when neither foot is on the ground (running). In steady, repetitive motion, walking and running cannot co-exist. This bundle of features defines the ***gaits of an adult human*** as phases. It is possible to conceive of additional gaits, e.g., skipping, crawling or swinging on crutches, and a definition of adult human gaits is open and provisional. In general, a list of phases is open and provisional.

24. To support detailed analysis, I extend the concept of phase to identify and distinguish ***particular*** kinds of activity, sometimes taking place under highly structured circumstances. For example, each particular keystroke on a computer keyboard, – e.g., "q" as opposed to "w" – constitutes a separate phase for purposes of analysis.

Generalizing this notion, it is often possible to use the concept of phases to set up a structural form that is approximately true and useful: a ***phase structure*** that is ***partitioned*** into ***phases***. E.g., the provisional phase structure "human gaits" is partitioned into "walking" and "running." Every continuous, repetitive upright leg-driven movement examined is either "walking" or "running" and no such movement is both "walking" and "running." At least, that's the model. Similarly, there is a phase structure of computer keyboard entry keystrokes that includes "q" and "w" and, under appropriate definitions, "Q" and "+." (Large-scale phase structures in metallurgy, ***phase diagrams***, have been investigated at enormous length and with many different alloys and have even been successfully predicted through computerized techniques, e.g., in the CALPHAD Project.)

Some phase structures are ***final***, meaning that no further definition is possible. Such a list of phases is no longer open or provisional. For example, a list of all possible single-key keystrokes available on a computer keyboard constitutes a phase structure that will not be altered as long as the keyboard is in use. Taking each of those possible next keystrokes as a phase of activity and the entire list as a phase structure, that phase structure is final. In constructing phase structures, each such structure is either provisional or final and this characteristic should either be stated or be clearly implicit. The general rule is that phase structures are provisional.

25. Construction of the thermal model is based on parallels between thermodynamic systems that have been investigated in physics and supposed activities of biological brains. The pivot of the construction is the ***thermodynamic critical state*** from which I draw Features I use to construct the ***Neuronal Critical State***. The "universal" notion is that each Neuronal Group can enter into the Neuronal Critical State and achieve that condition in common with each other Neuronal Groups. In the Thermal Model, two Neuronal Groups may participate in no activity together other than in the Neuronal Critical State

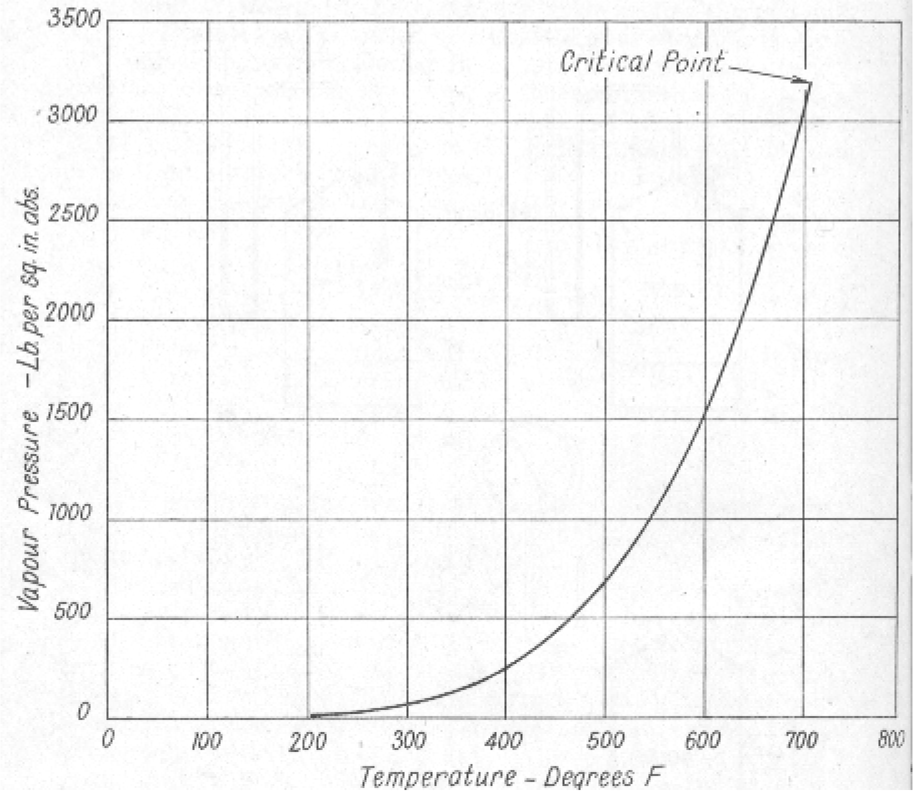
26. There are four chief kinds of thermodynamic systems that serve as originals for the thermodynamic critical state: (1) liquid-vapor models (e.g., liquid water and steam); (2) natural magnetic models (e.g., magnets made out of iron); (3) metal alloy models (e.g., brass made of copper and zinc); and (4) artificial magnetic models, inspired by metal magnets but chiefly ***mathematical magnet models*** named ***Ising models*** after the physicist who first explored their nature. The ***two-dimensional Ising model*** is the chief "physics original" on which the Idealized Critical State Model of brains is based. In 1944, Lars Onsager published his "solution" to the two-dimensional Ising model that opened the way to enormous progress, with a climax (but not a conclusion) achieved by Kenneth G. Wilson in about 1970 for which Wilson later received a Nobel Prize. A chief reference in this essay is a mathematically sophisticated review, namely, C. Domb, *The Critical Point: A historical introduction to the modern theory of critical phenomena* (1996). Domb was one of the leading researchers in areas opened up by "The Onsager Revolution," the title of a chapter in his book.

27. An Idealized fluid or liquid-vapor system is shown in the adjacent image. The system is constituted by a single substance, such as water, in two phases, liquid and vapor, enclosed in a chamber formed by a cylinder with a moveable piston head. Nothing can get in or out but the experimenter can set the temperature (T) and pressure (p) as desired within quite a large range, while adjusting the size of the chamber as needed. When T (temperature) and p (pressure) are at specific values and the system has reached a condition where nothing changes, the system is said to be in ***equilibrium***. "The same" temperature pervades the system as does "the same" pressure. As a matter of fact, the "same" results will be observed whenever T and p are set to the same specific values, e.g., the respective quantities of vapor and liquid (30% vapor and 70% liquid, say). The fact that "the same" results are observed when T and p are set the same is a result of the choice of system and of the Idealization. Such thermodynamic systems have no memory.

28. As a matter of fact, under the equilibrium conditions described, for any temperature there is, at most, one pressure for which both liquid and vapor will be present. For example, at 100 °C or 212 °F, liquid and vapor will co-exist at a pressure of one atmosphere. Some temperatures, e.g. 1000 °F, are so hot that it is impossible to produce liquid no matter how high the pressure. The ***critical point*** is reached at the highest temperature at which liquid can be produced. Or, rather, a temperature just ***incrementally*** above that highest temperature for production of a liquid. This is the ***critical temperature, T_c***, found in company with the critical

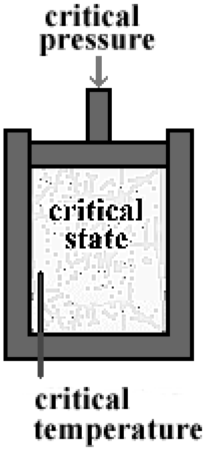
pressure, p_c.

29. Here's how a standard text shows and describes the critical point of the liquid water-steam system. W. J. Kearton, *Steam Turbine Theory and Practice* (5th ed. 1948) at p. 18 and Fig. 9:



"The relationship between temperature and vapour pressure continues up to a temperature known as the *critical temperature*, which is defined in the following manner. At all temperatures above the critical, it is impossible to liquefy water vapour by pressure, no matter how great the pressure employed. The critical temperature of water is 374.1 °C or 705.4 °F. As the temperature approaches the critical, the vapour pressure also approaches a definite pressure known as the *critical pressure*. The critical pressure of steam is about 3210 lb. sq. in. abs. Fig. 9 shows the variation of vapour pressure up to the critical point."

30. As described by the original experimenter Andrews in the 1860's, in a system using carbon dioxide, on reaching the T_c of about 31 °C, the surface between liquid and gas disappeared. "The space was then occupied by a homegeneous fluid, which exhibited ... a peculiar appearance of a moving or flickering striae throughout its entire mass." Quoted in Domb at 97. "Striae" apparently refer to channel-like variations or bands. The adjacent image is poorly representative.



The visual phenomena, called ***critical opalesence***, is dramatized by appropriate lighting in lecture demonstrations. "It is indeed striking to observe a colourless transparent fluid suddenly becoming opaque and changing colour in a narrow band of temperatures around T_c. As the temperature is lowered, the fluid splits into colourless liquid and gas with a meniscus separating them." Domb, at 97.

31. What is most significant here is that a ***tiny change in temperature*** can drive a far-reaching phase transition. Since we will be looking at "tiny changes," I will introduce a symbol "δ" for a tiny change. For example, $T = T_c - \delta T$ means "a temperature that is just a tiny bit less than T_c." The previous paragraph states the essence of ***Phasic Cycling***, discussed in detail as Feature Two. At $T = T_c$, the system is weirdly disordered. At $T = T_c - \delta T$, the system is ordered. The system can be cycled between the two states with little difficulty, just a "tiny change" in temperature. The show is interesting for water that displays critical opalescence and perhaps even more interesting for Neuronal Groups where, upon "cooling," the system resolves into one phase out of many possible phases contained in a phase structure.

32. Phenomena similar to that of steam and carbon dioxide are displayed by natural magnets and certain metal alloys. Magnets lose their distinctive power when heated in a furnace. In 1895, Pierre Curie noted correspondences between critical point phenomena in magnets and fluids. "Even though the classical equations of state of fluids and magnets are very different ... the pattern of critical behavior is the same." Domb at 91. Later researchers investigating metal alloys such as brass named their critical temperature "the Curie temperature" in honor of the original borrower. These researchers clarified the "important new concept of long-range order ... a significant distinction is drawn between long-range order and long-range forces. It is stated clearly that short-range forces can give rise to long-range order." Domb at 17. The metal alloy researches were then used for conceptual or mathematical models of magnetism, i.e., the Ising model. Domb at 113. This is universality in action.

33. It is possible to account for critical state behavior by general notions that are independent of the details of the system under consideration. Each unit in a critical point system interacts directly with its nearest neighbors and indirectly with other units more distant. Thus, the activities of any two units are correlated through multiple pathways. The correlation between two units along each of the interaction paths that connects them ***decreases*** exponentially with the length of the path. On the other hand, the number of such interaction paths ***increases*** exponentially with distance between the two units. The relative strength of the two exponential influences, one as opposed to the other, varies with temperature. When the system is "quite

cold," one influence is overwhelmingly dominant and the phases are sharply partitioned; at the other extreme, when the system is "quite hot," the other influence is overwhelmingly dominant and nothing is stable. At the critical point, the two influences exactly balance, and the influence of each unit extends throughout the system strongly affecting every other unit. A disturbance at each point will affect each other point with equal force and reciprocally. Thus, a system at the critical point is characterized by ***correlations of infinite range***. Away from the critical point there is no balance. Much of the foregoing is a paraphrase of language in H. E. Stanley, *Scaling, universality, and renormalization: Three pillars of modern critical phenomena*, Rev.Mod.Phys. **71**, No. 2, Centenary 1999, S358-S366 at S365.

Another way of saying this is, that, at the critical point, the ordering principle of "nearest neighbor" is lost and, without this chief source of order, order becomes impossible. In fanciful analogy, even in a hall of mirrors it may be possible to find one's way because of variations in the sizes of images; those images formed by multiple reflection grow progressively smaller by some percentage, x%. From the viewer's perspective, the smaller images are more distant. As the fanciful temperature increases, however, x declines toward 0 and the distant images grow relatively larger until, at the critical point, x reaches 0 and all the images merge. There is no way to distinguish a nearest neighbor image or particle from an image or particle more distant. The spatial measure is lost. Everything becomes incorrigibly confused.

34. In this essay, I extend the foregoing images of critical state activity in thermodynamic systems to describe an Idealized system of Neurons organized in Neuronal Groups that are organized, in turn, in Assemblies of Neuronal Groups. Consider substituting "Neuron" for "unit" in the preceding paragraph. In the physics models, the nearest neighbors are particles that interact through an energy potential and/or a "Hamiltonian" mathematical function. In Neuronal models, nearest-neighbor Neurons interact through Axonic Projections where one Neuron transmits Virtual Energy to its neighbor; and there are Axonic Projections in each direction.

In physics models, the interaction between units is stated in static terms. For liquids and metals, the interaction between two particles is assumed to be in the form of a "potential energy" formulation that depends only on the distance between the two particles and the physics provides models of the results even when the exact form of the dependency is not known. For the mathematical magnetic models, the interaction is defined in terms of "up" and "down" states and by the differing amounts of energy stored in various combinations of nearest-neighbor configurations.

In the thermal model of brains, the interaction is stated in terms of ***equilibrated activities***. Neurons are active and their activity is qualitatively more complex than that of static units. To preview a part of the model discussed in detail below, I suppose, when generally considering the activities of biological neurons, that when two neurons are adjacent in a neuronal group and all the neurons in the group are "the same," a higher level of activity in one neuron will induce a higher level of activity in the adjoining neuron and vice-versa. If left undisturbed by external influences, activity in the group will tend to level out at a maximum aggregate level that is supported by a flow of real energy being supplied to the neuronal group by continuous blood flow that provides sugar. I suppose that the chief activity is directed transmission of aggregated neuronal pulsations from one neuronal group to another; this is modeled in Idealized Brains by circulating pulse-waves of Virtual Energy. The real interaction is dynamic and more complicated than a static form but the definition is usefully constrained by the static forms. These are Idealized requirements of "undisturbed by external influences," "leveling out" and "continuity" (collectively, "equilibrated"). These requirements are not much satisfied in nature but provide a useful starting point because of the clarity achieved thereby. Then deviations can be investigated, beginning with deviations that are incremental, coordinated and progressive.

B. Phasic Cycling

35. Computerized images of mathematical models provide an insight into what is occurring in the systems studied by physics. Below the critical temperature, phases are clearly defined. There are occasional, highly localized phase transitions generated by random heat fluctuations but these quickly disappear. It's like a little bubble of steam rising from the bottom of a hot pan of water that is quickly absorbed by the cooler surrounding liquid. The aggregate volume of little bubbles in the system remains constant but they flicker into existence here and there, typically in a random fashion. Above the critical temperature there is only swirling noise, like superheated steam. Just at the critical temperature a different image appears: clumping that is more than transient, less than enduring and that forms indeterminate partial coherences where fragments coalesce and drift apart and in which all sorts of waves are moving in all sorts of ways. In an 1869 lecture, Andrews, the original researcher declared that "if any one should ask whether it is now in a gaseous or liquid state, the question does not, I believe, admit of a positive reply." (Quoted in Domb at 10.)

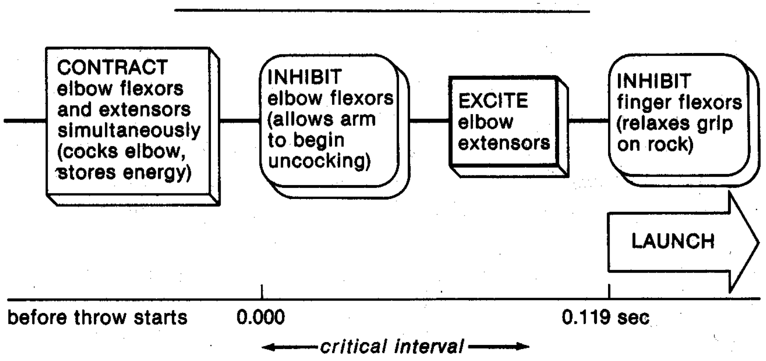
36. There is no structure inside a thermodynamic system at the critical point. Even more seriously, no structure can be maintained; if a structure, a waterdrop say, were to be inserted into the system and the system kept at the critical point, the structure would dissolve into indeterminate transient coherences and lose all existence. The critical point is the point of universal meltdown. However, when the aggregated activity is reduced just slightly, by a tiny cooling in temperature, structure may appears in the form of partitioned phases in a phase structure, e.g., a pool of water separated by a surface from steam. In the thermal model of brains, ***selection*** can occur at this point, that is, selection among the phases in a phase structure. The thermal model states ***that*** a selection occurs without stating ***which*** phase is selected.

37. Extending such imagery to the biological domain, I suggest that, at the critical point, activity in a neuronal group is highly disordered. There is nothing that is going on in the thermal model that has informational content. Informational content does, however, can emerge when the activity is slightly reduced.

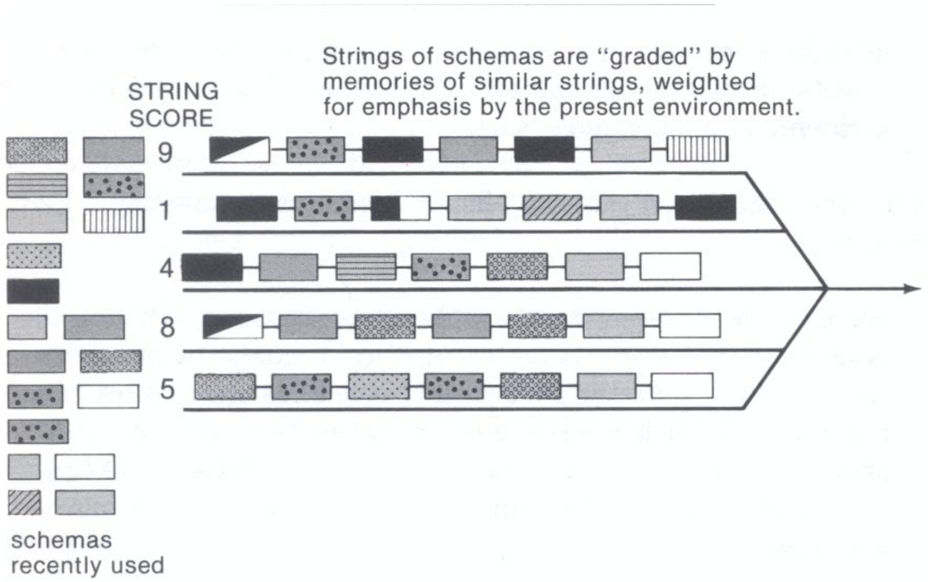
38. In the Thermal Model, activity of intelligence is episodic rather than continuous and a major form of such activity is assembling of modules. I presume ***modularity*** and assembling of modules in both the psychological domain and the biological domain. Ideally, modularity means that a system is made up of units where chief activity of a unit remains "the same" at all times while the units are re-organized for diverse purposes and under diverse circumstances. This modularity includes the presumption that modularity in the psychological

domain has ascertainable relationships to modularity in the biological domain; that is, that particular units in one domain have categorizable relationships with particular units in another domain, such as relationships categorizable by origin, by natural property and/or by construction, and that particular organizations of units in different domains are similarly related. Modularity is generally presumed by those attempting to model mind-brain interactivity and I use modularity to shape the model in mathematical ways without suggesting that mathematical ways are appropriate to model all activities of brains. This essay focuses on those activities of brains occurring under those circumstance that are ***most suitable*** for mathematical treatment and these are ***Idealized*** activities. Modularity and an Idealized model support each other.

39. For example, as illustrated in the images below, Calvin has a modular view of mental activity that includes, at the base, detailed sequencing of “modular motor commands” (first image) and that then extends to a metaphoric model (second image) based on a “candelabrum-shaped railroad marshaling yard” with converging “tracks” where mental activity is analogized to constructing and selecting among “trains of thought” and where “there is surely a lot of activity going on there, because they are shuffling and mutating, trying new schemas for both sensory templates and movement programs, creating new sequences.” (W. Calvin, *Cerebral Symphony* (1990), figures and text at 248 and 262-263.)



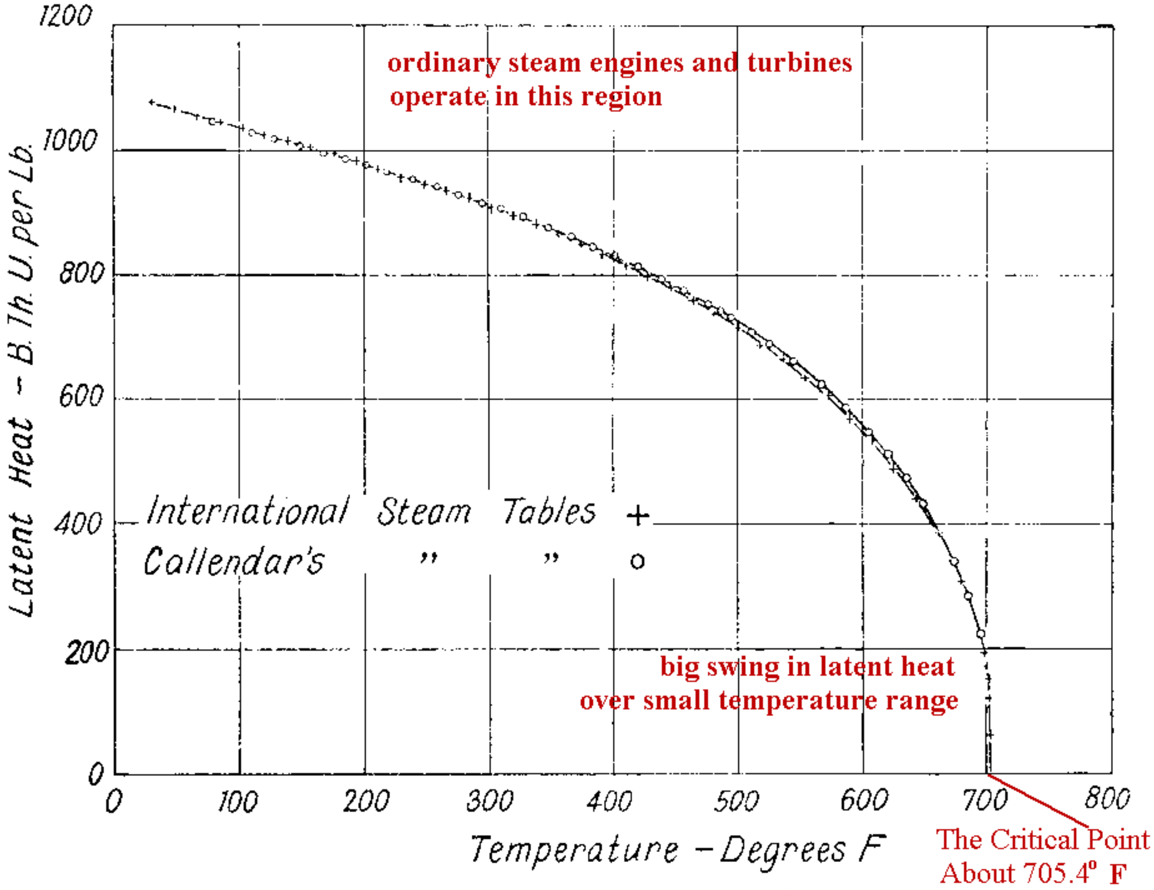
Modular motor commands, strung together to plan throw.



40. There are large classes of activities that can be described by modular units, including all keyboard performances and that run a span, at the least, from children's toys to computer programming to governmental bureaucracies. These activities all share common features that Calvin's railway metaphor highlights. For the Thermal Model, the most interesting features revolve around the ***hooks*** between the railway cars. Metaphorically, the hooks between railway cars identify a major question about brains.

41. Hooks between railway cars have two functions that oppose each other and that must be balanced. First, a hook ***fixes*** one car to another. Second, a hook allows for ***assembling and disassembling trains*** of cars. A heavy hook with a tight-fitting connection is best for permanent fixation, the kind of permanent fixation that will maintain the connection despite twisting and banging on a long journey. For quick assembling and disassembling, on the other hand, the hook should be light and with a loose connection that is easy to slip. In contrast to heavy, tight, fixed hooks good for stressful journeys, hooks good for the inner railway yard are light and highly mobile.

42. Critical point principles show how a hook can vary between heavy/tight and light/mobile. At the critical point, liquid water and steam are indistinguishable and merge into a unique state, a kind of indeterminate goopiness where surface tension is zero and blobs of all sizes emerge, merge and dissolve incessantly. Another way of saying this is that, at the critical point, "no energy" is required to change liquid water into steam (or vice-versa) or that the "Latent Heat of Vaporization" is 0. The following diagram from W. J. Kearton, *Steam Turbine Theory and Practice* (5th ed. 1948) (comments in red added) shows this central feature for the system formed by liquid water and steam. It is factual (and appears similarly factual for all critical point systems) that, as the system approaches the critical point from a lower temperature, the "Latent Heat of Vaporization" falls very rapidly from a high figure. I am suggesting that something like the "Latent Heat of Vaporization" (or, better, the Gibbs Free Energy difference required for a phase transition) is the "hook" for connecting activity patterns involving neuronal groups. With just a small upward swing in temperature, so the metaphor goes, the hook can shrink from huge to tiny, allowing for easy connecting and disconnecting of the units, before the temperature drops a bit and the connections become fixed. I suggest that repeated upward and downward swings of temperature in the region just below the critical point constitutes ***phasic cycling***, where phases are merged, then separated anew, then merged again.

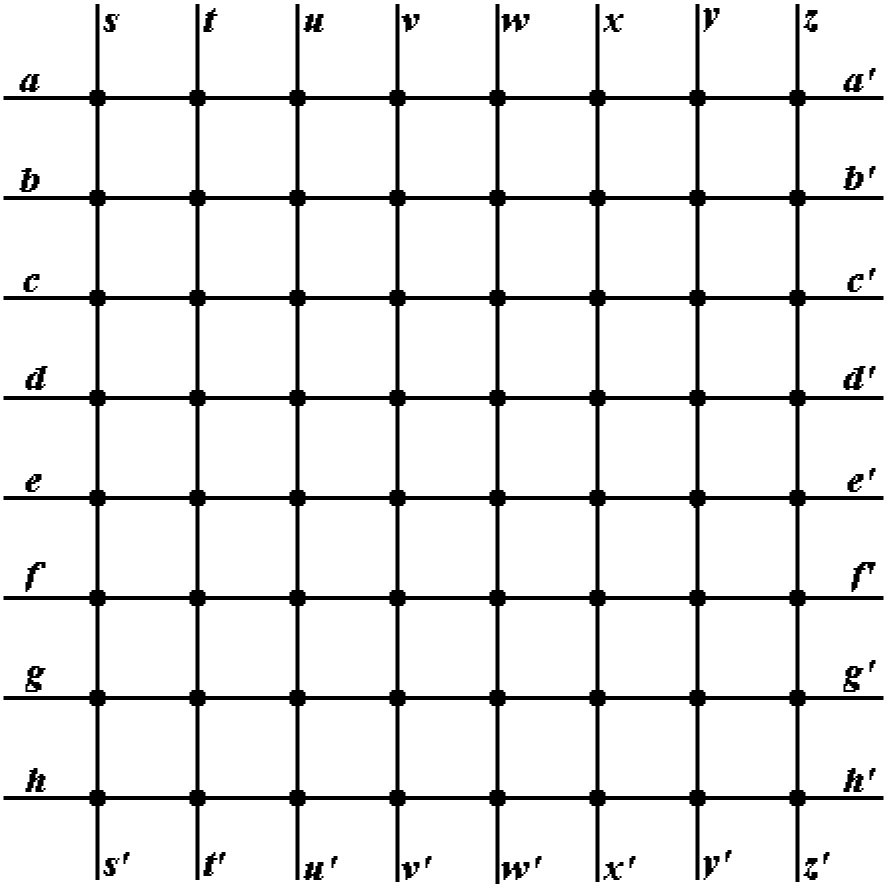


ordinary steam engines and turbines operate in this region

big swing in latent heat over small temperature range

The Critical Point
About 705.4° **F**

FIG. 11. --Latent Heat of Vaporization



Idealized Field of Neuronal Groups - no activity

43. The foregoing critical point features are embodied in a conceptual construction that is developed into a Structural Engine. To start off the construction, suppose we have an "Idealized" Field of Neuronal Groups as indicated in the diagram above that constitutes a module of Idealized Brains. The diagram indicates 64 Neuronal Groups each linked to nearest neighbors, 4 nearest neighbors in the interior, 3 nearest neighbors at an edge and 2 nearest neighbors at a corner, subject to "matching" unprimed and primed links and possible "inputs" or "outputs" vis-a-vis other modules of Idealized Brains. A particular device model based on this design will specify the size of the Field (m rows by n columns), essential properties of the Neuronal Groups, the essential properties of the links, the "matching" if any of primed and unprimed edges, the nature of any inputs or outputs and the resulting activities of the assembly. ("Inputs" and "outputs" are rudimentary references to a more developed model where there are pulses and waves of Virtual Free Energy.) A device model also specifies the nature of a Neuronal Group, namely, that the Neuronal Group is constituted by Neurons in a pattern that replicates the pattern of the Field of Neuronal Groups but at a lower level. (Alternatively, the organization of Neuronal Groups in an assembly of Neuronal Groups replicates, at a higher level, the organization of Neurons in a Neuronal Group.) In this essay, the focus is on the activities of Neuronal Groups among themselves and the only important properties of Neurons are those that support activity of Neuronal Groups.

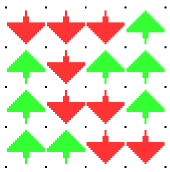
44. In an Idealized Field of Neuronal Groups, each Neuronal Group is “the same,” sometimes said to be “identical.” This means that all have the same essential properties and operating principles. However, each Neuronal Group has certain “values” that are variable and the changing value depends on the situations and activities in which the Neuronal Group is involved. Hence, two “identical” Neuronal Groups, side-by-side, can have different “values.” In the constructed devices, the most important varying value is “Virtual Free Energy Flow.” Although Virtual Free Energy Flow is based on the thermodynamics of Gibbs Free Energy, there are adaptive manipulations.

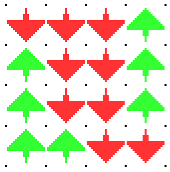
45. A Neuronal Group in the device domain is supposed to model the activity of a neuronal group in the biological domain. According to Edelman, *Neural Darwinism: The Theory of Neuronal Group Selection* (1987) at 4-5: “the brain is dynamically organized into cellular populations ... The units of selection are collections of hundreds to thousands of strongly interconnected neurons, called neuronal groups, and accordingly these act as functional units.” During development in gestation, there are “structurally variant neuronal groups” that are organized into “primary repertoires.” As a result of life and experience, various neuronal groups become organized into “secondary repertoires consisting of functioning groups that are more likely to be used in future behavior. Neurons in neuronal groups are populations, and populations form higher-order populations.” I suggest that these principles can be realized in an Idealized way in the Thermal Model.

In the Thermal Model, the link that connects two adjacent Neuronal Groups is a conceptual construct that is like a two-lane highway for Virtual Energy transfer. Call the lanes, ***semilinks***. Each semilink carries Virtual Free Energy from one Neuronal Group to another. Virtual Free Energy is in the form of pulses and waves. (According to the Thermal Model, we are most conscious of Big Swings in Virtual Free Energy flows.)

46. We have an image in the biological domain of neuronal groups exchanging signals in a fashion similar to that described above for the links and semilinks in the device domain. In the biological domain, such linkages appear to be included in what Edelman calls ***maps*** (*Neuronal Darwinism* at pp. 163 *et. seq.*). In brief, bundled axons (nerve fibers) rooted in one neuronal group are anatomically projected and make contact in a “cabled” way with another neuronal group. Virtual Free Energy Flow represents in the device domain the aggregate of the signaling between neuronal groups in the biological domain.

47. Another point of attachment is a conceptual system of ***mathematical magnets*** that is called ***the Ising problem*** and that is especially useful here. In the simplest Ising problem, magnets are arranged in a square ***quadratic*** pattern. This is “the same” form used for Fields of Idealized Brains and the similarities support borrowing. In the Ising problem, each magnet can be oriented up or down. Each magnet interacts only with its four nearest-neighbors on adjacent rows in columns.





A quantity of energy is required to change a nearest-neighbor relationship from "two magnets in the same orientation" to "two magnets in different orientations." This means that when two magnets are in different orientations, there is a likelihood that one will flip that is higher than if they are in the same orientation; and this relatively higher likelihood is true at all temperatures. Of course, no flip takes place in isolation and one random flip in a field of magnets will have effects on other magnets. What changes at the critical temperature is that the power of the magnets to "hold together" is no longer enough to withstand the erosive forces of thermal activity and the "organized magnetic field" falls apart.

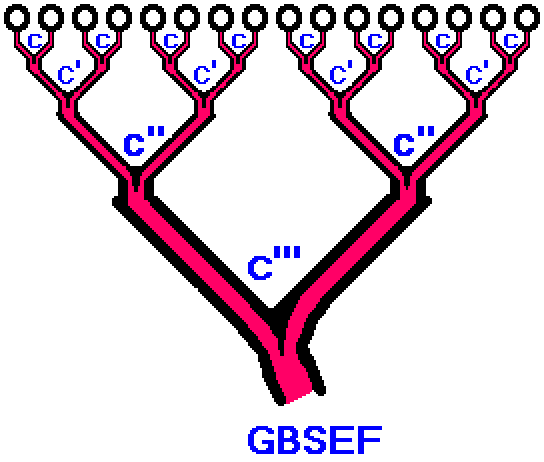
48. Flipping is easy when little Free Energy is required but becomes hard if much Free Energy is required. The amount of Free Energy required is affected by the temperature, a quantity that affects all magnets "the same." The shape of the "Free Energy required" curve looks something like that for steam but there are differences that the physics accounts for. A zero quantity of "Free Energy required" occurs by definition at the critical point and the slope just above the critical point is very steep.

49. To clarify the model using the Idealized Field of Neuronal Groups, it is possible to avoid edge effects by matching `a` with `a'` and so forth until completion by matching `z` with `z'`. "Matching" means that the Neuronal Groups on a link line go around in a circle: `h` is next to `a` just like `c` is next to `d`, around and around. "Matching" all sixteen loose-hanging links in the Field gets rid of all the loose ends. The resulting architecture is "toroidal." Structural Engines are built around cyclical activity in toroids. It is as if the Neuronal Groups were spread out on the surface of a doughnut. Then there are no edge effects.

50. Now think of the Neuronal Groups on a toroid as exchanging energy. Because of all the Idealized conditions, there is an averaged uniformity to the energy exchanges. There are also important energy patterns, that I will identify as Circulating Virtual Free Energy Flow Patterns, that deviate from uniformity; but start off with the idea that all the links are charged with Virtual Free Energy Flow and that Virtual Free Energy is flowing in stable patterns, even if unequally. The Virtual Free Energy Flow is governed by conservation laws: in the crudest form, the aggregated amount of Virtual Free Energy Flow in the system is constant and the average amount of Virtual Free Energy Flow through a Neuronal Group is 0 (what Energy comes in also goes out and nothing goes out that did not come in, on the average) . Now consider what would happen if there were a small change in Virtual Energy Flow through a certain Neuronal Group q. Necessarily, there would have to be a corresponding change in the neighboring Neuronal Groups. Now here's how thermodynamics works: because of underlying constraints, e.g., equilibrium, if more Virtual Free Energy is flowing through Neuronal Group q, it has to come from somewhere else, and the only candidates are the nearest-neighbors. They will have to look elsewhere for compensation. Eventually, the small change is distributed equally through all the Neuronal Groups.

51. These notions about Virtual Free Energy Flow can be grounded in concepts drawn from the biological domain. Energy in brains is dependent on a supply of glucose that is modeled in the device domain as Blood Sugar Energy Flow. Blood Sugar Energy Flow is distributed to Neuronal Groups through Sugar Arbors as in the diagram below. In a fully Idealized system as presented here, the Global Blood Sugar Energy Flow Constraint is a constant on average and the settings on the various “c” constraints are all 50/50 on average. By constraint and uniform nature, each Neuronal Group receives the same Blood Sugar Energy Flow on average.

An "Ideal Brain"
Organelle of 16 Neuronal Groups
and constrained blood flow



8 c constraints
4 c' constraints
2 c'' constraints
1 c''' constraint
1 GBSEF constraint
16 Neuronal Groups

52. In the model, what happens in the Blood Sugar Energy Flow is at the lowest level of activity and other Energy Flows are derived from Blood Sugar Energy Flow. The Blood Sugar Energy Flow is constant on average but is subject to variations, Blood Sugar Energy Flow Fluctuations, that are limited in size and duration and that average out to zero. The Thermal Model incorporates three different ***time scales*** and activities involving Blood Sugar occur at the ***slowest time scale***. In other words, Blood Sugar Energy Flow remains relatively constant, even during a fluctuation, in comparison with other Energies where fluctuations are more rapidly generated and more rapidly disappear. In fact, things happen so slowly on the scale of Blood Sugar Energy Flow that we can almost forget it’s going on here.

53. Blood Sugar Energy Flow is chiefly important because it is the basis for Virtual Energy Flow. In order to state the basis, however, we need to have the device operating at the

critical point. In other words, the Blood Sugar Energy Flow is “set” so the device is operating at the Critical Point as a default. The Critical Point is the Zero Temperature for Idealized Brains. All modules of Idealized Brains are designed to reach “the same” Zero Temperature together. All temperatures of interest are Below Zero. (This is a clumsy feature but attempts to fix it only make it worse. There is an underlying logic that should eventually become clear.)