Quad Nets: Material Foundations for Thermal Device Models of Brains

ABSTRACT

Quad Net tiles

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Wave phases in a TQN

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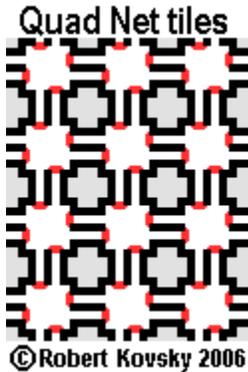
A Quad Net (QN) is a proposed physical material made up of interconnecting tiles. A pulsing elemental device occupies each tile and interacts through junctions with its neighbors. Pieces of QN material can be worked into device parts, e.g., a Toroidal Quad Net or TQN that maintains circulating waves of pulses. QN device parts are joined together to make up assemblies of increasing sizes in which various pulse patterns ("phases") are maintained.
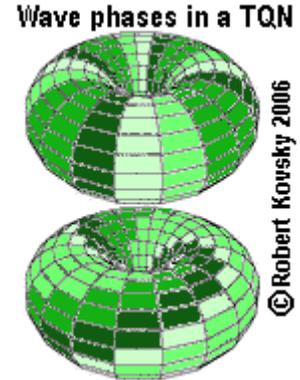
During operations, a QN device part cyclically falls into silence, then re-activates, selecting an actual phase from possible phases and maintaining the selected phase as the cycle proceeds. Phase selections are coordinated within assemblies of device parts; and phases are nested within larger phases. In imitation of neuronal signals in brains, some phases ("objects") organize sensations and other phases ("acts") drive muscles. Cyclically selected patterns of pulses in assemblies of QN device parts are models of sensory-motor activities in brains of animals.

In modeling brains, an elemental device mimics a neuron and a Quad Net is an abstract version of a sheet of interacting neurons. Tiled assemblies of QN device parts have an idealized correspondence to arrays of "architectonic modules" that neuroscientists (Arbib *et. al.*) observe in brains. During operations, QN device parts produce pulse bundles that suggest biological nerve signals driving muscles. There are structural and functional parallels to Edelman's Theory of Neuronal Group Selection; and a central principle of the QN model – proposed Shimmering Sensitivity – resembles Edelman's "reentry" in nature and reach.

QN device operations are described by thermodynamics based on researches by physical scientists into phase changes in natural and engineered systems of diverse kinds, such as water/steam, magnets, metal alloys and liquid crystals. Each system supports multiple distinct aggregate forms ("phases") and each has a "Critical Point" – defined by specific conditions such as a "Critical Temperature" – at which phases easily change into one another, back and forth, through reversible phase transformations. At the Critical Point, phases co-exist (suggesting QN Shimmering) and selection of phases can depend on tiny influences (suggesting QN Sensitivity). Quad Nets embody these principles in devices; and a sheet of Quad Net tiles is an activated cousin of the Ising Model, the tiled mathematical model of Critical Point magnetism.

Proposed large-scale constructions are engineered organisms with animal-like activities. A sensory-motor psychology is based on QN device operations. A construction path looks to Piaget's studies of developing intelligence in children. Basal activities are grounded in sensory-motor coordination and habitual repetition – activity tiling. Operating from this base, a device cyclically selects from among possible phases and realizes one phase. Each phase combines objects and acts; and the combinations are QN form of deeds, e.g., moves in a game of checkers.

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Advice for the reader: Images are the chief vehicle for the presentation and are available for separate viewing, preferably undertaken before reading the text. The main construction path in § 2 begins with Primal Quad Net (Image 7) and culminates in the Phase Transfer Controller (Images 30 through 35). The QN system of specifications and activations is developed through Images in § 4. Computers provide superior views of Images, with variable scales of magnification, in contrast to Images printed on paper.

List of Images

§ 1.   Survey of the Quad Net Model

a.   Quad Nets are tiled constructions in space and time

A Quad Net is a proposed physical material with engineered properties, like an alloy or a semiconductor. A chief distinction is that a Quad Net is an activated material made up of pulsing elemental devices, in contrast to the atoms that occupy sites in traditional materials.

Image 1 shows interior views of a Quad Net (QN). The spatial array of elements in Image 1.a resembles a two-dimensional version of atoms in a silicon crystal or grain of iron (Kittel). An elemental device is installed in each spatial element, perhaps looking like a computer chip. Each elemental device interacts with 4 nearest neighbors through reciprocal junctions shown in red, resulting in collective activity, such as the wave shown in Image 1.b.

Image 1: QN, an activated material

a. spatial array   b. activated QN
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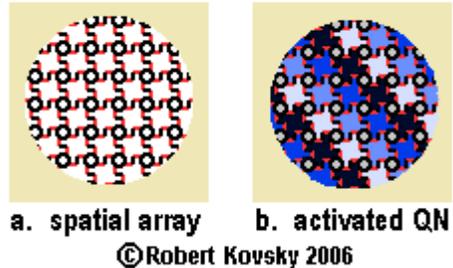
Activities are forms of content in Quad Net constructions, in contrast to "states" used in models of traditional materials. QN activities depend on settings of device specifications that are like settings of channel and volume controls on a radio (§ 4).   Although principles of activity are different, the wave in Image 1.b resembles a sound wave in metallic crystals that is modeled in terms of electrostatic forces and momentary distances between electrical charges (Kittel, 143).

The primal activity of an elemental device is **pulsing** as shown in Image 2: a series of discharges with a period of time, τ_φ, between any two successive discharges. A discharge occurs at a pulse moment, idealized as instantaneous.   The period τ_φ is variable and there are settings of specifications where the period is indefinitely long, a condition of **silence**.

Image 2: Activity of the primal pulser

pulse moments

τ_φ Time   ©Robert Kovsky 2006
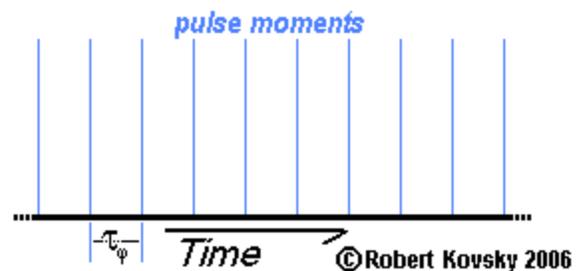
A discharge in one elemental device produces an **interaction** that may cause the next discharge in a nearest-neighbor to be triggered or speeded up (excitation) or, alternatively, to be blocked or slowed down (inhibition). Because of interactions, and as controlled by settings of specifications, discharges in Quad Net devices occur collectively in distinct ordered ways called **phases**, e.g., the wave phase shown in Image 1.b. Many phases are presumed to be driven by influences that are not shown; e.g., the wave phase in Image 1.b is driven by an **engineer** who sets specifications and controls activities in specific ways. In higher-level designs, device parts drive one another in various ways and some drivers are also responsive to the environment.

As the images show, the QN model begins with **tiling** of space, time and phasic activity: a germinal unit is replicated; and interconnecting units match up edge-to-edge to occupy a domain. Idealized tiling – uniform and unbounded – is the primal origin of QN constructions. Closures, modifications and assemblies then lead to additional possibilities and extensive development.

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b.   Spatial organization of Quad Net devices

As shown in Image 3, a full-fledged Quad Net device construction would have five general levels or scales of spatial organization.

(1) A Thermal Device stands at the largest scale, imitating the nervous system of an animal and operating an engineered organism like a puppeteer operates a marionette.   The engineer constructs the Thermal Device and acts as the master puppeteer.

A Thermal Device is made up of (2) assemblies of (3) device parts. "Assemblies" includes nested "subassemblies" and other useful hookups that may be devised. A chief form of assembly is a circularity, a ring of device parts connected to each other in a series.

An operating device part is identified by its *repertoire* – the collection of distinct and specific phasic activities the device part can maintain. A device part is constructed from (4) one or more pieces of Quad Net material. E.g., the simple Cylindrical Quad Net (CQN) shown here carrying a pulse bundle is constructed from a piece of Flat Quad Net.   (5) The elemental devices in the Quad Net operate at the smallest scale of spatial organization.

Image 3: Spatial organization of QN devices

An engineered organism

Large-scale Thermal Device assembled from device parts

circularity subassembly shown as if "dissected" from large-scale assembly

Cylindrical Quad Net (CQN) - device part detached from circularity, "cut open" and spread out for viewing

an elemental device

piece of Flat Quad Net

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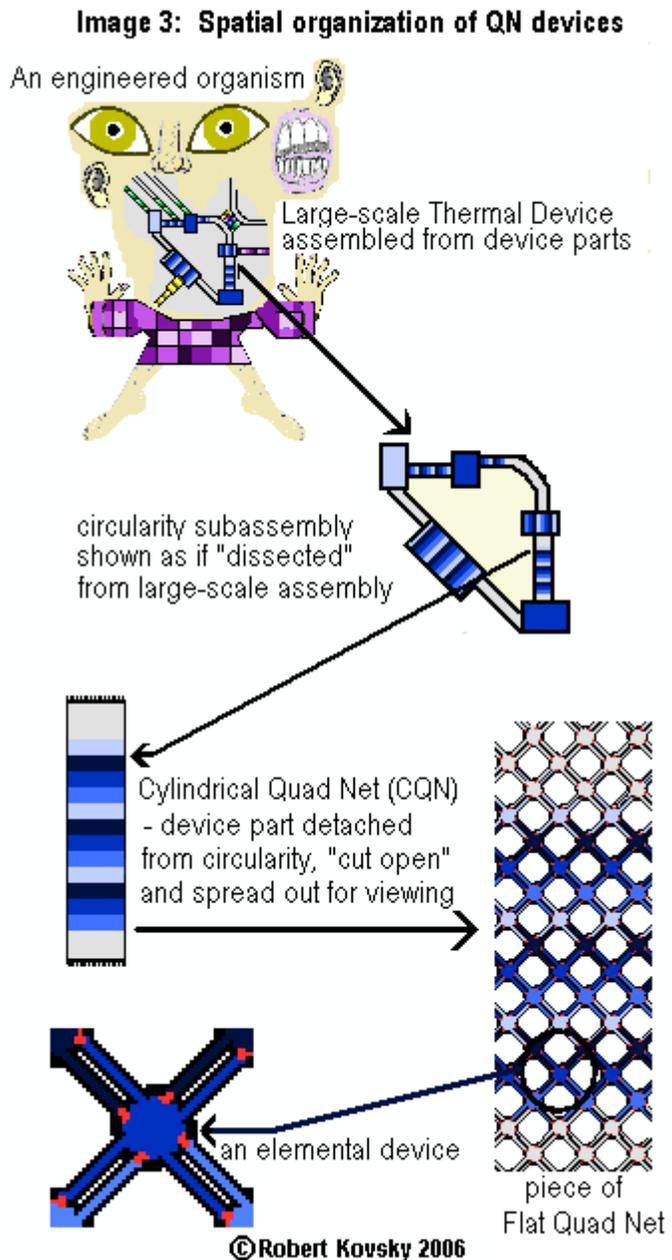
Quad Net devices is the most general class that includes Thermal Devices, assemblies and subassemblies of device parts, device parts, pieces of Quad Net and/or elemental devices and all combinations of or constructions using such items. Principles of pervasive similarity (§ 2.h) mean that various devices operate under a common set of principles regardless of size or level and regardless of the details of internal structure or external organization.

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c.   Tilings are nested to control pulse patterns

QN activity typically takes the form of ***pulse bundles***, e.g., in the CQN in Image 3. An exemplar in Image 4.a shows uniform pulsing activity alternating with silence (operating details in § 4.f). The control parameter ε in Image 4 acts like a temperature that controls freezing and melting. But QN devices operate independently of any hot or cold temperature shown on a thermometer.

Image 4   Temporal organization of pulses
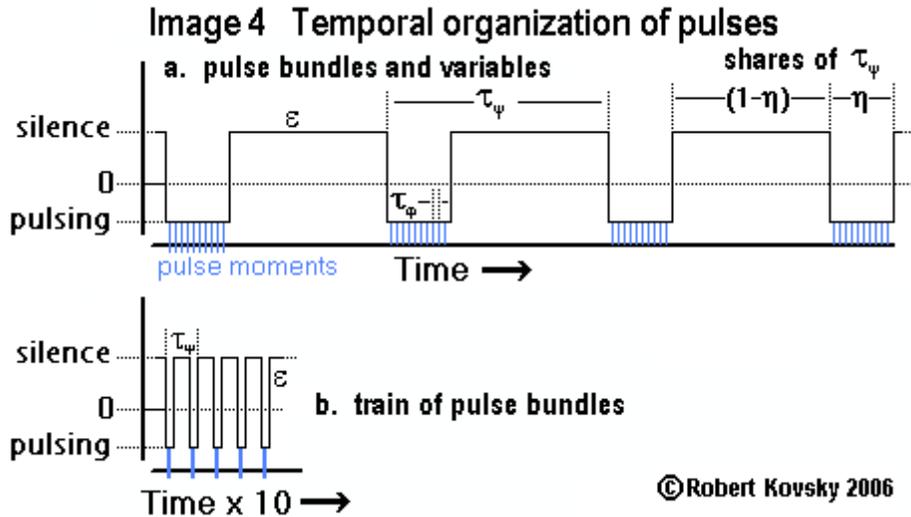
In a large-scale engineered organism, pulse bundles drive ***motor units*** that deliver force impulses to the environment, adjustable through τ_φ, τ_ψ and η.   In organization and function, a pulse bundle resembles a burst of action potentials in nerves driving muscles and the result is like a muscle twitch of a specified duration and force (See Kandel *et. al.*, 553-556, 614-615, 672). The activity is similar to that of the jellyfish where a "nerve-net of simple cells is adequate for all its needs, the same convulsive message being repeated over and over again, simultaneously between all centres: push, push, push!" (Walter, 18).   Activities of QN devices and biological organisms may be similar, but underlying designs have substantial differences; e.g., primitive jellyfish apparently began with random nets of neurons that evolved through organizational variations (Satterlie) rather than with the idealized constructions of Quad Nets.

In Image 4.b, pulse bundles appear in a regular sequence, making up a ***train of pulse bundles***. Such a train is temporally tiled, where the temporal tile has period τ_ψ. There is temporal ***tiling within a tiling*** or ***nested tilings*** in time. Perhaps the motor activity resembles that of a finger repeatedly typing "c - c - c - c" on a computer keyboard with a certain force. A nested tiling in time means ***cycles within a cycle***; and there can be multiple levels of nesting. At the next higher level, perhaps several fingers type a more complex tiling: "c-a-t-(space)-c-a-t-(space)-c-a-t..."

Organized QN activity has a general ***pulsational form***: activity alternating with silence. This form defines a course of development that begins with simple pulses and that constructs more complex forms from the simple pulses, including complex forms that produce smooth action. The pulsational form appears on multiple scales of space and time. On the scale of an organism, activity resembles that of a person playing ping-pong and hitting the ball with distinct strokes.

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Temporal "tilings within tilings" have spatial counterparts, e.g., the hierarchy of Quad Nets shown in Image 5. Two separate and independent Quad Nets are connected, where one is finer (black walls and red junctions shown in Image 5.a) and the other coarser (blue walls and yellow junctions in Image 5.b). The terms come in a pair: "finer" of one is with respect to the other's "coarser"–and vice-versa.

To provide a clearer view, some connections in the finer QN are deformed by stretching (see § 2.b). Then, each coarser elemental device is connected to nine elemental devices in the finer Quad Net through one-way orange junctions, producing hierarchical units shown in Image 5.c. An enhanced and magnified view of the connections is shown in Image 5.d. The junctions are in 3 distinct classes – identified by red, orange and yellow – each with variable settings of specifications.

Image 5: Hierarchy of Quad Nets

a. finer QN   b. coarser QN

c. after deformation and connection

d. connections (x 2)

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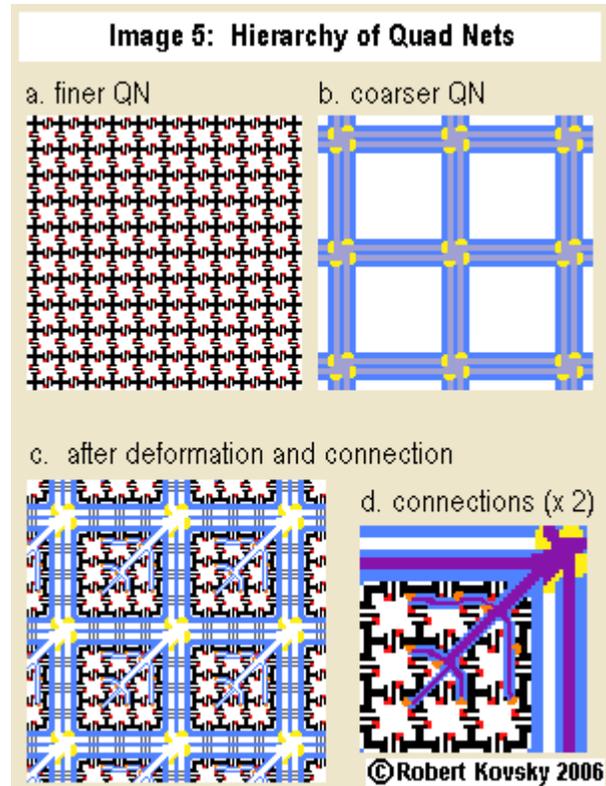
It is useful to imagine three dimensions and a vertical displacement between the QNs, like an elevated railway above a grid of streets. Further, the blue/yellow QN can be finer with respect to an even coarser Quad Net: like temporal pulse trains, spatial hierarchies can be nested in levels.

Image 6 shows tiled activity where nested temporal pulse patterns inhabit a spatial hierarchy. A "slow-paced" purple wave (τ_ψ) in the coarser QN drives and defines "fast-paced" green pulse bundles (τ_φ) in the finer QN. Operational details are in § 4.f.

Image 6: Bundled waves in a hierarchy of Quad Nets   ©Robert Kovsky 2006

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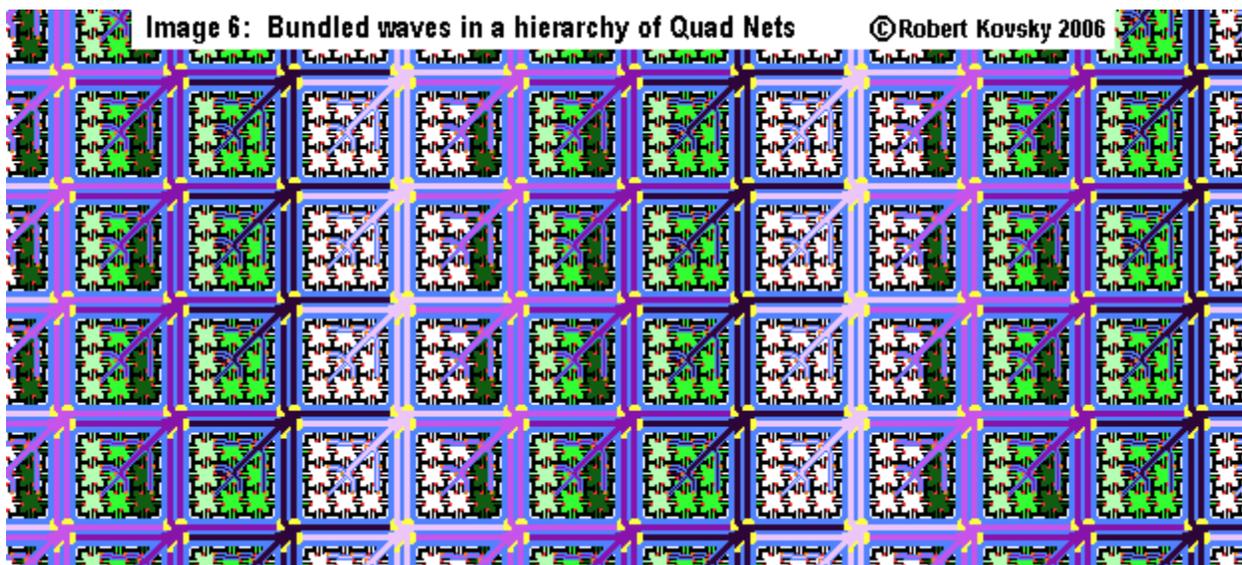
d.   Periodic and collective pulse patterns or "phases" in QN device parts

Factually, many a physical material takes on distinct aggregate forms – called **phases** – that can be changed into one another through heat treatment, e.g., *solid* ice, *liquid* water, and the *gas*, steam. Metallurgists use the concept of phase to describe how an alloy can have different properties depending on thermal history (Porter & Easterling). For example, two distinct kinds of steel are "martensite" and "bainite."   A metallurgist can put identical mixtures of materials into two crucibles, start them at a single high temperature and produce the two different steels by **quenching** the two bodies of material in different ways.

Operations in Quad Net devices are cyclically productive of patterns of collectively organized pulses, which are QN phases. E.g., in Image 4, each time the temperature-like parameter ε passes downward through 0, the device produces a pulse bundle with a distinct τ_φ. The chief such phases are waves, oscillations (like waves but without direction) and circulations in operating circularities like that shown in Image 3. The phase concept also extends to pulsing of an elemental device (Image 2), where the period of the pulsing extends to infinity and silence.

Quad Net devices operate like the metallurgist's laboratory, the potter's kiln or the cook's oven. The engineer uses Quad Net devices to produce phases like cooks use ovens to produce meals. In other words, suggests the Quad Net model, **we cook up our perceptions, objects, acts and activities**, in contrast, e.g., to arguments that we compute them. Each perceived object, act, etc. is an actual phase realized out of possible phases, like an actual meal (ingredients plus preparation) realized out of possible meals or an actual alloy realized out of possible alloys.

Viewing another aspect, Quad Net devices operate cyclically in ways that resemble cyclical processes operating in heat engines, e.g., an early steam engine that produces a work stroke as steam condenses inside a cooling chamber. Quad Nets are **idealized thermodynamic systems**, like the Ideal Gas, Carnot's Ideal Heat Engine and the Ising Model of magnetism. Features similar to those seen in such systems are adapted to the Quad Net model, guided by an abstract thermodynamics that applies equally to activities as to states (Truesdell, Lecture 1).

A general principle is that a device part can maintain multiple distinct phases but no more than one such phase during the productive part of a cycle. A device part's **repertoire** consists of distinct phases that the device part can maintain, e.g., the repertoire of phases in Image 11. Each cycle, during a Critical Moment, the device part **selects** a phase from its repertoire. When the selecting is over, the phase is fixed for the rest of that cycle. Often the selection is determined by dependencies that lead to selections in a simple way, e.g., the same selection over and over; but sometimes the selection is subject to **tiny influences** or can even be indeterminate (see § 3).

Selection of a phase in a "downstream" device part may depend on a prior selection in an "upstream" device part. Dependencies follow around a circularity. To maintain a circulation, a change in phase in one device part may require changes in phase in several device parts in the circularity. Then, the circulation is itself a different phase. When QN devices perform simultaneous selections within an assembly of device parts, I suggest that the selections can be coordinated in imitation of the **binding principle** that coordinates activities in distinct brain parts that are relatively distant from one other (see § 5).

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e.   Introducing the Critical Point argument

In sum, a Quad Net device part is a tiled construction made up of pulsing elemental devices.   A device part produces patterns of pulses called phases, e.g., bundles of pulses in waves; and it maintains one such phase during each cycle, while cyclically selecting one actual phase from a repertoire of possible phases. The engineer adjusts collective settings of specifications of elemental devices to define the device part's repertoire and to control the selections.

Enter the cycle of a representative device part while there is an existing phase. Then, the existing phase is silenced. Finally, a new phase is generated; and the cycle is repeated with the new phase.   During part of the cycle – the **Critical Moment** – the device part selects the actual phase from possible phases in the device part's repertoire.   That is, for a limited time, the device part can generate **multiple distinct phases as possibilities** and there can be shifting among possibilities in a **reversible** fashion.   One phase easily converts to or "turns into" another phase, and back again.   As shown in Images in § 3, **Shimmering** identifies a condition of co-existing multiple phases, reversibly interconverting, that can occur during a Critical Moment.

As the cycle progresses, one phase is **selected** to become the actual phase and that phase becomes fixed. All other possible phases are thus excluded. The selection may be subject to **influences**, an open class of activities that can include a fixed phase in another device part (e.g., resembling a need or an intention), environmental stimuli and/or a process run by the engineer. When the selection is changed by tiny changes in influences, there is **Sensitivity**. After a Critical Moment, the fixed phase can influence selections in other device parts. Compare the activity to that of a cat moving one foot at a time, while other feet are fixed during each move.

In § 5, principles of physics developed to account for Critical Point Phenomena (CPP) in natural materials are adapted to support proposed Shimmering Sensitivity during Critical Moments in Quad Net devices. The chief principle is that reversible phasic interconversions occur at the Critical Point. The adaptation is based on the **universality** of Critical Point principles, applicable e.g., to steam, magnets, metal alloys and liquid crystals (Domb), and on a central role played by **tiled** systems in CPP. Physicist Lev Landau introduced the concept of an order parameter that tracks phase changes at the Critical Point (Kadanoff); and Hans Haken and his students adapted that concept to describe neurobiological and psychological activity (Kelso).

Attempts to model CPP mathematically lead to daunting formulations, e.g., infinite sums of infinite sums of infinite sums...   A collective change is only implicit in such formulations. After extraordinary efforts, clear answers were provided for some easy problems, most notably by Onsager; but the successes themselves, and the steepening difficulties, suggest that mathematics may not be suited to describe selective processes in QN constructions (Domb, Stanley, Istrail).

To circumvent such impediments, I propose experiments using physically manufactured QN materials that are assembled into constructions (see § 2) and controlled through settings of device specifications (see § 4). As practical vehicles for exploring Critical Point principles, experiments with QN devices may produce results that are unobtainable by mathematics.

f.   Quad Net models suggest models of brains and psychology

Quad Net constructions – physical, operating devices – exist independently of any function as a model. QN constructions are, nonetheless, obviously intended to imitate neuronal structures and to mimic neuronal activity (see, e.g., Freeman, 342-343). Similarly, the QN model suggests an independent QN psychology based on general principles that reflect human psychology.

As a chief focus, features of the Quad Net model also identify important features of both biological brains and successful human intelligence, namely: (1) tiled environments, structures, activities and products; and (2) cyclical selections. These chief features also identify major limitations inherent in QN constructions: devices are designed to operate under specific conditions and are limited to specific repertoires; and activities are based on ideal tiled forms that may be clumsy when patched together.

Tiled assemblies in Quad Net constructions fit within the Modular Architectonics Principle seen in many diverse structures in brains (Arbib *et. al.*). Biologists observe that different kinds of connected neurons make up an anatomical unit; and units are replicated and joined so as to form interconnected arrays. E.g., in primates, visual cortex neurons appear in "'quasi-crystalline' structures of regular patterns formed by structural units coexistent with and superimposed on one another" (*Id.*, 219), language that also applies to the hierarchy of Quad Nets in Images 5 and 6.

In *Neural Darwinism, The Theory of Neuronal Group Selection* (1987), Edelman presents a brain model where anatomical forms are the primal basis for sensory-motor selections. A ***neuronal group*** is "a collection of cells of similar or variant types, ranging in number from hundreds to thousands, that are closely interconnected in their intrinsic circuitry" (46-47). Neuronal groups are organized into larger-scale operating structures called ***maps*** or ***mappings*** ("the ordered arrangement and activity of groups of neurons and large fiber tracts," 107). Large-scale mappings support a particular kind of circulating or reciprocating activity called ***reentry*** (60-64).

For Edelman, processes of selection are operative in different ways and at multiple levels. E.g., selection processes determine cell growth, organize neuronal groups *in utero* and constrain their development after birth. Selection also describes how an organism engaging in sensory-motor activity determines action on the basis of perceptions: "[M]otor and sensory structures can be understood only as a coordinated selective system ... selections by early signals in both motor and sensory systems acting *together* in global mappings is considered to be crucial ..." Senses generate "samples [of] various aspects or features of the environment" in local maps and "Connection of these local maps in a global mapping serves to link these samples by reentry so that the various representations of features are *correlated* in space and time... A global mapping provides the minimal unit capable of such function..." (210, emphasis in original).

Constructions presented here follow such features of Edelman's model. A Quad Net device part corresponds to a neuronal group; and assemblies of device parts correspond to structures of neuronal groups. Device parts are hooked up to other device parts in ways that "map" pulse patterns from part to part. Quad Net selective processes are of focal importance. It is proposed (§ 5) that phases may be selected through the Shimmering and Sensitivity of the far-reaching Critical Point Activation that resembles Edelman's reentry and that acts on a "global" or

"assembly" level. The imagery of one approach resonates with that of the other, even though the proposed physical principles are different (thermodynamics here rather than "darwinism").

Cyclical activity of brains – typically seen via EEG – is foundational of all brain science. Walter (109) suggests that "alpha rhythms are a process of scanning–searching for a pattern– which relaxes when a pattern is found" while Skarda & Freeman (172) "think that the notion of 'destabilization' provides a better description of the essentials of neural functioning than the concept of pattern completion. In an alert, motivated animal, input destabilizes the system, leading to further destabilization and a bifurcation to a new form of patterned activity." The QN model partakes of both interpretations, with a cycle that includes a Critical Moment, where destabilization of a device part is followed by selection of a new phase, perhaps a phase that completes a pattern, and then by relaxation into that phase.

In the Quad Net model, the primal, ideal form of activity is eternal production of uniform tiles. This is a confining form of activity; but, limited escape is made possible by cyclical device operations that allow for changes within a repertoire. Nesting allows for levels of changes. During each cycle, the resident phase in a device part or device part assembly is silenced; and selection of a new phase may depend on an influence, such as a signal from a sensory organ and/or a fixed intention. The organism can thus produce evolving activity that is approximately cyclical, with continual variations. The variations may depend on the environment, e.g., as the organism travels through a terrain. An organism may be successful in reaching a goal despite a limited repertoire if the terrain is relatively clear, solid and flat.

Psychological activity of infants develops from the "Primary Circular Reaction": "The repetition of the cycle which has been actually acquired or is in the process of being acquired is what J. M. Baldwin has called the 'circular reaction' ... [In] the transition between the organic and the intellectual ... the first habits ... [are] due to an activity ... it seems to us that the concept of 'circular reaction' is precisely destined to express the existence of this active factor, the principle of habit, and at the same time the source of an adaptational activity which intelligence will prolong by means of new techniques..." (Piaget, 1936, Ch. II, Introduction, § 5.) In the QN model, tiled cyclical activity is primary and variations are based thereon.

Psychological selection was described by William James (224) as "Voluntary Attention" and "we get it in the sensorial sphere whenever we seek to catch an impression of extreme *faintness*, be it of sight, hearing, taste, smell or touch; we get it whenever we seek to *discriminate* a sensation merged in a mass of others that are similar; we get it whenever we *resist the attractions* of more potent stimuli... We get it in the intellectual sphere ... when we strive to sharpen and make distinct an idea ... or resolutely hold fast to a thought [] discordant with our impulses." Similarly, in Quad Nets, multiple possibilities lead to a single realization, as shown in § 3.

Activities in Quad Net devices resemble sequences and harmonies in a musical performance. I suppose that tiled sounds in music produce tiled cycles in brains or Quad Net devices, with cycles within cycles, leading to "theme and variations." Shared features among productions are based in the larger cycle and variable features depend on shorter-cycle selections within the larger cycle. (See Calvin, 250 – "movement melodies" in "behavioral repertoires" –and Edelman as to birdsong, 300-303.)

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To apply these concepts, consider a laboratory task of "typing to dictation, letter by letter." A speaker steadily pronounces a sequence of letters, punctuation marks, etc. – e.g., "g-o-o-d-hyphen-b-y-e" – and the typist executes keystrokes in response. During **one cycle**, the typist **hears one sound** and **executes one keystroke**. Treating such a cycle as exemplary, an imitative Thermal Device operates cyclically to **produce** a **sensory object** (a sound of a letter-name) and a **motor act** (a keystroke) and the productions are **coordinated** (changing the object changes the act). In a larger psychological model, such units of production are called **deeds**.

In sum, a deed is a cycle of activity that produces an act and an object. Deeds may be produced one after another – e.g., when typing a sequence of letters to dictation. Moreover, typing a sequence of letters – e.g., typing the word "good-bye" – is one distinct deed (and so represented verbally) that contains a sequence of deeds. These are nested deeds. Typing sequence after sequence makes up another nesting, call it a task. The laboratory proctor may supervise task after task. The proctor's laboratory assignment is one duty in a day of duties. Living through the whole day is one distinct deed. Days are tiled into weeks, months and years.

Specific human activities clearly show features of nested tilings and/or cyclical selections. A game or sport makes tiles and nests of tiles out of "moves," e.g., a ping-pong stroke tiled into points, then into turns, wins/losses and tournaments. Each move involves a selection, e.g., between slam stroke and drive stroke in ping-pong. Computer programmers use tiled arrays of hardware units to control re-iterated branchings of commands and routines. Lawyers and judges manage a pending case (among many cases) through supervised sequences of distinct decisional proceedings. "Practice makes perfect" in collective sensory-motor arts such as ballet corps or marching band, each thoroughly tiled. In all these activities, we shape the forms of the activity to suit the nature of our intelligence as much as possible, so that intelligence does its best work.

Consider **walking**, a tiled activity where each activity tile, each **footstep**, involves the transfer of body-weight from a rearward foot to a forward foot. As weight is transferred, the forward foot presses against the fixed resistance of the surface under the foot and the sensations establish a stable object, a **foothold**. This object is an **enduring phase** (larger cycle) that organizes a series of varying sensory phases. While the foothold is being established, the leg muscles on the same leg begin an act, a **legthrust**. Usually, the thrusting of the leg strengthens the stability of the foothold. By the time the legthrust is over, the other foot starts to establish the next foothold. The deed (footstep) is a cycle of activity that produces an object (foothold) and an act (legthrust).

[A similar description is found in a Buddhist practice of "mindfully walking up and down" using a repeated sequence of phases (Thera, 96). Many spiritual practices teach absorption and/or concentration through tiled activity, e.g., prayer, breathing exercises, meditation.]

A common organizational form – tiled deeds – models both typing to dictation and walking. Selection processes involving walking can have various forms; and typing to dictation and walking have similar forms of selection when walking occurs in the city where footholds are solid. Each distinct key on the typist's keyboard is like a slab of clean, solid sidewalk: both support confident planting of the finger or foot. Walking requires different forms of selection when walking occurs in wilderness, where the stability of a foothold is sometimes uncertain and subject to unforeseen features of the terrain, e.g., rocks, water or brush.

Breaking footholds can occur with serious consequences during mountaineering adventures on snow and ice, sometimes even plunging mountaineers into the depths of a crevasse. Dangers arise because, as high-altitude winter snow matures during spring and summer, it becomes encrusted, presenting a hard surface, but with softer material or voids underneath. The strength of the crust varies over the terrain and during a day, often allowing for easy travel but with a risk of breakthrough. In response, a mountaineer sometimes proceeds with "light catlike steps" (The Mountaineers, 203). When crossing a glacier with possible hidden fissures or crevasses, "(t)he entire team must remain constantly alert ... with the lead man ready to leap back from a crumbling bridge, or lean forward to span the gap, or if worse comes to worst, to extend his arms and ax hoping to find support within his reach." (*Id.*, 245.)

During such risky mountaineering travel, weight is deliberately transferred by means of coordinated muscular action involving the whole body; and, at the same time, the forward foot (booted and all) is used as a sensory organ that detects any change in the solidity or stability of a developing foothold. If breaking is detected, the forward foot is withdrawn and the footstep is *reversed*. All the mountaineer's physical resources, e.g., those used to produce "light catlike steps," are directed towards maintaining the capacity for such reversible action – "to leap back from a crumbling bridge" – up until the last possible moment. There is a Critical Moment while the mountaineer maintains a capacity for reversing a footstep. The Critical Moment passes, however, and then, the deed, the footstep, becomes ***irreversible***.

Development of a psychology suited to Quad Net devices looks to guidance from Piaget (1946) at 289 and 291: "A system of operations such as the elementary operations of arithmetic or geometry and logical seriations and nestings, can equally well be considered as a set of objective transformations ... Moreover, ***the characteristic feature of operations is their reversibility***... Rational operations are, in fact, systems of aggregates, characterized by a ***definite mobile and reversible structure***... It is for this reason that in our view a static analysis of discontinuous, stratified levels is unacceptable, whereas [a] functional dynamism ... while respecting structural variety, makes it possible to ... grasp the specific role of mental life: ***the achievement of complete mobility and reversibility***, which are unattainable on the organic plane." (Emphases added.)

§ 2   Quad Net Material Constructions

"Matter is commonly found in the form of materials. Analytical mechanics turned its back upon this fact, creating the centrally useful but abstract concepts of the mass point and the rigid body, in which matter manifests itself only through its inertia, independent of its constitution; 'modern' physics likewise turns its back, since it concerns solely the small particles of matter, declining to face the problem of how a specimen made up of small particles of matter will behave in the typical circumstances in which we meet it. Materials, however, continue to furnish the masses of matter we see and use from day to day: air, water, earth, flesh, wood, stone, steel, concrete, glass, rubber..." (Truesdell & Noll, 1.)

a.   Primal Quad Net (PQN)

Image 7   Primal Quad Net Field

© 2006 Robert Kovsky
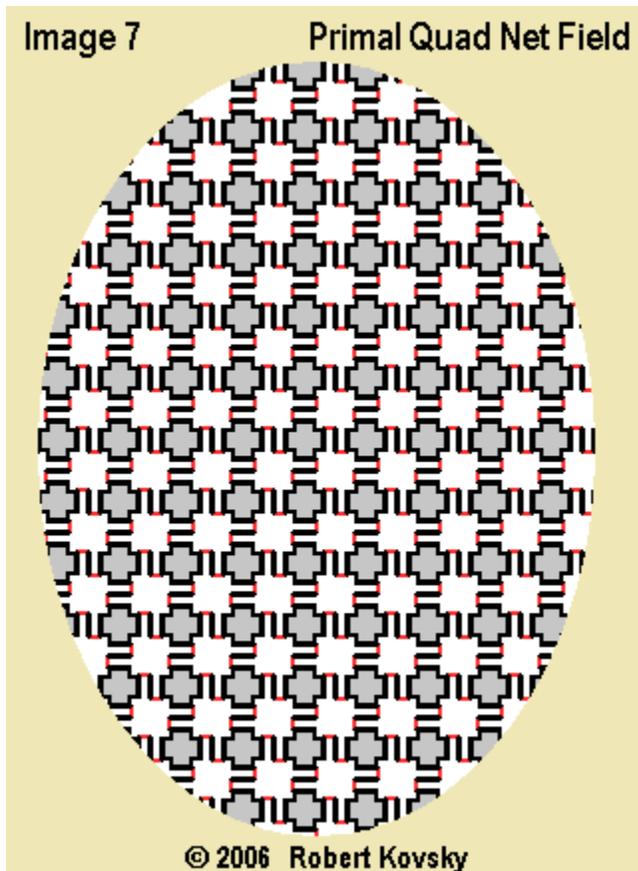
Presented as if actually existing, **Primal Quad Net** (PQN) is a physical material made up of uniform tiles that connect edge-to-edge to form a spatial collective. Each tile contains a pulsing elemental device, all of a single design.

Image 7 shows an interior view of the spatial field of PQN. There is **no** boundary specification and the boundary, if any, is unknown. The oval frame is for presentation purposes, suggesting a hole cut into something else.

In contrast to analytical mechanics that starts with a static void, Primal Quad Net starts with a **plenum of activity**. It is also a particular plenum. Another approach might use "Hex Net," "Oct Net" or a combination.

PQN has regularities, e.g., (1) reciprocity between nearest neighbors; (2) translational invariance and (3) four-fold rotational symmetry. In other words: asymmetrical actors are paired with reciprocators; there is no preferred place; and four directions are equivalent to one another.

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Features of Quad Net are shown in Image 8, using PQN as an exemplar.

The operating *elements* of QN (Image 8.a) occupy distinct spatial units; and each element is set off by partitioning of space that establishes properties of elemental *integrity* and *distinction*. That is, each element is whole unto itself and each can be specifically identified. Distinctive colors are added to images for purposes of presentation.

Partitions are made up of *walls* and *junctions*. A junction has a preferred direction called *onto* (Image 8.b).

In an operating elemental device, interactions involving a junction cause effects in the onto direction but not in the direction that is the reverse of onto. A wall has no preferred direction and nothing happens through a wall.

A junction is the working tip of a spatial *projection* that sets off from the *body* of an element, as shown in Image 8.b.

Access is "open space," like holes in a fishing net. The feature is optional; compare Image 5.a with Image 8.a.

A tile is a minimal unit of Quad Net and can be variously defined. One definition is indicated by the "tile" square around the yellow element in Image 8.a.

Nearest neighbors share junctions. In Image 8, yellow elements are nearest neighbors to green elements but not to blue elements.

Image 8: Features of elemental Quad Net

a. elemental details

▬▬▬ -- walls

▬▬▬ -- elements

▬▬▬ -- junctions

▬▬▬ -- access

"a tile"

b. definitions

onto

project'n

body

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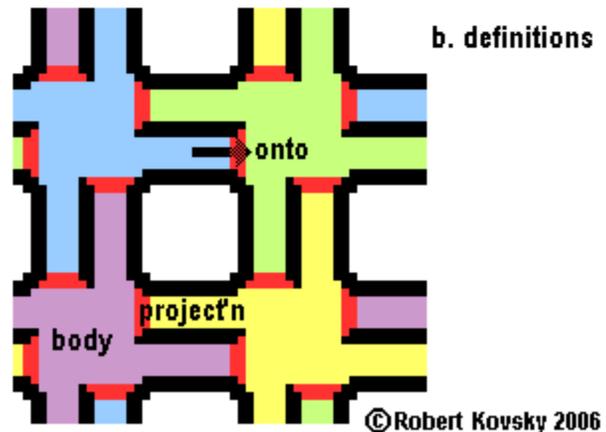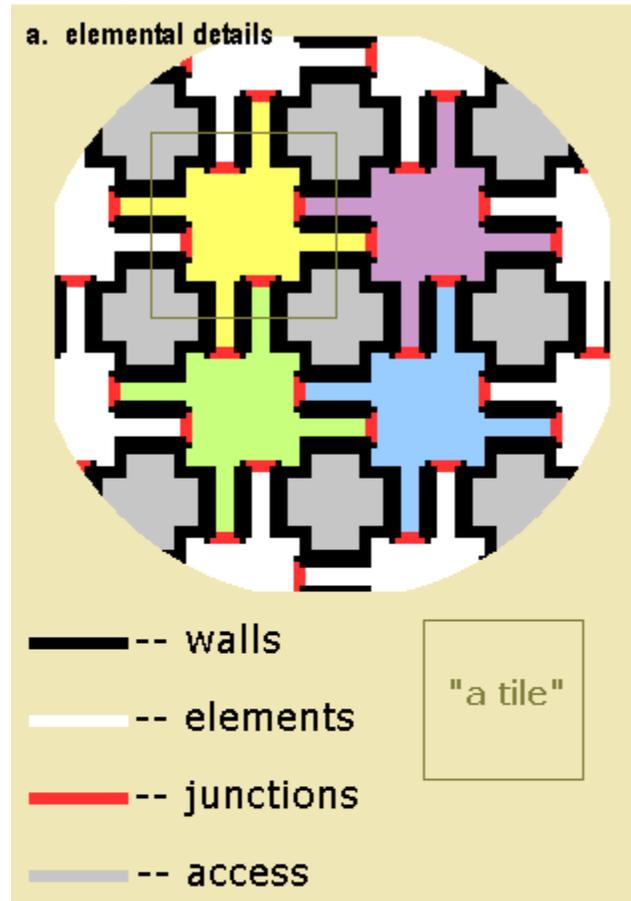
b.   Deformation of a Quad Net

Deformation of a Quad Net is permissible. During deformation, junctions must remain unchanged and the distinction and integrity of elements must be preserved. Such a deformation has no affect on Quad Net properties or device operations and is ***inconsequential***.

Image 9 shows systematic deformation of a Quad Net. All elements are uniform except for edges modified for a clearer presentation. Blue and green colors are used as visual aids.

In Image 9.b, blue elements and green elements have been separated. A single long projection is extended from the body of each element and splits into multiple projections near elements of the other color.

In an operating Quad Net, such deformations are inconsequential and do not affect function. In an idealized elemental device, a pulse is immediately effective at all junctions regardless of deformations. (Actual devices can be adjusted to approximate this idealization.)

The deformed elements in Image 9.b look more like biological neurons, with a single long "axon" that projects from a cell body and splits up near the targets. The gathered "axonic projections" suggest bundles of nerve fibers.

Image 9: Deformation of Quad Net

a. QN prior to deformation

b. QN after deformation

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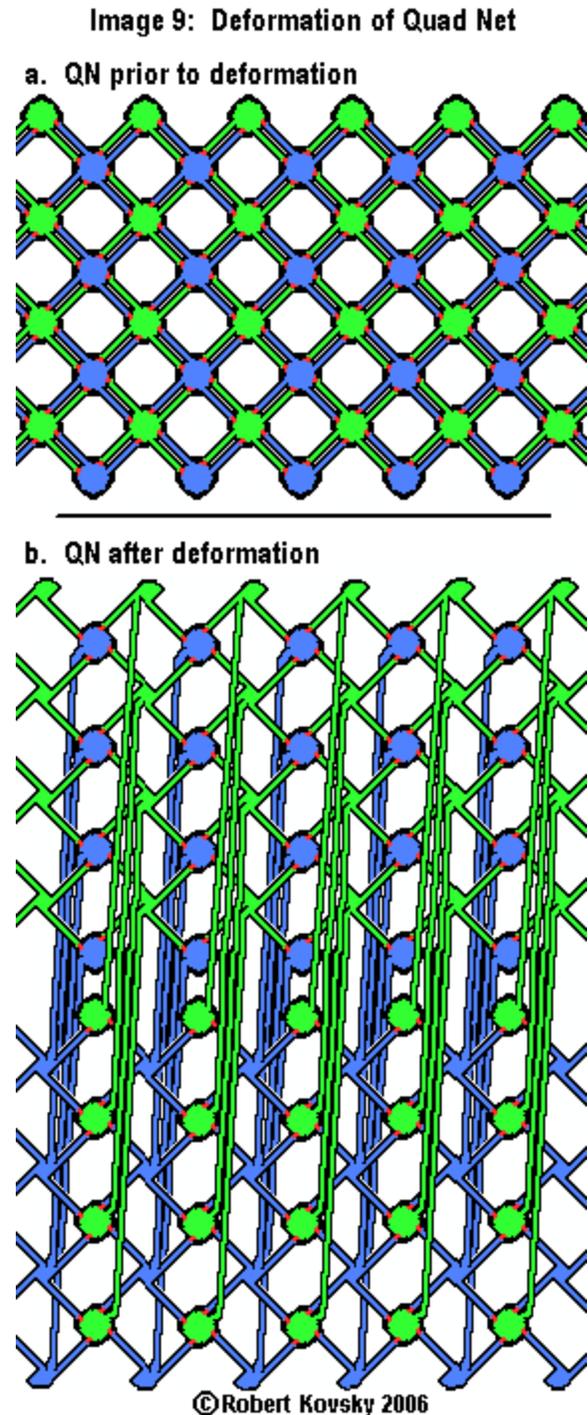
c.   Wave Phases in Primal Quad Net

Image 10 shows a wave in PQN, with a focus on a circled "test element." The **successive frame format** resembles frames in a movie film. Conditions at time t = 4 δ are identical to those at time t = 0 and repetitive cyclical activity is maintained. The **cycle span** of a phase is the number of elemental devices needed for a germinal activity tile, e.g., 4 in Image 10.   (This is also the number of pulses in such activity tile.) In PQN, the cycle span can be any real number greater than 2, e.g., 2.1 (the element is ready for only a very short time).   In specifying a wave phase, direction is the primary property and cycle span can be varied while maintaining a direction.

Image 10   Passage of a wave through Primal Quad Net

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refractory element — refractory/ready element — ready element — responding element — refractory element

element discharge — neighbors discharge — element discharge

T I M E

t = 0   t = 1δ   t = 2δ   t = 3 δ   t = 4 δ
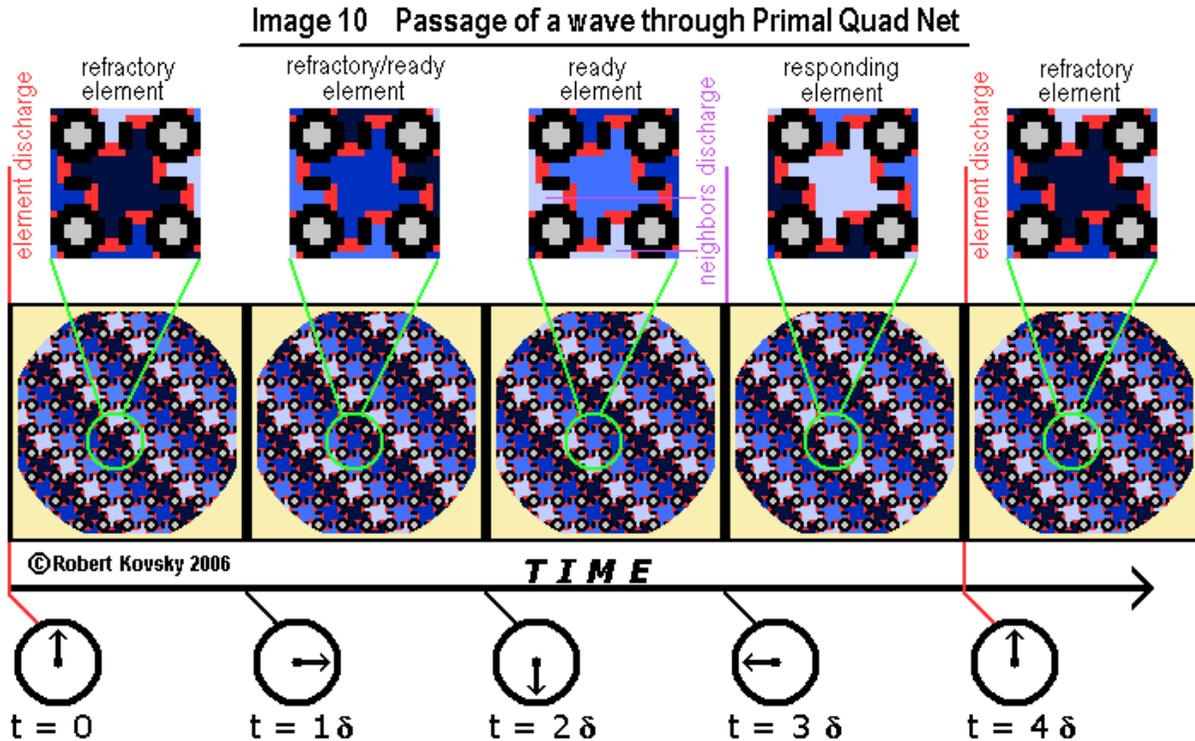
The **conditions** of the test element organize images of activity. The presentation picks up the cycle at t = 0 upon **discharge** of the test element. The discharging condition is momentary and is not shown. The first frame shows the **refractory** condition that follows, during which the elemental device is unresponsive to discharges in neighboring elemental devices. The test element becomes **ready** at some variable point after time 1 δ and before time 2 δ – it can then respond to a discharge in a neighboring elemental device but is not actually responding. A **responding** elemental device is under the influence of a prior discharge in a neighboring elemental device and is preparing to discharge.

A discharge is an instantaneous occurrence that, first, can influence neighboring elemental devices (perhaps changing them from ready to responding) and, second, turns the discharging elemental device to a refractory condition. After discharge, a refractory elemental device becomes ready only through the passage of time, the refractory period. A ready elemental device begins responding only when a neighboring elemental device discharges. After the neighbor discharges, there is a time delay, δ, before the test element discharges. The interaction delay δ is a specification of the phase and can be varied.   QN devices are variably slow responders.

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Image 11 shows a repertoire of phases in PQN. For crosswise and orthogonal wave phases, a representative frame includes an arrow showing the apparent direction of travel of a wave of discharges.
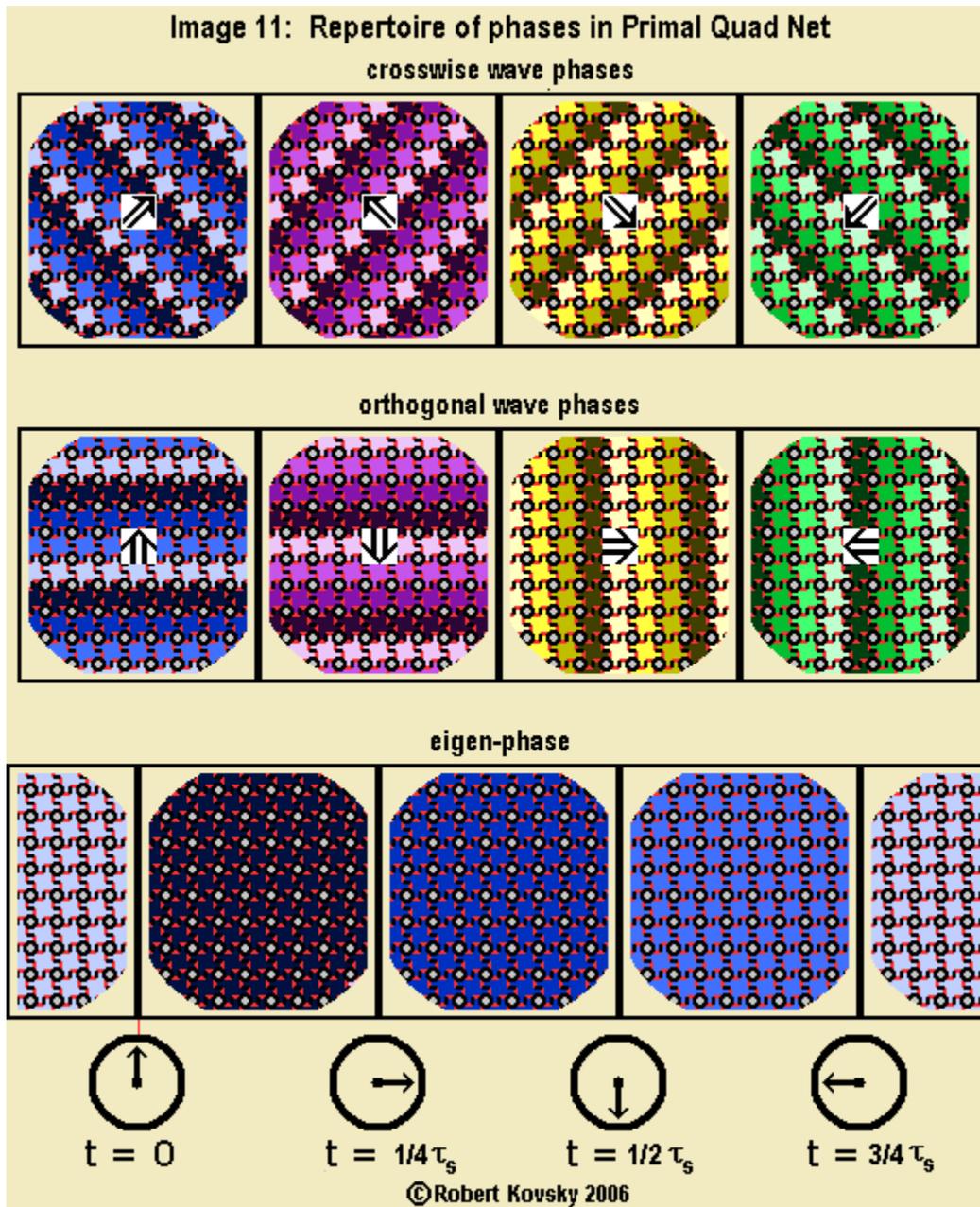
The last phase in the repertoire, belonging to its own class, is the ***eigen-phase***; and it is presented in the full successive-frame format. The name "eigen"– meaning "it's own" – is borrowed from quantum mechanics. The eigen-phase is a single specific phase, without direction or external influence, that involves the entire Quad Net in a collective discharge. Ideally, interactions are superfluous; each elemental device discharges spontaneously, all in unison. The period of the eigen-phase is τ_s (§ 4.b), which is longer than the period of all other phases.

d.   Modifications of the Quad Net field

Image 12 show modification of an interior piece of Primal Quad Net in a crosswise presentation.

In Image 12.a, unmodified PQN supports a phase from its repertoire.

In Image 12.b, showing spatial arrangements alone, half the projections and junctions have been "grayed out," indicating that the "grayed out" areas are being rendered inoperative. This modification is called *withering*.

In Image 12.c, withering is completed; and withered projections and junctions are removed. The modified Quad Net can maintain only a single crosswise wave phase, the one shown.   As to this phase, the function of the Quad Net has not been changed by the withering.

Withering that removes operating capacity is an extreme example of modification of a Quad Net field. Less extreme modifications might be embedded in cycles during which withering varies, e.g., from "no withering" to "full withering."

Image 12
modification by withering
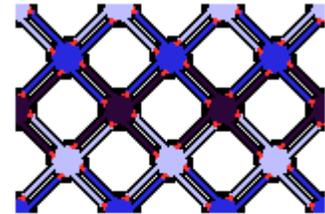
a. unmodified PQN
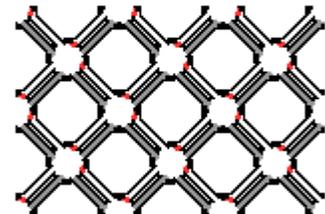
b. withering QN
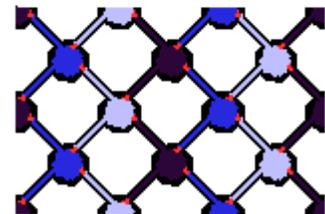
c. withered QN
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Image 13 shows modifications of PQN that especially support particular phases. The modified QN in image 13.a selectively maintains certain orthogonal waves and not others. Two distinct circulations are maintained in another modified QN (Image 13.b) while such circulations cannot be maintained in PQN. In the modified QN shown in Image 13.c, orthogonal phases have enhanced robustness relative to crosswise waves, compared to unmodified PQN.

Image 13: Examples of modifications of PQN to support various phases

a. modified to select and support particular orthogonal waves
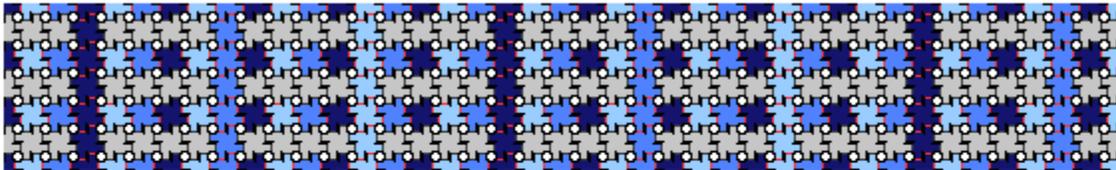
b. modified for circulations
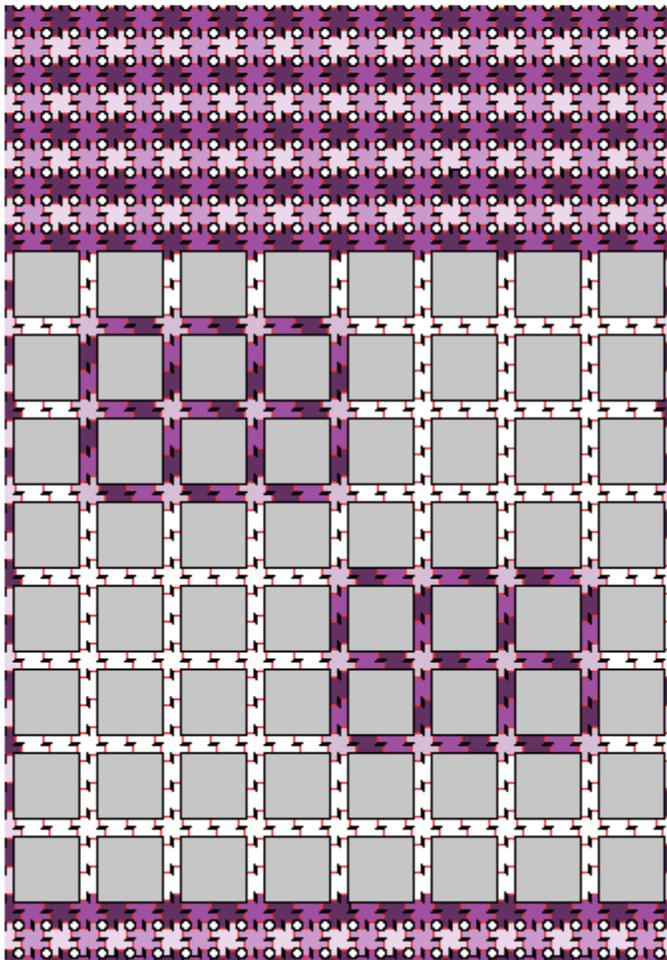
c. modified for orthogonal waves
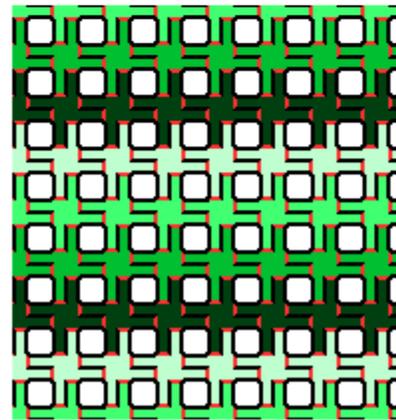
goes to

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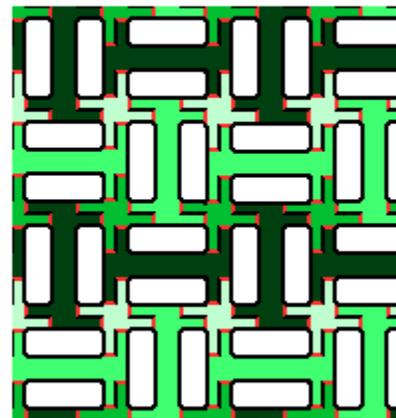
e.   Closure of pieces of Quad Net into regular forms

Image 14 shows two equivalent representations of a
piece of *Flat Quad Net* or FQN cut from Primal Quad
Net. The simplified lower representation allows for
easier visualization of forms and assemblies.

As a result of the cutting, there are *open pairs of
projections*; each pair is labeled with a letter, e.g., **a**,
d' and **w**, and each such label is distinct, e.g., **a** is
distinctly different from **a'**. It is as if all the labeled
projections were severed in mid-point and the ends
were left dangling.

A FQN has m rows and n columns and is of size
(m x n), e.g., 5x7 in Image 14.

Image 14: Flat Quad Net

©Robert Kovsky 2006

Closure is accomplished by "splicing" one open pair of projections to another open pair of
projections, e.g., splicing the open pair of projections **u** to the open pair of projections **u'**, closing
both open projections.   Closure can be partial or full.
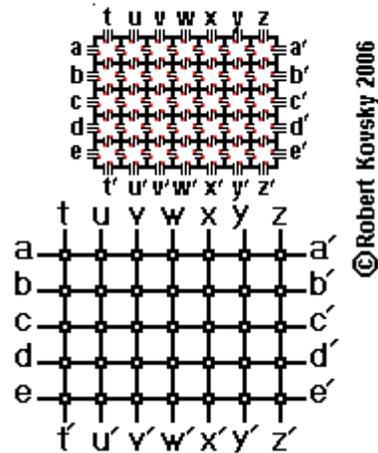
Image 15: Flat Quad Net (FQN) shaped into regular forms

a. Cylindrical Quad Net (CQN)

b. CQN in letter presentation

c. Toroidal Quad Net (TQN)

©Robert Kovsky 2006
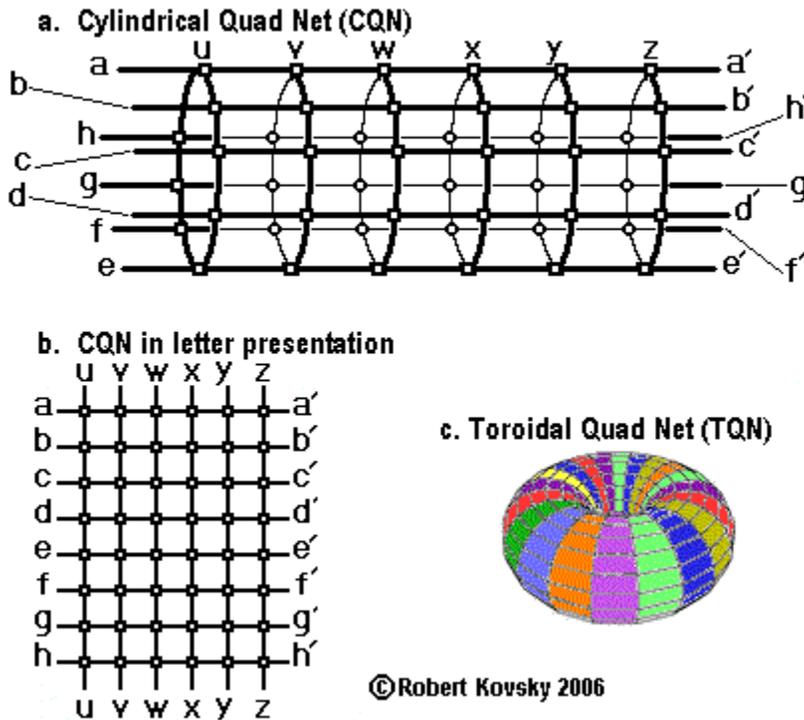
Partial closure of an 8x6 Flat
Quad Net produces the
Cylindrical Quad Net (CQN),
shown in Image 15.a.   The
"cylinder" is subject to
deformation and is shown in
an idealized geometrical form
for purposes of presentation.

The letter presentation in
Image 15.b is "identical" to
that in 15.a. E.g., one **u** is
"the same as" if it were
spliced to and merged with
the other **u**. The distinction
between **a** and **a'** remains.

Using a slightly different
form of presentation, a full
closure of a 20 x 20 FQN
produces the Toroidal Quad
Net (TQN) in Image 15.c,
with colors added for
presentational purposes.

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A collection of FQN's and CQN's can be spliced together to form a tiled assembly shown in Image 16.   This is the first of a developmental sequence of tiled assemblies that culminates in the Phase Transfer Controller (§ 2.i).

Image 16: Tiled assembly of Flat Quad Nets and Cylindrical Quad Nets

©Robert Kovsky 2006
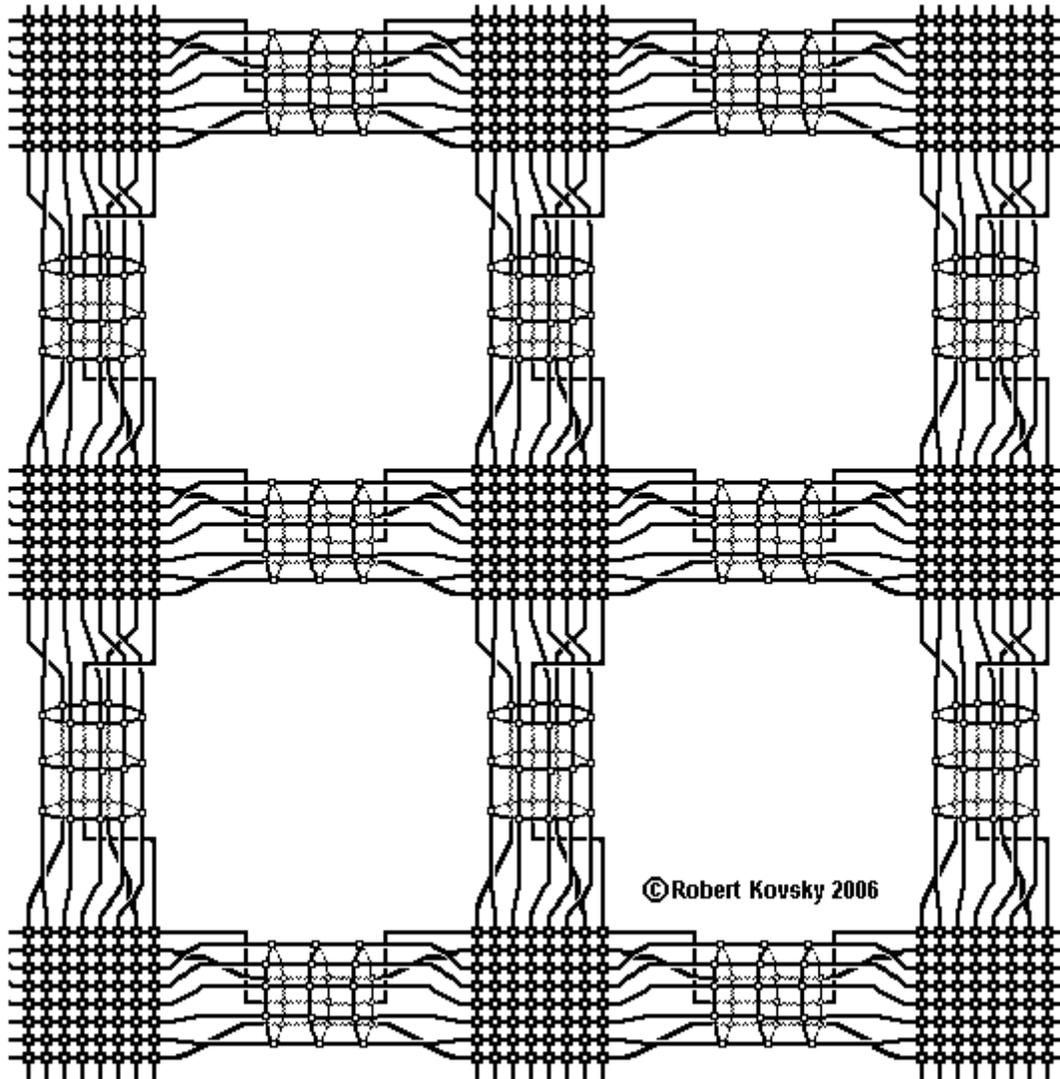
The tiled assembly in Image 16 resembles a Quad Net. Each FQN is like an elemental device, only in a collective way; and each CQN is collectively like a pair of reciprocating projections. The resemblance extends to a larger scale when considering closure of the tiled assembly. One possibility is that the tiled assembly extends indefinitely like Primal Quad Net; alternatively, the tiled assembly can be closed like an FQN is closed, partially into a cylinder like a CQN or completely like a TQN.

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f.   Attachments and assembly through projection modifications

In Image 17, a Cylindrical Quad Net (CQN) is attached to another QN through modifications that add new projections and junctions to elemental devices.   Projections added by modifications can be reciprocal, as here, or one-directional as in Image 29.a. New junctions can function the same as the old ones or can be governed by new specifications and settings.

Image 17: Projection modifications

a. unmodified Quad Net

b. CQN attached to Quad Net

©Robert Kovsky 2006
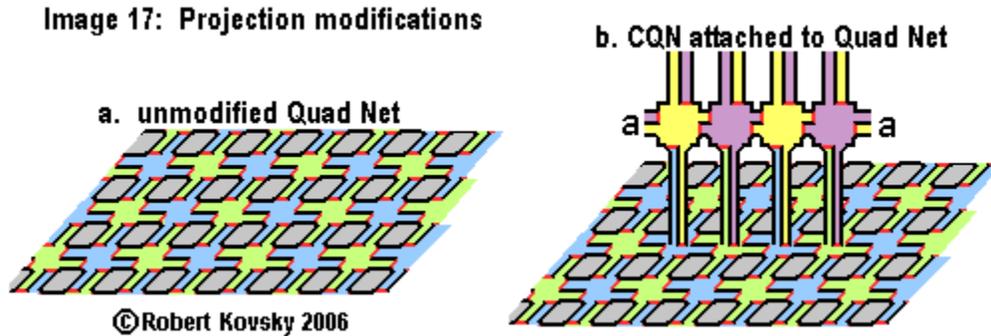
 A tiled assembly of Toroidal Quad Nets, shown in Image 18, is developed from the tiled assembly of Image 16. Each FQN becomes a TQN with closures indicated by matching letters. The toroids are interconnected by bundles of projections added through modifications.

Image 18: Tiled interconnected Toroidal Quad Nets

©Robert Kovsky 2006
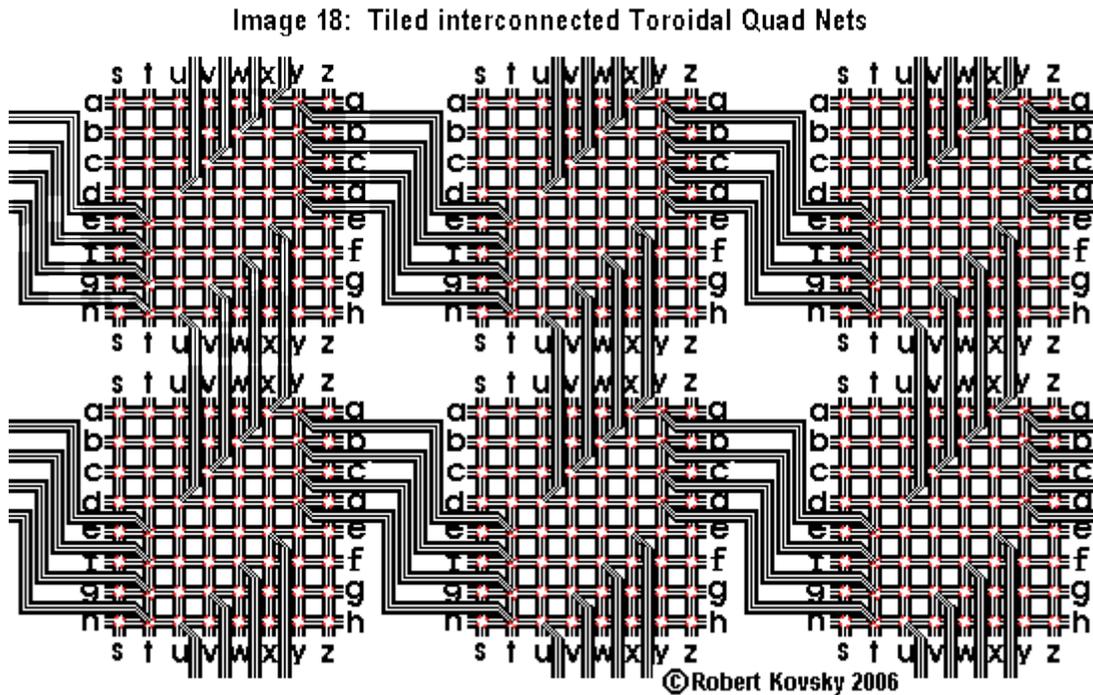
Summing up, the engineer has four techniques that are used in coordinated ways to construct Quad Net devices from a sheet of Quad Net material: (1a) cutting projections and (1b) splicing projections; and (2a) withering projections and (2b) attaching projections.

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The foregoing techniques are used to construct the decussation device part (Image 19). The device part uses a three-part *controlled interaction* (Image 29, § 4.f); and it combines incoming waves and generates an outgoing wave. Four pieces of 3 x 3 FQN are modified by attaching additional, controller projections and by withering cross-projections; then the four pieces are joined to eight external CQN's. In operation, there is no response to an isolated incoming controlling wave or to an isolated incoming orthogonal wave. Rather, it is an incoming controlling wave *coincident* with an adjoining incoming orthogonal wave that produces an outgoing orthogonal wave.

Image 19: phases in decussation device part

outgoing orthogonal wave phase

incoming controlling wave phase

incoming orthogonal wave phase © Robert Kovsky 2006
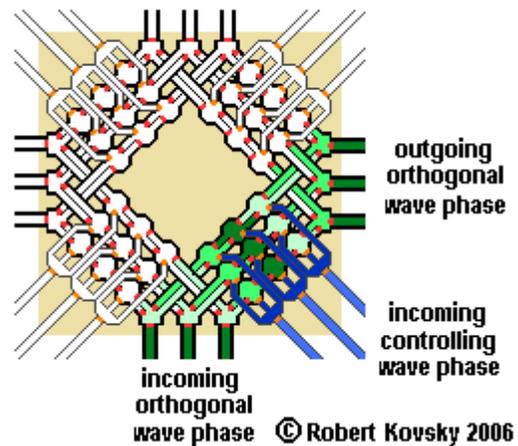
An operating decussation device part performs a logic-like function (Image 20.a). An incoming orthogonal wave will be transmitted "if and only if" an adjacent controlling wave is maintained and then it is transmitted in the direction selected by the controlling wave.

Image 20: Circulations in tiled assembly of decussation device parts

a. representation of operating decussation device part

b. two different circulations in tiled assembly of decussation device parts

© 2006 Robert Kovsky
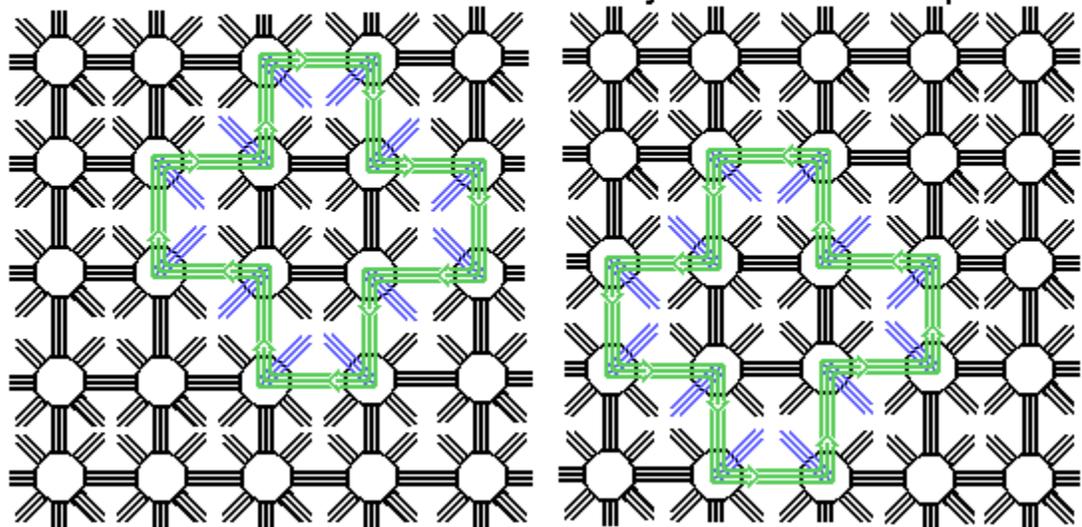
As shown in Image 20.b., a tiled assembly of decussation device parts supports different circulation phases. Each controlling wave phase is set by the engineer or other device parts. The effect is like striking a piano key and each circulation is like a cycling tune.

"Decussation" device parts are intended to suggest "decussation" structures (that have "crossing" pathways) in nervous systems and to mimic, in a rudimentary way, the apparent functioning of such structures in sensory-motor coordination (see Edelman, Table 1 at 145 and also 146-147).

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g.   Phasic Transfers between Quad Nets

Blue QN B and green QN G, identical QN's, are overlaid and connected in Image 21. There are internal projections within each original QN, shown with red junctions. A new pair of projections with orange junctions is attached by projection modifications so as to connect the two QN's. Image 21.e shows a magnified, enhanced view of the junctions.

Image 21: Connecting two Quad Nets

a. blue QN B

b. green QN G

c. QN's overlaid, unconnected

d. QN's overlaid and connected

e. magnified (x3) view of junctions

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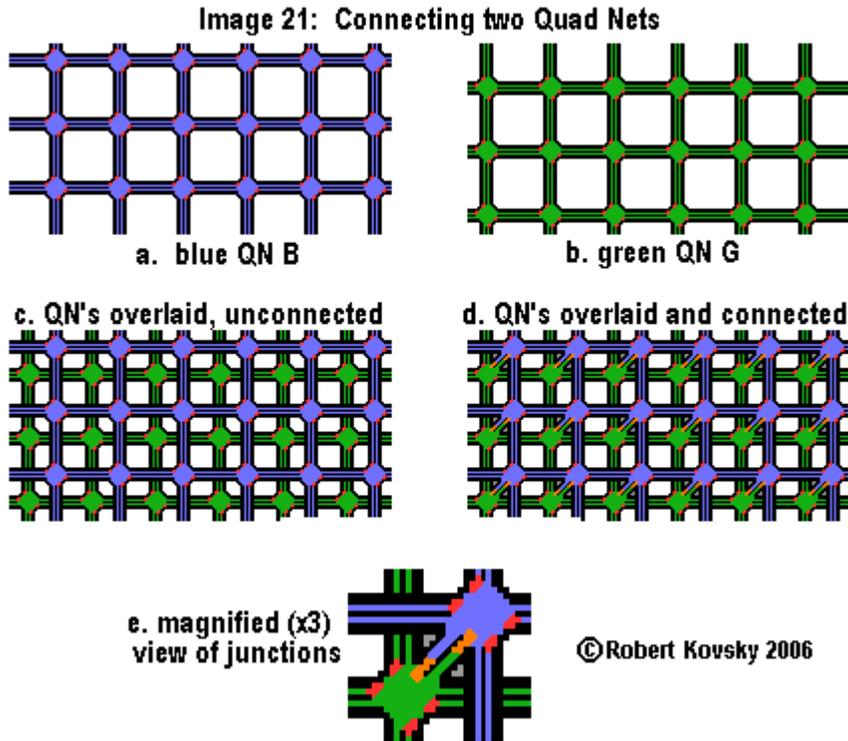
Connected identical Quad Nets can **transfer a phase** from one to the other in cyclical operations. The transfer is **selective**: a distinct phase in the first QN, the **leading** QN, generates the same distinct phase in the second QN, the **following** QN.

Image 22 shows a parameter ε that cycles around "0." The engineer controls ε, which is designed to act like a temperature that controls phase changes in physical materials (§§ 4.g, 5). When ε is solidly greater than 0, the QN is silent. When ε is solidly less than 0, the QN is pulsing periodically.

Image 22: Cycling epsilon

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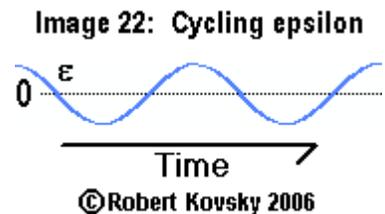
When ε is near 0, the situation requires closer examination. The Critical Point (identifying a Critical Moment in an operating cycle of a QN device) is near ε = 0. In general, as here, the timing and duration of a Critical Moment may depend on interactions and other influences.

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In a phasic transfer from QN B to QN G, each QN has its own ε cycle, $ε_B$ and $ε_G$ respectively; and the two cycles are coordinated or engaged. As shown in Image 23, the two ε's are displaced in time but are otherwise identical. $ε_B$ *leads* $ε_G$, particularly meaning that $ε_B$ passes downward through 0 or V_n, prior to $ε_G$. Correspondingly, $ε_G$ *follows* $ε_B$. Four collective conditions – at moments #, a, b and c in Image 23 – are examined in the following presentation.

Image 23
engaged ε's during phasic transfer
©Robert Kovsky 2006
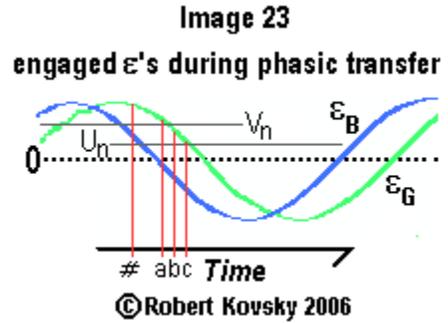
Image 24: Conditions in phasic transfers

refractory
unready
ready
responding
©Robert Kovsky 2006

Image 24 shows conditions of elemental devices involved in the phasic transfer. As before, a refractory elemental device is unresponsive to all interactions and one in a responding condition has been excited by a prior discharge in a neighbor. The ready condition is modified by introducing the *unready condition* and then defining both ready and unready in terms of a relationship between ε and the strength of interactions.

In Image 23, V_n measures the strength of an interaction between elemental devices in different Quad Nets; and U_n measures the strength of an interaction within each of the QN's. That is, V_n governs orange junctions in Image 21; and U_n governs red junctions. $V_n > U_n$ means that an interaction between elemental devices in different Quad Nets is stronger than that within a Quad Net.

Readiness is determined by whether ε is greater than or less than the interaction strength. When $ε > V_n$, the device is unready; but it becomes ready when ε decreases below V_n. That is, when the ε of QN G is below V_n, a discharge in an elemental device in QN B will change the condition of a connected elemental device in QN G from ready to responding. On the other hand, when the ε of QN G is greater than V_n, a neighboring discharge has no effect and unready elemental devices remain silent. Hence, as the ε of QN G passes downward through V_n, QNG changes from the unready condition to become ready as to QN B. At point # in Image 23, no interaction affects a green elemental device because $ε_G > V_n$ (and also $ε_G > U_n$). A discharge from a green elemental device could affect a blue elemental device ($ε_B < V_n$), but such event does not happen.

Similarly, when the ε of a QN is greater than U_n, discharges within the QN have no effect and the QN cannot maintain a phase on its own. At point # in Image 23, neither QN can maintain a phase on its own. When $ε < U_n$, a QN can maintain a phase (see Image 32).

As shown in Image 25, the Critical Moment here occurs while $ε_G$ in QN G is between U_n and V_n, as at points b and c in Image 23. The phase in QN G is selected during this interval in the cycle of $ε_G$ while QN G is responsive to QN B ($ε_G < V_n$) but also while QN G is unable to maintain a phase on its own ($ε_G > U_n$). QN B is leading QN G while QN G is performing its selection and the selected phase becomes fixed in QN G as the cycle progresses. It is like an instruction in education or computers.

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Image 25: The Critical Moment during phasic transfer between identical Quad Nets

a. leading phase in QN B
while QN G is unready

b. QN G becomes ready
and begin responding

c. following phase established
in QN G   ©Robert Kovsky 2006
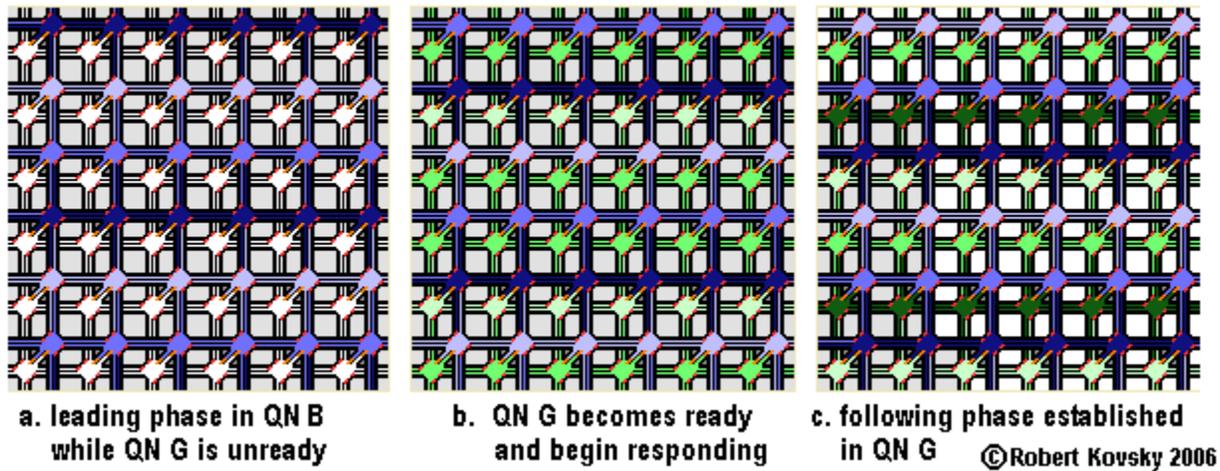
Images 25.a, 25.b, and 25.c show conditions at points a, b and c in Image 23. Image 25.a shows a wave in QN B while QN G is unready. During the step that occurs between Image 25.a and Image 25.b, ε_G becomes smaller than V_n and QN G becomes ready; then discharges occur in those QN B elemental devices that were in a responding condition in Image 25.a. Image 25.b shows the results: discharged elemental devices in QN B are in a refractory condition and corresponding elemental devices in QN G are responding because of the discharges in QN B.

Image 25.c shows conditions after a further step. QN G elemental devices that were put into a responding condition in Image 25.b have discharged and become refractory, but this is the only internal effect in QN G while ε_G remains above U_n. QN G elemental devices that are responding in Image 25.c do so only because of recent discharges in QN B. QN G is responsive to QN B but internally unresponsive. QN B *transfers* the wave to QN G. A different orthogonal wave in QN B would have been correspondingly transferred to QN G. In the next step, when $\varepsilon_G < U_n$, QN G will support the wave on its own and the influence of QN B on QN G will be superseded.

Identical QN's support an identical transfer, where there is no difference between the phases in the QNs other than a time delay. This transfer is reversible back and forth: if the leading and lagging ε's are reversed, the transfer runs the other way.

A more complex approach is required for crosswise wave phases. In some crosswise phases, a single neighboring discharge will change a ready elemental device to a responding condition, but in other crosswise phases, two neighboring discharges are required (see § 4.e). In the former case, there is co-existence with orthogonal waves; in the latter, orthogonal waves cannot be maintained. The engineer sets specifications to choose whether to include orthogonal waves.

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Image 26: "Scaler" executing non-identical phasic transfer

a. leading & following   ©Robert Kovsky 2006   b. independent
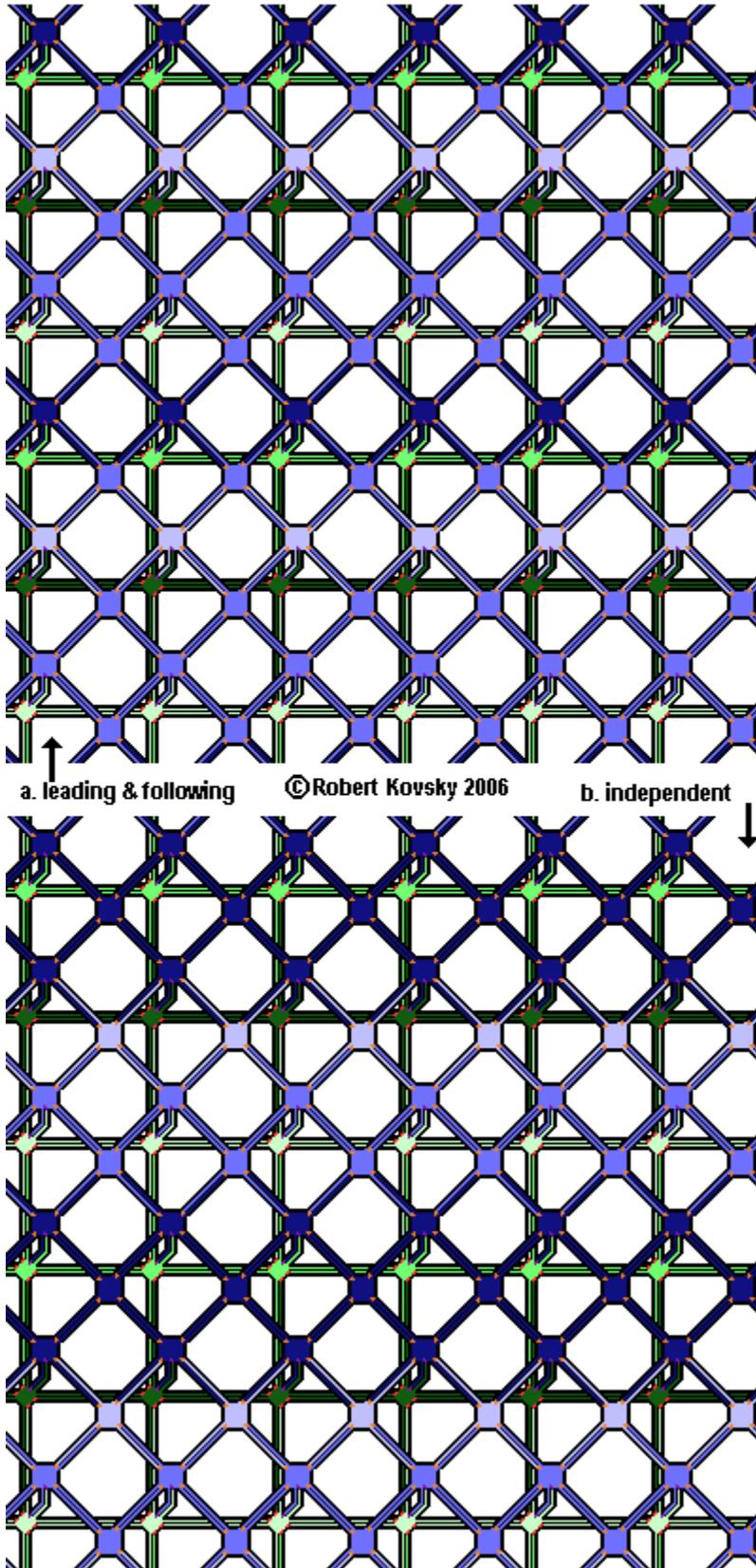
The "Scaler" device shown in Image 26 supports non-identical phase transfers that are similar to but also different from the transfer shown in Images 23-25.

In Image 26, QN B has twice as many elemental devices as QN G; and half the elemental devices in QN B are unconnected to QN G. Image 26.a shows a transfer at a stage similar to that shown in Image 25.c, i.e., $V_n > \varepsilon_B > U_n$. Here, the phase in QN G is leading and that in QN B is following. Blue elemental devices that are unconnected to QN G cannot change from ready to responding because $\varepsilon_B > U_n$. Previously discharged and presently refractory QN G elemental devices are the cause of responsive conditions in elemental devices in QN B.

Image 26.b shows how conditions change when $\varepsilon_B < U_n$. The wave now involves QN B elemental devices that are unconnected to QN G and QN B now maintains the phase independently of QN G.

Four orthogonal phases in QN G match four crosswise phases in QN B, with similar matches between crosswise phases in QN G and orthogonal phases in QN B. Scalar's transfers are reversible.

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Another device, "Scaler II," shown in Image 27, is closely related to "Scaler" in design. A change of scale, color changes, a 45° twist and deformations will turn one into the other.

In operation, Scaler and Scaler II are designed to work together. The two devices can be joined through a shared QN G to form a single device with three layers, made up of two devices sharing a QN. E.g., suppose QN G in Image 26.b is physically identical to QN G in Image 27. Then the engineer can produce a *sequence* of phasic transfers, with QN G as the pivot. In Image 27, the blue phase leads the green phase; and then the same green phase in Image 26.b leads the blue phase there.

Image 27 "Scaler II" showing phasic transfer

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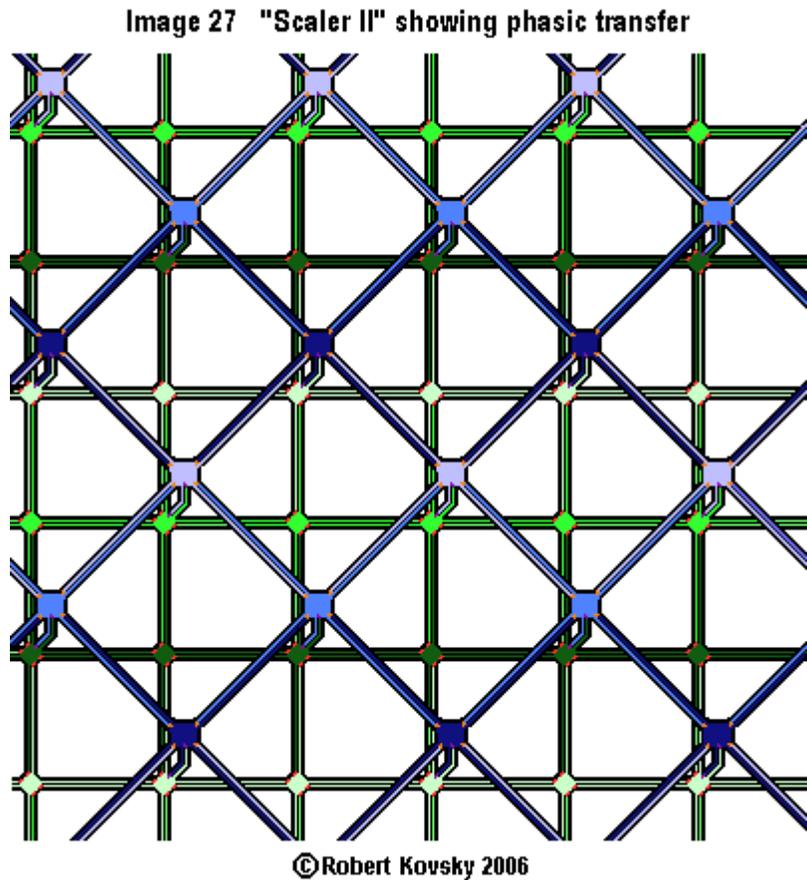
The approach can be extended to construct a variety of phasic transfers, differing in details. There is no limit to the number of transfers that can be sequenced, including any number of steps up and steps down. For example, it seems possible to assemble a dozen Scalar and Scalar II devices into a circularity structure where a phasic pulse bundle is maintained while undergoing a continual series of phasic transfers and selections. Various repertoires of transfers would be supported depending on settings of specifications.

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h.   Similarity and self-similarity in Quad Net Constructions

 An organizing principle is that of a *family of constructions* where each member of a family *resembles* all the others.   E.g., there is a family of Cylindrical Quad Nets (CQN's) described as "m rows by n columns;" and the members resemble one another physically and operationally.

A *psychology of resemblances* has great attraction. Beginning in infancy, intelligence works through imitation, as in "monkey see, monkey do" (see Piaget 1946). A primal resemblance relationship allows for comparison and combination, e.g., the new baby looks more like mother than father but has father's complexion. Resemblance relationships operate in many areas of human activity, including lawsuits (e.g., judicial precedents); artistic works, performances and criticism; and large-scale concepts that involve subjective perspectives (e.g., interpretations of history; formulation of public policy, comparative religion studies). Quad Net constructions are inter-disciplinary metaphors, simultaneously "similar to brains" and "similar to the Ising model."

Image 28 shows similarity and self-similarity in a purely spatial quad tiling.

That is, treating position and orientation (tilt) as unimportant, the structures A, B, C, D and E are all similar. Each step in the sequence involves a scaling up of size. Structure A, distinctively marked, is reproduced in Structure E (in three places) and E therefore illustrates *self-similarity*.   That is, a *part* of E is similar to the *whole* of E.

Phases in the Scalar and Scalar II devices (Images 26 and 27) and phases in spatial hierarchies (§ 1.d, Images 4 - 6) show "similar" similarities when organized into families of phases.

Image 28
Similarity and self-similarity in a Quad Tiling

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Image 29: Family of Quad Net constructions

a. PQN with controller projections attached onto

b. decussation device part

c. controller device element

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d. hierarchy of Quad Nets

Image 29 shows a family of QN constructions. The primal member of the family is PQN modified by the attachment of a one-way projection onto each elemental device (Image 29.a). The new projections are "controllers."

The modified PQN is shaped into a decussation device part (Image 29.b, like that shown in Image 19). An exemplary *controller device element* is based on this device part (Image 29.c) and used to model activation of the family in § 4.f.

Another way of organizing activity is by combining the controller projections into blocs, as in a hierarchy of Quad Nets, (Image 29.d and Image 5).

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i.   The Phase Transfer Controller

The culminating construction of this presentation, a member of the family of tiled assemblies, is the Phase Transfer Controller (PTC), an array of interconnected TQN's (Toroidal Quad Nets).

Image 30.a shows a new kind of QN tiling in blue. The underlying TQN's, each of a single size –
n x n – appear through small interior portions with blue connections to only one representative elemental device per TQN. In a full design, every elemental device in a TQN has four blue connections. Blue elemental devices make up CQNs, each of size $(1 \times n^2)$, with an effective two CQNs for one TQN (see Image 31).

Activity in the PTC is controlled by (1) purple controllers of elemental devices in the TQNs; and (2) green controllers of blue elemental devices in the CQN's.

Image 30   Phase Transfer Controller, elemental details
a. Toroidal Quad Nets with added controllers

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Image 30.a shows connections in a crude way. Image 30.b shows a representative tile with a full set of junctions.

During operations, orange junctions control inhibitory interactions while other interactions are excitatory (see Images 33 and 34). The organization of inhibitory and excitatory controllers in the representative tile resembles that of synapses on neurons that participate in "neuronal integration," said to lie under the "decision-making capability that is the brain's most fundamental activity." (Kandel *et. al.* at 166-170, citing Charles Sherrington.) In a rudimentary way, perhaps the PTC shows how this capability might be realized.

b. junctions in a PTC tile
©Robert Kovsky 2006
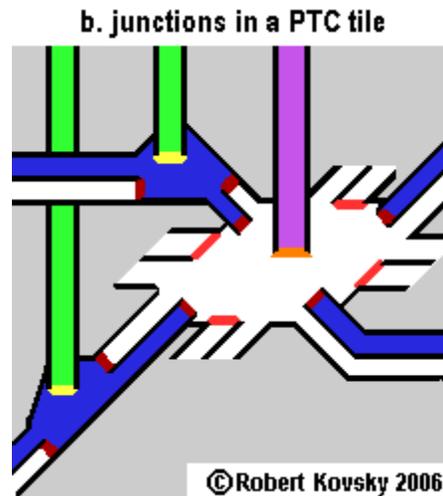
The new form of QN tiling (Image 30) also organizes the architecture and function of the PTC (Image 31). Purple controllers leading to individual elemental devices in a TQN in Image 30 are collected into ***controller buses***, shown in purple in Image 31; and green controllers in Image 30 are collected into green controller buses in Image 31. A controller bus is activated collectively, delivering control interactions at a single time onto all elemental devices in a TQN or CQN.

The PTC shows self-similarity: each TQN is similar to the body of an elemental device in a QN and each CQN is similar to a pair of reciprocating projections. Thus, development has produced a tiled array made up of QN device parts that is "like" a Quad Net made up of elemental devices, but on a larger scale, with more complex repertoires and with controllers.

Image 31   Phase Transfer Controller, architecture and functional organization

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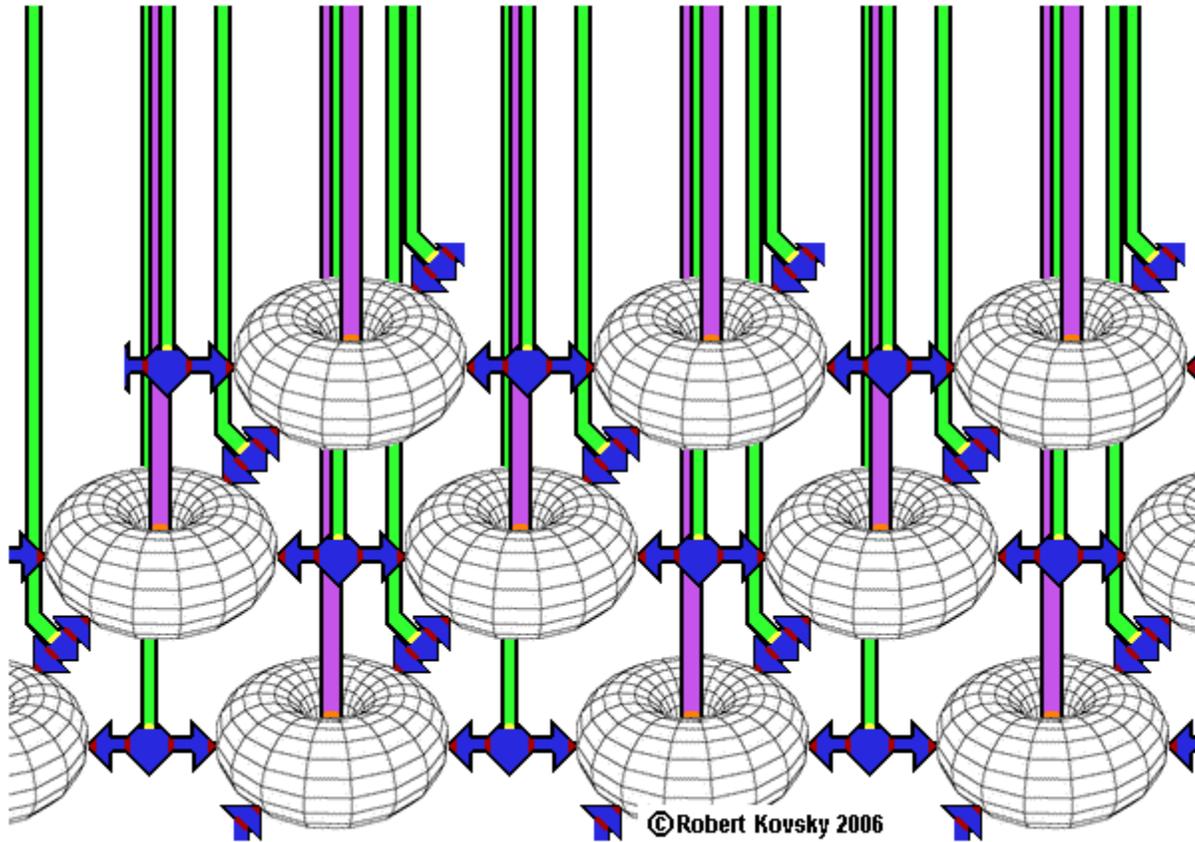
Phases such as those shown in Image 32.a can be maintained indefinitely in a TQN when there is a constant epsilon (Image 32.b). The repertoire of phases is the same as that maintained in PQN (Image 11). Formally, $0 < \varepsilon_o < U_n$, where U_n is the strength of the interaction inside the TQN.

Image 32: Maintained phases in Toroidal Quad Net (TQN)

a. representative phases

orthogonal phase   orthogonal phase   crosswise phase

b. common constant epsilon

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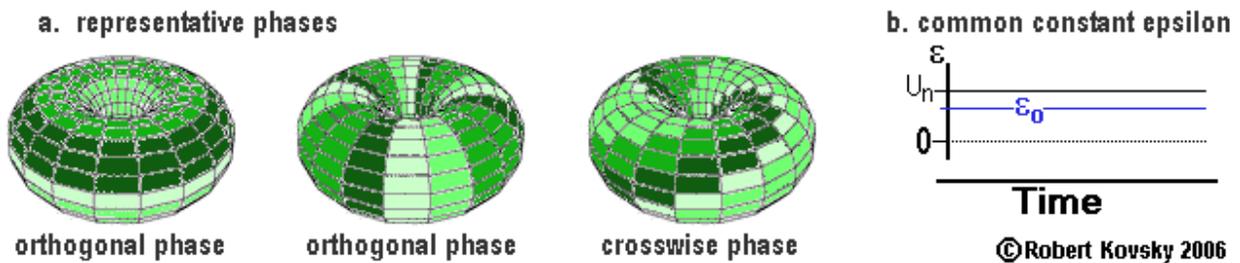
A controlled phasic transfer is charted in Image 33, identifying three moments – a, b and c – that are depicted in Image 34. V_n is the strength of interaction between a TQN and a CQN (Image 30, dark red junctions). U_n is the strength of an internal interaction in TQNs (bright red junctions). The ε's in the TQN and CQN device parts vary in response to controller interactions.

Image 33: ε's during phasic transfer

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Image 34: Controlled phasic transfer

a. two stable TQN phases, CQN silent

b. silencing of TQN, CQN silent

c. CQN active, phase transferred

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In Image 34.a, prior to the change in phase, two phases are separately maintained in two TQN's. In Image 34.b, the phase in one TQN is silenced by an inhibitory controller pulse. As TQN inhibition fades, the excitatory CQN controller is activated, transferring the phase maintained in the fixed TQN through the CQN onto the responsive TQN (Image 34.c).

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The phasic transfer in Image 34 resembles a computer instruction on the lowest-level, like "Clear and Add" that first erases and then writes information into an array of computer memory elements to record a number. There are also important differences. Distinct phases in QN devices are collective activities while memories in finite state machines are reducible to bits; and this difference becomes more important as larger QN device part assemblies are constructed. No less important are novel kinds of variability in QN devices. As a chief example, activities in QN devices can incorporate indeterminacy, a capacity foreign to finite state machines like computers.

Image 35: Indeterminate phase transfer
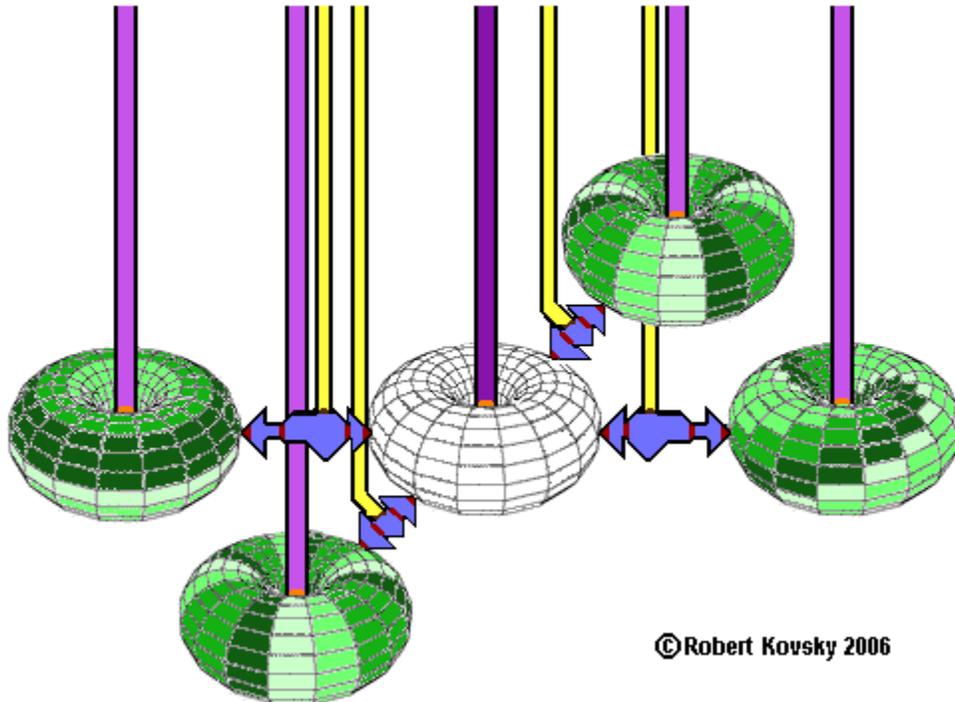
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An indeterminate situation is shown in Image 35. The inhibitory silencing of the central TQN is fading and all four CQN's connected to it are active, subjecting the central TQN to the influence of four distinct driving phases. Which, if any, of the phases will be transferred? Specifications governing QN devices have continuous settings and the engineer can balance activities as closely as desired or can make any one influence dominant. I suggest that, adaptating concepts developed in connection with the thermodynamics of heat engines (Truesdell & Bharatha) and metallurgy (Porter & Easterling), the engineer can construct a *phase diagram*, a multi-dimensional surface with coordinates defined by device part specifications and particular points identifying specific settings. Regions within the phase diagram would identify the different determinate phase transfers and areas of indeterminate phase transfer. Following the models, activity in a region of indeterminate phase transfers that is bounded by regions of determinate phase transfers can be analyzed in terms of activities in the determinate regions. That is, a phase diagram becomes a way to construct a map of phasic possibilities that lie under selections taking place during Critical Moments of Quad Net device operations.

§ 3. Critical Moments and the Principle of Shimmering Sensitivity

The Quad Net model includes a physical principle called ***Shimmering Sensitivity***, of chief importance during Critical Moments of QN device operations. As discussed in § 5, the principle of Shimmering Sensitivity is based on Critical Point physics. Here, the principle is viewed in action by means of Images.   The Images follow Quad Net activity that is controlled by the engineer through continuous adjustments of settings of specifications – a ***process*** – like those involved in the theory of ideal, reversible heat engines (Truesdell & Bharatha).

The images follow a cycle of activity in Primal Quad Net by reference to ε, a controlling parameter that resembles a temperature.   In Image 36, ε traverses a cycle around 0 and the Critical Moment occurs when ε crosses 0 during the downward swing. We pick up the cycle when $\varepsilon = \varepsilon_p$, at a convenient point on the upward swing of ε while $\varepsilon < 0$.

Image 36: ε for shimmering
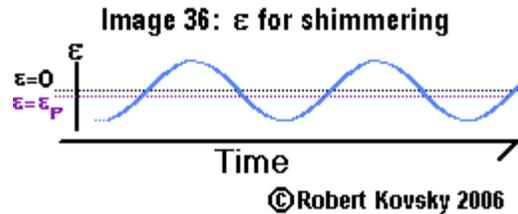
When $\varepsilon = \varepsilon_p$, the PQN maintains a crosswise wave in one of four possible phasic directions, as shown in Image 37. Each arrow points in the apparent direction of travel of the wave of discharges shown in the Image.

As ε passes upwards through ε_p, one and only one phase direction is maintained in the Quad Net.

Image 37:   Four final phases in Primal Quad Net

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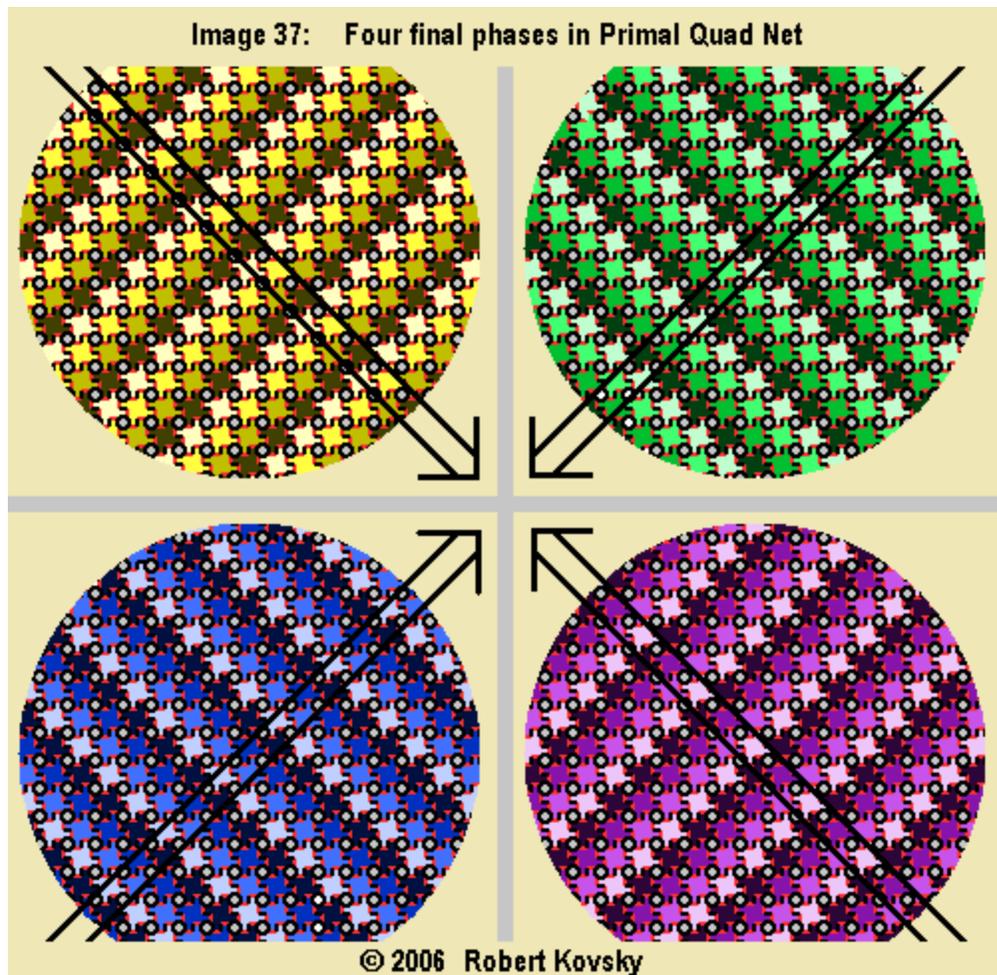
The particular phase direction at ε_ρ has been maintained throughout this cycle while $\varepsilon < 0$ despite changing values of settings and parameters.   As ε passes 0, however, the Quad Net becomes silent. The Quad Net remains silent as ε reaches the maximum and starts to decrease towards 0.

As ε crosses 0 in the downward direction, the Quad Net field passes through a Critical Moment. In a neutral or balanced system like PQN, no phasic direction is favored and each phasic direction has an initially equal likelihood of becoming established.

During the Critical Moment, germinal units of phases co-exist as *flickering fragments* in the Quad Net field, like those shown in Image 38. Momentarily "hot" elemental devices, orange in color, are sources of and boundaries of phase fragments.

Phase fragments are *mobile* and each advances in its direction of travel, acquiring elemental devices from other fragments and having its own taken.

Image 38: Shimmering made up of flickering phase fragments

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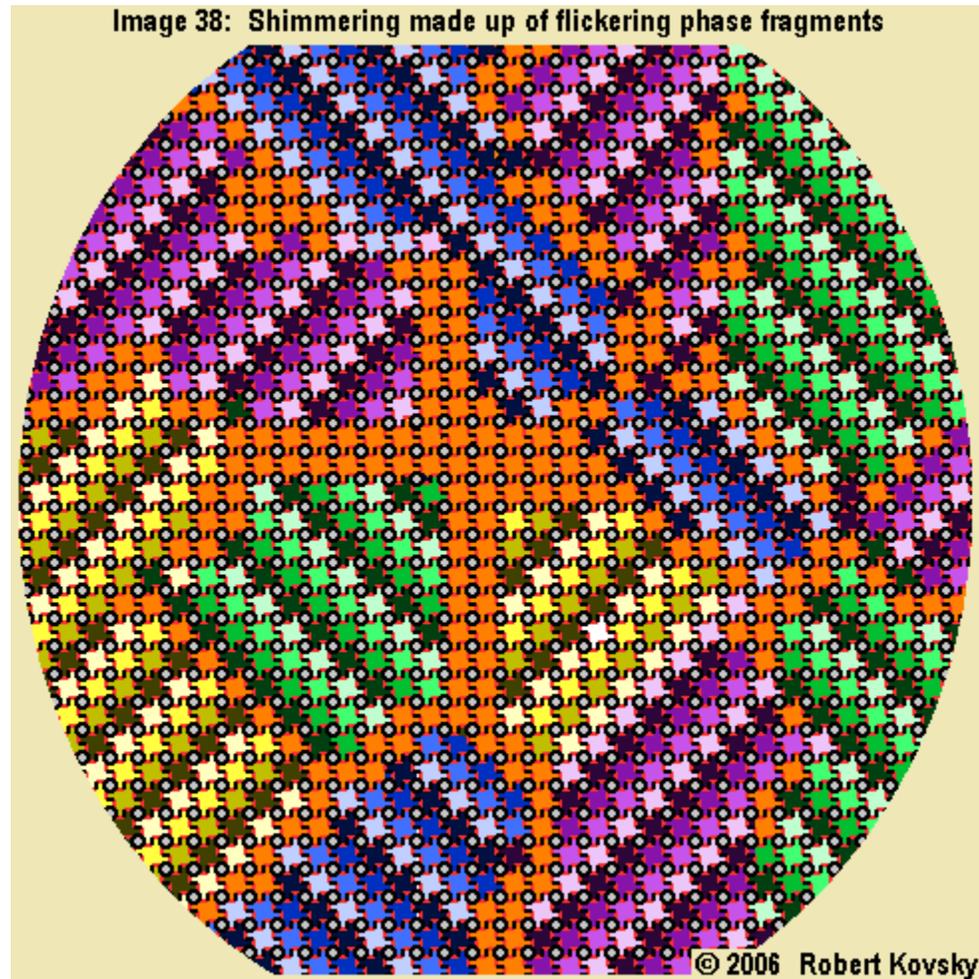
One phase is selected as ε decreases and the process proceeds. Let Image 38 be a momentary view of a restricted portion of an isolated Toroidal Quad Net of size 1000 x 1000. (i.e., made up of a million elemental devices (§ 2.e)). The engineer controls a process that increases cycle span (number of elemental devices in a minimal germinal unit) and the course of activity resembles the children's game of musical chairs: as some fragments grow, there is progressive crowding out until only one survives, which is thus selected and remains fixed until ε rises.

The imagery is partially based on theories of nucleation and growth of "grains" and "precipitates" and other phase changes in metal alloys during controlled heat treatment (Porter & Easterling, Hillerts, Gokcen). In the mathematical Ising Model of Magnetism, "spin elements"

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similarly align as the temperature passes downward through the Critical Temperature (§ 5).

If the Quad Net is completely isolated, the selection is indeterminate or determined by chance. But operating QN device parts are embedded in assemblies. During a Critical Moment, activity in a device part is subject to influences from other device parts that can affect the device part in varying ways. In complex assemblies, there could be many situations (e.g., Image 35) where influences are equal – or nearly equal – in their competing influence. I suggest that, during a Critical Moment, ***even a tiny change in an influence might change the collective result***; then, the device part is ***sensitive*** to that influence. This is a momentary condition. If, during its Critical Moment, a particular device part is sensitive to influences resulting from discharges in another device part, at a different moment in the cycle, the influential power may be reversed.

Image 38's "flickering fragments" suggest a method of construction, which is applied at the central region where four fragments are pictured as emerging from a common source. The method is to begin with the ***final*** repertoire of possible phases that the device part can maintain, as in Image 37. Then truncate and reduce each phase to a fragmentary but germinal tiling and juxtapose these in a single QN field. Supposing co-existence is possible during Critical Moments, the competing fragments of possible final phases collectively generate a condition of ***shimmering***. Thereafter, there is resolution of the competing and co-existing phase fragments into a single phase, at least during productive activity. In larger, speculative constructions, the process may include many cycles of selections where fragments are progressively eliminated until only one remains, occupying the field through its germinal power.

In a process of incremental elimination, each progressive change is reversible, or nearly so, if only a small additional input is needed for reversal. Also of importance, but beyond this presentation, are irreversible phase changes, where there is a bigger "jump" between conditions. During irreversible phase changes, Critical Moments are shortened so that continuity of phase selection is no longer maintained and the possibility of tracing the evolution of fragments is lost. A selection becomes subject to transient and unknown impulses and influences.

Quad Net constructions are directed to bringing many kinds of influence to bear on a given situation through diverse kinds of arrangements. The goal of development is to devise means for fragmentary, germinal phases to co-exist as possibilities in a shimmering way that pervades large structures. Influences that are weak locally may unite globally and become dominant. Further discussions in § 5 suggest that different device parts, spatially remote from one another, can participate together in coordinated selective processes where all influences are involved together and united by a principle that resembles the ***binding principle*** believed to be operating in brains – i.e., that organizes activities located in multiple brain parts that are distinct and relatively distant from one other. The Quad Nets model proposes multiple, shifting, cooperating and competing influences resolved through Shimmering Sensitivity, a principle that, as a matter of fact, can simultaneously perform selections on all scales but that is also so complex and with operations so subject to tiny influences and so obscured by irreversible processes as to be beyond the reach of analysis.

§ 4   Specifications and Activations

a.   The Simple Cycler

Specifications and activations are introduced through the Simple Cycler (Image 39), a ring of six uniform elemental devices, with collective settings of specifications.

Image 39.a, shows conditions of the elemental devices in the Simple Cycler, similar to those in PQN (§ 2.c). The cycle of an elemental device commences with a discharge that is very brief, idealized as an instant. Thereafter follows the refractory condition of duration τ_r; and then the ready condition that lasts until changed to a responding condition by a neighboring discharge. The responding condition has a duration δ, the interaction delay. After such delay, the elemental device discharges anew. Repetition follows.

In a directed phase, one or two germinal activity tiles appear to be traveling around the device part. As in § 2.c, the *cycle span of a phase* is the measure of a minimal, germinal activity tile; and the number of pulses temporally equals the number cells spatially. Regular (symmetric) directed phases of the Simple Cycler can have a cycle span of either 3 or 6 and can run in different directions, but only one regular cycle span and one direction at a time. The eigen-phase is like that of PQN in § 2.c, with pulsing in unison.

Image 39   Activity of the Simple Cycler

a. conditions of an elemental device

discharging   (none)
refractory
ready
responding

b. regular phases of the Simple Cycler

directed phases

counterclockwise   clockwise

three pulses/cells span the cycle

counterclockwise   clockwise

six pulses/cells span the cycle

undirected phase

eigen-phase

one pulse/cell spans the cycle

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The interaction delay δ, with dimensions of time, states the "clock-tick" interval between discharges in neighboring elemental devices. Because of the circular hookup each elemental device must pulse every $6\delta = \Delta$. When 3 pulses/cells span the cycle, some variance is possible in that two smaller periods, Δ_1 and Δ_2 make up Δ or $6\delta = \Delta = \Delta_1 + \Delta_2$. If, e.g., $\Delta_1 = 2.9\delta$ and $\Delta_2 = 3.1\delta$, the discharges in the two traveling germinal activity tiles will not be synchronous; rather each is independent. One will appear to be chasing the other, as if catching up and falling behind. Because some time is spent in readiness, $\Delta_1 > \tau_r + \delta$. There is another governing constraint, namely $\tau_r > \delta$; this means that a discharge must not cause "backfire" by directly influencing the elemental device that caused it to respond – such backfires would destroy the phasic direction. Therefore, $2\delta < \Delta_1 < 4\delta$ and likewise for Δ_2. The engineer controls or sets the specifications τ_r and δ. Other specifications determine τ_s, the period of the eigen-phase.

b.   The Virtual Energy model: internal specifications of elemental devices

Activities of pulsing Quad Net devices like the Simple Cycler are modeled using a ***Virtual Energy Store*** or VES that is like Internal Energy introduced by Clausius in 1850 in the first formal statement of the First Law of Thermodynamics (Truesdell, 8).   A thermodynamics approach begins with crude, minimal principles that are thereafter developed and extended.

As an underlying premise and as a basis for "Virtual Energy conservation," there is a ***steady-state inflow*** of an energy source called ***fuel energy***. In an electronic device, fuel energy is electrical. In humans, fuel energy is in the form of glucose carried by blood to the brain. In QN models presented here, fuel energy inflow to each elemental device is constant and the effect of any fuel energy fluctuation is null. Fuel energy becomes VES. Generally, VES increases, except upon pulse discharge; and increases in VES depend on settings of specifications and on interactions.

There are two kinds of specifications, ***internal specifications*** and ***interaction specifications***. Internal specifications, governing baseline activity prior to interactions, are stated for an isolated elemental device in which all interactivity has been "withered" as in § 2.c.

Begin with VES as a real variable such that $V_0 \leq VES \leq V_s$. V_0 is the reference or ground VES and V_s is the level of the Virtual Energy Store at which the elemental device spontaneously ***discharges a pulse***, i.e., when $VES = V_s$. Upon discharge of a pulse, VES is reset to V_0. V_0 and V_s are specifications set by the engineer or as a result of operations of other device parts.

Image 40 shows activity of an isolated linear elemental device where VES increases at a constant rate, R_c, the ***charging rate***, except during a discharge. As in § 1.a, a discharge is ideally instantaneous, a "pulse moment." The ***spontaneous discharge period*** τ_s is more specific than τ_φ previously used (§ 1.a).

R_c, V_0 and V_s are internal specifications and $\tau_s = [(V_s - V_0)/R_c]$. Additional internal specifications D and V_b are introduced in § 4.d.

Image 40   VES—isolated, linear elemental device

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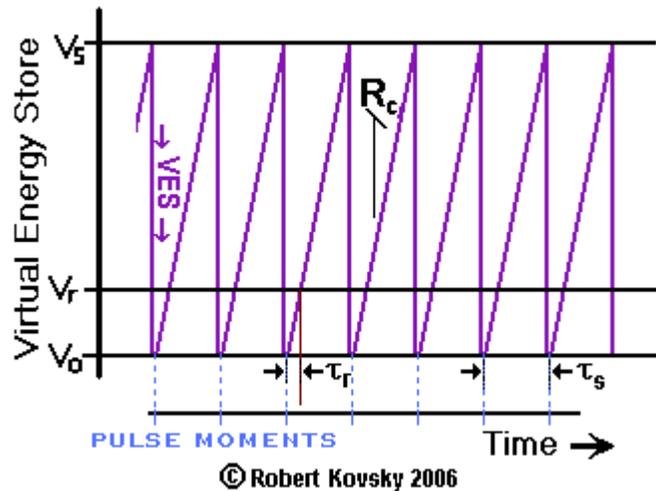
c.   The Virtual Energy model: interactivity and interaction specifications

Image 40 shows the refractory period, τ_r, during which the elemental device does not respond to interactions.   The interaction specification V_r is set to a value of VES that determines τ_r for a particular R_c and $(V_s - V_0)$.

After the refractory period of an elemental device is over, it can respond to a discharge in a nearest neighbor. To model such interactivity, I use a mechanism that adds "energies" using a transient *induced Virtual Energy pulse* or *interaction pulse*.

The *shape* or geometric form of an interaction pulse is chosen by the engineer to suit the task. Image 41 shows three shapes, each with operational and presentational advantages and disadvantages.

Interactions are similar with all pulse shapes. After a discharge in a neighboring element, there is an *interaction delay* δ before the interaction pulse commences to rise.

V_n is the *interaction strength*. Along with V_r (Image 40), δ and V_n are the *primary interaction specifications*, set to values by the engineer or through device operations.   All specifications are based in the elemental device rather than in the neighbors. A discharge in a nearest-neighbor is only a trigger for an interaction that is generated within the device itself.

The triangle pulse shape (Image 41.a) provides first-order analytic continuity and ease of manipulation. The gradual upward R_f slope contrasts with the leading cliff-edges of the other shapes. *Secondary interaction specifications* for the triangle pulse are R_f, the induction rate, and R_g, the reduction rate.

In the square pulse shape (Image 41.b), a classical form for electrical engineers, the secondary specification is ξ, the duration of the pulse.

In the exponential pulse shape (Image 41.c), the secondary specification is λ where the shape of the pulse has the form $\exp[-\lambda(t - \delta - t_o)]$, where t_o is the time of the neighbor discharge and $t > (t_o + \delta)$.   The duration of the interaction is so long that changes are inconsequential.

Image 41: Interaction pulses

a. triangle pulse

b. square pulse

c. exponential pulse

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Modeling an interaction calls for adding together (1) the VES generated from fuel energy inflow according to internal specifications and (2) induced Virtual Energy according to interaction specifications. Such an addition requires applying a principle of "conservation of Virtual Energy."   Without attempting to set forth a general basis for such a conservation principle in Quad Net devices, it appears reasonable to apply it in the limited form needed here where cyclical operations under continuous control are supported by steady state fuel energy inflow.

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Adding energies generates the ***Net Virtual Energy Store***, as in Image 42, showing a ***Net VES process***, where interactions induce an early discharge. Image 41 is based on the interaction specification $V_n = 0.1 (V_s - V_0)$, chosen for a clear presentation. Other specifications in Image 42 are $R_c = 1$, $R_f = 4$ and $R_g = 4/3$ on a common scale. (Here, δ and V_r are suitably small.)

Image 42   Induced discharge through Net VES process
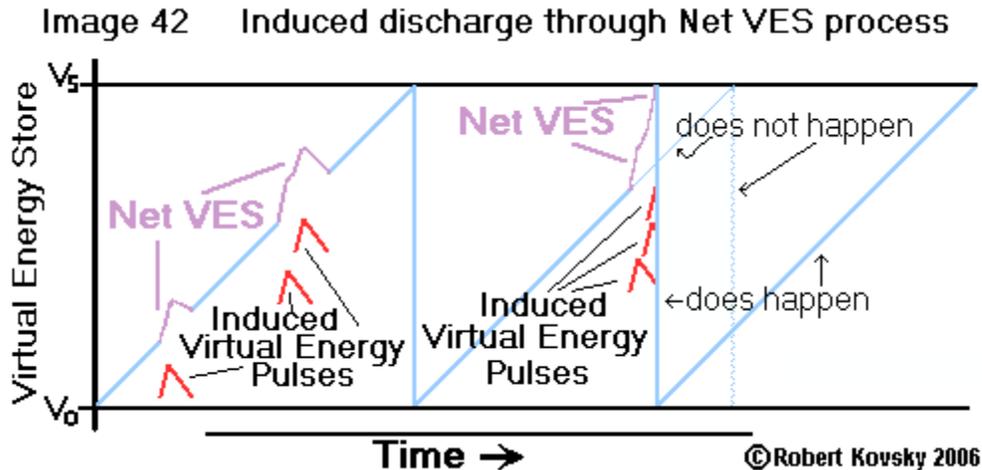
There is ***an alternative process*** for interactivity that is shown in Image 43, where, during a V_s ***reduction process***, a discharge in a neighboring elemental device temporarily reduces the V_s of the test elemental device, which then discharges at a lower level of VES.

Image 43   Induced discharge through V_s reduction process
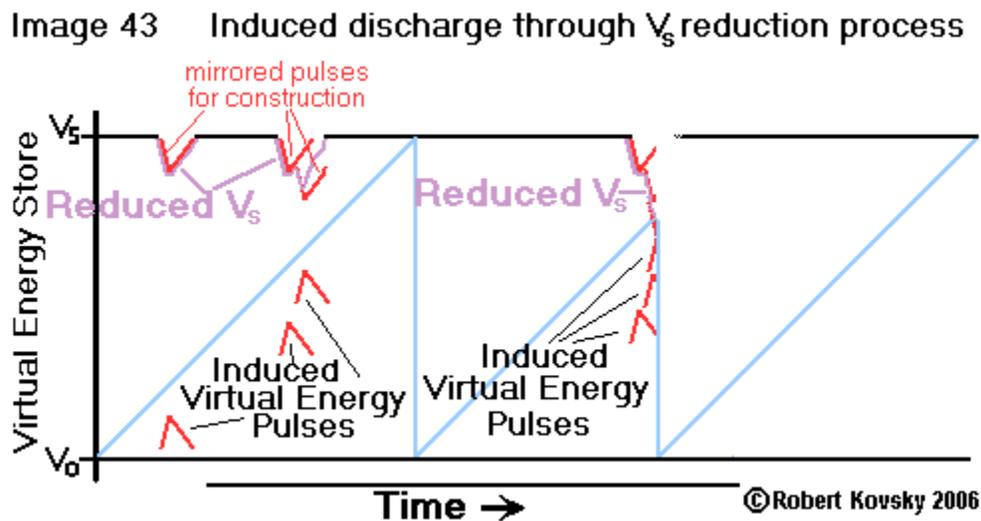
Specifications for Image 43 are the same as for Image 42. Construction of Image 43 mirrors that of Image 42. Both constructions reduce the distance between VES and V_s by the same amount in response to the interaction pulses. In both, when VES becomes equal to V_s, there is a discharge.

That is, Image 42 and Image 43 show activity of the elemental device that is "the same" as to results, but there are two different processes that reach that result. The two processes can operate independently and at different tempi. Then, independent processes can be combined (see § 4.f).

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Using a Net VES process, Image 44 shows the interaction and resulting VES of a linear elemental device in a Simple Cycler maintaining a regular directed phase "3 pulses per cycle." Each linear elemental device pulses with a period τ_i that is equal to $(3 \times \delta)$ where δ is set by the engineer. With $V_n = (V_s - V_r)$, a pulse in a nearest-neighbor causes a ready elemental device to discharge for any $\tau_i > \tau_r$. The constraint $\tau_r > (\delta + \xi)$, stated in a more exact form than in § 4.a, prevents "backfire," which would occur if an elemental device, having become ready too quickly, were to be triggered by a neighboring discharge that it itself induced. Important time scales are nested: $\xi << \delta < \tau_r < \tau_i$. If $\delta << \tau_r$ and/or $\tau_r << \tau_i$, the system supports greater variability in phases. E.g., the cycle span of a phase can be much greater than during operations where $2\delta \rightarrow \tau_i$.

Image 44   VES of elemental device in linear Simple Cycler

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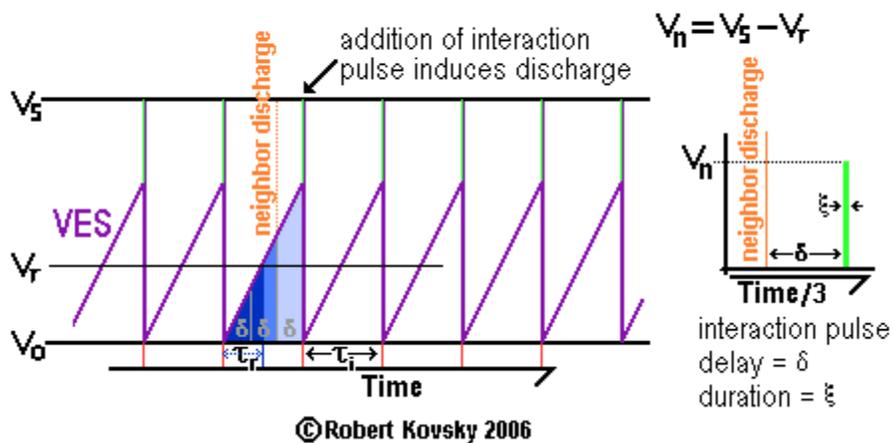
d.   Low-level and high-level activations

Modifying the linear elemental device leads to a more general elemental device that can also operate in a nonlinear fashion.   The modification is stated in the following equation:

(1) $d[VES(t) - V_0]/dt = R_c - D \times [VES(t) - V_0]$. This equation applies to the VES in an isolated device at all times except during a pulse moment (when $VES(t)$ changes from V_s to V_0). The new specification is D, a ***dissipation factor***. In (1), the higher the VES, the greater the dissipation. As $VES(t)$ increases, its growth rate decreases and $VES(t)$ reaches a maximum at $VES(t) = V_0 + R_c/D \equiv V_m$. The equation resembles that used in mechanics to model a frictional force that becomes stronger as velocity increases. When $D = 0$, the linear model returns.

(2) $VES(t) = V_0 + [(R_c/D) \times (1 - \exp(-D(t - t_0)))]$ solves (1) where t_0 is the time of the most recent pulse moment of the elemental device.   The trace in Image 45 shows the largest possible range for a particular $VES(t)$. Actual functioning depends on the value of V_s set by the engineer. Hence the trace is that of a ***functional*** that will generate different $VES(t)$ functions depending on the specifications, e.g., on the value of V_s.

When V_s is close to V_0, there is little dissipation and the linear form is dominant (Image 40). For higher V_s, dissipation increasingly affects the VES; the trace becomes nonlinear.

For high enough V_s, there is never a discharge. The elemental device is ***silent*** and VES approaches the asymptotic value, V_m.

Image 45 General VES(t) functional in isolated device

V_s for silent device

V_m VES(t)

VES

V_s for linear device

V_0

Time → ©Robert Kovsky 2006
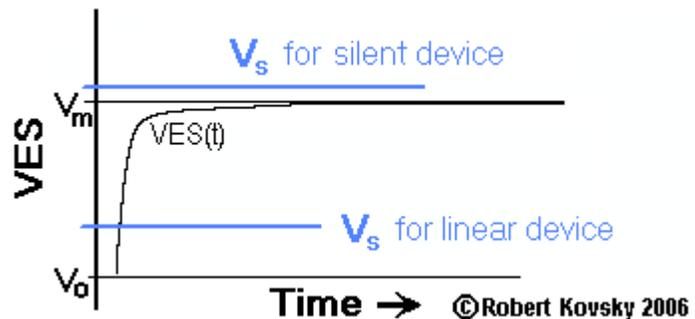
V_m is not a device specification or setting. V_0, R_c and D are specifications and their settings determine V_m. Consider a family of equations of the form (2) where $\Delta V = V_m - V_0$ is fixed while R_c and D vary together. When R_c and D are "high," $VES(t)$ will closely resemble a square wave or fast jump, looking like ⌐. For "low" R_c and D, $VES(t)$ will grow more slowly.

For further development, modify the elemental device so that VES is not reset all the way to V_0 upon a discharge. Rather, there is only a "partial discharge," down to V_b, a ***base VES level***. That is, after discharge, the elemental device begins recharging at V_b rather than at V_0. V_b is a new specification. The effect of this modification is shown in Image 46.

Image 46   Incorporating V_b into cyclical operations

V_m

V_b

VES

part of cycle omitted
by introduction of V_b

V_0

V_s

$V_s < V_m$

Time → ©Robert Kovsky 2006

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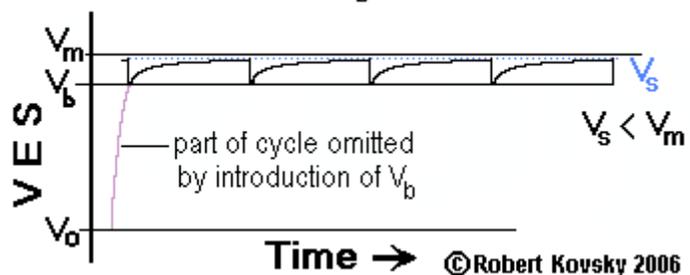
In sum, the internal specifications of an elemental device are V_0, V_b, V_s, R_c and D. The interaction specifications are V_r, V_n and δ, plus pulse shape and secondary specifications. A set of internal specifications and interaction specifications make up an *activation*.

Two distinct activations are shown in Image 47. The low-level activation (Image 47.a) is suitable for a linear device, e.g., the linear Simple Cycler operating as shown in Image 44. In such operations, VES(t) never approaches V_m. In high-level activations, VES(t) is close to V_m (Image 47.b).

The activations in Image 47 use a common VES(t) functional where R and D are the same. For greater versatility or energy-efficiency, linear devices can use lower R_c and D; but high-level devices generally want higher R_c and D for speed.

Image 47 Different activations based on a common VES(t) functional
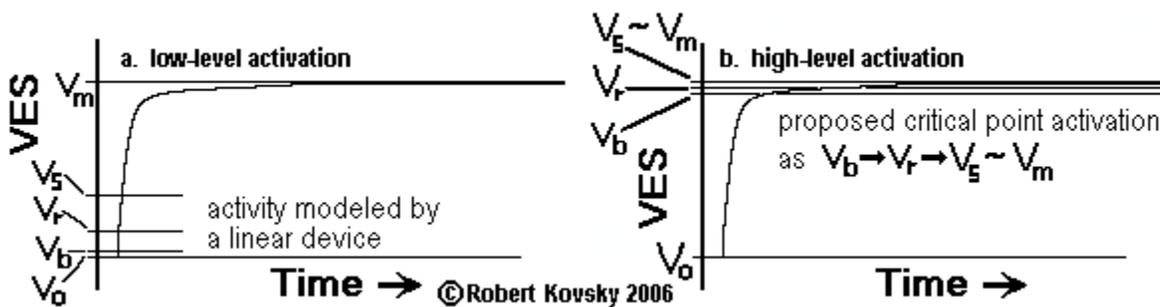
e.   Simple and summed interactions in high-level activations

Image 48 shows a Simple Cycler operating with a high-level activation and $V_s > V_m$. In some respects the operations are the same as those for the linear Simple Cycler (Image 44): the interaction pulses are identical and both interactions use a net VES process. The constraint $\tau_r > \delta + \xi$ is maintained. Other operations are different from those in the linear version. Here, discharge occurs only when induced – in contrast to the inevitable discharges in the low-level version. There is no eigen-phase. τ_s can extend to ∞ and so can δ; hence periods and cycle spans can be indefinitely long. This analysis also applies to high-level activations in PQN and to the TQN's in the Phase Transfer Controller (Images 32 - 35.)

Image 48 VES of elemental device in high-level Simple cycler

-43-
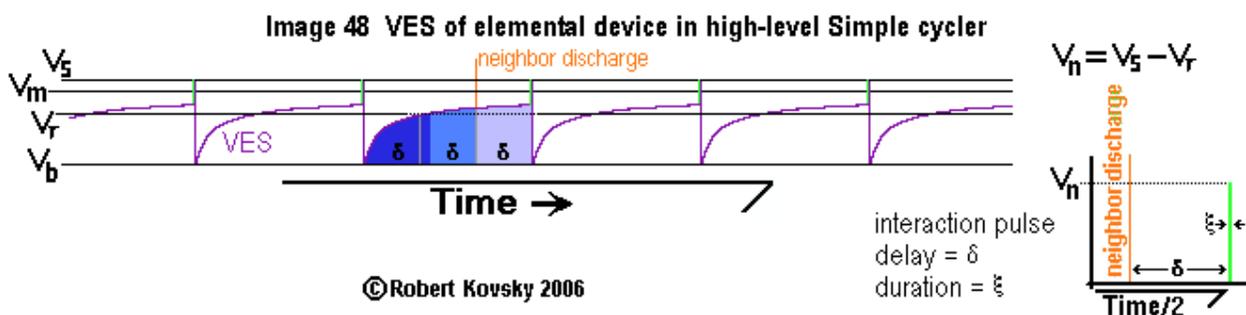
Two *phasic selectors* are shown in Image 49.a, each consisting of three elemental devices in a series and a particular arrangement of attachments to a Simple Cycler. The operations of the phasic selectors are caused by but do not affect those of the Simple Cycler. Each phasic selector responds to activity in the Simple Cycler in one phasic direction but not in the other direction.

Interactions driving the phasic selector are shown in Image 49.b, using a Net VES process. Interactions where "one discharge triggers," are the same as those occurring in the high-level Simple Cycler (Image 48). The interaction pulse – $V_n > (V_s – V_r)$ – is so large that a response will be triggered no matter what the VES, so long as VES > V_r. Hence, nothing depends on where VES is in the shaded range of Image 49(b)(1).

Image 49   Phasic selectors

a. attachments to Simple Cycler

b. specifications and interactions

(i) one discharge triggers

(ii) two discharges trigger

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Interactions are much the same for elemental devices where two neighboring discharges are required before the elemental device will respond, except V_s is higher than in the previous case and the new conditions are: (1) $V_n < (V_s – V_m)$ and (2) $2V_n > (V_s – V_r)$. Condition (1) means that a single discharging neighbor will not trigger a response, even if VES is as high as V_m. Condition (2) means that two discharging neighbors will trigger a response, even if VES is as low as V_r. The two conditions are pictured in Image 49.b(ii).
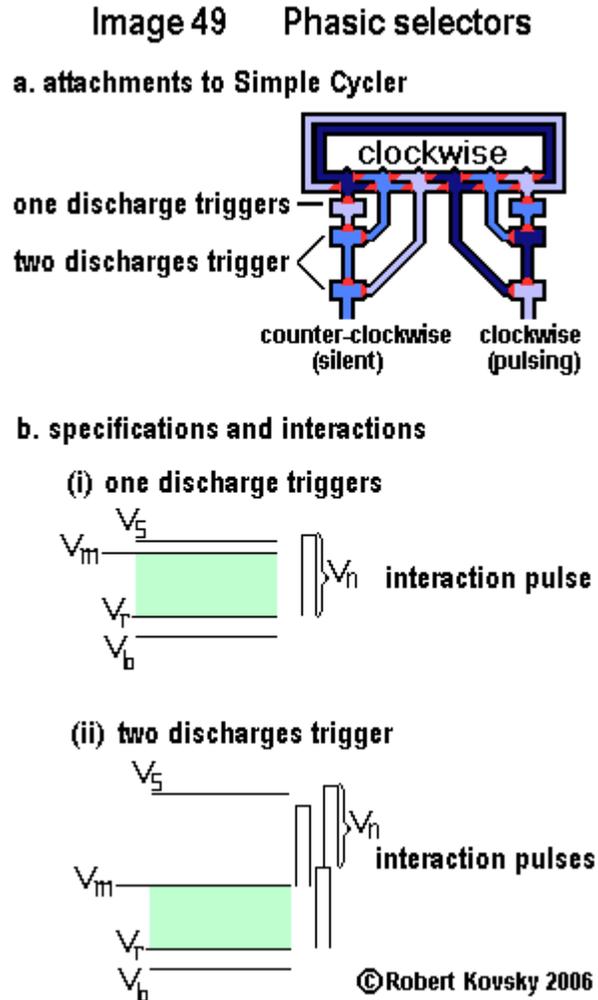
A similarly designed phasic selector responds to a wave in PQN that has a particular direction (Image 11). That is, an array of phasic selectors is attached to a PQN, where each branch in the array responds to exactly one particular wave direction. Each distinct phasic direction in the PQN causes pulsing in one distinct branch in the array while all other branches maintain silence. The PQN can act like a sense organ (see § 3) where phasic selectors signal the sensations.

The "two discharges trigger" interaction (Image 49.b(ii)) is the simplest example of a *summed interaction*.   More generally, the engineer can control the sensitivity of Quad Net devices like the elemental devices in the phasic selector by varying the V_s. For a sharp view, define $\gamma \equiv (V_s – V_r)/(V_m – V_r)$ and let γ be the operating control. When $1 < \gamma < 2$, the interaction is of the kind "one discharge triggers."   When $2 < \gamma < 3$, the interaction is of the kind "two discharges trigger."   The statement can be generalized to say that when $n < \gamma < (n + 1)$, the interaction is of the kind "n discharges trigger."

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The Simple Summer device part (Image 50) uses the same specifications and interactions as the phasic selectors, with a single γ applicable to all elemental devices. As output, the green elemental device pulses through its sole projection. The outward-facing violet projections make up a sensory detector; and they generate interactions in the junctions between the violet projections and the pink elemental devices. The Simple Summer is a coincidence detector: if enough violet projections are activated at nearly the same time, the green elemental device will pulse. "Nearly" is determined by the setting of ξ, the duration of an interaction. "Enough" is determined by the setting of γ.


Image 50: Simple Summer
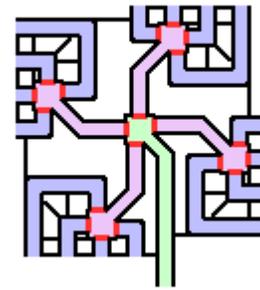
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Let γ in the Simple Summer have a variable setting. In general, V_s is mobile and V_m and V_r are fixed, so variability in γ is equivalent to variability of V_s. Suppose γ can vary between 1½ and 4½. If γ = 1½, a single discharge into any exterior (violet) projection will produce a pulse from the final (green) elemental device. If γ = 2½, there must pulses in a pair of violet projections leading to each of two of intermediary elemental devices, all four pulses in close temporal proximity, in order to produce a final pulse. If γ = 4½, all projections must be active together before the green elemental device will pulse.

f.   Controller interactions

Image 51 shows a representative controller element, belonging to the family of controller devices (Image 29). The *controlling phase* causes the condition of the central body to change from unready to ready/pulsing. The *direct phase* can be maintained only *while* the controlling phase is maintained. In variant forms (e.g., Images 33, 34), a direct phase is maintained *unless or until* an inhibitory controlling phase is maintained.

Image 51: Controller element

direct phase
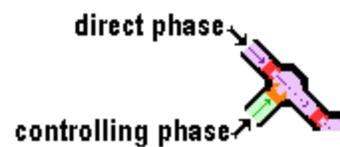
controlling phase

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Image 52 Controlled spontaneous activity

a. bundled spontaneous discharges

b. controlling interaction pulse
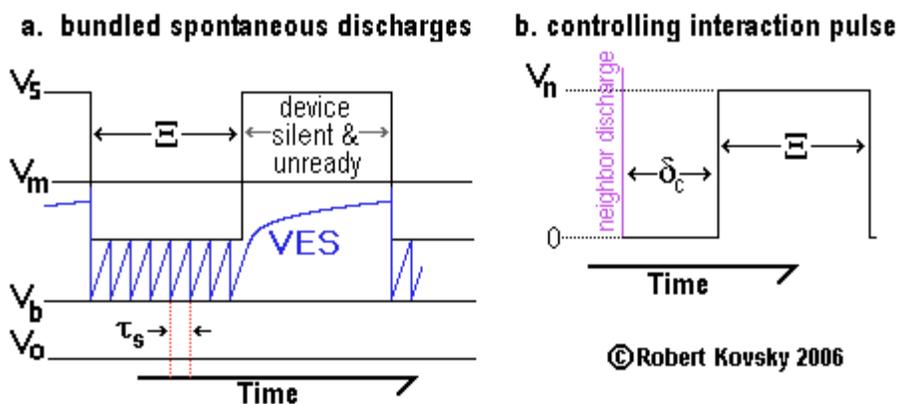
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Image 52.a shows a bundle of pulses produced by the controller element, using a V_s reduction process (Image 43). Image 52.b shows a square controlling interaction pulse (Image 41.b). There is no direct phase; discharges are spontaneous with period τ_s (§ 4.b).

In Image 53, the controller element is driven by a direct phase using a net VES process (see Images 42 and 44). The result is pulse bundles, a general form maintained in the family of controller devices shown in Image 29.


Image 53 Controlled driven activity

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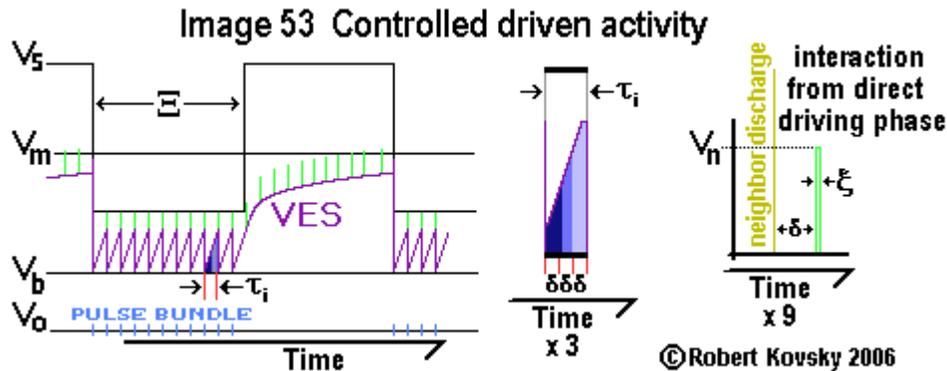
In controlled driven activity, periods are nested in each other, so that $\xi << \delta$, $\delta < \tau_i$ and $\tau_i < \Xi$. While remaining less than Ξ, τ_i can vary over a wide range and produce pulse bundles with different lengths and periods between discharges. The variance of τ_i depends on Ξ.

Operational activities described by Image 53 include the hierarchical pulse bundles shown in § 1, Images 4 - 6, where the controller interaction governs orange junctions. In Image 6, there are 2 pulses to a pulse bundle. This is a small number of pulses per bundle and the number can be larger with larger Ξ. A tiled bundle of exponential interaction pulses (Image 41.c) directed through controller projections can substitute for the single long square interaction pulse of duration Ξ that is shown in Image 53. Then, a bundle of controller pulses controls a pulse bundle in a driven wave.

g.   The proposed Critical Point Activation

Let $\varepsilon^\wedge(t) \equiv V_s(t) - VES(t)$. $\varepsilon^\wedge$ measures the distance between a device's momentary VES(t) and the condition when a discharge will occur. The distance shrinks as the VES(t) increases but also varies because of interactions. When $\varepsilon^\wedge = 0$, there is a discharge, after which $\varepsilon^\wedge$ increases quickly to $V_s - V_b$. $\varepsilon^\wedge$ is "the critical parameter" governing activity of the device.

In a low-level activation (Images 40 and 44), V_s is fixed and the important part of $\varepsilon^\wedge$ is VES(t). The situation is different in high-level activations. As shown in Image 49 (phasic selectors), there are operations where the momentary value of VES(t) is inconsequential: activities are the same no matter whether VES(t) is at V_r or at V_m or in between. For such activations, the "critical parameter" is approximated by $\varepsilon(t) \equiv V_s(t) - V_m$. An interaction strength $V_n = V_m - V_r$ or, equivalently, $V_n = V_m - V_b$, covers the range of possible consequential VES(t). Under such circumstances, $\varepsilon^\wedge(t)$ is bracketed: $\varepsilon(t) \leq \varepsilon^\wedge(t) \leq (\varepsilon(t) + V_n)$. As $V_n \to 0$, $\varepsilon(t) \to \varepsilon^\wedge(t)$.

An organizing concept is that V_s varies much more quickly than other specifications, e.g., R_c and D that determine V_m. Here, R_c, D and V_m are fixed while V_s cycles. Images showing ε (e.g., Images 23-25) are equivalent to those showing V_s if $\varepsilon = 0$ is set at $V_s = V_m$.

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Competing influences can be balanced during phasic selection. In Image 54, V_n measures the strength of the interaction onto the central TQN from the TQN on the left and W_n measures the corresponding strength of the interaction onto the central TQN from the TQN on the right. Now suppose that, during a sequence of selections in the central TQN, V_n is fixed while W_n varies from a quantity that is much less than V_n to one that is much greater than V_n. Clearly, at either extreme, the stronger influence will prevail. At the crossover, the results may be complex.

Image 54: Balancing influences during phasic selection

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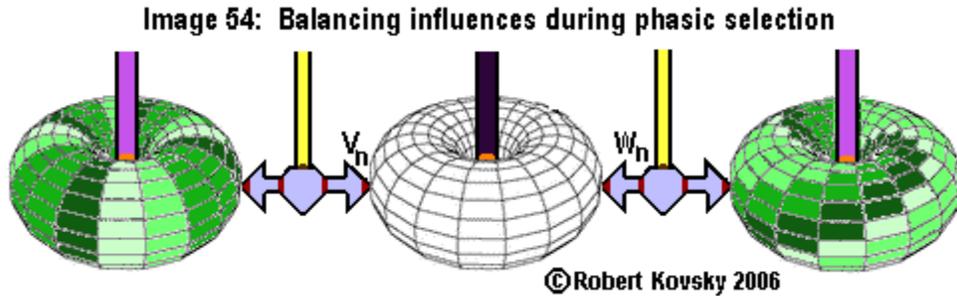
Based on such considerations, I propose a ***Virtual Energy Difference*** that identifies a quantity needed to cause a change of phase and that scales according to V_n (and W_n) in this case. The quantity resembles a Latent Heat (or enthalpy difference) of thermodynamics (Truesdell, Hillerts, Porter & Easterling; see also Kadanoff, Gockcen, Domb as to statistical mechanics). Accordingly, each phase in an operating QN is specified by a Virtual Energy. Under some circumstances, a phase is stable and a large addition of Virtual Energy is needed to change the phase. If, however, circumstances change so that phase changes can occur easily, then little or no Virtual Energy is needed to change one phase to another.

Following a thermodynamic model, the Virtual Energy needed to effect a phase change should approach 0 as the system approaches the Critical Point. $V_n \rightarrow 0$ is the suggested process. Hence, $V_m - V_r$ should also approach 0 because $V_n \geq V_m - V_r$. If V_m is fixed, $V_r \rightarrow V_m$.

Physically, I suggest that devices near the Critical Point Activation are generating phasic fragments and that reversible conversions occur easily amongst fragments. Fast pulsing facilitates reversibility and suggests that $V_b \rightarrow V_r$ to the extent allowed by $\tau_r > \delta$ and even in violation of that constraint. These limits ($V_b \rightarrow V_r \rightarrow V_m \sim V_s$ and $V_n \rightarrow 0$) constitute the proposed ***Critical Point Activation*** (Image 47.b). This activation appears to be a possible way to generate Shimmering Sensitivity in Quad Net devices.

To realize the Critical Point Activation by means of a thermodynamical process like that suggested in § 3, let V_b, V_r, and V_s all begin in a condition of maximum approach to V_m; meanwhile V_n and δ begin in a condition close to 0. Changes in specifications are controlled through processes where ε is varied. As ε crosses 0 in the downward direction and τ_r becomes greater than δ, the device generates fragments governed by the principle of Shimmering Sensitivity. Then, the principal quantities V_n, δ, $V_s - V_b$ and $V_s - V_r$ grow so as to progressively reduce the fragmentation, e.g., as suggested in § 3. Cycle spans grow longer, storing greater Virtual Energy. While ε is near 0, tiny influences can exercise selective power; but as the cycle progresses, more Virtual Energy is required to cause a phase transition and the selected phase becomes increasingly stable.

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§ 5   The Physical Basis of the Proposed Critical Point Activation

"Critical Point" concepts are based on researches in physics and related fields.   I use the term
Critical Point Phenomena or "CPP" to refer to physical phenomena observed experimentally in
pure fluids, e.g., water; in metal alloys, e.g., brass; in magnets; e.g., made of iron; and in
designed systems of liquid solutions and liquid crystals.   (See Domb, Anisimov, Gokcen,
Anisimov *et. al.*) Of chief importance is that Critical Point principles account for certain specific
phenomena observed in ***all*** the physical systems, which are otherwise very different, a fact called
universality (Stanley). The same Critical Point principles apply to the mathematical ***Ising Model***
of magnetism (Kadanoff).

Because of universality, each system provides insight for all. Consider the physical system made
up of liquid water and steam, two distinct phases. Image 55 (based on Kearton, Fig. 11) shows
two important features of behavior near the Critical Point when approached from lower
temperatures: the amount of "latent heat" approaches 0 and the slope of the trace approaches a
vertical condition. This is a highly unusual, even a "singular" mathematical form.

Image 55   Phase diagram for latent heat in water/steam system
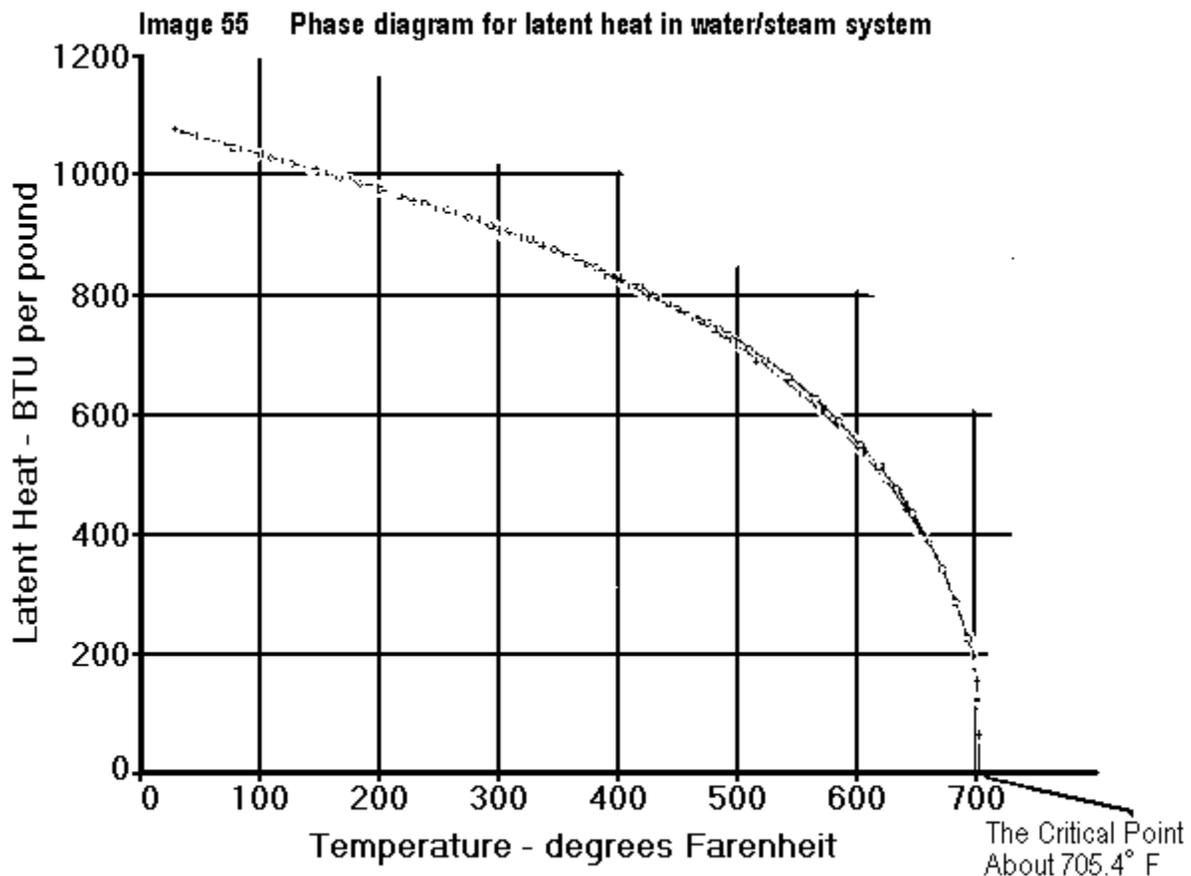
The trace in Image 55 shows the concept of ***latent heat*** that originated with Scottish scientist
Joseph Black (1728-1799) and his friend James Watt (1736-1819), whose improvements to the
Steam Engine were major events in the Industrial Revolution of the eighteenth century. Each
point in the trace in Image 55 states results of experimental investigations where liquid water and

steam in a closed container are maintained at constant temperature during measurements. During each experimental investigation, the system is "at equilibrium," meaning that no change is observable except for small changes introduced by the researcher. The latent heat of water is the amount of added heat needed to vaporize a unit of mass from liquid water to steam. If the same amount of heat is then withdrawn by cooling the system, an equal mass of steam will condense to liquid water. Because perpetual motion is impossible, the masses converted must be equal. Between changes, the system has a period of stability and changes are made as slowly as desired.

Except near the Critical Point, the amount of latent heat needed to convert phase in H_2O is surprisingly large: at atmospheric pressure, raising the temperature of a pound of water from 32 °F to 212 °F requires 180 British Thermal Units (BTU) of heat (energy) – this is one way BTU is defined – but converting that pound of hot water into steam takes over 900 BTU (Image 55).   No matter what the pressure, liquid water cannot be maintained at a temperature higher than the critical temperature, about 705.4 °C and denoted T_c, defining the Critical Point of H_2O.

At the Critical Point, **no** latent heat is needed to change liquid water to steam or back again: ***the phases reversibly interconvert***. Surface tension also decreases to zero (Domb at 202) and there is nothing to draw droplets of liquid water into ordinary round shapes. Below the Critical Point, there is a clear boundary between liquid and gas; but at the Critical Point, boundaries disappear (*Id*., 97).   There is liquid water but mingled with gas, and with parts thereof continually detaching and/or coalescing. ***Different shapes and sizes*** of droplets of liquid water are continually forming and dissolving in transient formations; and any transient formation can absorb all the liquid water as the temperature decreases. (See Sornette, 250-251, 283-87, 368-370.) This description is a basis for the "flickering fragments" shown in Image 38 in § 3.

In a more general thermodynamic form, latent heat becomes the an energy difference involved in a phase transition.   Energy principles are used in metallurgy to describe how different phasic forms can arise from a single mixture of materials (Gokcen, Porter & Easterling, Hillerts). Each phase has an Energy Content (e.g., enthalpy) and the material relaxes into the phase with the lowest Energy Content. When changing conditions produce a phase transition, the difference between the Energy Contents of the phases shrinks to 0. The stability of a phase with respect to another phase is measured by the Energy Content difference between phases.

As shown in Image 55, the "zero latent heat" condition in H_2O at the Critical Point is shown by a trace that approaches the vertical. The unusual "steep slope" feature reappears in the graph of a similar quantity in another physical system, namely, ***magnetization***, measured, e.g., by the number of thumbtacks a magnet can hold (Stanley). A magnet will mostly hold its strength as its temperature is raised until, suddenly, at the Critical Temperatue, T_c, the strength disappears. The strength is recovered when the temperature falls below T_c. In his 1895 publication, Pierre Curie noted the resemblance between a "steep slope" trace in Critical Point studies of a fluid system and one that he drew from his experiments with ferromagnets (Domb, 13). This was the first evidence of universality. The ***Curie Point*** in ferromagnets is the T_c above which such a magnet loses its inherent magnetic strength.

Image 56 (based on Domb, Fig. 5.12) shows the steep slope of the phase change in the mathematical Ising Model of magnetism. If the temperature is shifted from one side of T_c to the other, the system undergoes a complete change.   Just above T_c, there is 0 magnetization. Just below T_c, the magnetization is close to its maximum level. There is *sharp switching* as the temperature of the system shifts slightly around the Critical Point.   The switching is between a *condition of collective order* and a *condition of disorder*. (The sharpness of switching in QN constructions might depend, e.g., on the size of the device part and/or the complexity of any assembly where switching is collective.)

**Image 56: Phase diagram magnetization in the Ising model**
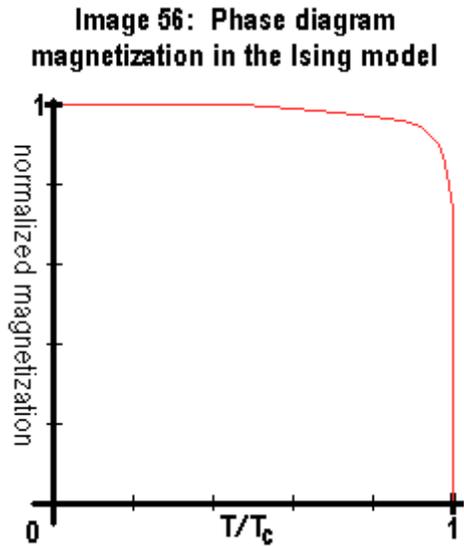
Image 57
Quad-Tiled Ising Model

$T \gg T_c$
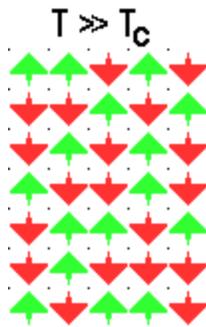
The Ising Model is illustrated by Image 57, where a planar tiled array of square cells extends indefinitely in all directions and each cell is occupied by a magnet identified by a "spin," suggesting a spinning top with an axis that identifies the magnetic field: either the north direction, shown in green, or the south direction, shown in red.   The magnetization sums the spins, +1 for each north spin, -1 for each south spin.   Each magnet interacts only with its four nearest orthogonal neighbors. If two neighbors are parallel, the energy in the interaction is less than if the two neighbors are antiparallel. The energy difference drives magnets to align collectively, but individual magnets are knocked out of alignment by thermal activity. When the magnet is very hot, as in Image 57, there is so much thermal activity that no stable constellation can maintain itself: the north and south spins magnets cancel each other on the average; and when magnetization is summed, the net result is near 0.

Follow a process that begins at T=0 (absolute zero), where all the spins are aligned, either all north or all south.   The system behaves equivalently regardless of north/south alignment as the temperature is raised from 0. At low T, a few spins are knocked out of alignment but the surrounding matrix of aligned spins exerts a collective force that corrects any delinquents. As the temperature rises, the delinquents increase and form blocks, corrected at first, but increasingly dense, until the collective become so depleted that it cannot cohere. Then there is disorder.

Next, follow a process that begins with an Ising Model system in a disordered condition at $T \gg T_c$, as in Image 57. The temperature is progressively lowered. The disordered condition persists all the way down to T_c. "Suddenly," as the temperature passes downward through T_c, nearly all of the spins snap into ordered alignment, either north or south. A small difference in temperature causes a big change in the condition of the material, i.e., there is sharp switching.

An important question is whether, as the temperature passes downward through T_c, the magnets align to the north or to the south. If there is no external magnetic influence, it is simply a matter of chance (Georgii *et. al.*). Experiment and theory confirm that, if there is any external magnetic

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influence, ***even the tiniest***, the magnets will align to that influence. This is called "infinite initial susceptibility" of magnets (Domb, 87-88).

I suggest that "susceptibility" in magnets becomes "Sensitivity" in Quad Nets. Sensitivity in a high-level Quad Net activation is measured by the V_n in an interaction needed to change a silent elemental device to a pulsing condition or vice-versa. A diminishing V_n is like a diminishing latent heat. In the proposed Critical Point Activation of § 4.g, V_n approaches 0 while $V_n \geq (V_s - V_m)$ — and the device is sensitive to this tiny influence.

When an Ising Model system is at the Critical Point, clusters appear in the form of transient structures, sometimes called "droplets," of various kinds, sizes and shapes. (See Domb at 215-218; Sornette at 250-251, 283-287, 368-370, Anisimov *et. al.* at 72-73; Kadanoff, Chapter 15; Green & Hurst, Chapter 1; Georgii, *et. al.*, § 6.) Any cluster could, if the temperature were lowered a bit, grow to occupy the field. In other words, ***multiple possibilities*** appear in an evanescent form.

Critical Point principles can be stated in a general form that appears to be suitable for application to QN operations. According to Sornette (407): "a critical phase transition is characterized by a so-called 'order parameter' (OP), say the magnetization in a magnetic or Ising spin system, as a function of a 'control parameter,' (CP), the temperature. A critical phase transition is characterized by the existence of a critical value CP_c of the control parameter, such that the OP goes continuously from zero above CP_c to a non-zero value below CP_c. Right at CP_c, the system is critical, i.e., it exhibits fluctuations at all length scales which are reflected into a singular behavior of the thermodynamic properties. One has thus to tune the CP close to CP_c to observe the self-similar structure."   The central notion, so stated, is reflected in the Virtual Energy Model of § 4, where the "control parameter" is ϵ and the "order parameter" identifies phasic activity such that "$\epsilon > 0$" is silence and "$\epsilon < 0$" is pulsing .   See also Sornette (267) as to Critical Point principles involving self-similarity and the renormalization group.

Multiple, evanescent formations are the basis of the laboratory phenomena called ***critical opalescence***, where light shining through a fluid at the Critical Point shows dazzling, ever-shifting, complex variations. The phenomenon was first seen in the 1860's, when Andrews made systematic observations of carbon dioxide gas and liquid. Critical Point principles apply to carbon dioxide only at an exact Critical Temperature and an exact Critical Pressure: 304.13 ± 0.01 °K (close to room temperature) and 7.375 ± 0.005 Mpa (about 70 atmospheres) (Anisimov *et. al.*). According to Andrews' original paper, when the Critical Point was reached, "the surface of demarcation between the liquid and gas ...disappeared. The space was then occupied by a homogeneous fluid which exhibited ... a peculiar appearance of moving or flickering striae ["bands"] throughout its entire mass." (Domb at 97.)   Domb states: "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." (*Id.*)

I suggest that features of Critical Point Phenomena (CPP) in natural materials set forth above can be imported into the proposed Critical Point Activation (CPA) in the Quad Nets model. In addition to shared features, there are important differences. CPP are natural but CPA is artificial. CPP are fixed properties of nature but CPA specifications and settings are adjustable. Material

particles involved in CPP are "passive" and do not contribute energy to a system but elemental devices involved in CPA are "active" and contribute Virtual Energy to the system. Overall, CPP is activity of simple particles of refined matter but CPA is activity of distinct, designed devices. A chief difference between CPP and CPA is the nature of investigation. In investigating CPP, a scientist attempts to maintain the system "at the Critical Point," e.g., at a specific temperature and pressure, treating the condition of the material as a "state" or fixed (Anisimov *et. al.*). In contrast, CPA involves cyclical activity with repeated passages through the Critical Point.

Notwithstanding the differences, I hold that the importation of features from CPP to CPA is justified. CPP arise in a natural way in tiled systems when, under specific "Critical" conditions, nearest-neighbor interactions generate collective behavior. Universality is a chief feature of CPP and suitable for application in an activated system. QN devices are intentionally designed to embody the features of the Ising model that support its phase-switching behavior. Perhaps the proposed leap from mathematical magnets to engineered devices is comparable to the leap from mathematical magnets to real fluids, already accomplished (Domb at 219, 231 *et. seq.)*.

Further justification is provided by other researches, such as a thermodynamic/statistical treatment of collective neuronal network devices, although using state-based designs different from the activity-based model presented here (Hertz *et al.*). Similar large-scale problems have been explored through self-organizing criticality (SOC) (Sornette, Kadanoff). As stated by the founders of SOC, (Bak *et. al.* at 581): "The criticality in our theory is fundamentally different from the critical point at phase transitions in equilibrium statistical mechanics which can be reached only by tuning of a parameter, for instance the temperature." However, Sornette (407) has suggested combining critical point principles with SOC principles.

There is a final and culminating feature of Critical Point Phenomena that guides development of the Quad Net model, a feature called **long-range order** that uniquely appears at the Critical Point (Domb, 117-118, 143-45). Given a system at equilibrium, suppose that a local fluctuation ("dissent") is introduced. The **correlation range** measures the region of interactive influence of that fluctuation: the greater the correlation range, the wider the region of influence. Generally, the correlation range varies with temperature and, of chief importance, it grows to infinity as the temperature approaches the Critical Point. Then, long-range order governs (Fisher).

Long-range order means that a unit's correlated or coordinated activity with a distant unit is about as strong as with a nearest neighbor. Because the only interaction between units is purely local (i.e., nearest-neighbor), this effect is astonishing. **Local interactions unite to form global or collective activity**. The phenomenon is based on a balance between one exponential factor that reduces a unit's influence as distance from it grows and that is temperature dependent and a second exponential factor where a unit's influence grows with distance based on the number of interaction paths between any two units and that is relatively independent of temperature. "Right at the critical point, the gently decaying power-law correlation factor in the number of interaction paths, previously negligible, emerges as the victor in this stand-off between the two warring exponential effects. As a result, two [magnetic] spins are **well correlated even at arbitrarily large separation**" (Stanley at S365, emphasis added).

Correlation at arbitrarily large separation recalls a principle (or problem) in neuroscience, the

binding principle. Edelman & Tononi at 106-107 state: "When we see a scene, we are not aware of colors, movements, and forms separately and independently but bind the color with the shape and the movement into recognizable objects. ... Binding, for example, assures the integration of the neuronal responses to a particular object contour with its color, position, and direction of movement. .... This binding principle...is repeated across many levels of brain organization."   The principle relies on imaging and EEG studies that show widely-separated brain centers are activated together (Posner & Raichle). In considering proposed "mesoscopic" activity (at scales of activity larger than neuronal), Freeman (372-73) states that "brain imaging of metabolic activity and cerebral blood flow [shows] involvement of large swatches of cerebral cortex in conjunction with diverse tasks ... The question is, how might mesoscopic domains become coordinated and form the macroscopic domains that may underlie the swatches."

Declaring that "the single word most significant for understanding the brain ... [is] *neuroanatomy*," Edelman & Tonini (42-47) discuss "three major topological arrangements in the brain that appear to be essential to understanding the brain's global functioning."   Of chief importance "is a large, three dimensional meshwork – the segregated yet integrated set of circuits constituting the so-called thalamocortical system ... comprised of a structure located in the depths of the brain–the thalamus–which receives sensory and other inputs. The thalamus is reciprocally connected to the cerebral cortex. ... the cortex and the thalamus are traditionally subdivided into a large number of areas that have different functions. This functional segregation is seen at many different spatial scales. ... Different cerebral cortical areas and their associated thalamic nuclei are also specialized."   Additional global systems involve "long, polysynaptic loops that are arranged in parallel" and "diffusely projecting value systems" such as one that "distributes a 'hairnet' of fibers all over the brain and can release the neuromodulator noradrenaline." Edelman & Tonini (107-110) identify human consciousness as being based in "dynamic reentrant interactions" ("reentry") involving the global systems, especially the thalamocortical system.

Such proposals provide goals and guidances for QN development. Despite differences between device models and biological originals, there are common themes of design. The Quad Net model suggests that the proposed Critical Point Activation is an engineered version of Edelman's "dynamic reentrant interactions" or "reentry." Reciprocally ordered interconnections between areas in the thalamus and the cerebral cortex suggest interactive assemblies like that of the Phase Transfer Controller, where control phases that have been selected in one place govern phasic transfers in another place. Imagery suggests that, through "correlations at arbitrarily large separation," phase selections may be coordinated in large scale assemblies of interconnected QN device parts collectively passing through Critical Moments. Perhaps investigations into such selections may provide an opening into phenomena of consciousness.

The development of a model of consciousness in brains is a useful goal, but practical problems involving Quad Nets are presently more rudimentary. This is a construction approach that must await actual physical materials before serious development can be expected; and progress, if any, will be incrementally acquired through experiments with functioning devices. I suggest a closer target for development: building a home for Shimmering Sensitivity.

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